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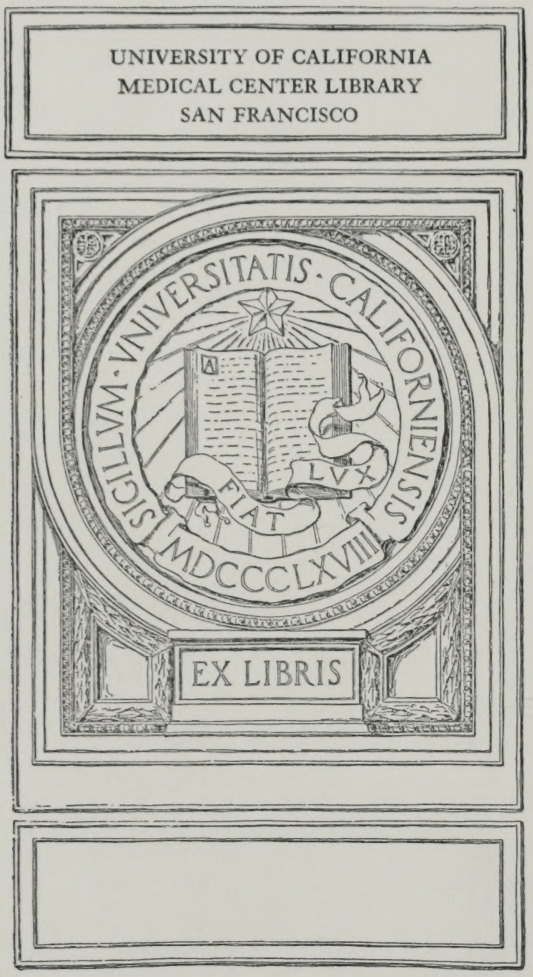

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Volume 2

Part 2

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assisted by

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and

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* Epidemiology and Biometeorology of Fungal Diseases of Plants. Mimeo. The Pennsylvania State University. Unpaginated, 1963.

** Reports published in the "International Journal of Biometeorology", Volume 8, Number -, 1964.

PART 2

ENTOMOLOGICAL BIOMETEOROLOGY

Chairman: W. O. Haufe

SYNOPTIC CORRELATION OF WEATHER WITH MOSQUITO ACTIVITY

W. O. HAUFE

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Abstract – A synoptic method of correlating mosquito activity with weather is described for univoltine species in subarctic environments. The relation between flight and the meteorological factors that are directly concerned with the use of air mass trajectories and tephigrams is illustrated with data for continuous samples of seasonal populations. The significance of endogenous rhythm and vertical dispersal is also considered in relation to a working model.

Zusammenfassung — Eine synoptische Methode zur Erfassung der Wechselbeziehung zwischen der Aktivität von Mücken und Wetterzuständen für einbrütige Arten unter subarktischen Bedingungen wird beschrieben. Die Beziehung zwischen Flug und meteorologischen Faktoren, die Luftmassen und Tephigramme berücksichtigen, wird mit fortlaufend gewonnenen Fängen demonstriert. Die Bedeutung des endogenen Rhythmus und der vertikalen Verteilung wird an Hand eines Arbeitsmodells diskutiert.

Résumé — On décrit ici une méthode synoptique permettant de mettre en lumière les relations existant entre les conditions météorologiques d'une part et d'autre part l'activité de moustiques n'engendrant qu'une seule génération par année dans les régions subarctiques. Au moyen des trajectoires suivies par les masses d'air et de «téphigrammes», on établit la relation existant entre les éléments météorologiques directement mis en cause et le vol des insectes. L'intensité de ce dernier est établi au moyen de captures continues. L'importance des cycles endogènes et de la répartition verticale des insectes est mise en évidence et discutée sur la base d'un modèle de travail.

In Canada considerable emphasis has been placed on the ecology and control of biting flies, particularly in the subarctic regions where fly attack in summer is a hindrance to economic development. Programs of research, begun in 1947, have been long-term in scope and some phases of laboratory and field work have been combined in an attempt to solve practical problems. Among the biting flies, mosquitoes in particular heavily infest large temperate as well as subarctic regions in summer and human activities depend on local chemical controls and other protective measures.

Basic to all fly problems is the need for information on variations in development and activity related to weather and climate. An essential part of the work on mosquitoes was devoted to the study of behavior patterns and weather systems, and particularly to investigation of effects of individual meteorological factors on cir-

cadian rhythms in flight activity. Concepts developed from critical laboratory experiments have been tested by sampling activities of populations in the field. The ultimate objective in these investigations is to develop and refine practical synoptic methods of correlating biting-fly activity with weather for efficient use of chemicals in control programs.

This paper is an attempt to consider briefly the progress that has been made toward the ultimate objective. Since many basic physiological relationships are involved in the complete interpretation of insect activities, time for one paper permits presentation of a practical concept only in an over-simplified form. However, reference to the more detailed literature and reports provide an assessment of some of the limitations that arise in dealing with biologically variable populations.

ECOLOGICAL CONDITIONS FOR SAMPLING MOSQUITOES

Practical biometeorological concepts developed so far in Canada are limited to the subarctic environments. The indigenous species are univoltine and develop after diapause to emerge in hordes within a few days in early summer. Intense activity continues through a period of 8 to 10 weeks for the most abundant forms although lower levels of activity are experienced throughout late summer and early fall for species near the northern limits of their distribution. All the abundant species are strong fliers and, depending on weather, apparently disperse for many miles during their life span.

The sampling site for most of the subarctic field studies was 12 miles south of Fort Churchill near Hudson Bay. Flat, low-lying boggy muskeg stretch inland for hundreds of miles in all directions to the north-west, west, south-west, south, and south-east from Hudson Bay. An endless system of pools provides extensive breeding grounds for dense populations of mosquitoes every year. Since dispersal is generally from west to east over a wide region, populations at Fort Churchill remain high with only minor fluctuations over the mosquito period. Significant drops in population are detected only during periods when circulation is steady from the north-east over the bay for periods of 48 hr or more.

Samples of mosquitoes were taken continuously in a visual-attraction trap (Haufe and Burgess, 1960). This device trapped mosquitoes flying through a constant air space between 2 and 8 ft above ground and within 3 ft of the trap in all directions horizontal from the centre. Efficiency of trapping was approximately the same for night and day and samples could be automatically separated at intervals set from 15 min to 1 hr throughout consecutive 24-hr periods. Although separation of samples permitted correlations related to any part of a day, the synoptic correlations for macro-scale consideration of weather in this paper pertain to bulk 24-hr samples separated at 08:00 hr.

Eleven species of mosquitoes are common in the populations at Fort Churchill. Of these, three account for more than 85 per cent of infestations and they contribute

to the dense swarms that are observed during peak periods of activity. The three species, *Aedes communis* De Geer, *A. hexondontus* Dyar, and *A. punctor* Kirby belong to the blacklegged complex and are closely related in their flight behaviour including the form of diurnal rhythms. For this reason, bulk samples for the 7 to 8-week period when these species were active represented the response of *A. hexodontus-communis-punctor* complex to weather systems within the limits of error recognized for macro-scale records in meteorology. Species had to be separated at short-term intervals to distinguish the behavior of other less abundant forms which exhibited very different patterns of activity to be considered in another report.

METEOROLOGICAL ENVIRONMENT

The science of meteorology does not yet have a universally accepted coherent picture of the mechanics of the general circulation of the atmosphere. Nevertheless, the concept of a study of mosquito response to weather must at least accord with the conventional concepts that meteorologists accept as a basis for practical use of meteorological method in analyzing weather data. Therefore, theory and technique for a simplified analysis of the meteorological environment related to mosquito activity generally followed the Rossby concept (In *Handbook of Meteorology*, Berry, Bollay and Beers, 1945).

Circulation in the lower atmosphere over the northern hemisphere depends on the rotation of the earth in relation to a meridional circulation system that operates between the north pole and the equator (Fig. 1). Mixing of air masses with different characteristics occurs in the regions of the horse latitudes and the polar front. In other regions changes in air masses moving along the ground are determined by the masses of land and water over which the air flows. Air masses subsiding at the pole tend to have comparatively uniform characteristics (low temperature, low moisture content) over long periods. Temperature and moisture content gradually increase as they flow southward. Severe and sudden changes in atmospheric temperature and humidity are experienced in the regions directly under the influence of the polar front. Here, arctic and tropical air masses are constantly battling for supremacy along a continuously advancing and retreating line of frontal contact. The polar front may advance southward to nearly 30° N latitude in winter (Fig. 2) and, in Canada, retreat northward to nearly 70° N in summer. Consequently, the pattern of circulation over North America displays a changing frequency of movement over the continent if the air is identified with its origin, i.e. continental polar, arctic, maritime polar, continental tropical, and maritime tropical (Fig. 2).

The mosquito season at Fort Churchill (58° 41′ N latitude) normally coincides with the period of most intense activity of the polar front at that latitude. For this reason, Fort Churchill was a most propitious site for correlating abundance and activity of mosquitoes with continental weather systems. Temperature and humidity were normally under the influence of the highly dynamic planetary flow pat-

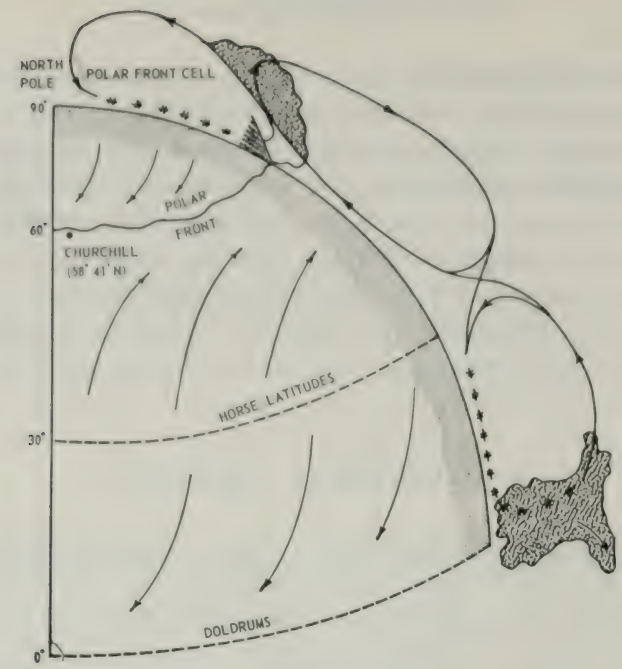

FIG. 1. Schematic system for the general atmospheric circulation over the northern hemisphere (after Rossby)

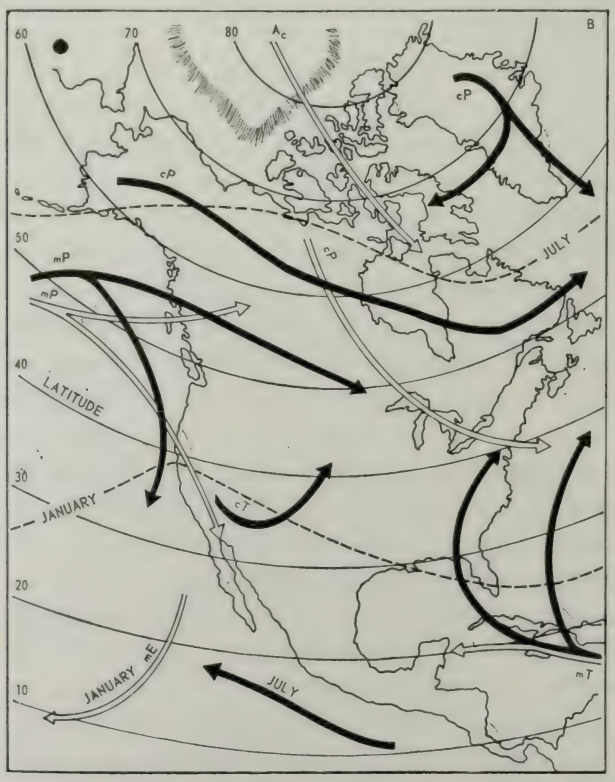

FIG. 2. Surface circulation of air masses over North America in relation to the summer and winter extremes of weather (after Berry, Bollay and Beers)

terns pertaining to the polar front at a time when mosquitoes reached the peak of their activities. Studies in this area provided an opportunity to analyze the influence of weather on activity continuously and simultaneously at macro-, meso- and micro-meteorological levels. Since the polar front is essentially a transition zone, incessantly regenerated and incessantly destroyed, the effect of weather on activity in an area with hordes of mosquitoes was often spectacular to observe. Moreover, the polar front expressed itself through the formation of quasi-horizontal waves that normally progress from west to east and follow each other at distances between 600 and 3000 miles. Continuous cycles of activity could be observed over relatively short periods of sampling. Furthermore, the cycles of activity could be clearly defined in relation to the strong temperature contrasts and the rapid succession of dry and moist spells that characterize subarctic areas in summer.

PHYSIOLOGICAL BASIS FOR CORRELATING ACTIVITY WITH WEATHER SYSTEMS

Experiments in the laboratory and in the field on physiological relationships between mosquito response and physical factors in the environment have provided a tentative basis for testing synoptic methods in correlating weather and activity (Haufe, 1954, 1957, 1958, 1961, 1962, 1963, and other unpublished reports). The treatment of data for activity and meteorological factors, to be useful for practical purposes, must be in nomographic form.

Measuring Activity

The activity of mosquitoes is related to a physiological cycling that largely depends on starvation and/or age after emergence and on the consummation of activities pertaining to the period preceding the time of measurement. This cycling of behavior is modified and completely or incompletely inhibited by weather conditions to varying degrees for short intervals of time. The result is difficult to measure since it is a very imperfect oscillation in numbers of individuals active during 24-hr periods. This is especially so during rapidly and abruptly changing weather conditions in the polar front zone. The extreme imperfections in the oscillation of numbers of active mosquitoes include occasional 24-hr periods with little or no activity. They may be a result of inhibition by unfavorable weather conditions or due to extended periods of rest after a sudden intense release of activity in a major part or all of the population. In this connection, adaptation to changes in environmental conditions is a primary factor in modulating the cycle or rhythm of activity and indicates that the stimulus-response physiology involved may be governed by the "law of initial value" (LIV) as conceived for many response functions in higher animals. For this reason, there is no simple linear relationship between environmental stimuli and flight response for populations of mosquitoes that are in various states of activity or in various stages of

maturity and starvation. For practical purposes, responses have to be predicted on the basis of weather characteristics that represent a relative change from those permitting the expression of the activity state to those inducing or accommodating the resting state following periods of activity, or vice versa.

These relationships are reasonably clear cut for heterogeneous populations of mosquitoes at the macrometeorological level, but require adjustments at the meso- and micrometeorological levels depending on variations in stage of starvation, age and previous activity, and on the influence of topographical features on the climate of the ecozone or habitat. A simple scheme for synoptic correlations is limited to species with clearly periodic emergence in relatively uniform types of terrain such as tundra, prairie or open grassland.

Response to Temperature and Humidity

The variation of mosquito activity in the subarctic environment is primarily dependent on temperature and humidity. Wind above 18 miles/hr has a definite effect on flight activity near the ground. Fog, especially radiation fog, inhibits the

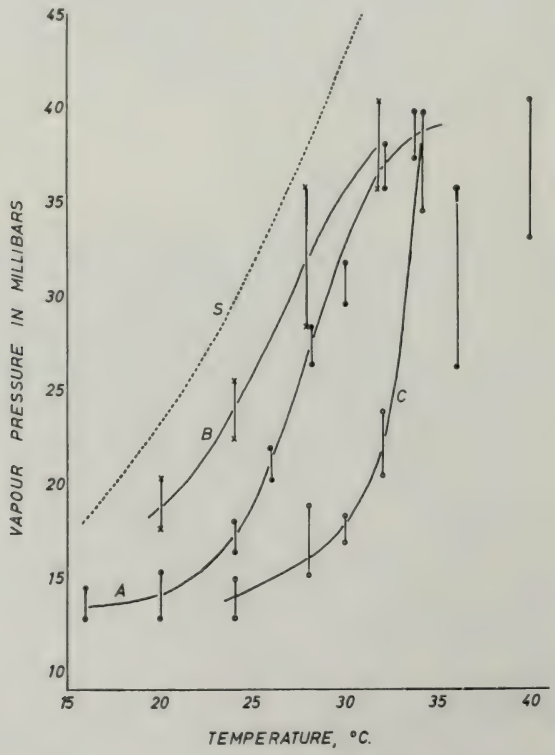

FIG. 3. Maximum duration of activity of *A. aegypti* as a regression between atmospheric water-vapor pressure and temperature. Curve A—3.5 day starved females, Curve B—6.5 day starved females, Curve C – 6.5 day blood-fed females, Curve S – saturation vapor pressure for air

activation of mosquitoes in their resting places. Both factors have to be considered in evaluating the response to temperature and humidity. Light appears to have little, if any, effect on flight activity except in special types of behavior such as swarming of males.

When the flight responses and activity periods of mosquitoes are measured

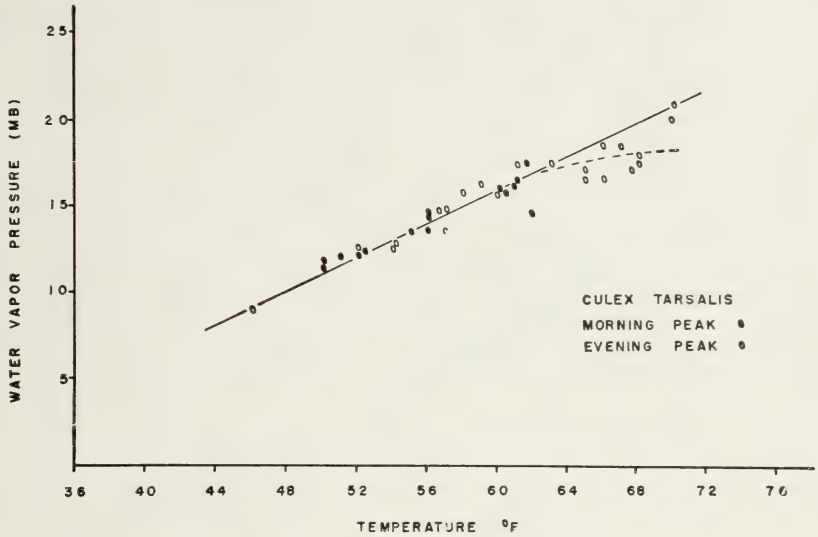

FIG. 4. Regression between atmospheric water-vapor pressure and temperature for daily peaks of activity at the 5-ft level for *Culex tarsalis* on open prairie

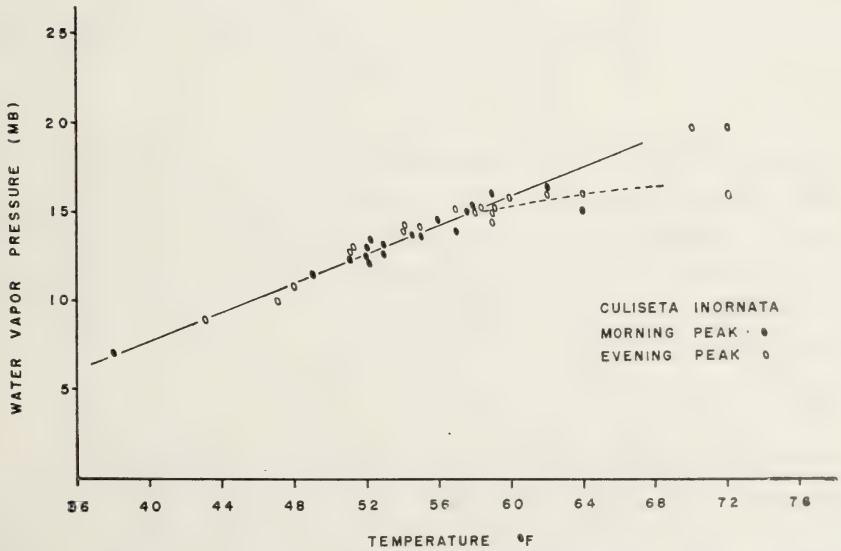

FIG. 5. Regression between atmospheric water-vapor pressure and temperature for daily peaks of activity at the 5-ft level for *Culiseta inornata* on open prairie

quantitatively in a climate chamber, the combinations of temperature and atmospheric vapor pressure supporting maximum activity form curvilinear lines (Fig. 3). These regression lines are usually slightly S-shaped for the more favorable range of the species' environment. They pertain to stabilized breeding and culturing in colonies from which test groups are conditioned to a standard environment (i.e. 23–24° C and 100 per cent R.H. for *Aedes aegypti* in Fig. 3) except while subjected to short-period hygrothermal stimulation for flight. Response and duration of activity vary with age and/or starvation.

Populations in the field sooner or later tend to approach heterogeneity in state of starvation and the response to hygrothermal environment is more variable. The peaks of consecutive circadian rhythms of flight activity show similar regressions (Figs. 4, 5) between temperature and vapor pressure when short-term (15 min to 1 hr) continuous interval catches are recorded for a whole season's activity. Point clouds show considerable variability, probably due to age distribution, degree of starvation, and other environmental factors such as wind and rain. However, for practical purposes, they provide straight-line estimates of response for individual species when they represent complete and continuously recorded seasonal sets of data.

Rhythms

Circadian rhythms are apparent in the activity of most, if not all, mosquito populations. Simultaneous sampling in subarctic environments of mosquitoes flying and those flushed from resting sites on the ground indicates that daily flight peaks represent variable portions of the total population in an area. A variation in flight activity with a periodicity of approximately 5 days appears to underlie the usual 24-hr rhythm for some univoltine species. A slight damping of this variation toward the end of the mosquito season indicates that this may be a feature of single-brooded species that emerge suddenly within very short periods of 2 to 3 days in northern climates. The observation of a 3 to 4-day cycle in the blood-feeding habits of *Aedes aegypti* in laboratory colonies suggests that the field observations may be related to feeding cycles. In connection with synoptic correlation of activity with weather it is essential to detect the long-period variations for some species and to apply approximate corrections in evaluating samples of flight activity for periods of 24 hr or less.

NOMOGRAPHIC ANALYSIS OF ACTIVITY IN RELATION TO HYGROTHERMAL ENVIRONMENT

Physiological relationships between response and environment as outlined briefly above may be integrated and applied to the standard psychrometric chart as a schematic method for synoptic predictions of mosquito activity (Fig. 6). Hygro-

thermal variation in the air as represented by a regression between moisture content measured as vapor pressure in millibars (mb) and temperature is limited to the area below the saturation line S. Except for the range of hygrothermal conditions outside those that are favorable for activity, the peak numbers of active mosquitoes for diurnal cycles of flight activity occur with combinations of temperature and humidity that fall approximately along straight lines, i.e. *(A)* for *Aedes hexodontus* and *(B)* for *Aedes punctor*. Activation of mosquitoes corresponds to weather changes that increase desiccation within limits that are set by the need to

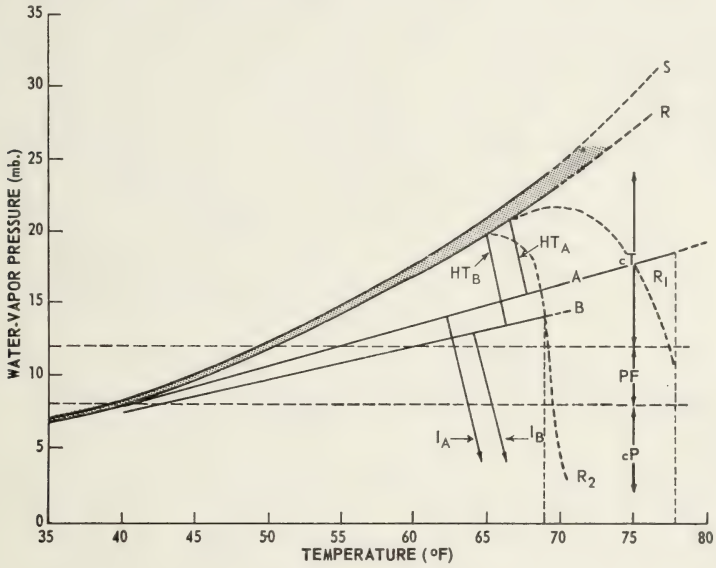

FIG. 6. Relation of an actogram for the *A. punctor-hexodontus-communis* complex to a psychrometric chart and the hygrothermal properties of air masses (See text)

maintain water regulation in metabolism (Ref. Edney, 1957). Thus, the lines A and B represent the hygrothermal conditions that support the maximum rate of activation of individuals in a cumulative frequency of response for heterogeneously adapted populations. In this case a diurnal distribution of active individuals in time corresponds with the cumulative frequency of individuals contributing to a single cycle in the activity of a population. The regression for *A. communis*, the third species in the complex being considered, falls between A and B and therefore has no special significance for synoptic analysis of the activity of the three species as a group. A and B represent an approximate limit for the group activity.

Departure of the hygrothermal environment in the direction I_A or I_B results in the restriction of flight through the need to maintain an adequate water balance. Departure in the opposite direction, HT_A and HT_B, induces the resting state when nearly saturated environments are encountered between S and R. Laboratory experiments in a climate chamber show that, at the critical temperature for flight

activity, the settling response becomes confused with the intense crawling behavior that replaces flight activity at high temperature. The broken lines R_1 and R_2 represent limits in *A. hexodontus* and *A. punctor* respectively for flight subject to increasing temperature. When the environment exceeds these limits on open tundra, mosquitoes cease flying and descend to the sparse moss and lichens where they continue to crawl actively. Since mosquitoes in this state of activity are highly attracted and land on a passing man or animal, bait samples correspond neither with visual-attraction trap samples nor with the meteorological parameters in this synoptic scheme described. Essentially, the moment *HT* represents the hygro-

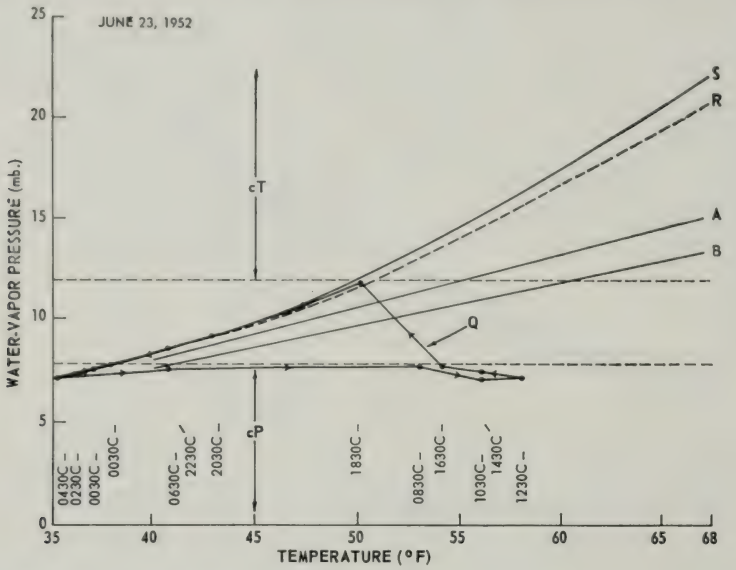

FIG. 7. Relation of the diurnal hygrothermogram to the hygrothermal properties of air masses and the regressions for mosquito activity (See text)

thermal conditions that are favourable for prolonged flight above ground and vegetation until fatigue or a sudden rest-inducing environment (*RS*) occurs.

Also superimposed on the psychrometric chart (Fig. 6) is a classification of the air masses that influence the hygrothermal environment in the polar front zone. When continental polar air *(cP)* prevails over Churchill, moisture content of the surface air remains quasi-constant for 24-hr periods and usually does not exceed a vapor pressure of 8 mb. Prevailing continental tropical air *(cT)* in the same area has vapor pressures exceeding 12 mb. Vapor pressures in the range 8 to 12 mb are associated with transition in the polar front zone during the displacement of tropical air by polar air (or *vice versa*), or by weak temporary invasions of tropical air in the local area. It is apparent from the activity regressions (*A* and *B*) that *A. hexodontus* and *A. punctor* are not typical arctic species since their activities for successful reproduction depend on at least a certain minimum frequency of invasions of modified tropical air in subarctic areas.

The influence of weather as represented by the diurnal regression between atmospheric moisture and temperature constitutes a third superimposition on the psychometric chart. This is illustrated separately (Fig. 7) to avoid confusing the scheme with a congestion of lines. The activity regressions (A and B), the saturation line *(S)*, and the delimitation of vapor pressures characterizing the transition between air masses are carried forward for orientation. The 4-figure numbers across the bottom denote the time (CST) for individual points directly above. The broken line with arrows represents the regression between vapor pressure (mb) and temperature as plotted at 2-hour intervals from 00:30 hr on 13 June to 00:30 hr on 14 June 1952. First it will be noted that vapor pressure is quasi-constant from 00:30 hr until 16:30 hr under the influence of continental polar air. Between 16:30 hr and 18:30 hr vapor pressure increased to 12 mb and near the saturation point. This sudden change coincided with the passage of a cyclonic centre 100 to 200 miles to the south of Fort Churchill and indicates the rather broad area over which mixing of air takes place in association with an approaching warm air mass. From 1830 C until 0030 C next day the regression between temperature and vapor pressure followed the saturation curve resulting in light rain showers during the early night.

A hygrothermogram *(Q)*, the path of the regression between vapor pressure and temperature on the psychrometric chart, is a criterion that may be used to predict the relative abundance of mosquitoes flying in successive diurnal cycles of activity. If Q remains below A and B for the diurnal meteorological cycle, there is little or no activity of *A. punctor* and *A. hexodontus* and flight is limited to small brief peaks, if any, early in the morning and late at night. If Q cuts directly across A and B, as in Fig. 7, activity is slightly greater in terms of numbers but duration is very short, often in the order of 20 to 30 min. If Q falls between B and R, i.e. in the area HT_B, for long periods in the diurnal hygrothermal cycle, maximum numbers become activated and the duration of activity is extended roughly in proportion to the length of time that Q remains within the boundaries of moment HT.

These relationships are illustrated by the trapping record and the plots of diurnal hygrothermal cycles for days during the 1952 mosquito season (Figs. 8 to 11). Q curves were plotted for four consecutive days (24–27 June) when catches were small (Fig. 8). For the first three days Q remained below B and daily catches were 870, 23, and 331 respectively. The largest catch, 870, corresponds with Q nearest to B. On the fourth day, Q followed regressions A and B but, except for the last reading, remained outside the zone of maximum activity potential HT_A. The catch for this period was 1090, greater than the previous three. Figures 9, 10, 11 represent 3 days (5, 15, 25 July) with much larger catches (20,200, 5110, and 16,400 respectively). The Q curve remained within the zone of maximum activity potential for from 10:00 to 14:00 hr on each of these days. The largest catch of the three is associated with the Q curve that remained nearest to the centre of the zone, i.e. between the desiccating conditions promoting immediate but short-lived activity

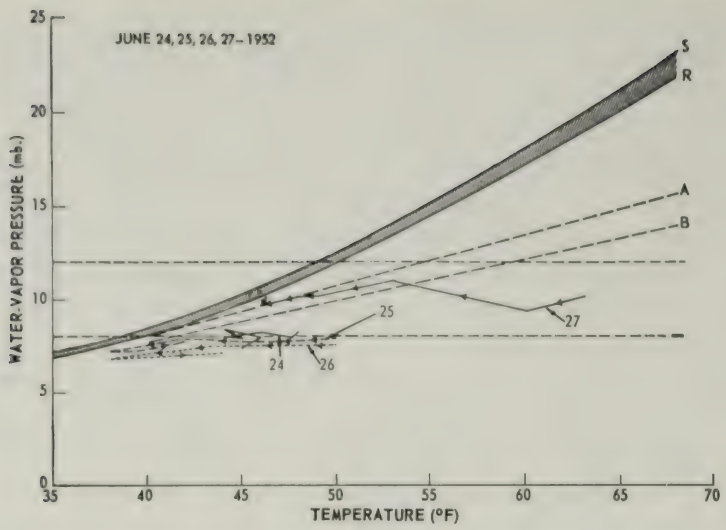

FIG. 8. Hygrothermograms related to low levels of mosquito activity

(AB) and the nearly saturated moisture conditions (RS) that induce settling and the resting state and eventual inactivity.

Thus, the actograms, $A \cdot HT_A$ for *A. hexodontus* and $B \cdot HT_B$ for *A. punctor* approximately define psychrometric conditions that facilitate activity during the desiccating phase of the diurnal weather cycle, and they indicate the lower limits for maintaining water balance in continuous flight. If actograms are known for individual species or for complexes of species with similar behavior, then hygrothermograms and synoptic charts showing air mass trajectories have direct application in explaining variations in activity. They may be used to calculate a biometeo-

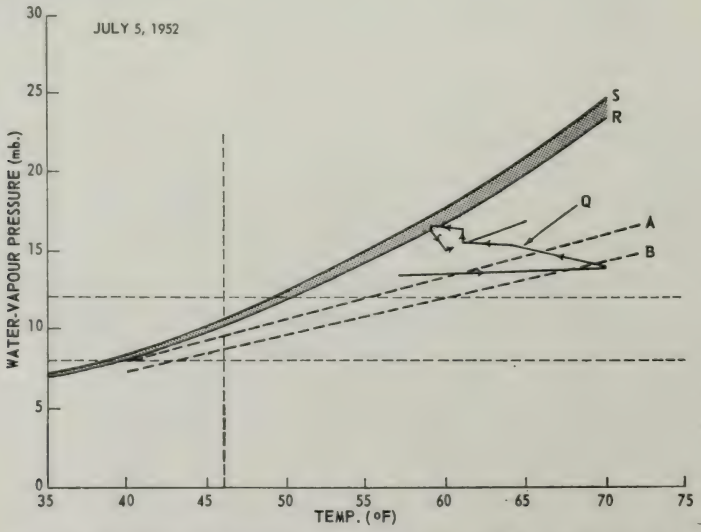

FIG. 9. Hygrothermogram associated with the direct influence of a cyclonic centre causing a very high level of mosquito activity at 5 ft

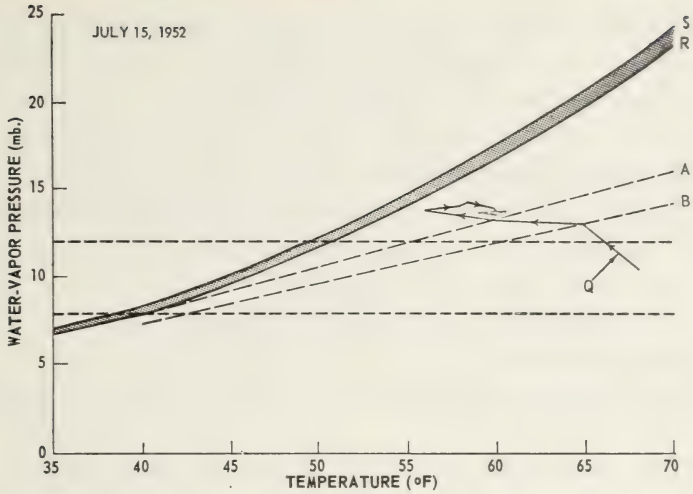

FIG. 10. Hygrothermogram associated with a stationary front that contributes to moderately high mosquito activity at 5 ft

rological index that represents relative favorability of diurnal cycles of weather for flight.

Trap catches in the subarctic studies were separated daily at 08:00 hr to standardize the sorting of mosquitoes and also to facilitate maximum correspondence with the schedule for preparing synoptic maps and tephigrams. A biometeorological index $(P_{Q_{HT}})$ was calculated for 24-hr periods corresponding to the trap catches of the *A. punctor-hexodontus-communis* complex of species. $P_{Q_{HT}}$ is a time-environment

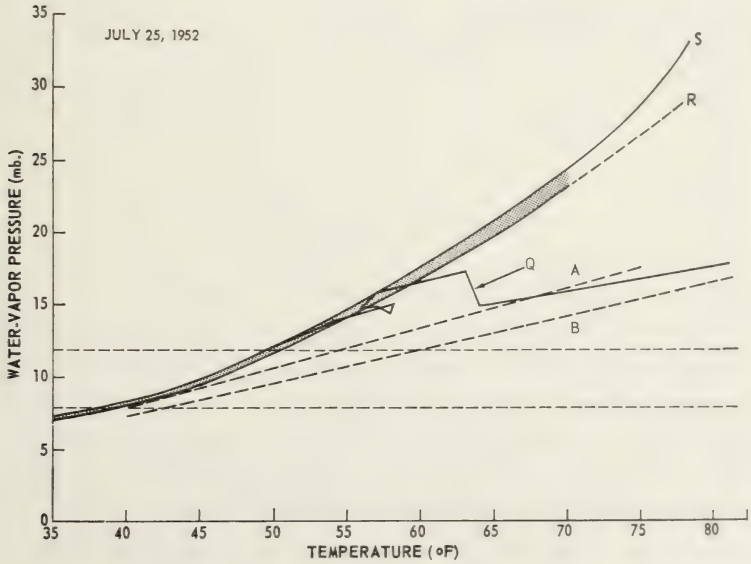

FIG. 11. Hygrothermogram associated with a low pressure trough and a cyclonic centre near the trapping site, conditions contributing to very high mosquito activity

index representing the relation,

$$P_{Q_{HT}} = \frac{(t_{Q_{TH}}+1)}{t_d(T+T_F)+1}$$

where

$P_{Q_{HT}}$ = the index of favorability for activity,
$t_{Q_{HT}}$ = the time in hours for which the hygrothermogram Q represents conditions favorable for flight in each empirical period (within the limits of moment HT, Fig. 6),
t_d = time in hours for an empirical observation period (e.g. 24),
T = air temperature
T_F = mean temperature for maximum activation of mosquitoes,

and $(T \pm T_F)$ is always a positive quantity through the selection of the proper sign.

Since there are biological limits to the behavior of mosquitoes certain limits are also established for $P_{Q_{HT}}$ depending on experimental measurements of flight activity. Flight is inhibited at high temperatures but activity continues in the form of crawling and probing (Haufe, 1964). Consequently, during high temperatures activity is confined to vegetation. There, mosquitoes may select more favorable conditions for limited flight and other forms of activity. Flight is inhibited abruptly in the open air at 69° F for *A. punctor* and *A. communis*. Flight activity of *A. hexodontus*, a hardy species, is reduced in intensity at 70° F and restricted to short flights along the ground up to 78° F. Therefore, an approximate mean upper limit of 70° F was imposed for T relating to the 3 species. For example, at an air temperature

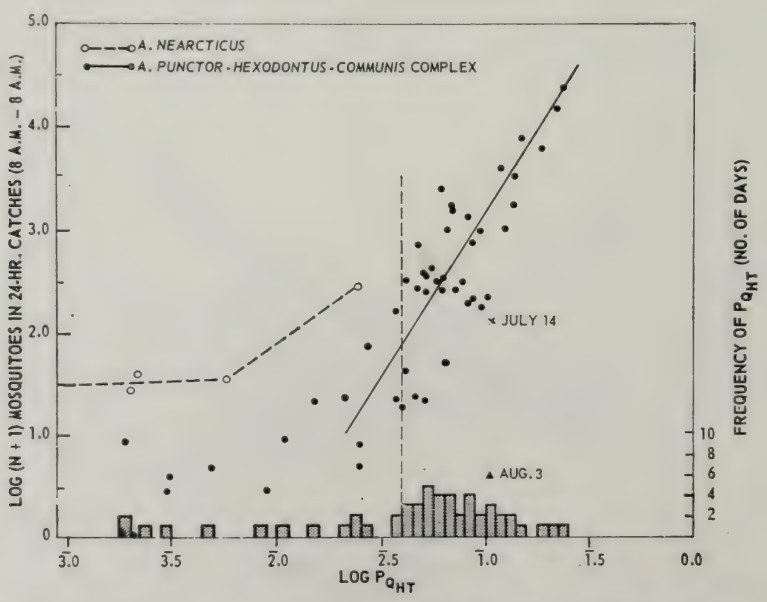

FIG. 12. The relation of the biometeorological index ($P_{Q_{HT}}$) and its distribution for the mosquito season to numbers of flying females caught in 24-hr periods

of 80° F $(T \pm T_F)$ = a maximum effective differential of 10° between 59 and 61° F, the most favorable temperature for flight and the temperature limiting activity to seclusion of vegetation. The ethological basis for this is made clear in another paper that deals with corrections for endogenous cycling of activity. The term $T_d(T \pm T_F)$ represents the degree hours above or below the mean temperature for maximum activation of mosquitoes. Essentially, when it is related to trap catches from an open air stratum between 2 and 8 ft above ground, it is modified to represent continuous flight out of all vegetative shelter.

The numerator and denominator of the biometeorological index incorporate +1 as the final term to accommodate the use of logarithms in calculations. It is found in practice that the regression $B \cdot HT_B$ (Fig. 6) represented the flight limits for the whole *punctor-hexodontus-communis* complex within the order of variation expected for dispersing populations, i.e. regressions for maximum activity of the 3 species are confined to the narrow band between A and B.

High humidity limits flight activity and induces settling and the resting state (Haufe, 1963). The limiting humidity varies with temperature. For the *punctor-hexodontus-communis* complex it is approximately 99 per cent R.H. from 38 to 50° F, 98 per cent R.H. from 50 to 58°, 97 per cent R.H. from 58 to 64°, and 96 per cent R. H. from 64 to 70°. This varying upper limit is also included in calculating $t_{Q_{HT}}$.

A clear relationship between the populations of mosquitoes in flight and the biometeorological index has been observed at Fort Churchill, i.e. for the *punctor-hexodontus-communis* period of 20 June to 9 August, 1952 (Fig. 12). *A. nearcticus* (impiger), one of the two arctic species, is completely adapted to the hygrothermal conditions of arctic air masses and requires a separate index as indicated by the displacement of points from those of the temperate species. The major exception on 3 August for activity of the temperate species is related to unusual conditions in air mass trajectories that are the subject of another paper.

DISCUSSION AND SUMMARY

Other aspects of variation in activity of mosquitoes must be considered in a complete concept of the relation between dispersal and weather. Endogenous cycles in the flight response (Haufe, 1963) are especially important for univoltine species in subarctic environments. They may be equally important in temperate or tropical regions where broods emerge periodically and where development depends on rainy seasons. The role of endogenous periodicities appears to be accentuated when flight activity is related to air mass trajectories and vertical hygrothermal gradients. These factors have been analyzed for subarctic environment at Fort Churchill. They are treated in a later paper that deals with the integrated use of synoptic weather maps and tephigrams in extending application of biometeorological indices for individual species.

Parameters used in synoptic correlation between insect activity and weather have to represent the space-time variations that are most important to the particular level of interaction. For example, the results of bioclimatological work on mosquitoes in subarctic Canada and those on various species studied by Williams (1961) in England and Scotland are significant in showing that statistical methods must be considered in relation to the period represented by insect samples and weather observations. Williams applied conventional methods of partial regression analyses to seasonal fluctuations in numbers of various groups of insects. He found that a large proportion of the variability in populations from year to year could be accounted for by changes in the rainfall and temperature of the three previous months. Not only were the estimates made from partial regressions fairly accurate, but the seasonal changes in regression (putting emphasis on temperature in winter and the rainfall in summer and autumn) were what might be expected from biological reasoning. The subarctic studies on mosquitoes in Canada were based largely on population statistics related to diurnal and other short-period variations that are partially an expression of endogenous rhythms in behavior. Partial regression analyses in this case were inappropriate and inaccurate (Haufe, 1950) for short-term cycles of activity as compared with seasonal fluctuations in Williams' investigations. Cyclic reversal of behavior in individual mosquitoes (Haufe, 1964) obscures the variances in partial regressions for small space-time intervals in correlations, but not for seasonal fluctuations representing mean populations and activity for one or more generations. It is significant that, in both types of investigations, temperature and moisture emerge as important weather factors that determine both abundance and activity.

Parameters in synoptic correlation of mosquito activity have to be considered primarily in relation to seasonal emergence, periodicity of endogenous rhythms, hygrothermal conditions, and vertical distribution. The modifying influence of other meteorological factors such as wind and rain must also be considered in estimating the effect of hygrothermal environment. Vertical distribution and variations in population density with height, not considered in this paper, appear to be complex and involve several factors, some of which have been extensively investigated for aphids and other insects by Johnson (1954, 1957a, 1957b).

SYNOPSIS OF DISCUSSION

Dr. Gloyne was interested in knowing why only surface temperature and vapour pressure were mentioned specifically in relation to the use of tephigrams. Since the tephigram contains much additional information, he was curious from a meteorological point of view how the use of the tephigram might be extended in its use for the type of problem described.

Dr. Haufe replied that the full use of tephigrams is recognized in synoptic studies of mosquito behaviour. Detailed analyses of population dispersal have been completed as the second phase of the investigations at lower latitudes, particularly for

migratory species in irrigated areas of the Canadian prairies. The above paper describes the relation at ground level between mosquito activity and variation in hygrothermal environment. This is primarily the result of alternation between "take-off" and "settling" behaviours which are demonstrated by mosquitoes under experimental conditions in the laboratory. However, the numbers of mosquitoes as observed locally in the field at ground level also depend on variations in the vertical distribution. Mosquitoes, especially the stronger fliers, respond to both horizontal and vertical gradients in the hygrothermal environment in the course of orientated flight. The relative density of mosquitoes at various heights during diurnally periodic flights is influenced by vertical hygrothermal gradients. In this connection, the tephigram provides the third dimension for information on hygrothermal gradients for variations in population density at ground level. The results of these studies are now being prepared for publication in another paper.

In further general discussion on synoptic approaches to problems of insect dispersal, Dr. Gloyne emphasized that meteorologists and biologists must decide on an adequate and mutually acceptable standard in sampling units, i.e. to provide data in which meteorological measurements and insect samples are equally representative in terms of the common unit of space in the environmental study. Dr. Haufe mentioned that this was the major problem in the mosquito studies in Canada. So far, for example, it has not been possible to obtain the facilities to replicate sampling for an adequate basic study. The mosquito work has had to be fitted in with the best existing meteorological facilities in a given area. The muskeg terrain in northern Canada is ideal for correlations from a biological point of view because it breeds dense stable populations of mosquitoes each season. However, distances are too great between well-equipped meteorological stations to provide adequate macrometeorological observations on local variations, i.e. for distances in the order of one hundred miles within the study area. Further studies have been conducted in an irrigated area in Alberta to take advantage of a more complete regular system of meteorological records; but in this case the correlations have to be based on a highly irregular production and movement of mosquito populations.

REFERENCES

Berry, F. A., Bollay, E. and Beers, N. R. (1945) *Handbook of Meteorology*. McGraw-Hill, London.

Edney, E. B. (1957) *The Water Relations of Terrestrial Arthropods*. Cambridge University Press, Cambridge, England.

Haufe, W. O. (1950) A preliminary report on the correlation of adult mosquito activity with meteorological conditions – Churchill, 1950. Veterinary-Medical Entomology Unit unpublished report, Can. Dept. of. Agric., 67 pp.

Haufe, W. O. (1954) The effects of atmospheric pressure on the flight responses of *Aedes aegypti* (L.). *Bull. Ent. Res.* **45,** 507–526.

Haufe, W. O. (1957) Importance of air movement as a factor in mathematical expressions for biological response to environment. Rep. First Biocl. Congr., Vienna, 23–27 Sept. 1957, Int. J. Bioclimat. Biometeor. I, IIIB, 1957.

HAUFE, W. O. (1958) Quantitative study of flight in adult mosquitoes by interactions of physical factors in the environment. Ph. D. Thesis, University of London, England.

HAUFE, W. O. and BURGESS, L. (1960) Design and efficiency of mosquito traps based on visual response to patterns. *Can. Ent.* **92,** 124–140.

HAUFE, W. O. (1961) Effect of adaptation on stimulation of flight in *Aedes aegypti* (L.) in a changing environment. *Can. Ent.* **93,** 522–539.

HAUFE, W. O. (1962) Response of *Aedes aegypti* (L.) to graded light stimuli. *Can. J. Zool.* **40,** 53–64.

HAUFE, W. O. (1963) Ethological and statistical aspects of a quantal response in mosquitoes to environmental stimuli. *Behaviour* **20,** 221—241.

HAUFE, W. O. (1964) Quantitative measurements of activity of *Aedes aegypti* (L.) (Culicidae: Diptera) in response to changes in the hygrothermal environment. Some critical experiments with a brief review for insects. *Int. J. Biometeor.* **7,** 245–264.

HAUFE, W. O. (1962) Summary report on the synoptic correlation of weather with mosquito activity at Fort Churchill, Manitoba, June–August, 1952. A report prepared for the Defence Research Board, National Defence Headquarters, Ottawa, Ontario, 45 pp.

JOHNSON, C. G. (1954) Aphid migration in relation to weather. *Biol. Rev.* **29,** 87–118.

JOHNSON, C. G. (1957a) The distribution of insects in the air and the empirical relation of density to height. *J. Anim. Ecol.* **26,** 479–494.

JOHNSON, C. G. (1957b) The vertical distribution of aphids in the air and the temperature lapse rate. *Quart. J. Roy. Meteor. Soc.* **83,** 194–201.

WILLIAMS, C. B. (1961) Studies in the effect of weather conditions on the activity and abundance of insect populations. *Phil. Trans.* B. **244,** 331–378.

THE ANALYSIS OF DISPERSAL MECHANISMS IN *CONOPHTHORUS CONIPERDA* SZ.

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Abstract – *Conophthorus coniperda* over-winters as callow adults in aborted cones on the forest floor. Emergence in spring is initiated by warming and increasing day length. While the beetles are cutting to the surface of the brood cones, they fill their guts, lose their normal thigmotropism and their flight inhibition. After emergence, the beetles are photopositive to diffuse light sources. The beetles take off in the warmest parts of the day and fly upward toward the diffuse sky light. On rising above the tops of the trees, being exposed to the point source of the sun, they are indifferent to light and orient to dark silhouettes. They probably locate the cones of the new crop by chemical stimuli.

Zusammenfassung – *Conophthorus coniperda* überwintern als ungefiederte erwachsene Käfer in verkümmerten Zapfen auf dem Waldboden. Das Auftreten im Frühling wird durch Wärme und verlängerte Tagdauer eingeleitet. Beim Durchbeissen an die Oberfläche der Zapfen füllen die Käfer die Därme, verlieren den normalen Thigmotropismus und die Flugunfähigkeit. Nachher sind sie für diffuse Lichtquellen photosensitiv. Zur wärmsten Tageszeit fliegen die Käfer aufwärts in Richtung auf das diffuse Himmelslicht. Im direkten Sonnenlicht über den Baumspitzen reagieren sie auf Licht indifferent und orientieren sich nach dunkeln Silhouetten. Die frischen Kiefernzapfen lokalisieren sie wahrscheinlich durch chemische Reizstoffe.

Résumé – *Conophthorus coniperda* hiverne comme insecte adulte, mais sans ailes dans des cônes malformés gisant sur le sol de la forêt. Sa sortie au printemps est déterminée par les températures plus élevées et par l'allongement des jours. En perçant les cônes pour gagner l'extérieur, les insectes se remplissent les intestins, perdent leur thigmotropisme naturel ainsi que leur incapacité de voler. Ils sont ensuite sensibles à des sources lumineuses diffuses. Pendant les périodes les plus chaudes de la journée, ces insectes s'envolent vers le haut c'est à dire vers la lumiére diffuse du ciel. Arrivés au-dessus des couronnes, c'est à dire dans les rayons directs du soleil, ils réagissent de façon indifférente à la lumière et s'orientent vers les silouettes les plus sombres. Ils localisent vraisemblablement les cônes frais des pins au moyen de substances chimiques attractives sécrétées par les arbres.

For many years it has been recognized that the dispersal of organisms from their breeding site is a fundamental characteristic of all living things. For a long time, however, the study of dispersal was confined to a more or less anecdotal examination of such spectacular movements as the migration of birds, the periodic migration of lemmings, seasonal movements of the larger ungulates and some of the

spectacular marine migrations. More recently, the biometeorological and behavioral aspects of the phenomenon in general have been of interest and in this contribution I present a summary of my investigations on the biometeorology and behavioral components of dispersal in a common scolytid.

The life history of *Conophthorus* is very simple (Godwin, 1959). The adult beetles bore holes in the petioles of the developing female flowers of white pine throughout its range in eastern North America. Mating takes place within the tunnels in developing cones and the adults feed in one and sometimes two cones as the gonads mature. The eggs are laid within the cones and the adults usually die close to the site of egg-laying.

Larvae hatch in late May, feed in the cones through June, and pupate. Severance of vascular tissue by feeding larvae causes the cones to abort. During midsummer the small aborted cones fall to the forest floor and within these cones the callow adults emerge from their pupal cases and pass the remainder of the summer and the following winter. The following spring the adults cut to the surface of the brood cones, emerge, climb up through the duff and fly to the developing cones of the current crop. It is quite remarkable in this life history that the adult insects remain at the feeding site from late July to the following May without emerging and without entering a true diapause. As we shall see later they also refrain from feeding during this entire period. Then suddenly in spring, the adults start to feed, emerge from the cones, fly actively to the new sites and just as suddenly lose their dispersive habit and again become sessile inhabitants of the host tissues. The behavior associated with dispersal thus may be resolved in the response of the insects to the environmental stimuli and the means whereby these responses are linked to the phenology of the host.

My first investigations were designed to examine the behavior of adults taken from the brood cones. A series of aborted cones containing callow adults was collected in the field at bi-weekly intervals from mid-August to the time of emergence in the following May. The adult beetles were dissected from these cones and maintained in petri dishes on wet filter paper. From the very start of the investigations on the behavior of these callow adults there was a persistent difficulty. When placed in a gradient apparatus, on a light board or in any other standard test situation, the insects persistently sought out and wedged themselves in the most acute angles in the sides of the arenas. Then they refused to move. If one used very large arenas the animals reacted in perfectly standard ways unless they encountered each other in the course of their movements. In that case they would squeeze together and refuse all further movement.

At first this reaction appeared to be merely a source of experimental difficulty and I responded by testing the animals one at a time in very large arenas where they could not locate the edges. In this way I was able to show that the thermal preferendum of the unaggregating insects changed as the insects were held in a temperature gradient (Henson, 1960). The effect of time and gradient on the temperature choice exhibited by the animals is illustrated in Table 1. As may be

Table 1.

Time (min)	Mean temp. °C	Time (min)	Mean temp. °C	Time (min)	Mean temp. °C
0	28.0	45	29.7 ±1.4	90	28.5 ±1.4
5	28.2 ±0.2	50	29.1 ±1.2	95	28.5 ±1.4
10	28.5 ±1.0	55	28.9 ±1.3	100	28.5 ±1.4
15	30.1 ±2.4	60	28.7 ±1.7	105	28.5 ±1.3
20	31.6 ±3.0	65	28.5 ±1.9	110	28.5 ±1.3
25	31.4 ±2.8	70	28.4 ±1.8	115	28.5 ±1.2
30	31.0 ±2.0	75	28.5 ±1.6	120	28.5 ±1.1
35	30.5 ±1.6	80	28.5 ±1.5		
40	30.0 ±1.5	85	28.5 ±1.5		

seen, after 20 min in the apparatus, the mean temperature chosen was 32° C. After an hour the mean temperature was 28.5° C. By similar means I was able to show (Henson, 1964) that the callow insects always chose the wet end of humidity gradients; that they were photopositive under virtually all circumstances; that they were susceptible to cold trapping at temperatures below 8° C and that their light reaction could be reversed at 42° C. Heat convulsion can be induced at 43° C. In addition, I found that these callow insects never flew. All the standard means of inducing flight in scolytid beetles were completely ineffective (Henson, 1962).

This last observation led me to examine the internal anatomy of the adults throughout their lives (Henson, 1961). A series of material collected throughout the entire year was dissected and it was shown that the flight muscles were anatomically normal from the time of emergence of the callow adults within the brood cones to within a few hours of their re-establishment following dispersal in the cones of the subsequent year's crop. At this point the flight muscles degenerated suddenly and just as suddenly the gonads became active.

The insects' guts were empty up to the time of emergence from the over-wintering cones. It appears that the callow adults are anatomically capable of flight, and there is at least a suggestion that the introduction of material into the gut is required before flight can occur.

At this point I undertook a series of experiments on the tendency of the insects to form groups or aggregations. First a series of groups of the insects varying in number from 10 to 100 were placed in the temperature-gradient apparatus. The insects chose higher mean temperatures as the group size increased (Table 2). A very large series of insects was then exposed in the gradient and the temperature chosen by each of the insects was recorded by a mapping technique. The results were plotted and the positions of the aggregated insects were indicated separately (Table 3). The unaggregated insects chose a mean temperature of 28.6° C, while those that were aggregated chose 31.5° C. Interestingly enough, the mean

Table 2. The Effect of Numbers of Insects in a Temperature Gradient on the Mean Temperature Chosen after 1 hr Exposure

Number of insects	10	20	30	40	50	60	70	80	90	100
Mean temperature	27.6	28.0	28.5	28.4	28.8	28.6	29.3	29.8	29.8	30.2
SD	0.7	0.9	1.4	1.6	1.7	1.8	2.5	2.4	3.0	3.4

Table 3. Distribution of Aggregated and Non-aggregated Insects in a Temperature Gradient

Temperature °C	27	28	29	30	31	32	33	34
No. non-aggregated	6	11	15	10	2	0	0	0
No. aggregated	0	2	0	4	10	8	6	2
Total	6	13	15	14	12	8	6	2

temperature selected by the unaggregated single insects after only 20 min in the gradient was equivalent to that shown by the aggregated insects after an hour. This strongly suggests that the aggregated insects are in the position they adopted only a few min after they were introduced into the gradient. On repetition of these experiments with a few variations I was able to show that the aggregations are formed as soon as the insects collide and that after their introduction into the gradient they tend to choose a rather high temperature and to move rather rapidly. The probability that such insects will collide and form stable aggregations is high. Those that do so are fixed by their aggregative behavior and the remainder move down the gradient as they lose water to occupy final temperatures of about 28.5° C.

The behavioral basis of this rather odd aggregation appears to be a simple thigmotropic reaction of a sort which, once engaged, prevents further orientation of the insect and largely inhibits further movement. Thus the aggregations are stable and almost immobile. They are not the result of chemical attraction and the basic response may be induced by surroundings which permit the animal to increase the degree of its body contact. The extent of the aggregation is influenced by a variety of environmental factors but only inasmuch as these factors modify the overall activity of the insect (Henson, 1961). By repeating these experiments throughout the course of a year I was able to show that the thigmotropic response is present throughout the adult life with the exception of the short dispers-

ive period. Adults trapped in flight from the forest floor to cones of the current crop are virtually without the thigmotropism. On the other hand, insects show some return of the reaction following the entry into the cones of the new crop and the degeneration of their flight muscles.

These findings focused my attention on the profound differences between the active dispersing insects and those found both in the over-wintering cones and the cones of the new crop. Other workers had recently shown (Godwin, 1959) that the adults emerge from the over-wintering cones after a short period of warm weather in the spring. In the laboratory I did a series of experiments on the conditions that would induce this emergence.

A certain amount of emergence could be obtained by simply warming up the cones in a moist atmosphere. However, the best emergence was obtained when the cones were held moist with a 12 hr day length at a temperature of 25° C during the light and 15° C during the dark. Continuous light inhibited the emergence about 60 per cent and continuous dark inhibited the emergence about 80 per cent. A change as small as 30 min in day length could be shown to affect the proportion of the beetles which emerged.

The beetles obtained in the laboratory by these means appeared to be, in the behavioral sense, equal to those trapped during dispersal in the field. They flew readily, their guts contained a good deal of material ingested from the over-wintering cones and their responses to temperature, humidity and discrete sources of light were rather similar to those obtained previously. In addition to their ability to fly, these insects were almost completely free from the thigmotropism which leads to aggregation.

An extensive series of experiments was done on the behavior of the "dispersive" (incubator emerged) insects. The effect of temperature on walking speed, (Table 4) was very similar in moist and dry air at temperatures between 10° and 30° C. Above that temperature in dry air the maximum speed was attained at 40° and the insects became disoriented at 42.5° C. In marked contrast, in saturated air the

Table 4. Effect of Temperature and Moisture on Walking Speed

Temperature °C	20	15	20	25
cm/min, dry air	4.6 ±0.8	6.1 ±3.5	9.1 ±4.9	10.0 ±5.1
cm/min, moist air	4.2 ±0.1	6.2 ±1.5	12.1 ±2.5	10.1 ±5.0
Temperature °C	**30**	**35**	**40**	**45**
cm/min, dry air	18.2 ±7.5	15.1 ±10.1	23.1 ± 6.3	0.0
cm/min, moist air	18.5 ±7.5	33.6 ±15.2	18.2 ±10.1	0.0

speed increased very greatly between 30° and 32.5° C. The maximum walking speed was attained at 35° and there was a spurt of activity at 42.5° with death ensuing at 45° C. The very high temperature at which the maximum walking speed was attained is in some contrast to the supposed preferred temperature. The choice exhibited was sufficiently far removed from the apparent temperature for optimum locomotion that gradient behavior of these insects was reinvestigated.

Table 5. Numbers of Insects at Various Temperatures in a Linear Gradient: Dry and Moist Air

Temperature °C	20	22.5	25	27.5	30	32.5	35	37.5
No. Insects, dry air	0	4	3	65	30	27	0	0
No. Insects, moist air	0	5	0	40	55	29	5	0

From Table 5 it will be seen that the behavior of the insects in gradients of temperature is not greatly influenced by the humidity. At both wet and dry conditions the insects congregate about 30° C.

In gradients of humidity, the insects chose saturated conditions at all temperatures when offered a choice between saturation and 75 per cent R.H. Similarly, they chose the higher humidity in conditions involving rather low humidity contrasted with saturation, except at very high temperatures. Particularly at the higher temperatures, the insects chose dryer conditions or were disoriented to humidity at lower humidity choices. This sort of behavior is rather unusual but it is probably related to the water conservation problems that the insects face. Under the range of experimental conditions used, the insects were probably dehydrated. When given a choice of humidities at the upper end of the scale they chose the one which would permit conservation of their moisture. At the lower humidities the insects became indifferent to moisture gradients. I would suppose the selective advantage of this behavior to the insect would be to permit it to orient by humidity gradient only within the very steep and moist gradients immediately surrounding a transpiring surface. In the dryer and less steep gradients of the open air, the insects would be disoriented to humidity or evaporation and thus would be free to move down the moisture gradient from the duff to the crowns of the trees while orienting by light or some other stimulus.

The insects in their dispersive phase undertook spontaneous flight most frequently at temperatures between 27.5° and 35° C (Table 6). Flight frequency was increased by exposure to dry air, provided this exposure did not persist long enough to induce water loss greater than 2 per cent of body weight. Preliminary exposure to light during the initial exposure to dry air increased the tendency

Table 6. Effect of Temperature and Preflight Conditions on Frequency of Spontaneous Flight

Temperature °C	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5	40.0
	Number of flights per 10 min, among 20 insects								
Light, dry air	1	9	14	17	18	13	11	6	4
Light, wet air	0	2	3	3	5	6	5	3	2
Dark, dry air	0	5	5	4	8	7	6	5	4
Dark, wet air	0	0	1	3	3	5	6	5	1

to flight (Henson, 1962). On flight mills the insects continued to fly for periods up to 5 km, but the vast majority of tethered flights were only of a few minutes' duration. Maximum flight took place at 15:00 hr in a 12-hr day with dawn and dusk at 06:00 and 18:00 hr respectively. In free flight in the laboratory the insects were indifferent to a point source of light in a horizontal plane. They were disoriented to point sources of light at altitudes above 30°. They were strongly photopositive to diffuse light at any altitude. When not orienting to light, as in the presence of a high point source, the insects tended to fly horizontal courses and to orient to dark silhouettes.

We may now summarize the sequence of events and responses in the spring which leads the over-wintering insects to emerge from their cones in the duff of the forest floor, to fly to the leaders of the overstory trees and to enter their reproductive phase in the cones of the new crop.

(1) The moist cones in the duff of the forest floor are warm during the period of day length approaching 12 hr.
(2) The beetles cut to the surface of the cones and fill their guts with the substance of the over-wintering cones.
(3) The filling of the gut suppresses the thigmotropism and flight inhibition.
(4) The beetles emerge into the duff.
(5) The photopositive beetles climb through the duff to exposed positions on the forest floor.
(6) After a period of warming in dry air, the beetles take off.
(7) The photopositive beetles fly upwards to the diffuse sky light and emerge above the trees.
(8) On emergence above the trees the beetles are exposed to the point light source of the sun and become disoriented to light.
(9) The light-disoriented beetles fly horizontally and orient to the dark silhouettes of the trees' leaders.
(10) They land on the leaders and locate the developing cones – probably by chemical stimuli. Once the beetles cut into the petioles of the developing

cones and ingest the fresh material, their flight muscles degenerate, their gonads become active, and the thigmotropic response is partially re-established.

We now have a suggestion of the beautiful mechanism which permits an insect to live in a very specific locality throughout many months and to exercise its dispersive capacity only under rigidly limited circumstances very closely related to the phenology of the tree. From the viewpoint of synoptic conditions it is clear that sufficient warming of the duff to permit emergence only occurs in periods of clear dry weather. The emerged beetles only fly in large numbers when they are able to bask in warm dry air at the surface of the duff from early in the morning until the mid afternoon. Under these weather circumstances it is virtually certain that the necessary light conditions which permit two discreet light reactions to occur in sequence will be found.

I have presented this material in some detail because I think that the mechanism involved is of general interest. I do not suppose that it is widely distributed in this exact form. I think that analogous mechanisms must be rather general. From the viewpoint of efficiency it appears clear that the existence of an intact mechanism throughout the life history of an animal but evoked only under very specific circumstances has considerable selective advantage over the necessary temporary establishment of this mechanism only when it is required. It is perfectly clear that the minute beetles require a considerable sequence of behavioral abilities in order to find their new breeding site. Each individual possesses the intact mechanism together with a single phenologically linked release mechanism. What is more, the nature of this release mechanism is such that the dispersive behavior will be evoked only under synoptic conditions well suited to its expression.

SYNOPSIS OF DISCUSSION

Dr. T. Lewis pointed out the similarity between the behaviour described for *C. coniperda* and that for some of the thrips, especially *Limothrips cerealium* Hal. Thrips also aggregate in crevices in autumn when they are positively thigmotactic and negatively phototactic. In spring these responses are reversed and the thrips emerge and fly away when the sun dries the bark. In dispersing they spiral away toward the diffuse light above the trees.

Dr. C. G. Johnson mentioned observations by other investigators in which the Scolytidae became photonegative after swallowing air. The positive phototaxis in *C. coniperda* after feeding suggested a contrasting mechanism. Mr. Reifsnyder (who presented the paper) was not in a position to comment for Professor Henson).

REFERENCES

GODWIN, P. A. (1959) White-pine cone beetle life history study. Northeastern Forest Experiment Station. Division of Forest Insect Research Quarterly Report, January–March 1959, 2/4.

HENSON, W. R. (1960) An effect of aggregation on the behavior of a beetle (*Conophtorus coniperda* Sz.) in a temperature gradient. *Yale J. Biol. Med.* **33,** 128–132.

HENSON, W. R. (1961) Laboratory studies on the adult behavior of *Conophthorus coniperda* (Schwarz) (Coleoptera: Scolytidae) I. Seasonal changes in the internal anatomy of the adult. *Ann. Ent. Soc. Amer.* **54,** 698–701.

HENSON, W. R. (1961) Laboratory studies on the adult behavior of *Conophthorus coniperda* (Schwarz) (Coleoptera: Scolytidae) II. Thigmotropic Aggregation. *Ann. Ent. Soc. Amer.* **54,** 810–819.

HENSON, W. R. (1962) Laboratory studies on the adult behavior of *Conophthorus coniperda* (Schwarz) (Coleoptera: Scolytidae) III. Flight. *Ann. Ent. Soc. Amer.* **55,** 524–530.

HENSON, W. R. (1964) Laboratory studies on the adult behavior of *Conophthorus coniperda* (Schwarz) (Coleoptera: Scolytidae) IV. Responses to temperature and humidity. *Ann. Ent. Soc. Amer.* **57,** 77–85.

INFLUENCE OF DARK ENVIRONMENT ON THE VARIOUS CHARACTERS OF *DROSOPHILA MELANOGASTER*

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Abstract – The authors reared *(Drosophila melanogaster)* in constant darkness for about 240 generations in 10 years to investigate effects of changes in the environment.

(1) The flies kept under constant darkness (the dark flies) became more sensitive to light than the flies kept under normal daylight environment (the normal flies). The dark-adapted flies showed more vigorous phototactic and photokinetic behavior under experimental conditions. After returning the "dark" flies to normal daylight environment, changed behavior was retained for more than 100 generations, showing that it was hereditary.

(2) The fecundity of the "dark" flies became greater than that of the normal flies.

(3) The developmental rate of the "dark" flies was retarded.

(4) The periodicity of daily emergence of the dark flies was altered, first becoming more obscure than that of the normal flies before the 135th generation, then becoming more distinct in the later generations.

(5) It is significant that the microstructure of the compound eye, when examined through the electron microscope, showed morphological variation related to behavioral and physiological changes in the fly. The microvilli of the rhabdomeres degenerated and the protoplasmic structure at the base of the microvilli became coarser. These characteristics were found to be common in cave animals having the compound eye.

Zusammenfassung – Die Autoren haben in 10 Jahren ungefähr 240 Generationen Taufliegen *(Drosophila melanogaster)* in konstanter Dunkelheit gezüchtet.

(1) Im Dunkel gezüchtete Fliegen wurden lichtempfindlicher als Normalfliegen. Die dunkeladaptierten Fliegen zeigten im Experiment lebhafteres phototaktisches und photokinetisches Verhalten. Wenn dunkeladaptierte Fliegen im Normaltag weitergezüchtet wurden, war das veränderte Verhalten noch nach 100 Generationen nachweisbar – ein Beweis dafür, dass es erblich ist.

(2) Die Furchtbarkeit der dunkeladaptierten Fliegen war grösser als der Normaltag-Fliegen.

(3) Die Entwicklungsrate von Dunkel-Fliegen war verzögert.

(4) Die Periodik des täglichen Erscheinens von Dunkel-Fliegen war verändert: bis zur 135. Generation war sie undeutlicher, dann wurde sie deutlicher als bei Normaltag-Fliegen.

(5) Die elektronenmikroskopische Untersuchung des Facettenauges zeigte morphologische Veränderungen, die in Beziehung zu der Veränderung der Physiologie und des Verhaltens der Fliegen standen. Die Mikrovilli der Rhabdomeren degenerierten und die protoplasmatische Struktur am Boden der Mikrovilli war grobkörniger. Diese Eigenarten sind charakteristisch für Höhlentiere mit Facettenaugen.

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Résumé – En 10 ans, les auteurs ont élevé environ 240 générations de mouches du vinaigre (Drosophila melanogaster) dans une obscurité complète.

(1) Les mouches élevées dans l'obscurité étaient plus sensibles à la lumière que les mouches normales. Elles présentaient, dans cette expérience, une plus grande activité phototactique et photocinétique. Si les mouches adaptées à l'obscurité étaient ensuite élevées à la lumière normale, cette modification était encore nettement perceptible après 100 générations. La preuve est ainsi faite que cette modification était héréditaire.

(2) La fécondité des mouches adaptées à l'obscurité a été plus grande que celle des mouches normales.

(3) Le développement général des mouches adaptées fut par contre plus lent.

(4) La périodicité de l'apparition diurne des mouches adaptées était modifiée: jusqu'à la 135 ème génération, on a constaté une périodicité moins nette, puis cette périodicité devient au contraire plus marquées que pour les mouches normales.

(5) L'examen des yeux à facettes au microscope électronique montre des modifications morphologiques qui sont en relation étroite avec les modifications physiologiques et celles du comportement des individus. Les microvilli des rhabdomères ont dégénéré et la structure du protoplasma situé à la base des microvilli présentait un grain plus grossier. Ces particularités sont caractéristiques pour les insectes vivant normalement dans des cavernes et possédant des yeux à facettes.

It is widely known that the cave animals show certain characteristics, for example, more or less degenerated eyes, degenerated chromatophores, degenerated wings, and well-developed bristles. But the mechanisms by which these characteristics have been brought about are not fully clarified at present.

Almost all Western scientists who have been studying *Drosophila* flies are of the opinion that no change can be induced by culturing them in darkness. This conclusion seems to originate in the early work of Payne (1910, 1911) and Northrop (1926).

The authors had some doubts about these conclusions. The relation between animals and environments is so close that it would be impossible for animals to remain unchanged when they were reared in total darkness for a long time. To get data supporting this hypothesis the authors planned an experiment and began to culture *Drosophila* flies in total darkness in 1954.

The purpose of this paper is to describe the general outline of the results of series of experiments and to introduce the results of the work of Drs. Kuwabara and Eguchi on the microstructure of the compound eye with the electron microscope.

MATERIALS AND METHODS

A couple of *Drosophila melanogaster*, Oregon RS strain, whose original stock had been cultured in Pearl's synthetic medium for about 140 generations since the spring of 1948, were separated from the original stock in 1954. The offspring were divided into 6 independent strains, of which 3 strains were reared under normal daylight conditions (the light series; aL, bL and cL) and the remaining 3 strains were cultured in continuous darkness (the dark series; dD, eD and fD). Both sets were cultured in Pearl's medium at 25° C.

RESULTS

Changes in Phototactic and Photokinetic Reactions

1. Ordinary experiment. At intervals of a few generations, or of several tens of generations, the phototactic reactions of the flies were tested. Test flies from the dark series were reared, for one generation from the egg stage, in normal daylight. Ten males or ten females, 2 or 3 days after emergence, were put into a test tube (Fig. 1; diameter 3.5 cm, length 40 cm) and dark adapted. Twenty min later, the flies were gathered at one end of the tube and the test tube was illuminated longitudinally from the opposite end, by a parallel light source (about 440 lux at the center of the tube). The flies began to move toward the light source, and the number of individuals passing across the line marked at the center of the test tube was counted every 15 sec during 1 min. The number passing across during the first 30 sec was taken as an index of the degree of "phototaxis + photokinesis". This counting was repeated three times with the same materials.

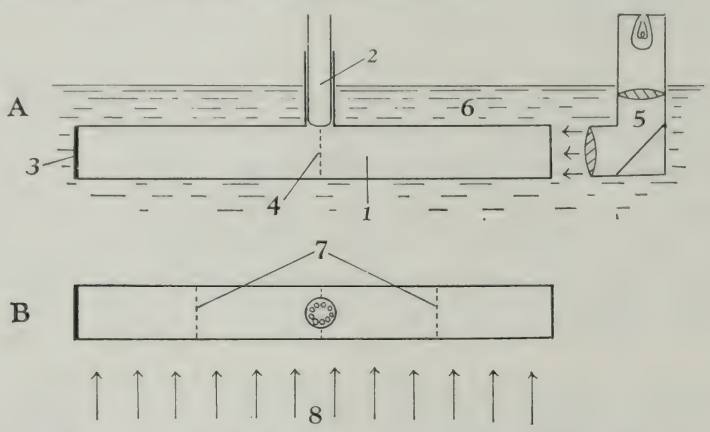

FIG. 1. Schematic representation of the experimental equipment for phototactic behavior.
A. Side view, when illuminated longitudinally by a parallel beam from a 100 watt electric bulb (5). 1. Test tube. 2. Side arm (diameter 1.5 cm, length 9 cm) for introducing flies to test tube, having a cylindrical, hollow glass stopper, the upper end of which was opened and the lower end perforated to ensure aeration of the test tube. 3. End of the test tube coated with black lacquer, from which the flies started toward the light source. 4. Central mark line. 6. Water with temperature controlled at 25° C. B. Top view, when illuminated from lateral side with diffused light (8). 7. Other mark lines

The light source was then extinguished and a diffused light source, which illuminated the side of the test tube at about 550 lux, was switched on (Fig. 1). The number of individuals moving within 1 min across three lines (drawn on the tube equally spaced) was counted. The numbers thus obtained were taken as an index of the degree of "photokinesis".

These sets of experiments were repeated twice for each strain with males and females respectively. Tables 1 and 2 show the differences in "phototaxis + photo-

kinesis" reaction between the normal and dark flies of the males and females respectively, and Tables 3 and 4 show the difference in "photokinesis" behavior between the normal and dark flies of the males and females respectively.

Table 1. Difference in the "Phototaxis + Photokinesis" Reaction of Males seen between the Normal Flies and the "Dark" Flies. Figures in parentheses show numbers of individuals (out of 10) which moved across the central line of the test tube during first 30 sec after the lamp was lighted after 20 min dark adaptation. Two values in parentheses are obtained with respect to different sets of 10 male flies. Bold-face figures indicate the averages of these numbers, which were summed up with respective generations and series. Figures written beside the L or D show the numbers of generations; e.g. $eD_{50}L_1$ indicates the flies of a strain grown in normal daylight after having been maintained in constant darkness for 50 generations

Date of Experiment	Normal light series			Dark series		
29–31 May, 1956	aL_{30}	(7, 4)	*5.5*	$dD_{33}L_1$	(6, 7)	*6.5*
	bL_{30}	(5, 7)	*6.0*	$eD_{33}L_1$	(7, 5)	*6.0*
	cL_{30}	(6, 9)	*7.5*	$fD_{33}L_1$	(7, 10)	*8.5*
	total		**19.0**	total		**21.0**
6–8 Nov., 1956	aL_{51}	(4, 0)	*2.0*	$dD_{50}L_1$	(4, 3)	*3.5*
	bL_{51}	(1, 1)	*1.0*	$eD_{50}L_1$	(4, 1)	*2.5*
	cL_{51}	(3, 5)	*4.0*	$fD_{50}L_1$	(7, 7)	*7.0*
	total		**7.0**	total		**13.0**
26–27 Nov., 1957	aL_{80}	(1, 4)	*2.5*	$dD_{79}L_1$	(2, 8)	*5.0*
	bL_{80}	(4, 4)	*4.0*	$eD_{79}L_1$	(1, 2)	*1.5*
	cL_{80}	(4, 6)	*5.0*	$fD_{79}L_1$	(4, 7)	*5.5*
	total		**11.5**	total		**12.0**
19–20 Dec., 1957	aL_{82}	(7, 0)	*3.5*	$dD_{81}L_1$	(9, 6)	*7.5*
	bL_{82}	(0, 3)	*1.5*	$eD_{81}L_1$	(2, 5)	*3.5*
	cL_{82}	(4, 3)	*3.5*	$fD_{81}L_1$	(4, 9)	*6.5*
	total		**8.5**	total		**18.5**
15–16 Nov., 1958	aL_{103}	(1, 0)	*0.5*	$dD_{107}L_1$	(3, 4)	*3.5*
	bL_{103}	(0, 2)	*1.0*	$eD_{107}L_1$	(3, 6)	*4.5*
	cL_{108}	(2, 7)	*4.5*	$fD_{107}L_1$	(5, 10)	*7.5*
	total		**6.0**	total		**15.5**
15–16 Oct., 1959	aL_{135}	(1, 4)	*2.5*	$dD_{134}L_1$	(4, 6)	*5.0*
	bL_{135}	(1, 2)	*1.5*	$eD_{134}L_1$	(6, 1)	*3.5*
	cL_{135}	(3, 8)	*5.5*	$fD_{134}L_1$	(2, 9)	*5.5*
	total		**9.5**	total		**14.0**
30 Nov.–1 Dec., 1960	aL_{168}	(1, 1)	*1.0*	$dD_{167}L_1$	(1, 0)	*0.5*
	bL_{168}	(2, 0)	*1.0*	$eD_{167}L_1$	(1, 0)	*0.5*
	cL_{168}	(2, 2)	*2.0*	$fD_{167}Li$	(8, 10)	*9.0*
	total		**4.0**	total		**10.0**
8–9 Feb., 1962	aL_{202}	(1, 1)	*1.0*	$dD_{201}L_1$	(0, 4)	*2.0*
	bL_{202}	(0, 1)	*0.5*	$eD_{201}L_1$	(2, 4)	*3.0*
	cL_{202}	(2, 5)	*3.5*	$fD_{201}L_1$	(3, 9)	*6.0*
	total		**5.0**	total		**11.0**
	Total sum		**70.5**	Total sum		**115.0**

"*F*" test shows highly significant difference between two series. ($F = 8.6$, $0.01 > \alpha > 0.005$).

Table 2. Results of an Experiment Similar to that Explained in Table 1, using Female Flies (Phototaxis + Photokinesis Experiment)

Normal light series			Dark series		
aL_{39}	(5, 5)	*5.0*	$dD_{38}L_1$	(7, 7)	*7.0*
bL_{39}	(3, 1)	*2.0*	$eD_{38}L_1$	(3, 3)	*3.0*
cL_{39}	(1, 5)	*3.0*	$fD_{38}L_1$	(6, 6)	*6.0*
total		**10.0**	total		**16.0**
aL_{51}	(0, 2)	*1.0*	$dD_{50}L_1$	(2, 3)	*2.5*
bL_{51}	(2, 2)	*2.0*	$eD_{50}L_1$	(0, 0)	*0.0*
cL_{51}	(1, 3)	*2.0*	$fD_{50}L_1$	(5, 0)	*2.5*
total		**5.0**	total		**5.0**
aL_{80}	(3, 4)	*3.5*	$dD_{79}L_1$	(3, 1)	*2.0*
bL_{80}	(0, 1)	*0.5*	$eD_{79}L_1$	(3, 6)	*4.5*
cL_{80}	(3, 5)	*4.0*	$fD_{79}L_1$	(6, 7)	*6.5*
total		**8.0**	total		**13.0**
aL_{82}	(10, 3)	*6.5*	$dD_{81}L_1$	(6, 6)	*6.0*
bL_{82}	(3, 0)	*1.5*	$eD_{81}L_1$	(6, 5)	*5.5*
cL_{82}	(4, 4)	*4.0*	$fD_{81}L_1$	(9, 7)	*8.0*
total		**12.0**	total		**19.5**
aL_{108}	(3, 3)	*3.0*	$dD_{107}L_1$	(4, 5)	*4.5*
bL_{108}	(1, 2)	*1.5*	$eD_{107}L_1$	(5, 0)	*2.5*
cL_{108}	(5, 3)	*4.0*	$fD_{107}L_1$	(8, 9)	*8.5*
total		**8.5**	total		**18.0**
aL_{135}	(0, 1)	*0.5*	$dD_{134}L_1$	(3, 1)	*2.0*
bL_{135}	(2, 3)	*2.5*	$eD_{134}L_1$	(3, 6)	*4.5*
cL_{135}	(4, 4)	*4.0*	$fD_{134}L_1$	(6, 5)	*5.5*
total		**7.0**	total		**12.0**
aL_{168}	(0, 1)	*0.5*	$dD_{167}L_1$	(1, 1)	*1.0*
bL_{168}	(0, 0)	*0.0*	$eD_{167}L_1$	(0, 2)	*1.0*
cL_{168}	(0, 2)	*1.0*	$fD_{167}L_1$	(10, 8)	*9.0*
total		**1.5**	total		**11.0**
aL_{202}	(3, 0)	*1.5*	$dD_{201}L_1$	(0, 1)	*0.5*
bL_{202}	(0, 1)	*0.5*	$eD_{201}L_1$	(3, 1)	*2.0*
cL_{202}	(3, 4)	*3.5*	$fD_{201}L_1$	(10, 6)	*8.0*
total		**5.5**	total		**10.5**
Total sum		**57.5**	Total sum		**105.0**

"F" test shows significant difference between two series. ($F = 7.2$, $0.02 > \alpha > 0.01$).

These results show that both male and female flies that were cultured in continuous darkness reacted more vigorously and were more sensitive to sudden illumination than those cultured in normal daylight.

The data show especially that photokinetic response in males and phototactic response in females are chiefly responsible for the difference in behavior.

2. Returning experiment. Do these changes persist after the dark flies are returned to normal daylight environment? If they persist, how long?

Table 3. Response of Male Flies in the Photokinesis Experiment. Each value in parentheses shows the average of three successive readings of the number of individuals which passed across the three lines on the test tube during 1 min, performed immediately after the "phototaxis + photokinesis" experiment had been finished. Two values in parentheses were obtained with respect to different sets of 10 male flies. The averages of these sets are indicated by italic letters, and the bold-face letters show the total sum of three series of the normal and the dark flies

Normal light series			Dark series		
aL_{39}	(30.0, 30.7)	*30.3*	$dD_{33}L_1$	(30.0, 33.0)	*31.5*
bL_{39}	(33.0, 68.7)	*50.8*	$eD_{33}L_1$	(44.3, 59.7)	*52.0*
cL_{39}	(26.0, 43.0)	*34.5*	$fD_{33}L_1$	(31.0, 60.0)	*45.5*
total		**115.6**	total		**129.0**
aL_{51}	(5.7, 6.0)	*5.8*	$dD_{50}L_1$	(7.3, 11.0)	*9.1*
bL_{51}	(11.0, 18.0)	*14.5*	$eD_{50}L_1$	(8.7, 10.7)	*9,7*
cL_{51}	(9.0, 21.0)	*15.0*	$fD_{50}L_1$	(19.3, 22.0)	*20.6*
total		**35.3**	total		**39.4**
aL_{80}	(5.0, 32.7)	*18.8*	$dD_{79}L_1$	(5.0, 47.7)	*26.3*
bL_{80}	(25.7, 30.7)	*28.2*	$eD_{79}L_1$	(18.0, 31.0)	*24.5*
cL_{80}	(5.7, 25.0)	*15.3*	$fD_{79}L_1$	(19.3, 62.7)	*41.0*
total		**62.3**	total		**91.8**
aL_{82}	(13.0, 58.0)	*35.5*	$dD_{81}L_1$	(51.3, 62.3)	*56.8*
bL_{82}	(37.7, 42.3)	*40.0*	$eD_{81}L_1$	(45.7, 47.3)	*46.5*
cL_{82}	(50.7, 13.3)	*32.0*	$fD_{81}L_1$	(56.3, 51.0)	*53.6*
total		**107.5**	total		**156.9**
aL_{108}	(8.3, 64.6)	*36.4*	$dD_{107}L_1$	(23.6, 61.6)	*42.6*
bL_{108}	(24.6, 49.3)	*36.9*	$eD_{107}L_1$	(40.3, 64.6)	*52.4*
cL_{108}	(29.6, 64.0)	*46.8*	$fD_{107}L_1$	(37.6, 93.6)	*65.6*
total		**120.1**	total		**160.6**
aL_{135}	(5.7, 30.3)	*18.0*	$dD_{134}L_1$	(5.7, 35.0)	*20.3*
bL_{135}	(12.3, 12.3)	*12.3*	$eD_{134}L_1$	(19.3, 16.0)	*17.6*
cL_{135}	(17.3, 49.0)	*33.2*	$fD_{134}L_1$	(15.0, 52.0)	*33.5*
total		**63.5**	total		**71.4**
aL_{168}	(2.7, 23.0)	*12.8*	$dD_{167}L_1$	(9.0, 37.0)	*23.0*
bL_{168}	(33.3, 9.7)	*21.5*	$eD_{167}L_1$	(79.0, 48.7)	*63.7*
cL_{168}	(18.0, 33.3)	*25.6*	$fD_{167}L_1$	(64.3, 72.7)	*68.5*
total		**59.9**	total		**155.2**
aL_{202}	(8.0, 7.3)	*7.6*	$dD_{201}L_1$	(24.3, 50.0)	*37.1*
bL_{202}	(14.3, 42.0)	*28.1*	$eD_{201}L_1$	(45.0, 49.3)	*47.1*
cL_{202}	(0.0, 27.0)	*13.5*	$fD_{201}L_1$	(41.3, 52.7)	*47.0*
total		**49.2**	total		**131.2**
Total sum		**613.4**	Total sum		**935.5**

"*F*" test shows highly significant difference between two series ($F = 15.8$, $0.005 > \alpha$).

To solve these problems, the dark flies were returned to the original normal daylight environment after 38 generations in the dark, and also after 81 generations in the dark. These experiments will be called "returning experiments" hereafter.

Table 4. Results of an Experiment Similar to that Explained in Table 3, using Female Flies (Photokinesis Experiment)

Normal light series			Dark series		
aL_{3}	(33.3, 44.3)	*38.8*	$dD_{38}L_1$	(23.3, 27.7)	*25.5*
bL_{3}	(9.7, 22.3)	*16.0*	$eD_{38}L_1$	(13.7, 41.3)	*27.5*
cL_{3}	(13.7, 19.0)	*16.3*	$fD_{38}L_1$	(17.7, 18.0)	*17.8*
total		**71.1**	total		**70.8**
aL_{51}	(7.0, 21.7)	*14.3*	$dD_{50}L_1$	(13.3, 9.3)	*11.3*
bL_{51}	(7.0, 10.7)	*8.8*	$eD_{50}L_1$	(8.0, 6.7)	*7.3*
cL_{51}	(7.0, 8.7)	*7.8*	$fD_{50}L_1$	(11.0, 6.3)	*8.6*
total		**30.3**	total		**27.2**
aL_{80}	(22.7, 12.0)	*17.3*	$dD_{79}L_1$	(18.3, 11.0)	*14.6*
bL_{80}	(17.0, 43.0)	*30.0*	$eD_{79}L_1$	(10.0, 36.3)	*23.1*
cL_{80}	(12.0, 26.7)	*19.3*	$fD_{79}L_1$	(41.0, 22.7)	*31.8*
total		**66.6**	total		**69.5**
aL_{82}	(52.0, 45.3)	*48.6*	$dD_{81}L_1$	(49.0, 44.7)	*46.8*
bL_{82}	(29.0, 20.3)	*24.6*	$eD_{81}L_1$	(41.3, 28.3)	*34.8*
cL_{82}	(59.3, 30.3)	*44.8*	$fD_{81}L_1$	(38.3, 55.3)	*46.8*
total		**118.0**	total		**128.4**
aL_{106}	(26.6, 39.6)	*33.1*	$dD_{107}L_1$	(42.0, 49.3)	*45.6*
bL_{106}	(14.6, 70.6)	*42.6*	$eD_{107}L_1$	(10.0, 30.0)	*20.0*
cL_{106}	(30.0, 33.6)	*31.8*	$fD_{107}L_1$	(50.6, 65.0)	*57.8*
total		**107.5**	total		**123.4**
aL_{135}	(15.3, 4.7)	*10.0*	$dD_{134}L_1$	(8.3, 7.7)	*8.0*
bL_{135}	(7.3, 24.7)	*16.0*	$eD_{134}L_1$	(8.0, 23.0)	*15.5*
cL_{135}	(21.0, 18.0)	*19.5*	$fD_{134}L_1$	(21.7, 29.7)	*25.7*
total		**45.5**	total		**49.2**
aL_{168}	(21.3, 13.3)	*17.3*	$dD_{167}L_1$	(33.7, 20.3)	*27.0*
bL_{168}	(19.3, 7.3)	*13.3*	$eD_{167}L_1$	(10.7, 34.7)	*22.7*
cL_{168}	(20.3, 28.3)	*24.3*	$fD_{167}L_1$	(54.0, 37.0)	*45.5*
total		**54.9**	total		**95.2**
aL_{202}	(28.7, 6.3)	*17.5*	$dD_{201}L_1$	(36.3, 21.3)	*28.8*
bL_{202}	(6.7, 35.3)	*21.0*	$eD_{201}L_1$	(21.7, 36.3)	*29.0*
cL_{202}	(10.7, 0.0)	*5.3*	$fD_{201}L_1$	(50.0, 51.3)	*50.6*
total		**43.8**	total		**108.4**
Total sum		**538.3**	Total sum		**672.1**

"F" test shows no significant difference between two series. ($F = 0.53$, $0.5 > \alpha > 0.2$).

(i) Returning experiment after 38 generations in the dark.

The results were published in another paper (Mori and Yanagishima, 1959). Briefly, the flies, whose features of photic reactions had been changed during the course of life in darkness for 38 generations, retained the new characters even after 10 to 20 generations in normal daylight.

(ii) Returning experiment after 81 generations in darkness.

It was found that characters acquired in the dark strongly persisted even after the flies were reared for 117 generations in normal daylight. It is clear that the acquired characters had become hereditary ones.

These experiments showed that the new characters were not firmly fixed during the life of 32 generations in the dark, but were definitely fixed during the life of 81 generations.

Changes in Developmental Rate

Having been cultured in the dark for 118 generations, the flies were induced to deposit eggs in the dark. The larvae hatched from the eggs were divided into two groups, one of which was cultured in the dark ($D_{118}D_1$ series) and the other in normal daylight ($D_{118}L_1$ series). The developmental rates for larvae and pupae were examined.

Table 5. Developmental Rates of Larvae and Pupae of the Dark-adapted Flies Tested in Dark ($D_{118}D$) and in Normal Daylight ($D_{118}L_1$) and of those of the Normal Flies in the Dark (L_{118} D_1) and in Normal Daylight (L_{118} L_1). 20 newly hatched larvae were put into a small glass bottle, having 15 ml of Pearl's medium with a drop of yeast solution on it. Each series had 5 bottles (that is, 100 newly hatched larvae were used for each series)

Series	Larval development		Pupal development	
	No. of larvae observed	Mean rate of development (hr)	No. of pupae observed	Mean rate of development (hr)
$aL_{118}L_1$	98	93.1	98	93.6
$bL_{118}L_1$	98	94.1	98	93.3
$cL_{118}L_1$	99	92.5	99	93.8
Mean		93.2		93.6
$aL_{118}D_1$	94	98.8	94	91.3
$bL_{118}D_1$	99	99.3	99	92.5
$cL_{118}D_1$	96	96.8	96	95.9
Mean		98.3		93.2
$dD_{118}L_1$	99	93.6	99	95.2
$eD_{118}L_1$	99	96.8	99	94.2
$fD_{118}L_1$	99	96.5	99	94.4
Mean		95.6		94.6
$dD_{118}L_1$	94	102.3	94	91.9
$eD_{118}L_1$	97	107.4	97	92.6
$fD_{118}L_1$	96	105.7	96	92.4
Mean		105.1		92.3

Larvae from the normal flies were cultured both in the dark ($L_{118}D_1$ series) and in normal daylight ($L_{118}L_1$ series) to serve as controls.

The results are shown in Table 5.

Statistical examination of the detailed data showed that every difference among these four treatments was highly significant for larval development (< 1 per cent), but was not significant for pupal development. The developmental rates for larvae in these four treatments were observed to be in the following order:

$$L_{118}L_1 > D_{118}L_1 > L_{118}D_1 > D_{118}D_1$$

In other words, the larvae developed faster in normal daylight than in the dark. Furthermore, if environmental light conditions during the experiment were the same, the rate of development was faster in the progeny of normal flies than in that of dark flies. These facts show that heredity was a factor in inducing the different rates of development, as well as the direct influence during the life of the individual.

Changes in Fertility

Newly emerged test flies from a colony reared in the dark for 94 generations were put into a glass tube (diameter 3.5 cm, length 14 cm) and were made to deposite eggs on Pearl's medium (with a drop of yeast solution), spread on a glass slide. Four tubes were prepared for each series, two of which were placed in normal daylight ($D_{94}L_1$), and two in the dark ($D_{94}D_1$). Each tube had 5 females and 5 males, and the glass slide was renewed every day for 7 days and the number of eggs on it was counted. Normal flies of the 92nd generation were treated in a similar way.

Table 6. Fertility of the Normal and Dark-adapted Flies in Daylight and Dark Environments. Figures show Total Number of Eggs produced by 10 Females during a Week

Series	No. of eggs produced in		Series	No. of eggs produced in	
	Daylight environment	Dark environment		Daylight environment	Dark environment
aL_{92}	561	736	dD_{94}	661	679
bL_{92}	615	864	eD_{94}	694	787
cL_{92}	469	578	fD_{94}	550	959
Total	1645	2178	Total	1905	2425

Table 6 shows one of the summarized results. From this table it is clear that flies always laid more eggs in the dark than in daylight. If the environmental light condition was the same the progeny of dark flies laid more eggs than those of normal flies. These facts indicate that the influence of light on fertility is hereditary and that the dark environment accelerates the production of the egg.

Changes in Type of Daily Emergence Rhythm

Ordinarily the flies emerge most vigorously from before sunrise till noon and only in small numbers during the night. What happens when they are kept in the dark for a long time?

Fifty newly hatched larvae were planted in a small glass bottle (diameter 3.5 cm, height 7.5 cm) on Pearl's medium with a drop of yeast solution. Twenty bottles were prepared for each series containing 1000 individuals. These bottles were placed in normal daylight and the numbers of emerging flies were counted every three hours. Tests were performed at the 26th, 39th, 51st, 80th, 112nd, 124th, 135th, 168th, 202nd, 223rd, and 238th generations.

Table 7. Daily Rhythm of Emergence of Dark-adapted Flies and Normal Flies. Figures indicate the Ratio (%) of Numbers of Flies emerged during the Night (18:00–3:00 hr) to Total Numbers Emerged. Data of Three Series of Dark Flies and Normal Flies are Summed up Respectively

Series / Generations	L (normal flies)		D (dark flies)
26	4.68	<	6.77
39	13.12	<	14.25
51	5.41	<	8.88
80	7.61	>	5.54
112	3.58	<	6.00
124	7.76	<	9.91
135	5.08	<	7.11
168	9.25	>	6.43
202	14.20	>	6.80
212	20.60	<	23.20
223	8.24	>	7.51
238	10.20	>	7.90

The difference of behaviour between the dark-adapted and the normal flies was calculated as the ratio of the number of flies emerged from 18:00 to 3:00 hr to the total number of flies emerged for the day. The results are shown in Table 7. Until the 135th generation the daily periodic in emergence appeared more conspicuously in the dark flies than in the normal flies, whereas after that this became reversed. Statistical examination of the detailed data (not mentioned here) showed that these differences were significant.

Changes in Microstructure of the Compound Eye

The microstructure of the compound eye was investigated with an electron microscope by Drs. Kuwabara and Eguchi of Kyusyu University.

Figures. 2, 3 and 4 show the results. First, compare Fig. 2 (normal fly) with Fig. 3 (dark fly). The regular, compact and fine arrangement of microvilli, and rhabdo-

meres and the substantial protoplasmic structure at the base of microvilli are characteristics of the normal fly. In the dark-adapted fly, the microvilli degenerated, the number decreased, the wall thickened, the arrangement became irregular, and near the base of the microvilli the protoplasmic structure was somewhat vacant. In Fig. 4 the state seems to be intermediate, that is, various changes that occurred during the life in the dark are reverting to the original normal state. This pheno-

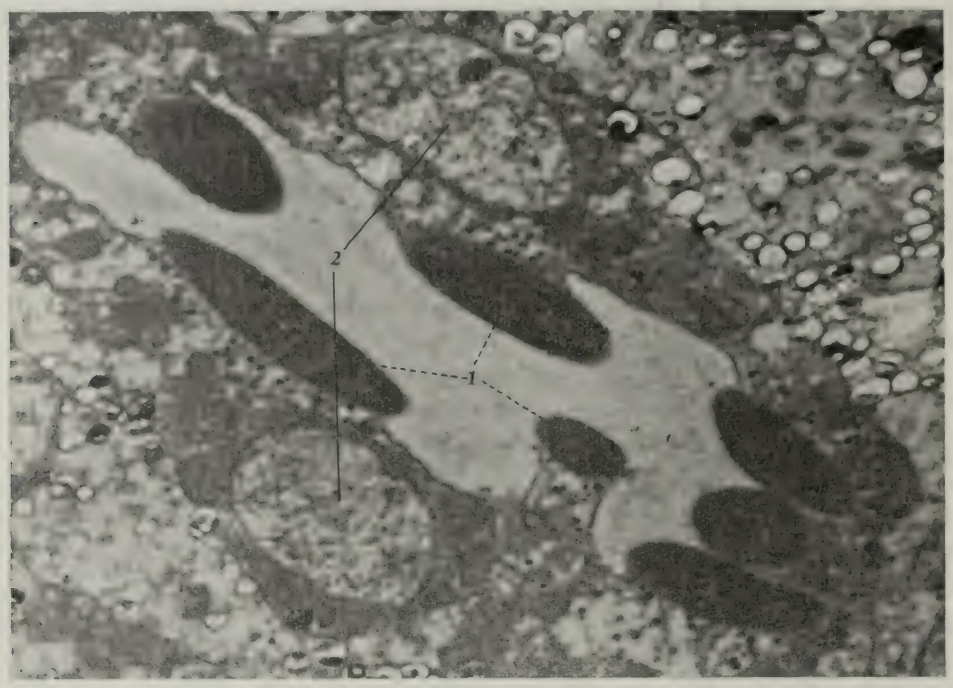

Fig. 2. Electron microscope photograph of an ommatidium of a normal fly. 1. 7 rhabdomeres, having regularly arranged microvilli, 2. Nucleus of retinal cell. (Kuwabara and Eguchi, in press)

menon suggests that the change is a more or less hereditary one, fixed to a considerable degree.

It must be emphasized here that according to the investigations of Drs. Kuwabara and Eguchi the trend of changes in *Drosophila* flies (as observed above), is the same as that in cave animals, i.e. some gammarids. These facts are significant in considering the origin of adaptation in cave animals.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to the members of the Adaptive Variation Research Group for kind encouragement throughout the course of the study, and to Dr. W. O. Haufe of the Agricultural Research Station of Canada, and also to Dr. W. A. Fairbairn of the University of Edinburgh, who kindly read the original manuscript and gave valuable criticisms.

SYNOPSIS OF DISCUSSION

Mr. Taylor inquired whether some selection could occur when removing the parents for successive generations, i.e. by choosing the most active flies. Dr. Mori stated that selection of active flies could not be a factor because every fly living in the bottles was transferred to new bottles where it laid eggs and died. The fact

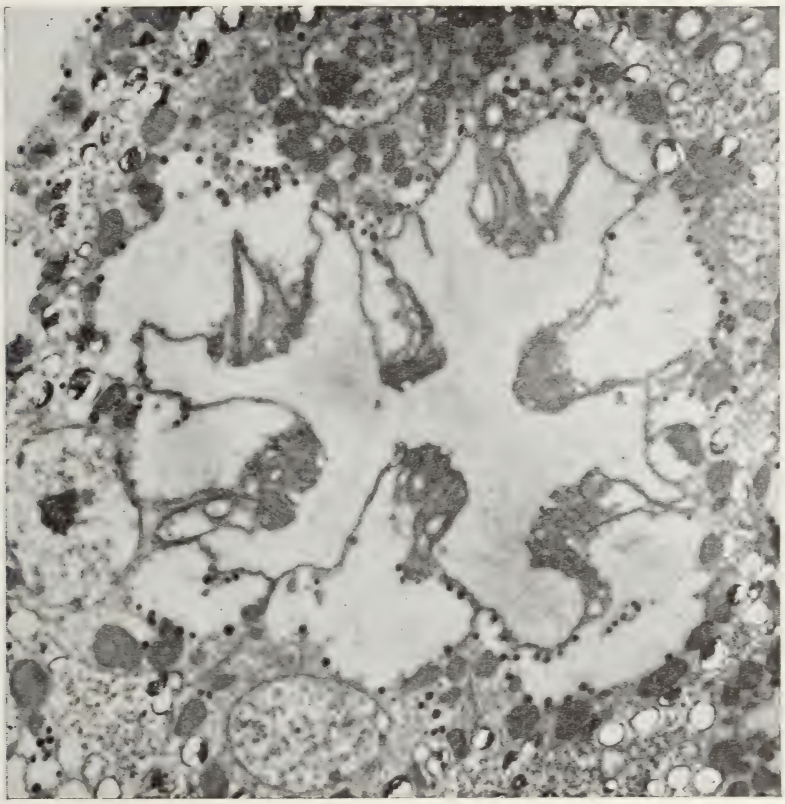

FIG. 3. Electron microscope photograph of an ommatidium of dark fly from 206th generation in dark (D). Number of microvilli decreased, arrangement irregular, wall thickened, and protoplasm near the base of rhabdomeres seems to be lacking. (Kuwabara and Eguchi, in press)

that the directions of change in fecundity and rate of development through individual life histories were the same as those observed after successive generations in the dark, and also the fact that the microstructural change in the compound eye was the same as that observed in cave animals, indicate that the environmental light conditions had a direct influence on the fly.

Dr. Haufe asked whether mortality rates were recorded for each generation. If these rates were different for the dark-rearing and light-rearing environments, they would influence the selection of genotypes in the populations. Dr. Mori replied that although he did not record mortality rates in each generation he checked cer-

tain generations during the course of the experiment and found no statistically significant differences.

Dr. Mori replied to Dr. Johnson's question whether indirect effects of light or small temperature differences could influence the development and behaviour of the flies. Bottles were kept in incubators, one of which was completely dark, the other penetrated by normal diffused daylight. The behaviour of larvae does not

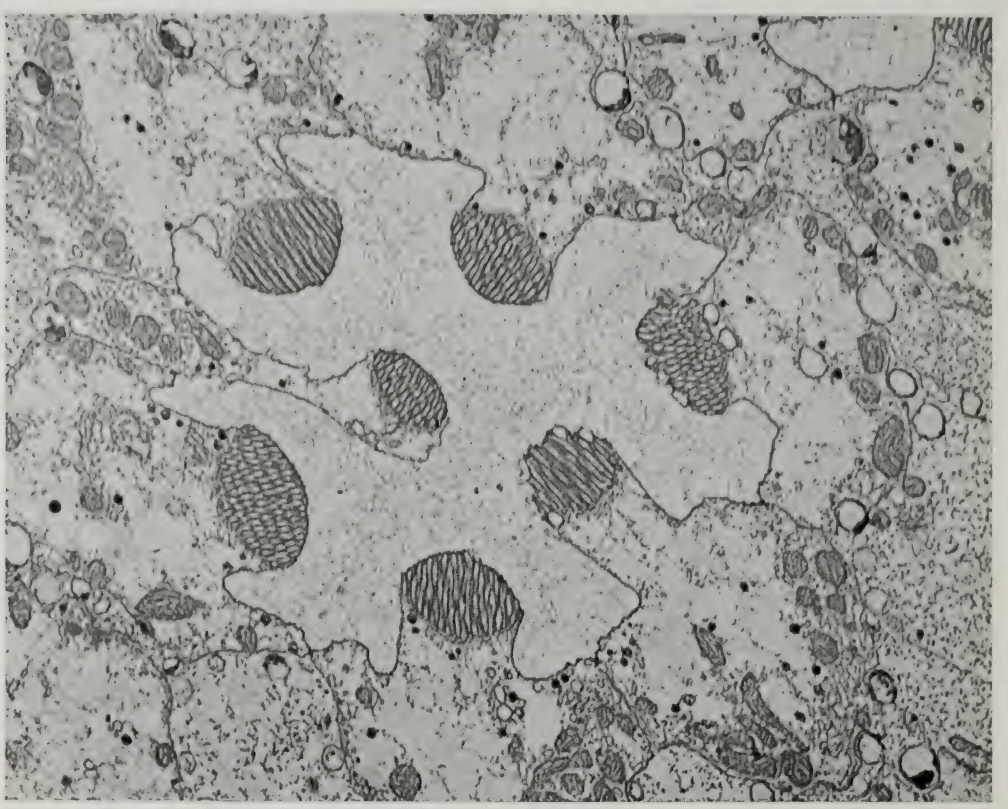

Fig. 4. Electron microscope photograph of an ommatidium of a 209th generation fly from a colony reared for 82 generations in the dark and then for 127 generations in normal daylight. A condition intermediate to Figs. 2 and 3. (Kuwabara and Eguchi, in press)

appear to be influenced by light since movement and feeding continues throughout the day. In the case of differences in fecundity of adults, light may have indirect effects because the activity of flies is affected by light. However, since the differences in developmental rate and other characters are observed between flies reared in different environments even when they are tested under the same light conditions, one has to conclude that the differences are due to the differences in rearing conditions.

In reply to Dr. Lewis, Dr. Mori stated that no significant colour changes have been observed in relation to rearing conditions.

REFERENCES

Kuwabara, M. and Eguchi, E. (in press) Morphological and physiological studies on degeneration of the compound eye of arthropods kept in cave.

Mori, S. and Yanagishima, S. (1959) Variations of *Drosophila* in relation to its environment VII. Does *Drosophila* change its characters during dark life? (1) *Jap. J. Genet.* **34,** 151–161.

Mori, S. and Yanagishima, S. (1959) ibid. (2) *Jap. J. Genet.* **34,** 195–200.

Northrop, J. H. (1926) Duration of life of an aseptic *Drosophila* culture inbred in the dark for 230 generations. *J. gen. Physiol.* **9,** 763–765.

Payne, F. (1910) Forty-nine generations in the dark. *Biol. Bull.* **18,** 188–190.

Payne, F. (1911) *Drosophila ampelophila* Loew bred in the dark for sixty-nine generations. *Biol. Bull.* **21,** 297–301.

MICROCLIMATE AND ITS APPLICATION TO INSECT ECOLOGY

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In an effort to evaluate the relationship between climatic and biological processes in natural ecological environments, two microclimate stations equipped with the necessary instruments to measure and record the microhabitats of insects were established in the dissimilar ecological sites of Brownsville and Monte Alto, Texas.

The Brownsville site was established in a wild life sanctuary wherein vegetation had been undisturbed for a number of years. The Monte Alto environment was situated in an orange grove where sound agricultural practices were followed.

Thermocouple thermometry was employed to sense and record temperatures, and paired wet and dry thermocouples were used to psychrometrically measure relative humidity 3 mm above and below leaf surfaces in the microhabitats of insects. Gross radiation was measured by a pyrheliometer and net radiation by a miniature radiometer. Precipitation, barometric pressures, and relative humidity were recorded on clock-driven mechanisms. Wind direction and velocity, temperatures (including dew point) and net radiation were recorded electrically; evaporation was manually recorded.

Temperature was recorded from 24 thermocouples located from 40 ft in the air to ground level in increments of 10 ft; leaf stem, soil, and insect body temperatures were all recorded continuously, night and day.

Data from these insectan microenvironments are expected to provide important information upon the influence of microclimate on insect activity and development. It is anticipated that simulation of those climatic factors considered to have the greatest influence upon the life cycle of the insect can be accomplished in a bioclimatic chamber and each factor qualitatively evaluated.

LONG DISTANCE MOVEMENT OF TWO MIGRANT LEPIDOPTERA IN RELATION TO SYNOPTIC WEATHER CONDITIONS

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Abstract — The Diamond Back Moth *(Plutella maculipennis)* and the Beet Army Worm *(Laphygma exigua)* are known to migrate over long distances. On two occasions, one for each species, their *movements* have been related to *wind trajectories*. These are the only two well documented instances of long distance travel of *migrant* British *Lepidoptera* related to *synoptic weather*. Both involve journeys of some 2,000 miles and continuous flight of several days.

Zusammenfassung — *(Plutella maculipennis)* und *(Laphygma exigua)* sind dafür bekannt, daß sie über große Entfernungen fliegen. Bei zwei Gelegenheiten, eine für jede der 2 Arten, wurden ihre Reisen mit den Windtströmungen in Beziehung gesetzt. Diese beiden Untersuchungen sind die beiden einzigen gut belegten Beispiele von Flügen der britischen Lepidoptera über große Entfernungen im Vergleich mit der Wetterlage. Es handelte sich um Reisen von einigen 2000 Meilen und mehrere Tage ununterbrochenen Flug.

Résumé — On sait que *(Plutella maculipennis)* et *(Laphygma exigua)* migrent sur de très grandes distances. On a mis en évidence la relation existant entre leur mouvement et les trajectoires des vents dans deux cas particuliers, un pour chaque espèce. Ces deux études représentent les deux seuls exemples vraiment bien fondés de vols de lépidoptères en provenance des Iles Britanniques, vols effectués sur de très grandes distances en relation avec la situation météorologique. Il s'agit de déplacements de quelques 2000 milles en vol ininterrompu de plusieurs jours.

At the end of June and the beginning of July 1958 reports of large numbers of the Diamond-back Moth (*Plutella maculipennis* (Curt.)) were received from Scotland and north-east England (French and White, 1960). On the morning of 28 June they were recorded at Aberdeen, and on 29 June they were seen by several observers on the St. Andrews Golf Course, Fife, where they were estimated to be between 30 and 60 millions per acre (70–150 million per hectare). The night of 29 June produced a sudden increase in the number of Diamond-back Moths caught in a light trap at Kincraig, Inverness-shire, and on the evening of 30 June tremendous numbers were reported simultaneously in many coast towns in the northeast of England between Berwick and Scarborough.

Other records were received from a ship in the North Sea on 1 July and from the Ocean Weather Ship "Weather Watcher" on 4 July, stationed 500 miles west of Cape Wrath and 300 miles south of Iceland, in mid Atlantic.

The arrival of these moths on the east coast of Great Britain and the records from ships at sea all suggested an immigration from some point to the east of the

British Isles. The literature showed that similar outbreaks had occurred sporadically throughout the last century and that these also were associated with swarms arriving on the east coast.

It was possible to decide the time of arrival of the moths in 1958 with fair accuracy, at three points:

1. East coast of Scotland, night of 29–30 June.
2. North-east coast of England, night of 30 June–1 July.
3. "Weather Watcher", 13:00 B.S.T. 4 July.

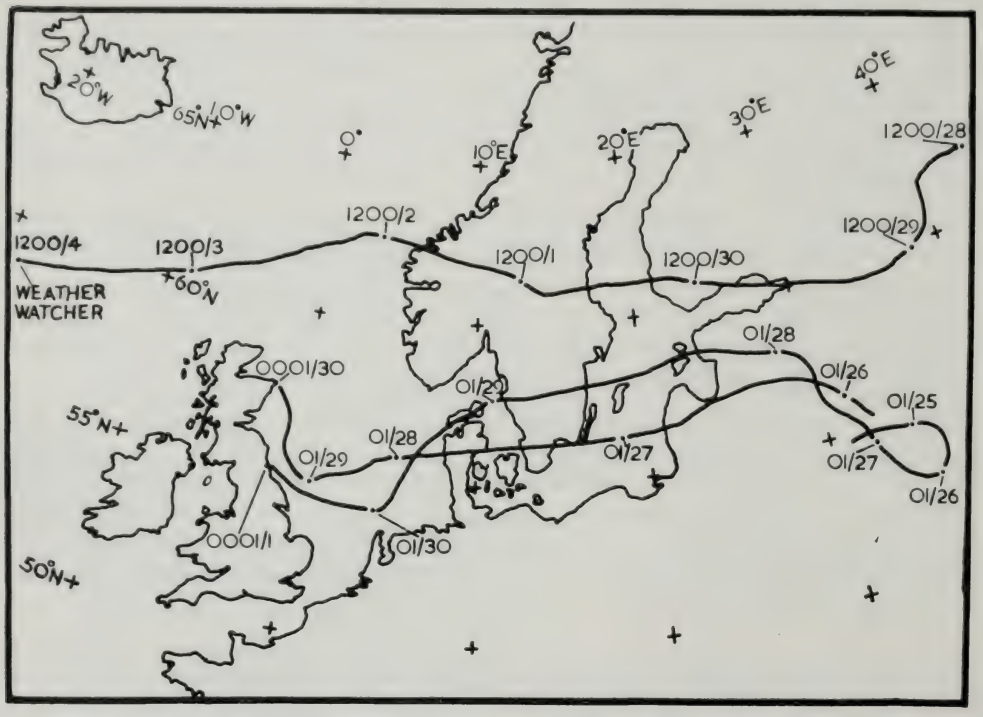

Fig. 1. Wind trajectories from Kinnairds Head on 30 June, from Newcastle on 1 July and from O.W.S. "Weather Watcher" on 4 July, 1958

From these three points the back-tracks of the winds were provided by the Meteorological Office. Figure 1 shows that these three tracks meet in N.W. Russia on the borders of the Baltic. Assuming that these tracks are the paths taken by the moths on their journey, then the moths must have remained airborne for 3–4 days to reach the coast of Great Britain and for about 4–5 days to reach the "Weather Watcher". The construction of these back-tracks made no allowance for the flight speed of the moths but this factor is, by comparison, negligible.

A much smaller invasion than that related above, by the Beet Army Worm (*Laphygma exigua* Hubn.), occurred in May 1962 into southern England (Hurst, 1963).

This moth occurs in very small numbers most years in southern England but in 1962 nearly 1,200 moths were recorded. Significantly the moth was reported for the first time from ten different localities in southern England, from Devon to Kent on the same day (6 May). The swarm seemed to be centred at Brockenhurst, Hampshire (10 miles S.W. of Southampton) where at least 100 were caught at about 22:00 hr G.M.T. on 6 May.

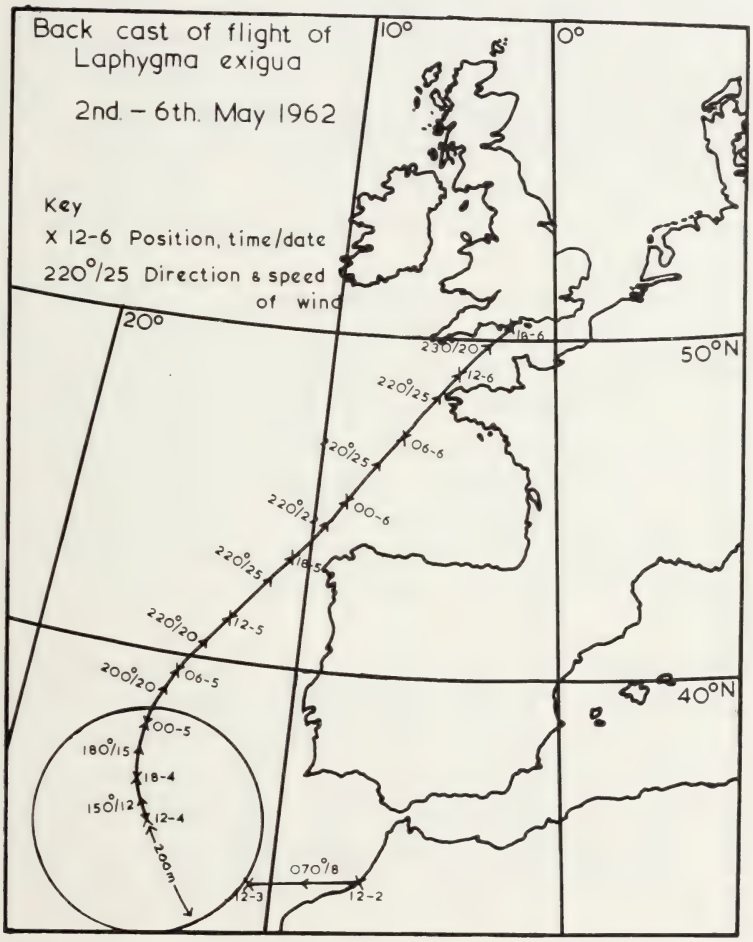

Fig. 2. Back-cast of flight of *Laphygma exigua* 2–6 May, 1962

A back-cast of the wind reaching the Hampshire coast on the night of 6 May was therefore made (Fig. 2) when a flight speed of 2 knots was allowed for the moths.

The back-track from Hampshire for some 54 hr is in a fairly definite south-westerly air current which establishes the moth 300 miles W. of Cape St. Vincent at 12:00 hr on 4 May. However, after this the situation became increasingly difficult to interpret because the area beyond was in a region of light anticyclonic winds and any observational support is lacking. The margin of error in estimating the track at the end of two days back-cast is probably represented by a circle of 200 miles radius.

If it is now assumed that the likely point of departure is the west coast of Morocco an examination of the surface and upper air data for the region of Rabat reveals that on:

1 May a cold front was approaching West Africa with south-west to west winds making flight in the desired direction impossible.

2 May the cold front was clear of the coast and a ridge of high pressure from West of Morocco towards west Spain gave north-east to east winds by the afternoon in the region of Rabat. Inland temperatures of 20–25° C would give lift to 4–5,000 ft and the moths would then be in an east-north-east airstream of 5–10 knots. Conditions were thus suitable for departure along most of the coast.

3 May similar opportunities for the moths to become airborne, exist as on 2 May, but the winds being lighter and more northerly were not quite as favourable for leaving Morocco. Also the time available to link up with the back-track from England would be inadequate.

Assuming a take-off from the coast of Morocco at 12:00 hr G.M.T. on 2 May the estimated 24-hr movement is shown in Fig. 2 which brings the moths to within the limits of error of the back-track from the south coast of England.

Thus it seems that the moths left the west coast of North Africa about midday on 2 May, were lifted to a height of about 4,000 ft, and subsequently were carried out on the southern flank of a ridge of high pressure extending from the Canaries to southern Spain and Portugal; after 24 hr their track changed from westerly to northerly. By 5 May the moths became affected by strong south-west winds associated with an Altantic depression which gradually brought them into the south coast of England.

In these two instances of *P. maculipennis* and *L. exigua*, it has been possible, by the use of back-tracks of winds, to suggest the almost certain course and origin of two immigrations into the British Isles. To move thus, these moths had to remain airborne continuously for up to 5 days, a physiological problem of no small magnitude requiring the apparent use of large quantities of food reserves as fuel; in both instances the upward movement in the airstream was very small and with *L. exigua* it never exceeded 5,000 ft so that gliding would not have contributed to their journey.

SYNOPSIS OF DISCUSSION

There was some discussion concerning the energy resources necessary for the moths to follow the course suggested by the "back-track", i.e. to fly north at 2 m.p.h. for 4 days. It is surprising that energy is sufficient to maintain this sustained amount of flight. These possibilities suggest that research on the energy resources of migratory insects in relation to flight range is needed to interpret the broader dispersal patterns of some insects.

Dr. Gloyne inquired whether there was any evidence of fall-out of moths along the path. He pointed out that, if the fall-out does occur, then there must be a very

favourable set of meteorological conditions involving the source, trajectory and density of migrants to ensure that some insects reach the target area. Dr. Johnson replied that there were observations to indicate fall-out along the way but so far the sampling network has been very open and observers have been dealing with first arrivals.

REFERENCES

French, R. A. and White, J. H. (1960) The Diamond-back Moth outbreak of 1958. *Plant. Path.* 9, 77–84.

Hurst. G. W. (1963) Small mottled willow moth in southern England 1962. *Met. Mag.* 92, 308–312.

THE PROGRESS OF RESEARCH AT ROTHAMSTED ON AERIAL MIGRATIONS OF INSECTS*

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Abstract — Investigations into the aerial migration of insects have involved the development of sampling techniques, both mechanical and analytical; the measurement of the spacial distribution of insects simultaneously at altitudes from the level of vegetation to thousands of metres; the description and analysis of the temporal sequence of events leading to the discharge of these insects into the air including their diurnal flight periodicity and to the tracking of the horizontal displacement of insects over thousands of kilometers. In all these aspects of migration weather is a fundamental factor.

Zusammenfassung — Forschungen auf dem Gebiet des Schwärmens von Insekten haben die Entwicklung sowohl mechanischer wie analytischer Untersuchungsmethoden gefördert: die Messung der räumlichen Verteilung von Insekten in Höhen von der Vegetations grenze bis zu tausenden von Metern, die Beschreibung und Analyse der zeitlichen Aufeinanderfolge von Vorgängen, die zum Ausschwärmen der Insekten in den Luftraum führen, einschließlich ihrer täglichen Flugperioden und der Bahnen der horizontalen Verteilung von Insekten über tausende von Kilometern. Bei diesen Fragen des Schwärmens ist das Wetter ein grundlegender Faktor.

Résumé — Afin de suivre les migrations d'insectes, il a été nécessaire de mettre au point de nouvelles méthodes d'investigation aussi bien mécaniques qu'analytiques. Il s'agit d'une part de la mesure de la répartition spaciale des insectes du sol à plusieurs milliers de mètres, d'autre part de la description et de l'analyse de la succession dans le temps de processus qui incitent les insectes à émigrer dans l'atmosphère. Ces méthodes ont également dû tenir compte des périodes diurnes du vol des insectes ainsi que de la répartition horizontale de ceux-ci sur des trajectoires s'étendant sur des milliers de kilomètres. Dans toutes ces questions de migration, les facteurs météorologiques jouent un rôle prépondérant.

An attempt has been made over the last few years to outline the essential features of a comprehensive system for dispersal of aphids. The principles established have been applied to other insects. The nodal points in our progress towards a functional system of dispersal for insects are given here.

Glick (1939) showed the importance of the upper air for insect dispersal and the huge populations of insects existing up to thousands of feet. In analysing these populations in relation to weather he followed the usual practice of correlating

*This and the following 5 papers briefly outline the research programme at Rothamsted on the effect of weather on insect dispersal. These papers, which were presented with illustrative data not reproduced here, are progress reports, summaries of work done and published in more detail elsewhere, and original contributions.

numbers, even numbers at different heights, with the weather at those heights. In common with many similar attempts to correlate weather with numbers at a particular height, no clear picture of the operative factors emerged. Some correlations were fortuitous, others the result of intercorrelation, some were not correlated, and those that were, were inconsistent and rarely very strong. The reason for this lay in the assumption that weather changes are the prime causes for changes in numbers flying, but this is not so. The first major task therefore was to separate out two distinct processes, namely the effects of weather on total numbers in the air as distinct from the effects of weather on the *relative* numbers at different heights (Johnson, 1951). This led to two lines of work; first, the simultaneous measurement of aerial density at various heights to establish a density-height gradient irrespective of total numbers involved; second, to measure the discharge rate of aphids at the terrestrial source of supply.

Techniques for measuring aerial density and for sampling it continuously hour by hour during the day and night were developed. The segregating suction trap in its various forms was developed (Johnson, 1951; Johnson and Taylor, 1955; Taylor, 1962). It was recognized early that a knowledge of flight periodicity and its causes was necessary to understand distributive processes and a close study was made of aphid flight periodicity. Contrary to popular belief, change in numbers flying from hour to hour was mainly a function of the production of alatae, not to differences in their flight behaviour in response to weather. There is only one flight at the source of aphids, namely the exodus. The numbers flying at the sources therefore are the result of serial changes in numbers moulting (which is periodic), length of the teneral period of the adult alate insects (which is temperature-dependent) and the weather affecting take-off. These three elements were associated quantitatively into a completely new theory of flight periodicity (Johnson and Taylor, 1957; Johnson, Taylor and Haine, 1957). The flight periodicity and the analysis in terms of these three factors is now being undertaken for a large number of other insects, as described elsewhere in this symposium (Lewis and Taylor; Lewis and Hurst). With one species, therefore, linear correlations of numbers in the air with weather factors tends to be very uncertain, although weather does play a great part in the process of aerial density change. The reason why linear correlations of aerial abundance are often obtained with several species together in relation to weather changes will be described in another paper in this symposium (Taylor, 1965a).

Turning now to the other aspect of dispersal, vertical distribution, the vertical density gradient can be formulated simply for many insect species and it can be explained largely in terms that apply also to the diffusion of inert particles (Johnson and Penman, 1951). However, biological factors such as flight periodicity in relation to the time of maximum convection, the duration of flight and the effects of weather on take-off and alighting lead to irregularities on the observed curve compared with that expected from the physical equations. This applies particularly to the gradients nearer to the ground, and this problem is also described in another paper in this symposium (Taylor, 1965b).

So far we have studied the periodic discharge, the vertical diffusion and the periodic disposition of small insects from the air, the development of methods for measuring density, and the separation of problems involving changes in total numbers in the air from those associated with relative abundance at different heights. These have set lines of procedure for the research. The analysis of flight periodicities in terms of development processes and flight thresholds alters the approach to the effect of weather on activity hitherto analysed largely in terms of linear regression. By formulating the density-height gradient total numbers in the air can be estimated and associated with discharge at the source while the gradient itself can be correlated with turbulence and convection.

However, another aspect of dispersal, namely the horizontal displacement of insects has not been neglected and trajectories of air masses bearing migrants have been traced back from the British Isles thousands of miles to Russia and into Africa to stress the long distance spread of specific pests. This subject also receives attention in another paper in the symposium (French).

REFERENCES

FRENCH, R. A. (1966) Long distance movement of two migrant Lepidoptera in relation to synoptic weather. *Biometeorology* II, Pergamon Press, Oxford, 565–569.

GLICK, P. A. (1939) The distribution of insects, spiders and mites in the air. Tech. Bull. U.S.D.A. No. 673, 150 pp.

JOHNSON, C. G. (1950) A suction trap for small airborne insects which automatically segregates the catch into successive hourly samples. *Ann. appl. Biol.* **37**, 80–91.

JOHNSON, C. G. (1951) The study of wind-borne insect populations in relation to terrestrial ecology, flight periodicity and the estimation of aerial populations. *Science Progress* No. 153, 41–62.

JOHNSON, C. G. and TAYLOR, L. R. (1955) The development of large suction traps for airborne insects. *Ann. appl. Biol.* **43**, 51–61.

JOHNSON, C. G. and PENMAN, H. L. (1951) Relationship of aphid density to altitude. *Nature (Lond.)* **168**, 337.

JOHNSON, C. G. and TAYLOR, L. R. (1957) Periodism and energy summation with special reference to flight rhythms in aphids. *J. exp. Biol.* **34**, 209–221.

JOHNSON, C. G., TAYLOR, L. R. and HAINE, E. (1957) The analysis and reconstruction of diurnal flight curves in alienicolae of *Aphis fabae* Scop. *Ann. appl. Biol.* **45**, 682–701.

LEWIS, T. and TAYLOR, L. R. (1966) Diurnal flight periodicity and insect migration. *Biometeorology* II, Pergamon Press, Oxford, 573–575.

LEWIS, T. and HURST, G. W. (1966) Take-off thresholds in Thysanoptera and the forecasting of migratory flight. *Biometeorology* II, Pergamon Press, Oxford, 576–578.

TAYLOR, L. R. (1962) The absolute efficiency of insect suction traps. *Ann. appl. Biol.* **50**, 405–421.

TAYLOR, L. R. (1966a) The mode of action of weather on insect flight. *Biometeorology* II, Pergamon Press, Oxford, 579–582.

TAYLOR, L. R. (1966b) The effect of weather on the height of flight of insects. *Biometeorology* II, Pergamon Press, Oxford, 583–584.

DIURNAL FLIGHT PERIODICITY AND INSECT MIGRATION

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Abstract — Insects were trapped in many different habitats, using suction traps which segregate the daily catch into hourly samples, and the diurnal flight periodicity curves for about 200 identified species from 10 Orders have been obtained. Catches for each species over a few days were combined to remove the effect of minor fluctuations in weather, and descriptive curves fitted graphically on probability paper to distinguish between separate populations flying at different times of the day, and to estimate the time and period of maximum activity. Examples were found of various species each with its peak activity at a characteristic time during the 24-hr cycle. Activity curves were either normal or skewed towards maximum or minimum light intensity according to the species. The Nematocera (Diptera) was the commonest group in all habitats and in some families there were colour differences between day and night-flying species.

Zusammenfassung — Insekten wurden in sehr verschiedenen Gebieten mit Ansaugvorrichtungen gefangen, die den täglichen Fang in stündliche Proben aufteilen. So erhielt man die Kurven für die tägliche Flugperiodik für ungefähr 200 bestimmte Arten aus 10 Ordnungen. Fänge jeder Art während einigen Tagen wurden kombiniert, um die Wirkung kleiner Wetteränderungen auszuschalten. Durch die Eintragung der erhaltenen Kurven auf Wahrscheinlichkeitspapier wurde zwischen den Flügen getrennter Völker zu verschiedenen Zeitpunkten des Tages unterschieden und der Zeitpunkt und die Periode der größten Aktivität bestimmt. Es wurden Beispiele von verschiedenen Arten gefunden, jeweils mit dem Gipfel der Aktivität zum charakteristischen Zeitpunkt während des 24-Stunden-Ablaufs. Die Aktivitäts-Kurven waren entweder normal oder gegen das Maximum oder Minimum der Lichtintensität entsprechend den einzelnen Arten verschoben. Die Nematocera (Diptera) war in allen Gebieten die häufigste Gruppe. In einzelnen Familien lagen Farbunterschiede zwischen den tag-und nachtfliegenden Arten vor.

Résumé — On a, par aspiration, capturé des insectes dans des régions très différentes l'une de l'autre. Ces échantillons ont pu être différenciés pour chaque heure due jour. On a ainsi pu établir les courbes diurnes de périodicité du vol pour environ 200 espèces appartenant à 10 ordres. On a combiné les captures de quelques jours consécutifs afin d'éliminer l'influence de faibles variations météorologiques. En reportant ces courbes sur des trames de probabilité, on a pu déterminer le moment de la journée et la durée de la plus grande activité. On a également pu différencier les particularités journalières du vol de races distinctes. On a trouvé des exemples de différentes espèces présentant, au cours d'un cycle de 24 heures, des pointes caractéristiques d'activité à un moment précis. Ces courbes d'activité étaient ou bien normales ou bien décalées vers le maximum ou le minimum de l'intensité lumineuse correspondant à l'espèce. Les nématocères (diptères) forment en toutes régions le groupe le mieux représenté. Dans certaines familles, on a pu distinguer des différences de couleur entre les insectes volant de jour et ceux qui volent la nuit.

INTRODUCTION

Daily flight periodicity is very important in insect migration and dispersal. Insects flying during the daytime are likely to be carried by turbulence and convection into the upper air and transported over long distances. In more stable air during the evening and night they tend to move more locally. The take-off and flight of individuals is expressed collectively for a population as a daily flight periodicity curve.

Techniques for studying this have been inadequate and so the relation of flight periodicity to dispersal has been neglected. Suction traps which automatically segregate the catch into hourly samples overcome this difficulty (Johnson, 1950; Taylor, 1951) and are being used to compile an atlas of flight periodicity for representative species from many families and habitats.

Catches for each species are combined over a few days to reduce the effect of minor fluctuations in weather and the periodicity curves fitted graphically on probability paper (Harding, 1949) to estimate the time and duration of maximum activity, and to distinguish between separate populations flying at different times of the day.

RESULTS

Examples have been found of various species whose peak flight activity may occur characteristically at certain times during the 24-hr cycle. Chrysomelid beetles, aphids and thrips, many of which are vigorous migrants, all fly in the warmest part of the day. Nectar-feeding Muscidae, predatory Empidae and most parasitic Hymenoptera fly during daylight. Lacewings (Neuroptera) are most active in the few hours before midnight, the gall wasp, *Neuroterus quercus-baccarum* L., just before dawn, many Staphylinid and Cryptophagid beetles at dusk. Flight in some fruit flies (Drosophilidae) and fungus gnats (Mycetophilidae) is confined to about an hour at dawn and dusk. Day-flying species fly only at light intensities between about 2,000 and 9,000 ft candles, but many crepuscular fliers, e.g. Tipulidae, Culicidae, Ceratopogonidae (Diptera) fly over a much greater range extending from less than 0.1 f.c. to about 1,000 f.c.

The shape of activity curves is either normal or skew, and the degree of skewness in relation to maximum light intensity is characteristic for closely related species. For instance *Drosophila subobscura* Coll. and gall midges (Cecidomyiinae) both fly at dusk; but numbers of *D. subobscura* gradually increase to a maximum as the light wanes, and quickly drop to a minimum, whereas the Cecidomyiinae do the opposite and appear suddenly, then gradually become less active as light decreases. Sometimes apparently irregular activity curves for a single species are caused by several different curves from a mixed population each with maximum activity at a different time and it may eventually be possible to distinguish migrating and non-migrating individuals in certain populations depending on the time of day they fly.

The commonest group in most habitats investigated is the Nematocera (Diptera) and in many of its families the colour of day and night-flying species differs. Most darkly pigmented moth flies, (*Pericoma* spp.), fungus gnats (Sciarinae) and Chironomidae fly in the daytime, but the pale grey, yellow and brown species are mostly crepuscular or night fliers. Similar colour differences are less frequent in other orders.

SYNOPSIS OF DISCUSSION

Dr. Haufe commented that the two populations postulated in each diurnal sampling of activity for a single species may suggest that one curve represents dispersing individuals during the period of take-off and the other represents those that have nearly completed their flight period. The activity of mosquitoes, for example, has different characteristics after extended activity under laboratory conditions in comparison with that immediately after take-off. Dr. Lewis could offer no explanation for the two curves since all the traps were operated at vegetation level. The important point was that the activity curves were consistent for daily catches.

Mr. Symmons felt that population differences should be inferred with caution from purely statistical distributions. There may be many reasons for the dawn and dusk peaks in trap catches and they may not depend on the existence of two populations each with a normal distribution in numbers, particularly when catches are limited to one level. In this connection Dr. Lewis explained that the description of flight activity curves by using probability paper is a convenience. It is not intended to imply specific statistical distributions. The biomodal patterns of flight activity are real and not a product of the method of analysis. For this reason a biological explanation is important in interpreting these patterns of diurnal flight activity.

REFERENCES

Harding, J. P. (1949) The use of probability paper for the graphical analysis of polymodal frequency distributions. *J. Mar. Biol. Ass. U. K.* **28,** 141–153.

Johnson, C. G. (1950) A suction trap for small airborne insects which automatically segregates the catch into successive hourly samples. *Ann. appl. Biol.* **37,** 80–91.

Taylor, L. R. (1951) An improved suction trap for insects. *Ann. appl. Biol.* **38,** 582–591.

TAKE-OFF THRESHOLDS IN THYSANOPTERA AND THE FORECASTING OF MIGRATORY FLIGHT

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Abstract — The temperature, light, relative humidity and windspeed thresholds for take-off were determined for various species of thrips, particularly *Limothrips cerealium* Hal. Temperature was the most important of these; the real flight threshold of the insect itself is 18.4° C, but apparent thresholds for take-off differ depending on the position, site and type of thermometry used. The thresholds were used as a guide to select six other meteorological criteria by which weather suitable for flight could be defined and mass flights forecast.

Zusammenfassung — Die Grenzwerte von Temperatur, Licht, relativer Feuchte und Windgeschwindigkeit für das Ausschwärmen wurden für verschiedene Arten von Blasenfüssern bestimmt, besonders für *Limothrips cerealium* Hal. Am wichtigsten war die Temperatur; der Fluggrenzwert für das Insekt selbst beträgt 18,4° C, aber die Grenzen für das Ausschwärmen sind unterschiedlich je nach Ort und Art der benutzten Temperaturmessung. Die Grenzwerte wurden benutzt, um 6 weitere meteorologische Kriterien zu bestimmen, mit denen das günstige Flugwetter festgelegt und Massenflüge vorhergesagt werden konnten.

Résumé — On a déterminé les valeurs-limite de la température, de la lumière, de l'humidité relative et de la vitesse du vent pour l'éclosion de différentes espèces de thrips, en particulier pour *Limothrips cerealium Hal.* La température représente ici le facteur principal: la valeur-limite en est de 18,4° C pour l'insecte lui-même, mais les limite de température d'éclosion varient d'un endroit à l'autre et selon la méthode de mesure des températures. Ces valeurs-limite furent utilisées pour déterminer 6 autres critères métérologiques au moyen desquels on a pu fixer les conditions atmosphériques les plus favorables à l'éclosion et, partant, prévoir des vols massifs.

MOST species of thrips fly during a few weeks each year, and in suitable weather mass-flights may occur. If all the meteorological factors necessary for take-off were known, days when large migrations might occur could be predicted. The thresholds for all the meteorological factors influencing take-off are therefore needed. Some of these were determined, particularly for *Limothrips cerealium* Hal., and used to define weather suitable for flight, and to forecast mass migrations.

MEASUREMENT OF THRESHOLDS

Thrips were trapped in a 9 in. segregating suction trap (Johnson, 1950; Taylor, 1951) as they left hibernation sites in pine trees in spring (Lewis, 1963) and as they flew above wheat in summer. Bark and air temperatures were measured continually with either copper constantan thermocouples or mercury-in-steel thermometers, and wind speed with a modified Sheppard cup anemometer (Lewis and Siddorn, 1959). Relative humidity was measured in a Stevenson's screen. Hourly catches of thrips were plotted against hourly values of maximum temperature, light, wind speed and relative humidity to give the threshold for take-off for each factor (Taylor, 1963; Lewis, 1963).

All species ceased take-off 1 to 2 hr before sunset when light intensity was between 10 and 2,000 f.c. Apparent temperature thresholds for take-off differed with the position and type of thermometer used. For *L. cerealium* whose true body temperature threshold for take-off is 18.4° C (Lewis, 1963), apparent thresholds were 14° C, 19° C and 20° C respectively using air temperatures near pine trees, bark temperature and air temperature among wheat. Temperature thresholds determined with mercury-in-steel thermometers for *Stenothrips graminum* Uzel., *Limothrips denticornis* Hal., and *Chirothrips manicatus* Hal. were approximately 14° C, 19.5° C, and 21° C respectively. Thrips took off most commonly at relative humidities between 32 and 40 per cent and at the commonest wind speeds of 2.5 to 4 m.p.h., although this may be correlative rather than causative.

WEATHER AND MASS FLIGHT

Temperature seemed to be the main meteorological factor influencing take-off; low light intensity inhibited flight in the evening; relative humidity and wind speed were less important. Field observations suggest that most mass flights occurred in sunny, settled weather. The six meteorological criteria for flight selected from measurements from synoptic charts, a Stevenson screen and radio-sonde soundings, to define days suitable for flight were;

(1) no rain or drizzle during the day
(2) maximum temperature at least 20° C
(3) mean temperature above that of previous day
(4) low adiabatic lapse rate with no convection above 5,000–7,000 ft.
(5) at least 1 hour of sunshine
(6) dewpoint in the range of 5–15° C.

The year 1956, seen retrospectively, would have had 99 days on which forecasts of mass flights would have been successful, 15 unsuccessful and 11 marginal. Most of the failures were when *Thrips* spp. and *Taeniothrips* spp. flew in warm sultry weather. These species do not require such settled weather for mass flights as *Limothrips* spp. *Chirothrips* spp. and *Stenothrips* sp. There was a larger proportion of satisfactory forecasts in 1957 and 1958.

SYNOPSIS OF DISCUSSION

In view of the sensitivity of mosquitoes to relative humidity, Dr. Haufe asked how the effects of relative humidity were separated from those of temperature in determining the six parameters mentioned for forecasts. For example, relative humidity largely determines whether mosquito flight continues during light rain showers. Dr. Lewis replied that the parameters were determined on the basis of whether thresholds could be detected for the variables. In accepting this technique of threshold analysis relative humidity was considered to be unimportant in limiting flight. Certain species of *Taeniothrips* have been observed flying during drizzle; but the traditional description of many species of *Thysanoptera* as "thunder flies" was not confirmed. So far variation in the duration of flight has not been measured in *Thysanoptera*.

REFERENCES

Lewis, T. (1963) The effect of weather on emergence and take-off of overwintering *Limothrips cerealium* Haliday (Thysanoptera). *Ann. appl. Biol.* **51,** 489–502.

Lewis, T. and Siddorn, J. W. (1959) A simple portable recorder for direction and speed of wind. *J. Anim. Ecol.* **28,** 377–380.

Johnson, C. G. (1950) A suction trap for small airborne insects which automatically segregates the catch into successive hourly samples. *Ann. appl. Biol.* **27,** 80–91.

Taylor, L. R. (1951) An improved suction trap for insects. *Ann. appl. Biol.* **38,** 582–591.

Taylor, L. R. (1963) Analysis of the effect of temperature on insects in flight. *J. Anim. Ecol.* **32,** 99–117.

THE MODE OF ACTION OF WEATHER ON INSECT FLIGHT

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Abstract – Past weather affects population density and present weather affects the proportion in flight. Thresholds of light and temperature determine if a species can fly; changes in numbers flying in weather above threshold values are caused by fluctuations in population density. Thresholds obtained from field samples are like those obtained in the laboratory. Regressions appear in field data in heterogeneous populations.

Zusammenfassug – Das vergangene Wetter beeinflußt die Dichte der Völker, das augenblickliche Wetter die Flugverteilung. Grenzwerte von Licht und Temperatur bestimmen, ob eine Art fliegen kann; Schwankungen der Flugzahl beim Flug in Wetterverhältnissen außerhalb der Grenzwerte werden durch Schwankungen in der Dichte der Völker verursacht. Die Grenzwerte aus Proben aus dem Freien gleichen denen aus dem Laboratorium. Regressionen treten bei Proben aus dem Freien in heterogenen Völkern auf.

Résumé – Le temps passé influence la densité des populations d'insectes alors que le temps momentané influence au contraire la répartition des vols. Des valeurs-limite de lumière et de température déterminent les possibilités de vol de chaque espèce. Les différences observées du nombre d'insectes en vol dans des conditions météorologiques comprises entre les valeurs-limite (maximum et minimum) sont conditionnées par la densité des populations. Les valeurs-limite déterminées en plein air correspondent à celles obtenues en laboratoire. On n'observe une régression parmi les échantillons recueillis en plein air qu'au sein de populations hétérogènes.

THE number of insects in the air is noticeably different at different times, and weather is partly responsible for this. The differences in aerial densities or numbers of insects flying from year to year, month to month, day to day and hour to hour are produced by the same factors acting in different ways. Weather, especially temperature, affects the local population density by acting accumulatively over many generations on rates of birth, development and death. The proportion of alate adults in the population depends usually on temperature and light acting on previous and present generations. The proportion of alatae that are flight-worthy at any particular time depends usually on temperature, light, humidity and possibly pressure acting on the parent and present generations. Only the proportion of flight-worthy alatae in flight at any one time depends on present, or immediately past, weather.

Attempts to analyse the effect of weather on flight have usually emphasized this distinction between the effects of past and present weather, referring all the accumulated effects of past weather to changes in population density and the

effect of current weather to so-called "flight activity". Williams (1951, 1961) used regressions to analyse the effects of past weather on current population density. Johnson and Taylor (1957) showed how past temperature determines the number of alatae *Aphis fabae* Scop. that are flight-worthy by acting on the rate of development of new adults. Otherwise little progress has been made in relating current flight-worthy populations to past weather.

The second part of the problem, the relation to current weather of the proportion of flight-worthy insects in flight, has been confused by the work on elementary flight physiology. This has not always clearly distinguished between the percentage of a population in flight and the consequences of their flight velocity. For example, the temperature × percentage activity curves of the flightless beetle *Ptinus tectus* by Gunn and Hopf (1941) show that the number of individuals moving in a dish rises steeply over a narrow range or temperature, a lower threshold, below which movement is apparently inhibited by cold. Then there is a wide range of temperatures at which the percentage active remains fairly constant, although the level at which it is constant depends on how the temperature is changing. At an upper threshold, activity falls rapidly to zero. This is a typical percentage activity × temperature response curve in which percentage activity is measured by the proportion of the limited population in the dish that is moving at any instant.

Curves for temperature × velocity of activity are quite different in shape. They rise slowly and regularly, like a regression relation, up to an optimum temperature sometimes fairly close to the upper thermal death point, and then they fall more quickly to zero.

In measuring the flight response to temperature, the number of flights per minute at each temperature has sometimes been recorded instead of the number in flight at an instant. In a small container where each flight is limited in extent, the number of flights per minute is a function of flight velocity rather than of percentage activity. It has, however, been called "flight activity" (Nicholson, 1934).

The aerial density of insects is a function of the percentage of the available population that is active. It is not dependent on velocity of flight. Analysis of flight activity of single species in the field, therefore, should be based on thresholds rather than regressions. However, if the available population fluctuates at the same time, it is necessary to consider the percentage occasions on which any flight occurs instead of the percentage of insects in flight. If the sampling method is sufficiently sensitive, perfect replicas of Gunn and Hopf's curves can be obtained (Taylor, 1963). Regressions appear when overlapping thresholds are combined in heterogeneous populations.

The flight response to light functions similarly to the response to temperature, again acting as a threshold rather than a regression. It differs, however, in having a wider range of responses by different insect species to the normally occurring light intensities. Whereas no insect flies at the lowest or highest natural temperatures, there are insect species that fly either at midnight or at noon-day. The night fliers may have no normally operative lower light threshold, and the day fliers

no normal operative upper light threshold. In addition some species, notably *Drosophilidae* and *Mycetophilidae*, have lower and upper light thresholds so close together that flight is restricted to a narrow band of light intensities and lasts for only a few minutes each day.

The mode of action of other climatic factors has been insufficiently studied to give any generalizations. Wind is reputed to reduce flight activity, although most available information comes from observation, and this has been shown to be unreliable for aphids (Johnson, 1952), thrips (Lewis, 1963) and chloropids (Calnaido, French and Taylor, 1965); with all these insects, numbers in flight are independent of wind speed. Other information comes from light-trap catches, but again this is not valid because the efficiency of light traps depends on wind speed (Hollingsworth, Briggs, Glick and Graham, 1961). It seems most likely that the effect of wind on flight will be highly specific. Reliable information on responses to humidity hardly exists, because the effect of temperature has not been satisfactorily allowed for, and there is as yet almost no information about the mode of action of atmospheric electricity and pressure from field analyses.

SYNOPSIS OF DISCUSSION

Dr. Baltensweiler pointed out the importance of determining whether thresholds change during the life span of an individual. Such changes would be significant in relation to highly unfavourable weather conditions that might prevent insects from flying for several days. Mr. Taylor had detected no changes in laboratory material, mainly aphids, but added that the available material was insufficient to provide a general conclusion.

Mr. Symmons was concerned about the interpretation of thresholds, i.e. does the spread in flight occurrence about the mean threshold temperature represent (1) variation in microclimate, (2) variation in reaction within a population, (3) a wide threshold range or a threshold with narrow boundaries subject to error in measurement? Mr. Taylor said there is always a threshold range comprising individual differences within a population, even when measured in the laboratory. This is increased in field samples by microclimatic differences. The degree of uniformity in both the population and the environment has been assessed from the standard deviation of the thresholds which are expressed as statistical distributions.

Rhythms are a feature of the activities of many insects that are influenced by environmental factors. Professor Halberg suggested some caution in the interpretation of temperature thresholds, particularly in connection with "diurnal" variations in activity, and made the following observations:

(1) 24-hour rhythms are now called "circadian" rhythms by many investigators since their period is close to 24 hours but usually not of exactly that length under certain conditions such as constant darkness or constant illumination. This applies to the laboratory rather than to the field situation. In the latter

context, many of us who work on rhythms speak of 24-hour synchronized circadian rhythms, rather than diurnal rhythms, since diurnal as an adjective is misleading by virtue of its use to denote both a fraction of the 24-hour period (e.g. in "diurnality" versus "nocturnality") as well as the entire 24-hour period.

(2) Under controlled conditions and referring again to laboratory work rather than to the field situation, one of the major lessons learned during the past decade in the field of temporal biology is the fact that the temperature coefficient of circadian rhythms is rather close to unity. The work of Pittendrigh is pertinent in this connection and this subject has been reviewed in particular by Hastings in the Cold Spring Harbor Symposium on Biological Clocks in 1960.

(3) Against this background, changes in threshold occur in response to stimulation other than light and darkness as these have been recorded in a mammal (the mouse) after removal of the eye (e.g. *Z. Vitamin-Hormon- und Fermentforschung* **10**, 225–296, 1959).

(4) The effect of temperature, i.e. in the cockroach, is circadian-system phase dependent as revealed by the work of Bünning.

REFERENCES

CALNAIDO, D., FRENCH, R. A. and TAYLOR, L. R. (1965) Low altitude flight of *Oscinella frit* L. Diptera: Chloropidae). *J. Anim. Ecol.* **34,** 45–61.

GUNN, D. L. and HOPF, H. S. (1941) The biology and behaviour of *Ptinus tectus* Boie (Coleoptera: Ptinidae) a pest of stored products. II. The amount of locomotory activity in relation to experimental and previous temperatures. *J. exp. Biol.* **18,** 278–289.

HOLLINGSWORTH, J. P., BRIGGS, C. P., GLICK, P. A. and GRAHAM, H. M. (1961) Some factors influencing light trap collections. *J. Econ. Ent.* **54,** 305–308.

JOHNSON, C. G. (1952) The changing numbers of *Aphis fabae* Scop., flying at crop level, in relation to current weather and to the population on the crop. *Ann. appl. Biol.* **39,** 525–547.

JOHNSON, C. G. and TAYLOR, L. R. (1957) Periodism and energy summation with special reference to flight rhythms in aphids. *J. exp. Biol.* **34,** 209–221.

LEWIS, T. (1963) The effect of weather on the emergence and take-off of overwintering *Limothrips cerealium* Haliday (Thysanoptera). *Ann. appl. Biol.* **51,** 489–502.

NICHOLSON, A. J. (1934) The influence of temperature on the activity of sheep blow flies. *Bull. Ent. Res.* **25,** 85–99.

TAYLOR, L. R. (1963) Analysis of the effect of temperature on insects in flight. *J. Anim. Ecol.* **32,** 99–117.

WILLIAMS, C. B. (1951) Changes in insect populations in the field in relation to previous weather conditions. *Proc. roy. Soc.* B. **138,** 130–156.

WILLIAMS, C. B. (1961) Studies in the effect of weather conditions on the activity and abundance of insect populations. *Phil. Trans.* B. **244,** 331–378.

THE EFFECT OF WEATHER ON THE HEIGHT OF FLIGHT OF INSECTS

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Abstract – Detailed measurements at 13 heights from 1 cm to 32 m show that the aerial density of *Oscinella frit* nearly conforms to expected diffusion dispersal right down to grass level. Many insects, especially night flyers, are restricted to a narrow layer of air near the ground and within this layer, vertical distribution is fairly uniform. Analysis is not yet complete. The height at which *O. frit* flew was not affected by sunshine or air temperature but was lowered by high wind, rain and increased eclosion.

Zusammenfassung – Genaue Messungen in 13 Höhenstufen von 1 cm bis zu 32 Metern zeigen, daß die Flugdichte der *Oscinella frit* nahezu der erwarteten Verteilung bis hinab zur Grashöhe entspricht. Viele Insekten, besonders Nachtflieger, beschränken sich auf die bodennahe Luftschicht; in dieser Schicht ist die Vertikalverteilung ungefähr gleich. Die Analyse ist noch nicht vollständig. Die Flughöhe der *O. frit* wurde nicht durch Strahlung oder Lufttemperatur beeinflußt, war aber niedriger bei starkem Wind, Regen und zunehmender Entpuppung.

Résumé – Des mesures exactes effectuées à 13 hauteurs différentes réparties entre 1 cm et 32 m ont montré que la densité de vol de *Oscinella frit* correspond approximativement à celle qui était présumée et cela jusqu'à la hauteur de l'herbe. Bien des insectes, et surtout les insectes nocturnes, ne volent qu'au voisinage immédiat du sol. Leur répartition verticale est pour ainsi dire uniforme dans cette couche. L'analyse des essais entrepris n'est pas encore complète. La hauteur de vol de *Oscinella frit* n'est influencée ni par le rayonnement ni par la température. Cette hauteur est par contre réduite par un vent violent, par la pluie et en cas l'éclosion massive.

CHANGES in the number and distribution of aphids hundreds of metres high in the air have been shown to be related to temperature lapse rate and there is conclusive evidence that insects of many other orders fly at these heights in well defined vertical density gradients (Johnson, 1957a and b). Less is known about gradients at lower altitudes (Taylor, 1960). An intensive study of the gradient of insect density, measured at 13 heights from 1 cm to 32 m over short grass and bare fallow, was therefore begun. Up to 2 m over grass, density was measured at 7 heights and striking evidence of the dependence of the distribution of small insects on atmospheric distributive processes, even down to the grass surface, was obtained.

For example, *Oscinella frit* L. has a density × height profile in the first 0.5 m over grass that is remarkably like that expected from diffusion theory (Johnson and Penman, 1951). Detailed analysis of vertical gradients of density of *O. frit* from 1 to 8 m over oats in 1961 show that increase in wind, rain and the number of new adults taking flight, all tend to lessen the mean height of flight, whereas mean air

temperature and hours of sunshine do not. In 1962 monthly mean gradients up to 32 m did not differ greatly from June to September and in that summer the weather differed less than usual between months (Calnaido, French and Taylor, 1965).

Analysis has been started of the density gradients of Lepidoptera, Hymenoptera and Diptera in the first 32 m and the effect of wind and lapse rate on them; other insect orders will be analysed subsequently but the whole analysis will take considerable time to complete.

REFERENCES

Calnaido, D., French, R. A. and Taylor, L. R. (1965) Low altitude flight of *Oscinella frit* L. (Diptera: Chloropidae). *J. Anim. Ecol.* **34,** 45–61.

Johnson, C. G. (1957a) The distribution of insects in the air and the empirical relation of density to height. *J. Anim. Ecol.* **26,** 479–94.

Johnson, C. G. (1957b) The vertical distribution of aphids in the air and the temperature lapse rate. *Quart. J. roy. Met. Soc.* **83,** 194–201.

Johnson, C. G. and Penman, H. L. (1951) Relationship of aphid density to altitude. *Nature, (Lond.)* **168,** 45–63.

Taylor, L. R. (1960) The distribution of insects at low levels in the air *J. Anim. Ecol.* **29,** 45–63.

SUMMARY REPORT

W. O. HAUFE

THREE afternoon sessions of this working group were devoted to presentation of papers and reports and to discussion of the main problems in studying the aerial dispersal and migration of insects. Discussion reflected a broad approach to an explanation of insect movements in response to meteorological environment. This was stimulated by the participation at times of representatives from related fields of research such as meteorology, forestry, and physiological rhythms in addition to the nucleus of ten entomologists.

Nine of the papers and reports prepared were submitted for publication in the proceedings with synopses of parts of the related discussion. Others, including those submitted by members unable to attend, may appear in regular issues of the *International Journal of Biometeorology.*

The need for some organization to facilitate comprehensive periodic reviews of progress in entomological biometeorology was considered by the working group. Ecological studies in entomology have produced a mass of descriptive information on relations between insects, climate and weather. However, development of insect biometeorology as an organized field of study depends largely on a successful integration of this existing knowledge. The entomological sessions in the congress were organized mainly to create a forum for a review of this situation in some specific areas of research.

The Executive Board of the International Society of Biometeorology authorized the constitution of a standing committee on entomological biometeorology. The functions and organization of the committee were considered along the following lines:

Functions — The committe will be instrumental in promoting the development of a "system of entomological biometeorology" as a means of organizing knowledge in the field of insect ecology. A "system of entomological biometeorology" is broadly conceived and, in addition to synthesis of concepts through critical reviews, it may include a preparation of a manual of field techniques, a compendium of instrumentation and calibration related to insect problems, annotated bibliographies, etc. The committe will be instrumental in channeling this activity through the International Society of Biometeorology and in promoting the *International Journal of Biometeorology* as a medium for integrating the knowledge in entomological fields of research. This may improve professional contact and organization among entomologists working in separated fields such as agriculture, forestry, medical science, and public health. Essentially the committee will attempt to

approach what physicists and chemists have done in organizing knowledge in their subjects to accommodate and stimulate future research.

Organization — The standing committee will be limited to six members representing the interests of entomologists in different geographic areas and in various fields of research. It will have flexibility with the addition of individuals with special interests and competence as required from time to time (from both inside and outside the International Society of Biometeorology) to accomplish objectives in developing a "system of entomological biometeorology". Appointment of a chairman for 3 year terms will preserve continuity between successive meetings of the Society.

Some agreement between meteorologists and entomologists must be reached on the units that are acceptable when certain conventional methods of observation are employed in relating insect samples to measurements of the factors in weather and climate. This was considered by both meteorologists and entomologists to be a problem basic to all biometeorological studies on insects, especially in synoptic correlations. Samples representing insect density, for example, and measurements of micro- and macroclimate should have equal statistical validity in terms of the air space or geographic area represented by the observations.

ENGINEERING BIOMETEOROLOGY WITH SPECIAL REFERENCE TO URBAN BIOMETEOROLOGY

Chairman: J. K. Page

LONDON'S HEAT-ISLAND

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Abstract — The London Climatological Survey has been established to investigate the degree to which London's climate is the product of its urban morphology. Temperature differences between central districts and rural areas outside the city are greatest by night, and in summer and early autumn, but the intensity and form of the warm air above London on any particular day or night depends upon atmospheric conditions, particularly of wind speed and direction, and cloud amounts. The form of the warm air, or heat-island, is closely controlled by the character of the urban development, especially the density and bulk of the buildings, and the size and distribution of open spaces within the built up area.

Zusammenfassung — Das London Climatological Survey wurde zu dem Zweck ins Leben gerufen, um zu untersuchen, wieweit Londons Klima das Produkt seiner Stadtlandschaft ist. Temperaturunterschiede zwischen zentralen Stadtvierteln und dem Grüngürtel ausserhalb der Stadt sind am grössten bei Nacht und im Sommer und Frühherbst; die Intensitat und die dreidimensionale Form des über London befindlichen Warmluftkörpers hängt jedoch in jedem einzelnen Fall, sowohl während des Tages als auch während der Nacht, vom allgemeinen Zustand der Atmosphäre, insbesondere der Windgeschwindigkeit and -richtung, ab. Die Form des Warmluftkörpers bzw. der „Wärme-Insel" (heat-island) steht in direkter Beziehung zu der Art der Oberflächenbedeckung, vor allem der Dichte und Massenerhebung der Gebäude sowie der Grösse und Verteilung der Freiflächen innerhalb des überbauten Gebietes.

Résumé — Le «London Climatological Survey» a été créé dans le but d'examiner dans quelle mesure le climat de Londres est influencé par l'agglomération urbaine. Les écarts de température entre les quartiers centraux de Londres et les régions rurales situées hors de la ville sont plus importants de nuit, en été et pendant les premiers jours de l'automne. Cependant, l'ampleur et la forme de l'air chaud qui repose au-dessus de Londres n'importe quand, de jour ou de nuit dépendent des conditions atmosphériques surtout de la force du vent, d'où il souffle ainsi que de la quantité de nuages. La forme de l'air chaud (heat-island) résulte exactement de la nature de la région urbaine, notamment de la densité et des dimensions des bâtiments. Elle résulte également du nombre et de la situation des espaces libres qui se trouvent dans l'agglomération urbaine.

THE first study of the urban influences upon climate was Luke Howard's work *The Climate of London*, first published in 1818, a second enlarged edition appearing in 1833. Luke Howard's account forms a remarkable pioneer study that has since been followed by similar and increasingly sophisticated investigations. In Great Britain, locations include Bath (Balchin and Pye, 1947, 1949–50), Leicester (Chandler, 1961a), London (Manley, 1958; Chandler 1960, 1961b, 1962a, b, c), Manchester (Manley, 1944) Nottingham (Tinn, 1939) and Reading (Parry 1954, 1956).

In London, Bilham (1938) Manley (1958), Marshall (1952) and Shellard (1959), among others had considered some aspect of London's urban climate, that is the manner and degree to which the climate of the city differs from that of its rural envelope, before the Geography Department of University College London initiated a detailed study of the capital's climate in the autumn of 1958. London, like other towns, modifies almost every element of the regional climate, the London Climatological Survey's aim was to throw some further light on these modifications, quantifying the degree to which London's climate is coincident with and the product of its urban morphology. Much attention has been paid to the mass of warm air, or heat-island, which characteristically lies within and above the city.

Within the built-up area of London and its immediate rural surrounds, there are seventeen climatological and synoptic stations making returns of daily readings to the Meteorological Office. By comparison with most other cities this cover is lavish but although the network enabled a preliminary statistical analysis of the broad features of London's temperatures (and other aspects of its climate) to be made, the distribution was too open a base for detailed maps and sections.

For this reason, additional readings have been obtained from two sources: first, 60 newly established climatological stations taking initially twice and then once-daily readings of temperatures (wet and dry bulb, maximum and minimum) and rainfall. Secondly, temperature and humidity traverses across the city yielding detailed lineal measures of these elements. The instrumentation for the traverses consisted originally of electrical resistance thermometers suspended from the roof-rack of a private car and with leads to galvanometers inside the vehicle—a technique similar to that used by Sundborg in Uppsala (Sundborg, 1950, 1951; Chandler, 1960) but when the Survey was extended out of its trial sector in north-east London to cover the whole of Greater London, the method would obviously prove too slow for realistic traverses across the full width of the city. For this reason, after January 1961, new autographic equipment was employed; highly sensitive electrical resistance elements, shielded and mounted ahead of a Land Rover, being connected to a self-balancing a.c. bridge instrument inside the vehicle. Temperature and relative humidity are alternately plotted on a moving chart and at a vehicle speed of 32 km/h, both are recorded every 81 m (Chandler, 1962c).

The temperature difference between central London (Kensington) and the surrounding countryside (Bayfordbury) is, like other cities, best developed by night (Fig. 1). Bayfordbury, north of London, stands 42.7 m higher than Kensington and we would expect it to average about 0.3° C cooler, nevertheless the anomalies in maximum and minimum temperatures at the two stations during 1959 were substantial, reaching as much as 9° C on one night. During 1959 there were 76 occasions when the difference in minimum temperature was 4.4° C or more, with a median value of 2.2° C. Differences in maximum temperatures were much less with a median value of 1.1° C. The few occasions on which London was cooler than outside can be explained mainly by local and frequently temporary difference in cloud amounts.

But the mass of warm air which sits above London changes in form from hour to hour and from month to month. It is best developed during the summer and early autumn (Fig. 2). This is a time when insolation is greatest and when winds

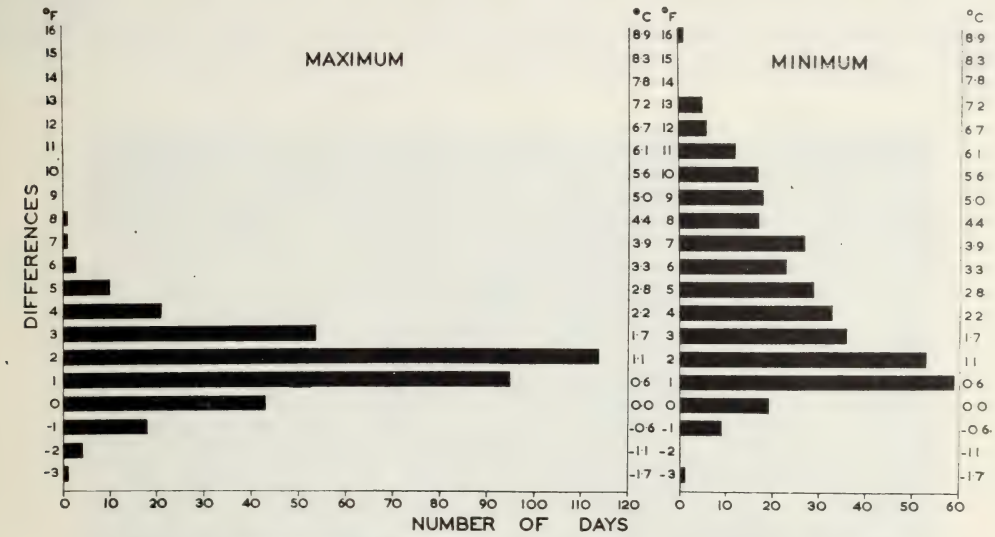

FIG. 1. Temperature differences, Kensington – Bayfordbury, 1959

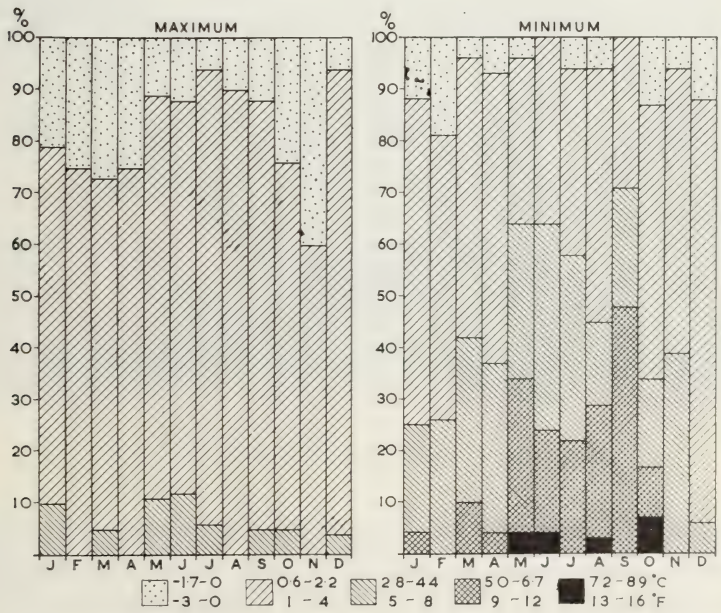

FIG. 2. Monthly temperature frequencies, Kensington – Bayfordbury, 1959

are light, inversions frequently forming on clear nights at heights of 90 – 150 m. Both the overall intensity and the form of the heat island are modified by atmospheric conditions, more especially by wind speed and direction and by cloud amounts.

Daytime heat-islands are not only weak but complex for the air is generally unstable and the warm air of the city sets off a succession of thermals which often rise to very great heights. The pattern, even on the broad scale is rarely constant for more than a few minutes: by night the warm air is frequently contained beneath an inversion. A number of situations will be taken to illustrate the changing form of London's heat-island under contrasted night-time conditions.

FIG. 3. Minimum temperatures 1–2 August, 1959

Figure 3 shows the distribution of minimum temperatures on the night of 1–2 August, 1959. One cannot be sure that this represents the distribution of temperature at any one instant for there will almost certainly be contrasts in the times of minimum at the different recording stations, but any differences are likely to be small. During the night in question northwesterly winds of about five knots were associated with an 8/8 cover of stratus and stratocumulus cloud whose base lowered from about 490 m at midnight to little above 150 m at dawn on 2 August. Although winds were light, the blanket of cloud prevented the free play of those heat-exchange processes which differentiate the city from its rural enve-

lope, thereby limiting the temperature contrasts to 2.8° C. The highest temperatures, it will be noted, were shifted downwind into the southeast inner suburbs of London. This asymmetric distribution is a common feature of nights with light winds.

A dense cloud cover, common in the winter months, is seen to reduce the overall intensity of London's heat-islands. The bearing of wind speeds can be seen in a

Fig. 4. Minimum temperatures 29–30 April, 1959

comparison of two nights. On 29 – 30 April, 1959 (Fig. 4) skies were clear except for a high, thin veil of cirrus, but the northerly winds were fresh; on the second night a fortnight later, 13–14 May, 1959 (Fig. 5), skies were again cloud-free but the winds, again from the north or north-northeast, were very light.

During the night of 29–30 April, 1959, a northerly wind of about 9.3 m/sec was associated with deep and active turbulence in the boundary layer near the earth's surface and the city's warmth was diffused both laterally and vertically, reducing the absolute heat-island intensity to only 2.2° C. The London Climatological Survey has shown that wind speeds below 5–6 m/sec are necessary for the

development of sharp urban-rural contrasts, and that the thermal effect of the city is entirely eliminated by wind speeds greater than about 11–12 m/sec. This compares with 8 m/sec for Bremen, Germany (Kratzer, 1956) and 4.46–6.7 m/sec for Reading, England (Parry, 1956).

The form of the heat-island early on 30 April stands in sharp contrast to that for the early hours of 14 May (Fig. 5). Winds were again from the north or north-northeast but were very light—less than 2.1 m/sec, and skies were clear. These

FIG. 5. Minimum temperatures 13–14 May, 1959

conditions, especially common in summer and early autumn, were associated with an inversion of temperature in the first few hundred feet and the consequence was an intense heat-island, 6.7° C warmer at the centre than outside. The conformity between the urban morphology and the shape and intensity of the heat-island is very remarkable. Steep thermal gradients lie at the margins, especially those in the northeast. Wind strengths in the south of the city were probably increased by turbulence (the Survey's investigation of wind speeds has shown this to be true for velocities of less than about 4 m/sec and in these areas the marginal tempera-

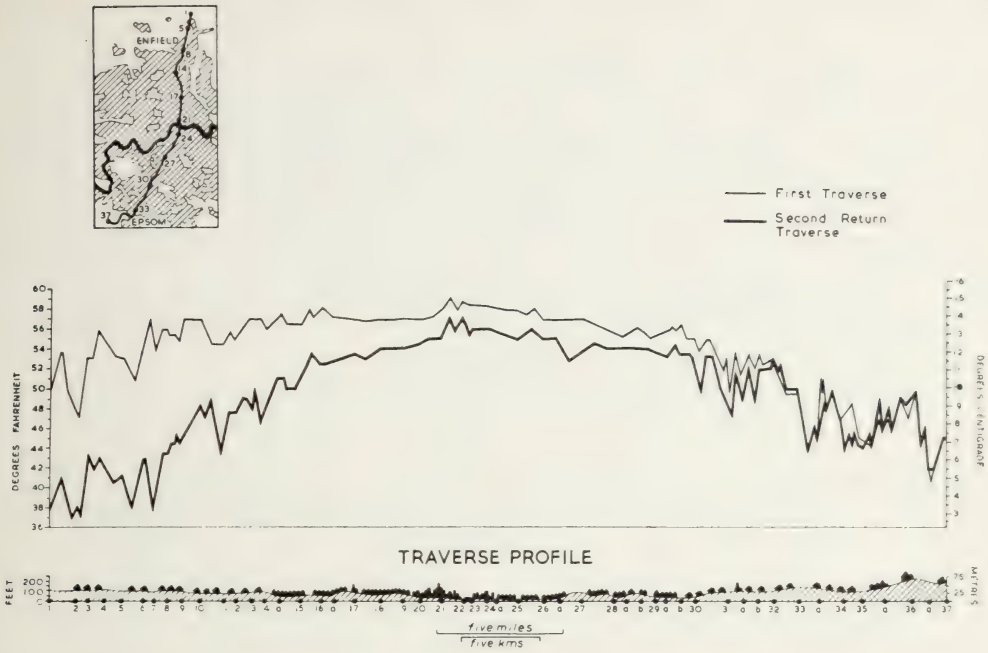

FIG. 6. Temperature traverse — actual readings, London 7–8 June 1962 (night)

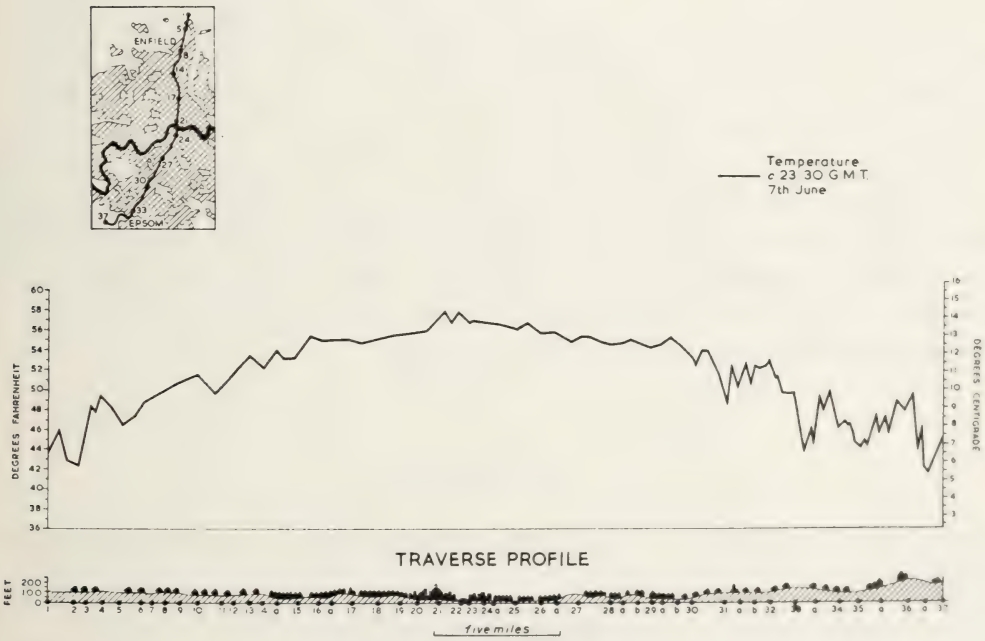

FIG. 7. Temperature traverse — mean values, London 7–8 June 1962 (night)

ture gradients were smoothed. With such intense thermal changes as existed in northeast and east London (between, for instance, the intensively settled areas of the docks area and the marshes of lower Thames-side) it is hardly surprising that light, pulsating, centripetal winds have been found around the urban margins, blowing towards the warmer air of central areas and these have been the subjects of a related investigation. The tongue of warmer air injected into the heat-island from the north on the night of 13–14 May 1959, coincides with highest ground and more open development in the upstanding areas of the North London heights. The central "peak area" of the heat-island coincides with an area of closely spaced, massive buildings and this close correspondence between urban form and climate has also received special attention.

The traverse method is the most suitable to study the more local details of variations in heat-island intensity for it gives closely spaced records which can, by double-traversing, be reduced to a common time base. Figures 6 and 7 show the actual and mean values respectively for such a traverse across London on the night of 7–8 June 1962, and serve to illustrate the close correspondence between the urban morphology and temperature, a feature which, incidentally, supports the idea that heat-island intensities are more dependent on the geography of the immediate environment than the overall size of the urban complex. In Fig. 7, behind the local complexities induced by small pockets of open ground (the general nature of the urban development is given in the traverse profile), three levels of intensity can be recognized to correspond with the three major urban zones — the small central business district with its massive building blocks; a surrounding ring of closely ranked terrace housing and factories built mainly before 1918; and finally, with a lower mean temperatures again, an outer zone of the urban-rural fringe having a typically open tracery development of semi-detached and detached houses along wide roads and with substantial open spaces in which temperatures are very much lower. Open spaces throughout the city have a significant control on temperatures. Other traverses are being conducted across the larger parks of central London and at their centres, they seem to be cooler by as much as 1–1.7° C.

The London Climatological Survey hopes, in the near future to enter the third dimension so that the two-dimensional near-surface picture can be tied in with measures of the changing depth of the heat-island.

REFERENCES

BALCHIN, W. G. V. and PYE, N. (1947) A microclimatological investigation of Bath. *Quart. J. roy. Met. Soc.* **73,** 297–323.

BALCHIN, W. G. V. and PYE, N. (1949–50) Temperature and humidity variations in an urban area of diversified relief. *J. Manchester Geog. Soc.* **55,** 1–23.

BILHAM, E. G. (1938) *The climate of the British Isles,* London.

CHANDLER, T. J. (1960) Wind as a factor of urban temperatures — a survey in north-east London. *Weather* **15,** 204–213.

CHANDLER, T. J. (1961a) Surface breeze effects of Leicester's heat-island. *East Midland Geographer* **13,** 32–38.

CHANDLER, T. J. (1961b) The changing form of London's heat-island. *Geography* **46,** 295–307.

CHANDLER, T. J. (1962a) Diurnal, seasonal and annual changes in the intensity of London's heat-island. *Meteor. Mag.* **91,** 146–153.

CHANDLER, T. J. (1962b) London's urban climate. *Geogr. J.* **128,** 279–302.

CHANDLER, T. J. (1962c) Temperature and humidity traverses across London. *Weather* **17,** 235–242.

MANLEY, G. (1944) Topographical features and the climate of Great Britain. *Geogr. J.* **103,** 255.

MANLEY, G. (1958) On the frequency of snowfall in metropolitan England. *Quart. J. roy. Met. Soc.* **84,** 70–72.

MARSHALL, W. A. L. (1952) *A Century of London Weather.* London.

PARRY, M. (1954): Local day-degree variations in the Reading area. *Meteor. Mag.* **83,** 307–9.

PARRY, M. (1956) Local temperature variations in the Reading area. *Quart. J. roy. Met. Soc.* **82,** 45–47.

SHELLARD, H. C. (1959) The frequency of fog in the London area compared with that in rural areas of East Anglia and South-East England. *Meteor. Mag.* **88,** 321–323.

SUNDBORG, A. (1950) Local climatological studies of the temperature conditions in an urban area. *Tellus* **21,** 221–231.

SUNBORG, A. (1951) *Climatological studies in Uppsala.* Meteorological Service, Uppsala.

TINN, A. B. (1939) Local temperature variations in the Nottingham district. *Quart. J. roy. Met. Soc.* **64,** 391–401.

LOCAL CLIMATIC MEASUREMENTS IN VIENNA

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Abstract – A brief review of studies made of the urban climate of Vienna is given. This review shows that the climate of this city has been explored more extensively than most cities, and investigations in other areas could well draw on the experience accumulated in Vienna.

Zusammenfassung – Es wird ein kurzer Bericht über das Stadtklima von Wien gegeben. Das Klima dieser Stadt wurde intensiver untersucht als das in den meisten anderen Städten, und daher können Untersuchungen in anderen Gebieten von den Erfahrungen profitieren, die in Wien gesammelt wurden.

Résumé – On donne un bref apperçu du climat de Vienne (Autriche). Le climat de cette cité a été étudié de façon plus approfondie que nulle part ailleurs, si bien que des recherches entreprises dans d'autres domaines peuvent profiter de l'expérience ainsi acquise à Vienne.

THE first meteorologists of Vienna had to busy themselves with the local climate of the city although they were not occupied directly with it. The position of the city and its topography means there are two climatic zones divided by a parting line running through the centre of the city. This parting line shows itself as a transition between two plant territories, each one distinctly different from the other, i.e. the Baltic in the west and the Pannonic in the east. The formation of such a distinct botanical borderline arises not only from the geographical features of the site but also from the orographic features, namely the higher situated western part of the city including the Vienna Woods and the low eastern part with its continuation in the Wiener Becken and further eastward in the Hungarian plain.

During the last decades the town has influenced the local climate by its growth and its spreading all across this border, so that today it is difficult to divide the orographic influence from the urban influence. The local climate of Vienna, therefore, depends on the complicated interaction of the above mentioned facts.

The first large scale researches on the town climate were made by Schmidt. In the years between 1920 and 1935 he investigated primarily the temperature and wind conditions at various points of the town, driving with great success in a car which became well nigh legendary in Austrian bioclimatic literature. By using this vehicle, it was possible to make the first temperature measurements across the town, a method which has proved since then almost perfect for preliminary surveys of the local climatic differences arising from particular weather conditions.

These research studies were continued by F. Steinhauser, F. Lauscher, M. Toperczer and H. Tollner from whom we got the results concerning the variation of the turbidity levels above the town made with pyrheliometers after 1930. My revered teacher Franz Sauberer was occupied with the investigations on the local climate in Vienna until his death in 1959, and published numerous papers concerning the town climate. He himself spoke about some of his work within the I.S.B. and this work is well known through his publications.

A compilation of his papers on this topic can be found in the 3 volumes *Klima und Bioklima von Wien*, a work published in three parts between 1955 and 1959, with the help of a subsidy from the Cultural Office of Vienna, and the Institute of Science and Art. This institution has helped support meteorological research on the town's climate since 1950.

This institution created a research group for town problems within the bioclimatic working group, maintaining the contact between scientists of different research disciplines concerned with research work concerning the bioclimate of the town. During the discussions held once a month throughout the year, there is an exchange of ideas on new work. Since 1960 we have selected each working year a primary subject, in cyclical order as follows:

(1) Regional climate differences in the region of Vienna;
(2) Meteorological condition in the streets;
(3) Biometeorological conditions in living rooms and other localities. (Vehicles, etc.)

Within the last three years, it was possible to include the following research topics among these studies:

Investigations of the regional distribution of wind direction and wind velocity.
Measurements of CO-concentration in the air.
Measurements of the turbidity in the town.
Turbidity in relation to wind conditions.
Investigations of the temperature conditions in the streets.
Measurements and records of wind velocity and directions in the streets.
Investigations of the influence of parks on the immediate surrounding areas and of the climate of the parks themselves with respect to their size and kind of planting.

More and more town planning specialists and the main "Institut für Raumplanung" take the local climate as a basis for proposals in town planning. Many contributions on local climate are included in such special studies, and consequently are not published in any other meteorological journal.

The following work has been done on the climatic conditions around and in houses and rooms:

A contribution on climates inside of courtyards.
Measurements of the surface temperature of walls, and street surfaces.
Investigations of the temperature of rooms.
Records of temperature and humidity in rooms with different types of heating system.
Measurements of the temperature of the walls of heated and unheated rooms during the winter.
Measurements of light intensity in rooms of different kinds.

For the above mentioned investigations we had and have in Vienna a permanent network of more than ten recording stations measuring temperature, humidity, wind velocity and wind direction all over the town. Moreover from time to time, we install short period recording stations and do measurements by hand as well as free driven vehicles for special problems.

AN INVESTIGATION OF URBAN TEMPERATURE VARIATIONS BY TRAVERSES IN SHEFFIELD (1962–1963)

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Abstract – The effects of both relief and urban functional variations on temperature distributions are shown from night and early morning temperature-traverse data collected during summer, autumn and winter. The significance of an industrial heat-island, and of the importance of open ground in Sheffield are indicated.

Zusammenfassung – Die Wirkungen von funktionellen Unterschieden des Reliefs und der Stadt auf die Temperaturverteilung wird erkennbar aus Temperaturmessungen während der Nacht bis zum frühen Morgen im Sommer, Herbst und Winter. Die Eigenarten einer industriellen „Wärme-Insel" und die Bedeutung von offenen Gebieten in Sheffield werden besprochen.

Résumé – Au moyen de la répartition des températures, on détermine l'interaction des différences de relief et de degré d'industrialisation de la ville. Ces températures furent relevées durant la nuit et tôt le matin en été, en automne et en hiver. On discute les particularités d'un « îlot de chaleur » dû à l'industrie et l'importance de zones non bâties à Sheffield.

In investigating the climate of an urban area presenting topographical complexities as diverse as those present in Sheffield many problems are presented, particularly with respect to the analysis of temperature regimes. The physique of the site, with a range of relief exceeding 1,000 ft guarantees a range of temperature of

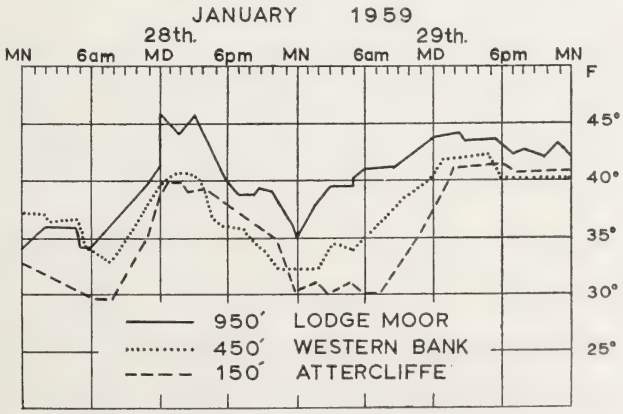

Fig. 1. Inversion of temperature (°F) characteristic of winter anticyclonic conditions in Sheffield, January 1959

some magnitude at all times and one which may mask, or modify the effects caused by other factors – particularly those associated with local variations in urban land-use (Figs. 2–4). The bold hilly terrain further ensures that under anticyclonic conditions marked inversion of temperature may occur, (Fig. 1) and this has been recorded as giving 10° F temperature differences for valleys at 100 ft and spurs at 950 ft.

During the autumn and winter of 1962–63 a number of temperature traverses were undertaken to investigate these differences more closely. Twenty-three valley traverses were made each with 89 observation points, under a variety of weather

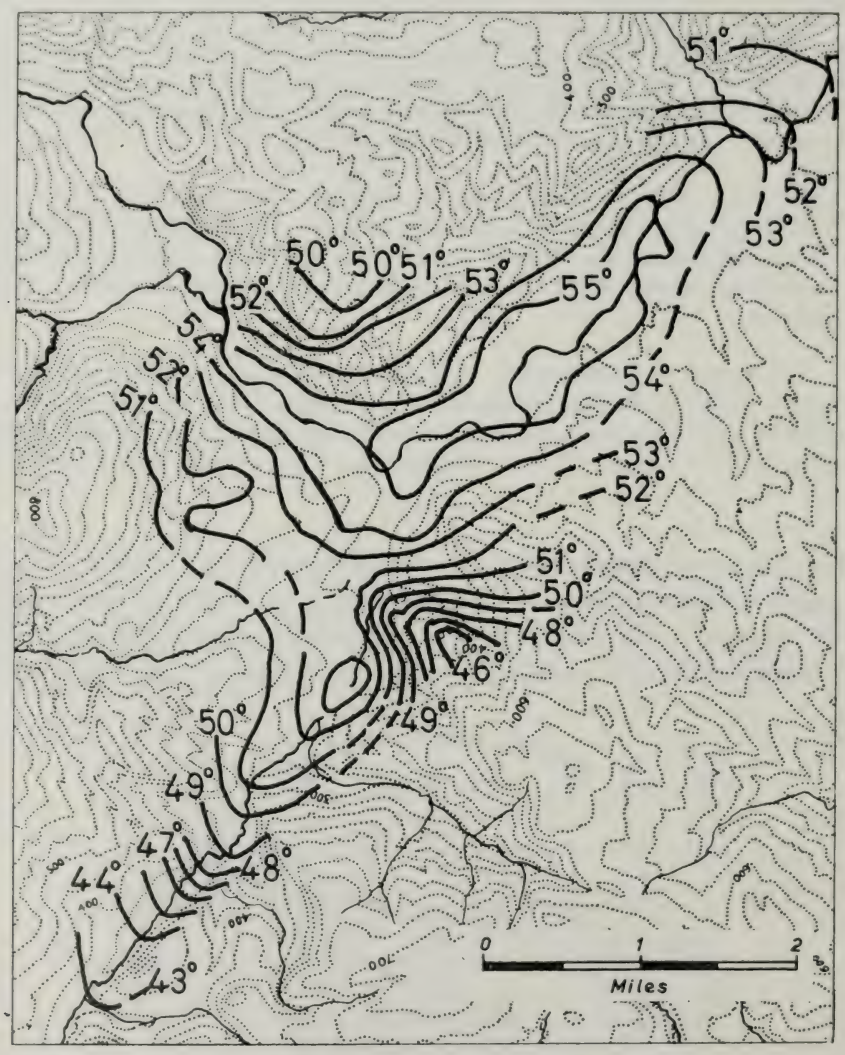

FIG. 2. Sheffield: temperature conditions at 22:42 – 0:32 h on 18 August 1962, (from temperature traverses, °F). The traverse illustrates night "heat-island" effects in the Don valley industrial area, under calm anticyclonic weather with clear sky and radiation under summer conditions, and following a sunny day

conditions both by day and night. Seven traverses were carried out consecutively at 4-hr intervals, within 24 hr, to assess changes in the diurnal pattern under anticyclonic conditions. In addition, under all weathers, a further eight longer traverses were made following a spiral course 41 miles in length crossing ridges and valleys and including 99 observation points. Some of the traverses were undertaken during the severe weather of January 1963.

The observations were made with a meteorological office balanced bridge aircraft thermometer indicator mounted on the front of a car rack one foot from the roof and 6 ft both from the engine and above ground. Dry bulb and wet bulb readings were obtained and on some traverses aneroid pressure readings were taken

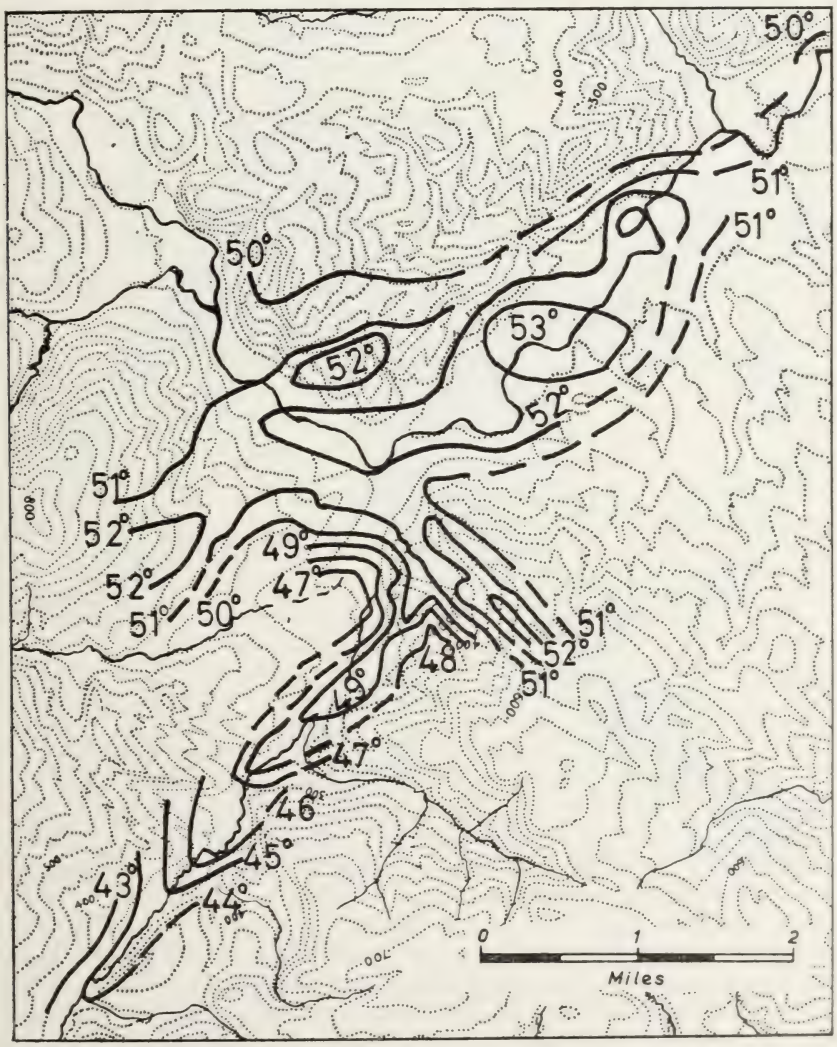

Fig. 3. Sheffield: temperature conditions at 22:06–23:19 h on 16 October 1962, (from temperature traverses, °F). This traverse illustrates the "heat-island" effects in autumn with all the conditions fulfilled for its pronounced development (calm clear skies, thin haze in valleys but clear skies on outskirts)

at each point so that to the details of temperature, relative humidity and vapour pressure could be added the computed potential temperature at each point. The latter is especially valuable when attempting to differentiate from relief factors, in this type of terrain, and we believe that this is the first occasion when potential temperature assessment has been used in interpreting traverses of this kind.

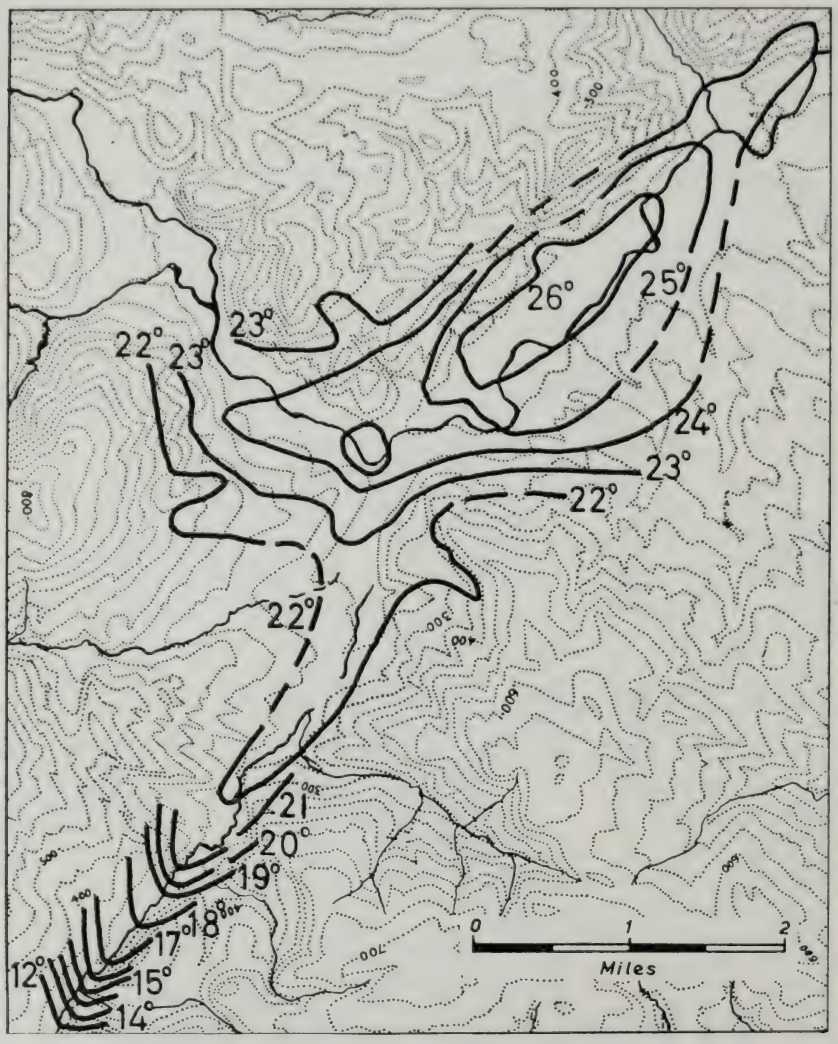

FIG. 4. Sheffield: temperature conditions at 22:00 – 23:34 h on 21 January 1963, (from temperature traverse, °F). This is an exceptional case of a strong "heat-island" which would otherwise occur only under favourable conditions in summer; but the coincidence of the following favourable factors caused this phenomenal temperature difference between the warmest and coldest points on the traverse: (1) a light breeze, E.N.E. (3); (2) a cloudless sky over the outskirts and hills with an uninterrupted stratus layer of high fog over the city and industrial area; (3) a layer of snow on outskirts which reflected the sunshine by day (5:30 h) whereas in town the snow clearance permitted absorption

In the accompanying maps only a first indication can be given of the kind of results that are emerging from this work. Figure 2 shows characteristic "heat island" conditions at 22 : 42 to 0 : 32 h in mid August under the combined effect of anticyclonic weather giving solar radiation income by day plus urban industrial heat income. Temperatures at night in the Don valley were 12° F warmer than in the valley 4 miles to the south west, and circulation from open park land to the south east of the city centre, at 600 ft, locally injected air 9° F cooler.

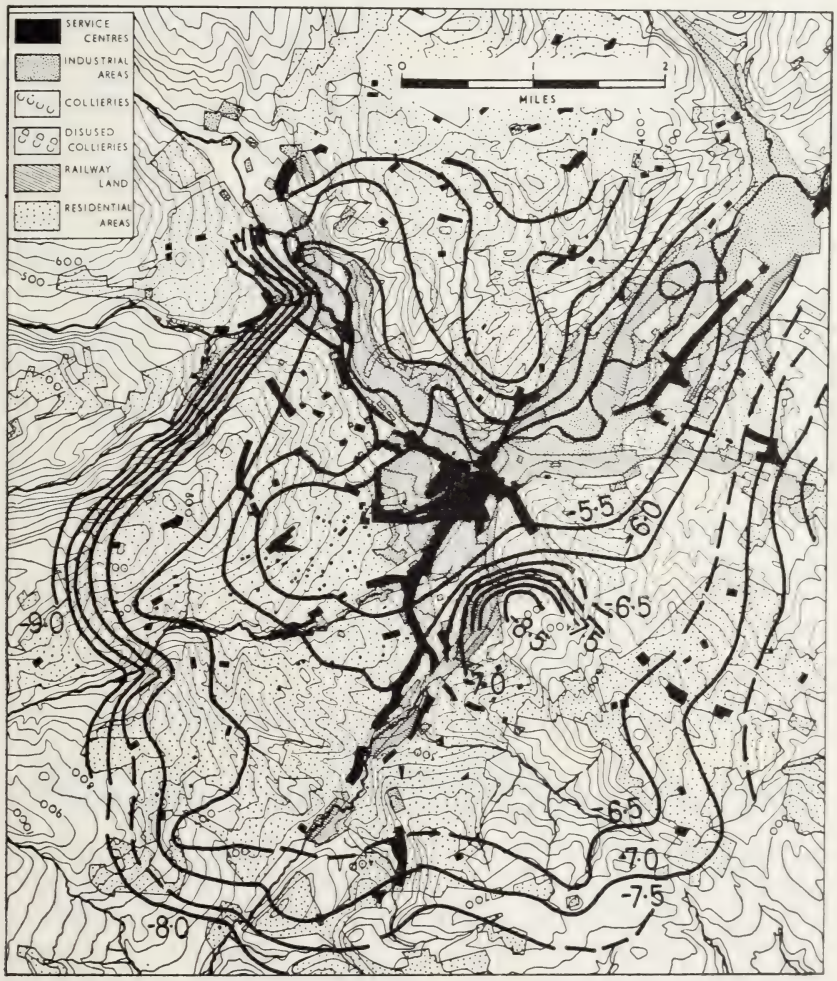

Fig. 5. Sheffield: temperature conditions at 5:03–7:07 h on 17 January 1963, (from a longer spiral traverse involving 99 recording points, and temperatures reduced to Potential Temperature (°C) to eliminate the effect of relief. The map shows the relation of Potential Temperature to urban land use. The traverse portrays "heat-island" conditions towards the end of the period of night radiation, just before dawn under midwinter anticyclonic conditions. During the traverse there was broken cloud cover, snow cover over the outskirts, slightly hazy weather, light breeze N.N.E. (2), with 1.1 hr sunshine on the preceding day

Figure 3 demonstrates characteristic "heat island" development over the same area and for the same hours in mid October. The Don valley at 150 ft was then 10° F warmer than the Sheaf valley to the south west, and this despite the longer time available in October for air drainage and the fuller development of valley inversions of temperature such that the spur slopes at 600 ft were then as warm as the industrial Don valley at 150 ft and 10° F warmer than the urban outskirts in the Sheaf valley, to the south west.

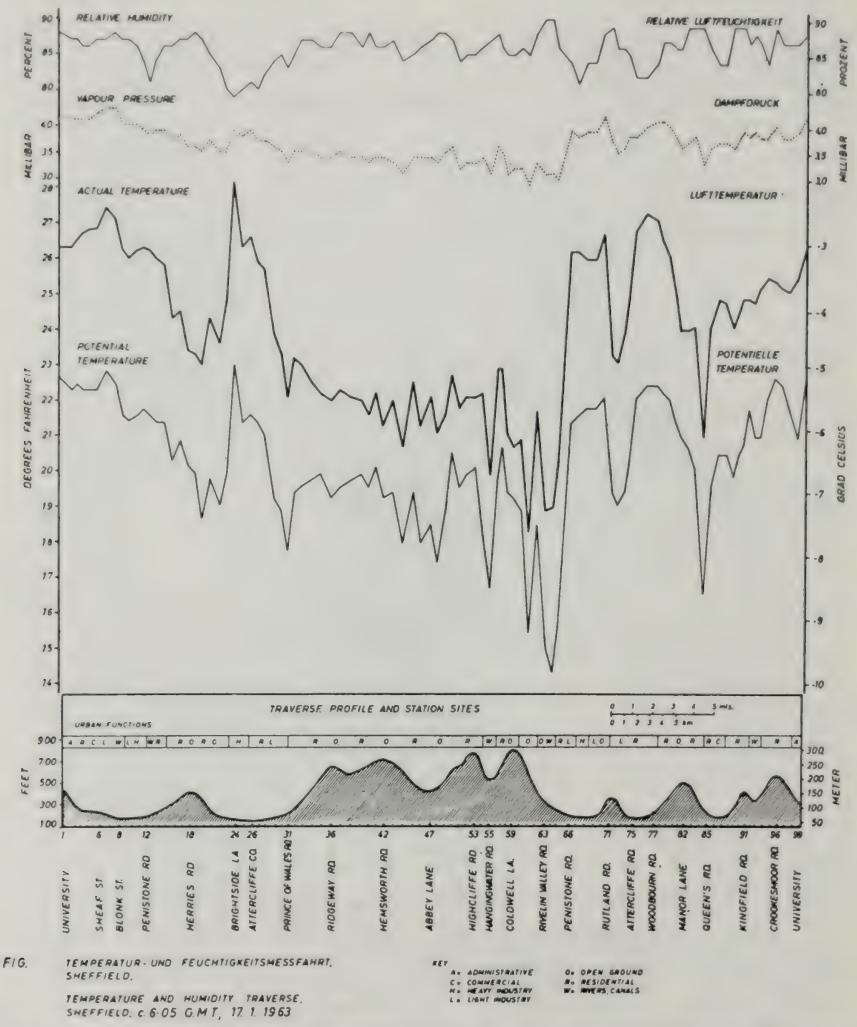

FIG. TEMPERATUR- UND FEUCHTIGKEITSMESSFAHRT, SHEFFIELD.

TEMPERATURE AND HUMIDITY TRAVERSE, SHEFFIELD, c. 6·05 G.M.T, 17. 1. 1963

KEY
A = ADMINISTRATIVE
C = COMMERCIAL
H = HEAVY INDUSTRY
L = LIGHT INDUSTRY
O = OPEN GROUND
R = RESIDENTIAL
W = RIVERS, CANALS

FIG. 6. Sheffield: graphical representation of weather elements (temperature and humidity) in relation to relief and urban land-use for the traverse shown cartographically in Fig. 5; 17 January 1963, at 5:03–7:07 h.

Key to urban functions above section:
A = Administrative; C = Commercial;
H = Heavy Industry; L = Light Industry;
O = Open Ground; R = Residential;
W = Rivers, Canals

Figure 4 shows a similar but more extreme pattern for a night in January 1963 when valley temperatures of 12° F in the outskirts were matched by 26° F in the industrial zone of the Don valley.

Figure 5 portrays conditions assessed from one of the longer traverses that were attempted crossing and recrossing a wider range of urban conditions during the significant hours of 5:00 to 7:00 h just before dawn, after continuous night radiation in January 1963. Anticyclonic weather prevailed with clear skies maintaining radiation and a snow cover over the outskirts, whilst in the centre of the city snow had been removed, and a slight industrial haze and cloud helped to conserve the urban heat income. Despite the duration of darkness, and night cooling, actual temperatures at 5:00 to 7:00 h ranged from 19° F in the outskirts to 28° F in the industrial core. The map shows both urban land-use and relief, but against this, potential and not actual temperatures are plotted, so that the influence of relief is eradicated in modifying the apparent temperature distribution. It will be noted that the potential temperature pattern indicates: (1) a "heat island" 4° C warmer over the industrial zone as compared with the outskirts; (2) the steepening of the temperature gradient where the fringes of open residential land give place to continuous open ground – notably in the vicinity of the main tributary valleys to the south west; (3) an interesting intrusion of relatively colder air off open park land near the centre of the town – a feature that has already been noted with reference to Figs. 1 to 3. The significance of changes in urban land-use in modifying temperature locally seems very evident.

Figure 6 expresses the traverse data of the last map in graphical forms as a continuous linear record, and underlines the severity of the fluctuations for this weather incident. Graphs for other traverse occasions, however, show a less sharply variable temperature pattern, according to differing humidity conditions, and the degree of the strength of air circulation associated with other weather types.

ACKNOWLEDGEMENT

To Professor Scorer, Imperial College, London, grateful acknowledgment is extended for the suggestion made by him, in discussion, that Potential Temperatures might resolve the difficulty of assessing urban effects in hilly terrain; such as exist in Sheffield.

The authors wish also to express their indebtedness to the Meteorological Office for the loan of recording apparatus for this work.

A CONTRIBUTION ON CLIMATES INSIDE COURTYARDS IN THE CITY OF VIENNA*

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Abstract – Special features of temperature and humidity distribution inside two courtyards of different size in the city of Vienna were studied by recording temperature and humidity. For the larger courtyard (area 8 × 15 m, height 20 m) in summer the measured temperature showed a difference of about 10° C compared with that of the surroundings. For the smaller one (area 2 × 4 m, height 20 m) the difference was 20° C. Further results were the reduced amplitude of the daily temperature range and the warming up of the courtyards in winter due to heating in the buildings. The vertical temperature profile was registered by the aid of an electric plummet.

Zusammenfassung – Durch Registrierungen der Temperatur und Feuchtigkeit in zwei verschieden grossen Höfen in Wien wurden die dort auftretenden Besonderheiten im Temperatur- und Feuchteregime genauer erfasst. So ergaben sich im grösseren Hof (8 × 15 m Fläche, 20 m Höhe) im Sommer Temperaturunterschiede gegenüber der Umgebung bis zu 10° C, im engen Lichthof (2 × 4 m Fläche, 20 m Höhe) bis gegen 20° C. Weitere Eigenheiten sind die Verringerung der täglichen Temperaturschwankungen und die Überwärmung der Höfe im Winter durch die Heizung der Gebäude. Das vertikale Temperaturprofil wurde durch gelegentliche Messungen mit einem elektrischen Temperaturlot erfasst.

Résumé – On a étudié des états spécifiques de la distribution de la température et de l'humidité à l'intérieur de deux cours de différentes grandeurs à Vienne (Autriche). On y a enregistré la température et l'humidité. Dans la plus grande d'entre elles (8 m sur 15 et 20 m de hauteur) la température était de 10° C. plus élevée qu'aux alentours. Dans la plus petite vitrée de surcroît (2 m sur 4 et 20 de hauteur) on a enregistré des différences de 20° C. Comme autres particularités, on peut mentionner la réduction des variations diurnes de la température, le réchauffement des cours en hiver par suite du chauffage domestique. Le profil vertical de la température fut établi sporadiquement au moyen d'une sonde électrique.

THE temperature regimes of two courtyards of different sizes were observed, as part of a wider investigation of the local temperature and wind-distribution in a city. Automatic recording instruments were placed on the ground of two courts. The air temperatures of the surroundings were recorded in thermometer screens placed on the roof of the buildings and in a meadow nearby. The vertical thermal stratification in the courts was measured by the aid of an electric plummet. The larger courtyard had an area of 15 × 8 m and a depth of 20 m, the smaller one of 4 × 2 m and the same depth.

*The original German version of the complete paper has been published in "Wetter und Leben", **15**, 137 – 146 (1963).

The effect of the reduced turbulent exchange, the great heat capacity of the surrounding walls, the shadowing effect of the surroundings and frequent stagnation of cold air on the ground of the courts, resulted in large modifications of air temperature. The most important observation was that temporal variations of temperature were reduced in the courtyard.

The greatest temperature differences between the courtyards and their surroundings arise during clear days with low wind speeds. During the night only small

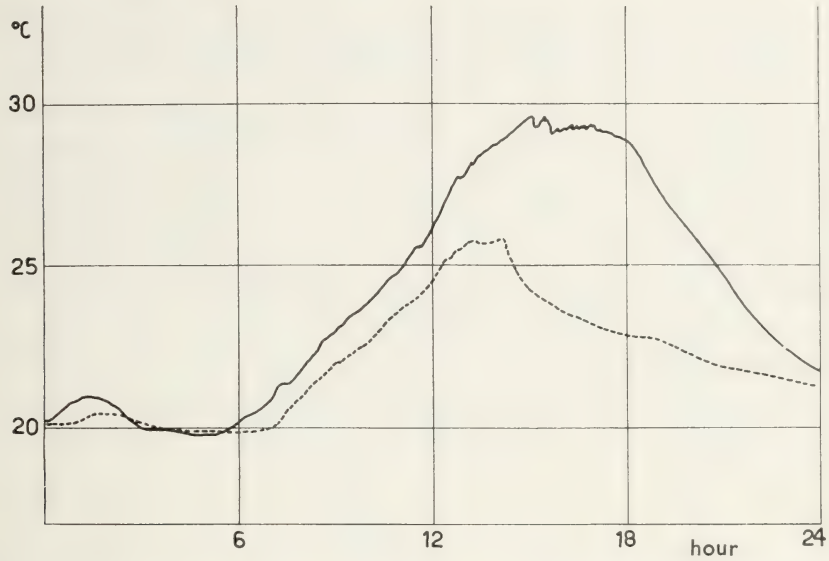

Fig. 1. Daily variation of air temperature on a clear summer day on the roof (—) and in the court (– – –)

differences arise, as the stronger cooling on the outside effects a labile stratification in the courtyards and a stronger turbulent exchange. The stable stratification in the daytime leads to temperature differences up to 10° C in the wider court. The increasing stability of the stratification during the day explains the observation that in many cases temperature rise on the ground stops before the maximum temperature outside is reached and a decrease of temperature during the afternoon takes place. Figure 1 shows a typical case of that kind. In narrow courtyards temperature differences up to 20° C could be observed between the ground and the surroundings.

More details about the temperature regime could be gained by measurements of the vertical temperature distribution in the courtyards. Fig. 2 shows such measurements on clear days. On both days the meteorological conditions were very similar, and the seasonal differences do not influence the results.

In the wider courtyard the accumulation of cold air on the ground during the day is clearly seen. In the narrow court a much stronger lapse rate of temperature was found with nearly linear temperature increase with height. Stable and labile

stratification alternate nearly every day in wider courts; in very small courts the stable stratification dominates during summer, the labile one during winter.

Further special features of air temperature variations in courts can be observed. The influence of courts on temperature conditions, as described above, can be observed on nearly all days during summer. The mean daily variations of the individual months over the period of 15 months investigated also show the described deviations. Only bad weather with strong winds destroys the special microclimate.

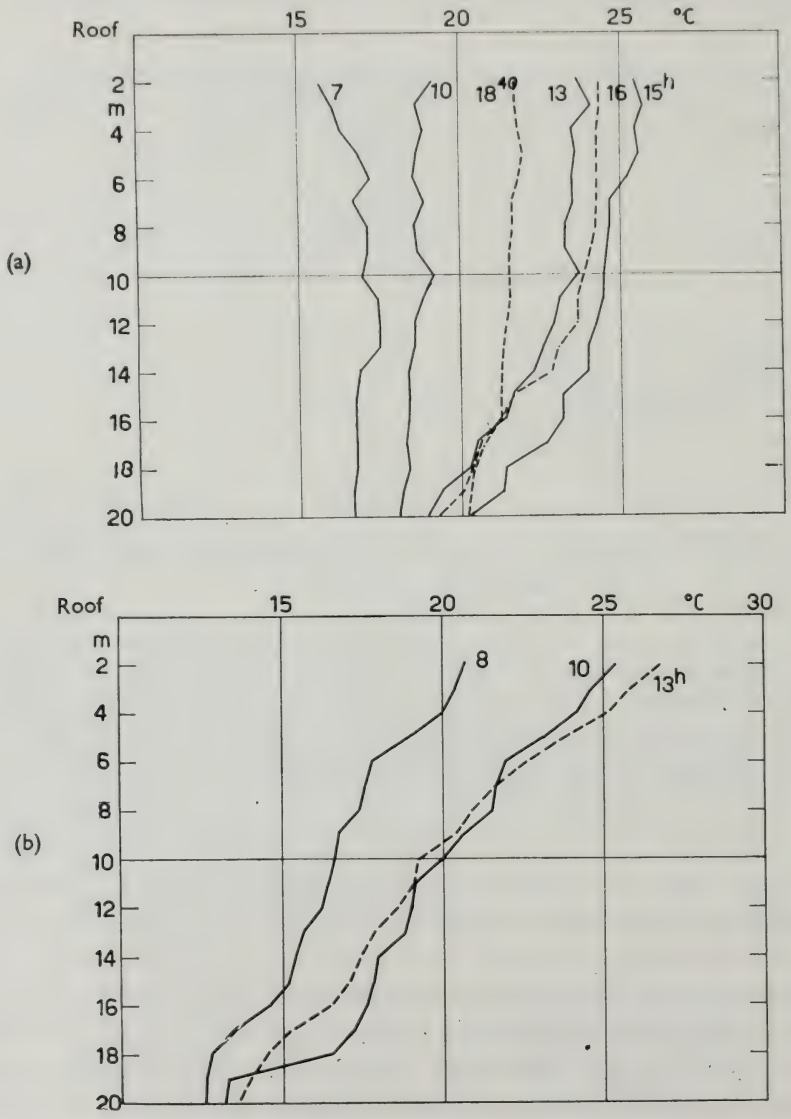

Fig. 2. Vertical temperature distribution on a clear day with low wind

(a) in the wide court (20 September 1961)
(b) in the narrow court (16 June 1962)

During the winter time the temperature level of both courts lies above the level of the surroundings all day long. This is an effect due to the heating of the buildings.

The following conclusions can be drawn from the frequency distribution of temperature differences between the courtyard stations and the surroundings.

1. Lower temperatures than outside are relatively frequent during summer in the wider court, 7 per cent all hours. Periods with 0–2° C higher occur inside such courts with greatest frequency.
2. In the wider court we very seldom find values more than 2° C higher than the surroundings. Such differences are the most frequent differences in the narrow court during winter.
3. The influence of courts on temperature is shown very clearly by the daily fluctuations of air temperatures. The fluctuations in the courts are smaller than in the surroundings on nearly all days. The diminution of the daily fluctuations in the wider courtyard results chiefly from the lowering of the maximum temperature. The minimum temperatures are not very different. In the narrow courts only very small daily variations arise. There is however a discernable difference between times with labile and stable thermal stratification. This fact explains the greater fluctuations in winter (with values about 1–2° C), while during summer they amount to a few tenths of one degree only.

ERGEBNISSE VON KONTINUIERLICHEN WINDAUFZEICHNUNGEN IN WIENER STRASSEN

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Abstract — Records of wind velocity and wind direction have been made during the period July 1961–March 1962 in many streets of Vienna. An analysis of the wind pattern has been made for certain weather types. Only periods of well developed wind direction have been considered at the base station, namely Vienna–Leopoldau. A relationship between wind direction and the street system was found. Generally the velocity of the wind in streets is reduced. A reduction factor is sufficient for calculating the diminution of the wind speed with air coming from N.W. or S.E. However, in Vienna when the wind direction was "west" it proved impossible to find any linear relationship. A station in the park area (Stadtpark) showed an ideal protection effect due to trees and shrubs.

Zusammenfassung - In der Zeit von Juli 1961 bis zum März 1962 wurden Windregistrierungen in einigen Straßen Wiens vorgenommen Analysiert wurden die Windverhältnisse während bestimmter Wetterlagen, d. h. während Perioden einheitlicher Windrichtungen an einer Basisstation, nämlich Wien–Leopoldau. Bei der Windrichtung konnte eine Anpassung an den Verlauf der Straßenzüge und für einzelne Richtungen eine durch die Verbauung bewirkte Verwirbelung festgestellt werden. Die Windstärke ist allgemein stark gebremst. Für die Richtungen SE und NW genügt ein Faktor zur Berechnung der Abschwächung des Freilandwindes (aus einer Windrichtung). Für die Richtung W jedoch ist der Zusammenhang nicht linear. Eine Station im Parkgelände (Stadtpark) zeigt die ideale Windschutzwirkung von Baum- und Buschbewuchs.

Résumé — De julliet 1961 à mars 1962, on a effectué divers enregistrements du vent dans certaines rues de Vienne (Autriche). On a ensuite analysé les conditions de vent pendant des périodes de vents réguliers, c'est à dire durant des situations synoptiques déterminées. Pour ce faire, on s'est servi des observations d'une station de base: Vienne–Leopoldau. La direction générale du vent s'adaptait au tracé des rues, mais, dans certains cas particuliers, on a constaté la formation de remous dûs aux bâtiments environnants. La vitesse du vent est en général, fortement affaiblie. Pour les directions sud-est et nord-ouest, on peut calculer pour chacune d'elles la vitesse du vent en ville en multipliant celle d'une station extérieure par un facteur de correction. Pour les vents d'ouest, la relation n'est par linéaire. Une station située dans un parc (parc municipal) montre l'effet protecteur idéal des arbres et des buissons.

In der Zeit vom Juli 1961 bis zum März 1962 wurden in einigen Wiener Straßen Windregistrierungen vorgenommen. Zweck dieser Untersuchungen war es, Aufschluß über die Luftbewegungen in der bodennahen Luftschicht zu erhalten, in der sich der Mensch aufhält. Für diesen sind, je nach der Herkunft, Luftmassen angenehm, wenn sie reine Luft heranführen, oder unangenehm, wenn sie durch allerlei Ursachen verunreinigte Luft zubringen.

Über einem Stadtgebiet erfährt nun aber die großräumige Luftbewegung verschiedene Veränderungen. Die erhöhte Rauhigkeit der verbauten Oberfläche führt zu starker Abbremsung der Windgeschwindigkeit in Bodennähe, die Windrichtungen werden sich im allgemeinen dem Verlauf der Straßen anpassen und können sogar starke Drehungen erfahren. Überdies besitzt die Stadt noch ein eigenes thermisches Windsystem, das hier jedoch nicht berücksichtigt wurde.

Analysiert wurden für diese Betrachtungen die Windverhältnisse während bestimmter Wetterlagen, die in Wien häufig sind. Dazu wurde eine Vergleichsstation, Leopoldau, die im Nordosten der Stadt liegt und weitgehend ungestörte Windverhältnisse wiedergibt, herangezogen.

Die Meßstationen in den Straßen wurden nach den für Wien am häufigsten auftretenden Arten der Verbauung und des Straßenverlaufes aufgestellt. Und zwar

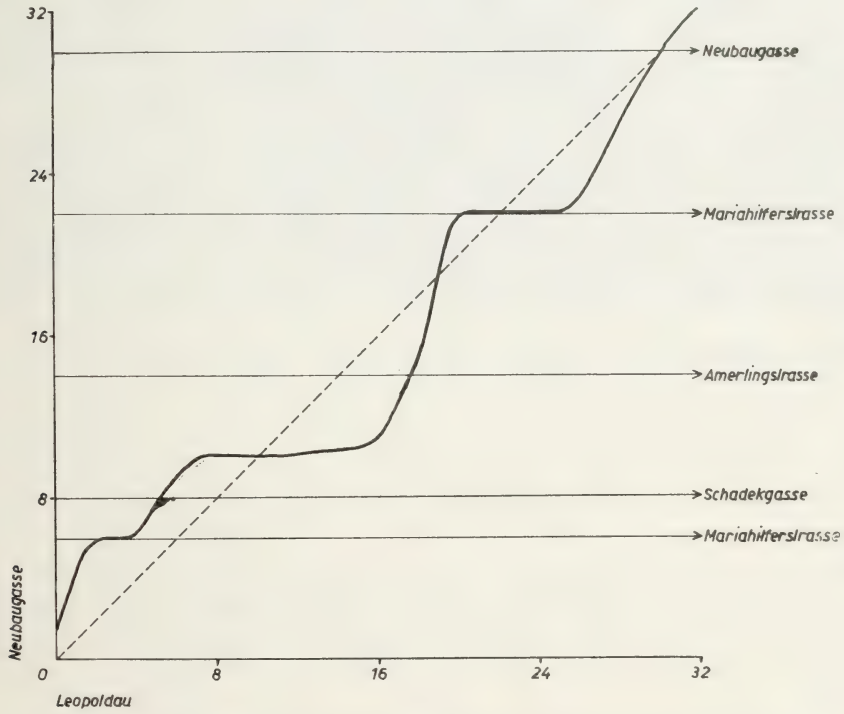

Abb. 1. Windrichtungsvergleich Leopoldau—Neubaugasse

stand eine Station im Stadtkern, eine in einer Langen Häuserchlucht auf einer Kreuzung und eine auf einer breiten wenig verbauten Straße. Überdies wurde noch eine Registrierstation in einer großen Parkanlage aufgestellt. Die Registrierung erfolgte mit elektrischen Windstärke-und Windrichtungsgebern. Die Aufstellungshöhe betrug allgemein cirka 4 m.

Wie nun nicht anders zu erwarten war, erfahren die Windrichtungen eine starke Ausrichtung durch die Straßen und damit eine starke Abbremsung, die, wenn Verwirbelungen auftreten, noch beträchtlicher werden kann.

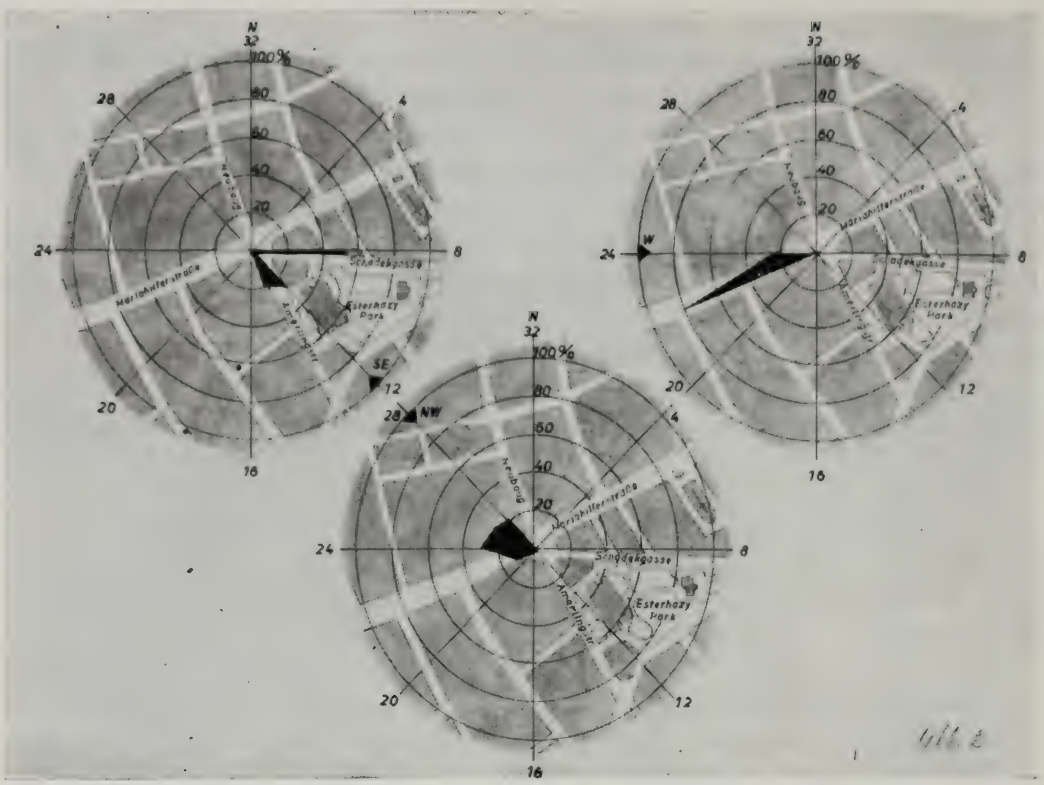

Abb. 2. Windrichtungsvergleich Neubaugasse–Leopoldau in % von Leopoldau

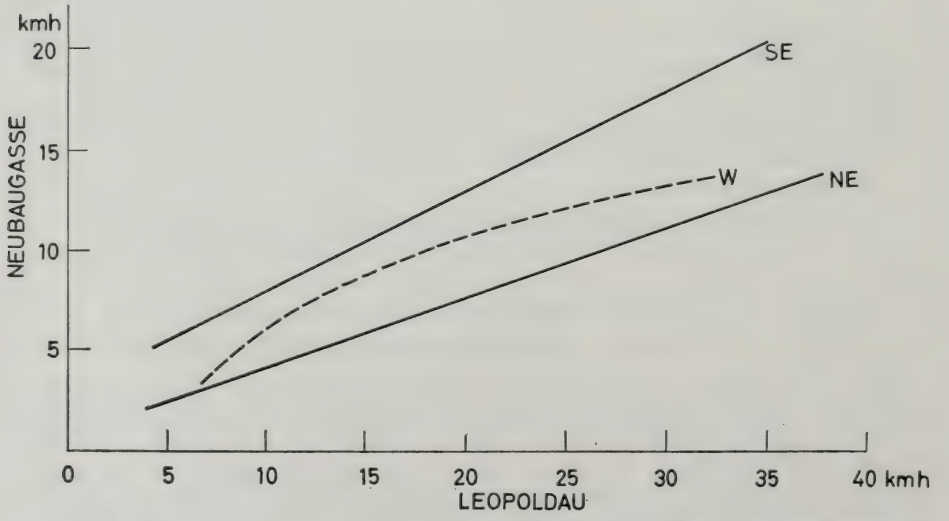

Abb. 3. Windstärkevergleich Leopoldau–Neubaugasse für die Windrichtungen W, NW und SE

Als Beispiel zeigt die Abb. 1 eine Gegenüberstellung der Windrichtungen im Freiland zu denen in einer der Straßen. Noch klarer und eindeutiger wird die Beeinflussung der Windrichtung in den Straßen, wenn eine konstante Windrichtung im Freiland zu der in den Straßen registrierten in Beziehung gesetzt wird. Die prozentualle Aufschlüsselung zeigt die Abb. 2, in der im Unterdruck die unmittelbare Umgebung der Station festgehalten wurde. Die Westwinde folgen genau dem Verlauf der Mariahilferstraße, SE-Winde strömen die Station durch zwei für sie günsstige Straßen an. Bei NW-Winden hingegen tritt eine starke Auffächerung ein. Möglich wäre wohl ein Anströmen der Station durch die Neubaugasse, jedoch erweist sich diese als zueng und zu verbaut.

Würde man nun an Hand der ersten Abbildung ebenso die Windstärke behandeln, also ohne Berücksichtigung der Bevorzugung oder Benachteiligung der Windrichtungen, würde man ein vollkommen unrichtiges Bild über die Windstärkeverhältnisse an dem betreffenden Punkt erhalten. Demzufolge wurden nur jene Windstärken verglichen, die an der Freilandstation über längere Zeit konstante Windrichtungen hatten. Für die beim Vergleich erhaltenen Punktwolken wurden Regressionsgerade berechnet, die in der Abb. 3 dargestellt sind. Als Resultat ergibt sich, daß SE-Winde unter geringerer Abschwächung als die W-und NW-Winde die Station erreichen. Entsprechend der starken richtungsmäßigen Auffächerung der NW-Winde, siehe Abb. 2, ist ihre Geschwindigkeitsverminderung bedeutend. Ein ganz anderes Bild bietet aber der W-Wind. Unter geringer Drehung strömt er die Station durch den 'Kanal' der Mariahilferstraße an, weist aber einen nichtlinearen Zusammenhang mit der Station Leopoldau auf. Worin diese Nichtlinearität ihre Ursache findet, ist Gegenstand weiterer spezieller Untersuchungen.

Bei den weiteren Stationen ergibt sich, je nach der Orientierung der Verbauung, ein günstigeres oder ungünstigeres Anströmen der drei behandelten Richtungen. Gemeinsam ist aber allen Stationen der nichtlineare Zusammenhang mit der Freilandstation bei W-Winden.

An der Station im Parkgelände ist der ideale Windschutz von Baum-und Buschbewuchs zu erkennen. Auch bei stärksten Winden im Freiland treten im Park minimale Werte der Geschwindigkeit auf.

THE URBAN "HEAT-ISLAND"

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Abstract – The results of a survey of local climate in Reading, England, are used to assess the causes of the varying strength of the urban warmth ("heat island") in different parts of the town. It is concluded that, for a town of this type, the density of the built-up area is the dominant influence, being more important than the smoke content of the air or the artificial warmth of buildings. The conditions of exposure at fixed recording stations are shown to be highly significant and the dangers of unrepresentative siting are stressed. A plea is made for the recognition of the essentially microclimatic character of the so-called "urban climate".

Zusammenfassung – Die Ergebnisse einer Untersuchung des örtlichen Klimas von Reading, England, werden dazu benutzt, um die Ursachen der unterschiedlichen Stärke der städtischen Wärme („Hitze-Insel") in den verschiedenen Teilen der Stadt zu ermitteln. In einer Stadt dieser Art ist die Dichte der bebauten Flächen von wesentlichem Einfluß und von weitaus größerer Bedeutung als der Rauch-Gehalt der Luft oder die künstliche Wärme der Gebäude. Der Anbringungsort von Meßgeräten (und deren unmittelbare Umgebung) an statischen Registrierstellen erweist sich als überaus wichtig und die Gefahren wahlloser Anbringung werden hervorgehoben. Es wird dringend befürwortet, den im wesentlichen mikroklimatischen Charakter des sogenannten „Stadt-Klimas" anzuerkennen.

Résumé – Les résultats d'une étude du climat local de Reading, Angleterre, fournissent la base d'un examen des raisons qui provoquent, d'une zone à l'autre, l'intensité variable de la chaleur urbaine («heat island»). On en conclut que, pour une telle ville, l'influence dominante n'est ni le taux de fumée dans l'atmosphère, ni la chaleur artificielle des bâtiments, mais simplement la densité de l'agglomération. Au sujet des postes d'observation, on souligne l'extrême importance des conditions d'exposition et les dangers du choix d'emplacements peu représentatifs. Il faut en outre reconnaître le caractère essentiellement microclimatique du soi-disant «climat urbain».

OF ALL the diverse elements that make up the urban climate, none has attracted as much attention and observation as the excess warmth or "heat island" and none, apart from air pollution, has more important bioclimatological implications. Ever since Luke Howard, the father of English climatology, measured temperature differences between a site in central London and what were then villages 4 miles away (Howard, 1833), a considerable body of information has accumulated regarding many towns in Europe and much of this is recorded in a well-known book by Kratzer (1937). A later, more up-to-date and extremely useful summary has been provided by Landsberg (1956).

Howard's classic observations in the early years of last century were made with thermometers of doubtful accuracy and exposure, though they led him to qualit-

ative conclusions with which one would hardly quarrel today. Since then many comparisons of urban and rural temperatures have been based on records of what came to be regarded as orthodox climatological stations, with standardized equipment sited in open exposures on the lawns of large gardens or parks. Quantitative conclusions drawn from these were by no means useless but suffered from the confusion of two different scales of climatic consideration, in that stations intended to be representative of a region were being used to provide comparisons of a local nature. The use of records from roof-top stations in some American cities further complicated the issues. Later, when networks of meteorological stations were established with the express purpose of investigating urban climates, as in the English towns of Bath (Balchin and Pye, 1947, 1949–50) and Reading (Parry, 1956), more attention was paid to local considerations. Meanwhile the technique of the rapid temperature traverse by motor vehicle was developed, yielding valuable studies, for example at Uppsala (Sundborg, 1951) and San Francisco (Duckworth and Sandberg, 1954): in these surveys, frequent temperature measurements could be made in the very streets of the city, and could be rendered virtually simultaneous either by averaging the results of inward and outward journeys along the same routes or by reference to a fixed base station. The most ambitious survey yet undertaken in that of London (Chandler, 1961, 1962a, b) and this has combined both the fixed station and the vehicle traverse methods, thus adding the advantages for statistical treatment of the former to the greater detail and realism of the latter.

Consideration of the diverse ways in which information has been gathered regarding urban "heat islands" compels one to doubt if the same feature has been measured in all cases. Second thoughts on a survey of local climate in the Reading area, supported by some later work, have given rise to the present paper, which, by considering the factors influencing the strength of the "heat island" effect in different parts of the town, draws attention both to its causes and to the problem of its measurement.

The causes of the "heat island" are known to be complex. Luke Howard perceived that the temperature of the city "partakes too much of an artificial warmth, induced by its structure, by a crowded population and the consumption of great quantities of fuel in fires". The urban structure, essentially one of horizontal and vertical surfaces of brick, stone and concrete, has a relatively low albedo, and large heat capacity so that it absorbs strongly the incoming solar radiation of the day, stores much of its heat and releases it slowly during the evening and night, while the moist, green vegetation-clad countryside not only absorbs less solar energy but must expend some of it on the evaporation of moisture and use some of it chemically in photosynthesis. Today it is recognized also that the urban smoke haze may well deplete incoming radiation thus possibly reducing day-time temperatures in the town below those of the surrounding country, but the same factor is even more effective at night, by blanketing the town and preventing the radiative heat loss which proceeds unchecked in rural areas. To these may be added the heat loss from

buildings, mainly during the heating season, and that liberated by the metabolism of a concentrated population and from the exhausts of motor vehicles. It is difficult to assess the relative importance of these various factors, as others have found – there is a full discussion by Sundborg (1951) – but the Reading data suggest conclusions that may be valid for at least this type of town.

It needs to be said that Reading was at this time a town of about 120,000 people: it lies in the Thames valley, in an area of modest though quite well defined relief, with the built-up area spreading along low terraces and plateaus which rise on either side of the river (as can be seen from the map and profile of Fig. 1). The town is largely residential and commercial, with some light industry, and, away from the old commercial nucleus and adjacent strips of older, densely packed housing, the urban texture is mostly relatively open, with family houses rather than flats and considerable green space in the form of gardens and parks. Thus Reading may be regarded as a fairly typical English provincial capital well outside major

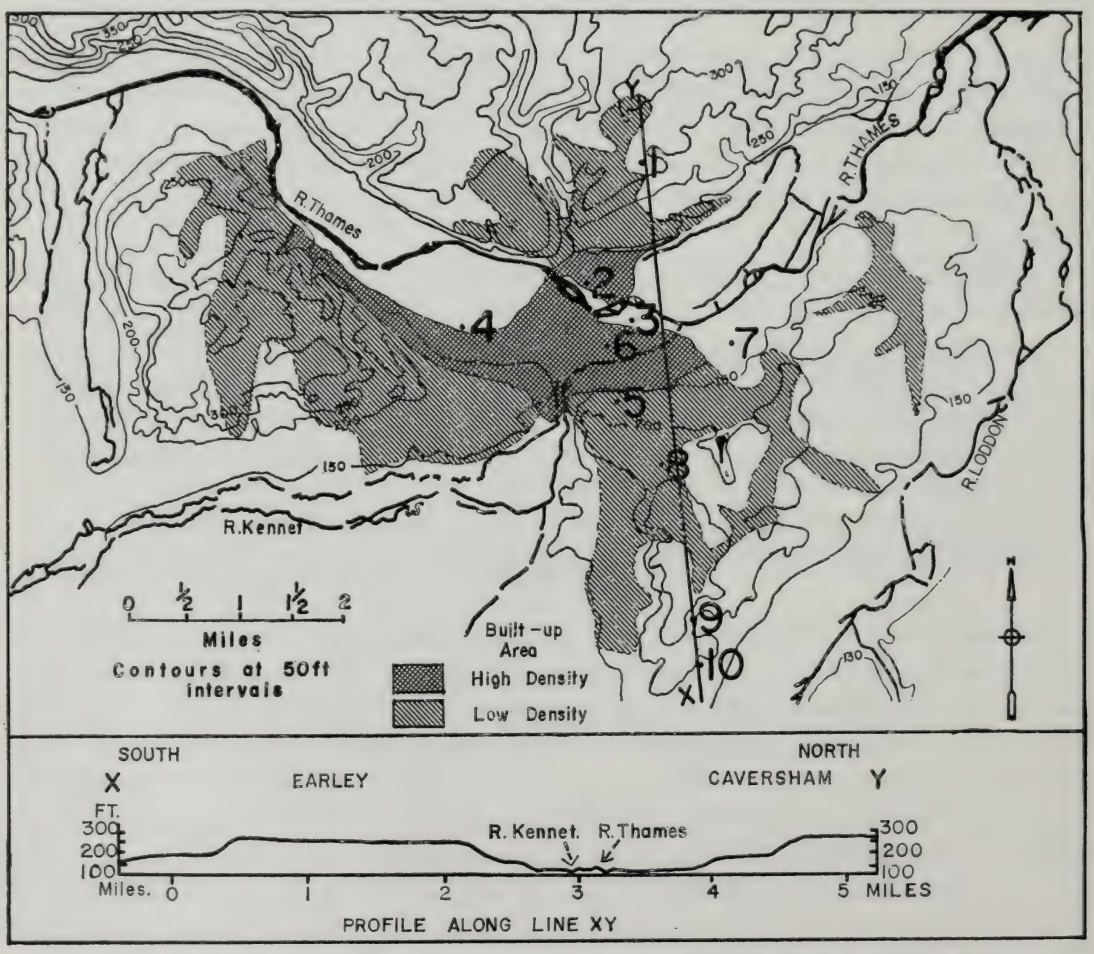

FIG. 1. The Reading area: relief, extent of built-up area and location of stations

industrial areas. Here 10 climatological stations were sited, largely along a north-south line chosen so as to embrace as fully as possible the various aspects of the town and 12 months of the data they provided have been extracted for the present enquiry.

Table 1. Mean Daily Temperatures and Two Examples of Minima on Contrasted Nights.

Station no.	Height (ft)	Site	Mean daily temperatures (°F) 12 months Dec. 1951–Nov. 1952			Minima 8 July 1952 (°F)	Minima 20 Oct. 1951 (°F)
			Mean	*Max.*	*Min.*		
1.	274	Rural	49.4	56.8	42.0	60	39
2.	125	Urban	50.1	57.5	42.7	61	37
3.	120	Rural	49.9	57.5	42.2	61	34
4.	141	Rural?	49.7	57.2	42.1	61	34
5.	152	Urban	50.4	57.5	43.3	61	40
6.	143	Urban	51.6	58.3	44.9	61	42
7.	141	Rural	49.8	57.3	42.3	61	34
8.	230	Urban	49.5	56.9	42.1	60	38
9.	248	Rural	49.2	56.6	41.9	60	40
10.	200	Rural	49.5	57.0	42.0	60	37

Table 1 lists the stations, gives their elevation and some indication of their exposure and their mean daily temperatures over the period. Only the "heat island" effect is our direct present concern but it will be clear from the table that differences in elevation, though small, are a complicating factor, quite apart from other variants (like aspect and subsoil) which are not taken into account. By grouping together stations of similar elevation (2, 3, 4, 5, 6 and 7), it will be seen that in terms of mean daily temperatures, the urban excess is small (less than 1° F) and for maximum temperatures even less (about 0.5° F), mainly because wind and turbulence, which tend to suppress local differences, are normally at their maximum during the middle of the day. It is in the minimum temperatures that the largest urban-rural contrast is found, about 1.5° F, an average figure that conceals much larger differences that develop on suitable nights. The remaining two columns of Table 1 serve as a reminder that the accompanying weather (particularly cloudiness and wind) is a vital permissive factor in the development of the "heat island". During the cloudy and windy night of 7–8 July 1952, this effect was non-existent and only the influence of elevation is discernible: on the clear, calm, anticyclonic night of 19–20 October 1951, however, the urban excess warmth amounted to 6–8° F. Nights of the former category, of course, far outnumber those of the latter.

Most interest clearly attaches to nocturnal conditions and attention from now will be concentrated on minimum temperatures. In Table 2 the stations are regrouped in order of increasing daily minimum temperatures and the other columns represent the various criteria that have been considered in an attempt to explain the "heat island".

Table 2. Mean Daily Minima in Relation to Various Urban Features

A Station no.	B Mean Daily min. (°F)	C Height (ft)	D Smoke ($\mu g\ m^3$)	E No.of dwellings	F All buildings	G Percent built-up	*H* Mean screening, angle (°)
9.	41.9	248	32.6	40	80	5	6.0
10.	42.0	200	32.6	61	110	5	5.4
1.	42.0	274	49.3	22	40	7	6.4
8.	42.1	230	51.9	275	371	13	13.5
4.	42.1	141	72.5	1165	1313	34	8.8
3.	42.2	120	68.5	84	121	14	2.6
7.	42.3	141	49.2	210	234	18	3.5
2.	42.7	125	61.5	771	999	32	13.9
5.	43.3	152	63.5	627	885	63	14.1
6.	44.9	143	61.9	118	753	90	14.7

Advantage has been taken of a survey, still in progress, of air pollution in the Reading area, in order to assess the influence of smoke concentration on mean minimum temperatures. For each of the former climatological stations, the nearest of the 37 pollution-recording stations was selected; in some cases the sites were practically identical. Although the two investigations cover different periods and the general level of pollution is no doubt different, there is no reason to assume any drastic change in its relative distribution. If this is accepted, it will be seen (column D) that there is no apparent relationship between mean minimum temperatures and mean smoke concentrations and it must be concluded that the smokiness of the air above a town like Reading is insufficient to exert the major influence on the development of the "heat island".

Attention was then turned to the contribution made by the heat loss from buildings. An average small house burning household coal will liberate something over 900 therms (2.27×10^7 kcal) a year due to the inefficiency of the open fire alone, quite apart from the heat lost through inadequate insulation of the interior. It is difficult, however, to make assumptions about the heat contributed by other buildings. From large-scale town plans it is possible to count the number of buildings and to distinguish between dwellings and other buildings and this was done withing a circle of radius 0.25 miles centred on each station (and supplemented by a rapid survey of the ground itself where the map evidence was insufficient). It is clear, however, (columns E and F in Table 2) that neither the counts of dwellings nor of all buildings bears much relation to the mean minimum temperatures, which suggests that artificial heat production does not play a large role in the genesis of the "heat island".

The next criterion to be examined was the urban texture or the actual density of the typical urban surfaces, following an idea suggested by Professor Gordon Manley. The areas of buildings, roads, squares, etc., were measured approximately by

counting squares on transparent paper placed over large-scale maps and the results stated as percentages of built-up area within circles of 0.25 mile radius from each station. Reference to Table 2 (column G) will show that these values display the best relationship so far with the urban warmth (even over-riding elevation differences) in that, with one notable exception, the order of increasing percentage of built-up area coincides with that of increasing daily minima. It must be concluded on this basis that variations in the strength of the "heat island" effect are substantially related to variations in the density of the built-up area.

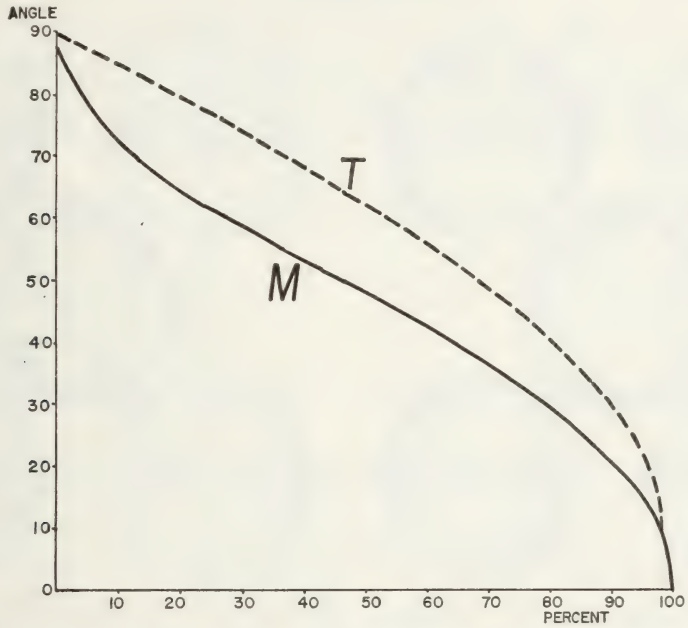

Fig. 2. Screening angle and reduction of outgoing radiation (after Lauscher)

There remains the marked discrepancy of station 4 which should, on this basis, have a higher minimum temperature than is in fact the case. This cannot be understood without a close look at the particular site of station 4, which raises the general question of the details of exposure at all stations. Luke Howard recognized that the city is "in great part, a collection of vertical surfaces, which reflect on each other the heat they respectively acquire . . .". Problems relating to the amount of open sky into which nocturnal radiation can freely proceed and to the screening effect by vertical surfaces which impede this heat loss (as well as possibly adding their quota of stored heat) have been studied by Lauscher, whose figures (quoted in Geiger, 1950) are presented in graphical form in Fig. 2. On the assumptions of clear skies and a vapour pressure of 5.4 mm, this graph relates the outgoing radiation from a horizontal plane to the steepness of the screening angle subtended by surrounding vertical surfaces: line M revers to screening by the walls of a symmetrical basin, T to that of a through valley: the effective radiation is expressed as a percentage of what would occur with completely open exposure (angle = 0). Clearly,

M will apply to a city square or enclosed garden and T to a city street, while for many sites in a town something between M and T would be appropriate.

In pursuit of this line of enquiry, the screening angles at each station were measured in all directions (using prismatic compass and clinometer) and the diagrams of Fig. 3 prepared. In each of these, the outer circle represents the horizon with completely open exposure and inner circles have been drawn for screening angles of 10°, 20°, 30° and 60°: the shading depicts the screened portion of the sky. These diagrams clearly differentiate "open" and "enclosed" sites. The comparisons may be

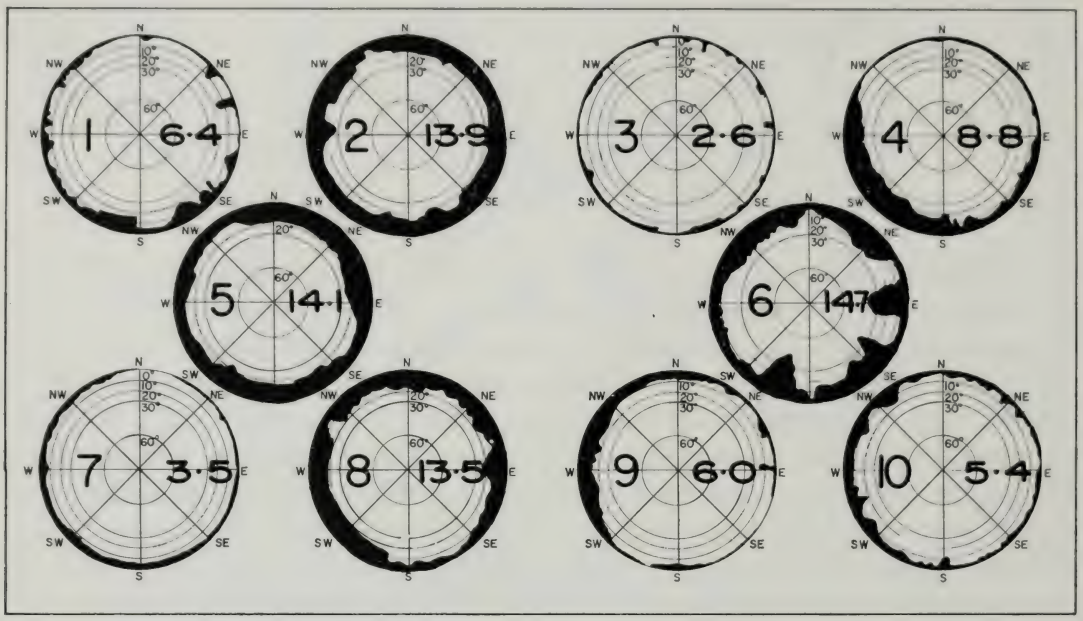

FIG. 3. Details of exposure at each station: left-hand figure – station number, righthand figure – mean screening angle

expressed numerically by measuring the screening angles in 16 directions and averaging them: the resulting mean screening angles are given in Fig. 3 and also in column H of Table 2.

It is now possible to appreciate why station 4, with its substantial proportion of built-up area and fairly high mean screening angle, behaves consistently as a "rural" station with open exposure. This site is on the very edge of the built-up area with buildings to the south and southwest but completely open to the north. Far from giving rise to features intermediate between rural and urban sites, this non-uniform screening is particularly conducive to low minima, because of the absence of vertical surfaces on the northern side to intercept and return the incoming radiation gained during the day.

Apart from this exceptional case, the values in column H of Table 2 do not show the best overall relationship with minimum temperatures: however if complications due to elevation are avoided by considering only the 6 stations of relatively

low elevation, the concept of the mean screening angle seems a useful one. In Table-3, these stations are arranged in order of their screening angles and the corresponding mean minima are also given but expressed as differences from the value at station 3 which has the lowest angle (column C): also added (column D) are the average minima on summer nights with mainly clear skies and calm or very light winds (again expressed as differences from station 3).

Table 3. Mean Screening Angle in Relation to Minimum Temperatures

A Station *no.*	B *Mean screening angle* (°)	C *Mean daily min.* (°F)	D *Mean min. radiation rights in summer* (°F)
3	2.6	0	0
7	3.5	+0.1	+0.3
4	8.8	—0.1	+0.3
2	13.9	+0.5	+1.1
5	14.1	+1.1	+2.9
6	14.7	+2.7	+3.7

It may be concluded that, of the various factors affecting the strength of the heat island in different parts of Reading, the smoke content of the air does not seem to play the major part attributed to it by Sundborg (1951), for example, in the case of Uppsala: artificial heating also appears to be a minor influence, as both Sundborg and Chandler (1962b) agree. The fact that Reading's urban warmth is greatest in summer, the season of least pollution and least artificial heating, supports these views. The density of the built-up area seems to be the dominant factor, as was concluded by Chandler for London and Duckworth and Sandberg (1954) for San Francisco. Consideration of screening angles stresses, as Manley has suggested (Parry 1956, discussion), the importance of the size and character of the enclosures in relation to the temperatures that are recorded there. Clearly, in fixed station surveys it is vital to site instruments in enclosures that are reasonably representative of the gardens and other open spaces of the town. Probably all "orthodox" stations (in Britain the highest permitted angle subtended by any obstacle is 26.5°) seriously underestimate the urban warmth, for even a short excursion with a clinometer will reveal open spaces with angles of 30°, 40°, even 60° (for example in tree-lined streets).

Perhaps it is most important of all to realize that to talk of the urban climate and the "heat island" is already to generalize to an extent that is more than justifiable at least for bioclimatological purposes. It is a large step nearer reality to recognize that the urban climate is actually a collection of varied microclimates, those of enclosed spaces (the interiors of buildings) and of partially enclosed spaces (streets,

gardens, squares, parks). Through the efforts of medical workers and heating and ventilating engineers, a good deal is known about the former: the study of the latter has hardly begun.

REFERENCES

BALCHIN, W. G. V. and PYE, N. (1947) A microclimatological investigation of Bath and the surrounding district. *Quart. J. roy. Met. Soc.* **73,** 297–323.

BALCHIN, W. G. V. and PYE, N. (1949–50) Temperature and humidity variations in an urban area of diversified relief. *J. Manchester Geogr. Soc.* **55,** 1–23.

CHANDLER, T. J. (1961) The changing form of London's heat-island. *Geography* **46,** 295–307.

CHANDLER, T. J. (1962a) Temperature and humidity traverses across London. *Weather* **17,** 235–242.

CHANDLER, T. J. (1962b) London's urban climate. *Geogr. J.* **128,** 279–302.

DUCKWORTH, F. S. and SANDBERG, J. S. (1954) The effects of cities upon horizontal and vertical temperature gradients. *Bull. Am. Met. Soc.* **35,** 198–207.

GEIGER, R. (1950) *The Climate Near the Ground.* Harvard University Press.

HOWARD, L. (1833), *The Climate of London.*

KRATZER, A. (1937) Das Stadtklima. *Die Wissenschaft,* Band 90. Friedr. Vieweg & Sohn, Braunschweig.

LANDSBERG, H. E. (1956) The climate of towns: In *Man's Role in Changing the Face of the Earth.* W. L. Thomas (ed.) University of Chicago.

PARRY, M. (1956) Local temperature variations in the Reading area. *Quart. J. roy. Met. Soc.* **82,** 45–57, Discussion 532–534.

SUNDBORG, A. (1951) Climatological Studies in Uppsala. Pap. Geogr. Inst. Uppsala Univ. No. 22.

THE BREAKING-IN OF WARM AIR ON 11 DECEMBER 1961 IN VIENNA*

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Abstract — The city of Vienna is located in a basin whose western boundary is formed by a chain of hills. Shallow masses of cold air filling the basin sometimes show considerable persistence. A case is described where the boundary between the cold air and warm oceanic air advected from the West oscillated for several hours over the inner part of the city, causing local fluctuations of temperature of more than 10° C. The path of the warm air generally followed the valley.

Zusammenfassung — Es wird ein Einbruch milder Meeresluft aus Westen in das Wiener Becken beschrieben, bei dem die Wirkung der uneinheitlichen Bergumrahmung des Beckens deutlich zutage trat. Es zeigt sich, dass der Einbruch der Warmluft bevorzugt entlang des Wientales erfolgte. Die Grenze der beiden Luftmassen verlagerte sich im inneren Stadtbereich durch mehrere Stunden hindurch periodisch vor und zurück, wodurch es örtlich zu wiederholten Temperaturschwankungen um etwa 10° C kam und grosse horizontale Temperaturunterschiede auf engem Raum auftraten.

Résumé — La ville de Vienne se trouve dans un bassin dont les limites ouest sont formées d'une chaine de collines. Des masses d'air froid peu épaisses et recouvrant le dit bassin présentent parfois une persistance considérable. On décrit un cas où la limite entre l'air chaud océanique venant de l'ouest et l'air froid préexistant oscille pendant plusieurs heures sur le centre de la cité causant des fluctuations locales de la température de plus de 10° C. L'invasion d'air chaud suit en général la direction de la vallée.

THE passage of mild maritime air from the west in the winter months to Vienna shows two phenomena. In one situation the cold air remains at the bottom of the basin of Vienna and the warm air takes a route over the cold air. This situation is commoner in Vienna than in the plains. The cause is the secluded basin of Vienna to the west. Thus the cold air remains for some time. In stormy changes of air masses the mountain-wall is no hindrance, and the temperature increases occur nearly at the same time everywhere over the whole Vienna area.

In certain cases the warm air only breaks through the surface of the cold air sea at some points. Then great differences of temperature occur within small areas. There remain some hours, while the cold air sea on the bottom is steady. Thus an oscillation of temperature due to warm air over the city is possible. An example of such a situation is described below.

* The whole paper is printed in *Wetter und Leben* **14**, 167 – 170 (1962).

A great cyclone over the North Atlantic moved over the continent on 11 December 1961 bringing a strong a belt of warm oceanic air. In higher parts of the region the temperatures increased very markedly on 10 December. In the lowland areas a thin cold air sea remained. On 11 December the surface of the inversion layer over Vienna lay at over 700 m above sea level.

The distribution of the temperature on the valley bottom were given by 14 recording stations distributed over the city and its nearer surroundings. The position of each station is shown in Fig. 1.

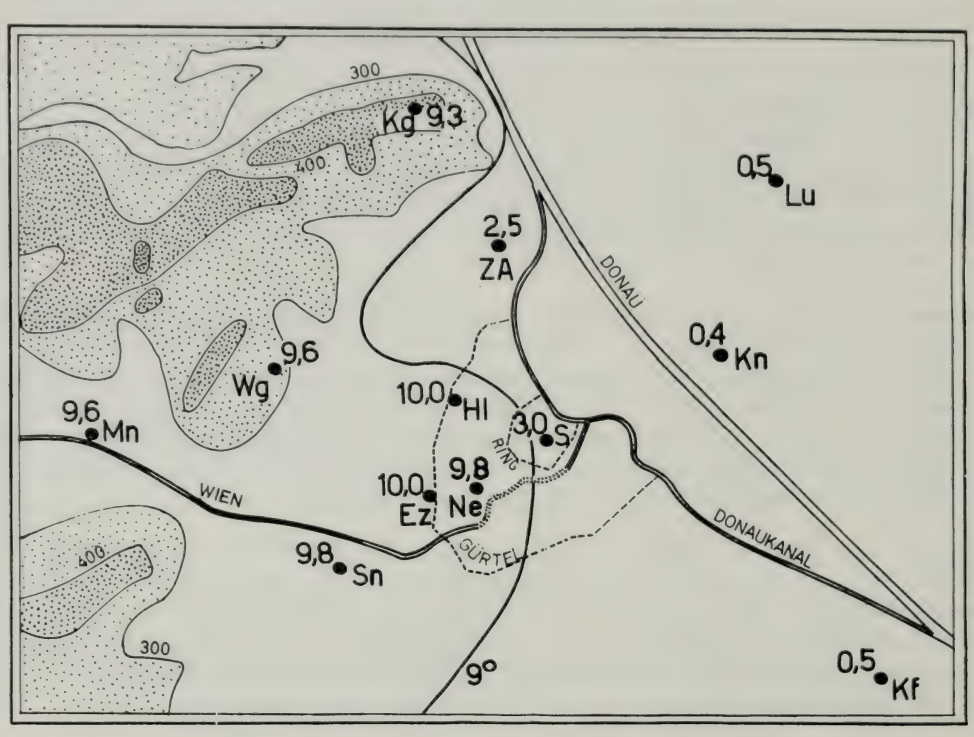

FIG. 1. Temperatures in the area of Vienna at 11 December 1961, 20:00 hr.

At the higher stations (Kahlenberg and Wilhelminenberg) the break through of warm air took place at 14:00 hr. The brief increase of temperature at the Zentralanstals für Meteorologie at 20:00 hr was linked with an increased wind velocity. A similar kind of change was found at the stations in the east and south of Vienna. (Fig. 2a).

The course of temperature in the city and Vienna valley was completely different. The recordings of temperature in the densely built up area are shown in Fig. 2b. The first increase of temperature was observed at these stations at 16:00 hr. The most westerly station "Europaplatz" shows the greatest effects. Here the high temperatures remained for the longest time. At the Mariahilfstrasse-Neubaugasse station only 1 km eastward the increased temperature lasted only for a short time. An hour later the warm air broke through. Down town three warm air waves of

progressive vehemence were recorded over a short time. After 20:00 hr all stations were covered by cold air which proceeded westward. By 22:00 hr the entry of warm air into the Vienna area was generally complete.

At the Schönbrunn and Mariabrunn stations (Fig. 2c) similar temperature oscillations were observed at the same time although these stations are on the border. Figure 1 gives a survey of the distribution of temperature at a selected moment. The temperatures at the recording stations for 20:00 hr are shown. This figure

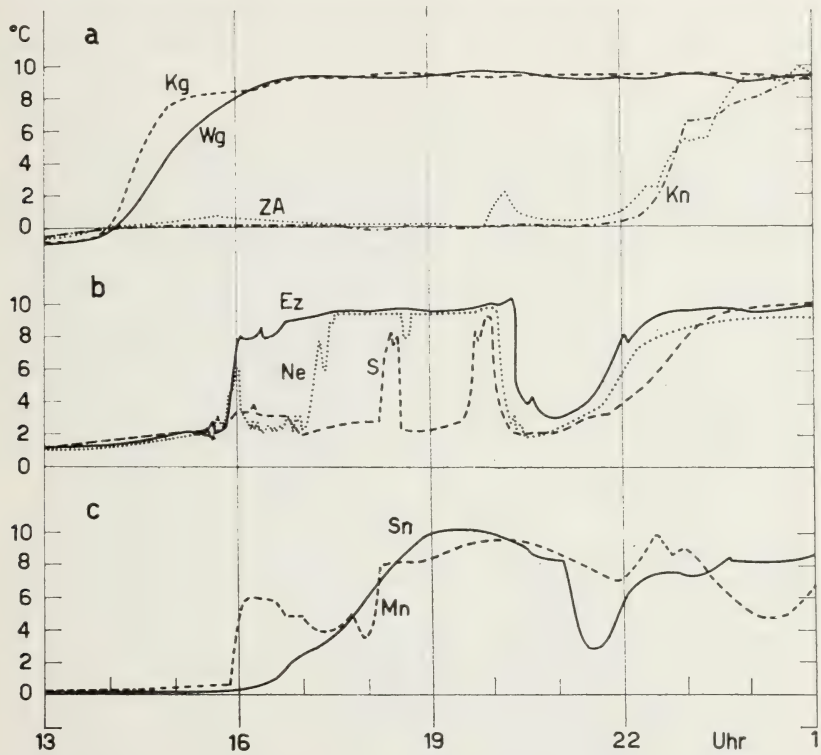

FIG. 2. Course of temperature at the stations in the area of Vienna at 11 December 1961, 13:00 hr – 12 December 1961, 01:00 hr.

shows that the break-in of warm air took place mainly in the Wiental, while the stations in the plain and at the border of Wienerwald were still inside the cold air sea. This seemed to be quasi-stationary because the frequent going to and fro of both air masses could be registered as changes of wind direction at the recording stations. The warm air came with increasing west winds, the cold air with increasing east winds.

The situation described above seems to take place only under optimal conditions, which are a strong but low inversion at the height of the Wienerwald and further a slow entry of warm air combined with only slight air motion. While the weather on 11 December 1961, showed the pushing away of the cold air sea in winter, one can suppose that when strong warm air breaks occur, the inversion is primarily broken through at orographically determined points.

PULLUTION CLIMATES OF TOWNS

METEOROLOGICAL EFFECTS ON CALIFORNIA AIR POLLUTION

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Abstract – Urban pollution experience in California arises from synergistic interaction of contaminants from a petroleum economy and certain features of a maritime coastal climate. The meteorologic effects of persistent inversions and a fugitive sea breeze coupled with pollution from extensive usage of motor vehicles produce episodic physiological strain on the urban population. Temporal changes in the available atmospheric mixing volume in concert with strong topographic influences and contrasting temperature effects on natural ventilation produce a variety of influences on primary and secondary pollution. Reactions, physical properties, and emissions of atmospheric contaminants undergo substantial changes depending on the state of the atmospheric environment. Humidity, solar energy, horizontal ventilation, inversion height and cloud cover play important parts in these respects.

Zusammenfassung – Die Luftverunreinigung in Californien entsteht durch Wechselwirkung zwischen dem Schmutz durch die Petroleumindustrie und bestimmten Eigenarten des Seeküstenklimas. Die meteorologischen Wirkungen einer anhaltenden Inversion und einer flüchtigen Seebrise verbunden mit Verunreinigungen durch Abgase von übermässig vielen Motorfahrzeugen bewirken episodisch physiologische Belastungen der Stadtbevölkerung. Zeitliche Wechsel der Ausmasse des vorhandenen atmosphärischen Raums zur Aufnahme der Verunreinigungen in Verbindung mit starken topographischen und stark unterschiedlichen Temperatureinflüssen auf die natürliche Ventilation belasten die primäre und sekundäre Luftverunreinigung. Reaktionen, physikalische Eigenschaften und Emissionen der atmosphärischen Substanzen unterliegen Veränderungen in Abhängigkeit von dem Zustand der Atmosphäre. Feuchte, Sonnenernergie, horizontale Ventilation, Höhe der Inversion und Bedeckung spielen dabei eine wichtige Rolle.

Résumé – En Californie, le haut degré de pollution de l'air provient de la combinaison des fortes émissions par l'industrie du pétrole et de certaines particularités du climat côtier. Les conditions météorologiques créées par une inversion permanente et une faible brise de mer liées à la pollution due aux gaz d'échappement d'un nombre particulièrement important de véhicules à moteur provoquent, à certains moments, une surcharge physiologique dans la population des villes. La variation périodique du volume atmosphérique disponible pour l'absorption de la pollution et les fluctations des influences thermiques dues au relief agissant sur la ventilation naturelle font changer la densité tant primaire que secondaire de la pollution. Les réactions chimiques, les particularités physiques et les émissions-mêmes des pollutions sont liées à des modifications de l'état de l'atmosphère. L'humidité, l'énergie solaire, la ventilation horizontale, la hauteur de l'inversion et la nébulosité y jouent un rôle important.

INTRODUCTION

California's largest metropolitan centers, Los Angeles and San Francisco, are located in a maritime coastal environment. This environment is isolated from arid and desert interior areas by multiple ranges of mountains along the State's vast meridional length (almost 10° of latitude) and by transverse ranges in the southern part (Fig. 1).

Annually persistent subsidence inversions combine with radiation inversions during fall and abnormally dry winter seasons to impede upward dispersal of air

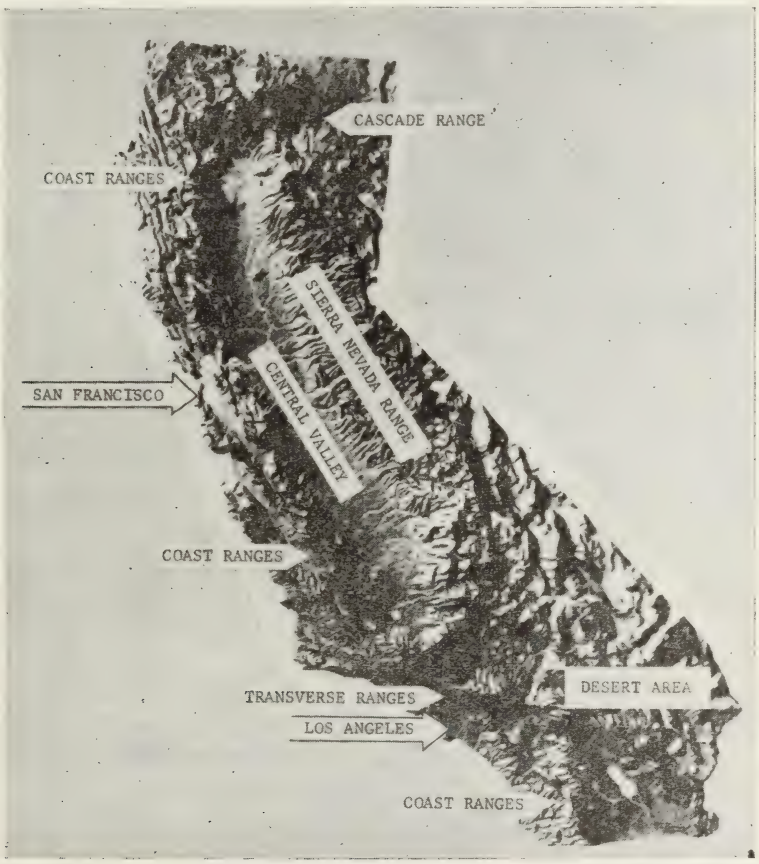

FIG. 1. Relief map of California showing major topographic details and locations of the San Francisco and Los Angeles metropolitan areas

pollution. Atmospheric pressure patterns that reduce or prevent inland penetration of the sea breeze, occur occasionally during summer and may occur frequently during fall and dry winter seasons. Diminished or absent ventilation by the sea breeze and the boundary condition of a persistent inversion provide the environment for pollution accumulation. Protracted for several days, these circumstances

may result in substantial daily increments in pollution concentrations. During such episodes, urban populations (particularly the very young and aged portions) suffer discomforts such as eye irritation, headache, or depressed respiratory function (Hausknecht, 1962).

Oxidants, consisting principally of ozone and oxides of nitrogen, and carbon monoxide cause discomfort among the urban populations of California. These and other pollution components such as olefinic hydrocarbons and nitroorganic compounds are characteristic of the petroleum economy. Extensive usage of 8.7 million registered motor vehicles (California Department of Motor Vehicles, 1963) results in a substantial burden of motor vehicle exhaust pollution in the larger urban environments.

EFFECT OF MIXING VOLUME

In general, the inversion height establishes the quantity of modified marine air available over California coastal cities for pollution dispersal. For a given inversion height, the effective mixing volume during daylight hours is a function of the vertical, turbulent flux of heat. Figure 2 shows graphically the determining factors which create the maximum mixing height. This height is referred dry adiabatically to the daily maximum temperature near ground-level. From an initial condition of stratification, pollution is mixed to the maximum mixing height. The dimensions and geometry of this density distribution provide the limiting condition on upward dispersion of pollution.

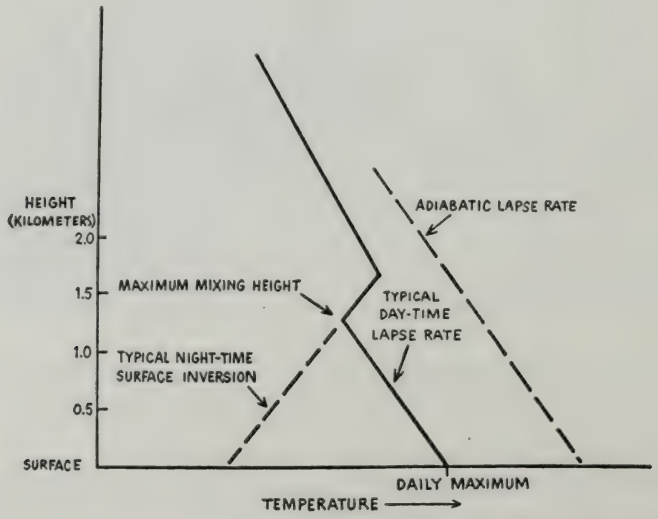

Fig. 2. Diagrammatic representation of the effect of turbulent heat flux on the modification of an inversion. The maximum mixing height is related dry adiabatically to the maximum ground-level temperature and establishes the effective mixing volume during midday hours

The effect of mixing volume on the photochemical, oxidant pollution experience during a $5\frac{1}{2}$ year period in the San Francisco Bay Area is shown in Fig. 3. The two curves represent upper limits of the highest reported oxidant concentrations as functions of afternoon (15:00 h PST) inversion base height for two ranks of inversion stability index* These results show that the adverse concentration level,[2] at or above which physical discomfort is due mainly to eye irritation, may occur if the

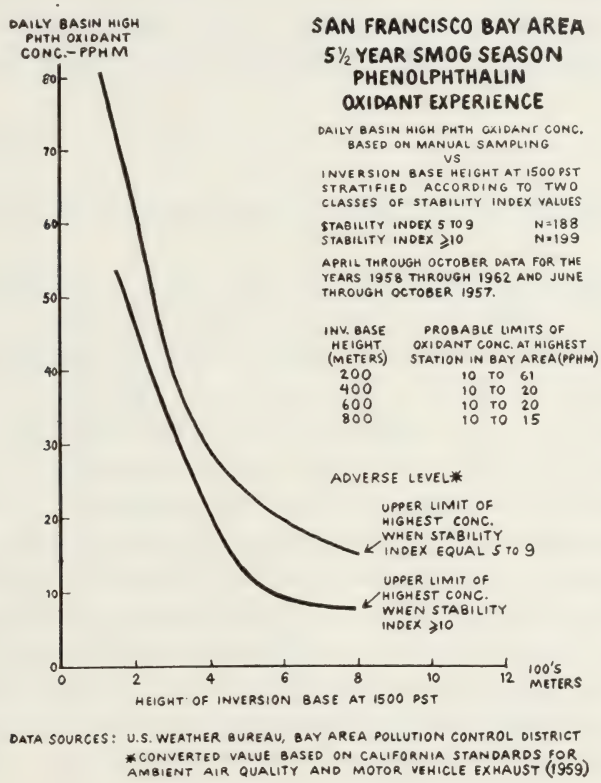

FIG. 3. The curves represent upper limits of the highest measured concentrations of oxidant in the San Francisco Bay Area for two ranks of stability index (see text) as functions of height of the inversion base at 15:00 h Pacific Standard Time

afternoon inversion base height is 480 m or less or 370 m or less depending on the magnitude of the stability index (5 to 9 or $\geqslant$ 10, respectively). Of the 387 occurrences of oxidant concentrations $\geqslant$ 0.1 ppm (phenolphthalin), about 106, or 27 per cent, had concentration $\geqslant$0.25 ppm (phenolphthalin).[+] The effect of increased inversion

* The stability index is derived empirically using dimensions which define the inversion; namely, its height of base, its thickness, and its potential temperature difference (Holzworth, 1961).

[+] The adverse concentration of oxidants is stated as $\geqslant$ 0.15 ppm (potassium iodide) for one hr by the California ambient air quality standard for oxidants. (State of California, 1959) 0.15 ppm (potassium iodide) oxidant is approximately equal to 0.25 ppm (phenolphthalin).

stability (large index values) imposes a lowered mixing volume for a given level of oxidant concentration. This results in enlargement of the area affected by the oxidant, and greater numbers of the population experience discomfort. In the case of lessened inversion stability, the mixing volume available increases somewhat. Areas affected by the oxidant are smaller, and are more closely situated to areas in which the photochemically reactive ingredients that cause oxidant are emitted.

Primary pollutants which do not participate in the photochemical production of oxidant, appear in highest concentration during those portions of the day when the greatest usage of petroleum fuels coincides with the occurrence of least mixing volume.

EFFECT OF TEMPORAL METEOROLOGIC CHANGES

Diurnal changes of atmospheric stability and other meteorologic changes which occur shortly after sunrise and after sunset influence both the production and the accumulation of primary pollution such as carbon monoxide. Thus, a bimodal peaking of the carbon monixide concentration occurs each twenty-four hours. The peak concentrations occur during hours when the mixing volume is less than when solar heating is effective in causing the turbulent flux of heat. Due to these circumstances the elevated concentrations of carbon monoxide are held near ground-level. The dosage experienced by the population is more prolonged during the evening hours and may be greater or less acute than during the early morning peak. Table 1 illustrates the diurnal variation of carbon monoxide concentration (ppm) in downtown Los Angeles for two days during January 1962, compared to the average diurnal variation for that month. The daily values are typical of variations observed during a high concentration episode. The monthly average

Table 1. Diurnal Variation of Carbon Monoxide Concentration (ppm) in Downtown Los Angeles January 1962

	Hours (PST)											
Day	*00*	*02*	*04*	*06*	*08*	*10*	*12*	*14*	*16*	*18*	*20*	*22*
7	20	17	14	12	12	12	10	11	11	20	30	22
10	22	22	22	31	47	16	11	7	12	10	8	7
Monthly average	13	12	10	14	21	12	10	10	12	16	16	16

Source: Los Angeles County Air Pollution Control District

indicates that the morning peak concentration usually is higher than that during the prolonged evening peak.

The dependence upon solar radiation of photochemically created oxidant influences the diurnal variation of this secondary pollutant. Table 2 contains data on

Table 2. Diurnal Variation of oxidant (KI) Concentration (ppm) in Dountoun Los Angeles August 1962

Day	Hours (PST)											
	00	*02*	*04*	*06*	*08*	*10*	*12*	*14*	*16*	*18*	*20*	*22*
14	0.01	0.01	*	0.01	0.11	0.24	0.24	0.19	0.14	0.07	0.01	0.01
15	0.01	0.01	*	0.01	0.02	0.12	0.21	0.17	0.11	0.02	0.01	0.01
Monthly average	0.01	0.01	*	0.01	0.05	0.15	0.15	0.11	0.08	0.04	0.02	0.01

* Instrument standardization time

Source: Los Angeles County Air Pollution Control District

the diurnal variation of oxidant (ppm) in downtown Los Angeles for two days during an August, 1962, pollution episode. These are compared to the average diurnal variation for that month. The single peak concentration occurs characteristically between 10:00 and 12:00 h PST in downtown Los Angeles. Peak concentrations which may reach higher values occur later in the day (12:00 to 14:00 PST) at locations farther inland due to the gentle movement of air. Table 3 shows this displacement in time at which the peak oxidant concentration occurred on the same days in Azusa, a small community located 32 km farther inland from down-

Table 3. Diurnal Variation of Oxidant (KI) Concentration (ppm) at Azusa, California August 1962

Day	Hours (PST)											
	00	*02*	*04*	*06*	*08*	*10*	*12*	*14*	*16*	*18*	*20*	*22*
14	0.01	0.01	*	0.01	0.09	0.17	0.23	0.33	0.20	0.12	0.07	0.02
15	0.01	0.01	*	0.02	0.06	0.14	0.35	0.39	0.38	0.11	0.04	0.02
Monthly average	0.01	0.01	*	0.01	0.07	0.16	0.26	0.26	0.17	0.07	0.02	0.01

* Instrument standardization time

Source: Los Angeles County Air Pollution Control District

town Los Angeles. It is through this spatial migration of the diurnal oxidant variation that large numbers of the urban and suburban population suffer eye irritation.

Seasonal variations of inversion height, mean wind speed, and solar energy combine during the summer months to maximize the photochemical creation of oxidants. Table 4 shows smoothed, mean monthly maximum oxidant concentra-

Table 4. Smoothed Mean Monthly Maximum Oxidant (KI) Concentration (ppm) in Downtown Los Angeles for the Years 1958 Through 1962

Year	Month											
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
1958	0.09	0.10	0.13	0.16	0.19	0.21	0.22	0.23	0.21	0.19	0.17	0.15
1959	0.15	0.15	0.16	0.18	0.20	0.22	0.24	0.24	0.22	0.20	0.17	0.14
1960	.13	.14	.17	.20	.23	.25	.27	.26	.23	.20	.16	.14
1961	.13	.13	.14	.15	.17	.19	.20	.20	.18	.16	.13	.11
1962	.11	.11	.13	.16	.19	.21	.24	.25	.23	.21	.17	.14
Average	.12	.13	.15	.17	.19	.22	.23	.24	.21	.19	.16	.14

Source: Los Angeles County Air Pollution Control District

tions (ppm) for Los Angeles during the years 1958 to 1962 inclusive. The values shown, which are highest in the summer, are representative of the oxidant levels experienced by the population during pollution episodes. The levels attained during these episodes are, on the average, at or well above the adverse discomfort

Table 5. Smoothed Mean Monthly Maximum Carbon Monoxide Concentrations (ppm) in Downtown Los Angeles for the Years 1958 Through 1962

Year	Month											
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
1958	22	19	15	12	10	9	10	11	14	18	20	21
1959	19	17	13	12	11	11	12	14	17	20	23	24
1960	23	20	18	15	14	14	15	17	20	24	27	29
1961	25	23	17	13	12	10	12	14	16	20	22	24
1962	24	22	20	18	17	16	16	18	20	22	24	25
Average	23	20	17	14	13	12	13	15	17	21	23	25

Source: Los Angeles County Air Pollution Control District

level set by the California Ambient Air Quality Standards (State of California, 1959).

Increased stabilization of the atmosphere during cold, rainless winters results in the occurrence of highest maximum concentrations of carbon monoxide during pollution episodes. Table 5 shows the smoothed, mean monthly maximum carbon monoxide concentration (ppm) in Los Angeles for the 5-year period ending with 1962. Relative to the 8-hr average concentration of 30 ppm classed as a serious level in the California Ambient Air Quality Standards (State of California, 1959), the episode experience in the Los Angeles Basin has resulted in 48 violations of the carbon monoxide standard during the 4 years ending with December 1962. Thus, substantial portions of the population have experienced significant elevation of carboxyhemoglobin level on these occasions.

It is important to note that the diurnal variation of the carbon monoxide concentration is related to variations in motor vehicle traffic (McCormick *et al.*, 1961) but that the seasonal variation in carbon monoxide, which is superimposed on the diurnal variation, is a function of the seasonal consumption of natural gas and fuel oil for domestic heating and electric power production (County of Los Angeles, 1961).

METEOROLOGIC EFFECTS ON ATMOSPHERIC REACTIONS

The essential ingredients and complex photochemical processes which result in the creation of Los Angeles-type smog have been described by Leighton (1961), Wayne (1962) and others. It is concluded generally that ultraviolet portions of the solar spectrum provide the driving force for the many reactions believed to occur. In addition to the effect of concentrations of the reactants, ambient temperature and humidity affect the rates of production of reaction products which cause eye irritation and other physiologic responses, as well as vegetation damage.

The effectiveness of ultraviolet radiation as a photochemical driving force is influenced by the opacity of the atmosphere due to the scattering and extinction efficiency of atmospheric aerosols. These include liquid and solid particulate. In the California coastal environment where marine stratus and atmospheric haze are characteristic features, the occurrence of photochemical smog is dependent on the absence of a cloud cover and to a small degree on the optical path length through the turbid portions of the atmosphere. Both natural and man-made aerosols which are hygroscopic, undergo size variations proportional to the ambient humidity (Orr *et al.*, 1958, 1959), and effect extinction and scattering of solar energy.

The essential meteorologic conditions for the rapid production of photochemical smog, assuming the necessary reactants are present at suitable concentrations, are: (a) a shallow marine air layer which is free of stratus clouds, (b) a strong inversion to resist any substantial increase of effective mixing volume due to turbulent

flux of heat, (c) exceptionally gentle breezes or calm conditions, (d) higher than normal ambient air temperature, (e) low ambient humidity to assure that hygroscopic aerosols will be at minimum size. The zenith angle of the sun should be small to minimize the extinction effects of the aerosols suspended in the shallow marine air layer. All of these conditions will prevail during the more severe episodes. These episodes may be alleviated most effectively and quickly by changes in ventilation or in the depth of the marine air layer.

SYNERGISM OF POLLUTANT AND METEOROLOGIC EFFECTS

The fact that adverse pollution levels in California occur in episodes, which may span several days or a substantial fraction of a month, is indicative of the degree to which meteorologic conditions may integrate effects of pollution emitted by a large city. There are several ways whereby meteorologic conditions associated with photochemical smog episodes can be maximized or made to persist in a maximized state so that certain physiological responses and vegetation damage may occur. It is of interest to discuss some of them.

During summer, an inverted, thermal low pressure trough extends along the length of the Great Central Valley of California. Several times during the summer, due to changes in the large-scale atmospheric pressure pattern, the thermal trough which normally lies over the Central Valley of California, will envelop the coastal areas. This interrupts the sea breeze mechanism and produces abnormally high maximum temperatures in the coastal areas. During the 2 to 4-day periods these conditions prevail, photochemical smog builds up to very high levels. Relief from the excessive heat and high pollution level is achieved with the reappearance of the sea breeze.

The most protracted pollution episodes may occur during the fall when the eastern Pacific high pressure cell pushes onto the land areas. Prolonged periods of air stagnation may occur during which abnormally high temperatures and shallow marine air layers dominate the coastal cities of California. High peak concentrations of photochemical pollution occur almost daily until the large-scale pressure pattern is altered by the encroachment of a storm front.

During exceptionally dry, cold winters, the daily incidence of radiation inversions which merge with the subsidence inversion causes exceptionally shallow stratification of photochemical smog reactants. Due to the lower solar altitude at midday in winter, smog occurrences are limited chiefly to southern California. The higher latitude of San Francisco apparently is sufficient to result in too little solar energy for the photochemical reaction to occur within the winter daylight period. Primary pollution such as carbon monoxide and oxides of nitrogen, as well as particulate pollution, undergo substantial elavations during the rainless periods, which fortunately do not occur every winter-season. During the wetter winter seasons, air pollution is not a problem in the San Francisco Bay Area.

ISOLATION OF POLLUTION CONCENTRATION TRENDS FROM THE EFFECTS OF LONG-TERM METEOROLOGIC TRENDS

Time series data on concentrations of primary and secondary pollutants are available for California urban atmospheres due to the use of continuous air monitoring instrumentation. Historical data on pollutant concentrations, as well as on pertinent, simultaneous meteorologic variates, permit long-term trend analysis by statistical filtering techniques applicable to time series data. Holloway (1958) and Panofsky and Brier (1958) have described smoothing and filtering techniques particularly suited to time series data having distinct annual cyclic variations.

The basic time series data used are monthly averages of pollutant concentrations and of meteorologic variates. By means of a filtering function which is weighted in proportion to a binomial coefficient distribution, variations more frequent than the annual cyclic variation can be filtered out. The time series which remains is a smoothed series possessing only the annual cycle variation.

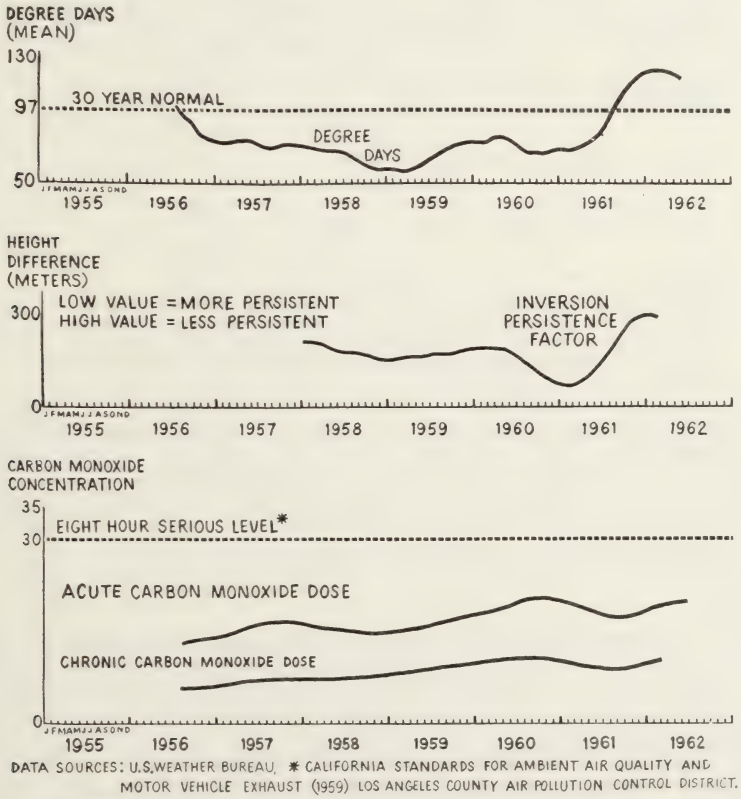

FIG. 4. Calculated trend lines of the chronic and acute carbon monoxide doses (mean concentration and mean maximum concentration) at Los Angeles, California, based on a time series of monthly concentration data covering the period: October 1955 to April 1963. Shown also for comparison are the trend lines of the inversion persistence factor and monthly degree-days in Los Angeles

Subsequent application of a uniformly weighted filtering function having zero frequency response for the annual cyclic variation, but which does not attenuate variations occurring less frequently than the annual cycle, results in trend lines of the variates. Neither of these filtering functions alters the mean of the time series.

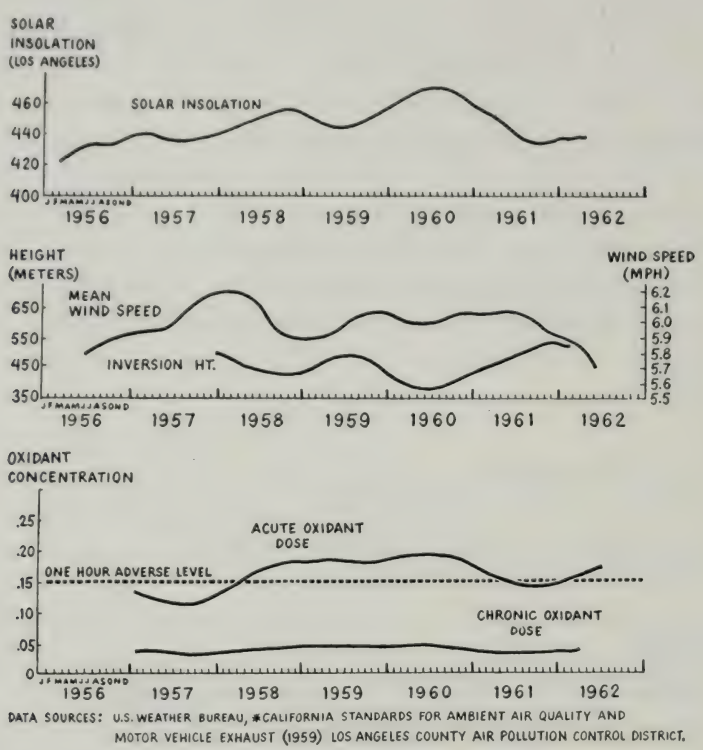

Fig. 5. Calculated trend lines of the chronic and acute doses (mean concentration and mean maximum concentration) of oxidants (KI) at Los Angeles, California, based on a time series of monthly concentration data covering the period: April 1956 to April 1963. Shown also for comparison are the trend lines of mean daily-height of inversion base, mean wind speed and solar radiation

Trend lines calculated by the above described means are shown in Figs. 4 and 5. Figure 4 shows the trend lines for the monthly average (chronic dose) and average maximum (acute dose) concentrations of carbon monoxide in the ambient air over Los Angeles, California, compared to the serious level concentration.* Comparative trend lines are shown also for the inversion persistence factor+ and

* 30 ppm for eight consecutive hours (State of California, 1959).

+ The persistence factor is simply the difference between the daytime and the nighttime inversion base heights. A low value of the factor means the inversion trend line was characterized by persistent inversion conditions and vice versa for a high value of the factor.

monthly degree days in Los Angeles. The trend lines represent time series from late 1955 to mid-1963, except for the inversion persistence factor, which series begins in mid-1957. The chronic and acute dose trend lines for carbon monoxide show a general upward trend which is indicative of the need to control carbon monoxide emissions, although the acute dose trend line is well below the serious concentration of 30 ppm.* The long-term fluctuations of the acute dose trend line for carbon monoxide appear to be related to the periodicities seen in the trend lines for the inversion persistence factor and monthly degree days.

A similar presentation of trend lines for oxidant concentrations measured in Los Angeles, California, is shown in Fig. 5 compared with the adverse concentration level and with trend lines of mean daily inversion base height, mean wind speed, and mean solar insolation. The general upward trend of the acute dose of oxidants is indicative of the need for controlling unburned hydrocarbon emissions from motor vehicles. Hydrocarbons have been shown to participate on photochemical reaction. (Leighton, 1961) The long-term variations of the acute dose trend appear to be related to appropriate variations in the trends of mean daily inversion base height and mean daily solar insolation. Furthermore, the acute dose trend has remained for some time above the adverse concentrations level of 0.15 ppm (potassium iodide) stipulated by the California ambient air quality standard for oxidants (State of California, 1959).

REFERENCES

County of Los Angeles (1961) Air quality of Los Angeles County. Technical reports of the Air Pollution Control District, Vol. II, pp. 88–89.

Hausknecht, R. (1962) Experiences of a respiratory disease panel selected from a representative sample of the adult population. *Am. Rev. Resp. Dis.* **86,** 858–866.

Holloway, J. L. (1958) Smoothing and filtering of time series and space fields. In *Advances in Geophysics,* Vol 4. H. E. Landsberg and J. Van Mieghem (ed.), Academic Press, New York and London, pp. 351–388.

Holzworth, G. C. (1961) A study of air pollution potential for the western United States. Presented at the 193rd Nat. Meeting Meteor. Soc., Davis, California, 20–22 June.

Leighton, P. A. (1961) *Photochemistry of Air Pollution.* Academic Press, New York and London, Chapters III–VII.

McCormick, R. A. and Xintaras, C. (1961) Variation of carbon monoxide concentrations as related to sampling interval, traffic, and meteorological factors. Presented at the 193rd Nat. Meeting Am. Meteor. Soc., Davis, California, 20–22 June, p. 10 (of pre-print).

Orr, C., Hurd, F. K. and Hendrix, W. P. (1958) The study of the solubility and rate of solution of fine aerosol particles. Georgia Institute of Technology, Engineering Experiment Station Scientific Report No. 1, U. S. Air Force Contract No. AF19(104)-1970, February.

Orr, C., Hurd, F. K. and Corbett, W. J. (1959) Aerosol size and relative humidity. *J. Colloid. Sci.* **13,** 472–482.

* Eight-hour concentration level which will produce significant elevated carboxyhemoglobin in the blood (State of California, 1959).

Panofsky, H. A. and Brier, G. W. (1958) Some applications of statistics to meteorology. Pennsylvania State University, College of Mineral Industries, University Park, Pennsylvania, Chapter VI.

State of California (1959) California standards for ambient air quality and motor vehicle exhausts, Department of Public Health, p. 11.

State of California (1960) Technical report of California standards for ambient air quality and motor vehicle exhausts. Department of Public Health, p. 15, pp. 37–54.

State of California (1963) Motor vehicle registrations. Department of Motor Vehicles.

Wayne, L. G. (1962) The chemistry of urban atmospheres. Technical reports of Los Angeles County Air Pollution Control District, Vol. III, Chapter 4.

THE SURVEY OF AIR POLLUTION IN AN INDUSTRIAL CITY: SHEFFIELD

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Abstract – Some preliminary cartographic results of air pollution survey in Sheffield under anticyclonic conditions, are considered in relation to peculiarities of site and urban functional patterns, and with reference to both hourly and daily records of changes.

Zusammenfassung — Einige vorläufige kartographische Ergebnisse der Übersichten über die Luftverunreinigung in Sheffield bei Hochdruck werden im Zusammenhang mit Lage und Funktion von Stadtteilen untersucht unter Verwendung von Messungen der stündlichen und täglichen Veränderungen.

Résumé — On examine ici quelques données cartographiques préliminaires de la pollution de l'air à Sheffield par situations anticycloniques et cela en relation avec le degré d'industrialisation et la position relative des différents quartiers de la ville. On utilise pour ce faire les variations horaires et journalières de la pollution.

THE Sheffield urban region presents unusual air pollution problems in view of its distinctive physical characteristics of urban site into which are integrated well defined patterns of industrial and urban land-use, serving a population of half a million.

The bold relief which ranges from 100 ft to over 1000 ft above sea level is associated with a starlike pattern of deeply sunk converging valleys which, under anticyclonic conditions, favour the drainage of stagnant stable air, sometimes in depth, preventing the free diffusion of pollutant matter. On the other hand, at times of active air circulation in this fragmented relief there will still be much variation in wind speed locally. On exposed ridges at 800 to 900 ft, wind speed records show speeds of from 42 to 16 mph. when, at the same time in the adjacent valley at 200 ft, velocities are no more than 19 to 4 mph.

Imposed on this physical pattern is an urban functional pattern associated with residential areas extending over the spurs and low plateaus, with industries – especially engineering and metallurgical – mainly (though not exclusively) consolidated in the low lying and highly congested Don valley. Furthermore, much of this industry is geared to shift systems operating continuously through the normal diurnal cycle of changing air stability, humidity, etc.

In relation to these varied influences, natural and man made, an attempt has been made to express cartographically the collective total effects of pollution

from all sources over the area and in relation to the daily (and in some cases hourly) changing weather conditions. Using in the first instance data collected for quite different purposes by the Medical Research Council, the Local Authority and the Department of Scientific and Industrial Research, maps such as those illustrated in Figs. 1 and 2 were plotted showing how variable may be the pollution climate over a city from locality to locality, day by day.

Figure 1 shows, for example, characteristic smoke distribution and its severity after a first day of anticyclonic weather in January when only very light southerly air circulation prevailed in otherwise stagnant stable air. More pronounced pollution centres were quickly developing in the Don industrial areas both above and below the elbow turn of the main valley, as at the same time, comparatively

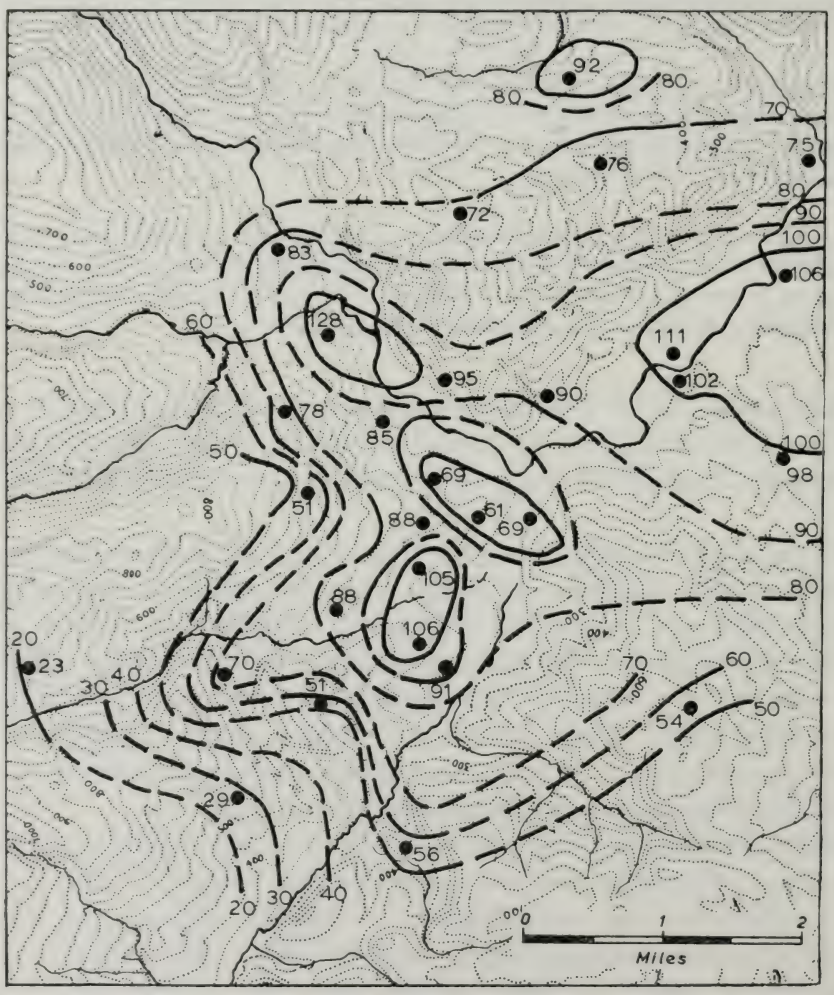

FIG. 1. Sheffield: Smoke Pollution, 26–27 January 1959, (First day of anticyclonic weather type) Pollution lines at 10 unit intervals (mg/100m^3) Air circulation 9:00. calm; 21:00 hr S.-S.S.E. (1) (116 miles in 24 hr) Contours (Relief) at 50 ft vertical interval.

clean smoke free patches of air survived even in the heart of the town near the spur end.

Figure 2 shows conditions three days later on the last of four consecutive days of anticyclonic weather. The amount of smoke pollutant held in the stagnant air had greatly increased and had extended areally. The weather records show however that, at the same time, the light southerly air drift had been replaced by air drift from the north west. With this change, despite the general build up in pollution, the centre in the upper Don shown on Fig. 1 had vanished by the fourth day and the centre in the lower Don moved towards the south east, i.e. "down-wind".

Cartographic analysis makes possible the comparison of data on an areal basis in other ways. Thus, Fig. 3 shows, comparatively, the areas associated with SO_2 pollution at 50 parts/10^8/day (1430 $\mu g/m^3$), for each of the third and fourth anti-

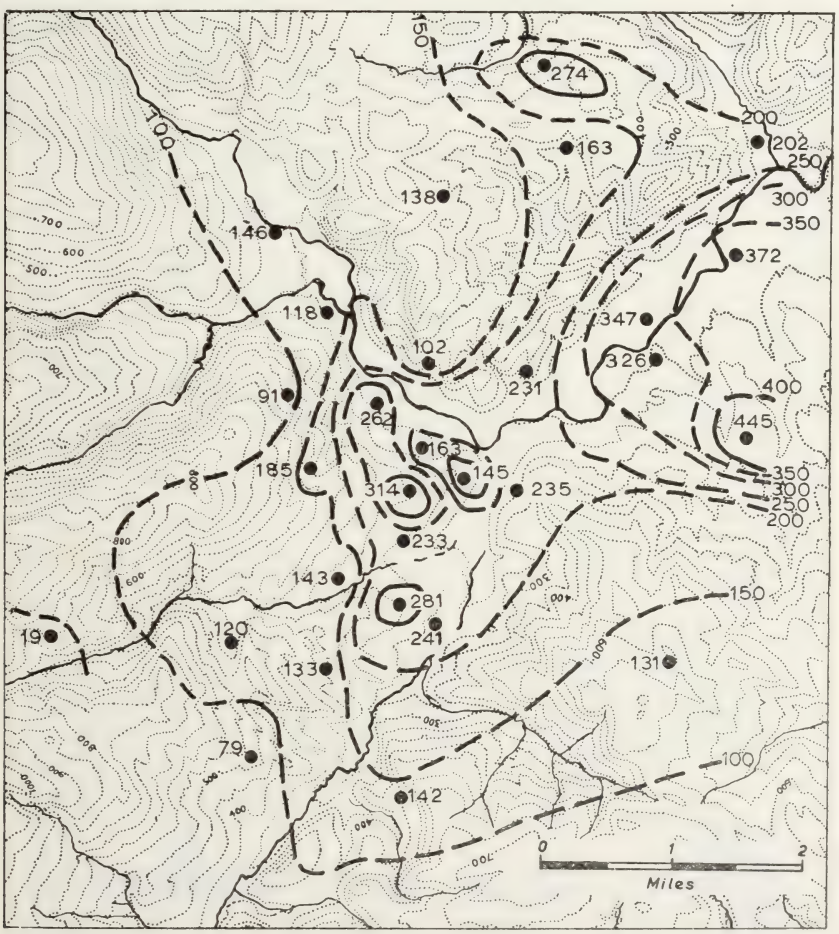

Fig. 2. Sheffield: Smoke Pollution 29–30 January 1959, (Fourth day of anticyclonic weather type) Pollution lines at 50 unit intervals (mg/100 m^3) Air circulation 9 : 00. calm; 21 : 00 hr N.W.(3) (8 miles in 24 hr) Contours (Relief) at 50 ft vertical interval.

cyclonic days under review, thus revealing not only the extent of the areas affected in this degree, but also the extent of the down-wind movement.

Figure 5, compiled from the content of each of 4 daily SO_2 maps and 4 daily smoke maps (taking from each map each day the limiting position of the value of 1000 $\mu g/m^3$ in each case), reveals comparatively in relation to both relief and urban land-use the maximum extent of these two measured values during this 4-day anticyclonic phase, and demonstrates the general restrictive effect of the higher relief in the west of the city. It shows also that the SO_2 was restricted to lower

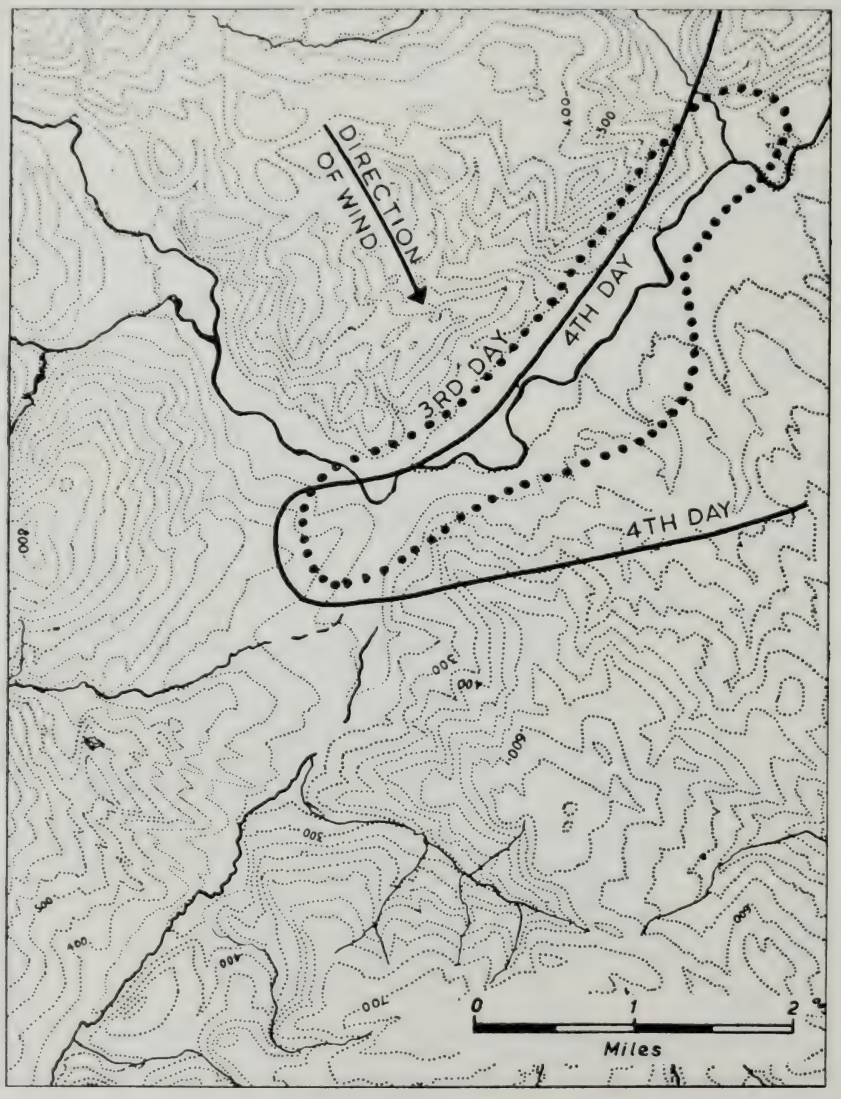

FIG. 3. Sheffield: SO_2 Pollution 29–30 January 1959, Urban areas with SO_2 concentration exceeding 50.0 p/10^8/day, on the third and fourth successive days of anticyclonic weather, and in relation to the direction of air circulation (N.W.)

altitudes, as compared with a somewhat wider range of smoke diffusion by altitude and area.

Figure 4 presents graphically the hourly smoke pollution changes for one station located upslope on a spur, (by the University), together with records of hourly changes for some of the associated meteorological elements during the four anticyclonic days under review for a selection of urban sites. The steady increase in daily peak pollutant values in relation to calms and inversion of temperature is very evident, but surprising to some may be the amplitude of the diurnal fluctuations in pollution even during periods of greatest severity, and the marked diurnal rhythm that is apparent.

For satisfactory cartographic analysis a close net of stations is required, and in the light of this preliminary work, and with the generous support of the Department of Scientific and Industrial Research, we are now engaged on an intensive survey of this kind in Sheffield, involving more than 50 stations recording daily SO_2 and smoke, so arranged as to make possible in due course, the analysis of

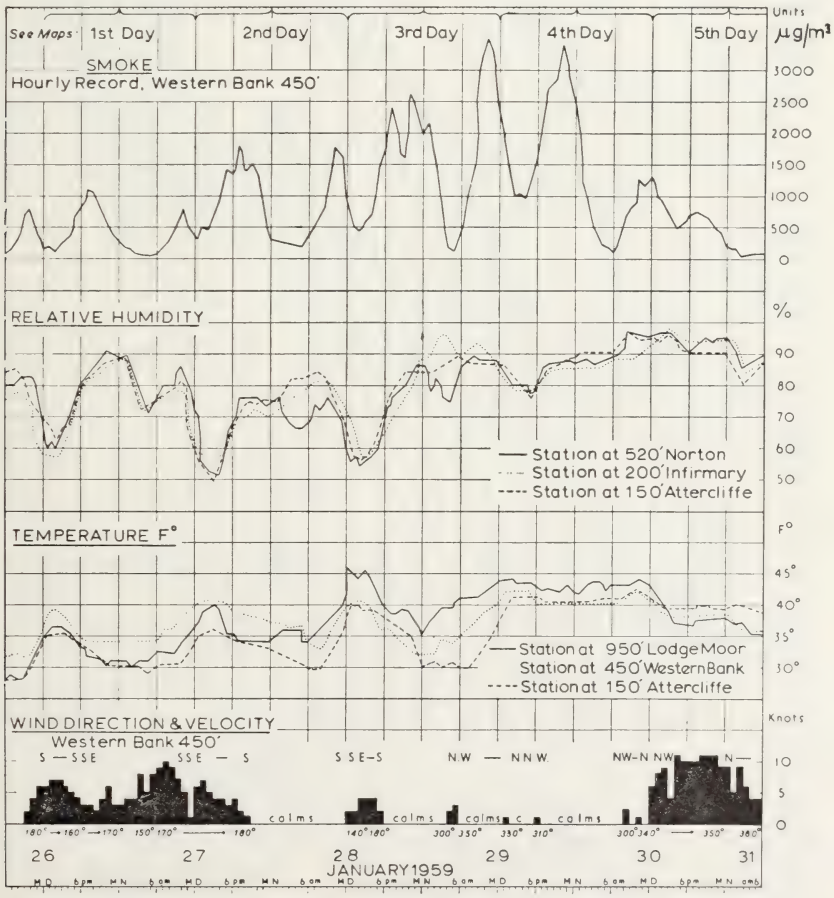

Fig. 4. Graph showing hourly changes in wind directions and velocity, temperatures, relative humidity, and smoke, for sites in Sheffield under anticyclonic conditions. 26–31 January 1959

conditions either cartographically over an urban area or at the same time in comparative linear groups as transects across different types of relief or types of functional urban land-use. The apparatus is operated by time switches to ensure that all records relate to the same hour-periods (the hourly changes in the smoke record show how necessary is this precaution).

In addition to the daily records, we plan to add 50 hourly smoke recorders and a number of hourly SO_2 recorders at the sites, so that changing hourly patterns over the urban area can be studied in relation to diurnal weather changes and other conditions. By extending this work over a period of not less than two years we hope to record a sufficient number and variety of weather incidents, typical and atypical, so as to indicate from specific events and examples, (rather than from longer term mean assessments) the extent and duration within the urban region of significant pollution values, and the factors – natural and otherwise – on which their occurrence has depended.

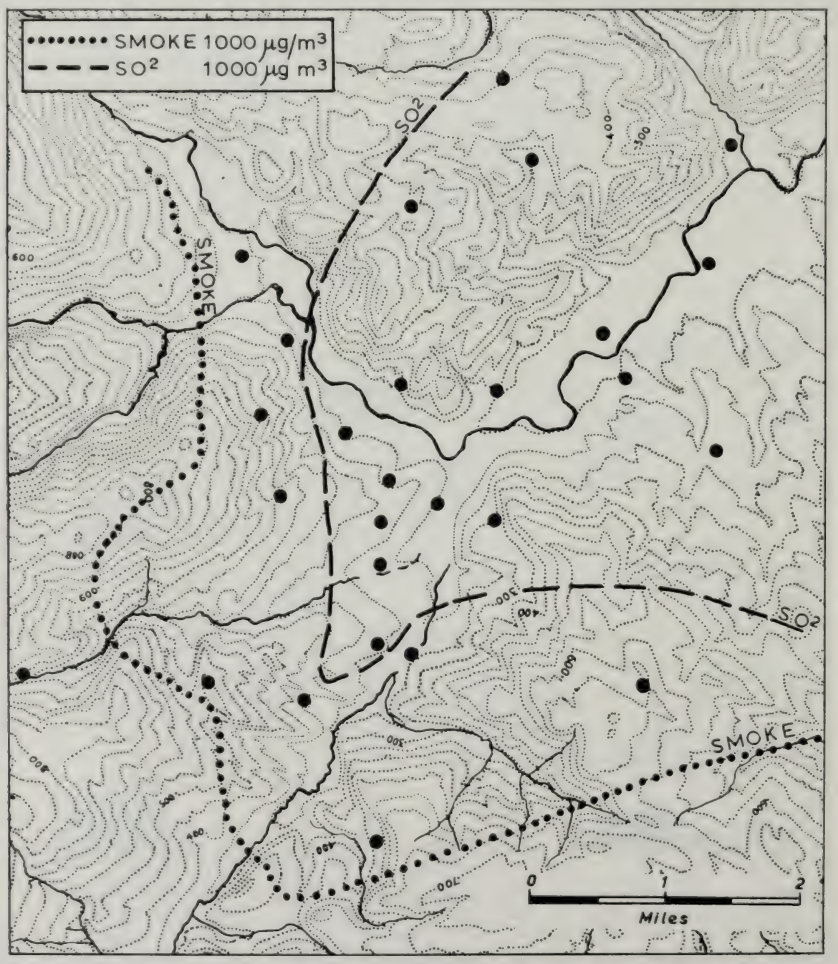

FIG. 5. Maximum extent of areas experiencing both smoke and SO_2 pollution at $1000 \mu g/m^3$, during the period 26 – 30 January 1959

ACKNOWLEDGEMENT

I am much indebted to Dr. P. J. Lawther, Air Pollution Research Unit, St. Bartholomew's Hospital, London, and to the Director, D.S.I.R., Warren Spring Laboratories, for allowing me the use of data.

For futher analyses see also: A Survey of Air Pollution in Sheffield Under Characteristic Winter Anticyclonic Conditions. A. Garnett, *Int. J. Air. Wat. Poll.* **7**, 3–968 (1963).

AIR POLLUTION AND URBAN CLIMATE

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Summary – Air pollutants, which have become a major health menace, show essentially similar behavior under the influence of meteorological factors, regardless of type and origin. In American metropolitan areas pollution concentrations are, by and large, a function of population density. As a dispersant the wind is the factor of primary importance; precipitation is next in effectiveness. In dry weather with low wind speeds intensity of solar radiation governs the production of irritating oxidants. Persistent stagnation conditions with low-level inversions will create in some industrial regions hazardous levels of pollution with increasing frequency. Adequate warnings can be issued but if proper control measures of the sources are neglected, the outlook for the industrial areas of the world is pessimistic.

Zusammenfassung – Luftverunreinigungen, die eine Bedrohung der öffentlichen Gesundheit sind, zeigen einigermassen gleichmässiges Verhalten unter dem Einfluss der meteorologischen Faktoren, unabhängig von ihrer Art und Herkunft. In amerikanischen Gross-Stadtgebieten sind die Verschmutzungskonzentrationen, im allgemeinen, eine Funktion der Bevölkerungsdichte. Der Wind ist der hauptsächliche Faktor für die Reinigung und der Niederschlag ist nächst verantwortlich. Bei trockenem Wetter und leichtem Wind beherrscht die Sonnenstrahlungsintensität die Produktion von oxydierenden Reizstoffen. Andauernde Luftruhe mit Bodeninversionen werden in einigen Industriegebieten mit erhöhter Häufigkeit zu gefährlichen Konzentrationen führen. Warnungen können zwar ausgegeben werden, doch werden diese wertlos bleiben falls, die Kontrolle der Quellen unterbleibt und daher sind die Aussichten für viele industrielle Bezirke der Welt schlecht.

Résumé – Les pollutions atmosphériques qui représentent actuellement une menace majeure pour la santé montrent des caractéristiques similaires dans leur essence selon l'influence des facteurs météorologiques, indépendenemment de leur type ou de leur origine. Dans les arondissements urbains d'Amérique, les concentrations de pollutions sont, en général fonction de la densité de la population. Le vent est l'agent principal de dispersion et la pluie en est un secondaire, pour leur élimination effective. Par temps sec et une atmosphère peu agitée, l'intensité de la radiation solaire est déterminante pour la production d'oxydants irritants. Des conditions persistantes de stagnation accompagnées d'inversions au voisinage du sol causeront, dans les régions industrielles, des concentrations dues au hasard avec une fréquence croissante. On peut prévoir ces conditions et alarmer le public. Pourtant, si le contrôle des effusions est insuffisant à l'origine on ne peut envisager l'avenir qu'avec pessimisme.

Air pollution is a symptom of urbanization and industralization. Although in some major cities the problem has been recognized for centuries the unparalleled

developments of the last lew decades have transformed pollution from a nuisance into a major health hazard. Population shifts from the countryside to urban and suburban communities have increased domestic sources of pollution. Even if industrial sources have been held in rein by ordinances and better technological control of effluents, the number of factories has increased everywhere. In many areas of the world the revolutionary changes in transportation systems, especially the phenomenal rise in the number of motor vehicles, have contributed a major share to air pollution.

The physical aspects of the contamination of the atmosphere have been fairly well documented and their surveillance is being rapidly expanded (Landsberg, 1962). Less satisfactory is the state of unravelling the chain of events leading to health damages. By the nature of the mass exposure most evidence is statistical, occasionally underlined by spectacular rises in morbidity and mortality when extraordinary meteorological conditions permit local accumulations of pollutants. Nonetheless a few assertions can be made without fear of scientific challenge (Heimann *et al.*, 1958; Prindle and Landau, 1962). Acute irritations and immediate allergic reactions are fairly obvious. It also is inescapable that older persons with primary afflictions of their cardiac-respiratory systems often succumb in episodes of high pollution. Animal tests using common pollutants of the atmosphere show poisoning with metallic compounds and have shown that neoplasms of respiratory organs can occur upon steady exposure to polluted air. Subacute effects of some pollutants, such as carbon monoxide, are still controversial.

The broad scale investigations into the various aspects of air pollution in the United States have made a number of generalizations possible. By and large, all pollutants from human sources act approximately alike under the influence of the atmospheric environment. That means, their derivatives with respect to space and time show a high degree of similarity. If we know what happens to one type, we can infer what happens to others. This makes it permissible, *pari passu*, to discuss interchangeably atmospheric effects on various suspended aerosols and gases. We can also state that metropolitan pollution has to be dealt with as an area or multiple area problem rather than as a problem of discrete point sources (Bouman and Schmidt, 1961). The fact that in some cities over half of the pollutants are from vehicular traffic makes this obvious (Prindle and Yaffe, 1962). Meteorological conditions will occasionally also contribute to overlapping of areal contamination clouds (Pack and Hosler, 1958).

The meteorological problems, in general, are broadly defined by the atmospheric circulation patterns. In simplest terms, those leading to high winds and precipitation will dilute and wash out pollutants. Conversely, those leading to stagnation, primarily characterized by low winds and by confining low-level inversions will lead to accumulation of pollutants. To the latter conditions solar radiation, especially in the short wave part of the spectrum, will add secondary photochemical transformations of certain pollutants. This may change certain compounds from lower to higher levels of biological reactivity.

Let me elaborate a few points which bear out these generalizations. The U.S. Public Health Service has for several years now sampled, under a uniform system, the air in 183 urban communities (U. S. Dept. HEW, 1962). These range from small towns to the major metropolitan areas. Obviously, a great many geographical and meteorological factors affect the local values. However, taken together it appears that population density determines to a considerable extent the base level of pollution. This is shown in Fig. 1 where the averages of the solid suspensions are shown as function of size of various cities. The largest and smallest average concentrations in each size category are also shown. The latter reflect the wide varia-

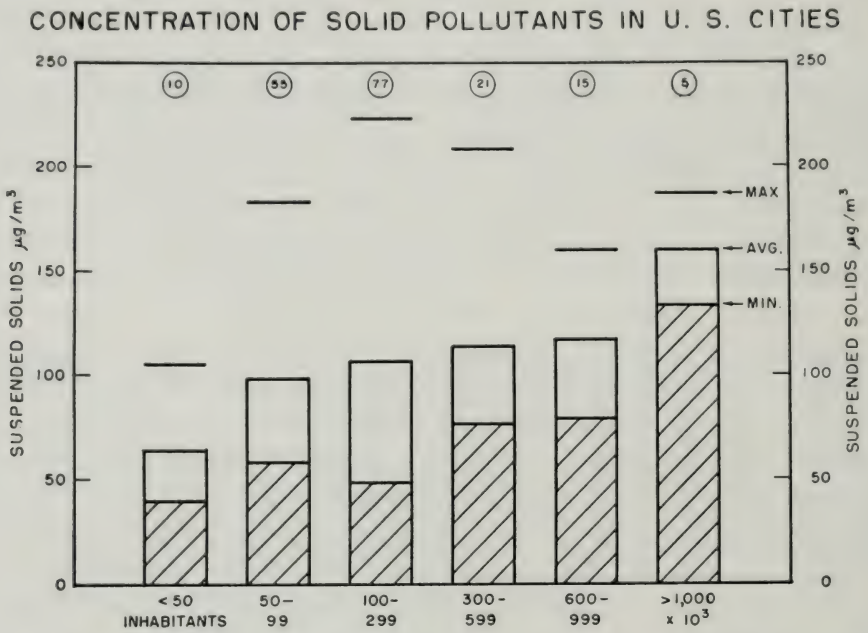

FIG. 1. Relation of suspended matter in air to size of cities in U.S. (Number in circle above columns indicates number of cities in particular size class, 1960 Census)

bility. However, this variability decreases as the size of the cities increases. In some of the smaller towns single industrial sources as well as orographic conditions and general geographical position contribute to the notable differences. Parenthetically, it has also to be remarked that the number of inhabitants, as indicated, is often arbitrarily limited because often suburban areas are politically separated from the cities and not added in the population sources. If contiguous urban areas and their census figures were used in such an analysis some of the variability would doubtlessly disappear.

The use of solid contaminants as a measure of the level of pollution is well warranted. The results of autopsies have shown how much of these city dwellers retain in their lungs, a factor which may well contribute to the increased incidence of emphysema (Nückel, 1962). Figure 2 shows the cumulative retention of particles by

sizes in the form of a probability diagram. This shows a logarithmic dependance on size which is consonant with the usual logarithmic probability distribution of pollutant size frequencies.

The primary variable in dispersing pollutants is the wind. This role can already be demonstrated by comparing the average pollution in U. S. metropolitan areas

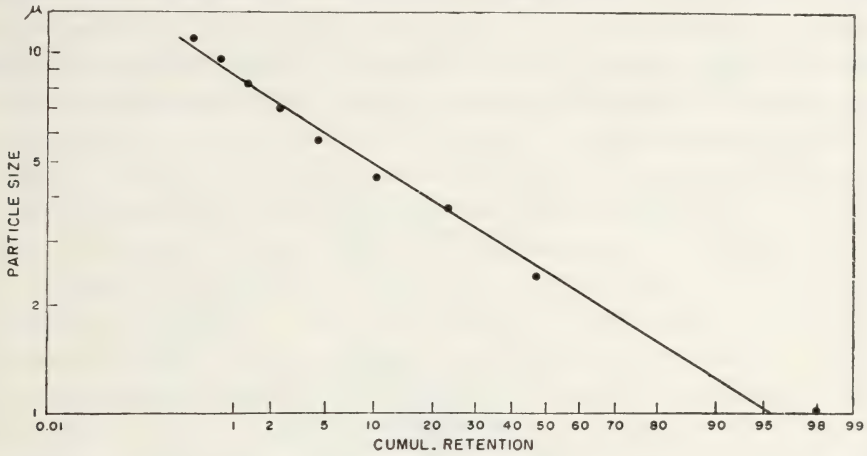

Fig. 2. Logarithm of particle diameter and cumulative frequency (on probability scale) of particles found retained in lungs

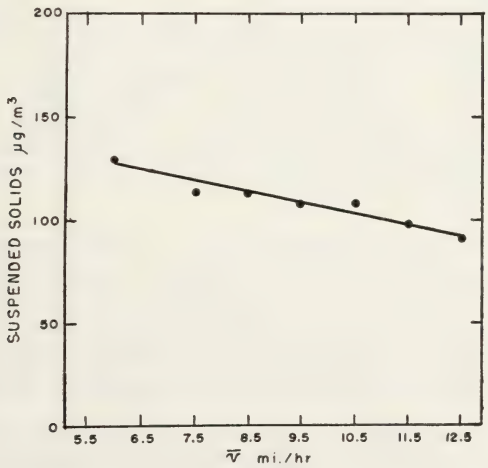

Fig. 3. Average solid pollutant concentration in relation to mean wind speeds in U.S. cities

with their respective mean wind speed. Figure 3 shows this effect. This is, of course, only a crude approximation but it is nonetheless interesting that it can be demonstrated even with bulk data.

The more subtle influences of wind in the spreading of pollution in a metropolitan area have recently been investigated in a very interesting study of Riehl and Crow (1962) for Denver. They showed here how light winds could advance a polluted

air mass gradually, at speeds of less than a mile per hour, over a metropolitan area.

In general, however, with higher wind speeds, and in the absence of exceptional vertical stability pollutants rapidly disperse or fall out. In this connection a great deal has been learned by the intensive studies in Louisville, Kentucky, and Nashville, Tennessee (U. S. Dept. HEW, 1961). The Louisville study particularly illustrates the transport of particulates from a pollutant source across the city area but also emphasizes the local production of pollutants by other than industrial sources. Well over half of the suspended matter was shown to be already present up-wind of the major center emission.

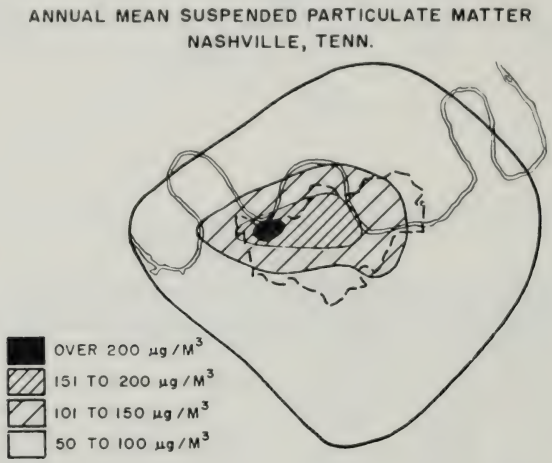

FIG. 4. Mean suspended particulate matter (annual value), Nashville, Tennessee (after Stalker and Dickerson, 1961)

Over longer intervals of time, representing all wind directions and many meteorological conditions, the pollutants decrease rapidly with distance from the source region. Orographic influences usually are still notable even in mean values but otherwise the nearly concentric decrease from the city center is quite remarkable. This is well illustrated by Fig. 4 taken from the Nashville survey (Stalker and Dickerson, 1961). The Nashville study also showed quite well the exponential reduction of sulfur dioxide concentration (S) from the center of the city. Larsen *et al.* (1961) have described this by the general background (S_b) and a probability function which represents the concentration in the center of town (S_c), the radial distance from the center (r) and a standard radial deviation (s_r). The data obtained fit at all seasons the model equation

$$S = S_b + S_c \exp\left[-\frac{1}{2}\left(\frac{r}{s_r}\right)^2\right].$$

It might be worth digressing to re-emphasize the role of sulfur dioxide and daughter products in urban air pollution. Among the agents that can produce

acute distress and precipitate disease this is undoubtedly the most important. The work of Dohan and colleagues (1962) has certainly demonstrated the connection to the number of respiratory disease cases. From a biometeorological viewpoint it should therefore remain the major target for elimination or neutralization at the source. In this respect it should be noted that sulfur oxides alone constitute about 20 per cent of the total 150 million tons of pollutants emitted annually into the air in the United States.

Meteorologically perhaps most interesting is the behavior of oxidants, especially ozone, in the pollution zone. The reason for this is the fact that the meteorological conditions contribute through the photochemical effects toward intensification of the biological effectiveness of pollutants produced by hydrocarbon combustion. The intriguing part is that these products are primarily subjected to the regular dispersing or accumulating effects of the atmosphere and in addition to the solar radiation. A great deal of study has been devoted to these in the Los Angeles area but they can form elsewhere as readily if the conditions are right. This can be illustrated by data collected on oxidant (expressed as parts per million of H_2O_2) in the Washington metropolitan area (U. S. Dept. HEW, 1962). The month of September 1962 was chosen as an example because it had an almost ideal equipartition of weather situations. The observations were subjected to a simple differential analysis, the end result of which is shown in Table 1.

Table 1. Mean Oxidant in ppm in Washington, D.C. (September 1962)

	Days with precip. more than trace *(T)*	Days with wind movement > 130 mi/24 hr but precip. $\leq T$	Days with wind $\leq$130 mi/24 hr precip $\leq T$ Sunshine $\leq$ 400 ly	All others
Number of days	8	7	10	5
Oxidant (ppm)	0.08	0.09	0.18	0.14

This shows that on days with either rain or fresh winds the oxidant value is only about half as high as on days with light winds and high values of solar radiation.

It is not too difficult for the meteorologist to assess the pollution potential of any location for which standard meteorological data are available. With upper air observations this is greatly facilitated. In first approximation frequency of low wind speeds will give an immediate comparison of various localities.

More comprehensive systems of analysis will use, of course, the frequency of occurrence of low-level inversions and the synoptically determined frequency of stagnation. Combinations of these two elements give a good estimate of the pollution potential of the atmosphere in various regions (Holser, 1961). In the United States various types of annual variation are experienced. There are three main areas with high pollution potential. The southeastern Appalachian Mountain area,

with a distinct autumn maximum, is prominent. This type extends with lower frequency into the Northeastern area and to the Atlantic Seaboard. In the interior Southwest and the intermountain region the highest pollution potential is in midwinter. Along the Pacific Coast days with considerable pollution accumulation can occur in other seasons but the maximum potential is also in winter.

Many of the most industrialized and populated areas around the Great Lakes and the northeastern Seaboard are fortunate in having a relatively low pollution potential. The atmospheric motions are, in general, sufficient to dilute the pollutants to a tolerable level. Nonetheless, even at present levels of emission and population density there is a high probability that once in three years a major pollution episode can be expected. With increased population, higher degree of industrialization and greater traffic densities of motor vehicles, the diluting and self-cleansing properties will become more and more taxed so that the frequency of adverse pollution episodes is likely to increase. The biometeorological consequences are very discouraging to contemplate. They are by no means a characteristic of the United States. They are now a menace in every industrialized area of the world. The literature is full of the details for the Soviet Union, for the Ruhr region, for the Midlands of England and London. Physicians have even given the symptoms local names such as Yokohama asthma or New Orleans asthma (Lewis *et al.*, 1962).

It is customary now for scientific congresses, especially those of an international character, to cast a look ahead at the world in the decades to come and to offer such advice as may be within their competency and within the grasp of available or obtainable knowledge. The biometeorologist has certainly an important role in this connection as regards the air pollution problem. A few statements can be made without challenge of contradiction.

With the expanding population of the world and the increasing industralization and mechanization air pollution will constitute in many areas an acute menace to health. The capability of the atmosphere to disperse and to eliminate pollutants is not infinite. In some spots the latent dangers of air pollution have become menacing with increased frequency. The meteorologist, with present knowledge, can make quite adequate probability estimates of air pollution potential in various areas. These should be heeded in future development of industry. The meteorologist can also make quite reliable short-range predictions of the day to day atmospheric changes which will permit or ought to prohibit release of polluting effluents (Niemeyer, 1960; Boettger and Smith, 1961). This practice, which is now an actuality for atomic power installations, was first recommended in the Trail Smelter case (Hewson, 1945). It should become a regular procedure for other damaging industrial fumes. Wherever possible suppression at the source should be attempted.

For the long-range future we cannot overlook the increasing contributions to atmospheric pollution of domestic heating and motor vehicle traffic. Better control of heating equipment and elimination of certain exhaust gases by after burners and similar devices are likely to be only interim palliatives. The long-range solutions must lie in other engineering measures. Among them are large-scale elect-

rification of heating and of city traffic. Radical redesign of car engines and the use of fuel cells may offer solutions. In mountainous terrain ducting of offensive industrial effluents into higher levels above the ground inversions and into the layer of higher wind speeds is a technically attractive possibility.

Unless these remedies are adopted we can look toward an era in which the evils of city climate will overwhelm – at least from time to time – the natural climatic forces. The clean, wholesome air will be overburdened by a witches brew of poisonous aerosol. The population will be an allergic lot, with subacute carbon monoxide and lead poisoning, suffering from chronic bronchitis and emphysema, dying from sulfur dioxide-induced cardiorespiratory insufficiency or alternatively from benzpyrene-stimulated lung cancer. The biometeorologist can only hope that control measures will eliminate this alternative.

REFERENCES

Boettger, C. M. and Smith, H. J. (1961) The Nashville daily air pollution forecast. *Mo Weather Rev.* **89,** 477 – 481.

Bouman, D. J. and Schmidt, F. H. (1961) On the growth of ground concentration of atmospheric pollution in cities during stable atmospheric conditions. *Beitr. Phys. Atm.* **33,** 215 – 224.

Dohan, F. C., Everts, G. S. and Smith, R. (1962) Variations in air pollution and the incidence of respiratory disease, 55th Annual Mtg. Air Pollut. Control Ass. Paper 62 – 11, 6 pp.

Heimann, H., Emik, L. O., Prindle, R. A. and Fischer, W. M. (1958) Progress in medical research on air pollution. Publ. Health Rep. **73,** 1055 – 1069.

Hewson, E. W. (1945) The meteorological control of atmospheric pollution by heavy industry. *Quart. J. R. Meteor. Soc.* **71,** 266 – 282.

Hosler, C. R. (1961) Low-level inversion frequency in the contiguous United States. *Mo. Weather Rev.* **89,** 319 – 339.

Landsberg, H. E. (1962) City air – better or worse. Symposium "Air Over Cities". U. S. Publ. Health Service, Taft Sanitary Engineering Ctr., Tech. Rep't. A 62 – 5: 1 – 22.

Larsen, R. I., Stalker, W. W. and Claydon, C. R. (1961) The radial distribution of sulfur dioxide source strength and concentration in Nashville. 54th Annual Mtg. Air Pollut. Control Ass. Paper 61 – 8, 6 pp.

Lewis, R., Gilkes, M. M. and McCaldin, R. D. (1962) Air pollution and New Orleans asthma Publ. Health Rep. **77,** 947 – 954.

Niemeyer, L. (1960) Forecasting Air Pollution Potential. *Mo. Weather Rev.* **88,** 88 – 96.

Nückel, R. (1962) Der menschliche Atemtrakt als Aerosolfilter. *Zbl. Aerosolforschg.* **10,** 207 – 235.

Pack, D. H. and Hosler, C. R. (1958) A meteorological study of potential atmospheric contamination from multiple nuclear sites. *2nd Geneva Conf., Waste Treatment and Environmental Aspect of Atomic Energy.* Pergamon Press, London. **18,** 265 – 271.

Prindle, R. A. and Landau ,E. (1962) Health effects from repeated exposures to low concentrations of air pollutants. Publ. Health Reports. **77,** 901 – 909.

Prindle, R. A. and Yaffe, C. (1962) Motor vehicles, air pollution, and public health. Publ. Health Reports. **77,** 955 – 962.

Riehl, H., and Crow, L. W. (1962) A study of Denver air pollution. Dep't. of Atm. Science, Colo. State Univ., Ft. Collins, Colo., Tech. Rep't. 33, 15 pp

Stalker, W. W., and Dickerson, R. C. (1961) Suspended particulate matter and sailing index; sampling station and time requirements for urban and pollution surveys, Pt. II. 54th Annual Meeting Air Pollut. Control Ass'n. 21 pp. (offset print).

U. S. Department of Health, Education and Welfare (1961) The Louisville air pollution study. Taft Engineering Ctr. Techn. Rep't. A 61 – 4, 172 pp.

U. S. Department of Health, Education and Welfare (1962) Annual Report of the Metropolitan Council of Governments Oxidant Sampling Networks—October 1961 – September 1962. Div. of Air Pollut., Publ. Health Service, 24 pp. (offset print).

U. S. Department of Health, Education and Welfare (1962) Air pollution measurements of the national air sampling network, analyses of suspended particulates 1957 – 1961. Taft Engineering Ctr., Publ. Health Service Publ. No. 978. 217 pp.

AIR POLLUTION PATTERNS IN THE READING AREA

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Abstract — A survey of air pollution in Reading, England, based on 37 stations using standard smoke filter/volumetric sulphur apparatus, aims to ascertain levels of smoke and sulphur dioxide in a mainly residential, commercial and light industrial town. Preliminary results are used to show, by a series of distribution maps, the spatial pattern of pollution in relation to wind conditions and to the character and density of the built-up area. Indications are that the area of maximum pollution is rarely displaced far from the closely built-up town centre, whatever the wind conditions. This is in accordance with the findings of previous surveys in this country, with which some comparisons are made. There is also evidence, however, that under certain meteorological conditions, considerable pollution may invade Reading from outside sources.

Zusammenfassung — Eine Messung der Luftverunreinigung in Reading, England, ausgeführt von 37 Stationen mit Hilfe von Normalrauchfilter/volumetrischer Schwefelapparatur, hatte das Ziel, den Gehalt der Luft an Rauch und Schwefeldioxyd in einer Stadt zu ermitteln, deren Charakter durch Wohnbezirke, Handel und Leichtindustrie bestimmt wird. Eine Reihe von Verteilungsplänen, die auf Grund vorläufiger Ergebnisse zusammengestellt wurde, zeigt die räumliche Verteilung der Verunreinigung im Verhältnis zu Windbedingungen und Charakter und Dichte geschlossener Ortschaften. Es zeigt sich, dass das Gebiet höchster Verunreinigung selten vom dicht bewohnten Stadtzentrum stark verdrängt wird, wie immer die Windbedingungen auch sein mögen. Dies stimmt mit den Ergebnissen früherer Messungen in Grossbritannien überein, die zu Vergleichszwecken herangezogen wurden. Es gibt Anzeichen dafür, dass unter bestimmten meteorologischen Bedingungen wesentliche Luftverunreinigungen auswärtigen Ursprungs in das Gebiet von Reading eindringen.

Résumé — Une étude de la pollution de l'air à Reading, Angleterre, étude basée sur les données de 37 stations d'observation utilisant l'appareil normal "smoke filter/volumetric sulphur", a pour but d'établir les taux de fumée et d'anhydride sulfureux dans une ville de résidence, de commerce et d'industrie légère. Les résultats préliminaires ont servi à établir, à l'aide de cartes de répartition des agents nocifs, l'image de la pollution en relation avec les vents, le caractère et la densité de l'agglomération. On indique que la zone de pollution la plus intense est rarement décalée par rapport au centre de la ville, et cela quelles que soient les conditions de vent. Ce fait est en accord avec les conclusions d'études antérieures faites en Angleterre (et avec lesquelles on établit quelques comparaisons). Cependant,on fait remarquer que, dans des conditions metéorologiques particulières, une forte pollution provenant de sources extérieures peut envahir la ville de Reading.

In England there is a popular distinction between the smoky industrial Midlands and North and the "clean" residential South where, apart from London, little smoke is supposedly produced. However, rapidly multiplying measurements of air pollution have shown clearly that wherever there is a sizeable cluster of population there is an

air pollution problem, which cannot be ignored. The current National Survey of Air Pollution in the United Kingdom (Clifton *et al.*, 1961) collects information from a large number of towns but it has also been possible to conduct intensive surveys of a few representative towns, one of which is Reading.* Reading, situated 40 miles west of London in the rural county of Berkshire, is a mainly residential, commercial and light industrial town of about 150,000 people and was selected partly because little was known about the level of pollution attained in a so-called "clean" town. The survey, which was sponsored by the Department of Scientific and Industrial Research and carried out by the Geography Department of the University with the support and co-operation of Reading's Chief Public Health Inspector, aimed at establishing 40 recording stations in the 15 square miles of the Reading area, each station using standard smoke filter/volumetric sulphur apparatus. Some preliminary results of this survey (which is still in operation though the more intensive part is over) are used with wind data from a fairly centrally placed and reasonably well exposed recording anemometer to show some typical patterns of pollution in Reading, especially in relation to wind conditions. On inspection these distributions prove to be interesting not only for what they are meant to illustrate but also for the less expected features that they sometimes reveal.

THE READING AREA

The geographical setting is one of an urban area occupying low terraces and plateaux rising both north and south of the wide valley floor of the river Thames. The highest point in the town is just over 340 ft and the lowest 120 ft, so that the local relief can be described as modest but definite. The urban texture of Reading is on the whole relatively open. Figure 1 shows the built-up area against the background of the relief and it can be seen that the close-packed commercial heart of the town is very small, even the older residential quarters, largely of terrace housing, are of limited extent, while newer, more open development of mainly semi-detached houses with large gardens makes up the bulk of the urban area. The sites of the recording stations are shown on this map, as are also railway lines and stations and main roads. Large industrial zones hardly exist in Reading but small pockets of industry occur here and there: in addition there are many scattered industrial chimneys with a distribution coinciding largely though not entirely with the older residential area. Some of these plants, of course, burn oil rather than solid fuel and so contribute sulphur dioxide rather than smoke to the atmosphere. It is also necessary to draw attention to the Smoke Control Areas (zones in which the burning of raw bituminous coal in open domestic grates is forbidden and the use of some smokeless fuel is required by law): a cluster of these "smokeless zones" is situated on the south-western edge of the town, while another occupies most of the commercial centre.

* The other two are Sheffield and Edinburgh.

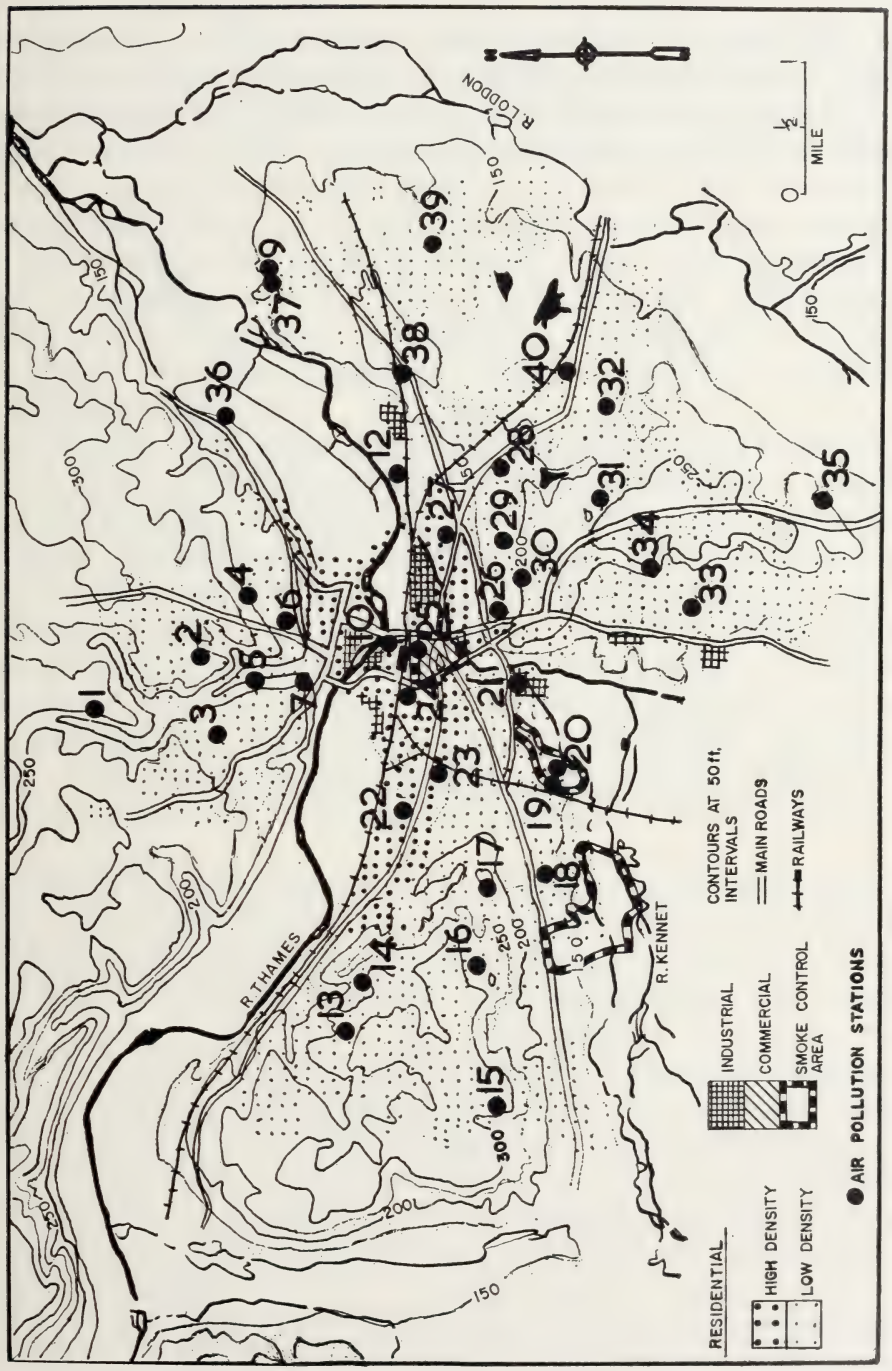

Fig. 1. The Reading area: relief, nature of built-up area and pollution recording sites

SOME SEASONAL AND MONTHLY DISTRIBUTIONS

On the maps that follow the distributions of smoke or sulphur dioxide are shown by isopleths against the background of the built-up area: the isopleths are in broken line where the evidence is uncertain. The first map (Fig. 2) shows the average daily smoke concentration in summer 1961 (taking this as June to September inclusive, the non-heating season). It can be seen that the area of highest smoke concentration coincides very broadly with the zone of high density housing: this

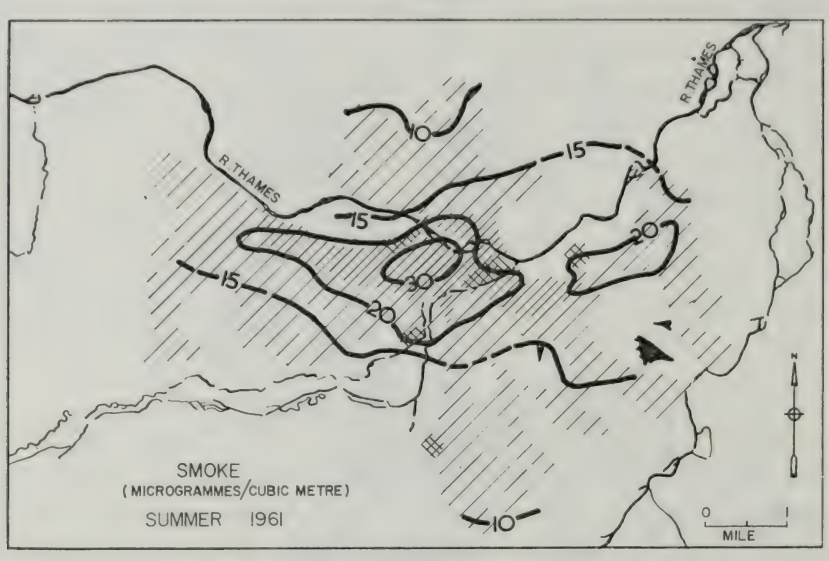

FIG. 2. Mean daily smoke concentrations, summer 1961

cannot be significant in itself since this is summer and no domestic fires are lit, but presumably by virtue of the fact that most industrial chimneys are within this area, the smokiest area is found centrally and the eastern fringe of the town has higher values than on the north, west or south: the reasons for this are not immediately apparent.

The corresponding map for the period November 1961 to March 1962 showed immediately the higher general level of smoke concentration in winter, something like 5 times the summer level, which suggests that domestic chimneys contribute something like 80 per cent of the total smoke pollution. A close relationship between the smoke distribution and the density of the built-up area is also apparent. This would seem to support the widely accepted view that "Smoke pollution at any point depends on the density of the population . . ." (Williams, 1960) and to emphasize the essentially local nature of air pollution. With the prevailing wind from the southwest a displacement of the maximum smoke concentration towards the northeast might be expected: in fact the smokiest area lies about 1 mile west of the town centre, which itself has at first sight an unexpectedly low value. Reference

to Fig. 1 however will show that this "hole" in the pattern is due entirely to one station (no. 25) situated within the central Smoke Control Area and it is presumably this feature that pushes the maximum smoke concentration away from the centre.

This suggestion is supported by consideration of the winter map of sulphur dioxide. The maximum concentration coincides emphatically with the town centre: the Smoke Control Area is ineffective because the related legislation is concerned with the reduction of visible smoke and not with sulphur dioxide. However this map also has its anomaly, another "hole" in the pattern west of the town centre representing a station (no. 24 on Fig. 1) in a closely built-up area, near main roads, railway sheds and various industrial chimneys, where high SO_2 values might be expected. But this station is also very near the cattle market and slaughter-houses, both potent sources of ammonia. It is, therefore, suspected that this is reducing the acid content in the hydrogen peroxide bubblers of the recording equipment: this problem is being investigated.

Apart from this there are certain broad similarities in the distributions of winter smoke and winter sulphur dioxide but also an important difference. The ratio of lowest to highest values is much greater in the case of sulphur dioxide than in the case of smoke: taking the isopleth values represented, these range from 50 to 200 for sulphur dioxide but only 50 to 125 for smoke, the units being the same in both cases. Viewing the data in another way, the ratio of smoke to sulphur dioxide is not far from unity in some suburban areas but decreases to about 0.6 in the centre. The winter smoke distribution shows that the eastern edge of the town is somewhat dirtier than any other, a feature also of the summer pattern: the same might be said of the winter sulphur dioxide distribution were it not for a lack of evidence on the southern fringe (where the southernmost station, No. 35, did not record sulphur dioxide at this time).

It is perhaps not to be expected that the effect of wind on the distribution of pollution will be very obvious where mean values over a whole season are considered. Figure 3 shows the smoke pattern for the month of January 1962 in which, as the wind direction frequency diagram indicates, winds blew almost entirely from directions between west and south. This distribution is very similar to that for the winter as a whole: it might be said that the smokiest part of residential south Reading is somewhat displaced eastwards and there is now a minor maximum in northeast Reading, but the smokiest zone of all remains west of centre (where the effect of the Smoke Control Area is again seen). The cleanest edge of the town is the southwest and the dirtiest the east but this might be expected with these wind directions. The corresponding map of sulphur dioxide repeats all the main features of the seasonal pattern.

In contrast November 1961 was a month with a large proportion of winds between north and east. Here again the pattern might be regarded as disappointingly similar to that of the winter season as a whole and of the other selected month. However the eastern edge of the town is still the smokiest: this does not reflect the

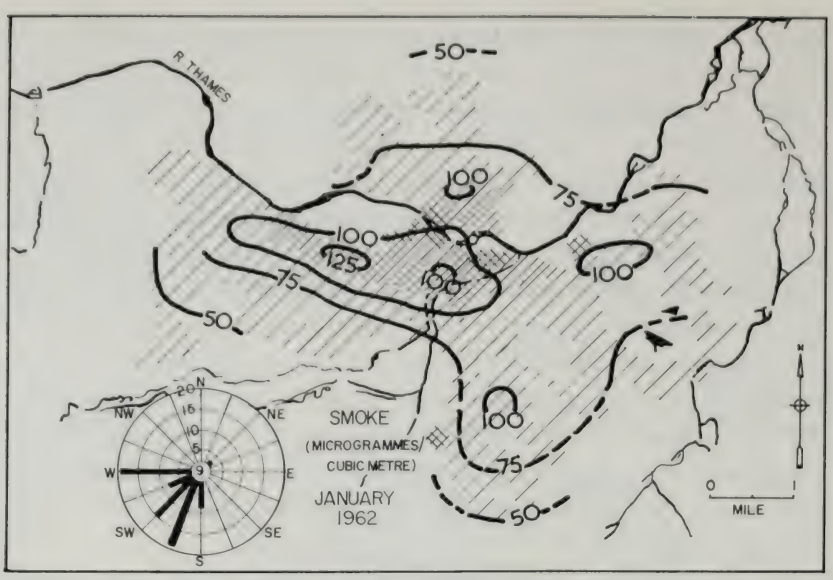

FIG. 3. Mean daily smoke concentrations, January 1962

density of the built-up area, still less is it to be expected with these wind directions. The November sulphur dioxide map shows nothing not already seen, though the level of concentration in the centre is certainly lower than in the previous examples.

POLLUTION UNDER PERSISTENT WIND CONDITIONS

It may help to turn to particular situations in order to pursue more closely this question of pollution and wind direction. For this purpose the wind direction traces of the recording anemometer (which was sited at station 26 on Fig. 1) were care-

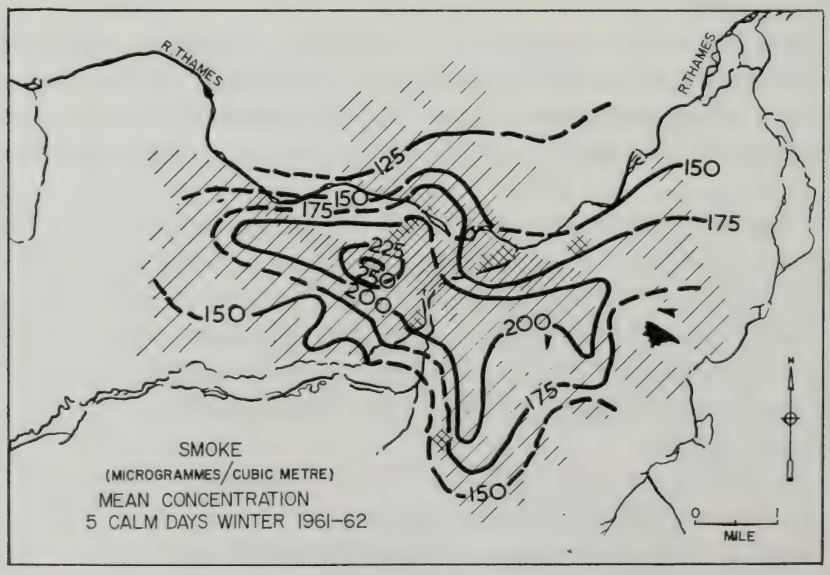

FIG. 4. Mean daily smoke concentrations on 5 "calm" winter days

fully examined and each day on which the wind direction remained fairly steady was assigned a mean wind direction. Days on which the direction fluctuated widely (usually more than $\pm 20°$ of the mean) were discarded. The mean wind speed of the day was also determined from the records of a run-of-the-wind anemometer. The examples that follow all concern smoke and the winter period 1961–62 (the analysis has not yet been extended to sulphur dioxide and to other seasons).

Days on which the mean wind speed did not exceed 1 mph were designated as "calm" (which is not meant to suggest literally still air). These were relatively rare but the daily smoke concentrations for 5 such days (not consecutive) were averaged and the resulting mean pattern is shown in Fig. 4. With the very slight air movement involved, the highest concentration coincides closely with the maximum emission and it is not surprising that the isopleths fairly faithfully pick out the shape of the built-up area, even to the extent of recognizing the presence of parks and open spaces.

THE EFFECTS OF WIND DIRECTION IN GENERAL

The foregoing examples of seasonal, monthly and short-period distribution have illustrated — leaving aside the more or less unpredictable local anomalies — at least the following points (a) the general relationship between pollution and building density (b) the dominant contribution to winter smoke of domestic chimneys (c) the relatively small effect of wind direction on the location of maximum smokiness (the presence of the central Smoke Control Area complicates this issue a little).

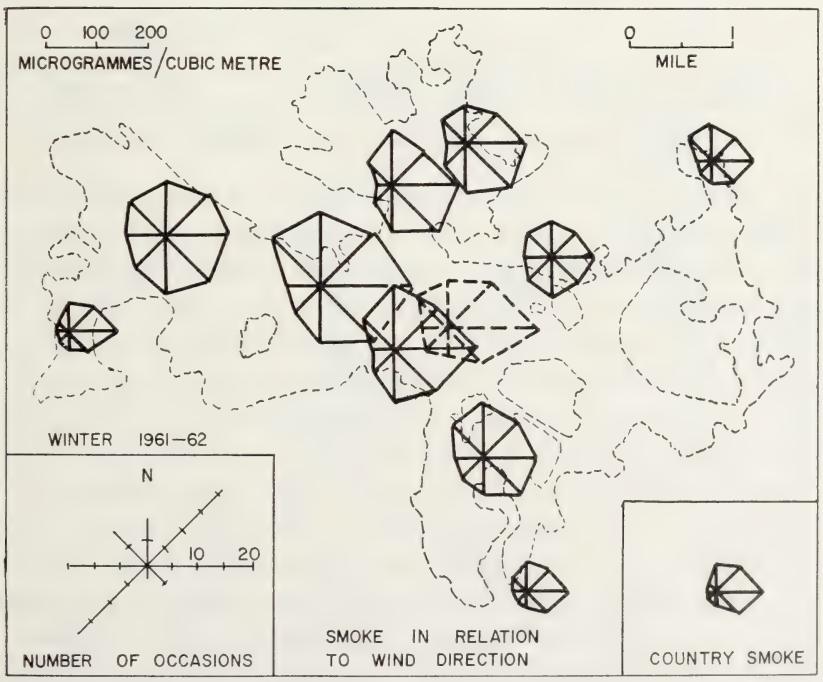

Fig. 5. Total smoke in relation to wind direction, winter 1961

All this is in accordance with the findings of previous investigations in this country, notably the classic survey of Leicester (D.S.I.R. 1945) in which the effectiveness of atmospheric turbulence as a natural remover of pollution was emphasised. Years before Goldmerstein and Stodiek (1931) following their studies in Berlin published under the title "Wie atmet die Stadt?" had concluded that ". . . the town breathes vertically." More recently Chandler (1961) has suggested that inwardly directed circulations of air associated with the warm interiors of towns may help to explain the very limited horizontal shift of urban pollution.

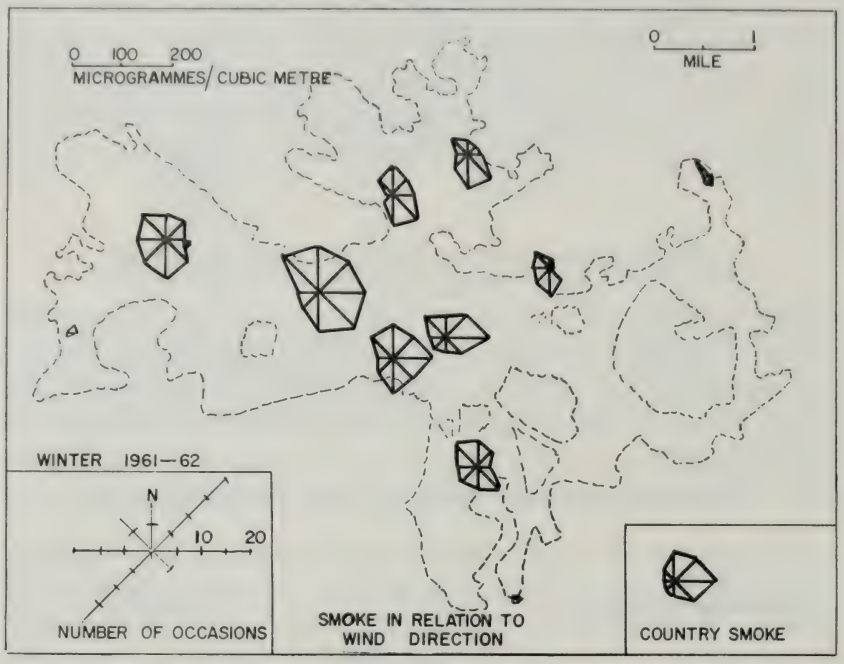

FIG. 6. "Reading smoke" in relation to wind direction, winter 1961

However, a further point of interest to emerge from the patterns shown is that the eastern edge of Reading is very often the smokiest even when the wind is from that direction and it is difficult to envisage this without appreciable horizontal drift of smoke from elsewhere. Figure 5 illustrates the general effect of wind direction on winter smoke concentration at 11 stations with practically continuous records (many of the other stations could not be visited on Sundays). The daily smoke values on more than 100 days of reasonably steady wind conditions were averaged in 8 categories of wind direction and these averages plotted in the form of "pollution roses" in which the length of each arm is proportional to the mean smokiness brought in from that direction. A wind rose showing the number of occasions of each wind direction gives some idea of the reliability of the smoke averages. It is clear that for nearly all stations, even those on the eastern edge of the town, the east is one of the smokiest directions if not the smokiest.

The smoke recorded by a given station is derived partly from Reading and partly from elsewhere and the latter contribution may usefully be called "country smoke".

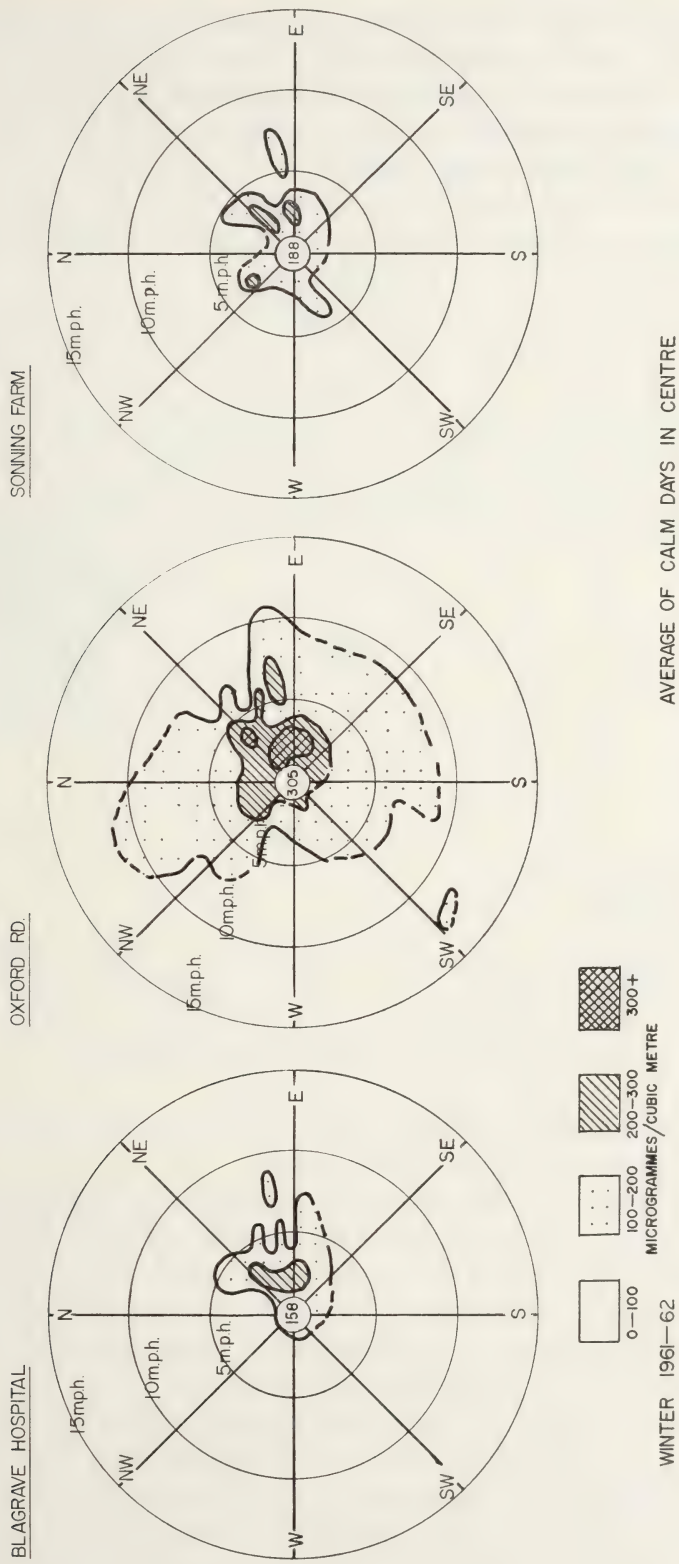

Fig. 7. Relation of mean wind direction, mean wind speed and daily smoke concentrations at selected stations, winter 1961.

For each wind direction it has been assumed that the cleanest station (nearly always the station at the windward edge of the town) receives only "country smoke" and the lowest values from all directions are incorporated into another rose broadly representing "country smoke" (on the same scale): this emphatically reveals the east as the smokiest direction.

If the "country smoke" values are subtracted from the pollution roses of Fig. 5, a new set of diagrams results, which should largely represent "Reading smoke".

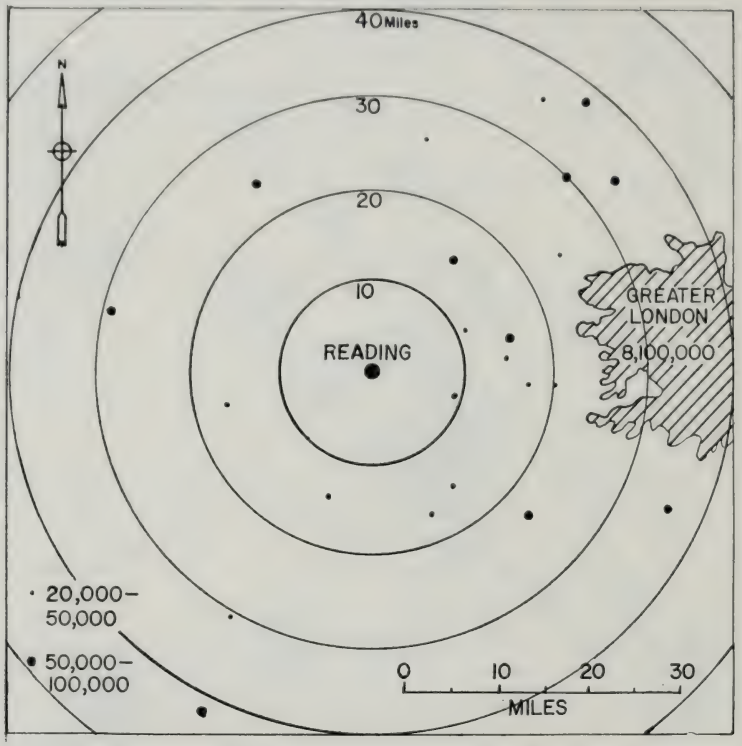

FIG. 8. Major pollution sources around Reading

This has been done in Fig. 6 in which there is now some tendency for the longest arms to point towards extensive built-up areas.

Returning to the overall picture it can be shown that the smoke brought in from the east is mainly an accompaniment of light winds. In Fig. 7 each daily value of mean wind direction and speed was plotted on a polar graph with radii representing direction and concentric circles representing speed and against each intersection was inserted the corresponding smoke concentration: when all values were so plotted, isopleths of smokiness were drawn in the usual way. Three stations have been selected, from the extreme west, centre and extreme east of the Reading area: but they all show (as do examples elsewhere in the town) that light mainly easterly winds bring the highest smoke concentrations. Figure 8 makes it plain what these distant pollution sources might be. Not only are there many more sizeable towns between northeast and southeast of Reading than in any other sector but beyond

them lies the vast extent of Greater London. No doubt further studies are needed, particularly of the stability of the airstreams concerned, but meanwhile it seems inescapable that, in certain anticyclonic conditions of light air movement under a low inversion, London smoke can drift westwards without much upward dispersion and can contribute substantially to Reading's pollution problem.

REFERENCES

CHANDLER, T. J (1961) Surface breeze effects of Leicester's heat-island. *East Midland Geographer* **15,** 32–38.

CLIFTON, M., CRAXFORD, S. R. and WEATHERLEY, M-L. P. M. (1961) The national survey of air pollution. *Proc. of the Brighton Conference of the National Society for Clean Air.*

D.S.I.R., (1945) Atmospheric pollution in Leicester, H.M.S.O. London.

GOLDMERSTEIN, J. and STODIEK, K. (1931) *Wie atmet die Stadt?* Berlin.

WILLIAMS, F. P. (1960) Pollution levels in cities. *Proc. of the Harrogate Conference of the National Society for Clean Air.*

PROCESSING OF METEOROLOGICAL DATA FOR ENGINEERING PURPOSES

ANALYSIS OF EXTERNAL CLIMATIC DATA FOR ENGINEERING DESIGN. SUMMARY REPORT

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THE discussion was opened by Dr. H. E. Landsberg, U.S. Weather Bureau, followed by Mr. H.C. Shellard, Meteorological Office, Great Britain.

H. E. LANDSBERG: The best way of processing the vast numbers of external climatological data that were available, to make them useful for engineering design was to develop statistical models which expressed the results in probabilistic terms. This also had the advantage that the choice of probability level was left to the designer, with whom it properly belonged.

Although a number of meteorological elements were normally distributed, this was by no means universal and some of the factors with which the engineer is particularly concerned are not, in fact, normally distributed. It was generally better to use the appropriate distribution function (e.g. Poisson, one of the three Fisher and Tippett functions, incomplete gamma function, etc.) than to transform the data to make them fit the normal distribution. Usually it was necessary to process the data electronically because there was so much of it.

A number of statistical models of climatic elements, relating to the U.S., were then illustrated by slides and briefly discussed. These included design temperatures for heating systems (lowest daily average temperature,) heating degree days for storage tank design, sixth highest daily dry bulb and wet bulb temperatures for air-conditioning, discomfort index and extreme wind speeds (fastest mile of wind) for the design of structures.

H. C. SHELLARD: The problems of analysing climatic data for engineering design were basically similar in all countries but there were differences in detail because of climatic and instrumental differences. Thus in the U.K. the base temperature for heating degree days was 5° F lower than in the U.S. and extreme wind speeds were expressed as maximum mean hourly and maximum gust speeds, instead of in terms of the fastest mile of wind. The statistical model used for extreme wind speeds and the results obtained in the U.K. and used for wind loading purposes were illustrated by slides. Some outstanding problems in this field, particularly the need for more information about (a) maximum speeds over short periods and variations with height over cities, and (b) topographical effects, were mentioned.

Some examples of analyses of climatic data involving combinations of elements were given. These included rainfall and wind (speed and direction), for driving rain

problems; temperature and wind, for siting of ventilators and water-pipes and for specification of mastics for glazing; and wet bulb and dry bulb temperatures for air-conditioning. Information relating to the distributions of physiological temperature scales, such as effective temperature, which involve air temperature, humidity and wind speed, could be provided by the climatologist, given the necessary definitions of the scale. Other engineering applications such as the routing of new motorways so as to minimize climatic hazards such as snow, fog and frost, and the estimation of the extent to which outdoor work may be interrupted by precipitation low temperatures and strong winds were also referred to.

DISCUSSION

Prof. Buchberg said that as an engineer he had found information based on hourly observations to be the most valuable. He had noted that radiation data had not been mentioned.

Dr. Landsberg indicated that hourly data were now very plentiful and that there was quite a lot of radiation data, although the limited number of stations measuring radiation was still a handicap.

Prof. Godske expressed the hope that statistical models would become available for the multiple distribution of extreme values, e.g. high wind and low air temperature.

Prof. Page thought that it was a most interesting development that the probabilistic approach had transferred decisions about safety to the designer. This was a good thing because only the specialist could take all the factors involved, including the particular application, into account. The cost of obtaining climatic data in suitable form and the time it takes to get them were important. What matters is what can be obtained at a reasonable cost before the design is finalized; one could get too much data.

Dr. Landsberg said that when an engineer asked for information about combined-elements he may not realize that he would receive a lot of redundant data, because practically all meteorological variables were interrelated. Both Prof. Godske and Prof. Robinson pointed out that this was not so if you compared different places, two places with a temperature difference of 15° C could receive similar amounts of radiation, for example.

Referring to Prof. Page's remarks Mr. Shellard said that the designer could often help by requesting climatological data at a much earlier stage; he also thought that the cost of obtaining such data was usually trivial in relation to the cost of the project.

INFLUENCE DE L'ENSOLEILLEMENT ET DE L'ÉCLAIREMENT SOLAIRE ÉNERGÉTIQUE ET LUMINEUX SUR LE CLIMAT INTÉRIEUR DES HABITATIONS

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Abstract – The various aspects of visual and thermal comfort are considered and basic rules are reviewed. Attention is also focused on the importance of the methods used for the predetermination of indoor light conditions, taking account of both cloud covered sky and clear sky. As far as thermal comfort is concerned, the role of glass is considered for winter and summer conditions. Finally, as sunshine conditions are related to meteorological conditions, indications are given for the tabulation of observational data.

Zusammenfassung – Betrachtungen über die verschiedenen Bedingungen des Licht- und Wärmekomforts werden gegeben. Die Bedeutung der Methoden zur Vorbestimmung der Raum-Lichtbedingungen wird erwähnt, da bewölkter und wolkenloser Himmel betrachtet werden müssen. Die Bedeutung von Glas unter Winter- und Sommerbedingungen für den Wärmekomfort wird besprochen. Da die Besonnung abhängig von den meteorologischen Bedingungen ist, sind Empfehlungen für die Zusammenstellung der Beobachtungsdaten gegeben.

Résumé – On envisage successivement les différents aspects du confort lumineux et du confort thermique pour lesquels on rappelle les règles essentielles. On insiste également sur l'importance des méthodes de prédétermination de l'éclairement lumineux intérieur qui doivent être basées à la fois sur les conditions de ciel couvert et de ciel serein. Quant au confort thermique, il y a lieu de tenir compte du rôle des vitrages en régime d'hiver et en régime d'été. Enfin le contrôle de l'ensoleillement étant lié aux conditions météorologiques du climat solaire, on indique sous quelle forme les données d'observation doivent être présentées.

AVANT-PROPOS

Dans une communication présentée à Davos en octobre 1959 sous l'égide du «Groupe international d'étude pour la climatologie appliquée à l'habitation et l'urbanisme», nous avions insisté sur l'intérêt de coordonner les programmes de recherches portant sur les observations suivantes: durée d'insolation, éclairement énergétique solaire direct et diffusé, éclairement lumineux en vue d'apporter aux problèmes de l'urbanisme et de l'architecture les données d'utilisation pratique concrètes.

A titre d'exemple, nous présentions en particulier l'application des observations du rayonnement solaire aux ilots bâtis selon l'orientation des façades, la largeur des voiries et la hauteur des immeubles ainsi qu'à l'orientation des terrains d'après leur pente et leur orientation.

Ces considérations, ayant fait l'objet de plusieurs notes (Dogniaux, 1960, 1961), ne seront pas réexaminées ici. Nous nous proposons simplement d'évoquer différents aspects liés au confort lumineux et thermique de l'habitation en relation avec les méthodes de prédétermination généralement admises et d'attirer particulièrement l'attention sur le caractère impérieux de traiter le problème dans son ensemble sous peine de préconiser des solutions partielles qui ne répondent pas aux exigences du confort des habitants.

CONFORT LUMINEUX

Lorsqu'on aborde la question de confort en général et de confort lumineux en particulier, il y a lieu de distinguer en tout premier lieu les locaux à usage professionnel et les habitations privées. Car si pour les premiers, les critères de valeurs d'éclairement recommandées sont régis impérieusement par la nécessité d'accomplir des tâches données dans les conditions de vision les plus confortables; il n'en va pas de même pour les habitations privées qui, dans le cadre de la vie familiale, doivent rester par excellence un lieu de détente et de repos où chacun puisse réaliser les conditions de séjour les mieux adaptées à son individualisme.

Dès lors il semble illusoire de prétendre édicter des normes d'éclairement normal trop strictes dans le cas des locaux à *usage domestique* où la personnalité et les aspirations particulières des occupants peuvent amener l'architecte à concevoir des projets qui s'écartent souvent des réalisations classiques techniquement mieux adaptées aux normes théoriques.

Il n'est pas paradoxal de dire que si l'éclairage naturel est préféré à l'éclairage artificiel, c'est avant tout parce qu'il est essentiellement variable et nuancé et qu'il permet à l'individu dont l'oeil s'accomode avec une égale aisance aussi bien aux quelques 100, 000 lux d'un soleil d'été à midi qu'à l'insignifiant quart de lux d'un beau clair de lune, de rechercher au gré de sa fantaisie le niveau et la qualité de lumière qui satisfont au mieux ses dispositions particulières.

Il en est tout autrement des locaux à *usage professionnel* où la qualité et les niveaux d'éclairage doivent répondre à des prescriptions strictes en matière d'hygiène du travail et d'impératifs de productivité. Dans ce cas, il est commode de se référer à des niveaux d'éclairement — ou du moins à des ordres de grandeur — recommandés en vue de l'accomplissement de tâches déterminées. Bien sûr, ces normes suivent de très près les normes établies pour l'éclairage artificiel. Il ne faut pas se dissimuler toutefois les difficultés de réaliser pratiquement d'éventuelles recommandations. En effet, il est possible d'étudier un éclairage artificiel techniquement supérieur à l'éclairage naturel, avec une intensité, une constance, une

composition spectrale convenant au mieux à un problème précis et d'atteindre ainsi plus facilement le confort visuel au sens physiologique.

Mais cet éclairage conditionné ne satisfera pas pour autant les exigences psychologiques liées intimement au confort. La vie dans une cave ou dans une prison sans fenêtre, même équipées d'un éclairage artificiel parfait est nettement moins agréable et moins supportable que celle dans un local muni de fenêtres ouvrant la vue vers l'extérieur.

Ce point de vue est lié au champ de vision et à sa limitation dans une pièce sans paroi transparente. En effet, l'oeil présente une certaine tendance à la fatigue lorsqu'il ne peut voir que des objets rapprochés. Une fenêtre permet d'étendre le champ en donnant à l'oeil la possibilité de regarder vers l'infini. C'est pourquoi, les techniques architecturales contemporaines tentent de plus en plus à préconiser d'énormes baies vitrées s'étalant du plafond au sol donnant l'impression aux occupants de prolonger vers l'intérieur les plantations, verdures et parterres de fleurs.

En conclusion, si logiquement, l'éclairage naturel est le plus apprécié, il est cependant de nombreux cas où, seul, il ne peut procurer l'éclairement requis pendant les heures imposées de travail.

Dans d'autres cas, la conception architecturale du lieu n'a pu trouver une solution permettant d'obtenir et de répartir la lumière en quantité suffisante.

Le rôle de l'éclairage artificiel s'impose alors afin de parfaire l'éclairage déjà obtenu naturellement en le complétant par des sources locales.

Pour réaliser un éclairage confortable, il ne suffit pas, d'une manière générale, d'obtenir un éclairement suffisant du lieu de travail ou de séjour permettant de réaliser une vision nette d'un objet déterminé avec un minimum de fatigue mais encore faut-il respecter certaines règles de contrastes de luminance et de dispositions des sources en vue d'éviter l'éblouissement et aussi d'impératifs d'ordre psychologique.

La solution du problème, en première approximation, consiste à préciser:

- l'éclairement optimum ou la quantité de lumière nécessaire;
- la manière suivant laquelle l'éclairement sera réalisé;
- la qualité de la lumière utilisée.

La notion de confort est liée à l'oeil, à ses performances et ses défauts. Quant à l'objet regardé, différentes caractéristiques peuvent influencer plus ou moins fortement les conditions de bonne visibilité.

L'oeil est un instrument d'optique merveilleux: aucun appareil photographique combiné à diverses émulsions sensibles ne pourrait s'adapter à des conditions d'éclairement aussi variées que celles auxquelles l'oeil peut s'accomoder. Il est très malaisé de fixer avec précision les limites d'éclairement entre lesquelles l'oeil peut voir.

Cependant la fonction visuelle ne s'accomplit confortablement que pour des niveaux d'éclairement compris dans des limites plus étroites. Ces valeurs d'éclaire-

ment optimum sont souvent données dans des tables; pour un exemple bien précis, les valeurs recommandées varient parfois du simple au double. De plus on constate qu'à l'heure actuelle les éclairements proposés sont nettement plus élevés qu'il y a une vingtaine d'années. De tels écarts montrent nettement que la question de confort évolue.

Mais l'éclairement n'est pas seul à être pris en considération; la luminance et surtout le contraste des luminances importe également. Il est dès lors permis de dire que l'éclairement requis doit être d'autant plus élevé que le contraste des réflectances est faible et que les dimensions du détail à examiner sont petites.

Partant de données physiologiques, il est possible de dresser un tableau donnant l'éclairement requis en fonction de l'importance des détails à percevoir et pour diverses catégories de contraste dans les luminances. Cette idée de contraste est à rattacher directement aux notions de contrastes de réflectances et de contrastes chromatiques.

Ainsi conçue, la questions du confort lumineux permet de préciser de manière assez nette l'importance de l'éclairement nécessaire en fonction des caractéristiques de formes, dimensions et couleurs des objets à voir. La distance de vision ainsi que d'angle sous lequel l'objet est vu interviennent dans l'acuité visuelle. A ce dernier point se rattachent les performances de l'oeil: il peut être normal ou rendu plus ou moins inapte par l'âge ou encore par suite de la présence de défauts qui peuvent souvent être corrigés par des lentilles appropriées.

Cependant, dans bien des cas, il ne suffit pas de réaliser l'éclairement au niveau requis pour un cas d'éclairage bien précis et d'en conclure pour autant que toutes les conditions de confort sont remplies.

Il y a lieu en effet de tenir compte, en plus, des différents facteurs suivants:

- qualité de l'éclairage, que l'on pourrait résumer par sa couleur, sa stabilité et sa répartition;
- la mobilité éventuelle de l'objet à regarder ou de la source lumineuse.

Les exigences du confort lumineux devraient encore porter sur une répartition convenable de l'éclairement du local de travail.

Un point essentiel qu'il importe de prendre en considération est l'éblouissement. Toute cause d'éblouissement susceptible d'entraîner une sensation d'inconfort, accompagnée ou non d'une diminution des facultés visuelles doit intervenir dans la qualité d'un éclairage. Bien des causes différentes peuvent intervenir et il n'est guère possible de les citer toutes. Les quelques exemples suivants permettent déjà d'en tirer l'importance.

1. Luminance des Sources et leurs Dimensions

Plusieurs sources lumineuses de moyenne intensité sont préférables à une source unique de forte intensité. En éclairage naturel, une grande fenêtre donne moins d'éblouissement qu'une petite.

2. Position de la Source par Rapport aux Yeux

Une source de forte luminance est d'autant plus gênante qu'elle se trouve proche du centre du champ visuel. Par contre, un écart angulaire relativement faible entre le centre du champ visuel et la direction de la source est moins gênant si la source n'a qu'une faible luminance.

On notera enfin que l'existence de contrastes chromatiques présente l'avantage d'assurer l'appréciation des reliefs sans avoir recours aux effets d'ombre trop marqués, peu favorables au confort visuel, et également d'éviter la monotonie qui résulterait d'un décor de luminance et de couleur trop uniformes.

3. Influence des Luminances de Fond

La notion de confort lumineux demande également que l'éclairement ne soit pas seulement limité au poste de travail. Un certain équilibre est nécessaire entre les luminances des différentes zones du champ visuel.

Habituellement, on table sur un éclairage général plus faible qui procurera une luminance de fond. Le rapport entre ces deux types de luminance n'est pas constant : il peut varier de 5 à 30 suivant la valeur de la luminance de fond. Un tel renforcement de l'éclairage localisé n'est cependant pas possible avec un éclairage naturel intégral : on le réalise alors par un éclairage artificiel de complément.

L'ÉCLAIRAGE NATUREL ET LE PARTI ARCHITECTURAL

La pratique architecturale, en matière d'éclairage naturel, consiste à prédéterminer les conditions probables d'éclairement à l'intérieur d'un local à partir de la géométrie du plan du bâtiment et des conditions données, voire d'hypothèses, sur la nature et la distribution des sources naturelles extérieures.

La détermination conventionnelle la plus commode se base sur des conditions extérieures correspondant à un ciel couvert (uniforme ou avec une distribution donnée). En aucun cas, cette hypothèse ne permet de tenir compte des variations de l'éclairement intérieur qui résultent de l'orientation du local, par ciel serein.

Et pourtant leur importance est appréciable comme on peut le voir en se rapportant aux travaux spécialisés en la matière (Dogniaux, 1962, 1963) et d'intéressantes considérations relatives à l'affectation des locaux peuvent être déduites selon qu'on souhaite ou non une uniformité d'éclairement à telle heure du jour ou au cours d'une journée selon la saison.

Il importe donc de mettre à la disposition des architectes des méthodes graphiques simples d'application basées sur des conditions de ciel serein (consulter à ce sujet le fascicule spécial édité par le Centre scientifique et technique du bâtiment, Paris).

CONFORT THERMIQUE

Le conditionnement thermique du milieu dans lequel l'être humain vit ou séjourne doit être basé sur les exigences fonctionnelles du corps humain. L'adaptation des conditions climatiques à ces exigences constitue les facteurs du confort thermique.

Dans les locaux d'habitation, ou même à occupation passagère, la nature des parois joue évidemment un rôle très important dans les conditions du confort thermique. La tendance architecturale, basée sur la conception de larges baies vitrées et de murs rideaux, de parois en matériaux légers à faible inertie thermique, pose avec acuité le problème du conditionnement thermique des locaux abondamment vitrés.

Le comportement des vitrages est donc à considérer sous la double optique: régime d'hiver, régime d'été.

RÉGIME D'HIVER

La transmission de chaleur à travers des parois vitrées en régime d'hiver est un facteur non négligeable du confort. L'utilisation de vitrages spéciaux multiples ou de doubles châssis doit être envisagée d'une part sous l'aspect économique et d'autre part sous l'aspect du confort thermique proprement dit.

Tableau 1. Valeurs du coefficient de transmission thermique pour différentes combinaisons de vitrages multiples pour les valeurs suivantes des coefficients d'échanges superficiels:

$$\alpha_i = 7;\ \alpha_e = 20 \text{ kcal/m}^2\text{/h/°C}$$

et de la conductivité thermique: 0,70 kcal/m/h/°C

Épaisseur du verre (mm)		k(kcal/h/m²/°C)		
		Épaisseur de la couche d'air		
		0,62 mm	9 mm	1,25 et 15 mm
Vitrages	2×3 mm	3,00	2,85	2,71
	2×5 mm	2,97	2,81	2,69
Doubles	2×7 mm	2,92	2,77	2,66
	2×9 mm	2,87	2,71	2,62
Vitrages	3×3 mm	2,05	1,92	1,80
	3×5 mm	2,03	1,89	1,78
Triples	3×7 mm	2,00	1,87	1,75
	3×9 mm	1,97	1,74	1,72

*Les tableaux 1, 2, 3, 4 sout extraits de Comité National Belge de l'Éclairage (1963).

Tableau 2. Témpératures superficielles intérieures de quelques types de vitrages en fonction de diverses températures extérieures et pour une température intérieure de + 20° C

(Valeurs de T_v pour T_i = +20° C)							
k	Type de vitrage		T_e °C				
	Verre	Espace d'air	−20	−10	0	+10	+30
5,07	3	—	−9,0	−1,7	5,5	12,7	27,2
4,96	6	—	−8,3	−1,2	5,8	12,9	27,09
3,00	2×3	0,62 mm	2,8	7,1	11,4	15,7	24,3
2,85	2×3	9 mm	3,6	7,7	11,8	15,9	24,07
2,71	2×3	1,25 mm	4,5	8,4	12,2	16,1	23,88
2,05	3×3	2×5,6 mm	8,2	11,2	14,1	17,1	23,9
1,92	3×3	2×9 mm	9,0	11,7	14,5	17,2	23,7
1,80	3×3	2×5,6 mm	9,7	12,3	14,8	17,4	22,6
2,94	2×6	0,62 mm	3,1	7,4	11,6	15,8	24,2
2,79	2×6	9 mm	4,0	8,0	12,0	16,0	24,0
2,67	2×6	1,25 mm	4,7	8,5	12,3	16,2	23,8
2,01	3×6	2×0,62 mm	8,5	11,3	14,2	17,1	22,9
1,88	3×6	2×9 mm	9,2	11,9	14,6	17,3	22,7
1,76	3×6	2×1,25 mm	9,9	12,4	14,9	17,5	22,5

Tableau 3. Pourcentage de l'energie solaire transmise par différents types de vitrages

Type de vitrage (verres de 6, 3/6, 7 mm)	Pourcentage d'énergie solaire transmise (courbe de Moon, masse 2)			Apport thermique total
	Visible (0,40–0,77 μ)	I. R (0,77–2,2 μ)	Global (0,40 2 μ)	En % de l'énergie solaire incidente (direct + rerayonné)
Verre clair ou glace polie claire	88	81	85	88,5
Verre gris	40	38	40	66
Verre absorbant	67	24	46	70
Doubles vitrages				
clair + clair	78	66	72	74
clair + gris	35	31	34	42
clair + absorbant	59	19	40	47
clair + clair réfléchissant	34	13	24	28

Si le coefficient de transmission thermique pour un vitrage simple, d'épaisseur comprise entre 2 et 10 mm, est d'environ 5 kcal/h/m²/°C, sa valeur diminue sensiblement lorsque l'on adopte des combinaisons doubles ou triples de vitrages (cf. tableau 1) et, de ce point de vue, les vitrages isolants peuvent aisément supporter la comparaison avec les fenêtres à double châssis en bois.

L'économie de combustible résultante peut être chiffrée et la rentabilité appréciée.

Un autre facteur d'inconfort des parois extérieures est dû à la zone froide voisine des parois résultant des pertes thermiques des parois et des échanges convectionnels et radiatifs du corps avec l'ambiance.

n — La surface réceptrice est maintenue constamment normale aux rayons solaires.
V — La surface réceptrice est un plan vertical perpendiculaire au plan d'incidence des rayons solaires.
M — La surface réceptrice est horizontale, H, ou verticale exposée à l'Est ou à l'Ouest, au Sud... (E, W, S,...)
En abscisse sont portés les différents jours de l'année, en ordonnée l'énergie totale reçue (exprimée en kcal. par mètre carré de surface plane).
On remarquera que l'exposition Sud est celle qui correspond à l'irradiation d'hiver la plus importante, l'irradiation d'été étant par ailleurs plus faible pour cette exposition que pour les expositions E, W, SE et SW.

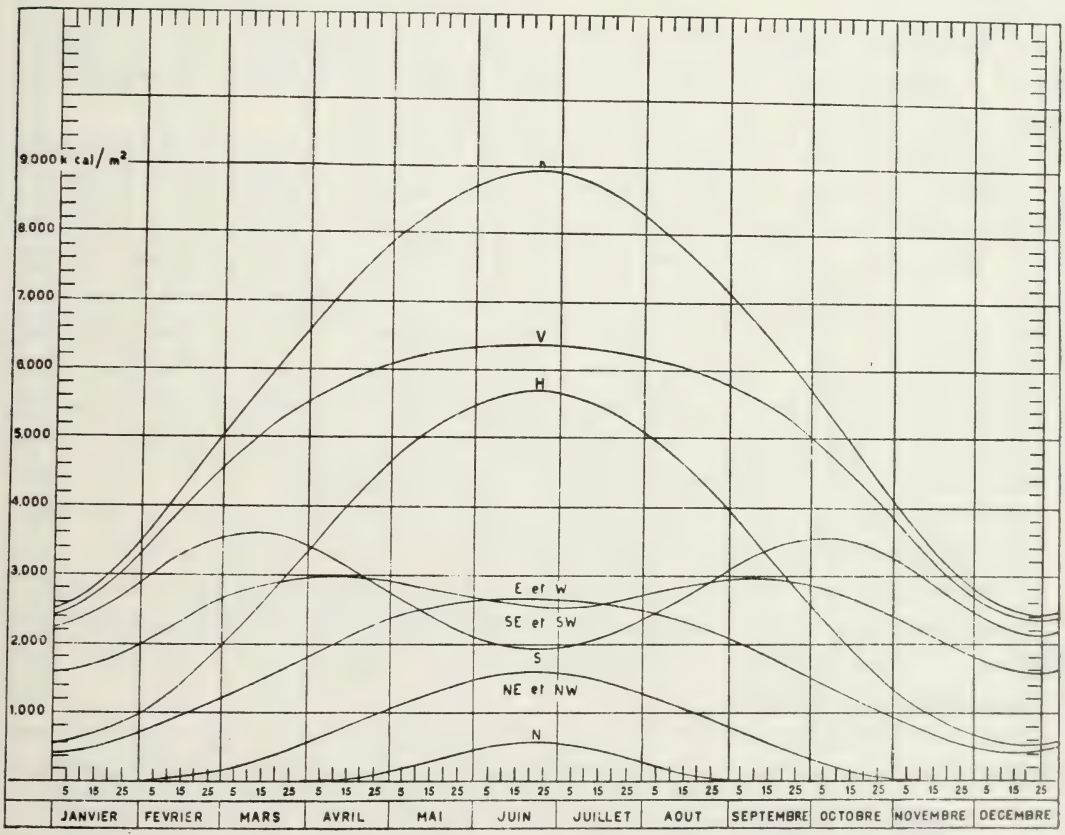

Fig. 1. Irradiation journalière directe par temps dégagé en Belgique. Figure extraite de „Données météorologiques concernant l'ensoleillement et l'éclairage naturel". Cahier n° 44/351 du C.S.T.B., Paris, 1960

De ce point de vue également, on peut constater par l'examen du tableau 2, la nette amélioration de température de surface obtenue par un double vitrage.

Considérer le problème sous ce seul aspect serait faire fi du rôle important des matériaux transparents perméables au flux solaire.

L'examen du tableau 3 donnant les apports thermiques totaux de différents types de vitrage conjointement à celui des courbes d'irradiation solaire sur les diverses surfaces verticales orientées données à la Fig. 1, montre à suffisance combien important se révèle le choix d'une bonne orientation dans les régions à hiver tempérés ou froids.

RÉGIME D'ÉTÉ

Les considérations relatives au régime d'hiver ne sont pas entièrement applicables au régime d'été. En effet, les échanges thermiques d'ambiance à ambiance n'ont dans ce cas qu'une influence réduite sur le bilan énergétique d'un local ensoleillé.

Les apports de chaleur solaire en été, joints à des températures de l'air extérieur élevées, exigent d'étudier des moyens appropriés pour contrôler le confort thermique à des conditions économiquement intéressantes.

Il est excessivement intéressant de pouvoir chiffrer, non seulement l'importance des apports thermiques solaires sur les diverses parois verticales d'une habitation, mais aussi de déterminer les instants auxquels se présentent leurs valeurs maximales. De l'examen de la valeur de la répartition de l'énergie incidente pour les différentes parois, il est possible de déterminer les orientations géographiques susceptibles d'être les plus critiques ou les plus favorables du point de vue de l'ensoleillement. La valeur de l'énergie reçue par diverses parois verticales peut naturellement être fortement influencée par les conditions atmosphériques et notamment la nébulosité. Mais c'est surtout l'énergie maximale qui peut atteindre les parois qu'il faut craindre, ainsi, on tablera toujours sur les valeurs maximales.

La figure 1 donne les valeurs de l'irradiation journalière directe par ciel dégagé pour diverses surfaces, et pour toute l'année.

Le tableau 4 donne quelques valeurs instantanées, horaires et journalières reçues sur diverses parois verticales. Ces valeurs ont été extraites de la brochure "Ensoleillement et orientation en Belgique, Tome II", publiée par l'Institut Royal Météorologique de Belgique.

Dans ce tableau, on notera les apports thermiques directs reçus pour diverses orientations et les heures solaires auxquelles correspondent les valeurs maximales.

A = apport en mcal/min/cm^2
B = apport en kcal/h/m^2
C = apport en kcal/jour/m^2.

L'examen des valeurs reprises dans ce tableau montre que:

Tableau 4

Rayonnement solaire direct reçu sur diverses surfaces verticales orientées, par beau temps.

Dates			N – E		E		S – E		S		S – W		W		N – W	
15/3	A	min	263	7 : 30	695	8 : 30	892	9 : 30	894	12 :	892	14 : 30	695	15 : 30	263	16 : 30
	B	h	143	7 : 30 à 8 : 30	400	8 : 30 à 9 : 30	530	9 : 30 à 10 : 30	534	11 : 30 à 12 : 30	530	13 : 30 à 14 : 30	400	14 : 30 à 15 : 30	143	15 : 30 à 16 : 30
	C	jour	313		1526		2853		3586		2853		1526		313	
15/6	A	min	664	6 : 30	865	7 : 30	727	9 : 00′	553	12 : 00	727	15 : 00	865	16 : 30	664	17 : 30
	B	h	384	6 : 30 à 7 : 30	507	7 : 00 à 8 : 00	434	8 : 30 à 9 : 30	330	11 : 30 à 12 : 30	434	14 : 30 à 15 : 30	507	16 : 00 à 17 : 00	384	16 : 30 à 17 : 30
	C	jour	1604		2669		2581		1954		2581		2669		1604	
15/9	A	min	357	7 : 30	754	8 : 00	883	9 : 30	841	12 : 00	883	14 : 30	754	16 : 00	357	16 : 30
	B	h	198	6 : 30 à 7 : 30	447	7 : 30 à 8 : 30	520	9 : 30 à 10 : 30	503	11 : 30 à 12 : 30	520	13 : 30 à 14 : 30	447	15 : 30 à 16 : 30	198	16 : 30 à 17 : 30
	C	jour	518		1807		2928		3403		2928		1807		518	
15/12	A	min	3	8 : 30	277	10 : 00	614	11 : 00	748	12 : 00	614	13 : 00	277	14 : 00	3	15 : 30
	B	h	1	7 : 30 à 8 : 30	162	9 : 30 à 10 : 30	365	10 : 30 à 11 : 30	446	11 : 30 à 12 : 30	365	12 : 30 à 13 : 30	162	13 : 30 à 14 : 30	1	15 : 30 à 16 : 30
	C	jour	1		409		1549		2190		1549		409		1	

- la paroi Sud reçoit une quantité d'énergie importante, mais hors de l'été;
- les parois Sud-Est et Sud-Ouest reçoivent des quantités d'énergie importantes pendant toute l'année, sauf l'hiver;
- les parois Est et Ouest reçoivent des apports non négligeables, mais surtout en été;
- la paroi Sud reçoit en hiver le maximum d'énergie solaire;
- la façade Sud reçoit en été le minimum d'énergie solaire et le maximum en hiver.

On pourrait en conclure aisément qu'une façade verticale orientée vers le Sud n'est pas soumise à un rayonnement direct important pendant l'été, mais qu'il n'en est pas de même pour les parois S-E et S-O. Il importera donc de réaliser le contrôle de l'ensoleillement aux parois S-E et S-O, et éventuellement de les étendre à l'E et O.

Au rayonnement solaire direct, il importe d'ajouter le rayonnement du ciel, ou rayonnement diffus. L'importance du rayonnement diffus est essentiellement liée aux conditions météorologiques. En effet, une atmosphère voilée par des fumées, des poussières ou de la vapeur d'eau et la présence de nuages diminue le rayonnement direct et augmente le rayonnement diffus. On peut estimer en gros, que les valeurs suivantes pour le rapport existant entre le rayonnement diffus (d) et le rayonnement direct (D) reçus sur une surface horizontale sont applicables pour la Belgique.

- ciel serein $\frac{d}{D} = 20\%$
- été (juin-juillet-août) (conditions moyennes) $\frac{d}{D} = 130\%$
- hiver (décembre-janvier-février) (conditions moyennes) $\frac{d}{D} = 500\%$

De ceci, on peut conclure que l'orientation présente, du point de vue de la radiation, une plus grande importance en été qu'en hiver, car au cours de l'hiver, la radiation est répartie plus uniformément sur les diverses façades qu'au cours de l'été.

Le *contrôle de l'ensoleillement* est un point non négligeable dans l'élaboration d'un bâtiment. En effet, le vitrage devrait idéalement pouvoir laisser pénétrer les calories gratuites du soleil en saison froide, et en atténuer l'ardeur en saison chaude, et cela sans trop réduire l'éclairement naturel des locaux.

Des techniques simples peuvent être choisies en vue de contrôler l'ensoleillement. Il a déjà été dit plus haut que l'orientation bien choisie des baies vitrées peut très efficacement assurer le confort thermique et le confort lumineux. L'orientation Sud est à ce point de vue la plus intéressante. Si certaines orientations sont favorables, d'autres le sont moins, mais tout dépend finalement de l'utilisation des locaux.

Des moyens artificiels de contrôle de l'ensoleillement peuvent être prévus, car de toute manière, il n'est pas toujours possible de choisir l'orientation la plus favorable.

Les études comparatives indiquant les valeurs d'énergie pénétrant dans le bâtiment à travers divers types de vitrages, munis éventuellement de persiennes

Tableau 5

Rayonnement solaire direct reçu sur diverss surfacees verticales orientées, par beau temps.																
Dates			N – E		E		S – E		S		S – W		W		N – W	
Max. de l'année	*A*	min	664	15/6 6 : 30	865	15/6 7 : 30	892	15/3 9 : 30	894	15/3 15/10 12 : 00	892	15/3 14 : 30	865	15/6 16 : 30	664	15/6 17 : 30
	B	h	384	20/6 6 : 30 à 7 : 30	511	15/5 7 : 30 à 8 : 30	530	15/3 9 : 30 à 10 : 30	534	15/3 15/10 11/30 à 12 : 30	530	15/3 13 : 30 à 14 : 30	511	15/5 15 : 30 à 16 : 30	384	20/6 16 : 30 à 17 : 30
	C	jour	1606	25/6	2669	15/6	2968 2942	5/4 5/9	3586 3535	15/3 5/10	2968 2942	5/4 5/9	2669	15/6	1606	25/6

A = 10^{-3} cal/min/cm^2
B = kcal/h/m^2
C = kcal/jour/m^2

vénitiennes, permettent de constater que le moyen le plus efficace pour arrêter le rayonnement solaire est la *protection extérieure*. Les dispositifs utilisés à cet effet sont les pare-soleil.

Lorsque les protections extérieures sont impossibles ou indésirables, on peut avoir recours aux protections intérieures : leur efficacité est cependant moins grande.

Un autre moyen de contrôle est constitué par les vitrages spéciaux, à propriétés absorbantes ou réfléchissantes, souvent dans le spectre infrarouge et parfois dans tout le spectre solaire.

CONCLUSION

Aux termes de ce bref exposé consacré à quelques considérations générales relatives aux aspects technologiques de la lumière naturelle et de son conditionnement à la fois lumineux et thermique, il n'est peut être pas inutile d'évoquer l'aspect social résultant de ses applications à l'éclairage des locaux habités.

Urbanistes, architectes, ingénieurs, éclairagistes, responsables à des degrés divers de la santé et de l'hygiène des habitants ont à faire face de plus en plus à des problèmes techniques assortis à des considérations esthétiques. Dans la recherche, sous cette double optique, d'un confort meilleur et mieux compris par l'homme dans l'habitation, il convient de ne pas compromettre par la réalisation technique d'un aspect défini du confort, d'autres aspects dont la satisfaction est parfois souhaitée avec une égale importance.

RÉFÉRENCES

COMITÉ NATIONAL BELGE DE L'ÉCLAIRAGE, (1963) L'éclairage naturel et ses applications, publication des Éditions SIC, Bruxelles (sous presse).

DOGNIAUX, R., (1960) Données météorologiques concernant l'ensoleillement et l'éclairage naturel. *Cahiers du Centre Scientifique et Technique du Bâtiment*, no. 44/351, Paris.

DOGNIAUX, R., (1961) Le facteur solaire et ses applications. *Technique de la Chaleur et autres formes de l'énergie*, Chap. III, no. 15–112.

DOGNIAUX, R., (1961) Données météorologiques concernant l'ensoleillement et l'éclairement énergétique en vue des applications pratiques. Conférence des Nations Unies sur les sources nouvelles d'énergie. Mémoire E/Conf. 34/S/59, Rome.

DOGNIAUX, R., (1962) Influence de l'orientation sur la composante directe du facteur de lumière du jour. *Cahiers du Centre Scientifique et Technique du Bâtiment*, no. 59/481. Paris.

DOGNIAUX, R., (1963) Détermination de la composante directe du facteur de lumière du jour dans le cas d'un ciel serein pour différentes expositions. *Lux*, no. 22.

NICOLET, M. et BOSSY, L., (1950) Ensoleillement et Orientation en Belgique. — Tome II. — Etude pratique des surfaces verticales orientées. *Institut Royal Météorologique de Belgique, Mémoires*. 36, 1950.

NICOLET, M. et DOGNIAUX, R. (1951) Ensoleillement et Orientation en Belgique, Tome IV. — Rayonnement reçu sur une surface horizontale. *Institut Royal Météorologique de Belgique, Mémoires* Vol. 39, 1951.

METHODS FOR MEASURING AND EXPRESSING THE PERMEABILITY OF CLOTHING MATERIALS FOR WIND, HEAT AND HUMIDITY*

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Abstract – Methods are described, which allow in a comparably short time measurement of the thermal insulation and resistance to water vapour diffusion of samples of clothing materials in single or multiple layers. The measurement is performed with air on both sides of the sample and allows the effect of convection through the material to have an influence upon the result. The accuracy of the method is shown to be sufficent for many practical purposes. The temperature gradient across the fabric can be altered. Thus, condensation phenomena during water vapour transport through the samples can be studied. The wind permeability is separately measured in the conventional way. Within the normal wind pressure range the amount of air passing the fabric seems to be approximately proportional to the linear air-speed, and the permeability could thus be expressed as a quotient between the air speed on both sides of the clothing. There seems to be little correlation between air and water vapour permeability except for the extremes of air permeability.

Zusammenfassung – Methoden werden beschrieben, die in einer vergleichsweise kurzen Zeit die Messung der Wärmeisolation und Verhinderung der Wasserdampfdiffusion von Bekleidungsproben in einzelnen oder mehreren Schichten gestattet. Die Messung erfolgt mit Luft an beiden Seiten der Probe; die Methode lässt zu, dass auch die Konvektion durch das Material mit auf das Ergebnis wirkt. Die Genauigkeit der Messung reicht für viele praktische Zwecke aus. Auch die Wasserkondensation beim Transport des Wasserdampfs durch das Material kann untersucht werden. Die Winddurchdringung wird mit konventionellen Methoden bestimmt. Innerhalb des Bereiches von normalem Winddruck scheint die Luftmenge, die durch das Material dringt, ungefähr proportional zu sein zu der linearen Luftgeschwindigkeit, und so könnte die Permeabilität ausgedrückt werden als Quotient der Luftgeschwindigkeit an beiden Seiten der Bekleidungsprobe. Ausser bei extrem hoher Luftpermeablität scheint keine Beziehung zwischen Luft- und Wasserdampfpermeabilität zu bestehen.

Résumé – On décrit ici des méthodes permettant de comparer – sur la base de courtes périodes – des pièces d'habillement en couches simples ou superposées. Cette comparaison se fait tant du point de vue de l'isolation thermique que de la diffusion de la vapeur d'eau au travers des dits échantillons. La mesure se fait en ayant de l'air de part et d'autre de l'échantillon. Elle permet en outre de tenir compte de la convection au travers du matériau. La précision de la mesure suffit pour répondre à de nombreuses questions pratiques. On peut aussi étudier la condensation de l'eau lors du passage de la vapeur au travers du maté-

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riau. La perméabilité au vent est déterminée de façon conventionelle. Dans les limites d'une pression normale du vent, il semble que la quantité d'air qui traverse le matériel est à peu près linéairement proportionnelle à la vitesse du vent. On a ainsi pu définir la perméabilité comme étant le quotient des vitesses de vent enregistrées de part et d'autre de la pièce d'habillement. Les cas de haute perméabilité mis à part, il semble qu'il n'existe pas de relation entre la perméabilité à l'air et à la vapeur d'eau.

WIND PERMEABILITY

It is common practice to study wind permeability of textile fabrics by applying a pressure difference across the fabric and reading the amount of air that passes. The results are expressed as litres air/20 $cm^2 \cdot 10$ mm water·min, or $ft^3/ft^2 \cdot 0.5$ in. water·min. For other purposes than mere comparison of fabrics, this is obviously a rather cumbersome mode of expression.

Using the same experimental technique, another measure can be obtained. The pressure differences used for measurements should be in the same order of magnitude as ordinary wind pressures (25 mm water corresponds to 20 m/sec). The relation between wind pressure *(p)* across a surface and wind speed *(v)* is expressed by the equation:

$$p = \frac{k\varrho}{2} \cdot v^2$$

where k is an aerodynamic coefficient dependent on shape, and ϱ is the density.

By measuring at different pressures (here 4, 8 and 16 mm water corresponding to 8, 11 and 16 m/sec) it can be shown that the passage of air through the textile obeys a similar equation,

$$p = \text{const} \cdot v^n,$$

where v_1 is the velocity through the fabric, n for practical purposes could be regarded as $= 2$ (see Fig. 1). There is a systematic aberration towards $n < 2$ especially for elastic fabrics. This may be partly explained by the extension of the measuring surface at the application of pressure.

The constant of the above equation can be used as a measure of resistance. It varies with the density of the air, which can here without seriously affecting the results be considered constant. Because the wind pressure, as well as the pressure across the textile fabrics, obeys the same general type of equation in regard to air speed, there should be a linear relationship between the wind speed and the air speed through the fabric when exposed to wind. Thus the wind permeability can be expressed as a quotient, $q = v_1/v_0$ where v_1 is the air velocity through the fabric and v_0 = the free wind speed.

Because of the square law relationship, Bernoulli's law can be applied for calculating q from corresponding values of pressure and air flow. Thereby the

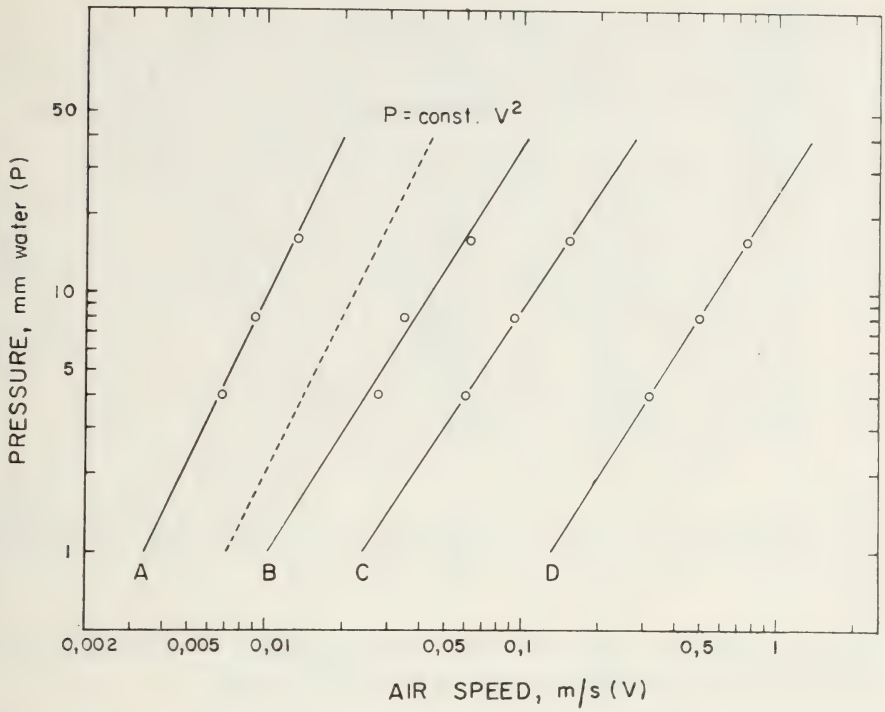

FIG. 1. Corresponding values for pressure and air flow through, A, an unelastic, B, C and D, elastic fabrics. The dotted line shows the inclination according to the equation p = const. v^2

equation

$$v_0^2 - v_1^2 = \frac{2p}{\varrho}$$

is obtained where ϱ = the density of the air, and p = the wind pressure or in this case the measuring pressure. As $v_1 = v_0 \cdot q$, the equation can be expressed thus:

$$p = \frac{\varrho}{2}\left(\frac{v_1^2}{q^2} - v_1^2\right) \text{ or}$$

$$\frac{1}{q^2} = \frac{2p}{\varrho v_1^2} + 1$$

If $q < 0.1$, which is usually the case, a simplified expression could be used:

$$q = v_1\sqrt{\frac{\varrho}{2p}}$$

This equation is shown in the form of a nomogram in Fig. 2, which gives the wind permeability quotient from corresponding data on air speed through the fabric and applied pressure.

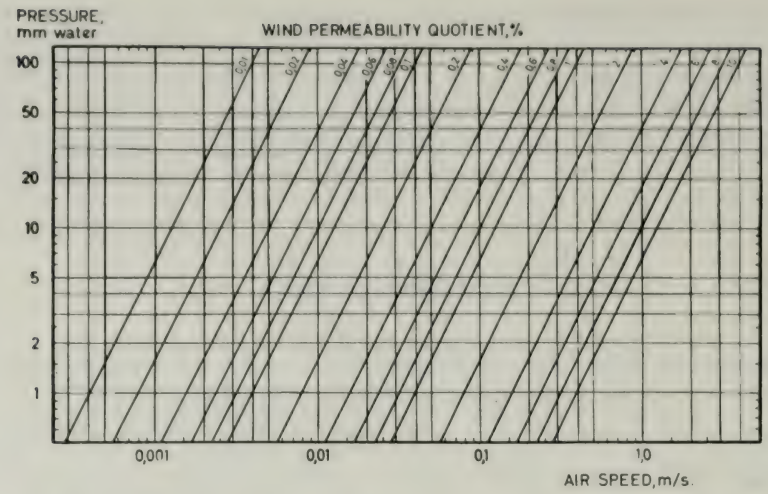

FIG. 2. Nomogram for calculating the wind permeability quotient, q, from corresponding data on pressure across and air speed through the fabrics

By simple substitution a formula for the combination of several layers can be obtained because the air speed is common to all the layers:

$$\frac{1}{q_r^2} = \frac{1}{q_1^2} + \frac{1}{q_2^2} + \ldots \frac{1}{q_n^2} - (n-1)$$

where q_r = the resulting q-value of the combination and $q_1 - q_n =$ the q-values of the components.

CONTROL EXPERIMENTS

Table 1 lists the results of measurements on some fabrics. Apart from the most elastic ones which are never used alone as wind protection, there seems to be a fairly good constancy of the wind permeability quotient measured at different pressures. When testing the combination formula for multiple layers, it transpired that when no considerable air space exists between the layers, the theoretically expected values were not valid. Instead, the following empirical formula was obtained:

$$\frac{1}{q_r} = \frac{1}{q_1} + \frac{1}{q_2} \ldots + \frac{1}{q_n}$$

The theoretically expected formula, however, was satisfied when the layers were separated by a 6 mm thick plastic ring, as can be seen from Table 1. The explanation for the empirical formula probably lies in an extra resistance in the thin space between the layers. From a theoretical point of view, the empirical formula is absurd, as two layers of zero resistance would give a permeability of 0.5

Table 1. Measurements of Wind Permeability

Fabric	Pressure mm water	Air-speed m/sec	Measured q %	Calculated q Theoret. form %	Calculated q Emp. form %
Cotton tricot	4	0.082	1.0		
Cotton tricot	8	0.095	0.9		
Cotton tricot	16	0.126	0.8		
Woollen cloth	4	0.060	0.8		
Woollen cloth	8	0.093	0.8		
Woollen cloth	16	0.150	0.95		
Canvas	4	0.0068	0.08		
Canvas	8	0.0090	0.08		
Canvas	16	0.0131	0.08		
Perforated Iron sheet*	4	0.082	1.0		
Iron sheet	8	0.095	0.9		
Iron sheet	16	0.126	0.8		
Iron sheet 1	8		4.4		
Iron sheet 2	8		2.2		
Iron sheet 3	8		10.4		
Iron sheet 4	8		6.0		
Iron sheet 5	8		1.8		
Iron sheet 1+1	8		2.0	3.3	2.2
Iron sheet 1+1+1	8		1.5	2.7	1.5
Iron sheet 1+2	8		1.4	2.0	1.5
Iron sheet 4+6 mm air+4	8		3.8	4.2	3.0
Iron sheet 4+4	8		2.8	4.2	3.0
Iron sheet 5+6 mm air+5	8		1.3	1.3	0.9
Iron sheet 5+5	8		0.9	1.3	0.9
Iroh sheet 4+6 mm air+5	8		1.9	1.8	1.4
Iron sheet 4+5	8		1.5	1.8	1.4

* Perforation area = 1 per cent of the total.

when combined. Within the permeability range that is of practical use, however, it has experimental support.

The possible use for this type of wind permeability expression can be illustrated by the following example. A clothed man standing upright is exposed to a wind of 10 m/sec. Assuming that his aerodynamic surface areas are equal to those calculated for radiation purposes by Underwood and Ward (1961) (a cylinder 0.23 m in diameter and 1.65 m in height) an exposure surface of 0.4 m^2 faces the wind. The aerodynamic reduction (because of the cylindrical form) by a factor of 0.6 will give the following amount of air passing through a clothing with a q-value of 1 per cent: $0.4 \cdot 0.6 \cdot 10 \cdot 0.01$ m^3/sec = 86 m^3/h. This, of course, is a purely theoretical example. Practical experience seems to suggest that a wind permeability quotient of more than 1 per cent means very bad wind-proofing, 0.5–1 per cent rather bad, 0.1–0.5 per cent medium, and below 0.1 per cent good.

APPARATUS FOR MEASURING THERMAL INSULATION AND WATER VAPOUR PERMEABILITY

The measurements are made by placing the fabrics between one donor chamber and one acceptor chamber (see Fig. 3). The donor chamber is closed by the fabric and heated electrically. The acceptor chamber is blown through with thermostat controlled air. By measuring at the same time the temperatures in the two chambers, the increase in temperature of the air flowing through the acceptor chamber, and the amount of air, the thermal insulation of the fabric can be calculated.

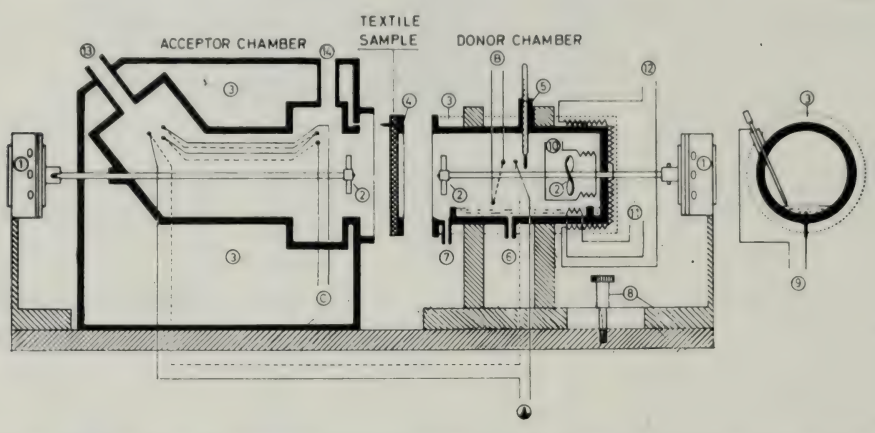

FIG. 3. Combined apparatus for measuring the thermal insulation and the water vapour permeability of textile fabrics. 1, 2: stirring motors and propellers. 3: Insulating cover. 4: Plastic ring keeping the sample. 5: Thermometer. 6: Water inlet. 7: Outlet for condensate. 8: Support allowing the donor chamber to be pushed against the other chamber, thus fixing the sample. 9: Electrodes for maintaining a constant water level. 10: Air heater. 11: Water heater. 12: Wall heater (to stop condensation). 13: Air inlet. 14: Air outlet. *A*, *B*, *C*, differential thermocouples for measuring respectively temperature gradient, wet bulb depression, and temperature increase of the air in the acceptor chamber

For measuring the water vapour permeability, a water level is kept in the bottom of the donor chamber. The water is heated electrically. Dry and wet bulb temperature in the chamber is measured and thus the water vapour pressure is known. By measuring the amount of water needed to maintain a constant level (by means of an electronic device and a magnetic valve) the amount of water vapour passing through the fabric per time unit is measured. The water vapour pressure gradient is known from the psychrometric data in the donor chamber and from those of the air passed through the acceptor chamber.

MEASUREMENTS OF THERMAL INSULATION

As the measurements of thermal insulation are made with air on both sides of the fabric, there will be a certain insulation on account of the surface bound air layer. The magnitude of this insulation depends upon the roughness of the surface. It was determined for a smooth surface by measuring the insulating value of one and then two 4 mm thick plates of acrylic plastic (Perspex). The difference in insulating value must be due only to the increase in thickness of the plastic layer. By subtraction of the difference between the two measurements from the value measured

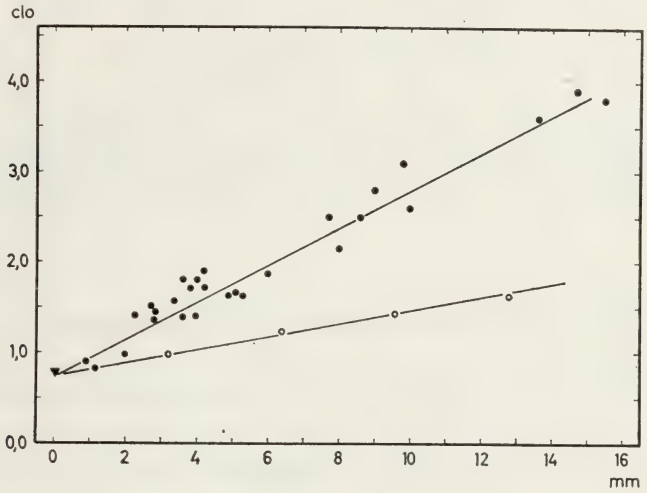

FIG. 4. The relation between the thickness of the fabric and its insulation value. Open circles = acrylic plastic. Triangle = blackened aluminium sheet. There is full agreement with the different indications of the insulation of the surface bound air layer.

for a single layer, the insulation value of the surface bound air was found to be 0.73 clo units. Approximately the same value was measured when a 0.02 mm thick blackened aluminium sheet was placed between the two chambers. This value can be considered as an apparatus constant if the air speed is kept constant. The increase in surface bound air insulation for fabrics with a rough surface is conveniently counted into the insulation values of the fabric. Control of the calibration of the apparatus was made by measuring cork sheets and acrylic sheets tested by Statens Provningsanstalt. The biggest discrepancy observed was 0.05 clo units.

Measurements on different fabrics were made showing a very close correlation ($r = 0.97$) between the thickness of the fabric and its insulation value, except for extremely porous or solid fabrics. See Fig. 4. The thickness of the fabrics was measured at a compression corresponding to 70 kg/m^2. By measurements of several layers in combination, the insulating effect of fabrics, that are so wind permeable that measured alone they have very low insulating powers, was demonstrated, as well as the insulating power of the air captured between the different layers (Fig. 5)

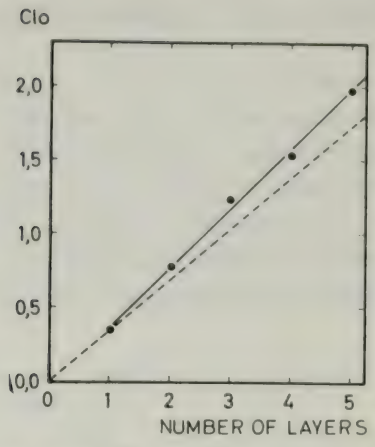

FIG. 5. Thermal insulation of an increasing number of layers of the same fabric. The insulation of the air captured between the layers is indicated by the deviation from the dotted line, which corresponds to simple addition.

MEASUREMENTS OF WATER VAPOUR PERMEABILITY

There is no generally accepted simple relation between the physical properties of fabrics, the water vapour pressure, and the transfer of humidity through textile fabrics. Thus, tests should be made in temperature conditions corresponding to those for the clothing in use. In the described apparatus, this can be obtained by setting the acceptor and donor chambers at appropriate temperatures. The physical process of humidity transport is a complex one, consisting of diffusion, hygroscopic absorption, surface absorption by hydrophilic fibres, convection, capillary condensation, etc. However, within certain limits the transfer of humidity is approx. proportional to the water vapour pressure gradient across the fabric. Therefore, the permeability values are given as $gH_2O/m^2 \cdot h \cdot mm\ Hg$ or as resistance values: $mm\ Hg \cdot m^2 \cdot h/100\ gH_2O$. The reproducibility of the measurements was tested by 16 tests on the same fabric. A mean value of 18.3 $g/m^2 \cdot mm\ Hg \cdot h$ was obtained, and the limits for 99 per cent confidence were $\pm 2.44\ g/m^2 \cdot mm\ Hg \cdot h$. Some of this inaccuracy may be due to condensation on the sample and to leakage, which can be diminished by a better designed apparatus.

Results of some measurements are shown in Table 2, from which it can be seen that the permeability for water vapour is considerable for most fabrics. There is no obvious correlation between the water vapour permeability and the thickness or wind permeability of the fabrics. This corresponds well with the observations of Fourt and Harris (1949).

Some measurements on multiple layer combinations were made. There seems to be no resistance owing to air between the layers, in opposition to thermal insulation, not even when the layers are separated by a plastic ring that gives an air space equal

*Table 2. Some Measurements of Water Vapour Permeability**

Fabric	Temperature °C		Water vapour pressure mm · mercury		Permeability g/mm Hg · m² · h	Resistence mm Hg 100 g · m² · h	Thickness mm	Wind permeability quotient %
	Donor	Acceptor	Donor	Acceptor				
1. Woollen cloth	47	30	67	8	18.3	5.5	2.0	0.81
2. Cotton tricot	47	30	48	10	27.0	3.7	2.2	4.4
3. Knitted wool	41	33	27	8	49.0	2.0	5.3	10.0
4. Canvas	40	34	32	6	30.0	3.3	0.8	0.062
5. Foam plastic	40	34	42	5	8.9	11.2	5.1	0.15
1.	41	20	43	6	18.3	5.5	—	—
1 + 1	48	38	61	10	9.1	11.0	—	—
1 + 4mm air + 1	43	34	48	6	9.6	10.4		

*Condensation was to be expected.

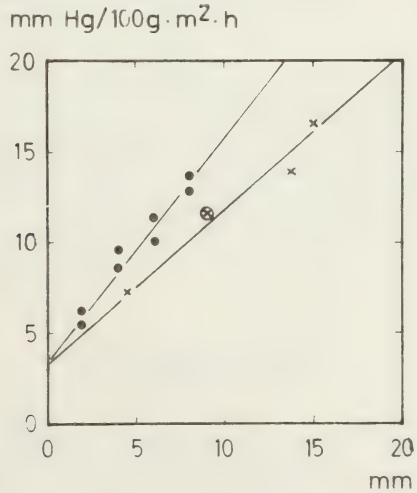

Fig. 6. Resistance to water vapour transport of one and more layers of the same fabric (points), and of felt samples of identical fabric but different thicknesses. The encircled value was obtained for two layers of felt.

to the thickness of two layers. On the other hand, the addition of one more layer causes a smaller increase in resistance than the measured value for the first layer (Fig. 6.) The same thing was found when measuring felts of identical fabric but of

different thicknesses. This may be due to part of the resistance being bound to some sorption process when the moisture enters or leaves the fabric. There is no linear temperature gradient through the layers during moisture transport.

Some tests were made with a temperature in the acceptor chamber so low that condensation within the fabrics was to be expected according to the law of the cold wall. For fabrics with normal water absorption capacity, however, condensation within the textile was never detected – not even by weighing the samples. In a nonabsorbing foam plastic, however, massive condensation occured (10 g for a sample surface of 66 cm^2).

REFERENCES

Fourt, L. and Harris, M. (1949) Physical properties of clothing fabrics, in: *Physiology of Heat Regulation and the Science of Clothing*. L. H. Newburgh (ed.), Saunders, London, Ch. 10, p. 291.

SIS (Standardisation Committee of Swedish Industry (1961) Ed. number 650016 SIS., Stockholm.

Statens Provningsanstalt (Swedish National Institute for Material Tests) (1959), Method ED 17. Stockholm.

Underwood, C. R. and Ward, E. J. (1961) The radiation area of the erect human body with respect to the sun. *3rd Int. Congress on Photobiology*. B. Chr. Christensen and B. Buchmann (ed.), Elsevier Publ. Comp., Amsterdam.

VEGETATION AS AEROSOL FILTER

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Abstract — Measurements of ragweed-pollen concentrations inside and outside a forested area during two seasons revealed that 100 m inside a dense coniferous forest more than 80 per cent of the pollen is removed from the air; deciduous trees seem somewhat less effective in this respect. Laboratory determinations of the filtering effect of coniferous and deciduous plant material on Aitken nuclei showed the coniferous material to remove on the average 34 per cent (477 measurements), deciduous material 19 per cent (348 measurements) of the submicroscopic particulate matter from the air.

Zusammenfassung — Die während zweier Jahre ausgeführten Messungen des Gehaltes der Luft an *Ambrosia elatior* Pollen inner- und außerhalb eines Waldgebietes ergaben, daß 100 m innerhalb eines dichten Nadelwaldes mehr als 80% der Pollen der Luft entzogen wurden; Laubbäume scheinen in dieser Hinsicht etwas weniger wirkungsvoll zu sein. Gemäß der Bestimmungen der Filterwirkung von Nadel- und Laubmaterial auf Aitkenkerne im Laboratorium werden durchschnittlich 34% (477 Messungen) dieser feinsten Staubteilchen durch Nadeln, 19% (348 Messungen) durch Laub aus der Luft beseitigt.

Résumé — Les mesures de la teneur de l'air en pollen d'*Ambrosia elatior* mesures faites au cours de deux saisons à l'intérieur et au dehors d'un terrain boisé, ont montré que plus de 80% du pollen a été soustrait de l'air à une distance de 100 mètres à l'intérieur d'une forêt épaisse de conifères. Des arbres à feuilles caduques semblent être un peu moins efficaces. Des essais de laboratoire ont montré que les conifères enlèvent de l'air en moyenne 34% (477 mesures), les arbres à feuilles caduques 19% (348 mesures) de la poussière submicroscopique et des noyaux d'Aitken.

INTRODUCTION

The increasing concern about air pollution in industrial regions and metropolitan areas has focused some attention also on vegetation as a possible means of partial aerosol removal. On the other hand, migration of urban population into greener suburban areas has exposed the allergic portion of this population to a increased hazard of airborne allergens, especially pollen from certain weeds. While there has been much speculation on the filtering effect of vegetation on organic and inorganic aerosols, actual measurements of this effect are relatively scarce. Some direct observations of dust- and Aitken nuclei concentration inside and outside forests (Geiger, 1950; Landsberg, 1938; Flach, 1939; Flohn, 1939) have demonstrated the filtering effect of vegetation. However, measurements of aerosol distribution

through city parks and cross-country do not permit conclusive interpretation of the results in terms of this effect, because the increasing distance from aerosol sources would also diminish the concentrations found in parks and forests. Two phases of pertinent investigations made at The Pennsylvania State University are concerned with (1) the filtering effect of forests on ragweed pollen *(ambrosia elatior)* and (2) laboratory determinations of the filtering effect of plant material on Aitken nuclei.

FORESTS AS POLLEN FILTERS

During the ragweed pollen seasons of 1953 and 1959 measurements of the pollen concentration were made in the Nittany Valley of central Pennsylvania, approximately 3 km E.S.E. of Boalsburg, Pa., at the approach to the Tussey Mountain Ridge, which rises 370 m above the valley (Elder, 1954; Kissinger, 1961). An aerial photograph of the region is shown in Fig. 1, in which the locations of the seven field

FIG. 1. Aerial photograph of ragweed-pollen sampling stations

stations used in this report are marked. The fields in the valley represent a copious source of ragweed-pollen; station 1 is located there. Station 2 is the boundary between the fields and a dense forest consisting mainly of hemlock with dense undergrowth of laurel and rhododendron; stations 3, 4, and 5 are located inside this forest along an access road. Station 6 is on the slope of the mountain where deciduous hardwood trees with undergrowth of blueberry bushes predominate. Station 7 is on top of a fire-tower above a mixed forest of slightly lesser density. During most of the observations winds from the N.W. quadrant prevailed, advecting polluted air from the valley to the stations.

The measurements during 1953 were made with a volumetric impinger (Elder, 1954) which poses problems for non-isokinetic aspiration speeds (Sheldon and Hewson, 1959); for this reason the measurements were repeated in 1959 with a rotorod sampler (Perkins, 1957) as modified at The University of Michigan (Sheldon and Hewson, 1959). The results however did not show any differences in pollen concentrations that could not be explained by the differences in the climatic conditions leading to, and prevailing during, the two pollen seasons (Kissinger, 1961).

In Fig. 2 the profile of pollen concentrations (on logarithmic scale) are shown over the topography (drawn to scale). The well-known diurnal and seasonal variations of pollen release by ragweed plants is obvious. The afternoon samples show lower concentrations than do the forenoon samples; moreover, the 1953 afternoon

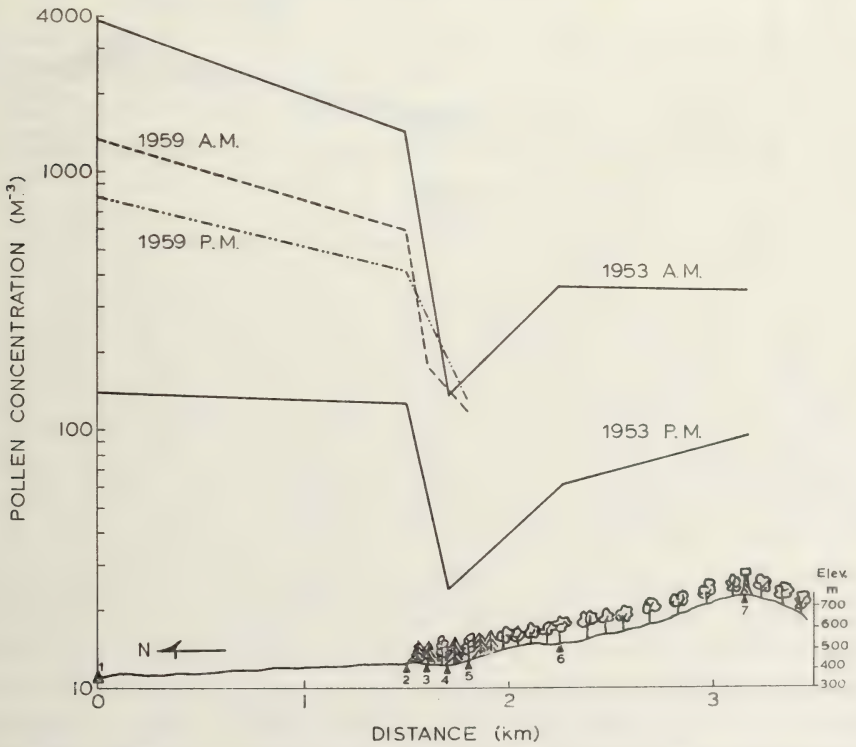

FIG. 2. Pollen concentrations (m^{-3}) at various stations and topographic profile

data were obtained during the early season (17–21 August), whereas the forenoon data were collected during the height of the season (24–28 August). In 1959 measurements were made on the same days from 14 to 29 August. Station 2 reveals a slight decrease in pollen concentrations at the field–forest boundary, although ragweed grows abundantly in the immediate vicinity. Nevertheless, the forest extension to the west and northwest of this station effects some filtering of pollen advected from greater distances by westerly winds. Stations 3,4, and 5, located within the

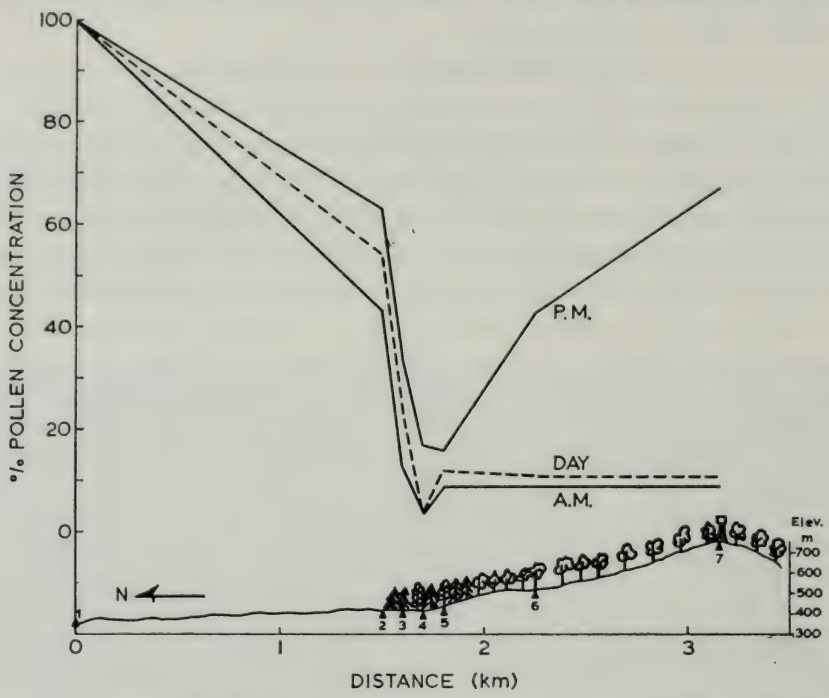

FIG. 3. Pollen concentrations at various stations relative to those at station 1

dense forest show the pronounced filtering effect of trees. At stations 6 and 7, which were not occupied in 1959, the concentrations are again somewhat raised; this demonstrates that larger distance from ragweed plants does not assure low concentrations. That pollen can travel large distances has been shown by Durham (1941) and Sack (1949). Here, obviously, the pollen does not reach stations 6 and 7 by transport from the distant sources through the forest, but by convective and turbulent transport, especially at station 7 located above the tree tops. Moreover, any filtering effect by the trees in horizontal transport was less effective at these stations because of the lesser density of the surrounding hardwood forest.

Turbulent transport causes some penetration of pollen from above through the tree crowns; this is shown by the fact that the reduction of pollen concentrations in the afternoon, when thermal instability is at its peak, is on the average somewhat less than in the forenoon. This is more clearly seen in Fig. 3 in which the data from both seasons are combined and expressed in terms of per cent of the respective

concentrations at station 1. The filtering effect of the forest is less in the afternoon than in the forenoon at all stations, especially at the elevated stations 6 and 7; nevertheless, the reduction of pollen concentrations in the dense evergreen forest is considerable, even at station 3 located only some 50 m inside the boundary between fields and forest. Special measurements of pollen concentrations made on five days between 28 August and 4 September 1953 in an open field with copious ragweed growth and 20 m inside a dense larch and pine stand on level terrain yielded an average pollen reduction of 30 per cent, with the wind blowing from the field toward the forest normal to the boundary between them.

While these results definitely point toward a positive effect of trees in removing pollen from the air, this effect is only partially due to filtering in the ordinary sense, i.e. due to inertial impaction of the pollen on vegetation. The well-known reduction of wind speed in forests is undoubtedly also responsible for the removal of pollen by facilitating their sedimentation, the rate of which is of the order of 40 m/hr. Thus it seems that minimum pollen concentrations should be found in dense forests composed of tall trees, preferably evergreens, and that in such an environment hayfever sufferers should find maximum relief.

EXPERIMENTAL STUDY OF FILTERING EFFECT OF VEGETATION ON AITKEN NUCLEI

Aitken nuclei, on which condensation of atmospheric water vapor takes place under suitable conditions, are smaller than ragweed pollen by two to three orders of magnitude. In order to investigate the possible filtering effect of plant material on these submicroscopic particles under controlled conditions, the apparatus schematically shown in Fig. 4 was used. It consists of a fog chamber (66 cm long, 4 cm diameter), *F*, through which a light beam from lamp, *L*, (fed by voltage-regulated power supply, *P*), passes onto a photocell, *C*, whose output is displayed on recorder, *R*. The fog chamber is lined with wet blotting paper so that air residing in it soon becomes saturated. When this air is expanded into the suitably evacuated buffer chamber, *B*, (with vacuum gage, *G*), a fog forms which reduces the illumination of the photocell. The air samples are alternately drawn through two identical rectangular tubes ($100 \times 22 \times 17$ cm), one of which is empty, *E*, and the other one, *V*, equipped with short branches from various trees. To create high concentrations of nuclei, a chamber can be placed over the ends of these tubes with the nuclei source, *S*, at variable distance from the tube orifices.

The air samples consisted of outdoor air, normal laboratory air, and laboratory air polluted to varying degrees with cigarette smoke, combustion products from an alcohol flame and from small pieces of smoldering cotton. It may be mentioned at this point that no significant differences in the filtering effects of vegetation were found for the nuclei from different sources, so that all results could be combined.

The measured optical density of the fogs in the chamber is a function of the chamber length, the time lapse between sampling and expansion of the air (Hosler, *et*

al., 1952), the expansion ratio (1.15 was used throughout), and the number and size of the fog droplets produced by the nuclei in the air sample (Neuberger and Gutnick, 1950; Neuberger, 1952). All experimentally controllable parameters were held constant so that the fog densities varied only with the Aitken nuclei aspirated with the air samples. The optical density of the fog is $D = -\log(I/I_o)$, where I is the light flux reaching the photocell through the fog and I_o is that through the fog-free air. The relative density difference between fogs produced in unfiltered and filtered air

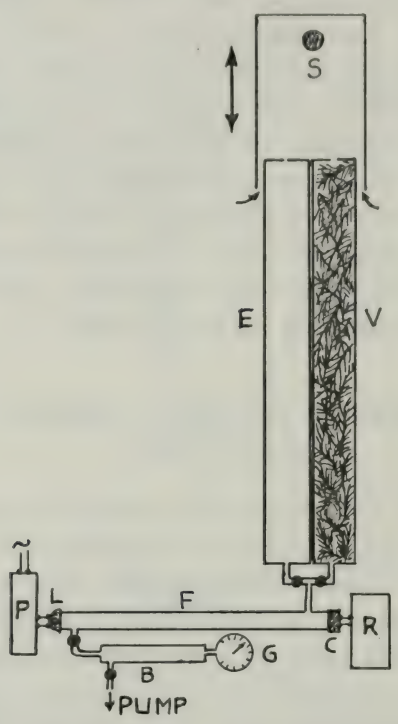

FIG. 4. Schematic diagram of apparatus for determinations of filtering effect of plants on Aitken nuclei

samples was taken as index of the filtering effect of various plants. Thus the "filter effect" is $F = 100(D_u - D_f)/D_u$ per cent, where D_u and D_f are the fog densities in unfiltered and filtered air, respectively.

Previous work by Geisenderfer (1951) with similar apparatus, using White Pine *(Pinus strobus)* and Black Cherry *(Prunus serotina)* as filtering material, showed the pine filter to be twice as effective as the cherry-leaf filter. Although an attempt was made to pack the two types of plant material as equally as possible into the filter chamber, the filtering areas of leaves and needles can not be made the same in a mechanical nor in an aerodynamical sense. In order to obtain additional information on the filtering behavior of plants, we made further laboratory tests with White Pine, Red Spruce (*Picea rubra)*, and Box Elder (*Acer Negundo)*. Since these test were made early in spring, Black Cherry leaves were not yet available.

Table 1. Filter Effect of Vegetation

	White Pine	Red Spruce	Box Elder	White Pine	Black Cherry
				(after Geisenderfer)	
Mean	31%	37%	20%	34%	17%
Median	28%	37%	18%	38	13%
No. of obs.	191	173	209	113	139

In Table 1 the results are summarized; on the average, the filter effect of coniferous trees is indeed greater than that of deciduous trees. The difference in filter effect between the two categories of plants becomes more obvious in the relative frequency distributions of the measured values shown in Fig. 5. Leafy plants exhibit a maximum frequency of filter effects of less than 20 per cent, whereas the filter effect of conifers has its maximum between 20 and 50 per cent. The difference between the two pine-filter distributions is presumably due to differences in pack-

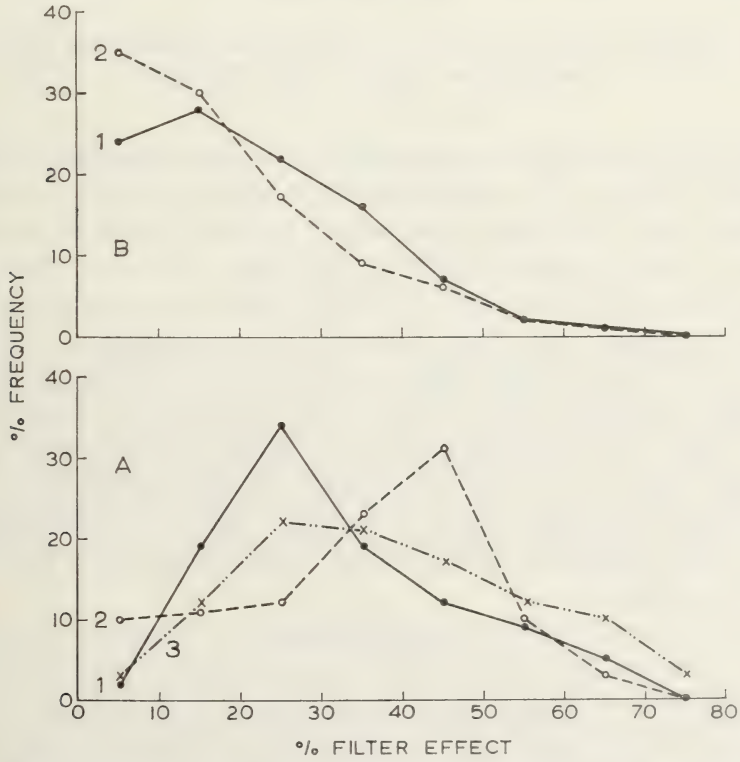

Fig. 5. Relative frequencies of filter effect of coniferous (A) and deciduous (B) plants. (A-1 white pine; A-2 white pine after Geisenderfer; A-3 red spruce; B-1 box elder; B-2 Black Cherry after Geisenderfer)

ing the plant material into the filter chambers. If we combine the observations with coniferous material and those with deciduous material, we obtain the two frequency distributions in Fig. 6; the greater filter effect of coniferous plants is

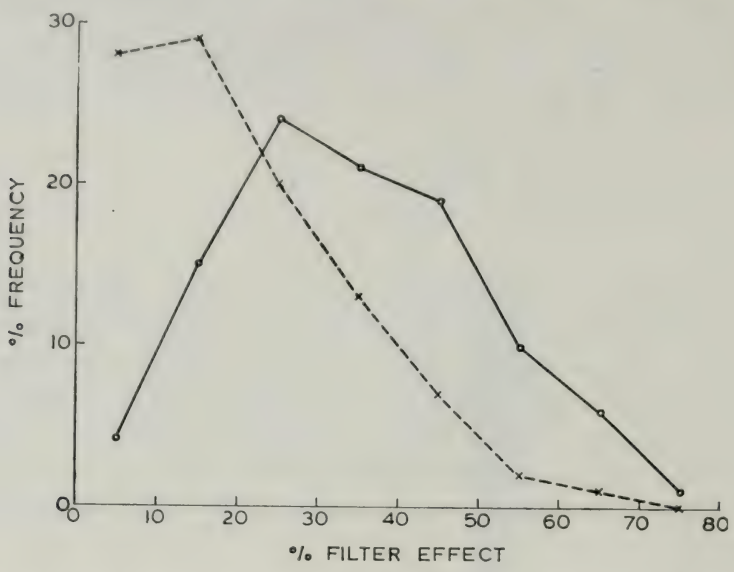

FIG. 6. Average relative frequencies of filter effects of coniferous (solid line) and deciduous (dashed line) plants

evident in the broad maximum between 20 and 50 per cent filter effect, in which range almost two-thirds of all observations fall, whereas more than three-quarters of the observations with deciduous material fall between 0 and 30 per cent. In the range between 70 and 80 per cent filter effect, there were five observations with spruce twigs as filter, but none with any of the other materials tested.

Considering the minute size of the Aitken nuclei, sedimentation can be neglected as a contributor to the total filtering process; however, because of the small size, diffusion to nearby surfaces becomes important, in addition to impaction. Pine and spruce needles are aerodynamically more favorable for impaction of nuclei than are leaves, while the latter are more favorable for nuclei losses due to diffusion. According to Fig. 6 impaction seems to outweigh diffusion. Also from a seasonal aspect is coniferous vegetation more effective in removing aerosol from the air than is deciduous vegetation.

In order to determine whether the filter effect is a function of the nuclei concentration, the average filter effects were computed for various classes of fog densities in unfiltered air as a measure of nuclei population. Figure 7 represents the averages for our observations together with the range (indicated by vertical lines) within which 68 per cent of the observations fell in the respective classes (approximately $\pm$ one SD). For fog densities of more than 0.60 there is an increase in filter effect for coniferous, but not for deciduous plant material; no explanation of this

phenomenon can be offered at this time. As compared to pine, spruce shows a slightly greater filter effect, which may be due to its larger number of needles and more uniform needle arrangement.

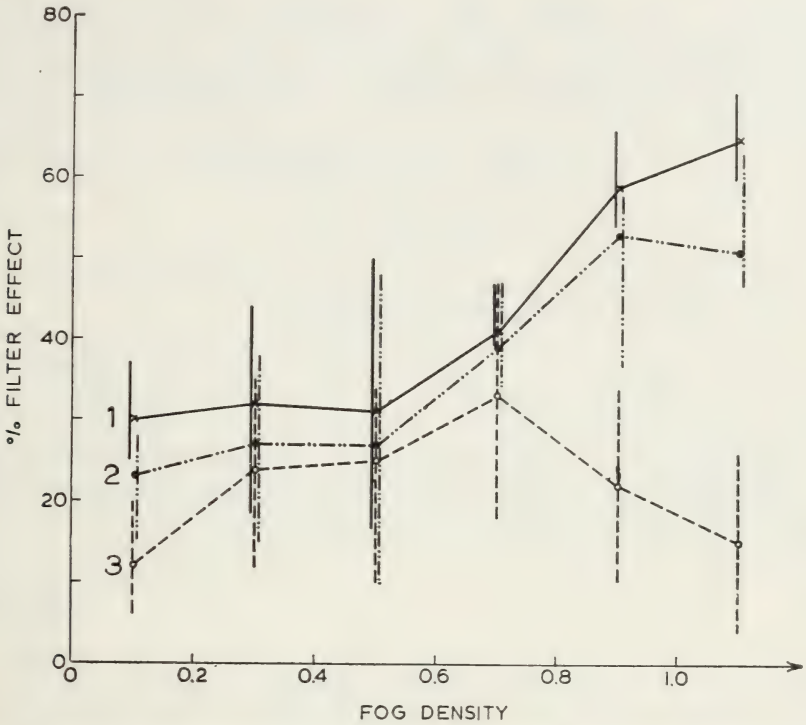

FIG. 7. Filter effects as function of fog densities (1–Spruce; 2 – White Pine; 3 – Box Elder)

CONCLUSION

It may be stated that dense stands of coniferous trees generally represent excellent natural filters of aerosols of both micron and submicron sizes. While deciduous trees also act as aerosol filters, they do not appear to be as effective as coniferous trees. The greater reduction of pollen than of nuclei concentrations seems to indicate that sedimentation, facilitated by the reduction of wind speed in forests, plays an important role in the total process of filtering micron-size particles.

REFERENCES

DURHAM, O. C. (1941) Methods in aerobiology. *J. Aviat. Med.*, **12**, 153–162.

ELDER, F. C. (1954) On the Distribution of Ragweed Pollen in the Atmosphere. M. S. Thesis, June 1954, The Pennsylvania State University, University Park, Pa.

FLACH, E. (1939) Ergebnisse von Kern- und Staubuntersuchungen im Westsächsischen Mittelgebirge. *Abh. Bäder- und Klimaheilkunde*, 3, Springer Verlag, Berlin, p. 101–112.

FLOHN, H. (1939) Bioklimatik der Kondensationskerne. *Abh. Bäder- und Klimaheilkunde*, **3**, Springer Verlag Berlin, p. 86–100.

GEIGER, R. (1950) Das Klima der bodennahen Luftschicht. *Die Wissenschaft*, Bd. 78, Vieweg & Sohn, Braunschweig.

GEISENDERFER, R. D. (1951) Filtering Effect of Vegetation on Aerosol. M. S. Thesis, January 1951, The Pennsylvania State College, State College, Pa.

HOSLER, C. L., BURKHART, M. D. and NEUBERGER, H. (1952) On the Effect of Time Lapse between Sampling and Expansion in the Aitken Nuclei Counter. *Bull. Am. Meteor. Soc.* **33**, 251–254.

KISSINGER, R. B. (1961) A Study of Ragweed Pollen Distribution. M. S. Thesis, January 1961, The Pennsylvania State University, University Park, Pa.

LANDSBERG, H. (1938) Amospheric Condensation Nuclei. *Ergebn. d. Kosm. Physik*, Bd. 3, Akad. Verlagsges., Leipzig, p. 155–252.

NEUBERGER, H. (1952) Air Pollution and Fog Properties. *Air Pollution, Proc. U. S. Tech. Conf. Air Poll.* McGraw-Hill, New York, Chap. 94, p. 807–811.

NEUBERGER, H. and GUTNICK, M. (1950) Experimental Study of the Effect of Air Pollution on the Persistence of Fog. Proc. *First Nat. Air Poll. Symposium*, Pasadena, Calif. 90–96.

PERKINS, W. A. (1957) The Rotorod Sampler. Second Semiannual Rep., CML 186, Aerosol Lab., Stanford University, Palo Alto, Calif.

SACK, S. SEN. (1949) How far can wind-borne pollen be disseminated? *J. Allergy*, **20**, 453–460.

SHELDON, J. and HEWSON, E. W. (1959) Atmospheric Pollution by Aeroallergens. Progress Rep. No. 2421-3-P, The University of Michigan Research Institute.

DER EINFLUSS VERSCHIEDENER KOMBINATIONEN VON UMGEBUNGSTEMPERATUR UND LUFTFEUCHTIGKEIT AUF EINIGE PHYSIOLOGISCHE REAKTIONEN DES MENSCHEN BEI KÖRPERLICHER ARBEIT

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Abstract – A young healthy man was exposed in a climatic chamber to various room temperatures and humidities at constant air speed for 2 hr daily. Groups of subjects were exposed for 6 hr daily, only the relative humidity being changed. At humidities below the critical level all subjects remained without complaints. Symptoms of intolerance occurred at humidities of about 10 per cent R.H. higher than the critical humidity. If the humidity was further increased tolerance decreased rapidly. Whether the physiological behaviour above the critical R.F. can be used as a criterion for permissible and non-permissible heat stress is discussed.

Zusammenfassung – Ein junger, gesunder Mann wurde in 135 Versuchen täglich 2 Stunden in einer Klimakammer konstanter Windgeschwindigkeit, verschiedenen Raumtemperaturen und relativer Feuchte ausgesetzt. Unter einigen Klimabedingungen wurden Versuche mit 6-stündiger Hitzearbeit bei 4 Gruppen von Personen durchgeführt. Dabei wurde nur die Feuchte variiert. Die Personen waren bei Raumfeuchten unterhalb der kritischen Feuchte völlig beschwerdefrei. Bei Überschreiten der kritischen Feuchte um etwa 10% R.F. traten Unverträglichkeitssymptome auf. Mit weiterer Steigerung der R.F. verringerte sich die Toleranzzeit stark. Es wird besprochen, ob das physiologische Verhalten bei der kritischen R.F. benutzt werden kann, um zumutbare von unzumutbaren Hitzebelastungen abzugrenzen.

Résumé – Un homme jeune et en pleine santé fut enfermé à raison d'un fois par jour à 135 reprises 2 heures durant dans une chambre climatisée. On le soumit alors à un vent constant, mais à des températures et des humidités variables. On a en outre effectué des essais sur des groupes de 4 personnes travaillant durant 6 heures dans une atmosphère surchauffée. Dans ce second cas, on n'a fait varier que l'humidité de l'air. Ces personnes n'ont ressenti aucune gène dans une atmospère plus sèche que l' «humidité critique». Dès que l'humidité relative dépassait de 10% le niveau critique, on a constaté des symptômes d'associabilité. Dans le cas d'une nouvelle hausse de l'humidité relative, la durée de tolérance fut fortement réduite. On cherche enfin à déterminer si l'on peut utiliser le comportement physiologique des individus au niveau critique de l'humidité pour délimiter l'irritabilité due à la chaleur qui peut encore être tolérée et celle qui ne peut plus l'être.

In vielen Fällen, in denen der Mensch in warmer Umgebung Arbeit leistet, wird die Frage gestellt, welche Klimabedingungen gesundheitlich zumutbar sind und von welchen Klimagrenzen ab die Notwendigkeit besteht, zur Vermeidung von Hitzeer-

krankungen das Klima des Arbeitsplatzes zu verbessern, die Arbeitsschwere herabzusetzen oder die Arbeitszeit zu verkürzen. Es ist vorerst aus verschiedenen Gründen nicht möglich, diese Frage allgemein befriedigend zu beantworten. Die erste der noch nicht hinreichend gelösten Teilfragen betrifft das Kriterium, auf Grund dessen man eine „Hitzebelastung" für unzumutbar bzw. für gerade noch

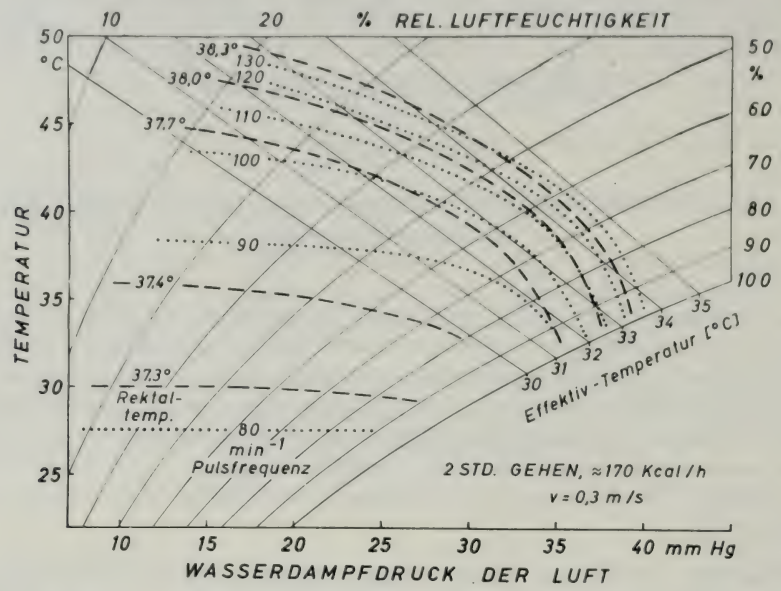

Abb. 1. Rektaltemperatur und Pulsfrequenz am Ende einer körperlichen Arbeit bei verschiedener Umgebungstemperatur und Luftfeuchtigkeit

zumutbar erklären sollte. In den bisher vorliegenden Vorschlägen wurden sehr verschiedene (zum Teil gleichzeitig mehrere) Kriterien benutzt, insbesondere das Ausmaß, in dem sich physiologische Reaktionen wie die Körpertemperatur, die Pulsfrequenz und andere während der Hitzeexposition veränderten (Ladell, 1947; Friedrich, 1948; Smith, 1955; Grandjean, 1957;, Brüner 1959;, Lind, 1960;), das Verhalten der Wärmebilanz des menschlichen Körpers (Linsel, 1951 Belding und Hatch, 1955, Houberechts *et al.*, 1958), der Grad der Herabsetzung der Leistungsfähigkeit (Ehrismann und Hasse, 1938) oder die Wahrscheinlichkeit, mit der das Auftreten einer Hitzeerkrankung zu erwarten ist (Yaglou und Minard, 1957; Wyndham, 1962). Die zweite, sich hier anschließende Teilfrage ist die, welche Kombinationen der Klimafaktoren Lufttemperatur, Luftfeuchtigkeit, Luftbewegung usw. äquivalente Belastungen, unter diesen speziell die gerade noch zumutbare Belastung hervorrufen. Man hat sich in diesem Zusammenhang besonders dafür interessiert, wie weit es möglich ist, die Grenze der zumutbaren Klimakombinationen durch Verwendung eines der zahlreichen, bis heute entwickelten "Hitzebelastungs-Indices" zu beschreiben. Ein Überblick über die wesentlichen, hierfür vorgeschlagenen Indices wurde kürzlich von Macpherson (1962) gegeben. Die bisher zu dieser Frage vorliegenden experimentellen Befunde zeigen, daß diese Möglichkeit

offenbar nur näherungsweise unter bestimmten Bedingungen besteht (Eichna *et al.*, 1945; Glickman *et al.* 1950, Wyndham *et al.*, 1953; Lind und Hellon, 1957; Koch *et al.*, 1960). Als weitere, noch offene Fragen sind insbesondere die zu nennen, wie weit für verschiedene Art, Schwere und Dauer der Arbeit, weiterhin für verschiedene Personen, besonders solche mit verschiedenem Hitzegewöhnungsgrad oder verschiedener Bekleidung verschieden hohe Zumutbarkeitsgrenzen anzusetzen sind.

In den Klimakammern des Max-Planck-Instituts für Arbeitsphysiologie wurden von März 1962 bis Mai 1963 Untersuchungen durchgeführt, die einige Beiträge zu dem aufgezeigten Fragenkomplex lieferten. Im folgenden wird ein Überblick über die bereits ausgearbeiteten Ergebnisse gegeben.

Bei den Versuchen wurde das Verhalten einiger physiologischer Reaktionen eines jungen, gesunden Mannes bei verschiedener Hitzearbeit verfolgt. Die Versuchsperson (Vp.), die mit Shorts und Schuhen bekleidet war und ad libitum trinken durfte, hielt sich in der ersten Versuchsreihe nach einer mindestens einstündigen Bettruhe stets vormittags 2 Stunden lang in einer Klimakammer entweder sitzend auf oder lief 3.5 km/h auf einer Tretbahn, teils in der Ebene, teils bei 3.5° Steigung, teils bei 6.5° Steigung. Die Sauerstoffaufnahme erreichte bei der schwersten Arbeit etwa das 6-fache der Ruheaufnahme. Die Tretbahnarbeit wurde alle 30 min durch 3-min-Pausen unterbrochen. Die Vp. verrichtete jede der vier Tätigkeiten durchschnittlich bei 8 verschiedenen Raumtemperaturen, insgesamt zwischen 18° C und 55° C. Bei jeder Raumtemperatur wurden im Durchschnitt vier Versuche mit jeweils verschiedener relativer Luftfeuchtigkeit (R.F.), insgesamt zwischen 11% und 96% vorgenommen. Alle Versuche fanden bei 0.3 m/sec Windgeschwindigkeit statt. Es wurden die Stoffwechselgröße, die Rektaltemperatur in 5 verschiedenen Tiefen bis zu 15 cm, die Temperatur im äußeren Gehörgang etwa 3 mm vor dem Trommelfell, die Pulsfrequenz und die Schweißabgabe gemessen.

Unmittelbar im Anschluß an jede Hitzeexposition begab sich die Vp. in eine 2. Klimakammer und erholte sich hier sitzend stets bei 26° C Raumtemperatur, etwa 40% R.F und 0.3 m/sec Windgeschwindigkeit. Während der Erholungszeit, die je nach der Schwere der vorangegangenen Belastung bis zu mehreren Stunden dauerte, wurde der Rückgang der Veränderungen der physiologischen Reaktionen verfolgt. Zusätzlich zu den während der Hitzeexposition auftretenden Reaktionen stand somit in dem Erholungsverlauf ein weiteres Kriterium für die Beurteilung der Hitzebelastungen zur Verfügung.

Die Vp. war etwa 2 Monate lang durch körperliches Training und Hitzeakklimatisation auf die Versuche vorbereitet worden. Der Grad ihrer Gewöhnung an Hitzearbeit wurde für alle Versuche dadurch weitgehend konstant gehalten, daß sie während der ganzen Versuchszeit zusätzlich zu den eigentlichen Versuchen in bestimmten Wiederholungen eine stets gleiche, 2-stündige, schwere Hitzearbeit leistete. Diese „Reakklimatisations-Arbeit" fand regelmäßig an oder nach Wochenenden und anderen freien Tagen statt, ebenso auch nachmittags nach einem eigentlichen Versuch, wenn dieser relativ leicht gewesen war.

In 135 Versuchen wurde zunächst festgestellt, welche Kombinationen von Raumtemperatur und Luftfeuchtigkeit bei den vier Tätigkeiten zu gleichen Veränderungen der physiologischen Reaktionen führten. Abbildung 1 zeigt als Beispiel in einem psychometrischen Diagramm die Ergebnisse einiger Versuche mit leichter Tretbahnarbeit. Es sind durch Kurven diejenigen Temperatur-Feuchtigkeits-Kom-

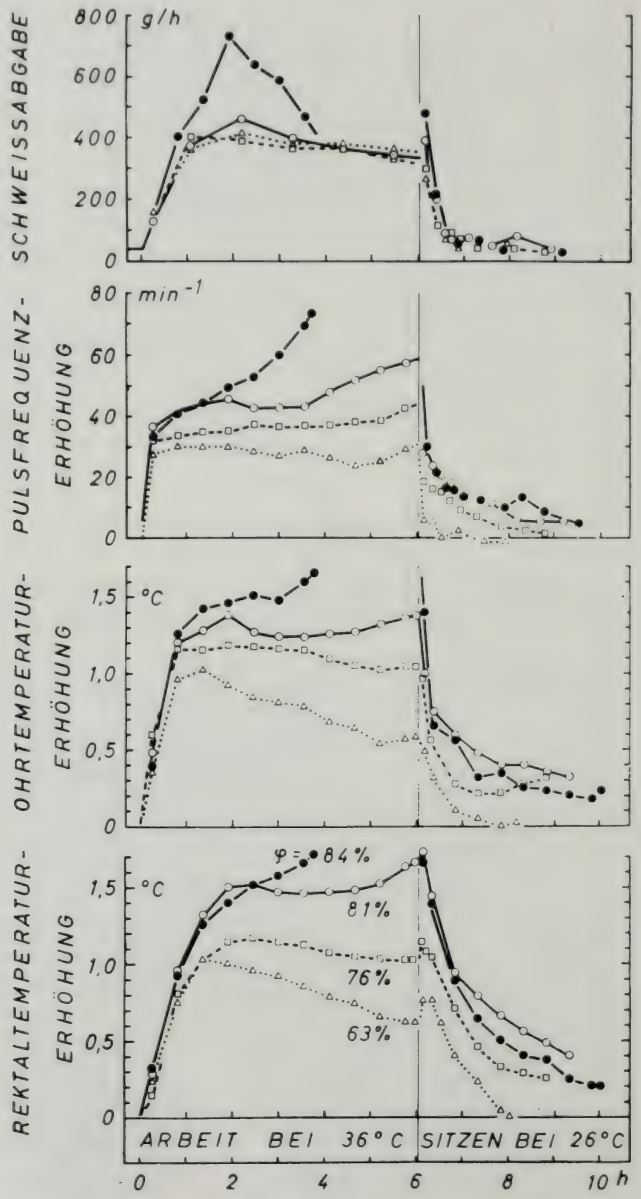

Abb. 2. Einfluß der Luftfeuchtigkeit φ auf den Verlauf einiger physiologischer Reaktionen eines Mannes beim Gehen in der Ebene (3.5 km/hr Brutto – Energieumsatz ca. 170 kcal/hr) bei 36° C Raumtemperatur und während der nachfolgenden Erholung bei 26° C und 40% φ ($v = 0.3$ m/sec)

binationen gekennzeichnet, bei denen am Ende der Arbeit die angegebenen Rektaltemperaturen und Pulsfrequenzen gemessen wurden.

Während die physiologischen Reaktionen bei relativ leichten Hitzebelastungen die Tendenz zeigten, sich im Verlauf der 2 Stunden auf annähernd gleichbleibende Werte einzustellen, stiegen sie bei starken Belastungen kontinuierlich bis zum Schluß der Expositionen an. Es wurden die Grenzen der Arbeit-Klima-Kombinationen ermittelt, bis zu denen die Reaktionen noch näherungsweise einen „steady state" erreichten. Im näheren Bereich dieser Grenzen wurden 4 Gruppen mit insgesamt 15 Versuchen durchgeführt, bei denen die Expositionszeit 6 Stunden betrug. Hierbei sollten die Grenzbedingungen für einen steady state genauer ermittelt werden. Bei allen Versuchen innerhalb jeder der 4 Gruppen wurden die Arbeitsschwere und die Raumtemperatur nicht verändert, sondern die Luftfeuchtigkeit von Versuch zu Versuch verschieden noch eingestellt. In den 4 Gruppen waren Tätigkeit und Raumtemperatur folgendermaßen miteinander kombiniert: 1. Sitzen bei 36° C, 2. Gehen in der Ebene bei 36° C, 3. Gehen in der Ebene bei 42° C, 4. Bergaufgehen, 6.5° Steigung, bei 30° C.

Abbildung 2 zeigt einige Ergebnisse von 4 Versuchen der 2. Gruppe mit R.F. von 63%, 76%, 81% und 84%. Auf der Abszisse ist die Versuchszeit aufgetragen. In den einzelnen Diagrammen sind die Verläufe der mittleren Rektaltemperatur, der Ohrtemperatur, der Pulsfrequenz und der Schweißabgabe darsgestellt. Die Körperinnentemperaturen stellten sich bei keinem Versuch auf völlig gleichbleibende Werte ein. Bei 63% und 76% R. F. fielen die Temperaturen nach einem etwa 1 bis 2 Stunden langen Anstieg kontinuierlich bis zum Schluß der Arbeit wieder leicht ab. Bei 81% R. F. war der Wiederabfall nur angedeutet. Er ging nach etwa 3 bis 4 Stunden in einen erneuten Anstieg bis zum Schluß über. Bei 84% Feuchtigkeit stiegen die Temperaturen kontinuierlich an, bis die Vp. nach knapp 4 Stunden die Arbeit erschöpft abbrach.

Der Verlauf der Pulsfrequenz war dem Verlauf der Körpertemperaturen nur bei den beiden hohen Feuchtigkeiten ähnlich. Während bei 76% die Körperinnentemperaturen ganz leicht abfielen, stieg die Pulsfrequenz kontinuierlich leicht an. Nur bei der niedrigsten Feuchtigkeit blieb die Pulsfrequenz wenigstens annähernd gleich hoch.

Die Schweißabgabe erreichte nach 1 bis 2 Stunden ein Maximum. Sie fiel dann bei den drei niedrigen Feuchtigkeiten kontinuierlich leicht bis zum Ende der Arbeit ab, wobei im Gegensatz zu den Körpertemperaturen und zur Pulsfrequenz ihre Werte nur wenig voneinander verschieden waren. Bei 84% R.F. stieg die Schweißabgabe erheblich höher an und fiel nach Erreichen eines Maximums wieder steil bis zum vorzeitigen Arbeitsabbruch ab.

Die Ergebnisse dieser 4 Versuche sind zusammen mit den Ergebnissen von weiteren meist 2-stündigen Versuchen mit der gleichen Arbeit bei der gleichen Raumtemperatur in Abb. 3 dargestellt. Das rechte untere Diagramm zeigt, daß die Erhöhung der Pulsfrequenz am Ende der ersten halben Arbeitsstunde mit der Luftfeuchtigkeit nur wenig anstieg. Am Ende der 2. Arbeitsstunde lag die Puls-

frequenz bei niedrigen Luftfeuchtigkeiten stets niedriger als nach 1/2 Stunde. Bis zur Luftfeuchtigkeit von etwa 70% unterschied sich die Pulsfrequenz nach 4 Stunden und 6 Stunden Arbeit kaum von der Pulsfrequenz nach 2 Stunden Arbeit. Oberhalb von 70% nahm die Pulsfrequenz nicht nur mit steigender Feuchtigkeit, sondern auch mit der Arbeitszeit stark zu.

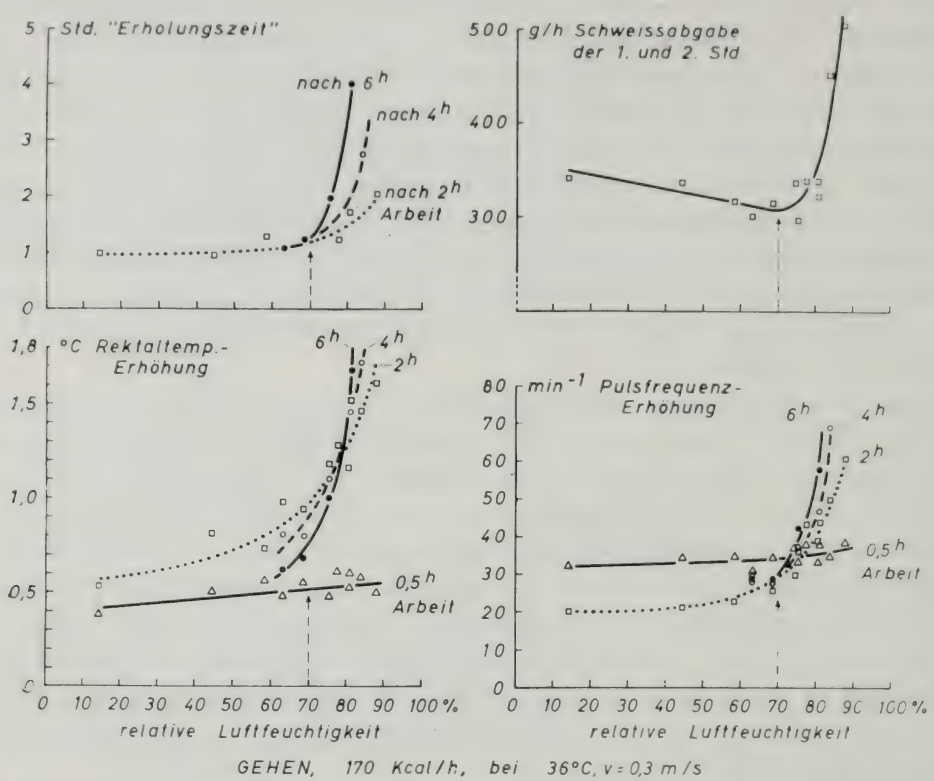

Abb. 3. Abhängigkeit einiger physiologischer Reaktionen eines Mannes bei verschieden langer Hitzearbeit von der Luftfeuchtigkeit

Die Kurve des rechten oberen Diagramms zeigt, daß mit steigender Luftfeuchtigkeit die Schweißabgabe in dieser Versuchsreihe zunächst leicht abnahm, um nach Erreichen eines Minimums im Bereich von 70% R.F. stark zuzunehmen. Im linken oberen Diagramm ist dargestellt, innerhalb welcher Zeit sich die Rektaltemperatur wieder bis auf 0.3° C ihrem Ausgangswert genähert hatte. Diese Zeit ist als Erholungszeit bezeichnet. Die Kurvenverläufe zeigen, daß sich die Erholungszeit mit steigender Feuchtigkeit zunächst kaum verlängerte, oberhalb von etwa 70% R.F. sowohl mit steigender Feuchtigkeit als auch besonders mit der Arbeitszeit zunahm.

Die Konvergenz dieser Ergebnisse legt es nahe, der Luftfeuchtigkeit im Bereich von 70% eine kritische Bedeutung beizumessen.

Das linke untere Diagramm läßt erkennen, daß die nach einer halben Stunde gemessene Rektaltemperatur mit der Luftfeuchtigkeit nur wenig zunahm. Am

Ende der 2. Stunde lag die Temperatur stets höher als nach einer halben Stunde und zwar entsprechend der punktierten Kurve umso mehr, je höher die Feuchtigkeit war. Das Überschneiden der 2-, 4- und 6-Stunden-Kurve im Bereich von 78% R.F. besagt, daß hier mit einem annähernd gleichbleibenden Verlauf der Temperatur zu rechnen war. Unterhalb dieses Wertes, also auch bei der als kritisch bezeichneten R.F. von 70%, fiel die Temperatur von der 2. bis zur 6. Stunde wieder leicht ab, oberhalb von 78% stieg sie außer mit der Feuchtigkeit auch mit der Arbeitszeit stark an.

Subjektiv fühlte sich die Vp. bei Luftfeuchtigkeiten unterhalb der kritischen Grenze relativ wohl, äußerte keinerlei Beschwerden und fühlte sich am Ende der 6 Stunden in der Lage, die Arbeit noch länger zu leisten. Bei dem Versuch mit 81% R.F., d. h. etwa 10% über der kritischen Grenze, war die Vp. am Ende der 6-stündigen Arbeit nahezu erschöpft. Bei 84% Feuchtigkeit betrug die Toleranzzeit nur etwa 4 Stunden, bei 88% Feuchtigkeit war die Vp. der Erschöpfung bereits nach 2 Stunden Arbeit nahe.

Die Ergebnisse dieser Versuchsreihe wurden in einer ähnlichen Form, allerdings mit quantitativen Unterschieden einiger Reaktionen, auch bei den Versuchen mit anderen Kombinationen von Arbeit und Raumtemperatur gefunden. In der erwähnten Reihe mit der gleichen Arbeit bei der Raumtemperatur 42° C war bei der zugehörigen kritischen Feuchtigkeit von etwa 30% die Schweißabgabe signifikant höher als bei 36° C, während sich die entsprechende Pulsfrequenz nicht sehr von dem bei 36° C gefundenen Wert unterschied. Sie lag im Mittel beider Versuchsreihen bei 32/min über dem Ruhewert. Auch die Höhe, auf der die Rektaltemperatur (etwas oberhalb der kritischen Feuchtigkeit) während der 6-Stunden-Versuche noch annähernd konstant blieb, war bei beiden Reihen mit etwa 1,1° C über dem Ruhewert gleich. Es wurden daher in Abbildung 4 folgende Kurven eingetragen: Kurve A gibt die Kombinationen von Raumtemperatur und Luftfeuchtigkeit an, bei denen sich im Verlauf der 2-Stunden-Expositionen bei der leichten Tretbahnarbeit die Pulsfrequenz um 32/min erhöht hatte. Kurve B kennzeichnet die Klimabedingungen, bei denen die mittlere Rektaltemperatur am Ende dieser Expositionen um 1,1° C angestiegen war.

Ein physiologischer Gleichgewichtszustand des Körpers wurde offenbar nur bis zu den durch Kurve A gekennzeichneten Klimabedingungen erreicht. Daß auch die Klimabedingungen, die von Kurve B angegeben werden, 6 Stunden lang erträglich waren, wird dadurch erklärt, daß die Störung des Gleichgewichtes relativ gering war und die Zeit von 6 Stunden für die Entwicklung eines vollständigen Erschöpfungszustandes noch zu kurz war. Hierfür spricht einmal, daß nach Arbeit unter den Bedingungen der Kurve B die Erholungszeit von der Arbeitszeit abhing, weiterhin, daß sich aus den Versuchen als 6-Stunden-Toleranzgrenze die unmittelbar oberhalb der Kurve B liegende Kurve C ableiten ließ. Es liegt daher nahe, die Kurve A als die Grenze der Klimabedingungen zu betrachten, die – bei 0,3 m/sec Windgeschwindigkeit, bei der angegebenen Arbeit und für die untersuchte Vp. – sicher bis zu 6 Stunden, wahrscheinlich noch länger zumutbar sind.

Zum Vergleich dieser Ergebnisse mit verschiedenen, besonders den von Macpherson (1962) zusammengestellten Hitzebelastungs-Indices sind zusätzliche Kurven in die Abbildung eingetragen. Den durch diese Kurven gekennzeichneten Klimabedingungen entspricht jeweils ein bestimmter Indexwert. Der Übersichtichkeit halber wurde darauf verzichtet, für jeden der genannten Indices Kurvenscharen seiner verschieden großen Werte einzuzeichnen. Außerdem wurden die Kurven so ausgewählt, daß sie sich ihrer Steigung nach staffelten. Den Indices ist gemein-

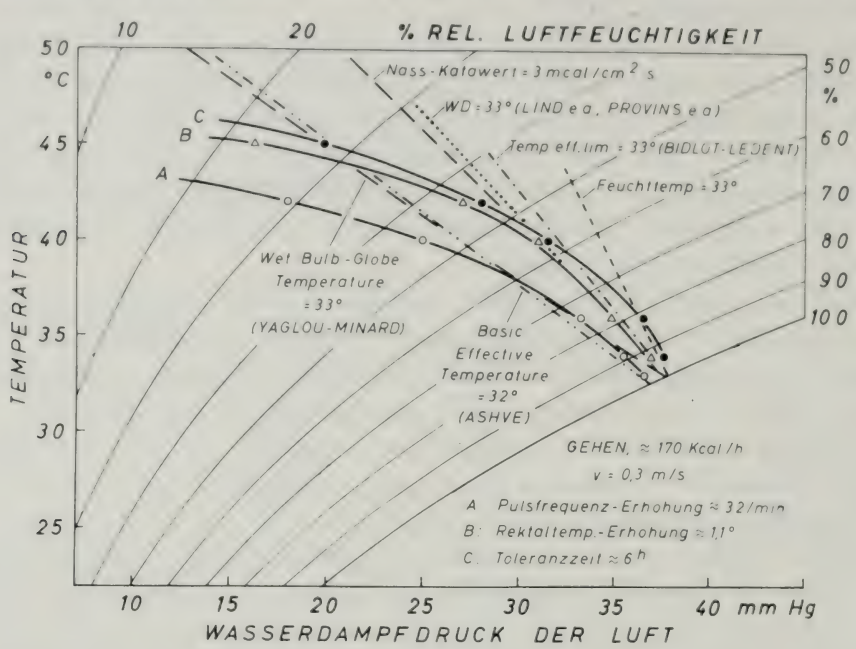

Abb. 4. Vergleich der „kritischen" Klimagrenzen und der 6-Stunden-Toleranzgrenze mit verschiedenen Hitzebelastungs-Indices I

sam, daß in ihre Werte nur Zahlenwerte der Klimafaktoren, nicht aber die Stoffwechselgröße des Menschen, eingehen. Da die Kurven aller Indices gradlinig oder fast gradlinig verlaufen, lassen sich die Klimabedingungen der gekrümmten Zumutbarkeitsgrenze A durch einen einzigen Wert dieser Indices nur näherungsweise in einem beschränkten Bereich beschreiben. Das wird durch die effektive Temperatur mit dem Indexwert 32° C, dem annähernd der Wert 33° C des wet-bulb Globe Thermometer Index (Yaglou und Minard, 1957) entspricht, relativ am besten erreicht, und zwar für alle Luftfeuchtigkeiten zwischen etwa 50% und 100%. Bei niedrigeren Feuchtigkeiten entsprechen diesen Indexwerten Klimabedingungen, die schwerere Belastungen hervorrufen.

Den Kurven A, B und C sind in Abb. 5 vier weitere Indices gegenübergestellt, die sich dadurch von den in Abbildung 4 besprochenen Indices unterscheiden, daß in ihre Werte nicht allein die Werte der Klimafaktoren, sondern auch die Stoffwechselgröße des Menschen primär eingeht. Außerdem entsprechen die eingetragenen Kurven den Werten der Indices, die (mit Ausnahme des Indexwertes von

Robinson *et. al.*) speziell als zulässige Grenzwerte für Hitzearbeit vorgeschlagen wurden. Es ist zu erkennen, daß die Klimabedingungen der Kurve A für Luftfeuchtigkeiten zwischen etwa 50% und 100% ziemlich genau dem Wert 100 des "Heat Stress Index" von Belding und Hatch entsprechen. Die nach der Gleichung von Houberechts *et. al.* ermittelte Grenze hat eine geringere Beziehung zur Kurve A. Nur der "P4SR-Index" und der „Index of physiological effect" liefern Kurven, die in ihrer gesamten Verlaufsrichtung den Kurven A, B und C entsprechen. Die

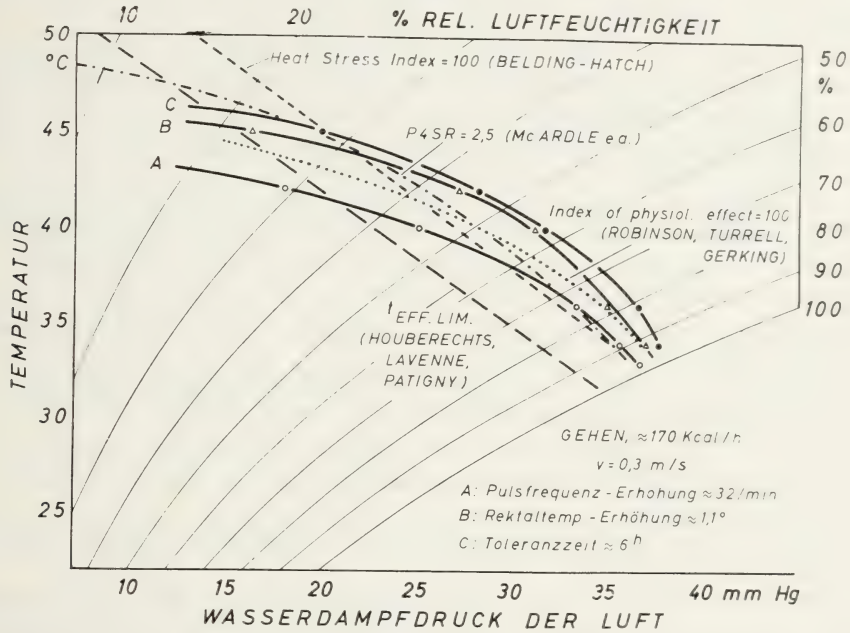

Abb. 5. Vergleich der „kritischen" Klimagrenzen und der 6-Stunden-Toleranzgrenze mit verschiedenen Hitzebelastungs-Indices II

Kurve für P4SR = 2,5 stimmt dabei mit der Kurve A für Feuchtigkeiten von etwa 60% bis 100% weitgehend überein. Die beste Übereinstimmung zeigt der Index von Robinson *et al.* (1945). Die Kurve A kennzeichnet praktisch die gleichen Klimabedingungen, die einem Indexwert von etwas weniger als 100 entsprechen.

Im Hinblick auf die anfangs aufgeführten Fragen lassen sich die bisher gefundenen Ergebnisse der beschriebenen Untersuchungen folgendermaßen zusammenfassen:

Es ist möglich, auf Grund des gemeinsamen Verhaltens der untersuchten physiologischen Größen „kritische" Kombinationen von Arbeitsschwere, Umgebungstemperatur und Luftfeuchtigkeit zu ermitteln, von denen anzunehmen ist, daß sie die Belastung des Menschen hervorrufen, die bei 6-stündiger Arbeit gerade noch zumutbar ist.

Die unter den angegebenen Versuchsbedingungen gefundene Zumutbarkeitsgrenze ließ sich durch verschiedene, zum Vergleich herangezogene Hitzebelastungs-Indices teils nur unvollkommen, teils mit großer Genauigkeit in einem weiten Bereich kennzeichnen.

LITERATUR

Belding, H. S. and Hatch, T. F. (1955)Index for evaluating heat stress in terms of resulting physiological strains. *Heat. Pip. Air Condit.* **27,** 129–136.

Bidlot, R. et Ledent, P. (1947) Que savons-nous des limites de températures humainement supportables? Communication No. 28 de l'institute d'Hygiene des Mines, Hasselt.

Brüner, H. (1959) Arbeitsmöglichkeiten unter Tage bei erschwerten klimatischen Bedingungen. *Int. Z. angew. Physiol.* **18,** 31–61.

Ehrismann, O. und Hasse, A. (1938) Über die zulässige Arbeitszeit bei hoher Temperatur und Luftfeuchtigkeit. *Arch. Gewerbepath. Gewerbehyg.* **8,** 611–638.

Eichna, L. W., Ashe, W. F., Bean, W. B. and Shelly, W. B. (1945) The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments. *J. Industr. Hyg.* **27,** 59–84.

Friedrich, H. (1948) Erträglichkeitsgrenzen für wechselnde Raumtemperatur und -feuchte bei Ruhe und Arbeit. *Pflügers Arch. ges. Physiol.*, **250,** 182–191.

Glickman, N., Inouye, T., Keeton, R. W. and Fahnestock, M. K. (1950) Physiologic examination of the Effective Temperature Index. *Heat. Pip. Air Condit.* **22,** 157–164.

Grandjean, E. (1957) Physiologische und hygienische Forderungen an das Klima von Arbeitsräumen. *Schweiz. Arbeitsgeber–Ztg.* Nr. 45, 1–8.

Houberechts, A. et Lavenne, F. Patigny, J. (1958) Le travail humain aux températures élevées. *Maroc. Méd.* No. 395: 328–345.

Koch, W. Jennings, B. H. and Humphreys, C. M. (1960) Is humidity important in the temperature comfort range? *ASHRAE J.*, April, 63–68.

Ladell, W. S. S. Effects on man of high temperatures. *Brit. Med. Bull.* **5,** 5–8.

Lind, A. R. (1960) Determination of environmental limits for everyday industrial work. *Industr. Med. Surgery,* **29,** 515–518.

Lind, A. R. and Hellon, R. F. (1957) Assessment of physiological severity of hot climates. *J. appl. Physiol.* **11,** 35–40.

Lind, A. R. Weiner, J. S. Hellon, R. F. and Jones, R. M. (1957) Reactions of Mines-Rescue Personnel to work in hot environments. National Coal Board Medical Research Memorandum No. 1, p. 16.

Linsel, E. (1951) Das Grubenklima. *Glückauf* **87,** 677–688.

Macpherson, R. K. (1962) The assessment of the thermal environment. *Brit. J. Industr. Med.* **19,** 151–164.

McArdle, B., Dunham, W., Holling, H. E., Ladell, W. S. S., Scott, J. W., Thomson, M. L. and Weiner, J. S. (1947) The prediction of the physiological effects of warm and hot environments. Med. Res. Council, Royal Naval Personnel Res. Comm., Report No. 47/391.

Provins, K. A. Hellon, R. F. Bell, C. R. and Hiorns, R. W. (1962) Tolerance to heat of subjects engaged in sedentary work. *Ergonomics* **5,** 93–97.

Robinson, S. Turrell, E. S. and Gerking, S. D. (1945) Physiologically equivalent conditions of air temperature and humidity. *Am. J. Physiol.* **143,** 21–32.

Smith, F. E. (1955) Indices of heat stress. Med. Res. Council Memorandum No. 29.

Wyndham, C. H. (1962) Tolerable limits of air conditions for men at work in hot mines. *Ergonomics* **5,** 115–122.

Wyndham, C. H. v. d. M. Bouwer, W. Paterson, H. E. and Devine, M. G. (1953) Examination of Heat Stress Indices. *Arch. Industr. Hyg.* **7,** 221–233.

Yaglou, C. P. and Minard, D. (1957) Control of heat casualties at military training centers. *Arch. Industr. Health,* **16,** 302–316.

SUMMARY REPORT

J. K. PAGE

It was clear from the start that the strength of the group had grown considerably since the London meeting, and that the group contained particularly strong physical interests, though there were a few biologists to widen the discussions. Each session was attended by about 30 delegates.

The first session dealt with *the Temperature Regime of Towns.* Broad similarities were noted between the results obtained in different cities and it is clear that understanding of this aspect of town climate is now advanced to the point where generalisations may be drawn. Interesting new material was presented on the climate of courtyards. It became clear in the course of the discussions that aspects of urban climate other than temperature were likely to have greatest biometeorological significance, namely wind and radiation.

The second session dealt with *the Pollution Climates of Towns.* Papers presented from America, Austria, and Great Britain all confirmed the growing importance of atmospheric pollution studies for urban planning. The urban pollution problem was becoming much worse in many areas due to heavy pollution by traffic fumes and also the new growth of industry. The small influence of wind in displacing the centres of pollution from the centres of production of polluting effluents was noted in a number of papers, confirming that urban pollution results from the interaction of a large number of small sources, and that it is the density of these sources which determines the distribution of pollution rather than wind direction. The pollution interaction of cities was also noted. Wind is, of course, of vital importance in the vertical diffusion process and the group agreed on the importance of giving greater priority to studies of atmospheric diffusion in towns. The radiative environment in towns was also discussed, and it was agreed that this topic also required more detailed exploration. The reduction of outgoing radiation due to obstruction by buildings was noted as a particularly important factor in urban meteorological studies.

The third session dealt with: *The Processing of Meteorological Data for Engineering Design Purposes.* The importance of keeping biologically linked meteorological parameters together in statistical processing was underlined. The statistical methods available were discussed and it was agreed that meteorological information should be presented on a probabalistic basis using suitable methods of extreme value analysis where appropriate. If such data is available to the engineering designer, he can make his decisions on safety factors in design knowing precisely

what risks he is taking. It was agreed it was not the meteorologists job to decide the factor of safety.

In the fourth session papers on a number of *Miscellaneous Topics* were considered. Wenzel gave a paper reporting his detailed physiological studies on thermal stress on one individual that revealed a number of difficulties with the existing scales used for thermal design purposes in engineering. The discussion showed that it was not possible to set up unique scales of thermally equivalent environments that were independent of rate of working. Dogniaux gave a review of the climatology of daylighting based on his extensive studies in Belgium. A paper was also given by Löfstedt on the permeability of clothing to air flow and on vegetation as an aerosol filter by Neuberger.

Plans for the future were laid and it was decided to concentrate on the air movement problems in cities, and the radiation climate of cities for the next Conference. The group remained concerned that their interests tend not to be represented among the general review papers given to the main sessions of the Conference.

SOLAR RADIATION BIOMETEOROLOGY

Chairman: †N. Robinson, Co-Chairman: I. Dirmhirn

THE INFLUENCE OF THE MULTIPLE SCATTERING AND REFLECTION ON THE SPECTRAL DISTRIBUTION OF THE SKY RADIATION

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MEASUREMENTS on multiple scattered sky radiation were made in Southern Italy in 1961. From the data the following conclusions were drawn. (1) The effect of multiple scattering is an essential constituent of diffuse sky radiation. This component must not be neglected over the continents with their man-made haze production. (2) It is obvious that the model of the Rayleigh atmosphere is not even an approximation to the real atmospheric conditions. These conclusions are emphasized because: (a) exact computations of the diffuse sky radiation which account for the multiple scattering have been conducted only for the Rayleigh atmosphere with the help of Chandrasekhar's theory; (b) computations of the diffuse sky radiation which account for the haze aerosol have been conducted only for the effect of primary scattering. The mathematical treatment of the multiple scattering due to the aerosol has been too difficult. Since the degree of polarization of the diffuse sky radiation is a good tool for finding out about the size distribution of the atmospheric aerosol, some examples of the regional distribution of the degree of polarization over the globe were presented. The discussion was restricted to the influence of the multiple scattering on the degree of polarization in a Rayleigh atmosphere. It is noted that the effect of multiple scattering can exceed that of primary scattering very appreciably especially if its ground albedo is high.

A STUDY OF THE RELATIONSHIP BETWEEN TURBIDITY AND WATER VAPOUR CONTENT OF THE AIR ON WARM DAYS WITH CLEAR SKY

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WHEN standard curves of radiation are established for use in calculations of the natural and artificial heat regulation of buildings the "maximum solar intensity curves" corresponding to the daily variation of solar and sky radiation for hot days in summer are generally used. However, it is evident that the main climatic element which is responsible for hot days in summer in our countries is more the result of the particular atmospheric situation resulting from the general circulation of synoptic air masses than the result of the distribution of energy of the solar radiation with a clear sky. The author has worked out a method which gives a simple formula relating the atmospheric turbidity to the average water vapour content of the atmosphere as obtained by means of radiosondes. For further information see:

R. DOGNIAUX Données météorologiques concernant l'ensoleillement et l'éclairage naturel, *Cahiers du C. S. T. B.*, Paris, no. 44/351, 1960.

P. CHAUVEL Puissance du rayonnement solaire. Détermination de l'énergie reçue par les bâtiments, *Cahiers du C. S. T. B.*, Paris, no. 439, avril 1962.

TECHNIQUES FOR THE INTEGRATION OF RADIOMETRIC MEASUREMENTS

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THE influence of the sensor characteristic on the design of new instrumentation for the totalization of the radiant flux from the sun and sky has been reviewed. In a new design, the overall performance characteristic should be analyzed realistically to obtain an economic optimum. Increase of accuracy is not a linear function of the necessary effort to obtain it. Future instrumentation will probably use electronic and hybrid electronic techniques for integration, operated directly from sensors which should have substantially increased output voltage levels. Present technology allows the design of all electronic integrating radiometric instruments for a price probably below the cost of a good radiometer and a matched analogue strip-chart recorder if the costs for development are not considered. Where analogue records of the instantaneous flux values are required besides the integral values, the ball-disk integrator and simple digital sampling and summing techniques will probably hold the field, with a slight preference for the digital technique because of its longer lifetime. Modern redesign of the Bellani type instrument may lead to a simple, useful integrating radiometer yielding daily totals, with no need for external operating power. For precision instrumentation, the all electronic digital integrator will probably conquer the field with its inherent capability of high accuracy and drift-free operation.

A PROPOSAL FOR A PORTABLE SECONDARY STANDARD ILLUMINATION METER

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THE excellent results of an effort spread over a few years to design and fabricate a caloric radiometer of high precision encouraged the use of the design for a secondary standard for *illumination* measurements. The requirements placed on a secondary standard for illumination measurement are easily stated. Such an instrument must yield read-outs which are measures of the radiation of sun and sky as sensed by the human eye, it must have extremely stable calibration characteristics over an extended period of time (preferably years), it should be independent of environmental conditions such as wind-chill and temperature, and last, but not least, it should be easy to transport and operate. Basically designed for a receiving aperture of 2 π solid angle and a flat receiving surface, other apertures should be possible after only slight modification. The problem to be solved, if the existing precision pyranometer is to be modified for use as a secondary standard for illumination measurement, is to find a suitable filter combination for the basic instrument which represents the spectral characteristic of the human eye with sufficient precision. The basic instrument as well as the considerations for the selection of suitable filter-material were presented. The computation technique for minimizing the errors made in matching the standard eyecurve were shown and the results obtained were given.

THE ESTIMATION OF MONTHLY MEAN VALUES OF DAILY TOTAL SHORT WAVE RADIATION ON VERTICAL AND INCLINED SURFACES FROM SUNSHINE RECORDS (FOR LATITUDES OF 60° N TO 40° S)

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A TECHNIQUE for calculating monthly mean values of total daily radiation on inclined surfaces from sunshine data was proposed. The first part dealt with the calculation of the mean values of total radiation on horizontal planes, using the conventional type of regression equation,

$$Q/Q_0 = a + b\frac{n}{N}$$

where Q is the monthly mean daily total radiation, Q_0 is the corresponding monthly mean daily radiation outside the atmosphere, a and b are constants which are climatologically determined and $\frac{n}{N}$ is the percentage possible sunshine expressed as a fraction. The second part dealt with the separation of the mean horizontal diffuse radiation from the total radiation, using a regression equation of the form:

$$D_H/Q = c + d\,\varphi/\varphi_0$$

where D_H is the monthly mean daily diffuse radiation on a horizontal plane, where c and d are climatologically determined constants and where Q has the same meaning as before.

The monthly mean value of the daily radiation on the horizontal plane $\Sigma I_D \sin\theta$ may be found from the relation

$$\Sigma I_D \sin\theta = Q - D_H, \text{ where } \theta = \text{solar altitude.}$$

The third part dealt with the conversion of direct radiation on the horizontal plane to direct radiation on inclined planes. Factors were given for the following surfaces: (a) vertical facing equator; (b) vertical facing pole; (c) vertical facing east or west; (d) vertical facing equator tilted at 45° to horizon; (e) vertical facing equator tilted at angle to horizontal equal. These factors are based on radiation curves obtained by using standard radiation curves.

The fourth part dealt with the estimation of diffuse radiation on inclined surfaces using the isotropic approximation. The limitations of the isotropic estimation

were discussed and certain empirical correction factors proposed to take into account. The fact that the method of analysis is restricted to monthly mean values of possible sunshine and so is not applicable to daily values of sunshine and the need for further field observations were stressed. The accuracy of prediction appears to be in the order of ± 5 per cent for monthly means. It is shown that collector orientation for maximum efficiency is influenced very much by the diffuse radiation climate in any locality and it is suggested that attention must be given to the problem of properly utilizing the diffuse energy in flat plate collectors, particularly in humid tropics where half the available energy may be diffuse. The contents of this paper have been published in Proceedings of U.N. Conference on New Sources of Energy.

THE SCATTERED SKY RADIATION, ITS MEASUREMENT AND THE INSOLATION OF VARIOUS OBJECTS

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THE scattered sky radiation is defined as the energy received on a horizontal plane from the complete hemisphere when radiation from the direct solar beam is excluded. Two types of shading device have been used to intercept the solar beam: (a) a disc of appropriate diameter moving in a suitable trajectory; (b) a stationary frame. The author and a colleague have developed the necessary formulae and diagrams for the computation of the necessary corrections in order to obtain the real values of the scattered sky radiation. For biometeorological investigations, e.g. the insolation of a human body or its parts, or a tree, special computations have to be made.

THE HEATING POWER IN EILATH (RED SEA). A COMPARISON OF TWO METHODS BY MEANS OF DAVOS-FRIGORIMETERS

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THE authors have investigated the cooling power at Eilath during the summer months of 1962 and 1963. The town of Eilath has a special geophysical situation as it lies on the northern tip of the Gulf of Akaba (Red Sea). It is daily exposed to a northern wind which crosses the Negev desert and reaches Eilath as a dry hot wind. As the temperatures in Eilath reach more than 40° C during some hours of the day in the summer the cooling power was expected to become negative and is then termed heating power. The method of Wierzejewsky and the method of Thams for the determination of the heating power were applied simultaneously by means of Davos-frigorimeters. The intention of the authors was to find out whether there was a relationship between the results obtained by the two methods for the determination of heating power, and thus to determine the critical temperature at which the cooling power changes its sign.

ON THE ATMOSPHERIC LONG WAVE RADIATION

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THE atmospheric radiation in Bergen during the period December 1957 to June 1959 was discussed. Records with a Schulze radiation balance meter in Bergen have been used to find empirical formulae by which the downward atmospheric radiation could be estimated. The statistical analysis of 230 observations during clear sky conditions showed that the atmospheric radiation can be expressed by a simple linear regression equation: $A_0 = 0.925\sigma T^4 - 0.030$, the correlation coefficient being as great as $r = 0.949$. If water vapour pressure is taken into account the multiple regression equation then found is: $A_0 = 0.738\sigma T^4 + 0.0055 + 0.0365$ and the multiple correlation coefficient $R = 0.961$. To explain the results indicated by these equations, it is assumed that in a maritime climate regime the air usually contains so much water vapour that the observed variations in the atmospheric radiation is largely dominated by variations in the air temperature. Only when the visibility is less than 10 km does the turbidity of the atmospheric radiation increase to an immeasurable amount. The effect of cloudiness was discussed. 2344 observations show the "relative" downward directed atmospheric radiation, when tenths of the sky were covered by clouds, could be expressed by a second degree regression equation. Compared to other investigations the results indicate that the downward atmospheric radiation under clear sky conditions is usually greater in a maritime climate regime than in a more continental regime provided air temperature is the same.

SOLAR RADIATION ON VERTICAL SURFACES IN THE ABSENCE OF AN ATMOSPHERE

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THE total direct solar radiation per unit area which would be received during the day in the absence of the atmosphere can be determined for any surface of given inclination and azimuth by integrating analytically the appropriate equation obtained from spherical astronomy. The choice of the limits over which the integration is to be performed requires care, but in the case of a vertical surface facing north, south, east or west, can be shown to obey simple rules. The integration can be extended to cover any period of time for which the change of solar longitude is known. For a wall facing east or west no complication arises beyond the presence of a simple elliptic integral of the second kind with fixed modulus, for which tables are available. In other cases more complicated forms of elliptic integrals appear and the method does not seem to offer any advantage over that of numerical integration. Approximate values of the direct solar radiation on vertical surfaces with clear and cloudy skies may be determined using average transmission coefficients. The calculation of tables of the total direct solar radiation received on vertical urfaces in the absence of atmospheric depletion was undertaken. These tables ive the daily radiation on vertical surfaces facing north, south, east and west, or the first, 11th and 21st day of each month of the year at 10° intervals of atitude.

A SIMPLE THERMOPILE FOR THE MEASUREMENT OF SURFACE TEMPERATURES IN THE FIELD

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A DESCRIPTION is given of a radiation meter without an infrared filter which measures the heat radiation emitted by a surface even in the presence of strong reflected solar radiation. A whitened thermopile is mounted in a bore in an aluminium block which can be closed by means of a glass shutter of known temperature. In this way it is possible to separate the effects of the thermal radiation emit-

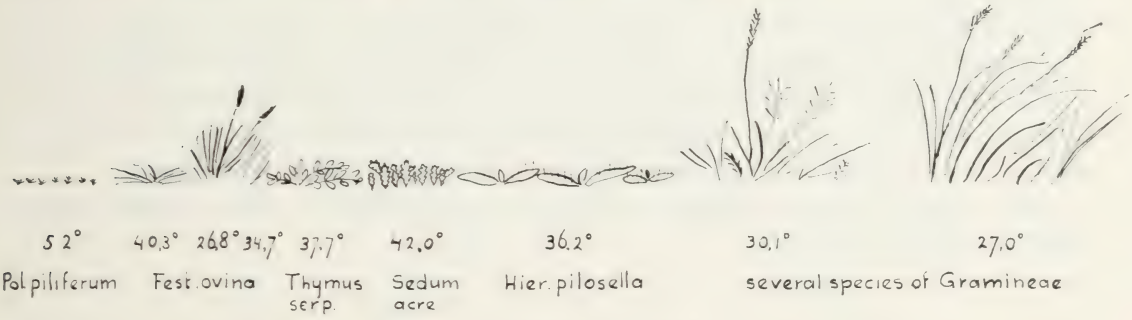

FIG. 1. Coaxial graph relating the diffuse radiation from the sky to solar height, season of year, turbidity and cloudiness of the atmosphere

ted by a surface from the solar radiation reflected by it. An example of the great differences in surface temperature of patches of different vegetation on a few square meters of dry grassland as measured with this instrument is given in the figure.

THE DIFFUSE SKY RADIATION AS A FUNCTION OF METEOROLOGICAL AND ENVIRONMENTAL FACTORS

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DATA collected during a 5-year period at Locarno-Monti, on the southern side of the Alps, were used to investigate the relationship between the diffuse sky radiation and the zenith distance of the sun, the turbidity, and the cloudiness. By grouping the data by months it was possible to show quantitatively the same seasonal dependence of the surface albedo and of the direct reflection from the slopes. By applying the coaxial method for the graphical determination of stochastic interrelations a presentation of the results in a multicurve graph for practical use was possible. The reliability of empirically obtained sky radiation estimates was checked against a series of values measured independently. Analysis of the deviation frequency showed in addition that the more parameters are taken into account in the multiple correlation procedure the better is the relationship.

The complete paper, written in German, is published in *Arch. Meteor. Geoph. Bioklim.* B. **12**, 458–474.

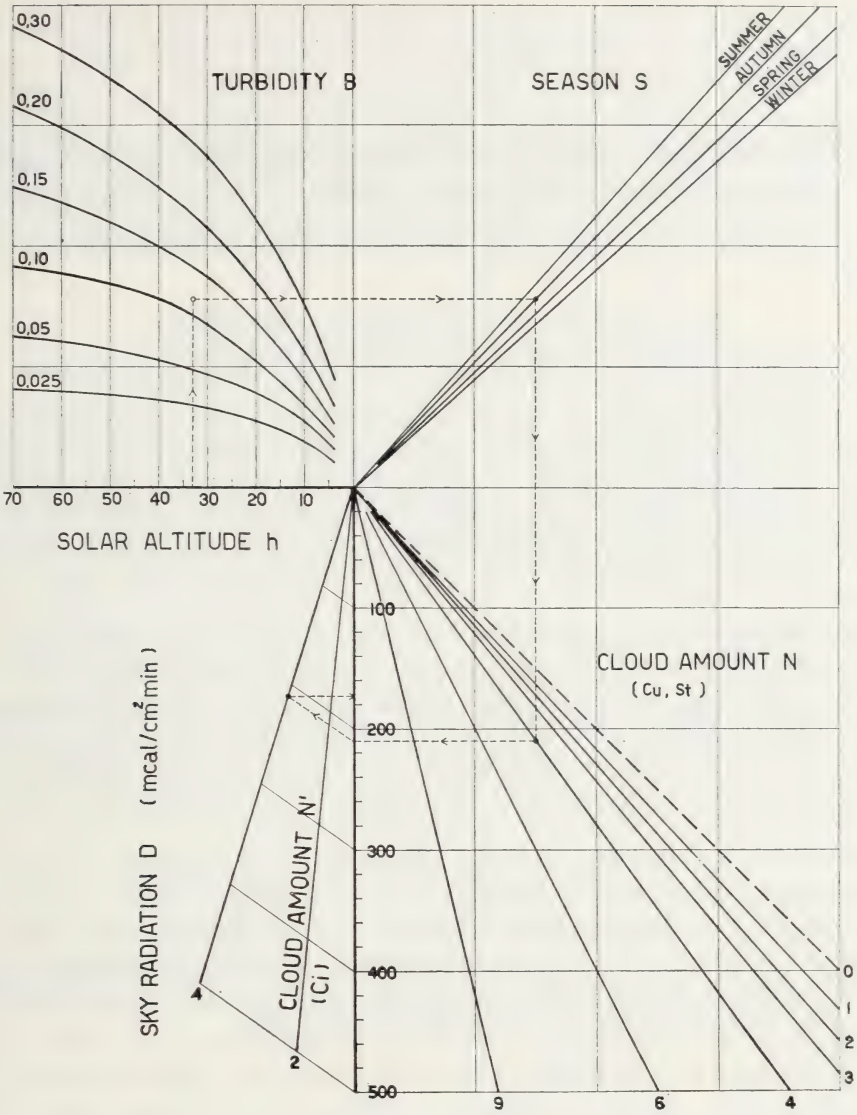
TURBIDITY B
SEASON S
SUMMER
AUTUMN
SPRING
WINTER
0,30
0,20
0,15
0,10
0,05
0,025
70 60 50 40 30 20 10
SOLAR ALTITUDE h
100
200
300
400
500
SKY RADIATION D (mcal/cm² min)
CLOUD AMOUNT N
(Cu, St)
CLOUD AMOUNT N'
(Ci)
0
1
2
3
4
2
9
6
4

FIG. 1.

AN AUTOMATIC SKY SCANNING RADIOMETER FOR MEASURING THE DISTRIBUTION OF RADIATION FROM THE SKY AND INTERPRETATION OF THE MEASUREMENTS

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Abstract – An automatic sky scanning radiometer which samples the distribution of sky scattered solar radiation and nocturnal atmospheric long wave radiation at fixed or variable time intervals is described. The interpretation of the data in terms of fluxes on surfaces of any inclination and orientation based on computed zonal contributions of concentric circular zones with the sun or any other fixed or variable point as pole is given.

Zusammenfassung – Ein automatisches Himmelsprüfradiometer wird beschrieben, welches stichprobenweise die Verteilung der gestreuten Himmelsstrahlung und der nächtlichen Gegenstrahlung in fixen und variablen Zeitintervallen liefert. Die Interpretation der Ergebnisse in Gliedern von Strömen an den Oberflächen verschiedener Neigung und Orientierung auf berechneten zonalen Abschnitten konzentrischer Kreiszonen – mit der Sonne oder irgendeinem anderen fixen oder variablen Punkt als Pol wird mitgeteilt.

Résumé – On donne la description d'un radiomètre automatique qui sélectionne par échantillonnage la distribution de la radiation solaire diffuse du ciel et la radiation atmosphérique nocturne à ondes longues et cela pour des intervalles fixes ou variables. On y interprête les données du flux reçu par des surfaces de différentes inclinaisons et orientations, flux calculé en partant de divisions zonales de surfaces circulaires concentriques au soleil ou à un autre point fixe ou variable utilisé comme pôle.

INTRODUCTION

For a rational assessment of the heating and cooling loads of buildings, reliable information on the magnitude of the various radiation components which together make up the net radiation exchange at the outside surface of an exposed building element is a basic requirement. Very little useful information of this type, however, exists. The usual approach is to base assessments of the various components on standard meteorological measurements making certain assumptions as to the distribution of diffuse short-wave radiation, terrestrial long-wave radiation, solar radiation reflected from the ground, and so on. In this paper attention will only be given to the distribution of short-wave sky radiation and nocturnal atmospheric long-wave radiation.

In most instances the only source of meteorological data is the national weather service and, in the case of radiation, measurements are usually made with reference to a horizontal surface. Measurements of direct intensity of solar radiation are also sometimes available. For building design purposes, however, radiation data are required with respect to vertical and inclined surfaces and additional measurements are, therefore, necessary if a realistic interpretation of the influence of radiation on the thermal performance of buildings is to be made.

DISTRIBUTION OF DIFFUSE SKY RADIATION

Measurements of diffuse sky radiation incident on vertical surfaces of different orientation in Pretoria (Van Deventer and Dold, 1966), for example, have shown that the assumption usually made, viz, that a vertical surface of any orientation receives one-half of the diffuse radiation falling on a horizontal surface, is incorrect. Under clear sky conditions the distribution of diffuse radiation over the sky dome is far from uniform, primarily as a result of scattering by haze in the atmosphere, the scattering being most intense around the sun's position in the sky. In order, therefore, to be able to predict what proportion of the diffuse sky radiation incident on a horizontal surface under clear sky conditions will fall on a vertical or inclined surface of given orientation, much more information on the distribution of diffuse radiation from the sky is necessary.

To facilitate such a study for both diffuse short-wave and atmospheric long-wave radiation, a special automatic sky scanning radiometer, illustrated in the attached Fig. 1, was designed and built. Basically the instrument consists of a sensitive Moll-type thermopile with a sensitivity of 23 mv/cal/cm^2/min mounted in a tube containing diaphragms giving a half-angle of aperture of 5°06′ (the same as a standard Linke–Fuessner actinometer). The tube in turn is mounted in such a way as to allow both horizontal and vertical movement. For practical reasons, sampling of sky radiation is done according to a fixed pattern, viz, at 12° intervals on vertical arcs spaced $22\frac{1}{2}°$ apart on a horizontal circle, each vertical transit commencing at 6° above the horizon. This gives a measuring grid of 120 points on the sky dome (Fig. 1).

Allowance is made for the thermal inertia of the thermopile by stopping it for a fixed period at each measuring station, this period being adjustable at from 2 to 60 sec.

In view of the fact that the instrument is continuously exposed to outdoor conditions and that no provision is made to stabilize the thermopile reference temperature, the temperature of the thermopile reference junction is also measured at fixed intervals. Furthermore, to eliminate as far as possible a temperature build-up in the thermopile due to radiation, a shutter is interposed between the radiation source and the thermopile. However, except when the complete measuring cycle becomes too long, the shutter is interposed only after every 15 measuring stations,

i.e. after a complete vertical sweep. The shutter operation is completed during the time the instrument moves from one azimuth setting to another. The length of time between the initiation of vertical sweep cycles can also be adjusted to be from 2 to 60 sec.

Allowing for the indicating time of the thermopile and taking care not to permit excessive temperature build-up, the time taken for a full cycle of measurements, i.e. for 120 measurements, is 30 min. The length of the interval between full measuring cycles can be adjusted to be from 2 to 60 min.

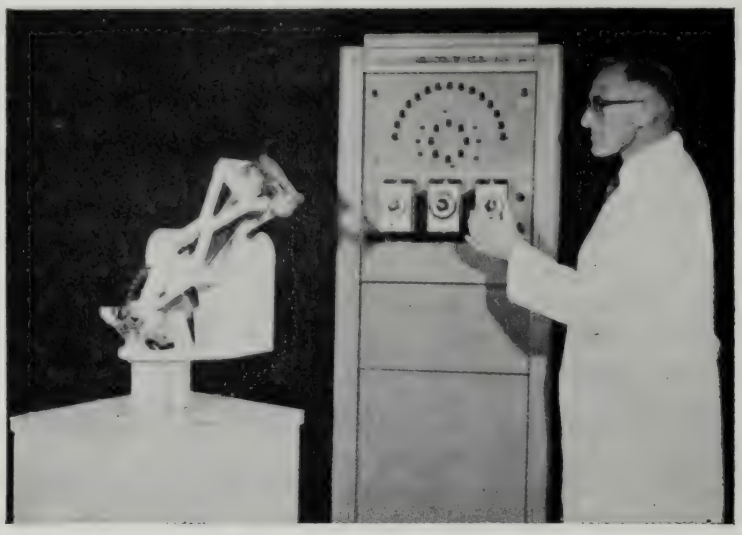

Fig. 1.

In order to facilitate the programme a high sensitivity digital recorder is being developed in which use will be made of a sensitive quartz suspension galvanometer and angular digitizer. This will enable the data to be recorded in binary code on punched paper tape, thus making direct computer processing of the data possible.

For computational purposes the sky dome is regarded as being divided into concentric circular zones with the sun as centre. Some of the zones are, of course, terminated by the horizon when the angular distance from the sun is large. The arithmetic mean of the measurements at the grid points falling within a particular zone is calculated and defined as the mean zonal intensity.

Measurements of sky brightness distribution conducted under clear sky conditions by Kimball and Hand (1921), Hopkinson (1953), Richards and Rennhackkamp (1959), Paix (1963), and others show that there is a symmetry about the global brightness or luminance distribution and that the minimum brightness occurs in the quadrant opposite to the sun's position and separated from it by about 90°. Pokrowski (1929), Tousey and Hulburt (1947) and Johnson (1960) have also justified approximately this distribution of luminance and thus of diffuse sky radiation, theoretically, assuming a flat earth.

In the Tousey–Hulburt evaluation, as well as in Pokrowski's evaluation, use is made of an average scattering coefficient of Rayleigh scattering, that due to atmospheric haze being ignored. This latter assumption is probably valid at high atmospheric levels, but at low levels the dust content of the atmosphere should be taken into account by way of a complex scattering coefficient defined with respect to molecular and dust or haze scattering.

The turbidity coefficient defined by Ångström (1929, 1961) is a measure of the quantity of haze in the atmosphere. There should, therefore, be some kind of relationship between the pattern of the sky radiation distribution and the turbidity coefficient. This follows from its definition. By implication, it should then be possible to predict a mean sky radiation distribution if the turbidity climate of a place is known.

From the distribution of diffuse sky radiation it is possible to calculate the diffuse radiation flux on surfaces of any inclination and orientation. For computer processing of the distribution data and the evaluation of diffuse radiation fluxes on any surface, the following procedure is followed. Firstly, the mean zonal intensity for concentric circular zones around the sun as pole is calculated according to the method already outlined. Secondly, the area of each zone which contributes to the radiation flux of any given plane is calculated by applying well-known formulae of spherical trigonometry. In this connection it is convenient to define the arbitrary plane in terms of the azimuth and altitude angle of the normal to its exposed side.

Various configurations are, of course, possible depending upon the position of the sun and the aspect of the surface and whether a particular zone is bounded by the plane through the horizon and a plane through the surface. A series of different formulae for the zonal contributions must thus be determined for surfaces having different aspects and for each sun position selected.

In order that a mean angle of incidence for radiation from a particular zone may be taken without incurring errors exceeding certain predetermined limits, it is usual to divide into sufficiently small solid angle zones the portion of the sky that contributes to the radiation on a given surface. A much simpler technique can, however, be used. The radiation received by a plane from any point in any zone to which it is exposed may be represented by a vector whose angle of incidence with respect to the plane can easily be calculated. The magnitude of vectors from any point in a given zone will be assumed equal. This follows from the definition of a mean zonal intensity. The sum of these vectors will pass through the centroid of the zonal area under consideration and its magnitude will be given by the product of the mean zonal intensity and its area.

The accuracy with which the position of the centroid of the zonal area can be calculated will determine the accuracy with which the radiation flux received by a plane can be calculated.

Finally, the total diffuse short-wave flux received by a given surface is calculated by a simple summation of the various appropriate zonal contributions. Thus, if the distribution of sky radiation based on a knowledge of the turbidity climate is

known, the flux of diffuse sky radiation on surfaces of any inclination and orientation can be assessed. For design purposes the ratio of this flux to the total flux received by a horizontal surface is most appropriate (Van Deventer and Dold, 1966).

NOCTURNAL ATMOSPHERIC LONG-WAVE RADIATION

The need has long been felt for more extensive information on the emissivity of the nocturnal sky. This applies in particular to the nocturnal clear sky which is the prevailing sky condition over the greater part of the interior of South Africa. Under such conditions, of course, maximum radiation cooling of surfaces on or near the ground takes place. The instrument described above lends itself very well to a study of this nature.

Because the emissivity of the sky is, amongst other things, a function of optical depth in the atmosphere, it is appropriate to divide the sky into concentric circular zones spaced equally about the zenith as pole. The procedure for calculating the mean atmospheric emissivity with respect to a given exposed surface is a simplified version of that required for calculating mean diffuse radiation flux, because a fixed co-ordinate system can now be used. Otherwise the reasoning remains the same.

An aspect which also requires further investigation is the dependence of the distribution of emissivity on water vapour and aerosol content of the atmosphere. Fuller investigation of this problem forms an important part of the programme.

REFERENCES

ÅNGSTRÖM, K. (1929) On the atmospheric transmission of sun radiation and on dust in the air. *Geogr. Ann., Stockh.* **11**.

ÅNGSTRÖM, A. (1961) Techniques of determining the turbidity of the atmosphere. *Tellus*, **13**, 214–223.

HOPKINSON, R. G. (1953) Measurements of sky brightness distribution at Stockholm. Building Research Station Note no D268, Watford, D. S. I. R., Nov., 1–5.

JOHNSON, J. C. (1960) *Physical meteorology*. The Technology Press of the Massachusetts Institute of Technology and Wiley, New York, Aug., 112–117.

KIMBALL, H. H. and HAND, I. F. (1921) Measurement of sky brightness and daylight illumination at Washington, D. C. *Mon. Weath. Rev., Wash.* **49**, 481.

PAIX, D. (1963) *Measurement of the luminance distribution of the sky near Sydney, Australia.* IES Monograph no. 6A, Jan., 1–10.

POKROWSKI, G. J. (1929) Über die Helligkeitsverteilung am Himmel. *Phys. Z.* **30**, 697–700.

RICHARDS, S. J. and RENNHACKKAMP, W. M. H. (1959) Measurements of outdoor lighting conditions and their application in design for interior illumination. *S. Afr. elect. Rev.* **50**, 1–7.

TOUSEY, R. and HULBURT, E. O. (1947) Brightness and polarization of daylight sky at various altitudes above sea level. *J. Opt. Soc. Am.* **37**, 78–92.

VAN DEVENTER, E.N. and DOLD, T. B. (1966) Some initial studies on diffuse sky and ground reflected solar radiation on vertical surfaces. *Biometeorology II. Proc. Third Int. Biometeor. Congress*, S. W. Tromp and W. H. Weihe (ed)., Pergamon Press, Oxford. 735–742.

SOME INITIAL STUDIES ON DIFFUSE SKY AND GROUND REFLECTED SOLAR RADIATION ON VERTICAL SURFACES

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Abstract – Information on the various short wave radiation components falling on vertical surfaces of any orientation in warm climates under various sky cover conditions is virtually non-existent. Some data, based on preliminary measurements in Pretoria, are presented together with a description of the measuring techniques employed and application of such data in practice.

Zusammenfassung – Es gibt praktisch keine Unterlagen über die verschiedenen kurzwelligen Strahlungskomponenten unter verschiedenartigen Bewölkungszuständen, die in warmen Klimaten auf Vertikalflächen beliebiger Richtung einwirken. Einige Werte, die auf vorläufigen Messungen in Pretoria beruhen, werden zusammen mit einer Beschreibung der angewandten Messtechnik und der praktischen Verwendung dieser Werte angegeben.

Résumé – Il n'y a presque pas d'information au sujet des différentes composantes de rayonnement à onde courte qui tombe sur les surfaces verticales de n'importe quelle orientation en climats chauds sous les différents aspects climatiques du ciel. On donne quelques chiffres basés sur des mesures préliminaires faites à Pretoria, et une description de la méthode de mesure employée ainsi que l'application pratique de tels chiffres.

INTRODUCTION

The importance of solar radiation to the thermal response of buildings, particularly in warm arid climates which are characterized by clear skies and high solar radiation fluxes, is not always appreciated. For a rational assessment of the influence of solar radiation on the thermal performance of a building, the solar radiation fluxes normal to the various components of the building must be known. Few actual measurements of these quantities have been made and, in practice, most solar radiation measurements are limited to those for horizontal surfaces. The designer has, therefore, to resort to evaluations of fluxes on the various components of a building based on certain assumptions as to the distribution of sky radiation and short-wave radiation reflected from the ground.

One assumption usually made is that the diffuse sky radiation flux on a vertical surface is one-half of the flux on a freely exposed horizontal surface. This assumption is not valid, however, because in practice the distribution of sky radiation is

not uniform. In addition, the influence of radiation reflected from the ground or other surrounding surfaces is often ignored because of lack of information.

Before embarking on an extensive research programme, it was considered necessary to make certain preliminary measurements as very little was known of the relative importance of the contributions of the various components of short-wave radiation to the total flux on a vertical surface or of the most suitable measuring techniques. Consequently, new techniques had to be developed or existing ones had to be adapted in order to measure these components in the most realistic way. The purpose of this paper is to present some information on the measuring techniques adopted and to give some indication of the relative importance of the two short-wave radiation components.

MEASURING TECHNIQUES

The measurements of the solar radiation fluxes on north-, south-, west- and east-facing surfaces did not include the direct component from the sun. The evaluation of this component presents no real problem since it is a simple matter to calculate it from standard meteorological measurements.

1. Diffuse Radiation Component

Five Kipp pyranometers were used, one mounted horizontally and the other four vertically facing the four cardinal directions. Originally, each pyranometer was shaded from the sun by an adjustable shadow-ring of appropriate dimensions, but these rings were discarded later for reasons that will be explained.

For practical reasons, the radiation falling on the above pyranometers was not recorded in absolute units but as ratios of the vertical flux to the horizontal flux, by making use of a voltage ratiometer recording technique. The ratiometer is basically a potentiometer in which the reference voltage is the e.m.f. generated by the horizontal pyranometer. Ratios determined in this manner do not, however, strictly represent the true ratios of vertical to horizontal fluxes. Corrections have to be applied with respect to the internal resistance of the reference e.m.f. source, the differences in sensitivity of the pyranometers, differences in the response of the pyranometers due to mounting position, and the screening effect of the shadow-ring.

(a) *Correction for internal resistance of the reference e.m.f. source.* Because of the internal resistance of the reference source, the true e.m.f. is given by

$$E_H = V_H\left(1 + \frac{r_H}{r_p}\right)$$

where E_H = true e.m.f.,
V_H = measured e.m.f.,

r_H = internal resistance of the reference source,
r_p = resistance of the potentiometer

(b) *Corrections for differences in sensitivity of the pyranometers.* The appropriate corrections were derived by comparing the sensitivities of the pyranometers in a horizontal mounting position on two occasions approximately eight months apart. The sensitivities of the individual instruments remained consistent to within 2 per cent over this period.

(c) *Corrections for difference in response due to mounting position.* In all cases it was found that the sensitivity of the pyranometer increased by about 1.6 per cent when mounted vertically, primarily as a result of the change in the direction of convection currents over the thermopile surface.

(d) *Shadow-ring correction.* The shadow-ring, of course, does not only shade the pyranometer from the sun but also screens it from other parts of the sky and, in the case of vertically mounted instruments, from parts of the ground as well. Shadow-ring corrections were determined in the standard way (IGY Instruction Manual).

From considerations of primary scattering of energy out of the direct beam due to turbidity, and its dependence on optical air mass and of the cosine response of the pyranometer, it can be shown that the shadow-ring corrections are independent of angle of incidence for a given value of turbidity (Drummond, 1956). This was substantiated by the results of tests carried out with the instruments previously described.

However, turbidity of the atmosphere greatly affects the magnitude of the correction. In fact, it has been suggested that the magnitude of the shadow-ring correction is a relative measure of atmospheric turbidity (Drummond, 1956). Furthermore, it is extremely difficult to evaluate the correction under cloudy sky conditions, because it is not only a function of the degree of cloud cover and cloud type, but also of the pattern of the cloud cover which, amongst other things, determines whether the sun is obscured or not at any given time.

For these reasons it was found impractical to use shadow-rings in measuring the ratio of diffuse radiation flux on vertical surfaces to that on horizontal surfaces under cloudy sky conditions.

An alternative procedure tried was to record the total radiation flux on the vertical and horizontal surfaces separately as well as the direct intensity of solar radiation normal to the sun. By calculating the direct sun component on the different surfaces, the diffuse plus reflected component could be derived by subtraction for the occasions on which the sun was not obscured by cloud. This method has the obvious limitation that it can only be applied for unobstructed sun conditions. Furthermore, it has to be assumed that the pyranometer has a true cosine response, which is not the case at high angles of incidence.

To overcome all the above difficulties it was decided to use motorized shading-discs.

Diffuse radiation flux measured in the way described above of course also includes solar radiation reflected from the ground. Measurements of the latter were, however, made independently and are discussed in the next section.

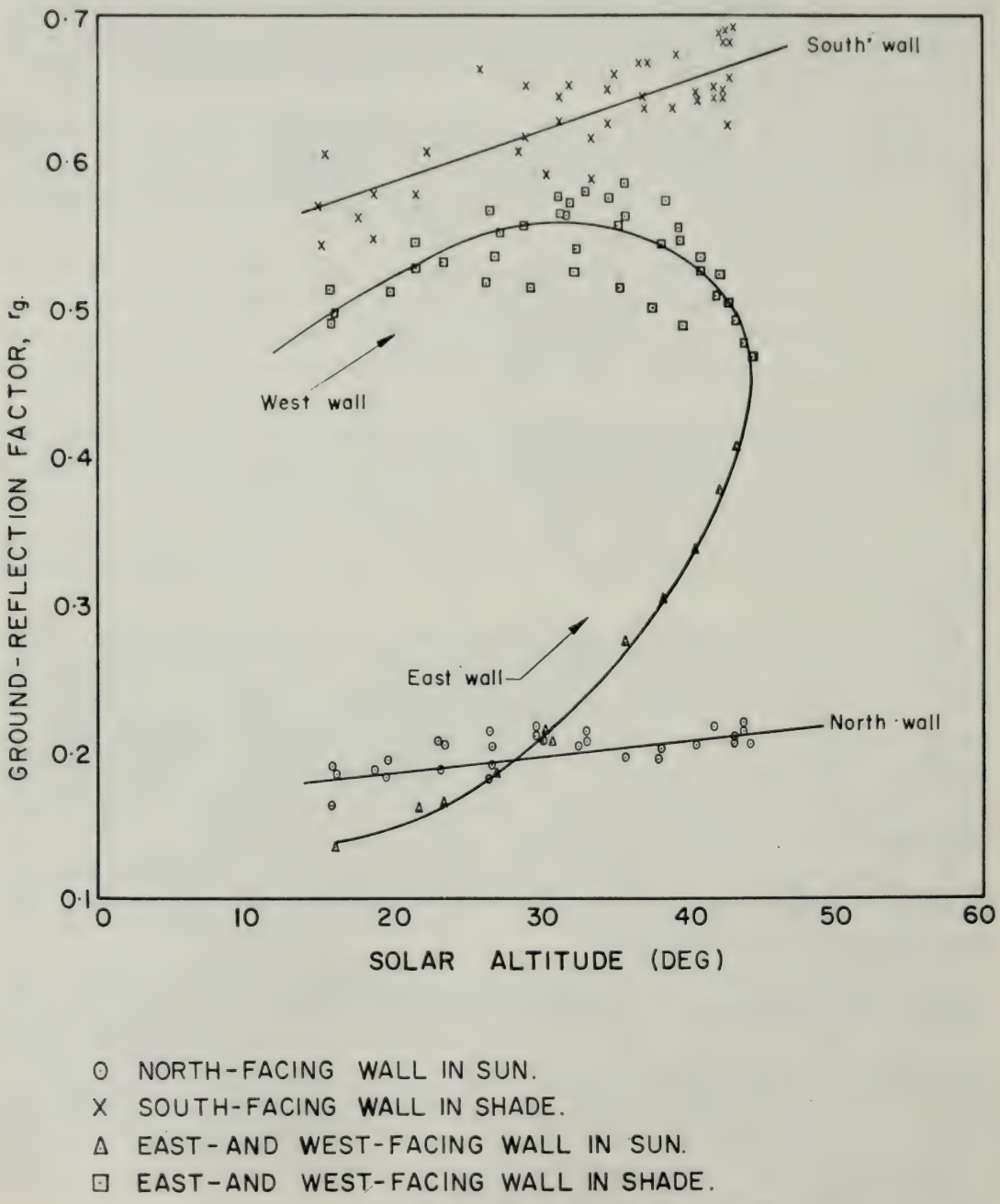

Fig. 1. Variations of ground reflection factor with solar altitude for walls of different aspect both in sun and shade

2. *Ground Reflected Component*

In order to measure the ground reflected and diffuse sky components separately, use was made of a detachable semi-circular anti-reflective screen. The screen could be attached in such a way as either to exclude or to admit all the radiation reflected from the ground.

DISCUSSIONS

1. *Diffuse Radiation*

(a) *Clear sky conditions.* Clear sky measurements of diffuse plus ground reflected components were made during the winter–spring period June–October 1962. Unfortunately it was not possible to measure the atmospheric turbidity during this period.

For analysis the ratios of vertical to horizontal fluxes were grouped according to solar altitude and azimuth. For the sake of generality, azimuth in this context is defined as the difference between the azimuth angle of the sun and the azimuth angle of the normals to the surfaces under consideration.

The ratios were then plotted against solar height for given values of azimuth. These relationships were found to be linear for solar heights between 30° and 70°, the latter value being the maximum solar height experienced during the period of measurement. For solar heights less than 30° the ratios showed great variability as a result of turbidity and the large values of optical air mass involved and were, therefore, discarded for the purpose of this study.

From these relationships the ratios for every 10° of solar height from 30° to 70°, for every 10° of azimuth from 0° to 180°, were read off and are tabulated in the attached table.

By extrapolating the lines to a solar height of 90° they should then intercept the 0.5 value of the ratio if the ratio is one of diffuse fluxes only. It was found, however, that the intercepts lie between 0.6 and 0.75 in most cases. These higher values result primarily from the added contribution of ground reflection.

The values given in Table 1 show that on the average vertical surfaces receive more diffuse radiation, i.e. diffuse radiation from the sky plus ground reflected radiation, than a horizontal surface which, of course, is only exposed to the sky. The ratios vary from 1.0 for high solar heights around noon to more than 2 for low solar heights occurring during the first hour or two after sunrise and last hour or two before sunset. The ratios greater than about 1.5 are perhaps slightly misleading in the sense that they are unrealistically high. At low solar altitude with a turbid atmosphere there is strong circumsolar diffuse radiation. The angle of incidence of this intense circumsolar radiation is small with respect to a pyranometer facing either east or west, but large with respect to one mounted horizont-

Table 1. Ratios of Diffuse Sky plus Ground Reflected Solar Radiation on Vertical Surfaces to Diffuse Sky Radiation on a Horizontal Surface for Different Solar Heights and Azimuth Angles under Clear Sky Conditions for Pretoria

Azimuth (degrees)	Ratio				
	Solar height (degrees)				
	30	40	50	60	70
0	2.1	1.8	1.6	1.4	1.1
10	2.0	1.8	1.6	1.4	1.1
20	2.0	1.8	1.5	1.3	1.1
30	1.9	1.7	1.5	1.3	1.1
40	1.8	1.6	1.4	1.2	1.0
50	1.7	1.5	1.4	1.2	1.0
60	1.7	1.5	1.3	1.2	1.0
70	1.7	1.5	1.4	1.2	1.0
80	1.9	1.7	1.4	1.2	1.0
90	1.8	1.6	1.4	1.2	1.0
100	1.8	1.6	1.4	1.2	1.0
110	1.8	1.6	1.4	1.2	1.1
120	1.7	1.5	1.3	1.2	1.0
130	1.7	1.5	1.3	1.2	1.0
140	1.6	1.4	1.3	1.1	1.0
150	1.7	1.5	1.3	1.2	1.0
160	1.8	1.6	1.4	1.2	1.0
170	2.0	1.7	1.5	1.2	1.0
180	2.0	1.7	1.5	1.3	1.0

ally. Assuming that the sensitivity of all these pyranometers is identical then, due to their cosine response, a vertical pyranometer will give a larger output than a horizontal one, falsely implying that the vertical instrument receives more radiation. In future measurements it is hoped to take account of the cosine response of the pyranometers when reducing the records.

Despite the foregoing the results nevertheless indicate how important ground reflected radiation can be, particularly if it is borne in mind that a vertical surface can never receive more diffuse radiation from the sky than a horizontal surface.

(b) *Cloudy sky conditions.* Measurements of diffuse ratios, including ground reflection under cloudy sky conditions, were made during the autumn of 1963, after which they had to be discontinued because of the cloudless conditions generally experienced in Pretoria in winter. Although a fairly large number of ratios was determined in this manner, only about 50 can be considered as representing cloudy conditions and this is considered too small a sample from which to draw any valid conclusions. Nevertheless, with the sky approximately half-covered by

cloud the ratio seemed to be of the order of 1.0, whilst, under overcast conditions, the ratio was on the average about 0.5.

In order to get valid information on the quantitative contribution of the short-wave radiation components under cloudy sky conditions, very extensive measurements will have to be made, because the magnitudes of the various components are functions not only of cloud type and cloud amount but also of cloud distribution in the sky.

2. *Short-wave Radiation Reflected from the Ground*

More than 100 observations of the ground reflected component of solar radiation on the vertical surfaces under cloudless conditions were made during July 1963.

The ground surface surrounding the observation station was reasonably free from obstructions, the closest solid obstruction being an experimental building of roughly the same dimensions as the observing station and approximately 100 yards removed from it to the west. The surface itself was reddish-brown soil with patches of mown grass.

For the purpose of this paper the ground reflection was expressed as

$$r_g = \frac{r}{d_v + r}$$

where r_g = ground reflection factor,
r = ground reflected component of solar radiation on vertical surface,
d_v = diffuse radiation component on vertical surface,

i.e. ground reflection is given as the ratio of the ground reflected component to the total diffuse radiation on the vertical surface.

The values of the ground reflection factor, r_g, are plotted in Fig. 1. against the complement of the angle of incidence of the direct solar beam with respect to the ground or, in other words, the solar altitude. The reflection factor with respect to surfaces in shade and in the sun are indicated separately.

Considering firstly the ground reflection factor with respect to the west wall, it will be seen that the values of r_g for the wall in shade, for the range of solar altitudes during the period of measurement, increase at first, reach a maximum and then start decreasing rapidly as the sun moves to its maximum altitude at solar noon, a turning point being reached at solar noon when the surface is still just in shade. This decrease continues as the surface becomes sunlit, but at a decreasing rate.

This phenomenon can be explained on the basis of the increase of the diffuse radiation component as the surface becomes sunlit and the continuing increase in the contribution of this component as the angle of incidence of the strong circumsolar band of diffuse radiation decreases, the accompanying increase in ground

reflection being small in comparison with sky radiation. The initial increase in r_g values for surfaces in shade is attributable to the fact that the intensity of the direct beam increases with solar height, causing a similar increase in the ground reflected component. As the sun moves through these low solar altitudes the increase in the diffuse component from that part of the sky to which the surface is exposed does not increase at the same rate as the other two components, because the main increase in diffuse radiation intensity takes place in the vicinity of the sun. With increasing solar altitude, however, the zone of strong circumsolar diffuse radiation intensity moves into that part of the sky to which the surface is exposed.

Essentially, the same reasoning applies for the east-facing surface, but in the case of north- and south-facing surfaces the situation is different. During winter a north-facing surface is sunlit for the full period of daylight hours, while a south-facing surface is not exposed to the sun at all.

A great many more observations will have to be made, not only to cover the full range of solar altitude variations and other types of surrounding surface but also the effect of measuring the ground reflected component at varying heights above the ground. Nevertheless, the above information is indicative of the importance of the ground reflected component and its variation with respect to a wall in shade and sunlight.

REFERENCES

Radiation instruments and measurements. *IGY Instruction Manual*, Part VI. (1957) Pergamon Press, London, 426–429.

Drummond, A. J. (1956) On the measurement of sky radiation. *Arch. Meteor. Geoph. Biokl.* B, 7, 437–465.

RADIATION IN RELATION TO BIOLOGICAL OBJECTS

THE BALANCE OF RADIATION IN THE FOREST AND ITS BIOLOGICAL FUNCTION

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Abstract – By the structural, vertical arrangement of plants and of plant stands the external energy in the form of radiation is available inside the stand room in typical vertical distributions. Therefore the importance of this energy distribution for the plant life inside the stands has been considered. The principal connections between the energy exchanges and the physiological processes of plants are shown. The vertical profile of net radiation and of the other characteristic meteorological elements like temperature, wind, CO_2 and evaporation, inside the stands are explained. The vertical distribution of energy results in an important biological zonation of plant stands: The upper layer of the trees is a zone of maximum transpiration. The light-crown is the layer of maximum positive net-assimilation and the shadow-crown, as well as the stem-room below, are layers of negative plant matter production.

Zusammenfassung – Infolge des strukturellen vertikalen Aufbaues der Pflanzen und der Pflanzenbestände steht die primäre äußere Energie in Form von Strahlung im Bestandsraum in typischen vertikal gegliederten Verteilungen zur Verfügung. Es ist daher überlegt worden, welche Bedeutung die Energieverteilung für das Pflanzenleben im Bestande hat. Die prinzipiellen Zusammenhänge zwischen den Energieumsätzen und den pflanzenphysiologischen Vorgängen werden dargelegt. Sodann sind die Vertikalprofile der Strahlungsbilanz und anderer charakteristischer meteorologischer Zustandsgrößen wie Temperatur, Wind, CO_2 und Verdunstung aufgezeigt. Die vertikale Energieverteilung resultiert in einer biologisch wichtigen vertikalen Zonation im Pflanzenbestande: Die Baumschicht oberhalb der Lichtkrone (= Gipfelraum) ist die Zone maximaler Transpiration, die Lichtkrone ist die Schicht maximaler positiver Nettoassimilation und die Schattenkrone und der darunterliegende Stammraum sind Zonen negativer Bilanz der Pflanzenproduktion.

Résumé – Par suite de l'étagement vertical des plantes à l'intérieur des peuplements forestiers, l'énergie primaire extérieure disponible sous forme de rayonnement se scinde verticalement à l'intérieur du peuplement en étages typiques. On recherche ici à expliquer la signification qu'a la répartition de l'énergie disponible pour la vie des plantes. Pour ce faire, on expose tout d'abord les relations de principe existant entre les échanges d'énergie et les fonctions phytophysiologiques. On indique ensuite les profils verticaux du bilan de radiation et d'autres facteurs météorologiques tels que la température, le vent, le CO_2 et l'évaporation. Après la mise en parallèle des fonctions énergétiques vitales des plantes et des profils verticaux des échanges d'énergie, on tire pour terminer les conclusions biologiques qui en découlent. La répartition verticale de l'énergie se traduit dans le peuplement par un étagement important du point de vue biologique. La couche située au-dessus des couronnes (étage des têtes) présente la plus forte transpiration; les couronnes occupent la

zone de la plus forte assimilation nette; alors que les parties ombragées de la couronne et les troncs ont un bilan de production ligneuse négatif.

PLANT life is dependent upon energy exchanges. These cause, and govern the course of, photosynthesis and photolysis; and regulate the intensity of the uptake of water and nutrients from the soil, the movement of sap within the plant, and transpiration.

Energy is made available to the plants from the external environment mainly by radiation and the heat in the surrounding air: the internal energy in the form of the sensible and the chemically convertible heat of the plant mass, is of secondary importance; and in any case such exchanges are governed by the external sources of energy. By reason of the vertical arrangement of the plant structure the external energy becomes available in characteristic vertical profiles.

According to the relationships mentioned above the importance for plant life of the vertical distribution of available energy will be considered. First the main relationships between energy exchanges and physiological processes will be dealt with; next the characteristic measured components of the distribution of energy within the stands will be set out; and finally, after linking the energy functions of the physiological processes with the vertical profiles of energy exchange, certain biological consequences will be drawn.

FUNCTIONAL DEPENDENCE OF PLANT LIFE UPON ENERGY EXCHANGES

(a) Transpiration

The largest energy exchanges in plant life are associated with transpiration (T) which increases proportionally with the evaporating power of the air. The factor of proportionality, i.e. the evaporation-enthalpy, amounts to between 575 and 590 cal/g water according to the temperature.

As long as the stomata of the transpiring organs are open, the transpiration (T) increases with the available external energy as given by Hofmann (1955) and Kortüm (1956/57) viz.

$$T = w_s(S + B) - w_v \alpha_L (1 - f)$$

where

S = net radiation
B = interior heat flux in the plant
$(1-f)$ = the saturation deficit
w_s, w_v = coefficients depending on the temperature
α_L = the heat transfer coefficient.

The vertical distribution of water vapour exchange in the plant stand depends, on the one hand upon the vertical distribution of the transpiring plant surfaces,

and on the other hand on the distribution of radiant energy, temperature of air and plant tissue and upon the exchange of heat and water vapour. For these exchange processes, profiles of wind velocity and turbulent coefficient are criterions.

(b) The Flux of Sap

Compared with the energy utilised in transpiration, that required for the uptake of water and nutrients from the soil, and for the transport of water to the transpiring plant surface, is relatively small (Table 1). For a daily evaporation of 2 mm depth of water, the energy required to lift the water to the top of a tree 20 m high amounts only to about 1×10^{-5} cal/cm^2 min.

Table 1. Comparison of Energy Involved in Various Plant Functions, as a Percentage of Net Radiation

Transpiraton	Assimilation	Respiration	Flux of sap
60	1.5	0.5	0.001

(c) Photosynthesis, Gross-assimilation

The energy exchange in photosynthesis is given by the equation

$$6 \text{ Mol } CO_2 + 6 \text{ Mol } H_2O + 700 \text{ cal} \rightleftharpoons 1 \text{ Mol } C_6H_{12}O_6 + 6 \text{ Mol } O_2$$

where 4000 cal are required for the synthesis of 1 g of glucose from CO_2 and the water of plant sap. Associated with this, 2700 cal are necessary for the assimilation of 1 g CO_2.

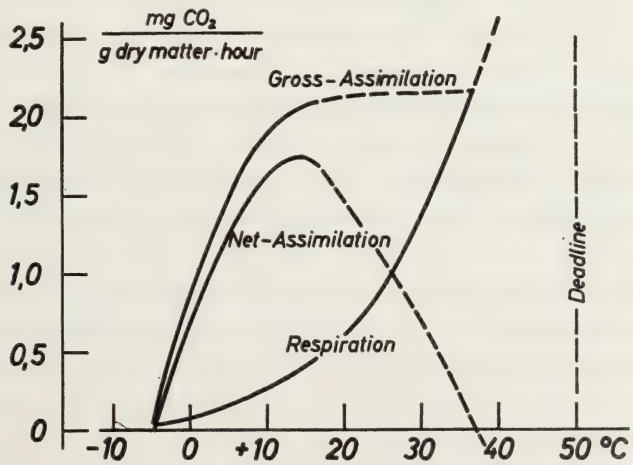

Fig. 1. Dependence of gross and net-assimilation, and of respiration, in the temperature of needles of a cembra-pine, exposed to the sun. Tranquillini (1955)

For the conversion, only energy in the visible spectrum (and with maxima near 430 mμ and 650 mμ) is needed, and hence photosynthesis can only be effective in the daytime. For physiological reasons, photosynthesis reaches a maximum at about 40×10^3 lux, and on a clear summer day about 3 mg of assimilate are formed per cm^2 of ground surface – this corresponds to about 10 cal of solar radiation.

Thus, the vertical distribution of photosynthesis within the plant stand depends on the distribution of the assimilating organs and the vertical profile of light energy. The amount of energy in the visible spectrum increases with that in the complete solar spectrum. In general, plant and air temperature will increase with net solar radiation and hence the relationships between assimilation and these two variables will be similar to that between light and assimilation. In Fig. 1 is shown the dependence of assimilation on temperature as derived by Tranquillini (1955) for cembra-pines.

(d) Photolysis, Respiration

The energy exchanges during photolysis are also given by the assimilation equation. Each gram of glucose which is split into water and CO_2 by the uptake of oxygen supplies about 4000 cal. Respiration takes place from all parts of the plant both by day and night and increases with rising temperature (see Fig. 1). As temperature increases almost proportionally with the radiation exchange, the energy exchanges during respiration are strictly correlated with radiation exchange and with net-radiation.

(e) Net-assimilation

The net energy exchange associated with the process of assimilation results from a balance between the expenditure of energy during photosynthesis and the heat release during respiration. This balance is negative in the daytime since photosynthesis then predominates. It amounts to between 1 and 5 per cent of the energy from sun and sky (see Wassink, 1948; Baumgartner, 1956; Bray, 1962, and others). At night the balance is positive, heat is released during respiration and amounts to some 20 to 60 per cent of that used in photosynthesis, depending on the type of plant and the temperature. Thus only some 40 to 80 per cent of the gross assimilation is retained.

The joint action of photosynthesis and photolysis results in the net assimilation increasing to an optimum as the available external energy increases, followed by a decrease due to an almost constant level of photosynthesis and a sharply increasing respiration. Finally, for a certain level of external energy more plant material may be consumed than is produced.

It would be incorrect to measure the energy expended in producing plant material by considering only that directly utilised in photosynthesis. Assimilation is dependent on the process of transpiration. Koch (1957) found the "productivity

of transpiration", i.e. the ratio of the produced dry plant matter (g) to the quantity of transpired water (g), to be of the value 11.3×10^{-3}. That means for assimilation of 1 g CO_2 as an average 90 g water has to be transpired. Energetically seen the ratio is of the order 2700 cal : 90×590 cal or 5×10^{-2}. In other words the economy of plant production requires more than 20 times the energy as evaluated for the chemical process of assimilation separately. In line with these statements are the results of Turner (1960). He found that the production of plant material by the alpine cembra pine is related to the various ranges of radiation intensity as follows:

Radiation (cal/cm² min)	Net-assimilation
<0.02 (below 1600 lux)	Negative balance of plant matter; owing to the lack of light, the photosynthesis is smaller than the respiration
0.02–0.3 (about 1600–25000 lux)	Positive balance of matter; net assimilation increases with increase of light intensity
0.3–0.7 (about 25000–60000 lux)	Optimal balance of matter
>0.7 (more than 60000 lux)	Positive balance of matter; but due to the increase of stomata-closure and the increasing respiration, the balance of matter is reduced and at a definite limiting radiation may become negative

These results are in good agreement with those of Gaastra (1962) who reported optimum production of plant material even at about 0.2 cal/cm² min. We may suggest that maximum production will occur when the various exchanges of radiant energy result in a net value of about 0.5 cal/cm² min.

THE ENERGY DISTRIBUTION WITHIN STANDS

The discussion so far shows that to account for the physiological economy of plants, the following meteorological data are essential: net radiation, heat exchange between plant surface and the air, CO_2 content of air within the stand, and the vertical profile of light intensity. It is now proposed to deal with the distribution of these variables within the plant stand.

(a) Net Radiation

Net radiation is defined as the balance of the radiative fluxes towards the upper surface of the stand and through this level. The vertical distribution of net radiation in a young spruce forest near Munich, Southern Germany in 1952 on a hot day

in high summer is shown in Fig. 2. Measurements were taken at six levels above the ground.

The maximum exchange takes place in the upper layer of the "light" crown (refer to Fig. 3) of the forest stand. Towards the interior, the radiation exchange decreases rapidly. If the relative height of the ground surface is denoted by zero,

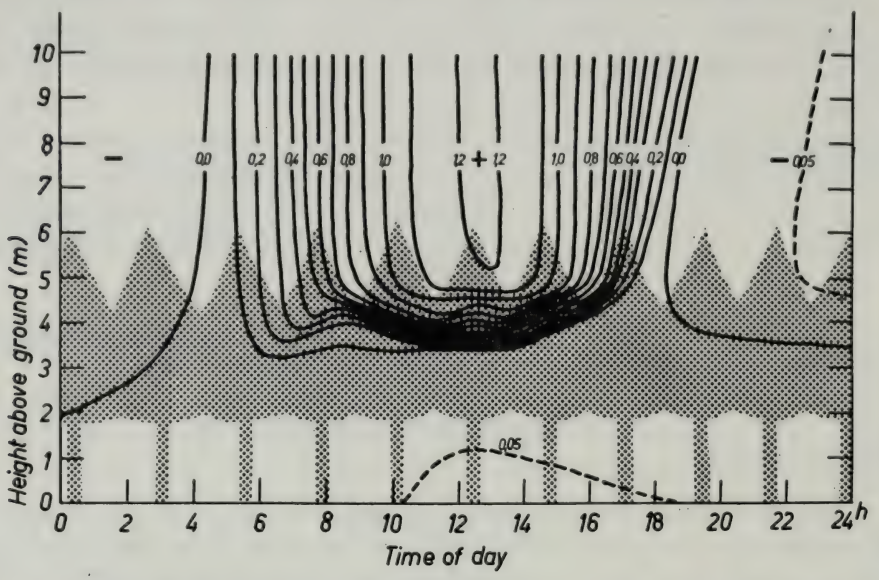

FIG. 2. Vertical distribution of net radiation on a hot day in high summer in a young spruce forest near Munich

and the average height of the tops of the trees by 1.0, radiation exchange within the forest is distributed as follows:

Relative height:	0 – 0.2	– 0.4	– 0.6	– 0.8	– 1.0	–
Radiation exchange (%)	6	1	5	46	40	2

The figures show that at a relative height of 0.5 there is a steep gradient in the radiant energy exchange (see Fig. 3), 88 per cent of the energy supplied by radiation being transformed in the upper half of the stand and only 12 per cent below that level. Denmead, Fritschen and Shaw (1962) report a similar result for maize, 73 per cent of the available energy being transformed in the upper half of the stand.

(b) Temperature, Wind, CO_2, Potential Evaporation

The vertical distributions of temperature, wind velocity, CO_2 and potential evaporation (obtained by measurements with the Piché-evaporimeter) are set out in Fig. 3. Along the ordinate is a "model" tree derived from measurements of the heights of trees in a 100 m² test plot. Four zones are defined, viz the "stem-room"

(or trunk-space), the "shadow" crown, the "light" crown and that occupied by the tree-tops (the "top storeys").

During the daytime the maximum air temperature occurs at a relative height of 0.7; the night minimum is found lower in the stand at a height of about 0.2. The temperature range in the vertical profile amounts to about 5° C.

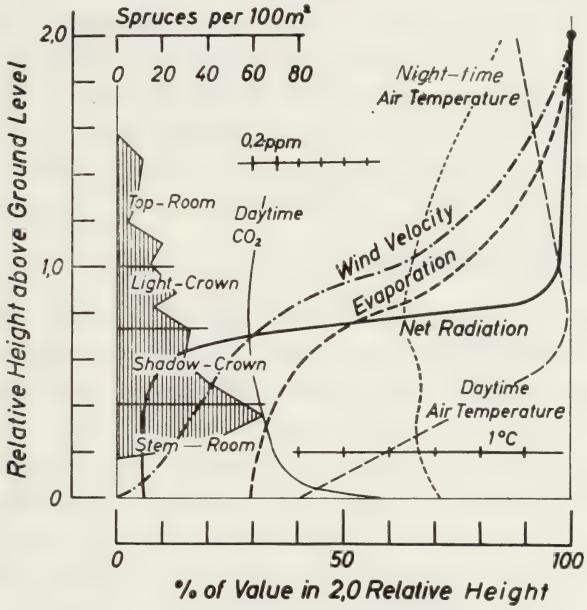

FIG. 3. Vertical distribution of various meteorological parameters in a young spruce forest

The wind velocity within the stand is small. It increases slowly through the "light" crown, but rapidly in the zone of the tree tops and above. The maximum turbulent exchange of air is observed in the tree tops (see also Inoue, 1962; Uchijima, 1962).

The distribution of CO_2 is quoted from Miller and Rüsch (1960). There is a shallow minimum at the level of the "light" crown, towards which there is a flux of CO_2 both from above and below. The gradient of CO_2 concentration is high at low levels but is associated with a low exchange coefficient, whilst the gradient down from the atmosphere to the stand is small but the exchange coefficient is relatively large.

The vertical profile of potential evaporation within the stand is roughly parallel to those of both radiation intensity and wind velocity.

THE IMPORTANCE OF THE VERTICAL DISTRIBUTION OF ENERGY FOR THE PHYSIOLOGY OF PLANTS IN STANDS

The linkages between plant physiological functions dealt with in Section 1 and the detail of energy distributions considered in Section 2 lead to the following deductions.

(a) With Respect to Transpiration

The large gradients of net radiation and of wind velocity in the zone of the "shadow" crown implies that plant tissue in the "light" crown and especially in the uppermost portion of the stand form a region in which the maximum transpiration stress is imposed upon the plant's surfaces. However, the leaf area index (LAI, i.e. the ratio of the integrated leaf area per unit area of ground surface) increases from the top downwards towards the "light" and "shadow" crowns, although the transpiration stress decreases. As a result the greatest amount of water vapour lost by transpiration takes place in the lower part of the "light" crown: similar results have been found by Penman and Long (1960) and Inoue (1962).

(b) With Respect to Photosynthesis

The vertical variation of light intensity within the stand which is important for photosynthesis, is almost coincident with that of net radiation. As maximum assimilation is reached at 30000 lux, the light in the upper parts of the crown is more than sufficient. Greater light intensities than 30000 lux cause contraction of the stomata which inhibits the exchange of CO_2 and of water. Accordingly, as far as light intensity is concerned, the zone of the most intense photosynthesis should lie in the upper parts of the "shadow" crown. However, CO_2 concentration also regulates photosynthesis and has a minimum at a relative height of 0.9 and a maximum towards the trunk-space: accordingly the optimum level for CO_2 assimilation occurs where the "shadow" crown ends – at a relative height of about 0.7. Finally, taking account of the leaf area index which indicates the number of assimilating plant surfaces, it is to be expected that the most intensive production of plant material will occur between the upper and the lower "shadow" crown (see Fig. 4).

(c) With Respect to Respiration

Respiration reaches its maximum where temperature is highest; thus during the day per unit area of plant tissue most CO_2 will be respired from the upper portion of the main crown. Temperature over the whole stand will vary by several degrees during the day, and loss of plant matter per unit area of plant surface will vary less over the stand than will the other physiological processes.

(d) With Respect to Net-assimilation

The strongly varying profile of photosynthesis and the relatively uniform distribution of respiration, implies big variations in net assimilation: the production of plant matter being positive above the "shadow" crown and negative below. This finding also follows if the relationships found by Turner (1960) are applied to the case under consideration – the restricted production of material allied to the rela-

tively high respiration renders the trunk space below the "shadow" crown a region where plant matter is lost. The continued existence of plant material there is caused by the transport of assimilates against the sap flow, by means of which more material will be supplied in the "shadow" crown and below than will be consumed by respiration. Above the "shadow" crown the production is positive with an optimum at the level where the crown itself opens out in the "top storey" of the stand.

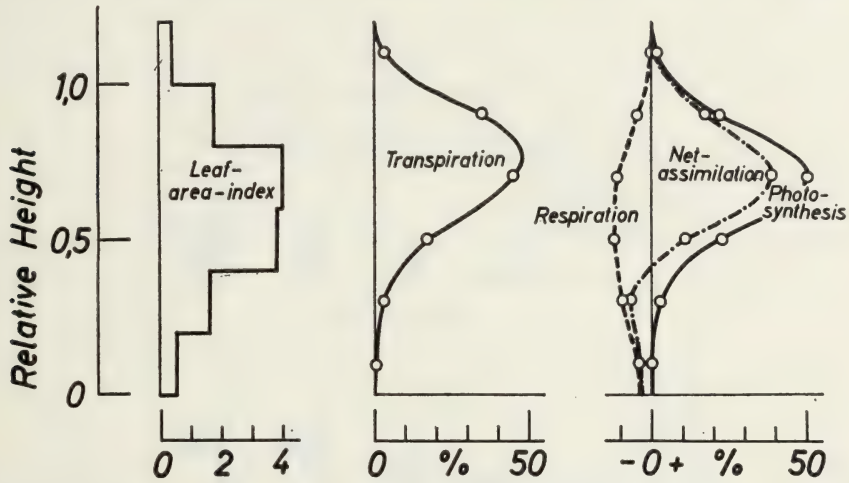

FIG. 4. Vertical profiles of potential photosynthesis, respiration, net-assimilation and transpiration arising from the distribution of energy and the vertical structure of the stand

From that level to the tree tops net assimilation per unit area should be decreasing.

As hypotheses we may postulate:

(i) The top storey of the trees and the upper "light" crown occupy the zone of most intensive transpiration.
(ii) The lower light crown and upper "shadow" crown experience the best conditions for photosynthesis.
(iii) Below the "shadow" crown, energy considerations dictate that respiration exceeds photosynthesis.

EFFECT OF THE DISTRIBUTION OF ENERGY ON THE STRUCTURE OF THE STAND

The zonal distribution of energy influences the structure of the stand, the sociology and composition of individual plants in the stand. The distribution of the organs of transpiration and assimilation are closely correlated with the distribution of energy exchange and with the meteorological variables within the stand which govern the balance of plant material.

These relationships are well illustrated by data from the investigations of Stern and Donald (1962) (Fig. 5). They determined the dry matter for each 3.5 cm thick layer of a mixed grass and clover stand at various dates after sowing. The main increase of plant mass has been observed in the zone of maximum light, which, as the plants grew, was located at increasing heights above ground. Simultaneously plant mass below the level of maximum light decreased. The leaf-area index was a maximum at the level of maximum exchange of radiation. However, a simple

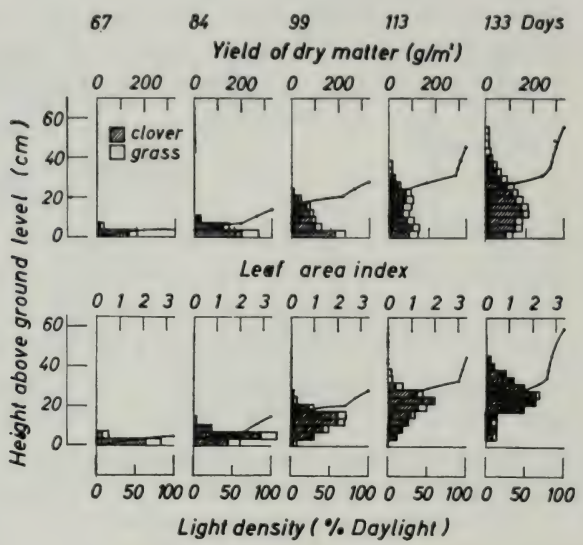

FIG. 5. Distribution of light and vertical arrangement of plant mass and leaf area index within a grass-clover stand. (After Stern and Donald, 1962)

"cause and effect" statement is not possible as each factor is mutually dependent on all the others.

In addition to the vertical zonation of a dense stand with a trunk space devoid of needles, there exists also an axial pattern in the "shadow" and "light" crowns. This structural adjustment to the distribution of light and energy is well illustrated by the investigations of Burger (1952) on wood, leaf quantity and accretion; (see Assmann, 1962, Fig. 61 p. 110). The tree crown has, around the main stem, a core almost devoid of needles which adjoins the crown mantle.

CONSEQUENCES TO AGRICULTURE AND FORESTRY

The relationships elucidated above are already used empirically in agriculture and forestry, when the density and structure of plant stands are managed. By such operations the quantity of plant material and the quality of the product are both influenced. The effects of these cultural measures are not least due to changes in

the vertical distribution of energy (see Tanner, Peterson and Love, 1960; Yao and Shaw, 1961).

We may conclude that by changing the density of the stand, and especially by varying the vertical structure of plant and plant stand, we can effect improvements in the efficiency of water usage through transpiration, and CO_2 consumption through assimilation. It is hoped that the relationships dealt with above will be studied more intensively and that the hypotheses advanced may stimulate this work.

ACKNOWLEDGEMENT

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REFERENCES

Assmann, E. (1962) *Ertragskunde*. Bayerischer Landwirtschaftsverlag, München.

Baumgartner, A. (1956) Untersuchungen über den Wärme- und Wasserhaushalt eines jungen Waldes. *Ber. Dtsch. Wetterdienst*, **3,** Nr. 28.

Burger, H. (1952) Holz, Blattmenge und Zuwachs. *Mitt. d. Schweiz. Bundesanst. f.d. Forstl. Versuchswesen.*

Bray, I. R. (1962) Estimates of Energy Budgets for a Typa (Cattail) Marsh. *Science*, **136,** 1119–1120.

Denmead, O. T., Fritschen, L. J. and Shaw, H. R. (1962) Spatial Distribution of Net Radiation in a Corn Field. *Agron. J.* **4,** 505–510.

Gaastra, F. (1962) Photosynthesis of Leaves and Field Crops. *Netherl. J. Agric. Sci.* **10,** 311–324.

Hofmann, G. (1955) Die Thermodynamik der Taubildung. Ber. *Dtsch. Wetterdienst*, **3,** Nr. 18.

Inoue, E. (1962) *The Environment of Plant Surfaces.* Symposium Paper No. 3, Canberra Coll. on Environmental Control of Plant Growth, Canberra, Australia.

Koch, W. (1957) Der Tagesgang der "Produktivität der Transpiration" *Planta*, **48,** 418–452.

Kortüm, F. (1956/57) Ein Beitrag zur Bestimmung der Verdunstung der natürlichen Erdoberfläche. *Wiss. Z. Humboldt-Universität Berlin, Math. Naturwiss. Reihe*, **6,** 433–438.

Miller, R. and Rüsch J. (1960) Zur Frage der Kohlensäureversorgung des Waldes. *Forstwiss. zbl.* 79, 42–62.

Penman, H. L. and Long, I. F. (1960) Weather in Wheat: An Essay in Micrometeorology. *Quart. J. roy. Meteor. Soc.* **86,** 15–50.

Polster, H. (1950) *Die physiologischen Grundlagen der Stofferzeugung im Walde.* Bayer. Landwirtschaftsverlag München.

Stern, W. R. and Donald, C. M. (1962) Light Relationships in Grass-Clover Swards. *Austr. J. Agric. Res.* **13,** 599–614.

Tanner, C. B., Peterson, A. E. and Love, J. R. (1960) Radiant Energy Exchange in a Corn Field. *Agron. J.* **52,** 373–379.

Tranquillini, W. (1955) Die Bedeutung des Lichtes und der Temperatur für die Kohlensäureassimilation von *Pinus Cembra*-Jungwuchs an einem hochalpinen Standort. *Planta*, **46**, 154–178.

Turner, H, (1960) Jahresgang und biologische Wirkung der Sonnen- und Himmelsstrahlung an der Waldgrenze der Ötztaler Alpen. *Wetter und Leben* **13**, 93–113.

Uchijima, Z. (1962) Studies on the Micro-Climate within Plant Communities. (2). The scale of Turbulence and the Momentum Transfer within Plant Layers. *J. Agric. Meteor.* **18**, 58–65.

Wassink, E. C. (1948) See Gaastra (1962)

Yao, Y. M. and Shaw, R. H. (1961) The Effect of Plant Population and Planting Pattern of Corn on Radiation Interception and Water Use. Final Report U.S. Weather Bureau Contract CWB-9783 Iowa State University.

THE IMPORTANCE OF SOLAR RADIATION IN FOREST REGENERATION BY GROUPS

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Abstract – The problems of forest regeneration are intimately concerned with solar radiation. In group working a certain amount of protection is afforded by the forest. The shade cast in small groups varies with the height of the stand and with the sun's altitude. The shadows cast by stands of different sizes in mid-summer and at the equinoxes are recorded for different locations at 51°, 55°, and 59° north latitudes. The mean daily totals of total solar radiation are recorded for four separate months, in central Scotland, in southern England, Stockholm, Copenhagen, Brussels and Rouen. The size of the forest gaps created for regeneration, which should be between 0.4 and 2.0 hectares, is discussed. A series of light intensity values as percentages of full light in the open is given for four different types of groups in two different forests in Scotland.

Zusammenfassung – Die Probleme der Aufforstung sind mit der Sonnenstrahlung eng verbunden. Bei der Aufforstung von kleinen Bereichen im Wald bietet dieser selbst einen gewissen Schutz. Die Beschattung kleiner Gruppen hängt von der Höhe des Bestandes und von der Stellung der Sonne ab. Es werden Schatten verschieden grosser Bäume im Hochsommer und den Äquinoktien für verschiedene Orte in 51°, 55° und 59° nördlicher Breite angegeben. Der tägliche Mittelwert der Sonnenstrahlung wird für 4 Monate für Mittelschottland, Südengland, Stockholm, Kopenhagen, Brüssel und Rouen angegeben. Die Grösse der Lichtungen für Wiederaufforstungszwecke soll zwischen 0,4 bis 2,0 Hektar liegen. Werte der Lichtintensität in Prozent der Globalstrahlung werden für 5 verschiedene Typen in 2 Wäldern in Schottland berichtet.

Résumé – La méthode de régénération forestière par groupes revêt une importance considérable en sylviculture. Les problèmes du rajeunissement y sont étroitement liés au rayonnement solaire. Il ne faut pas abattre tous les arbres, car, ce faisant, on détruirait le microclimat forestier. L'ombre projetée par de petits groupes varie avec la hauteur des arbres et la hauteur du soleil. L'ombre projetée par des arbres de hauteurs différentes est reportée pour le milieu de l'été et les équinoxes et cela pour des endroits situés par 51°, 55° et 59° de latitude nord. Les moyennes quotidiennes du rayonnement solaire total sont rapportées ici et tirées pour quatre mois différents, en Ecosse centrale, dans le sud de l'Angleterre ainsi qu'à Stockholm, Copenhague, Bruxelles et Rouen. La dimension des trouées faites pour la régénération est en outre discutée. On propose de compter de 0,4 à 2,0 ha. Enfin, on donne pour cinq types de groupes différents une série de valeur d'intensité lumineuse exprimée en pour-cent de la lumière maximum tombant en rase campagne. Ces valeurs se rapportent à deux forêts distinctes situées toutes deux en Ecosse.

THE method of obtaining forest regeneration by groups is recognized as being of considerable importance in forestry on the Continent, and is now of necessity, being

critically examined in British forestry. The problems of group regeneration are closely concerned with solar radiation, and it is only by its careful study that the difficulties of that type of regeneration can be resolved.

It is now realized that extensive clear felling of forests is undesirable. It destroys the forest environment which has been created slowly, and the ensuing regeneration must start on exposed situations with obvious disadvantages from weed growth and exposure, until cover of some kind is again produced. This has been stressed, for instance, by some Belgian foresters, including Roisin (1959), and there is now a general trend towards felling in a restricted manner, so as to create small areas for regeneration within the forest environment, wherein a certain amount of protection is afforded.

Variations in latitude and in elevation cause obvious changes in the growth of the individual tree species, which in turn, affect productivity from the forest. The range of latitude in any country is important in regard to the intensity of solar radiation due to the varying altitude of the sun. Solar radiation is, in fact, of vital importance when forests are cut so as to create small protected gaps in which regeneration by natural or artificial methods is required.

Variations in the intensity of solar radiation reaching the earth's surface occur with the inclination of the earth on its axis and the resulting variation in the altitude of the sun during the year. The intensity of the solar radiation reaching a given surface, varies due to a number of factors, including the geographical location, elevation, aspect, slope, exposure or shelter, amongst others. When there is any substantial obstructive element, then a shadow is cast in which the light intensity and the radiant heat received, are reduced.

The sun's azimuths and altitudes vary with the seasons and they affect the depth of the shadow cast on a restricted area, such as a gap in woodland where a well or hole of a kind, is created. These variations, taken from astronomical tables, are given in Table 1, which for three different locations, gives the azimuths of the rising and setting sun, measured east or west of north, and for the maximum altitude of the sun for the winter and summer solstices and for the equinoxes. The lengths of shadows at 12 noon, cast by the two heights of trees of 22.86 and 30.48 m are given at the summer solstice and at the equinoxes.

This table illustrates the difference in lengths of shadows cast at mid-day by the two heights of trees or tree stands, at latitudes of 51°, 55°, and 59° North. It will be seen, therefore, that the shadow cast by a tree stand 30.48 m in height, varies at mid-summer from 21.8 m on latitude 59° N at the height of the growing season, to 15.9 m on latitude 51° N, whilst at the equinoxes in March and September, the shadows cast by the same height of stand varies from 50.6 m on latitude 59° N to 37.6 m on latitude 51° N.

The distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas, has been recorded by Day (1961), the radiation being measured in mw hr/cm^2/day. The striking variations between the solar radiation in Scotland, southern England, the Channel Islands, Sweden, Denmark, Belgium and

Table 1. Azimuths of Rising and of Setting Sun, Maximum Altitudes of Sun, and Shadow Lengths at Different Latitudes

Location	Latitude	Azimuths rising and setting sun measured east or west of north			Maximum altitude of sun at 12:00 h			Shadow lengths at 12:00 h for tree heights of 22.86 m and 30.48 m			
		Winter	Summer	Equinoxes	Winter solstice	Summer solstice	Equinoxes March and Sept.	Summer		Equinoxes March and Sept.	
								Tree ht. 22.86 m	Tree ht. 30.48 m	Tree ht. 22.86 m	Tree ht. 30.48 m
								Metres	Metres	Metres	Metres
Oslo and Stromness	59° N	138° 25′	37° 7′	89° 16′	7° 40′	54° 28′	31° 2′	16.3	21.8	37.9	50.6
Flensburg and Annan	55° N	132° 16′	44° 21′	89° 18′	11° 38′	58° 28′	35° 1′	14.0	18.7	32.6	43.5
Brussels and Southampton	51° N	127° 53′	49° 24′	89° 20′	15° 37′	62° 28′	39° 1′	11.9	15.9	28.2	37.6

north-west France are recorded in Table 2, with due acknowledgements, from Day's charts in the paper under reference.

This table demonstrates the variation in the mean daily totals of the total solar radiation over a wide range. It will be observed that there is a definite maritime influence in the English Channel and on the North Sea coasts: the values do not follow approximate lines of latitude, but exhibit great variation due to the continentality of western Europe. It will be noted that there is a higher total solar radiation at Rouen than in Stockholm, which in turn, records a higher value than that of central Scotland. The Channel Islands have the highest total for the recorded series. The totals of the solar radiation for the four months are given, for easy comparison, between the seven locations.

Table 2. Mean Daily Totals of Total Solar Radiation mw hr/cm²/day

Location	January (1)	March (2)	June (3)	September (4)	Total (1, 2, 3 & 4)
Stirling (central Scotland)	50	200	450	225*	925
New Forest (south England)	70	260	550	300	1180
Channel Islands	80	300	700	375	1455
Stockholm	30	210	565	275*	1080
Copenhagen	60	260	550	325	1195
Brussels	60	230	475*	300	1065
Rouen	80*	280	550	375	1285

(* Interpolations)

Attention must be drawn to the valuable information on the radiation climatology of northern Europe, recorded by Black (1960), who shows the distribution of global radiation for the geographical region between latitudes 51° and 61° North, and longitudes 5° to 30° East, in charts for each month. The radiation is recorded, as opposed to Day's charts, with isopleths in cal/cm²/day, and shows the striking variation in the solar radiation values in this portion of northern Europe, the author drawing attention to the area of "high" radiation over southern Scandinavia.

It need scarcely be stressed, therefore, that the conditions of total solar radiation in gaps created for the purpose of obtaining regeneration in Scotland, in the south of England, in southern Scandinavia and in north-west France are very different, and that the area of these gaps and of their overhead canopy openings, vital in successful forest regeneration in each area, can only be assessed in each region by the competent forester.

A considerable amount of research by a number of workers on light intensity has been carried out for some decades; thanks to the realization of its importance and to the improvement in instrumentation in recent years, more useful measurements are now possible. The results already show how important the subject is in modern forestry with its necessary stress on quality, production, forest economics and the replacement of the exploited forest. A series of important papers too, has become available in recent years and Roussel (1962) has produced a valuable paper on solar radiation, in connexion with regeneration by groups and by bands; this paper should prove of great value in the practice of both artificial and natural regeneration of forests.

The size of the forest gap is of primary importance: it has been found that if clear felling is to be avoided, then the area of the forest gap may be somewhere between 0.2 and 2.0 hectares; although smaller gaps than 0.2 hectares have been used, they have numerous disadvantages, principally because insufficient light and warmth reach the forest floor. Any felling of over 2.0 hectares is in the nature of a local clear felling and it too, has several disadvantages. In certain Belgian forest regeneration operations (Roisin, 1959) it has been suggested that the gaps should not be more than 0.5 hectares. Gaps between 0.4 and 0.8 hectares have much to commend them in forest stands of about 20 m in height.

A certain number of projects in the measurement of light intensity in different sizes and shapes of groups have been made by the writer; two series of measurements have been selected for recording here.

The first series was made in a regeneration gap of 0.16 hectares formed by a rectangle of 40.2 m (north to south) by 26.5 m, in a mixed irregular conifer-leaf tree stand of 23 m in height. The average light intensity reaching the floor of the gap was 65 per cent of the full light; that in the southern quarter was 25 per cent, because of the shade cast by the trees on the southern edge of the gap, while the average light intensity in the remainder of the gap was 78.9 per cent of full light. This proved in fact, to be too small a gap, as it was only small groups of European larch (*Larix decidua* Mill.), in the north-east portion, which grew satisfactorily; the other light demanding species did not suceed. It is considered that the size of group should be from 0.4 to 0.8 hectares to obtain satisfactory results in a forest stand of this type.

In the second series, measurements were made in south-west Scotland, in circular gaps of 0.04, 0.12, 0.40 and 4.05 hectares in a Sitka spruce (*Picea sitchensis* Carr.) stand, aged 30 years and averaging 15.8 m in height on the better sites, and with a density of approximately 1060/hectare. There were two treatments in the 0.04 hectare gaps; in the first, ten trees (average height 12 m), were left, while in the second all trees were removed. The resulting measurements showed that there was 26.2 per cent of full light in the open in the gap with 10 trees, and 35.3 per cent in the 0.04 hectare gap with no trees; there was 39.3 per cent in the 0.12 hectare gap (with a tree height of 15.8 m), and 48.3 per cent in the 0.40 hectare gap (with a tree height of 12.8 m).

The mean light intensity in the Sitka spruce stand was 13.6 per cent of full light. At 13:00 h in mid-July, the light intensity in the 0.40 hectare gap was 29.0 per cent on the southern perimeter, 45.5 per cent on the eastern edge, 40.3 per cent on the western edge and 48.5 per cent on the northern perimeter. The intensity of the light was reduced for a distance of approximately 7 m from the southern edge of the gap.

It is obvious that when planting is carried out in regeneration gaps of about 0.04 hectare, only shade tolerant species may be used; that in larger gaps such as the 0.40 hectare, shade bearing species should be used for a distance from the southern perimeter of the gap, equal to the depth of shadow cast on the southern edge of the tree stand by the sun at mid-summer. It will also be necessary to plant the shade tolerant species along the eastern and western edges of the gap for a shorter distance from the stand. The strong light-demanding species should be planted in the form of an ellipse whose centre, in the northern hemisphere, should be north of the centre of the forest gap.

In British forestry it is probable that the forest regeneration gap can usefully be between 0.2 and 1.0 hectare in extent, but the final decision can be made only with due consideration for the geographical location, the latitude, aspect, degree of slope, the soil fertility and the general economic conditions, all of which must be correlated with the objects of management of the forest.

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REFERENCES

Black, J. N. (1960) A contribution to the radiation climatology of Northern Europe. *Archiv Meteor. Geoph. Biokl.* **10,** 182–192.

Day, G. J. (1961) Distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas. *Meteor. Mag.* **90,** 269–284.

Roisin, P. (1959) La Transformation des Pessiéres. *Bull. Soc. Roy. Forest. Belg.* **66,** 153–190.

Roussel, L. (1962) Étude Théorique Élémentaire de la Trouée et de la Bande. *Bull. Soc. Forest. France. Comté et des Provinces de l'Est.* **32,** 552–560.

MEASUREMENTS OF RADIATIVE HEAT EXCHANGE OF SINGLE BIOLOGICAL OBJECTS

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Abstract — The radiative heat exchange of a single biological object can be determined by making use of the Gauss Integral Theorem. The mean value of the integral of the radiative flux normal to a closed surface over a radiative heat source was measured by means of two balanced net radiometers mounted diametrically opposite each other and moving in a helical path so as to sweep out a vertical elongated cylindrical surface surrounding the object, in this case a man. The two radiometers were connected so as to cancel the signal generated by the general ambient flux. End effects, which are minimized by the prolongation of the cylinder above and below the object concerned, were measured separately. Some indoor results are given but preliminary tests indicate this system to be useful out of doors as well.

Zusammenfassung — Die Strahlungsbilanz eines einzelnen biologischen Objectes kann bestimmt werden, indem von dem Gauss'schen Integralsatz Gebrauch gemacht wird. Das Integral der Normalkomponente des Strahlungsstromes über einer geschlossenen Oberfläche wurde mit 2 diametral einander gegenüber montierten Strahlungsbilanzmessern bestimmt, die sich spiralförmig auf und ab bewegten und so einen länglichen Zylindermantel beschrieben, welcher das Objekt, in diesem Falle ein Mann, umgab. Die beiden Strahlungsbilanzmesser wurden auf gleiche Empfindlichkeit gebracht und so geschaltet, dass sich die Signale des Umgebungsstrahlungsfeldes aufhoben. Endeffekte, die dadurch verhindert wurden, dass der Zylindermantel sich über und unter das Objekt erstreckte, wurden getrennt gemessen. Einige Resultate in einem geschlossenen Raum werden angeführt. Vorläufige Experimente haben gezeigt, dass dieses Verfahren auch im Freien anwendbar ist.

Résumé — On peut déterminer les échanges radiatifs d'un objet biologique isolé, si l'on fait usage du théorème de l'intégrale de Gauss. L'intégrale au flux radiatif normal à une surface déterminée a été mesurée par deux bilanmètres de rayonnement disposés diamétralement l'un en face de l'autre et se déplaçant par un mouvement hélicoïdal le long d'une surface cylindrique entourant l'objet, en notre cas un sujet humain. Les deux bilanmètres étaient connectés en opposition de manière à annuler le flux ambiant. Les effets de bord étaient diminués par l'étendue du cylindre au-dessus et en-dessous de l'objet. Ils ont été mesurés séparément. Quelques résultats de mesures effectuées en laboratoire sont présentés, mais les tests préliminaires indiquent la possibilité d'utiliser ce dispositif pour des mesures à l'extérieur.

INTRODUCTION

A direct and rapid method of measuring the radiative heat gain or loss of biological objects is important since radiation is often one of the main modes of heat exchange between the object in question and the environment. This is particularly true of human beings where radiative heat loss may account for as much as 60 per cent or more under certain circumstances. On the other hand, situations such as exposure under desert conditions or in some artificial environments may arise where radiation is actually a heat load on human and animal subjects, outstripping the metabolic heat production.

Apart from that, any study of the reactions of the human or animal body to temperature extremes (e.g. thermal stress) would be incomplete without knowing the radiative net exchange.

Methods for determining the radiative exchange between a biological object (as a rule a human object) and the environment were essentially of two types; indirect and direct.

In the indirect methods the radiative exchange was estimated from configuration (shape) factors and the radiation temperature of the object and the surroundings (e.g. Guibert and Taylor, 1952, Dunkle, 1963), or in the case of sheep standing in the tropical sun (Priestley, 1957) from general considerations of the atmospheric long-wave radiation field with the solar load suitably added.

Another indirect method is due to Bentzinger *et al.* (1958) who lined the inside of their "gradient calorimeter" with a layer acting as heat flux meter thus measuring the sum of radiative and convective heat exchange. With means to measure the convective part separately, the radiative part could be determined.

Only two attempts to measure directly the radiative heat exchange are known to the author and none of these permit the presence of noticeable amounts of direct short-wave radiation.

In the first an unshielded radiometer in the form of a semi-circle was rotated round the object (Visser, 1960). Because of the complexity of the radiometer the whole system could only be calibrated by means of test bodies of supposedly known radiation output. Results were apparently disappointing, calibration varying with different radiant temperatures of the surroundings and also sizeable background readings were obtained without any heat source. Since there is neither a theory of the method nor a detailed description given in the paper it is possible that some of the above shortcomings were due to the radiometer having equal sensitivity along its length instead of progressively reduced sensitivity toward its rotating axis and thus not giving correct weighting according to the different areas covered by the different elements.

In the second method (Kaletzky, Macpherson and Morse, 1963), which strictly speaking is not a direct method, the actual net radiation per unit surface area of a human being was measured by holding a net radiometer consecutively at 30 points close to its surface and multiplying the properly averaged result by the independently

estimated effective radiation area of the subject. A complete scan by this method took over half an hour.

The method described in the following permits scanning the subject in about one minute and has a conservatively estimated accuracy of 5 per cent. The radiometers are independently calibrated and, because of the balanced nature of their arrangement, readings can be taken even in the presence of strong asymmetrical external radiation fields (e.g. sunlight).

THEORY

According to the Integral Theorem of Gauss, the integral of R_n, the radiative flux (per unit surface area) normal to a closed surface, A, equals E the total amount of radiant heat produced or absorbed within the volume, V, bounded by A. i.e.

$$\int_A R_n \, \mathrm{d}A = \int_V \operatorname{div} R \, \mathrm{d}V = E \tag{1}$$

It is seen from Fig. 1 that if a mean value of R_n ($\bar{R}_n$) is obtained by scanning a net radiometer over an elongated cylindrical surface A_1 such that the net radiometer scans equal areas in equal times (e.g. a helical path run through at uniform speed) and if in addition mean values of R_h over the end areas A_2 and A_3 ($\bar{R}'_n$ and

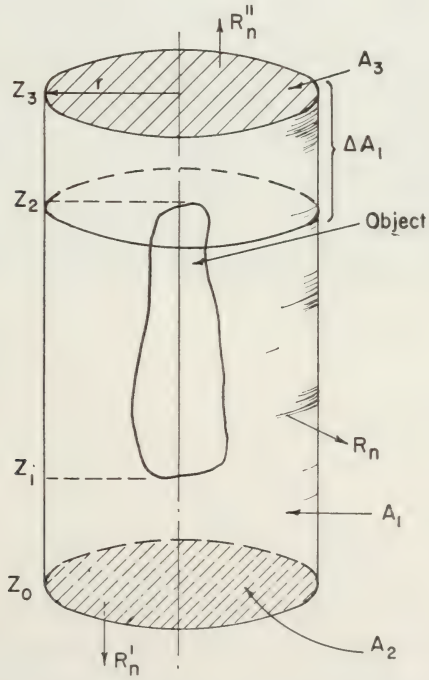

FIG. 1. Radiative heat exchange of object

$\overline{R}''_n$) are obtained then eq. (1) can be rewritten as (with $A_2 = A_3$)

$$\int_A R_n \mathrm{d}A = \bar{R}_n A_1 + (\bar{R}'_n + \bar{R}''_n) A_2 = E \tag{2}$$

It is clear from the physics of the problem that as A_1 extends further and further above and below the object the contribution of $A_2(\bar{R}'_n + \bar{R}''_n)$ would become progressively smaller so that eq. (2) can further be simplified to

$$E = \bar{R}_n A_1 \tag{3}$$

The assumption embodied in eq. (3) means that all the disturbance to the general radiation field due to the introduction of the object has been completely analysed by the scanning over of A_1.

PRACTICAL METHOD

Based on the theoretical consideration of the previous chapter the following arrangement, schematically shown in Fig. 2, was used.

Two polythene-shielded net radiometers (Funk, 1959) are mounted opposite each other on a hoop, 1.17 m in diameter, made of aluminium tube. The hoop is suspended from a rotating arm by a thin nylon-covered cable acting also as signal wire for the radiometers. The nylon wire itself was fixed onto two stationary drums such that as the cross arm rotates the wire either winds itself on or unwinds itself. In this way the radiometers sweep out, in a helical path, an elongated cylindrical

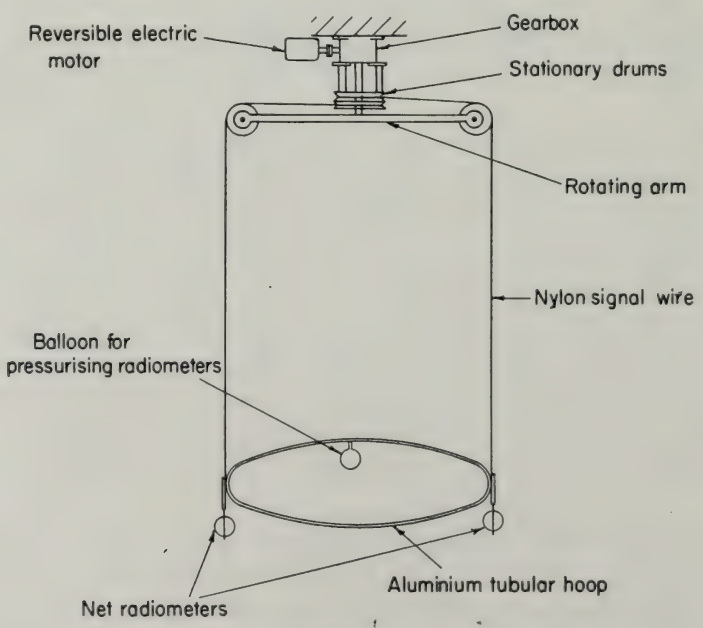

FIG. 2. Schematic arrangement of scanning unit

surface surrounding the object. The drum diameter was chosen such that for each rotation of the cross arm the vertical displacement of the hoop amounted to 23 cm. With the cross arm rotating at 10 turns per minute and a total vertical displacement of 2.3 m one scan only takes about one minute.

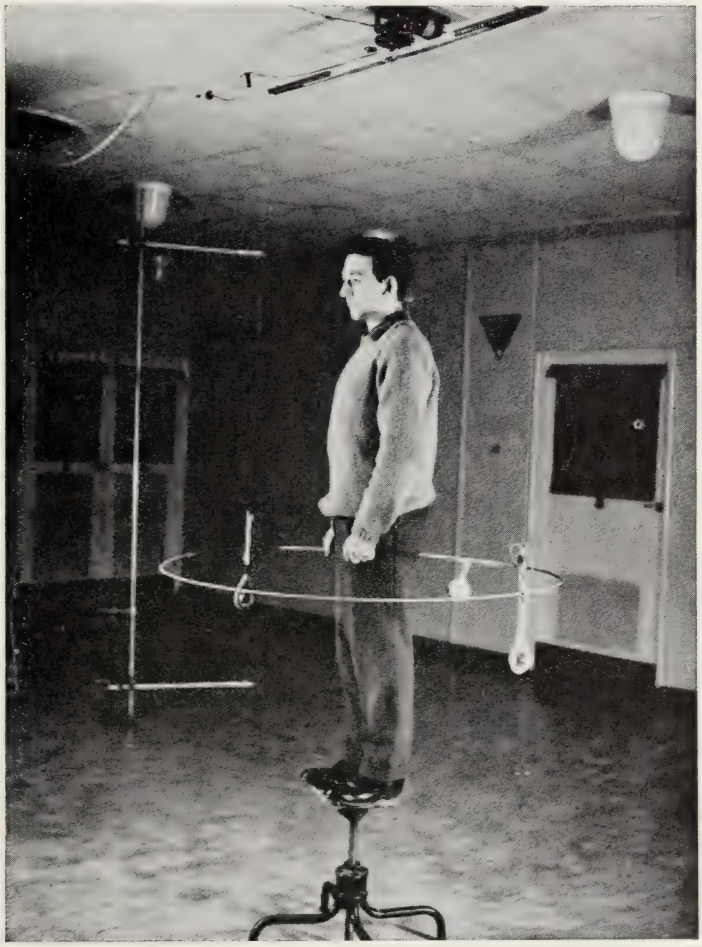

Fig. 3. Experimental arrangement for measuring radiative heat exchange

The hemispheres of the radiometers were kept inflated by rubber balloons, the normal dry gas supply not being necessary on account of the low relative humidity indoors.

The diameter of the hoop should not be too small since the object (in this case a human being) should retain a certain amount of freedom of movement, and thus a radiometer "sees", as well as the object, a great deal of the surroundings. The two radiometers were therefore electrically balanced for equal sensitivity and connected to a potentiometric recorder (1 mV f.s.d.) so that they would give a signal output only for a resultant radial flux in line with the radiometers.

It is easily seen that if the ambient field is either isotropic or parallel no output would result at any time with no object being scanned. With an inhomogeneous ambient field an output may still result; however this would normally be greatly reduced compared to results using only one instrument.

With the working room only about 2.9 m in height eq. (3) of Section 2 could not be sufficiently satisfied. It was therefore necessary to correct for end effects caused by the flux through A_2 and A_3. Two more net radiometers were mounted one above the other at heights corresponding to z_2 and z_3 on a stand. These were again electrically balanced and connected in opposition so that again the ambient field would normally produce no output – their output being proportional to $R'_n + R''_n$. These two net radiometers are seen in the background of Fig. 3 which shows the actual experimental arrangement.

Before and after any run, two readings were taken with these radiometers one near the centre and the other towards the periphery of A_2 and A_3. Results showed (a) that these two readings never differed very much so that the weighted mean of the two readings would fairly accurately give the fluxes through A_2 and A_3 and (b) that these fluxes were never more than 10 per cent of the total.

RESULTS AND DISCUSSION

Table 1 shows a summary of the results obtained so far and samples of actual traces are shown in Fig. 4.

The test subject was a male assistant, 19 years of age, 1.63 m in height, weighing 59 kg. The test room was a lecture room with windows on one side. The curtains were partly drawn except for the experiment during which sunlight was permitted to enter the room, intentionally creating very severe conditions as far as light and shadow were concerned.

The net radiometers have a time constant of only 13 sec so that end effects near the beginning and end of the trace are small. Nevertheless, because of the short time involved, the subject was usually scanned four times and the averaging of the trace carried out over scans 2 and 3.

Scans without the subject (background readings) were carried out frequently and the readings, which never exceeded a few per cent, subtracted from those taken with the subject in position.

The results are consistent with what is generally known about the radiative heat exchange under such environmental conditions, the radiative heat loss being of the order of one half the metabolic rate for the clothed and somewhat over two-thirds of that rate for the nude subject (about 53 and 85 W respectively). (The subject having only just undressed was not in thermal equilibrium.)

It is also interesting that the radiative loss of the previously nude test subject when dressed again was 10 per cent lower than before undressing took place. The good agreement despite the expected irregularity of the trace (Fig. 4c) between the

Table 1.

Date	Run No.	Clothing	Posture	Air Speed m sec^{-1}	Temperature		Radiative Loss (watts)			Remarks
					Dry bulb °C	Wet bulb °C	Through A (cylindrical surface)	Through A_2 and A_3 (end areas)	Total	
12/6/63		—	—	0			−0.9	+0.9	0.0	Background reading with sunlight
12/6/63	1	Clothed	Standing	0			48.5	4.6	53.1	With sunlight
12/6/63		—	—	0			−1.8	0.9	−0.9	Background reading without sunlight
12/6/63	2	Clothed	Standing	0			53.6	4.6	58.6	
17/6/63	1	Clothed	Standing	0	19.3	13.3	52.3	6.4	58.7	
17/6/63	2	Clothed	Standing	1	19.0	13.6	40.2	4.4	44.6	
17/6/63	3	Nude	Standing	0	19.0	13.6	77.9	6.7	84.6	Without sunlight
17/6/63	4	Clothed	Standing	0	18.9	13.6	48.5	4.9	53.4	
18/6/63	1	Clothed	Standing	0	17.4	12.4	48.6	2.5	51.1	
18/6/63	2	Clothed	Crouching	0	17.4	12.3	41.9	5.3	47.2	

readings with and without spotty winter sunlight through glass are noteworthy, the approximately 10 per cent reduction in radiative heat loss being very realistic. The low levels of background readings are also gratifying.

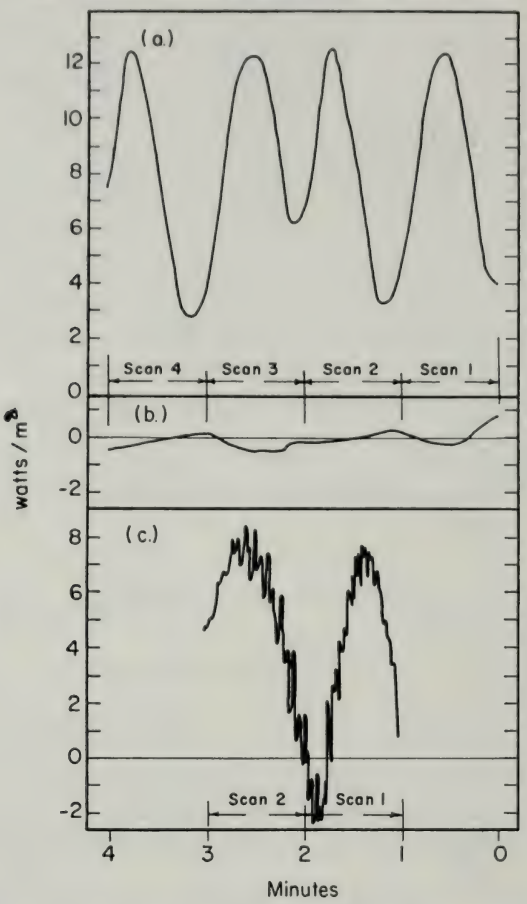

FIG. 4. Actual recordings of radiative heat exchange

REFERENCES

BENTZINGER, T., HUEBSCHER, R. G. MINARD D. and KITZINGER C. (1958) Human calorimetry by means of the gradient principle. *J. appl. Physiol.* **12,** Suppl., 51.

DUNKLE, R. V. (1963) Configuration Factors for Radiant Heat Transfer Involving People. *J. Heat Transfer, Trans. ASME, Sec. C.* **85,** 71–76.

FUNK, J. P. (1959) An improved polythene shielded net radiometer. *J. Sci. Instrum.* **36,** 267–270.

GUIBERT, A. and TAYLOR, C. L. (1952) Radiation area of human body. *J. appl. Physiol.* **5,** 25–37.

KALETZKY, E. MACPHERSON, R. K. and MORSE, R. N. (1963) *J. Inst. Eng. Aust.* (In press).

PRIESTLEY, C. H. B. (1957) The heat balance of sheep standing in the sun. *Aust. J. Agric. Res.* **8,** 271–280.

VISSER, J. (1960) The direct measurement of heat loss from a human body – II radiation. CSIR Special Report No. N157 South African Council for Scientific and Industrial Research. Pretoria, 2nd Aug. 1960.

ÜBER DAS EINDRINGEN DER STRAHLUNG IN WASSERPFLANZENBESTÄNDE

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Abstract – A small photometer adapted for measurements under water was used to measure the penetration of radiation of different wavelength in the regions of water-plants (*Elodea canadensis* and *Cara*). Conclusion about the bioclimate were drawn from the radiation distribution. The light transmission of single leaves was compared with these results.

Zusammenfassung – Mit Hilfe eines kleinen Unterwasserphotometers wurde das Eindringen der Strahlung verschiedener Wellenlängen in Bestände von *Elodea* (Wasserpest) und *Cara* (Armleuchteralge) unter natürlichen Bedingungen studiert. Es werden Schlüsse auf die Auswirkung der gefundenen Strahlungsverteilung auf das Bioklima im Bereich der Bestände gezogen. Die spektrale Lichtdurchlässigkeit einzelner Blätter wurde mit obigen Resultaten verglichen.

Résumé – Au moyen d'un petit photomètre sous-marin, on a mesuré dans quelle mesure le rayonnement de différentes longueurs d'ondes pénètre à l'intérieur de cultures d'*Elodéa* et de *Cara*, et cela dans des conditions naturelles. On en tire diverses conclusions quant à l'influence de la répétition constatée du rayonnement sur le bio-climat des dites cultures. La pérméabilité spectrale de feuilles isolées a été comparée en laboratoire avec les résultats mentionnés plus haut.

Die Kenntnis des Eindringens natürlicher Strahlung in Bestände von Wasserpflanzen ist zur Beantwortung verschiedener Fragen über den Lebensraum im Bestand nötig. Die Fragen betreffen den Strahlungsrest, der in verschiedener Bestandstiefe noch anzutreffen ist und die in verschiedener Tiefe absorbierte Strahlungsmenge zur Lösung von Problemen des Wärmehaushaltes der Bestände.

Im vorliegenden Fall wurden spektrale Strahlungsmessungen in den Beständen von *Elodea canadensis* (Wasserpest) und von *Cara*, einer Armleuchteralge, im Lunzer Mittersee durchgeführt.

Beim Mittersee handelt es sich um einen Quellsee mit einer durchschnittlichen Wassertiefe von 1–2 m. Der See hat klares und auch im Sommer infolge der unterirdischen Quellzuflüsse und der starken Durchflutung kaltes Wasser. Der Grund des Sees ist fast durchwegs von dicht geschlossenen, 60–70 cm hohen Beständen der *Elodea* und an manchen Stellen von etwa 30 cm hohen *Cara*-Beständen und von *Fontinalis* (Quellmoos) bedeckt.

Die Messungen wurden mit einem für diesen Zweck gebauten Unterwasserphotometer durchgeführt, dessen Empfängerelement einen Durchmesser von nur 3 cm aufweist und das vom Boot aus horizontal in den Bestand eingeschoben

werden konnte. Durch die geringen Dimensionen des Empfängers gelang dies zumeist ohne Störung des natürlichen Bestandwuchses.

Als Anzeigegerät diente ein μ-Amperemeter, dem bei geringen Strahlungsintensitäten noch ein Transistor-Gleichstromverstärker mit einem maximalen Verstärkungsfaktor von 1 : 20 vorgeschaltet werden konnte.

Die spektrale Differenzierung wurde mit folgender Kombination von Absorptionsfiltern der Fa. Schott und Gen. erzielt:

Filter	UG 1+BG 12	BG 12	VG 9	OG 2+BG 18	RG 2	RG 5
opt. Schwerpunkt	380	435	525	590	660	700 mm

Wie in jedem Bestand so ist auch hier die Intensität der Strahlung örtlich sehr stark verschieden. Bei der vorliegenden Arbeit wurde versucht, durch möglichst zahlreiche Messungen

(1) zu einem Mittelwert zu gelangen, der für den Bestand charakteristisch ist und
(2) die auftretenden Extremwerte sowie die Häufigkeit der verschiedenen Werte festzustellen.

Aus praktischen Gründen wurde es vorgezogen, die Durchlässigkeit der Bestände in Prozenten pro 10 cm Bestandsdicke anzugeben.

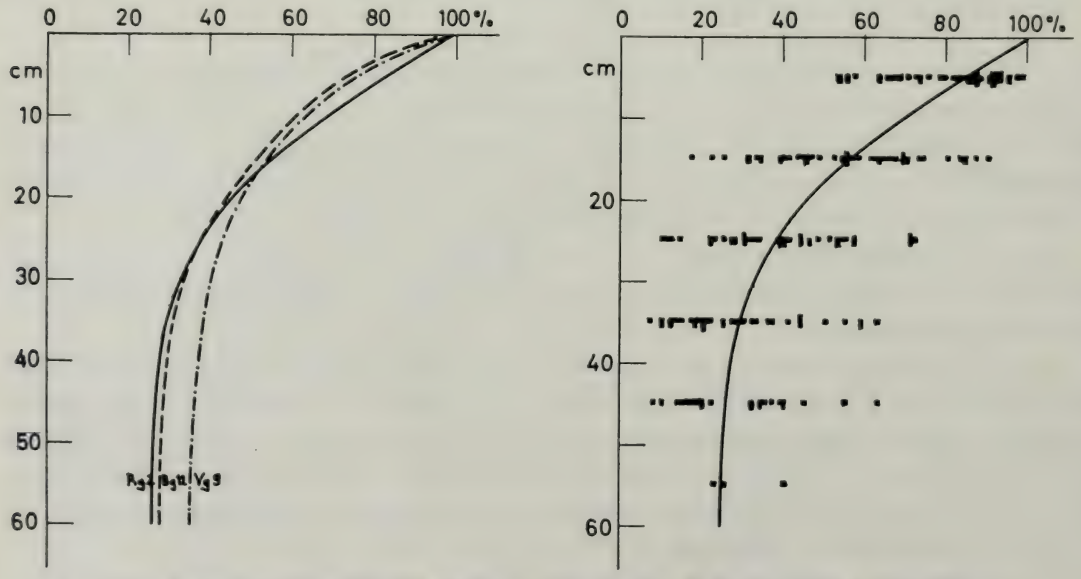

Abb. 1. Durchlässigkeit des *Elodea*-Bestandes in %/10 cm für den blauen, grünen und roten Spektralbereich (links); Einzelwerte mit Mittelkurve (rechts)

Abbildung 1 zeigt die auf 10 cm Bestandsdicke bezogene Durchlässigkeitsverteilung im Bestand für den blauen, grünen und roten Spektralbereich.

100% wurden an der Bestandsobergrenze angesetzt. Diese wurde dort definiert, wo die höchsten Triebe der nie ganz gleichmäßig hohen Pflanzen endeten. Die Dichte des Bestandes nimmt von oben nach unten erst stark, dann langsam zu. Dies hat eine Abnahme der Durchlässigkeit von etwa 80%/10 cm im oberen Bereich bis auf etwa 30% in 40–60 cm Tiefe des meist 60 cm hohen Bestandes zur Folge.

Bei den Darstellungen in dieser Arbeit ist die Durchlässigkeit des Wassers nicht extra berücksichtigt, sondern ist in den Ergebnissen für die Bestandsabsorption enthalten. Es bedarf vielleicht des Hinweises, daß die dadurch bedingten systematischen Unterschiede bei dem sehr reinen Wasser des Mittersees 1–4% Absorption/10 cm betragen.

Die örtlichen Streuungen sind sehr groß. Dies zeigt die rechte Darstellung in Abb. 1. Es erhebt sich daher die Frage, ob die Berechnung eines Mittelwertes sinnvoll ist und wesentliches über den Lichtgenuß im Bestand aussagt. Hierzu wurde

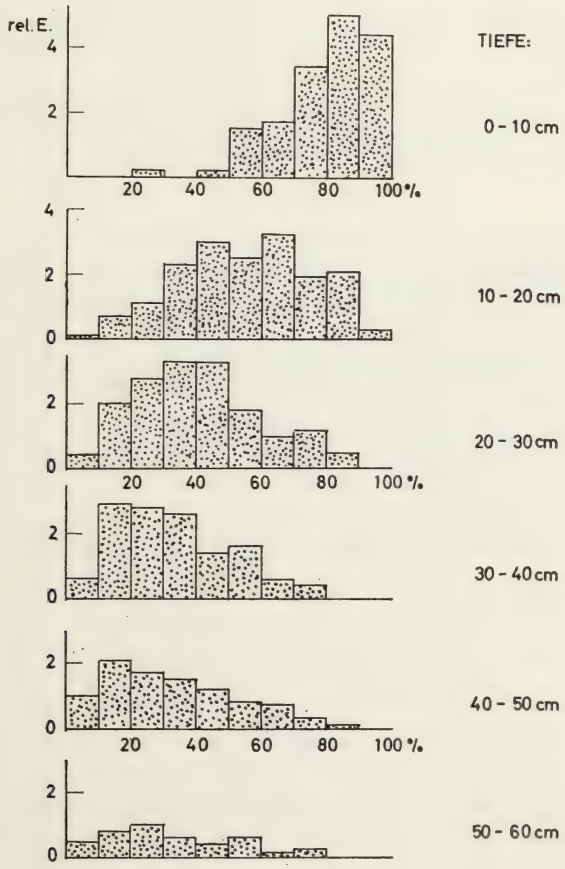

Abb. 2. Häufigkeitsverteilung der Strahlungsdurchlässigkeit in verschiedenen Tiefen des *Elodea*-Bestandes, in %/10 cm

die Häufigkeitsverteilung der gemessenen Durchlässigkeitswerte bestimmt, die in Abb. 2 für verschiedene Bestandstiefen dargestellt ist.

Es zeigt sich daraus, daß in einem derart dichten Bestand, in dem bald nur noch diffuses Licht vorhanden ist, der Mittelwert auch dem häufigsten Wert nahekommt. Abb. 3 stellt die in verschiedener Bestandstiefe im Mittel vorhandene Strahlungsmenge in Prozenten des Wertes an der Bestandsoberfläche dar. Dabei sind die

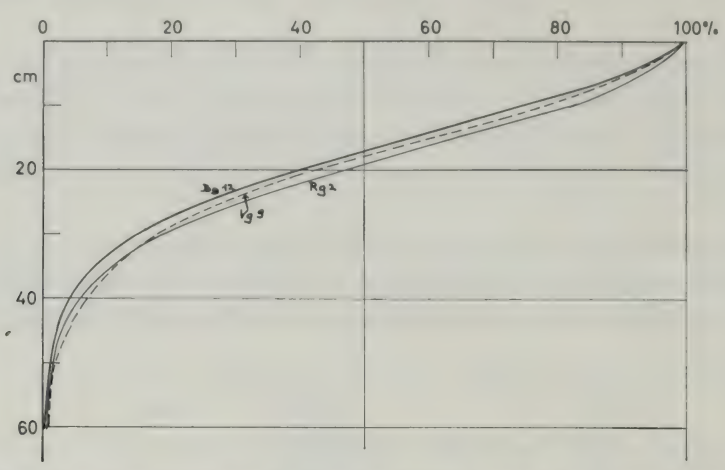

Abb. 3. Strahlungsintensität in verschiedenen Tiefen des *Elodea*-Bestandes in % des Oberflächenwertes

Kurven für den blauen, grünen und roten Spektralbereich eingetragen. Die geringen spektralen Unterschiede sollen später genauer erörtert werden.

Näherungsweise kann aus der Abbildung ersehen werden, daß die Strahlung in 20 cm Bestandstiefe auf etwa 40%, in 40 cm auf 5% und in 60 cm auf etwa 0,5% des Oberflächenwertes zurückgeht. Die Einzelwerte schwanken jedoch z. B. in 40 cm Tiefe von etwa 1–20%. Der in 60 cm Bestandstiefe (1,20 m unter der Wasseroberfläche) gefundene Mittelwert würde bei Absorption durch Wasser vom

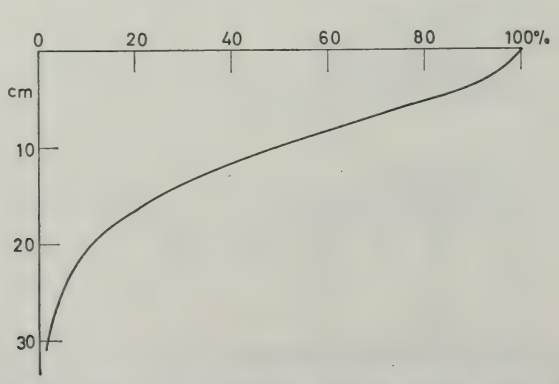

Abb. 4a. Durchlässigkeit im grünen Spektralbereich im *Cara*-Bestand (%/ 10 cm)

Reinheitsgrad des Mitterseewassers im Grün erst in 29 m Tiefe, im Blau in 16 m und im Rot in 12 m Tiefe eines Sees anzutreffen sein.

Zum Vergleich seien noch die im Bestand der *Cara* gefundenen Werte dargestellt.

Der nur etwa 30 cm hohe Bestand ist bedeutend dichter. Die Strahlung geht bereits in 10 cm auf 50%, in 20 cm auf 10% und in 30 cm auf etwa 2% des Oberflächenwertes zurück. Auch hier nimmt die Durchlässigkeit des Bestandes erst

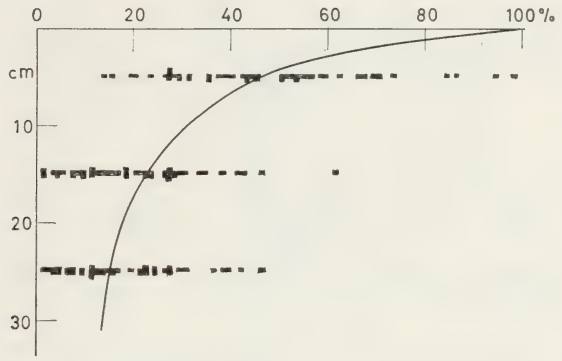

Abb. 4b. Strahlungsintensität in verschiedener Bestandstiefe (Oberflächenwert = 100%)

rasch, dann nur mehr langsam ab. Die Streuung der Einzelwerte ist noch größer als bei den *Elodea*-Beständen, was sich aus der großen Uneinheitlichkeit der relativ niedrigen Bestände erklärt.

SPEKTRALE UNTERSCHIEDE IN DER STRAHLUNGSDURCHLÄSSIGKEIT

Hinweise auf die spektralen Unterschiede der Strahlungsabsorption enthielten bereits Abb. 1 und 3.

Die Strahlungsdurchlässigkeit einzelner Blätter weist große spektrale Unterschiede auf. Abbildung 5 zeigt Aufnahmen der spektralen Durchlässigkeit von Einzelblättern verschiedener Wasserpflanzen nach Dirmhirn. Die Unterschiede sind vor allem durch die Chlorophyll-Absorption bedingt.

In natürlichen Beständen werden, wie bei zahlreichen Untersuchungen an Landpflanzen festgestellt wurde, diese Unterschiede etwas abgeschwächt. Dies wurde, vielleicht sogar in stärkerem Maße, im Unterwasserbestand festgestellt.

Durch das Eindringen ungefilterten Lichtes durch Bestandslücken sowie durch Reflexion und Absorption an nicht chlorophyllhaltigen Medien werden die Unterschiede teilweise ausgeglichen. Immerhin ist das Grün-Maximum der Chlorophyll-Transmission und der Anstieg der Durchlässigkeit gegen das Infrarot in den Kurven der Abb. 6 angedeutet.

Das in Abb. 6 dargestellt Ergebnis ist aus dem Zusammenspiel von eindringendem und gefiltertem Licht zu erklären. In den oberen Teilen des Bestandes ist das

eindringende Licht noch stärker wirksam, daher können sich die typischen Merkmale des gefilterten Lichtes nicht so stark durchsetzen. In tieferen Schichten treten sie dann allmählich stärker hervor.

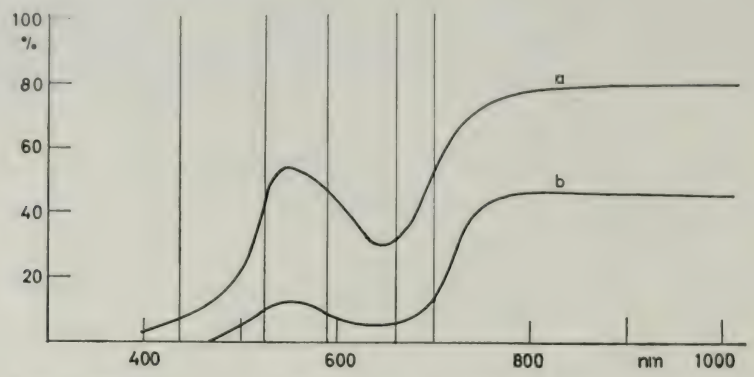

Abb. 5. Durchlässigkeit eines Blattes von *Potamogeta perfoliata* (a) und eines Seerosenblattes (b), nach Dirmhirn (1963)

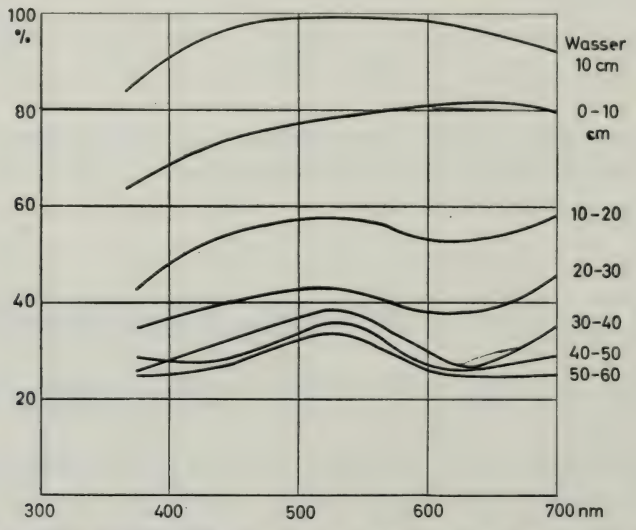

Abb. 6. Spektrale Durchlässigkeit der einzelnen 10 cm-Schichten des *Elodea*-Bestandes sowie des Wassers des Mittersees

AUSWIRKUNGEN AUF DIE TEMPERATURVERHÄLTNISSE IM BESTAND

Die Zonierung der Strahlungsabsorption in den Beständen bedingt charakteristische thermische Schichtungen, auf die abschließend hingewiesen werden soll.

Die Abbildung 7 enthält links oben die Darstellung der Gesamtstrahlung im freien Wasser und im Inneren eines *Elodea*-Bestandes, dessen Oberfläche etwa 1 m unter der Wasseroberfläche liegt, am Mittag eines Sommertages. Die in den einzelnen Schichten absorbierte Strahlung wird zum überwiegenden Teil in Wärme umgesetzt

und zum restlichen Teil für Photosynthese verbraucht. Die pro Minute in den einzelnen Schichten absorbierten Strahlungsbeträge sind im Teil (b) dargestellt. Nimmt man an, daß die während eines ganzen Tages eingestrahlte und absorbierte Wärme

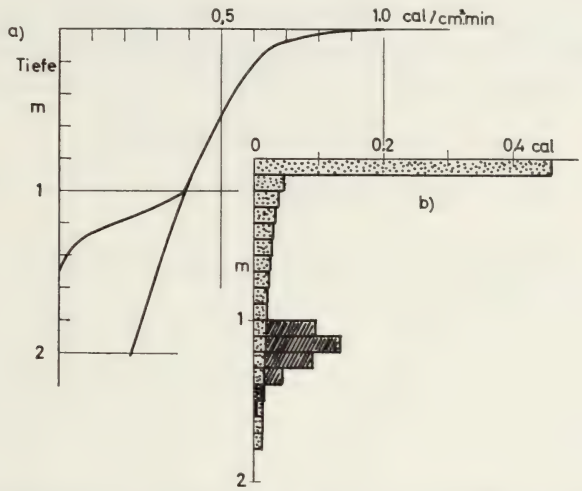

Abb. 7(a) Strahlung in verschiedenen Tiefen des Bestandes und des freien Wassers. (b) Betrag der absorbierten Strahlung in cal/cm^2 min

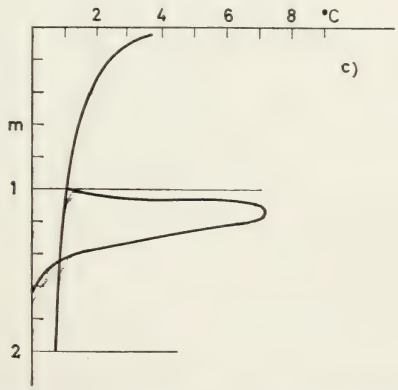

Abb. 7(c). Temperaturänderung durch Strahlungsabsorption im Laufe eines Tages

in den einzelnen Schichten gespeichert wird, so ergibt sich die in Abb. 7(c) dargestellte Kurve der Temperaturänderungen. Eine derartige Temperaturkurve ergibt für Wasser eine stark labile Dichteschichtung. Neben dem sehr langsam wirkenden Temperaturausgleich durch Wärmeleitung und dem im Bestand stark gebremsten turbulenten Austausch wirkt sicher die Labilität der Schichtung stark ausgleichend, so daß das Wasser oberhalb des Bestandes von unten her allmählich erwärmt wird und sich eine ungefähr isotherme Schicht von 0 bis 1,2 m Tiefe mit Temperaturänderungen von 3–4° pro Tag und Temperaturunterschieden von 1–2° C gegenüber dem freien Wasser ausbilden wird. Das tagsüber bei sommerlichem Schön-

wetter im Bestand auftretende Temperaturprofil wird demnach gegenüber dem des freien Wassers folgende Besonderheiten aufweisen: (1) Das Wasser über dem *Elodea*-Bestand der angegebenen Struktur sowie in den oberen 20–30 cm des Bestandes wird bei ungefähr isothermer bzw. leicht labiler Schichtung mit einem Temperaturmaximum in 20 cm Bestandstiefe um 1–2° wärmer sein als das freie Wasser, (2) unterhalb dieser Tiefe wird der Bestand kälter sein als das freie Wasser, und es werden nur geringe strahlungsbedingte Temperaturänderungen auftreten.

LITERATUR

Dirmhirn, I. *Das Strahlungsfeld im Lebensraum.* Akad. Verlagsges., Frankfurt am Main, 1964.

STUDIES ON THE RADIATION CLIMATE IN THE KARST OF YUGOSLAVIA

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RADIATION measurements were carried out in the Karst of Yugoslavia during spring and summer 1963. Investigations of the albedo and radiation on surfaces of different inclination showed the high reflection of bright rocks. The intensity of global and sky radiation was in very good agreement with that at the same altitude in the Alps. Only the diurnal variations of sky radiation showed higher intensities during the morning and evening. Further investigations will show whether these high intensities are due to the high reflection in the Karst or not.

The paper, written in German, was published in: *Wetter und Leben* **15**, 235 – 241 (1963).

THE RADIATIVE, THERMAL AND HYDROBALANCE AT LEOPOLDVILLE

W. SCHUEPP

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FROM measurements of the components of the radiative, thermal and hydrobalance of Leopoldville, Congo, the following conclusions were drawn: (1) The seasonal variations of net radiation are governed by the opposite variations of solar radiation which are minimal in June and July and the outgoing terrestrial radiation which is maximal at the same time; (2) the daily amplitude of the radiation temperature of the ground due to solar radiation is reduced to half by evapotranspiration in the wet season; (3) the daily radiation temperature of the ground is in phase with the solar radiation; (4) the minimum of the radiation temperature of the ground is higher than the "grass minimum" measured by means of an alcohol thermometer; (5) the temperature of the solid surface of the ground is always higher than the temperature at the surface of the vegetation cover (lawn); (6) the seasonal variation of the ground temperature, at 10 cm depth is determined more by the possibilities of evapotranspiration than by the seasonal variation of net radiation.

RADIATION IN THE ALPINE TUNDRA

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THE *alpine tundra* is above timberline and is usually at a considerable altitude, in Colorado being above 3800 m. Because of the altitude, on clear days, the solar radiation is very intense with an enrichment of ultraviolet. The surface of the ground where there is soil heats up very rapidly and reradiates upwards a strong flux of radiation. The total radiation flux (downwards plus upwards) which is incident upon plants is greater in the alpine tundra during midday than at any other location on the surface of the earth. The nocturnal cooling is enormous and the surface temperature of the ground and of plants drops to quite low temperatures. Values of observed radiation were given and a description of a typical midsummer diurnal cycle of total radiation flux. A high mortality was found among alpine plants because of the extreme intensity of the radiation regime.

TEMPERATURE EQUIVALENT OF SOLAR RADIATION LOAD ON MAN

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A METHOD was described of determining the increment of air temperature which would produce a physiological effect on man equivalent to that induced by the solar radiation load imposed under open summer conditions in mid-latitude deserts. The method consists of: (a) exposing subject to solar radiation in a transparent chamber with control temperature, humidity, and air movement; (b) exposing the same subject to the same conditions with the solar radiation exluded, but at various temperatures above that used in the solar exposure; (c) establishing regression equations of physiological reactions on air temperature from the preceding step; (d) determining from these regression equations the air temperature which, acting alone, would have produced the same reaction as the solar exposure (ECAT) and, (e) determining the increment of air temperature equivalent to the radiation load (ITER) by subtracting from ECAT the air temperature prevailing during the solar exposure (ACAT). A brief description was given of the solar chamber and the air-conditioning equipment, which is installed in two trailers for transportation. A detailed description of the method is published by D. H. K. Lee and J. A. Vaugham in *Int. J. Biometeorology* 8, 61–69 (1964).

INFLUENCE OF PART-TIME FILTERING OF SOLAR AND SKY RADIATION ON GRAPE DEVELOPMENT IN AN ARID ZONE CLIMATE

H. B. SCHULTZ and L. A. LIDER

Department of Meteorology, University of California, Davis, California, U.S.A.

The quality and color of grapes are highly variable from year to year in all wine producing regions. An analysis of the radiation effects is difficult because of the complexity of the environmental factors. The rather uniform and cloudless weather in California, however, permits such study of the radiation effects by controlled modifications of the conditions such as temporary covering of the plants with plastic materials.

SUMMARY REPORT

INGE DIRMHIRN

THE Committee on Solar Radiation held three afternoon sessions as part of the Third Congress of the International Society of Biometeorology in Pau. Exact investigations of meteorological radiation are relatively recent compared with those of other meteorological factors. Our knowledge of the biological effect of natural radiation is less than that of other meteorological parameters. The major theme of the session was to develop the radiation balance between a single biological object and its environment out of the existing large scale meteorological radiation field and its modifications by local orographic conditions.

The first session, therefore, dealt with large scale meteorological radiation conditions on the ground, general physical radiation behaviour, and instrumentation. It was found that for a large scale investigation more sophisticated instruments are necessary in the present state of our knowledge of meteorological radiation components. For small scale observations which are important for single biological stands we are mostly limited by lack of experience in studies of the incoming and reflected radiation. Therefore, simple and easy to handle instruments would be sufficient for a first survey.

This was especially confirmed during the second afternoon session where variation of the large scale radiation climate by the local environment was discussed. Inge Marisavljević-Lisać showed the great influences of mountain climate and high reflection of limestone rocks. Completely changed radiation fields are found within free stands as pointed out by Baumgartner and water plant stands as described by Mahringer. These changed radiation fields are partly used in forest regeneration (Fairbairn). The success in cultivation of grapes by artifically shielding the surplus radiation in the hot climate of California was shown (Schultz).

The third session dealt with the important influence of radiation on man. The natural as well as the artificial atmospheric pollution and its influence on radiation on vertical surfaces such as housewalls (Page and Sibbons) were discussed; radiation tables to be used by architects were presented. The heat exchange by a single human being as dealt with in the papers by Funk, Robinson and Lee aroused great interest and were followed by a long discussion.

The papers and the discussions showed the increasing interest in the influence of radiation in biology. However, most participants were meteorologists and only a few biologists, such as plant physiologists, ecologists, zoologists and physiologists, were present. It was pointed out in the final discussion that more effort should be done in future to improve cooperation between physicists and biologists.

POLAR AND ANTARCTIC BIOMETEOROLOGY

Chairman: J. Rivolier

CONTRIBUTION A L'ÉTUDE BIOMÉTÉOROLOGIQUE SUBANTARCTIQUE KERGUELEN, CROZET, NOUVELLE-AMSTERDAM

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Abstract – The circumpolar subantarctic belt is described as an exact bioclimatological entity. The author discusses the climatological and geophysical aspects of this region and related problems of animal and plant biology in relation to the environment.

Zusammenfassung – Der zirkumpolare subantarktische Gürtel stellt eine bioklimatologische Einheit dar. Die klimatologischen und geophysikalischen Eigenarten dieses Gebietes werden im Zusammenhang mit Fragen der Tier- und Pflanzenbiologie in Beziehung zu dieser Umwelt besprochen.

Résumé – Zone de transition par excellence, le ceinture circumpolaire subantarctique présente une véritable entité bioclimatologique. L'auteur, après avoir situé ces territoires dans le contexte climatologique et géophysique qui leur est propre, aborde les problèmes de biologie animale, de biologie végétale en rapport avec ces facteurs d'environnement. Cet exposé n'a pas la prétention de résoudre les problèmes, mais de faire naître un travail coopératif et de bioclimatologie dans l'ensemble des Terres Subantarctiques.

Les Iles Australes Françaises, Archipel des Kerguelen, Archipel des Crozet, Iles Saint-Paul et Amsterdam, occupent dans l'Océan Indien une situation qui a été définie comme étant subantarctique (Aubert de la Rüe, 1953).

Deux ordres de faits légitiment cette dénomination:

- la notion de convergence
- l'étude des masses d'air en altitude.

Convergence

L'Étude des convergences, objet de travaux océaniques déjà anciens mais toujours d'actualité, a été reprise par Tchernia (1951) puis Delépine (1962) dans le cadre plus précis des Iles Australes Françaises.

Tandis que le bloc Crozet-Kerguelen, intéressé par la convergence Antarctique est baigné partiellement par les eaux polaires, le bloc Saint-Paul-Amsterdam en lisière de la convergence subtropicale oscillant suivant les saisons du Nord au Sud de ces Iles, est baigné par des eaux beaucoup plus chaudes (Schott). Encore faut-il s'entendre sur le sens à donner à cette convergence suivant qu'on la considère

comme « terme neutre de frontière subtropicale » (Bohnecke) et passant aux environs du 40 ème parallèle (41°30 pour Tchernia) ou comme « convergence de courants » (Koopman) aux environs du 30° parrallèle.

Masse d'Air en Altitude

De par leur situation géographique, Kerguelen et Crozet subissent l'influence directe et quasi permanente des masses d'air polaires. Il semble en outre que Crozet soit situé dans une zone de cyclogénèse importante dont l'étude est commencée depuis deux ans mais prendra corps avec l'installation d'une base permanente début 1964. Cet air polaire n'intéresse Saint-Paul et Amsterdam que de façon saisonnière, en hiver, alternant avec des masses d'air chaud tropical en été, si bien que la

Tableau 1. Nlle. Amsterdam. Climatologie de la

	Janvier	Février	Mars	Avril	Mai	Juin
1° Température.						
Maximum absolu	24°,3	24°,0	23°,8	21°,0	20°,4	18°,3
Minimum absolu	8°,3	6°,4	7°,5	5°,6	4°,1	3°,4
Maximum moyen	19°,4	19°,4	18°,4	16°,7	15°,4	13°,8
Minimum moyen	14°,2	14°,5	13°,6	12°,3	11°,2	9°,4
Température moyenne	16°,8	17°,0	16°,0	14°,5	13°,3	11°,6
2° Humidité relative						
Moyenne	81	82	80	81	82	81
3° Précipitations						
Hauteur moyenne en mm.	110,9	86,7	109,7	80,9	102,6	120,9
Nombre de jours avec précipitation	15	13	16	17	19	23
4° Vent						
Pointe maximum en m/sec	46	45	44	40	44	56
Nombre de jours où le vent atteint ou dépasse 16 m/sec	9	8	9	12	19	24
24 m/s	1	2	2	3	6	13
Vitesse moyenne en m/sec	6,4	6,2	5,9	6,4	7,9	10,0
5° Insolation						
Moyenne en heures	176	134	136	102	109	102

tropopause oscille entre 11 000 et 14 000 m suivant les pulsations froides ou chaudes. On observe parfois les deux tropopauses simultanées (Dolet, 1957).

Ainsi, météorologie et océanographie se complètent utilement pour définir dans cet hémisphère Sud une zone comprise entre les 40ème et 50ème parallèles, zone de transition entre régions tropicale et polaire, analogue géographiquement à notre zone tempérée de l'hémisphère Nord, mais dont la physionomie est bien différente, se rattachant par de nombreux points au continent Antarctique par suite d'interpénétrations biologiques et météorologiques justifiant son qualificatif de subantarctique.

Les quelques remarques déjà faites au sujet des convergences et des masses d'air permettent de définir « météorologiquement » le climat dont l'élément déterminant est la « perturbation ».

Côte Nord 1950-1959 (d'après Bouvier, Meteonat)

Juillet	Août	Sept.	Octobre	Novemb.	Décemb.	Annuellement	
16°,3	16°,1	16°,1	17°,5	19°,2	22°,3	Maximum absolu	24°,3
2°,8	3°,2	3°,1	3°,1	4°,7	6°,6	Minimum absolu	2°,8
13°,1	13°,1	13°,7	14°,5	15°,5	17°,5	Maximum moyen	15°,9
9°,1	9°,1	9°,5	10°,0	11°,2	13°,1	Minimum moyen	11°,4
11°,1	11°,1	11°,6	12°,3	13°,4	15°,3	Température moyenne	13°,7
83	82	81	81	83	83	Moyenne	82%
106,7	90,9	67,4	71,0	92,1	88,9	Total moyen	1 128,7 mm
23	23	19	19	18	17	Total moyen	222 jours
42	48	53	52	52	44	Maximum absolu	56 m/sec
21	21	19	17	16	10	Total moyen	185 jours
7	7	7	5	4	2	Total moyen	59 jours
8,6	8,9	8,9	8,3	8,2	7,1	Moyenne	7,7 m/sec
105	120	119	149	152	162	Total moyen	1 566 heures

Dans cette partie de l'hémisphère Sud, les perturbations sont remarquables par leur *rapidité*, leur *activité* et leur *pureté* et ces caractères s'affirment au fur et à mesure qu'on descend vers le Sud.

On a pu dire que le vent était la clé du climat dans l'hémisphère Nord. Ici, il n'est qu'une partie d'un tout et c'est vraiment la perturbation dans son entité qui est agissante.

Il n'est pas rare d'observer le passage en une journée de tous les éléments d'une perturbation, tête, corps, traîne, avec changements de vent en direction et en force, variations de pressions, précipitations, afférents à ces divers éléments constitutifs qui s'inscrivent en courbes trés accidentées sur les diagrammes des instruments de mesure. Après une période de calme de courte durée, une autre perturbation se

Tableau 2. Kerguelen. Climatologie de Port-aux-Français

	Janvier	Février	Mars	Avril	Mai	Juin
1° Température						
Maximum absolu	+20°,8	+20°,6	+18°,9	+17°,6	+16°,2	+12°,9
Minimum absolu	− 0°,4	− 0°,6	− 0°,7	− 2°,7	− 6°,4	− 9°,4
Maximum moyen	+10°,7	+11°,5	+10°,5	+ 9°,3	+ 6°,9	+ 4°,7
Minimum moyen	+ 3°,5	+ 4°,0	+ 3°,6	+ 2°,8	+ 1°,0	− 0°,7
Température moyenne	+ 7°,0	+ 7°,8	+ 7°,1	+ 6°,0	+ 4°,2	+ 2°,0
Nombre de jours avec gelée sous abri	1	1	1	4	11	20
2° Humidité relative						
Moyenne	71	70	73	75	78	81
3° Précipitations						
Hauteur moyenne en mm.	80,7	54,7	66,1	101,9	120,3	112,8
N. de jours avec précip.	18	13	16	19	22	22
N. de jours avec chute de neige	3	3	3	6	9	14
4° Vent						
Pointe maximum en m/sec	52	48	62	59	70	65
Nombre de jours où le vent atteint ou dépasse						
16 m/sec	25	20	21	23	25	25
24 m/sec	12	9	11	13	13	12
Vitesse moyenne en m/sec	10,4	9,5	9,3	9,8	10,2	9,9
5° Insolation						
Moyenne en heures et dixièmes	186,9	174,9	166,3	128,3	93,1	71,2

manifeste jusqu'à «rupture» de cette «famille» marquée par une accalmie plus longue parfois de quelques jours avant l'arrivée de la famille suivante.

En raison de leur situation septentrionale, Saint-Paul et Amsterdam n'appartiennent plus en été au même type de temps, et changent d'étage. Un vaste anticyclone centré sur l'Océan Indien détourne au Sud les familles de perturbations si bien que ces Iles jouissent alors d'une situation météorologique subtropicale relativement stable, troublée seulement par des perturbations d'origine tropicale, séquelles de cyclones en provenance du Mozambique ou de la Réunion ou bien par de rares fronts froids venant du Sud mais peu actifs.

Les deux tableaux donnent une idée très succinte de l'aspect climatologique de ces Territoires (Tableaux 1 et 2).

1951–1959 (d'après Bouvier, Meteonat)

Juillet	Août	Sept.	Octobre	Novemb.	Décemb.	Annuellement	
+12°,9	+15°,0	+12°,8	+16°,1	+16°,6	+22°,1	Maximum absolu	+22°,1
− 7°,0	− 6°,2	− 6°,1	− 5°,1	− 3°,7	− 1°,4	Minimum absolu	− 9°,4
+ 5°,1	+ 5°,2	+ 5°,2	+ 6°,9	+ 7°,9	+ 9°,6	Maximum moyen	+ 7°,8
− 0°,5	− 0°,6	− 0°,5	+ 0°,4	+ 1°,3	+ 2°,9	Minimum moyen	+ 1°,4
+ 2°,3	+ 2°,3	+ 2°,4	+ 3°,7	+ 4°,6	+ 6°,2	Température moyenne	+ 4°,6
19	20	18	14	9	1	Total moyen	119
80	80	76	74	71	71	Moyenne	75%
105,7	85,0	102,8	60,7	86,6	84,3	Total moyen	1 081,6 mm
22	20	21	21	19	17	Total moyen	230 jours
14	13	14	12	11	6	Total moyen	108 jours
67	67	70	62	59	61	Maximum absolu	70 m/sec
26	25	25	26	23	24	Total moyen	288 jours
15	14	16	12	10	11	Total moyen	148 jours
10,6	10,4	11,1	10,7	10,2	10,2	Moyenne	10,2 m/s
93,4	119,1	137,8	173,7	183,7	189,7	Total moyen	1 718,5 heures

Météoropathologie

L'influence des perturbations atmosphériques sur la fine mécanique des êtres vivants n'est plus à démontrer.

Nous en soulignerons les effets dans les territoires subantarctiques en raison même du caractère de ces perturbations.

Deux ordres de réactions sont à retenir:

(a) – réactions neuro-somatiques d'origine neuro végétative et hormonale

(b) – réactions neuro psychiques, consécutives à l'environnement.

(a) Céphalées, fatigabilité, accélération du rythme cardiaque, modification de la pression sanguine, instabilité neuropsychique avec sensation de tension nerveuse pouvant conduire à l'associabilité ou à l'agressivité, troubles du sommeil, signent les réactions vago-sympathico-hormonales et viscérales consécutives. Un juste équilibre ne s'établit que pour être à nouveau perturbé. Ce perpétuel réajustement, si imperceptible qu'il soit, est à l'origine de la fatigabilité enregistrée chez presque tous les membres des missions en fin de séjour.

Nous avons relevé à Nouvelle Amsterdam deux types de situation engeandrant ces manifestations météoropathologiques:

– amorce de perturbation avec chute barométrique importante de 1030 à 980 mb, par exemple, en quelques heures, puis passage de front actif froid avec rotation du vent, violentes rafales et remontée brutale de la pression barométrique. Les troubles observés sont généralement proportionnels à l'activité du front ou des fronts qui passent. En particulier, plus l'activité du vent au Sud est forte et plus les sujets en ressentent les effets. Il s'agit d'une réelle allergie aux discontinuités météorologiques.

– situation anticyclonique stable, avec pressions élevées, (1035–1040 mb) ven. calme ou nul, ensoleillement, ou nébulosité consécutive à un léger voile de stratust

Ce sont deux situations opposées. Leur répercussion sur l'organisme peut s'expliquer par des phénomènes électriques qu'il conviendrait évidemment de mesurer exactement.

Par contre, détente manifeste avec sensation de bien-être par temps calme mais basse pression (1010 mb ou au-dessous) avec précipitations légères sous forme de pluie ou avec nappes de brouillard – situations typiques en secteur chaud – ou encore par vent d'Est et pluies de type tropical.

Nous avons réalisé l'expérience suivante. Montage: un galvanomètre est relié à deux électrodes d'aluminium (le platine serait plus indiqué), plongeant dans de l'eau de mer, à distance l'une de l'autre. Nous avons enregistré le passage d'un courant de faible intensité, mais nettement décelable, précédant chaque rafale de vent de une à trois secondes suivant le cas. Ce qui tend à confirmer le passage d'un flux électrostatique accompagnant à l'avant les masses d'air en déplacement et disparaissant avec le passage effectif de la rafale. Nous n'avons malheureusement

pas pu enregistrer un diagramme (sur papier photographique) faute d'appareillage et de local.

(b) A ces signes viennent s'ajouter les effets directs ou indirects, simples ou associés, des divers paramètres atmosphériques sur les organes des sens, vue, ouïe, sens tactile, équilibre, etc . . . avec comme résultante la constitution de situations d'environnement météorologique telles que « atmosphère » de tempête, ou de temps pluvieux, ou de temps de neige, ou de beau temps « ensoleillé » et ayant la valeur d'un choc climatique dans des régions soumises à des variations de décors météorologiques très rapides. Leur influence neuro-psychique n'est pas à négliger en fonction du tempérament des sujets qui y sont soumis (hypothalamiques par exemple) joint aux conditions de vie communautaire et d'isolement, cet environnement météorologique devient un facteur déterminant d'inadaptation de certains individus.

Le fait que des naufragés aient pu vivre pendant des mois dans des régions froides comme Crozet ou Kerguelen – et les naufrages étaient fréquents parmi les phoquiers du siècle dernier – prouve que l'adaptation y est possible, dans des conditions absolues de dénuement. Ce sont là des expériences de survie avant la lettre et dans des conditions initiales beaucoup plus mauvaises (récit de Lesquin rapporté par Milon).

Le problème se pose différemment dans des bases organisées. L'homme y est à l'abri, chauffé, jouissant d'un confort relatif, habillé en conséquence. Il reconstitue « son » microclimat (problèmes intéressants, notamment en ce qui concerne l'humidité physiologique et la notion de confort). L'alimentation dans ces bases est parfaitement équilibrée grâce aux produits locaux (légumes venant sous chassis ou en serre ou même en pleine terre) permettant l'apport de crudités telles que radis, carottes, salades; élevage d'animaux ensauvagés tels que moutons à Kerguelen, bovidés à Amsterdam, volailles. Ce problème de nutrition reprendra tout son intérêt lors de la création de la station de Crozet courant 1964 (Ile de la Possession) dans un pays désertique et sans ressources locales actuelles.

Les courbes pondérales mensuelles des hommes, ascendantes pendant la première moitié du séjour, traduisent un gain de plusieurs kilogs. Elles restent stationnaires ensuite ou bien redescendent quelque peu les deux derniers mois de campagne. Outre la sédentarité relative, la tonicité du climat décuplant les appétits est le principal facteur à envisager.

Une étude sur la qualité du sommeil en rapport avec les phénomènes météoroclimatiques a échoué. L'enquête reposant sur des interrogatoires dont les réponses ne souffrent pas de fantaisies, les réponses exactes et rigoureuses furent irrégulières pour un même sujet et les conclusions à en tirer n'eurent aucune continuité.

On ne peut donc parler d'agression climatique vraie. Les paramètres, pris isolément, ne sont pas assez actifs. Le froid en pathologie polaire représente un type d'agression, une entité qui n'est pas à envisager dans les régions subantarctiques où seul le vent peut provoquer des conjonctivites par exemple, en association avec la nature pulvérulente de certains terrains.

Nous signalerons sur le plan épidémiologique des épidémies de fièvre *Q* à Kerguelen parmi les membres de l'Etablissement et dont le mouton semble bien être le réservoir de virus (Bourlaud, 1957) et à la Nouvelle-Amsterdam des épidémies de grippe sans associations microbiennes secondaires, évoluant en milieu fermé, sans contacte avec le monde extérieur, sur le mode endémo épidémique, en particulier en hiver ou au printemps.

ANIMAUX ET VÉGÉTAUX. INCIDENCES MÉTÉORO-CLIMATIQUES

Si l'homme sait reconstituer son biotope d'origine, animaux et végétaux doivent, pour subsister, utiliser au mieux les ressources que leur offrent des terres inhospitalières, en particulier les microclimats dont les petites espèces dépendent étroitement.

L'étude de ces microclimats s'avère donc indispensable mais est rendue ardue, parfois impossible, dans certaines régions d'accès malaisé ou éloignées des bases de départ. On est souvent surpris par de telles observations qui montrent à quel point on peut être loin de la vérité en considérant uniquement les données météorologiques de la station principale. On ne saurait comparer par exemple le climat de la côte Nord de la Nouvelle-Amsterdam à celui du plateau central situé à 600 m d'altitude, balayé par les vents, généralement noyé dans la brume. Et sur ce plateau, il convient de considérer telle ou telle orientation d'une anfractuosité ou d'un accident de terrain qui modifie considérablement les conditions climatiques. Le profil climatique de Port-aux-Français (Kerguelen) ne peut servir à l'étude des conditions écologiques de l'Ile Australia par exemple.

Ces considérations, banales en d'autres lieux, prennent ici toute leur valeur et revêtent une importance particulière dans l'étude d'une faune et d'une flore encore mal connues. L'implantation de l'instrumentation adéquate, notamment d'enregistreurs mensuels, est une condition essentielle souvent mal comprise des profanes.

Il est évident que la répartition de la faune et de la flore est en étroite relation avec les données climatiques générales. Certaines espèces animales se contentent de normes climatiques moins rigides et l'on peut suivre aisément leur répartition dans la zone subantarctique depuis la convergence subtropicale jusqu'à la convergence antarctique. Pourtant cette répartition est différente suivant les espèces et pose des problèmes biologiques bien particuliers.

Nous nous contenterons d'exposer ici quelques faits — simples constatations ou amorces de problèmes — se rapportant à la faune et à la flore de ces régions.

Éléphants de mer *(Mirounga leonina)*. Nombreux à Kerguelen où ils vivent suivant un rythme « orthodoxe », ils ne viennent qu'en petit nombre à la Nouvelle-Amsterdam, d'Octobre à Mars. Leur effectif ne dépasse jamais la quarantaine. On n'y a jamais observé de femelles. Les individus jeunes atterrissent en majorité en début de saison laissant la place après leur mue à des individus plus âgés (Paulian). Les marquages que nous avons effectués en 1959—60 nous ont prouvé que ces

animaux ne font que transiter. Cette migration saisonnière, l'absence de femelles, l'ignorance où nous sommes des lieux d'origine et de destination de cette population, sont autant de questions en suspens. Le facteur climatique y joue un rôle certainement prépondérant.

Si le Léopard de mer *(Hydrurga leptonyx)* vit normalement à Kerguelen, il n'a été observé à Amsterdam qu'une seule fois en dix années.

Inversement l'Otarie type *Arctocephalus gazella*, exceptionnelle à Kerguelen, affectionne les rivages de la Nouvelle-Amsterdam où elle abonde et accomplit tous les cycles de sa vie.

L'Avifaune est non moins intéressante. Le Gorfou sauteur *(Eudyptes cristatus)* se rencontre sur tous les rivages subantarctiques, tant à Saint-Paul et Amsterdam qu'à Kerguelen ou Crozet. Sa zone de répartition est donc très vaste et les influences climatiques semblent ne pas intervenir sur le choix de l'habitat. Cependant ses habitudes et son comportement sont sensiblement différents suivant le climat. Les dates d'arrivée à terre, d'accouplement, de ponte, de départ sont décalées: arrivée en mi-Août à Amsterdam, en Septembre à Heard, en Novembre à Kerguelen. Notons qu'à Amsterdam cette date ne varie que d'un ou deux jours et que trois années de suite le même oiseau bagué a été trouvé le premier suivi d'autres congénères également bagués et dans les mêmes nids. Il semble donc bien que les individus reviennent dans les zones climatiques dont ils ont l'habitude. Par contre, le Manchot Royal *(Aptenodytes patagonia)* ne dépasse pas la zone froide.

L'Albatros à nez jaune *(Thalassarche Chlorohynchos)* vit dans la partie tempérée de la zone subantarctique et on le trouve en abondance à Saint-Paul et Amsterdam mais il est inconnu à Kerguelen. De même le Fuligineux à dos sombre *(Phoebetria fusca)* affectionne une zone comprise entre les 38° et 42° parallèles et est commun à la Nouvelle-Amsterdam. Par contre le Pétrel géant *(Macronectes giganteus)* vit beaucoup plus au Sud et seuls quelques individus ont été vus à la Nouvelle-Amsterdam mais ne semblent pas y nicher. Mêmes remarques pour le Skua *(Catharacta skua)* à cette différence près que quelques individus nichent à la Nouvelle-Amsterdam.

La faune planctonique qui pullule dans les mares et les cours d'eau (Cladoceres, calanoides etc . . .) présente des variétés différentes suivant les Territoires. Mais ici le microclimat revêt toute son importance pour l'étude des biotopes, température, vent, ensoleillement interviennent directement en ce milieu. La répartition des espèces et même des genres, ainsi que le rythme de certains cycles, oeufs, d'été ou d'hiver, des daphnies par exemple dépend donc étroitement de ces paramètres.

L'adaptation des animaux domestiques ensauvagés (bovidés à Nlle-Amsterdam, ovins à Kerguelen) ou d'animaux importés d'autres régions du globe (Rennes à Kerguelen) mérite également une étude suivie qui a été partiellement réalisée pour certaines de ces espèces. Notons que tous ces animaux se sont parfaitement adaptés.

La flore présente des problèmes aussi variés.

L'absence de sphaignes à Kerguelen et Crozet, leur abondance à Nouvelle-Amsterdam et Saint-Paul est-elle liée au climat, malgré un biotope favorable?

L'adaptation de Phylica nitida, rhamnacée d'origine tropicale, à Nouvelle-Amsterdam et Tristan da Cunha, marque la limite Sud de répartition des arbres.

Le vent joue un rôle non négligeable dans la répartition des cryptogames dont il disperse les spores souvent à grandes distances.

La flore marine n'échappe pas non plus à cette influence et sa répartition, son métabolisme sont liés pour une part aux facteurs climatiques tels que température, vent, ensoleillement qui agissent directement ou par l'« intermédiaire » du milieu marin. On ne trouve pas de Durvillea dans les eaux d'Amsterdam; par contre, Laminaria pallida représente la seule espèce de ce genre dans les eaux australes (Delépine). Une relation vraisemblable existe entre les phénomènes ionosphériques et la biologie des grandes algues brunes.

L'adaptation des plantes diverses, dont de nombreuses légumineuses, a parfaitement réussi à la Nouvelle-Amsterdam, en pleine terre, bien que les vents du Sud-Ouest soient particulièrement néfastes à ces cultures. A Kerguelen, il est nécessaire de les abriter sous chassis ou sous serre.

L'arboriculture, par contre, malgré des essais réitérés, est vouée régulièrement à l'échec. Quelques très rares espèces réussissent à végéter, tout au plus, à l'abri du vent dans des coulées (Nouvelle-Amsterdam). Il serait pourtant intéressant de pouvoir adapter certaines espèces pour la création de haies protectrices.

L'étude systématique de la Flore, des conditions écologiques et notamment climatiques, déjà très avancée dans les Iles Australes Françaises, ouvre la voie à des études comparatives fort instructives.

Il existe donc dans cette vaste zone subantarctique de multiples phénomènes biologiques (répartition, migrations, adaptation, rythmes de vie, comportements . . .) étroitement liés aux facteurs météorologiques et plus spécialement climatiques, et qui représentent pour le chercheur une source abondante de travaux à venir dont certains sont déjà en cours.

BIBLIOGRAPHIE

Aubert, De La Rue, E. (1953) *Les Terres Australes.* Presses Universitaires de France.

Bourlaud, J. (1957) Syndromes pseudo grippaux de type épidémique observés aux Kerguelen chez des Européens. *Bull. Soc. Path. exotique,* **6,** 870–874.

Bouvier, R. (1960) La Météorologie Nationale dans l'Océan Indien Austral. *Revue du Secrétariat général à l'Aviation civile,* **106,** 43–66.

Chauvin, R. (1956) Quelques phénomènes étranges en rapport avec la Météorologie et qui intéressent les biologistes. *Ann. Biol.* **7,** et **8.**

Delepine, R. (1963) Un aspect des études de biologie marine dans les îles australes françaises. – Les discontinuités océanographiques dans l'Ouest de l'Océan Indien. *CNFRA* **3.**

Dolet, A. (1957) Études des observations en altitude. Ile Nouvelle Amsterdam 1951–1956. *Météorologie Nationale* (travail inédit).

Milon, P. (1962) Un naufrage et un séjour ancien aux îles Crozet *TAAF* 19 et 20 34 73.

Paulian, P. (1953) Pénnipèdes, cétacés, oiseaux des iles Kerguelen et Amsterdam. *Mémoires de l'Institut Scientifique de Madagascar* Série A. T. 8: 111—234.

PAULIAN, P. (1957) Note sur les phoques des îles Amsterdam et Saint-Paul. *Mammalia*, **3** 211–225.

PICCARDI, G. (1961) The problem of the relationship between spacial and Terrestrial phenomena and chemical tests. *Atti della Fondazione Giorgio Ronchi* **2**, 109–121.

PRUCHE, Y. (1961) Aptitude au climat et régulation thermique. *TAAF*, **17**, 4–20.

Le lecteur trouvera dans certains de ces ouvrages ou articles une bibliographie importante.

CONSIDÉRATIONS SUR LE BILAN THERMIQUE À LA STATION CHARCOT (ANTARCTIQUE)

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Abstract – During the IGY the heat balance was studied at Station Charcot (69°30′S, 139°01′E); the short-wave radiation balance was calculated from global radiation and measurements of the albedo of the snow. Under clear skies a linear correlation was found between the albedo and solar altitude. Under clear skies the net long-wave radiation which is about 40 cal/cm^2/day during the winter decreased with decreasing air temperature. During the 1957 winter (15 July–1 September) the mean values of the heat balance were (cal/cm^2 day): (a) radiation balance 37.1; (b) heat content snow 2.4; (c) convective and sensible heat 34.7.

Zusammenfassung – Der Energiehaushalt wurde während dem IGY in der Station Charcot bestimmt (69°30′ S, 139°01′0). Die Messung der einfallenden und reflektierten Globalstrahlung ermöglicht die Bestimmung der Strahlenbilanz im sichtbaren Bereich und einer Beziehung zwischen der Albedo und der Sonnenhöhe bei klarem Himmel. Bei klarem Himmel wurde auch die Beziehung der Lufttemperatur und der effektiven Strahlung bestimmt, die ungefähr 40 cal/cm^2/Tag beträgt. Während des Winters 1957 (15 Juli–1 September), zerlegt sich der Energiehaushalt in folgende Komponenten (cal/cm^2 Tag): (a) Strahlenbilanz 37,1; (b) Bodenwärme 2,4; (c) Wärme durch Phasenwechsel und Konvektion 34,7.

Résumé – Au cours de l'AGI on a étudié le bilan thermique à la Station Charcot (69°30′S, 139°01′ E); les mesures de rayonnement global incident et réfléchi permettent d'étudier le bilan radiatif dans le domaine du visible et de mettre en évidence, pour les journées claires, une relation entre l'albédo et la hauteur solaire. Le rayonnement effectif, dont la valeur est voisine de 40cal/cm^2/jour durant les mois d'hiver, a été relié à la température de l'air dans les mêmes conditions de ciel clair. Au cours de l'hiver 1957 (15 juillet – 1 septembre) le bilan thermique se décompose de la facon suivante (cal/cm^2 jour): (a) bilan radiatif 37,1; (b) contenu de chaleur du soleil 2,4; (c) chaleur transférée sous forme de changements d'état et d'échanges convectifs 34,7.

PROGRAMME DE MESURES, APPAREILLAGE, MÉTHODES

Au cours de l'Année Géophysique Internationale, l'étude des paramètres conditionnant le bilan thermique a été réalisée à la Station Charcot* (69° 30′ S, 139° 01′ E).

* Altitude	2.400 m
Température moyenne annuelle	– 38° C
Vent moyen	9,5 m/sec

Les mesures de rayonnement ont été faites à l'aide de radiomètres absolus (pyrhéliomètre d'Angstrom, actinomètre de Linde et Feussner) et secondaires (thermopiles de Volochine avec coupelles de verre ou de Lupolen H*), l'ensemble des appareils ayant été contrôlé avant le départ au Service du Rayonnement de l'Institut Royal Météorologique de Belgique; la durée de l'insolation a été enregistrée à l'aide d'un héliographe de Pers.

Des détecteurs ont été placés sur une tour micrométéorologique d'environ 10 m de haut; ils ont permis d'enregistrer les vitesses de vent (anémomètres à coupelles Lambrecht) et les différences de température (thermorésistances Hartmann et Braun protégées contre le rayonnement) à 5 niveaux différents.

D'autres thermorésistances permettaient l'enregistrement de la température, dans le névé, jusqu'à une profondeur de 18 mètres, une étude plus détaillée étant réalisée entre la surface et deux mètres à l'aide de thermistors soigneusement étalonnés.

BILAN RADIATIF

La durée d'insolation en fonction du temps, mesurée sur les papiers héliographiques, est représentée Fig. 1 (Tableau 1); elle montre qu'aucune trace d'ensoleillement n'est pratiquement visible durant 2 mois d'hiver.

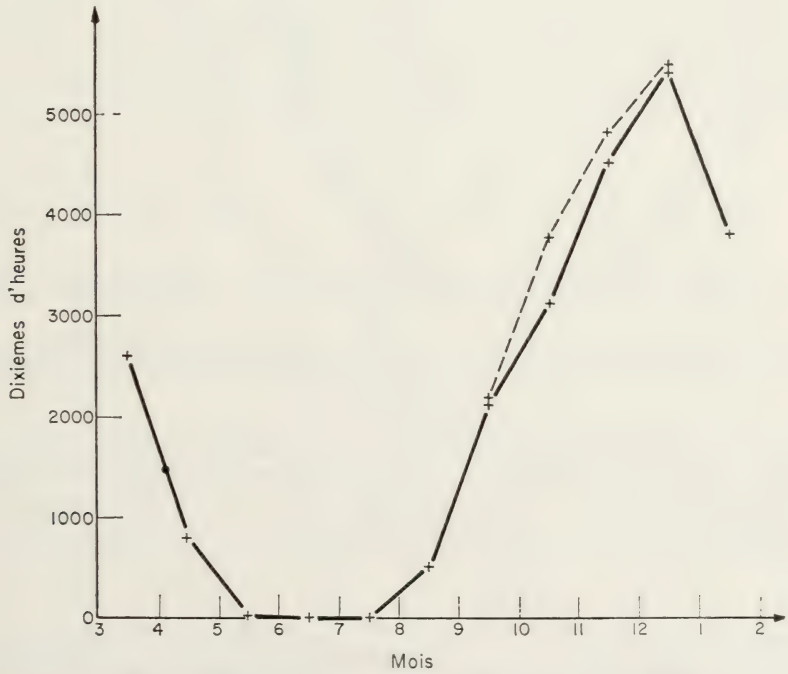

Fig. 1. Station Charcot 1957. Durée de l'insolation

+ Toutes les valeurs sont données dans l'échelle I.P.S.

* Ces coupelles nous ont été gracieusement fournies par le Dr R. Schulze.

Tableau 1. Station Charcot. Valeur de L'Insolation Mensuelle (dixièmes d'heures)

Mois	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septemb.	Octobre	Novemb.	Décemb.
1957			2593	792	29	0	0	496	2133	3112	4503	5391
1958	3813								2154	3751	4830	5518

Le bilan radiatif a pu être calculé dans le domaine du visible à partir des enregistrements du rayonnement global incident et réfléchi (Fig. 2, Tableau 2); les résultats obtenus pour la Station Pioneerskaya, dont les conditions sont comparables avec celles de la Station Charcot, ont été portés sur la même figure

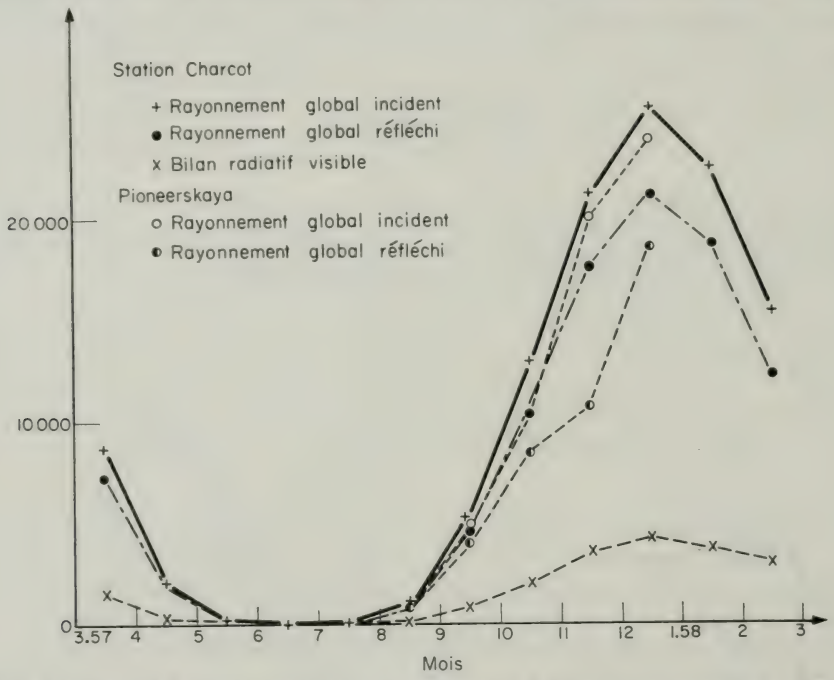

Fig. 2. Station Charcot 1957. Rayonnement global incident et réfléchi–bilan radiatif

Tableau 2. Station Charcot. Rayonnement Global Incident et Réfléchi Mensuel

Années	1957										1958	
Mois	Mars	Avril	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Dec.	Janv.	Févr.
Rayonnement global incident	8717	2133	197	0	51	1006	5399	12872	21172	25490	22488	15347
Rayonnement Global réfléchi	7239	1834	175	0	45	880	4623	10905	17617	21242	18765	12313

La mesure du rayonnement global durant les journées claires, au moment de la culmination (Fig. 3) nous permet d'étudier la variation de l'albédo en fonction de la hauteur solaire (Fig. 4, Tableau 3). La mesure de l'albédo est un problème difficile

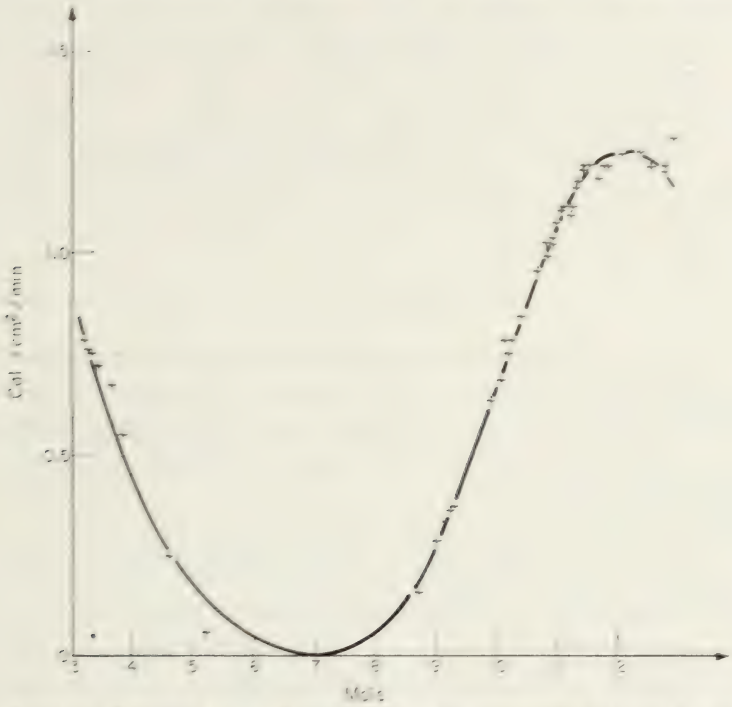

Fig. 3. Station Charcot 1957. Jours clairs. Rayonnement global à la culmination

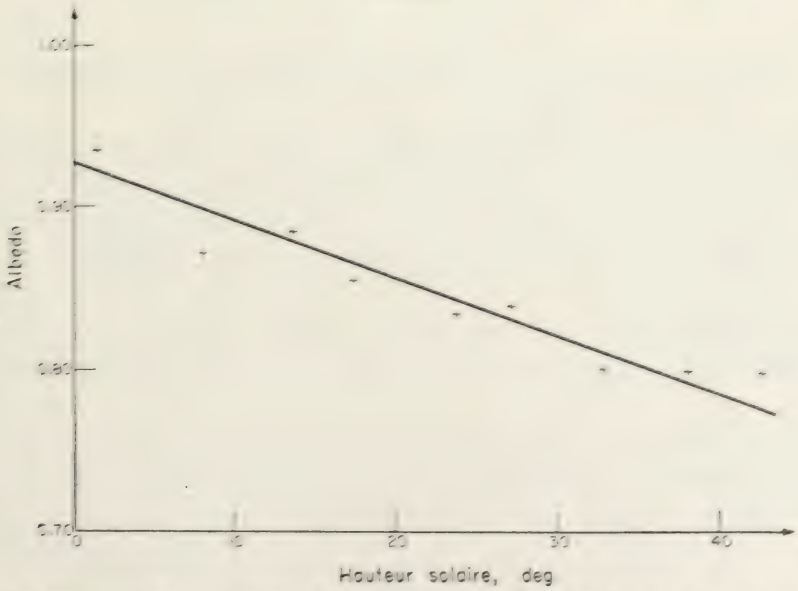

Fig. 4. Station Charcot 1957. Jours clairs. Variation de l'albédo en fonction de la hauteur solaire

Tableau 3. Station Charcot. Jours Clairs. Variation de L'Albédo en Fonction de la Hauteur Solaire

Intervalles	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	25°–30°	30°–35°	35°–40°	40°–45°
Albédo	0,935	0,872	0,885	0,855	0,834	0,839	0,800	0,799	0,800
Hauteur solaire Moyenne	1°30'	8°	13° 40'	17° 12'	23°45'	26°58'	32° 45'	37° 55'	42° 42'
Nombre de mesures	2	2	3	4	11	14	12	22	26

pour de faibles hauteurs solaires ou sur un terrain accidenté; pourtant nos résultats mettent en évidence sa décroissance nette lorsque la hauteur solaire croît, de façon encore plus accentuée que dans le cas des résultats de G.H. Liljequist (2, short wave radiation, p. 89); par ciel couvert nous avons aussi obtenu des valeurs de ce coefficient supérieures à 0,90.

Le rayonnement effectif a été enregistré à partir de détecteurs constitués par des thermopiles recouvertes de coupelles en «Lupolen H». Les thermopiles ont été, dans ce cas, étalonnées à partir des appareils absolus dans le domaine du visible; la constante de transformation ainsi obtenue a ensuite été corrigée d'un facteur de 1,15 de façon à tenir compte de l'absorption du «Lupolen H» et de la sensibilité moindre du noir de fumée au rayonnement infra-rouge. Les mesures ont été rendues difficiles, particulièrement dans le cas de journées ensoleillées, par le manque de

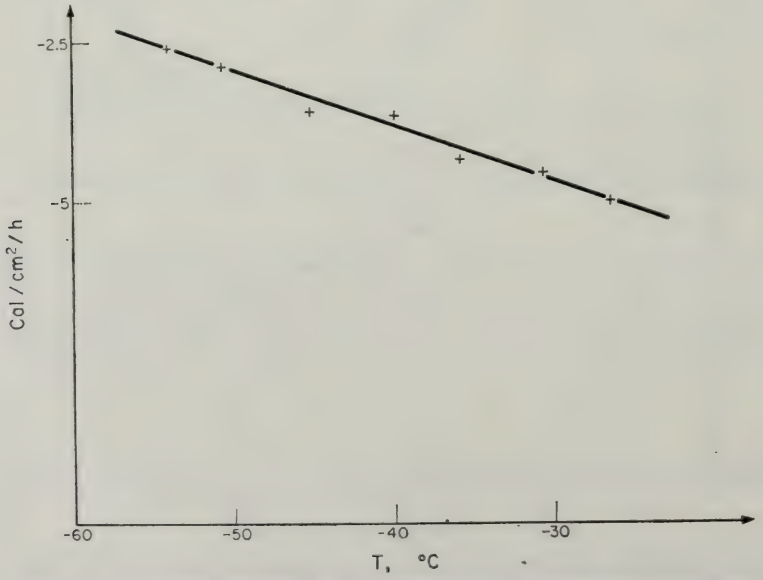

Fig. 5. Station Charcot 1957. Jours clairs. Rayonnement effectif

Tableau 4. Station Charcot. Jours Clairs. Rayonnement Effectif

Intervalles de température	-58°- -53°C	-53°- -48°C	-48°- -43°C	-43°- -38°C	-38°- -33°C	-33°- -28°C	-28°- -23°C	-23°- -13°C
Rayonnement effectif	-2,61	-2,86	-3,51	-3,64	-4,35	-4,57	-5,00	-4,98
Hauteur solaire moyenne	54°1 C	50°7 C	45°3 C	40°0 C	35°9 C	30°8 C	26°6 C	16°°1 C
Nombre de mesures	49	116	83	19	27	7	6	1

résistance mécanique des coupelles, la surface de celles-ci devenant irrégulière et partiellement dépolie sous l'influence des chasse-neige.

Le rayonnement effectif ainsi mesuré a donné des valeurs moyennes de 39,1 et 43,3 cal/cm²/jour au cours des mois de juillet et août 1957, les chiffres correspondants pour Pioneerskaya étant (Rusin, 1958), 38,7 et 51,6.

Dans le cas de journées avec ciel clair, il nous a été possible de mettre en évidence une relation moyenne entre la température de l'air et la valeur du rayonnement effectif (Fig. 5, tableau IV.) La perte radiative ainsi obtenue est très supérieure à celle donnée par H.C. Hoinkes (1960), mais en assez bon accord avec les résultats de G.H. Liljequist (long wave radiation and radiation balance, p. 126).

STRUCTURE DE L'ATMOSPHÈRE AU VOISINAGE DU SOL

La structure thermique de l'atmosphère est fortement influencée par le vent catabatique soufflant pratiquement en permanence et entre les niveaux 0 et 10 m les gradients de température observés sont le plus souvent inférieurs à 0,5° C.

Nous avons choisi deux journées illustrant les différents types de structure que l'on rencontre.

Le 21 décembre, le bilan radiatif positif entraîne une structure instable de l'atmosphère; la vitesse du vent croît proportionnellement au logarithme de la hauteur (Fig. 6).

Cette représentation logarithmique a été vérifiée (Lorius, 1962) aussi dans le cas de chasse-neige (Fig. 7) .L'ensemble des mesures effectuées montre en effet, dans ce cas, une relation linéaire entre le logarithme du chasse-neige et le logarithme de la hauteur au-dessus du sol.

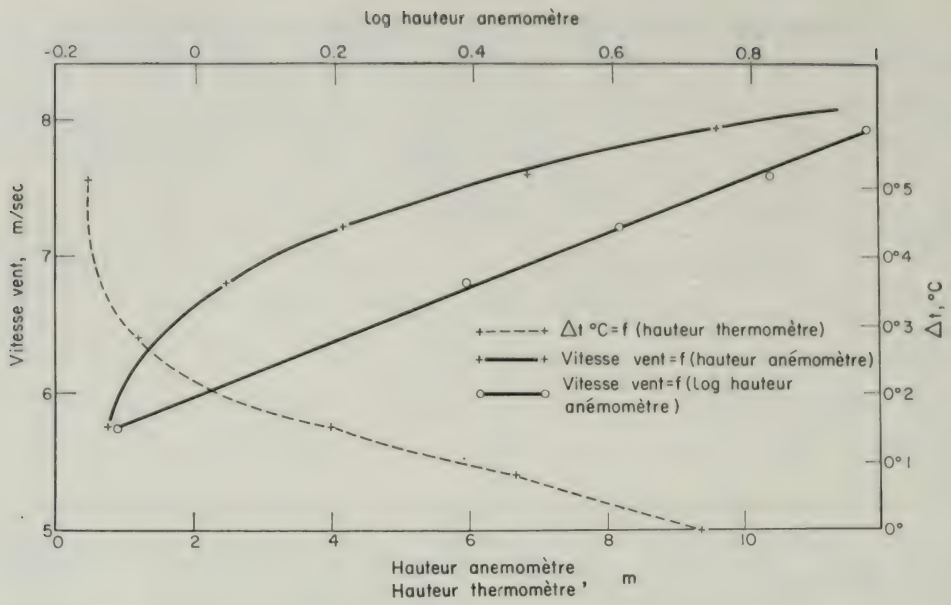

Fig. 6. Station Charcot 21 décembre 1957. Structure de l'atmosphère.

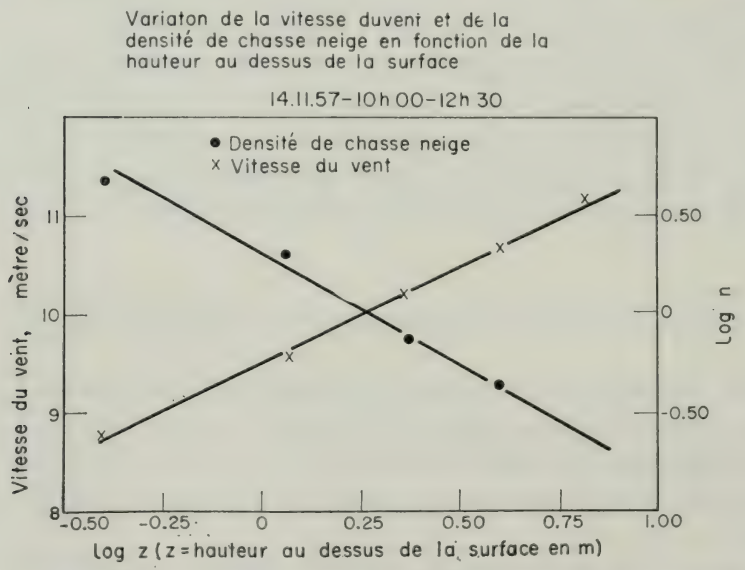

Fig. 7. Station Charcot 14 novembre 1957. Structure de l'atmosphère et densité de chasse-neige

BILAN THERMIQUE DURANT UNE PÉRIODE DE L'HIVER 1957

Considérons l'équation du bilan thermique:

$$(R_g - R_r) + R_e + Q_c + Q_E = QS$$

avec:

R_g = rayonnement global incident
R_r = rayonnement global réfléchi
R_E = rayonnement effectif
Q_c = échanges convectifs
Q_E = échanges sous forme de changements d'état.
Q_s = variation du contenu de chaleur du sol.

Au cours de la période considérée, la valeur de Q_s a été obtenue selon une méthode fréquemment utilisée (Hoinkes, 1960) à partir des mesures de température effectuées dans le névé (Fig. 8).

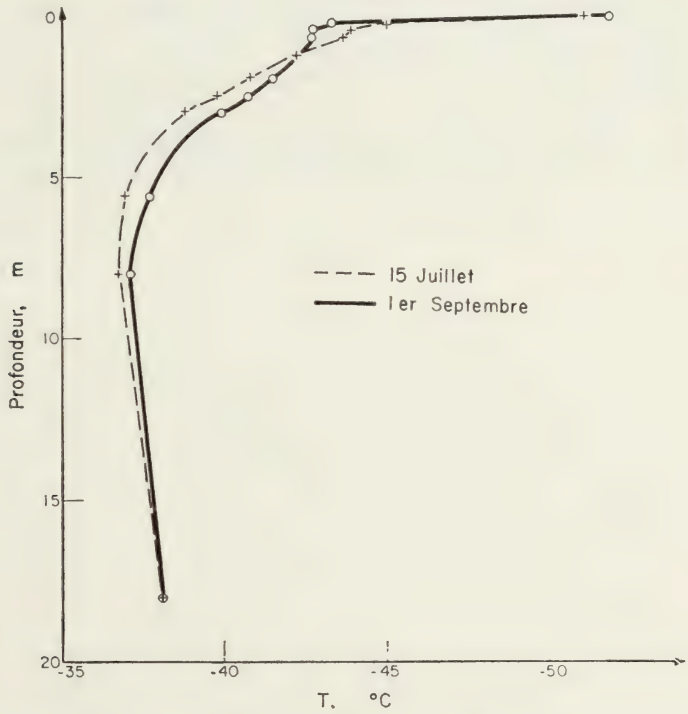

Fig. 8. Station Charcot 1957. Températures dans le névé (15 juillet–1er septembre)

A partir de ces courbes le calcul a été effectué en utilisant la formule:

$$Q_s = \int_0^\infty c\varrho\, \Delta t\,(z)\, \mathrm{d}z$$

en adoptant pour la chaleur spécifique de la glace c la valeur de 0,43 cal/g/°C et en utilisant les mesures de densité effectuées en profondeur (Lorius, 1962)

On trouve ainsi que le contenu de chaleur du sol a varié de 116 cal/cm^2 durant cette période. En respectant l'équation du bilan thermique nous pouvons donc écrire:

$$130 - 1911 + Q_c + Q_E = -116$$

Les échanges de chaleur se produisant sous forme convective et par suite de changements d'état, seraient donc de l'ordre de 1665 cal/cm^2.

Les essais de calcul des échanges thermiques à partir des profils de vent et de température n'ont pour l'instant pas été concluants, par suite sans doute des faibles valeurs du gradient de température dans l'air au voisinage du sol.

BIBLIOGRAPHIE

RUSIN, N. P., (1958) Bilan de radiation de la surface neigeuse en Antarctique. *Bull. d'Information des Expéditions Soviétiques en Antarctique* **2**, 25.

LILJEQUIST, G. N., Energy Exchange of an Antarctic snow field. *Norvegian–British–Swedish Antarctic Expedition*, 1949–1952, Scientific results, vol. II.

HOINKES, H. C., (1960), Studies in glacial meteorology at Little America V. *Antarctica, AIHS, publ. (U.S.A.)* **55**, 29–48.

LORIUS, C., (1962) Contribution to the knowledge of the Antarctic Ice sheet: a synthesis of glaciological measurements in Terre Adélie. *J. Glaciology* **31**, 79–92.

APPAREILS DE MESURES ET POSSIBILITÉS D'INVESTIGATIONS BIOCLIMATOLOGIQUES

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Abstract – The study of the correlations between meteorological and physiological-pathological phenomena is extremely complicated because of the difficulty of obtaining comparable parameters and the complexity of the apparatus used. Bioclimatological investigations make it possible to analyse the common meteorological factors, radiation, atmospheric electricity, radioactivity, air pollution, and to study microclimate. A synopsis of the major meteorological and seasonal events should also be made. Experimental investigations can be of different types, e.g. physiological, pathological, or based on dynamics and statistics of certain physiopathological phenomena. The polar environment is suitable for all types of biometeorological investigations.

Zusammenfassung – Es ist sehr schwierig, die Beziehungen zwischen meteorologischen Faktoren und physiopathologischen Reaktionen zu studieren. Dies hängt nicht nur mit den Schwierigkeiten zusammen, messbare und vergleichbare Parameter zu finden, sondern auch mit der Kompliziertheit und der Wahl der Instrumente. Die biometeorologischen Untersuchungen sollen die gebräuchlichen meteorologischen Elemente, Strahlung, Luftelektrizität, Radioaktivität und Luftverunreinigung berücksichtigen. Hierzu gehört das Studium der Mikroklimate. Eine Übersicht über die grossen meteorologischen und von der Jahreszeit abhängenden Ereignisse muss angelegt werden. Die Untersuchungen können verschiedener Art sein, z. B. physiologische und pathologische und statistische Untersuchungen, die sich mit physiopathologische Phänomenen befassen.

Résumé – Il est très complexe d'étudier les corrélations existant entre les phénomènes climato-météorologiques et les phénomènes physio-pathologiques. Cela tient non seulement aux difficultés d'envisager des paramètres mesurables et comparables, mais aussi à la complexité et au choix des appareils. L'enquête bioclimatologique doit permettre l'analyse des éléments métérorologiques conventionnels, de la qualité du rayonnement, de l'électricité atmosphérique, de la radio-activité, des éléments dynamiques dans un temps donné (par exemple déperdition thermique), de la pollution atmosphérique. Doit s'y ajouter l'étude des microclimats. Enfin parallèlement une appréciation synoptique des grands évènements météorologiques et saisonniers doit être faite. Les investigations qui en découlent peuvent être de différents ordres, définition bioclimatologique d'un secteur donné, recherches physiologiques couplées, recherches pathologiques couplées, recherches dynamiques et statistiques portant sur des phénomènes physiopathologiques.

INTRODUCTION

La bioclimatologie est une science naissante et l'étude des corrélations entre les phénomènes climato-météorologiques et la physiopathologie en est à ses balbutiements. Difficultés de définir tous les éléments qui interviennent dans l'environne-

ment climatique, difficultés de choisir, apprécier et chiffrer les signes cliniques mis en parallèle, difficultés d'établir les corrélations, énormes appareillages, coopération de toute une équipe, investigations de longue durée et sur un grand nombre de patients, tout concourt à faire avorter les tentatives de progression dans cette connaissance. Et pourtant on soupçonne, on constate parfois la modulation d'une maladie en rapport avec un facteur collectif, celui-ci n'appartenant pas en propre au sujet et étant donc d'origine cosmique. Tout le monde connaît le regroupement étonnant des infarctus ou l'évolutivité paradoxale d'un asthme ou d'un coryza spasmodique. On sait aussi bien que certaines localisations géographiques sont bénéfiques pour certaines individualités morbides. Sur le plan physiologique, on peut s'étonner de la réalisation ou de la non réalisation de certains records inhabituels d'un champion, dans un sens hyper ou hypo anormaux pour lui et pour lesquels on ne retrouve aucune cause personnelle. Un autre exemple paradoxal est à citer : dans certaines zônes de montagne (lugares de puna des Andes par exemple) les montagnards ressentent une accentuation du mal des montagnes par rapport à une altitude plus élevée à laquelle ils vont se sentir mieux alors que la pression partielle d'oxygène est plus basse que dans la zône de puna. Autant de faits vérifiés analogiquement mais dont les raisons profondes, la cause physique et le mécanisme physiopathologique, nous échappent.

En particulier, on ne sait pas quels sont les paramètres ou les phénomènes bioclimatiques qu'il faut étudier comme ayant probablement un retentissement sur l'organisme. La pression atmosphérique certes mais essentiellement surtout dans ces extrêmes en rapport avec les accidents aigus ; l'hygrométrie, les radiations, le vent, un front orageux . . . L'influence du vent, par exemple, est bien connue, mais agit-il par ses qualités propres ou par les particules qu'il transporte ou par sa charge électrique ou parce qu'il annonce un phénomène météorologique caractérisé lui-même par d'autres éléments. Ainsi, si l'on constate la variation d'un paramètre parallèlement à l'évolution d'un élément pathologique, ce paramètre ne représente pas automatiquement la cause première ; il peut très bien n'être que le reflet d'un phénomène plus complexe et plus général qui va varier parallèlement à ce paramètre mais est passé inaperçu.

DÉFINITION D'UNE TECHNOLOGIE BIOCLIMATOLOGIQUE

Des mesures systématiques à l'aide d'appareils appropriés doivent être faites. Certaines sont aisées à réaliser ; d'autres, très complexes, demandent la fabrication à la demande d'appareils de détection et d'enregistrement.

(A) Enquête bioclimatologique d'un lieu géographique donné

Elle comprendra des mesures classiques de météorologie et l'étude de bien d'autres paramètres.

(1) *La température* – températures minima, maxima, moyennes
– utilisation de thermomètres classiques extemporanés et d'enregistrement; abris.

(2) *La pression atmosphérique* – pression moyenne; sens et valeur des modifications de pression.
– utilisation de barographe; et de baromètre à mesure de contrôle.

(3) *Le vent* – vitesse et direction; importance de l'élément rafale.
– utilisation d'anémomètre, et de girouette enregistreurs.

(4) *L'hygrométrie* – humidité relative, humidité absolue
– utilisation d'hygrographe à cheveux et thermomètres.

(5) *Les précipitations* – appréciation visuelle
– enregistrement par pluviographes.

(6) *L'ensoleillement* – mesure quantitative de la durée journalière d'ensoleillement.
– utilisation d'héliographe de Campbel ou Jordan.
Il est classique en outre d'apprécier la nébulosité et la visibilité.

(7) *La qualité du rayonnement* – appréciation quantitative et qualitative basée sur l'utilisation des piles radiométriques variables dans leur conception selon le rayonnement étudié. De toutes façons l'élément actif de la pile capte l'émission lumineuse et la traduit en intensité sous forme d'un courant électrique ou d'une notation en calories. Un appareil enregistreur souvent très sensible peut être utilisé à la sortie de la pile.

Les différents rayonnements étudiés habituellement sont les suivants:

Rayonnement solaire direct: on mesure le rayonnement émis par le soleil au cours d'une visée, le soleil étant perpendiculaire à la surface réceptrice. L'appareil se nomme pyrrhéliomètre ou actinomètre. Dans certains cas, l'appareil peut suivre le mouvement du soleil (pyrhéliographe) et dans ce cas on effectue un enregistrement continu.

Rayonnement global: on mesure le rayonnement du soleil plus celui du ciel tombant soit sur une surface horizontale, soit sur une surface sphérique qui reste fixe et n'est pas orientée dans une incidence perpendiculaire au rayonnement solaire. L'appareil se nomme pyranomètre ou solarimètre; il existe des appareils enregistreurs (solarigraphes).

Rayonnement diffus: on mesure le rayonnement global moins le rayonnement solaire direct. Le rayonnement est reçu comme dans le cas précédent sur une surface horizontale fixe. Il s'agit donc du même appareil avec un cache-soleil (disque se déplaçant dans l'azimuth du soleil et mû par un moteur, ou arc métallique orienté dans le plan de la trajectoire solaire et déplacé manuellement chaque jour en fonction de la hauteur du soleil).

Rayonnement solaire réfléchi: on mesure le rayonnement global réfléchi par le sol, la surface réceptrice étant tournée vers le bas et étant placée horizontalement et d'une manière fixe. L'appareil se nomme albédomètre; enregistrement possible.

Rayonnement effectif: On mesure la différence des rayonnements propres à l'atmosphère et au sol en tenant compte des longueurs d'ondes de l'infra-rouge. Les appareils utilisés sont le pyranomètre effectif et le pyrgéomètre.

Rayonnement ultra-violet: On peut se servir d'un photomètre ou mieux utiliser une thermopile calée sur les longueurs d'ondes intéressées et portant des filtres.

Rayonnement infra-rouge: On peut aussi utiliser certains photomètres à cellules de cadmium ou de silicium ou une thermopile calée sur les longueurs d'ondes intéressée et portant des filtres.

Rayonnement radiatif: On mesure la totalité du rayonnement en tenant compte de ce que le sol reçoit et réfléchit, du rayonnement global, du rayonnement solaire réfléchi, du rayonnement effectif.

Rayonnement cosmique: Il n'y a évidemment intérêt à faire cette mesure qu'en altitude. On peut utiliser des éléments photographiques ou des cultures bactériennes sensibles aux radiations cosmiques.

(8) *L'électricité atmosphérique* – pour mesurer l'electricité atmosphérique, on utilise des appareils conçus souvent à partir de principes fort différents et qui vont tenter de quoter soit la valeur du champ électrique dans son sens et son intensité, soit l'ionisation et la conductibilité. Disons d'emblée qu'aucun de ces appareils ne satisfait complètement l'esprit, que les valeurs trouvées sont rarement d'une autenticité absolue et indiscutable et que les phénomènes parasites sont rarement entièrement exclus des mesures. Heureusement, pour nous, biologistes, la notion de variation a souvent autant d'intérêt que l'appréciation d'un chiffre absolu. La bioclimatologie a des critères bien différents de ceux de la physique de l'atmosphère.

La mesure du champ électrique peut consister à prendre la différence de potentiel existant entre deux points situés à des niveaux différents. On peut prendre le ddp entre un point de l'atmosphère et le sol ou entre deux points de l'atmosphère. C'est la première solution qui est la plus fréquemment utilisée dans les mesures au sol. Il faut donc avoir un appareillage de captation et un appareillage de mesure et d'enregistrement. La captation peut être réalisée par un collecteur radioactif qui se met en équilibre électrique avec l'atmosphère au point de l'espace où il est placé. Ainsi une source de rayons alpha émet dans un petit volume d'air autour du collecteur. Quand une différence de potentiel existe entre le collecteur et l'air environnant, les ions libérés par le rayonnement entrent en mouvement et viennent charger le collecteur jusqu'à ce que celui-ci ait atteint le potentiel de l'air. Un potentiomètre, qui peut être enregistreur va effectuer à distance la mesure.

Un autre dispositif de captation et de mesure a été conçu sur un principe different. Une electrode soumise à l'influence du champ électrique acquiert une

charge qui va dévier un électromètre. Une autre électrode, de forme annulaire et entourant l'électrode captrice, va être portée à un potentiel convenable pur annuler cette déviation et la connaissance de ce potentiel donnera la valeur du champ.

Nous passons évidemment sur tous les dispositifs de tarage et d'asservissement que ces appareils comportent en raison de l'énorme distance qui existe entre le principe théorique et la réalisation pratique d'un enregistrement utilisable. En fait, il faut préciser que ces mesures d'électricité atmosphérique vont souffrir d'un nombre de causes d'erreurs important et pas toujours faciles à éviter, ne serait-ce que l'influence du vent et de la pluie sur les parties captrices. Si théoriquement on peut faire une mesure du champ électrique en prenant la ddp entre un point situé à un mètre ou deux du sol et le sol considéré comme zéro, pratiquement il n'en va pas de même à partir de l'instant où l'on réalise techniquement l'installation. Le capteur n'est pas un point nul, il n'est pas isolé dans l'espace, il faut bien qu'il soit, soit suspendu, soit supporté ; il existe un système de cablage le reliant à la partie enregistreuse, un bâtiment voisin dans lequel se trouve l'enregistreur ; autant d'obstacle et d'éléments conducteurs qui peuvent modifier le champ électrique et ceci d'autant plus fortement que l'ambiance est humide. Ces critiques sont du reste applicables à des degrés plus ou moins grands à toutes les mesures d'électricité atmosphérique. Pour y remédier, les expérimentateurs ont évidemment imaginé de multiples systèmes de contraintes, intervenant même sur l'état du sol ou des locaux, gazon, gravier, carré de sol artificiellement isolé, fosse pour les enregistreurs, etc . . . .

Une amélioration a certainement été apportée par l'électronique en ce qui concerne la partie mesure et enregistrement. Un autre principe de capteur a résulté de ce progrès de la connaissance. Il s'agit des « field-mills », « moulins à champ », ou plus explicitement « modulateurs à interception de champ ». Ces appareils comportent des électrodes exposées puis soustraites périodiquement au champ électrique à mesurer. Ils fournissent entre les électrodes et le sol une tension hachée proportionnelle à ce champ. Les signaux envoyés peuvent être recueillis par un enregistreur électronique adapté. Nous renvoyons, en particulier ici, à la thèse de Jardel dans laquelle il est décrit en détail la mise au point et la réalisation d'un appareil original de mesure de champ basé sur le principe des moulins à champ.

Les appareils mesurant l'ionisation et la conductibilité s'adressent au principe de déperdition c'est-à-dire à la décharge progressive des corps conducteurs dans l'air. On peut faire circuler un courant d'air entre les armatures d'un condensateur cylindrique relié à un système de mesure électrométrique ou électronique. Il convient en outre de réaliser un appareillage permettant de différencier les gros ions et les petits ions. On utilise parfois deux appareils, l'un qui prend tous les ions, un autre qui ne capte que les petits en raison d'un réglage de débit et en arguant sur l'extrême mobilité des petits ions.

Il existe un appareil électronique dit ionomètre enregistreur qui est sensé donner les différentes charges en ions et la conductibilité. Le principe général de l'appareil consiste en une accumulation des charges ioniques sur des conducteurs isolés, initialement non chargés et dont le potentiel par rapport à la terre, initialement nul,

prend une valeur proportionnelle à la somme algébrique des charges accumulées. L'accumulation se fait pendant un temps déterminé et intéresse un certain volume d'air. Le potentiel atteint par l'électrode captrice en fin de période d'accumulation est mesuré à l'aide d'un électromètre électronique enregistreur. La mesure effectuée, cette électrode est automatiquement déchargée par remise à la terre, puis nouvelle période de mesure. Deux équipements parallèles permettent de mesurer l'importance des deux types d'ions. Les gros ions sont captés par filtration d'air dans une « tuyère d'intégration »; les petits ions sont captés par l'action d'un champ électrique transversal au courant d'air dans la « tuyère de conductibilité ».

Malheureusement, là encore, les phénomènes parasites troublant les mesures d'électricité atmosphérique sont nombreux et l'on peut en particulier se poser bien des questions en nettoyant les « tuyères » et en voyant les nombreuses particules animales, végétales et minérales qui s'y sont déposées...

(9) *La radioactivité* — la radioactivité du sol doit être connue.

La radioactivité atmosphérique fait l'objet de deux types de mesures: radioactivité naturelle et radioactivité artificielle. Les appareils de réception et de comptage sont actuellement au point et existent dans les stations spécialisées.

(10) *Les éléments dynamiques sur un temps limité* — il est parfois utile de regrouper certains paramètres pour réaliser une mesure correspondant plus à ce qui se passe dans la réalité. Par exemple, mesure de la déperdition thermique à l'aide d'un frigorigraphe, où l'on apprécie non plus des paramètres statiques (température, force du vent, humidité atmosphérique), mais le nombre de calories/minute perdues en fonction de tous les paramètres d'une ambiance.

(11) *La pollution atmosphérique* — intérêt majeur dans les cités: analyses gazeuses, particules solides, microbulles d'hydrocarbure, allergènes.

(12) *La dispersion pollénique* — il faut dresser des cartes statiques et dynamiques de la dispersion pollénique réelle d'un lieu, selon les saisons et les conditions météorologiques. Ce travail demande évidemment la coopération de différents spécialistes (médecins, palynologues, météorologistes).

Evidemment, certaines des mesures citées correspondant au cas général le plus complet, peuvent présenter un intérêt plus ou moins grand selon le lieu envisagé. En régions polaires, le frigorigraphe (type Mörikofer par exemple) prend sans conteste le pied sur la dispersion pollénique qui elle, est inexistante.

(B) Etude d'un microclimat donné

Il s'agit ici d'un autre problème visant souvent à recouvrir un secteur précis d'une étude bioclimatologique générale et présentant un intérêt soit pour les médecins, soit pour les hygiénistes. Comment définir scientifiquement une certaine ambiance close et artificielle? On applique les mêmes moyens d'enquête mais avec évidemment une autre optique et en tenant compte qu'il s'agit de mesures à une

échelle métrique réduite et qu'il faut donc intégrer de façon absolue les faits locaux d'échanges en rapport avec le mode de vie, c'est-à-dire les incidences spécifiques aux conditions données de ce microclimat.

(C) Appréciation synoptique des grands mouvements météorologiques

Soit en raison d'une étude précise (cf. plus loin) soit pour contrôler et interprêter l'enquête bioclimatologique classique, il est indispensable que tout travail de bioclimatologie soit couplé avec une coopération de spécialistes de la météorologie qui vont pouvoir fournir certains éléments très importants par des sondages d'altitude, des recoupements géographiques d'information etc..., ainsi la hauteur de la troposphère, l'appréciation d'un ensemble météorologique donné et de ses déplacements (front dépressionnaire, front tropical etc...). Par exemple on peut noter que la simple définition globale des éléments météorologiques régionaux peut permettre des interprétations médico-physiologiques du plus haut intérêt. Ainsi, au même titre que tout médecin sait que lorsqu'il pleut, le malade atteint du rhume des foins n'a pas de crise en raison de la fixation des pollens, certaines conditions très générales de météorologie définissent un ensemble favorable ou défavorable à l'apparition de certaines manifestations morbides.

DÉFINITIONS DE SYSTÉMES DE CORRÉLATION

Les thèmes de recherches et d'études peuvent être très variés. Nous ne ferons donc qu'évoquer certaines possibilités en ayant soin de préciser les moyens d'établir une corrélation.

(A) Définition bioclimatologique d'un secteur donné

On enregistre systématiquement les paramètres évoqués plus haut. On les ordonne et on les moyenne. On contrôle et interprête les données par les éléments de synthèse régionale ou générale fournis par les spécialistes de la météorologie.

L'accumulation des mesures au cours des mois et des années permet de définir avec précision la valeur climatologique d'un secteur donné. Mais si cela n'est pas très passionnant aux yeux d'un médecin, ce travail a déjà au moins un gros intérêt, celui de préciser de quoi l'on parle lorsqu'on évoque la climatologie de tel ou tel lieu. On en connaît alors toutes les incidences de façon scientifique et il ne s'agit plus d'une appréciation purement empirique et sans valeur. Certains jugements exprimés quant à un endroit géographique donné seraient souvent révisés avec étonnement après une étude de ce genre.

(B) Recherches physiologiques couplées

Après cette première corrélation, c'est-à-dire ce recollement analytique et synthétique des paramètres climatiques, un autre type d'études est à envisager:

Rapports des éléments climatologiques avec des phénomènes physiologiques. On choisit un ou plusieurs paramètres physiologiques, études de fonctions, de constantes biologiques, et parallèlement à l'étude des phénomènes et des données climatologiques, on note les valeurs de ces mesures physiologiques systématiquement répétées sur un certain nombre d'individus durant un temps donné. Par exemple: mesures de coagulation (temps de Quick, temps de Howel, thrombélastographie), ou consommation d'oxygène. On apprécie leur variation chez des sujets normaux en fonction des variations climatologiques. Il faut évidemment avoir des séries suffisantes pour pouvoir chercher et éventuellement trouver les corrélations.

(C) Recherches pathologiques couplées

En étudiant certains phénomènes pathologiques, certaines manifestations de maladie dont les phases sont en rapport avec les variations climatiques, on peut établir les corrélations souvent plus aisément que si l'on s'adresse comme précédemment à des sujets normaux. On peut par exemple dans une même ville noter tous les infarctus du myocarde, toutes les embolies pulmonaires, tous les asthmes graves ... Certains signes cliniques ou para-cliniques doivent être dans chaque cas systématiquement recherchés et notés, par exemple dans l'asthme, la séméiologie de début de la crise, la température, la tension artérielle, la formule sanguine etc. pour permettre par la suite de trouver une corrélation. Il faut dans ce genre d'enquête avoir établi au préalable avec rigueur ce que l'on pourrait appeler les paramètres pathologiques (c'est-à-dire la symptomatologie évoquée plus haut) afin de pouvoir les comparer statistiquement avec les paramètres climatologiques et pour cela il faut trouver une grille donnant des valeurs en intensité sinon aucune comparaison rigoureuse ne sera possible ni l'emploi d'aucune machine électronique de dépouillement.

(D) Recherches dynamiques et statistiques portant sur des phénomènes pathologiques

Dans le cas précédent, on peut admettre que bon nombre de cas échapperont à la statistique, les malades, par le fait du pur hasard ayant été protégés artificiellement du phénomène cosmique noté. Il sera parfois difficile d'apprécier si une augmentation de 5 pour cent d'asthmes graves dans une ville donnée est en rapport avec un phénomène climatique présent en ce lieu. C'est du reste pourquoi il faut pousser l'étude en profondeur en notant les valeurs des symptômes. Pour sensibiliser la réaction, on peut imaginer une enquête statistique beaucoup plus satisfaisante. Imaginons que, non pas tous les médecins de France, mais par exemple le 10e d'entre eux, et bien réparti géographiquement, acceptent de renvoyer systématiquement une carte-lettre toute préparée à l'avance sur laquelle figurera le nom de certaines affections, qu'il n'y aurait qu'à cocher avec l'heure et la date lorsqu'on les diagnostiquerait. En même temps, on étudierait sur carte le déplacement géographique d'un grand phénomène météorologique, par exemple un front

froid. La comparaison du nombre de cas pathologiques avec les lignes de déplacement du phénomène météorologique est alors tout-à-fait intéressante, car dans ce cas, une augmentation de 5% de certains phénomènes pathologiques se déplaçant avec le phénomène météorologique est indiscutablement lié à lui.

APPLICATIONS AUX PAYS POLAIRES

Ces notions peuvent être extrapolées aux problèmes physiopathologiques qui nous préoccupent en régions polaires.

(1) Définition scientifique de l'environnement bioclimatique d'un secteur donné. Ce travail n'a pas encore été fait.

(2) Définition scientifique d'un microclimat donné: intérieur d'une base, zone précise d'implantation d'une base, roockerie de manchots, nids etc ...

(3) Corrélations entre les variations de l'environnement bioclimatique et la physiologie des individus séjournant en pays polaires lors d'un hivernage. Corrélations avec les variations quotidiennes et les variations saisonnières.

(4) Corrélations entre les variations de l'environnement bioclimatique et la pathologie, soit pathologie des indigènes des régions polaires, soit pathologie somatique mais surtout psychique et psychosomatique des groupes d'hivernage.

(5) Corrélations entre les variations de l'environnement bioclimatique et la physiopathologie de la faune environnante.

(6) Corrélations entre les variations de l'environnement bioclimatique, la physiopathologie de la flore environnante.

CONCLUSIONS

Il existe donc un large champ de travail à peine entamé. Mais il ne faut pas s'illusionner sur les difficultés qu'il présente, tenant aux différents points évoqués plus haut, tant sur le plan appareillage, sur le plan expérimentation physiopathologique que sur le plan corrélations. Devant la difficulté du choix, la nécessité de chiffres nombreux, les problèmes posés par l'interprétation, il est absolument indispensable que ces recherches de bioclimatologie soient conçues selon des plans de coordination et de coopération. Utiliser les mêmes appareils, faire le même type de mesures, effectuer des recherches de corrélations analogues, multiplier les cas, échanger les résultats, discuter des difficultés, tels sont les points qui nous paraissent indispensables si l'on veut progresser dans cette connaissance, voie nouvelle d'interprétation d'un certain nombre de phénomènes de la vie et dont nous voyons naître les premiers pas encore mal assurés.

GEOPHYSICAL STUDIES UNDERTAKEN BY POLAR AND SUBPOLAR RESEARCH LABORATORIES

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THE laboratories of the subarctic islands and the polar regions in general are particularly suitable for biometeorological and geophysical studies. Both climatological conditions and physiological responses are more striking in these regions. The geophysical studies made in the islands of French Australia were described. The author discussed the correlations of meteorological and geophysical data with the results of biological investigations which could be made in the establishments of these islands.

POLAR ASYMMETRY OF THE GEOGRAPHICAL COAT

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INVESTIGATIONS carried out in the Southern Hemisphere suggest that the principal structure of the geographical coat is not its zones (belts) but its asymmetry. Zones of the geographical coat are a subordinate structure. This conclusion is derived from an analysis of the data showing that all basic components of the geographical coat (hydrosphere, geosphere, biosphere) are polarly asymmetrical. Paleographical analysis shows that the polar asymmetry of the geographical coat is a phenomenon peculiar to the earth which developed in the course of many geological periods.

RÔLE DU MUSCLE DANS LES RÉACTIONS DE LUTTE CONTRE LE FROID

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Abstract – The maximum metabolism in the cold is compared with the maximum metabolism of muscular work. The importance of the muscular factor in regulation of heat production in the cold is shown by the results of experiments on motor paralysis and curarization and by elimination of various hormones. Heat production by muscular exercise can play a part in cold defence. The metabolic processes during muscular work and the response to cold are compared. No fundamental difference could be established. A relationship between heat production without shivering and muscular heat production is indicated. Thermogenesis without shivering is most important in long-term acclimatization.

Zusammenfassung – Der maximale Stoffwechsel in der Kälte wird mit dem maximalen Stoffwechsel bei Muskelarbeit verglichen. Die Bedeutung der Muskeln für die Regulation der Wärmebildung in der Kälte ist ersichtlich aus den Experimenten über Muskellähmung und Kurarisierung und die Ausschaltung verschiedener Hormone. Wärmebildung durch Muskelarbeit kann bei der Kälteabwehr beteiligt sein. Die Stoffwechselprozesse bei Muskelarbeit und Kälteabwehr werden miteinander verglichen. Ein wesentlicher Unterschied ist nicht feststellbar. Eine Beziehung zwischen Wärmebildung ist nicht festellbar. Eine Beziehung zwischen Wärmebildung ohne Zittern und Wärmebildung durch Muskelarbeit ist gegeben. Wärmebildung ohne Zittern ist ein Ausdruck für bestehende Akklimatisation.

Résumé – Une comparaison est établie entre métabolisme maximal au froid et métabolisme maximal du travail musculaire. On montre l'importance du facteur musculaire dans les possibilités de thermogénèse de régulation au froid, d'après les résultats des expériences de paralysie motrice et de curarisation ainsi que par l'exclusion de divers facteurs hormonaux. L'activité musculaire de l'exercice s'intègre d'ailleurs dans la thermogénèse de réchauffement. Le problème de la nature des combustions lors de l'exercice musculaire ou de la lutte contre le froid est envisagé; aucune différence fondamentale ne peut être établie. L'existence d'une interaction entre thermogénèse sans frisson et thermogénèse musculaire est d'autre part indiquée. La thermogénèse sans frisson est liée avant tout au phénomène d'adaptation à longue échéance.

La *thermogénèse* de lutte contre le *froid* a été localisée différemment suivant les auteurs: Certains attribuant au foie et aux viscères abdominaux le rôle principal, d'autres invoquant l'intervention du muscle soit par son activité contractile, soit même en dehors de toute activité décelable.

Des arguments divers sont invoqués en faveur de l'une ou l'autre conception (Chatonnet, 1959, 1961): Les uns, assez peu convaincants basés sur la topographie

thermique lors de l'exposition au froid, d'autres sur les modifications métaboliques en l'absence de frisson visible ou après curarisation, paralysie par section nerveuse ou éviscération.

Nos propres résultats chez le *chien*, basés sur des *expériences* d'énervation musculaire plus ou moins étendue, indiquent que la capacité de thermogénèse au froid est directement liée chez cet animal à la masse de muscle fonctionnellement intacte (Chatonnet, 1951).

Les rares expériences s'attachant à mesurer la consommation d'oxygène locale en même temps que le débit sanguin restent difficiles à interpréter en raison même de la faible étendue des territoires considérés. A plus forte raison, les expériences sur coupes de tissu isolé s'écartent-elles des conditions normales et ne peuvent-elles que déceler des adaptations métaboliques à longue échéance. Ces mesures *in vitro* donnent cependant une indication de la part que peut prendre, dans la dépense globale de l'organisme, chacun des tissus considérés dans les conditions de repos évidemment. L'accord est assez bon entre les estimations de calorification rapportée à la masse tissulaire et la valeur du métabolisme de base de l'organisme entier (Myers, 1947; Brozek et Grande, 1956; Bard, 1956). Ainsi pour Drabkin (1950), l'ensemble des viscères (foie, cerveau, rein et coeur) représentant 5 pour cent du poids corporel utilisent 70 pour cent de l'oxygène consommé; dans les mêmes conditions de repos, le muscle squelettique représentant 42 pour cent du poids n'est responsable que de 15 pour cent du métabolisme de base total.

On ne peut cependant juger des possibilités thermogénétiques d'un territoire uniquement à partir des valeurs de repos et il est préférable de considérer ses capacités dans les conditions d'activité maximale.

C'est ainsi que différents auteurs ont pratiqué l'évaluation des capacités thermogénétiques maximale déployées par chacun des territoires considérés, lors de l'exercice de son activité la plus spécifique par exemple: *exercice musculaire* d'une part, *ADS* et possibilité de *thermogénèse hépatique* d'autre part.

Le foie et les viscères qui, dans les conditions de repos présentent une dépense énergétique élevée, se révèlent incapables d'augmenter cette dépense lors de l'activité fonctionnelle accrue au delà de 30 à 40 pour cent (Brandt *et al.* 1955; Dosekun, Grayson et Mendel, 1960).

Le muscle squelettique par contre, qui présente au repos et «in vitro» une faible dépense est capable d'augmenter sa consommation d'oxygène dans des proportions très élevées, comme on le sait par les expériences de perfusion. Sur l'animal entier, la dépense provoquée par l'exercice musculaire intense est certes attribuable avant tout au muscle et entraîne un accroissement du métabolisme atteignant, selon les auteurs, sur des durées longues, 5 à 8 fois la dépense de repos et sur des durées brèves, 14 à 15 fois le métabolisme de repos (Brody 1945, Doebeln 1956).

Au cours de la lutte contre le froid proprement dite, la thermogénèse maximale que l'organisme peut opposer à la déperdition accrue s'élève, chez le chien anesthésié, à 5 ou 6 fois le métabolisme basal (Hegenauer et Penrod, 1950) 6 fois selon Grosse-

Brockoff et Schoedel (1943) 2 à 7 fois selon Kramer et Reichel (1944) chez l'homme, à 5 fois selon Adolph et Molnar (1946) ou à 4 fois et demi selon Iampietro et collaborateurs (1958).

Nos propres résultats récents (non publiés) indiquent chez le chien une possiblité de calorification approchant 10 fois le métabolisme de base chez l'animal non anesthésié lors d'un *refroidissement* à la fois interne et externe. Si l'on compare ces derniers résultats avec ceux déjà signalés pour l'exercice musculaire, on constate que les augmentations sont du même ordre de grandeur dans les deux cas.

Ceci peut être interprété comme révélant l'équivalence des différentes modalités du fonctionnement musculaire du point de vue thermogénétique si l'on admet que le frisson représente le facteur principal de thermogénèse chez cet animal. On sait d'ailleurs que l'activité musculaire se trouve effectivement impliquée dans la régulation au froid puisqu'à côté du frisson thermique proprement dit, la simple augmentation du tonus musculaire, de même que l'activité volontaire sont mises en jeu spontanément par l'organisme exposé au froid.

Le problème de *l'intégration de l'exercice musculaire* proprement dit dans la régulation a fait l'objet de nombreux travaux. D'après nos propres expériences, la thermogénèse résultant d'une activité musculaire imposée par stimulation électrique des muscles du train postérieur se substitue complètement à la thermogénèse de régulation due au frisson, alors qu'elle s'ajoute à la dépense de base.

Chez l'homme Lefevre et Auguet (1933) avaient déjà montré que la thermogénèse de l'exercice pouvait se substituer à celle de la lutte contre le froid. Il s'agit là de conditions où les deux activités, thermorégulatrice et volontaire, sont en compétition et s'exercent parallèlement sur les mêmes territoires.

Par contre, chez la souris et chez le rat adaptés au froid, Hart (1950, 1960), constate une addition des effets thermogénétiques. Chez les petits mammifères, la substitution de la chaleur de l'exercice à celle exigée par la régulation thermique est possible, lorsque cette dernière s'exerce par le frisson, c'est-à-dire par des commandes à effets immédiats. C'est le cas du Rat adapté à 30° C (Hart, 1960).

Ce rôle de l'activité musculaire n'est cependant pas exclusif dans la régulation. On a décrit une thermogénèse sans frisson ou régulation chimique au sens restreint. W. B. Cannon l'assimile à la thermogénèse due au système sympatho-adrénalinique. Elle paraît avoir peu d'importance chez l'animal non acclimaté au froid. Hemingway et Hathaway (1941) lui attribuent les 5 pour cent d'augmentation du métabolisme qui précède le frisson. Chez le chien, personnellement, nous n'avons pu mettre ce phénomène en évidence; d'autre part, Hammel-Windham et Hardy (1958) observent chez cet animal exposé au froid que le métabolisme revient à des valeur strictement basales dans l'intervalle des bouffées de frisson. Par contre cette «non shivering thermogenesis» joue un rôle capital chez l'animal acclimaté au froid, où elle se manifeste en dehors de toute activité musculaire décelable à l'E.M.G., activité à laquelle elle se substitue (Sellers, Scott et Thomas, 1954; Heroux, Hart et Decopas, 1956). Le frisson, cependant, peut s'ajouter à ce mécanisme lorsque l'agression du froid est trop importante.

L'étude «in vitro» de la respiration de la plupart des tissus de l'animal adapté au froid montre un accroissement de leur métabolisme (You et Sellers 1951, Weiss 1957). Le muscle lui-même participe à cette réaction et paraît même être responsable, sur l'animal entier, de la majeure partie de la thermogénèse sans frisson du rat adapté au froid, selon Depocas (1956) puisque elle s'observe encore chez l'animal éviscéré. Il faut noter que parallèlement la vascularisation des muscles s'accroît au cours de l'adaptation (Heroux et St-Pierre, 1957). Enfin, Jansky et Hart (1963) montrent que les muscles du rat adapté au froid perfusés et curarisés, doublent leur consommation d'oxygène sous l'effet de la noradrénaline ou de l'exposition au froid. Dans ces phénomènes d'adaptation, le rôle important de commande de la thermogénèse de régulation semble dévolu aux facteurs endocriniens: La médullo-surrénale et la nor-adrénaline intervenant ici de façon prépondérante (Hsieh et Carlson, 1957).

En dehors de l'adaptation au froid, on connaît de rôle des *facteurs hormonaux* dans la constitution du métabolisme de base. Peu de données, par contre, se rapportent à leur intervention dans les capacités thermogénétiques maximales de l'animal exposé au froid. On sait que plusieurs hormones «non thermogènes» à la neutralité thermique sont indispensables à une bonne régulation chimique; c'est le cas des hormones cortico-surrénales.

Nous avons montré que les hormones thyroidiennes sont nécessaires à une pleine efficacité thermogénétique du frisson chez le chien.

L'ablation de la glande et la restitution hormonale influencent de façon importante le niveau du métabolisme maximal au froid. Les effets qui ne se manifestent qu'en présence d'une activité de frisson déjà importante se rattachent aux notions hormonales «permissives» pour lesquelles on peut envisager un processus de découplement.

L'action calorigénique de l'adrénaline, toujours décrite dans les conditions de neutralité thermique où son importance apparaît minime au regard de la demande thermique que peut occasionner l'exposition au froid, peut-elle être plus importante dans les conditions de métabolisme maximal au froid?

Nous avons observé (Chatonnet, 1961) chez le chien, que l'adrénaline comme la noradrénaline, manifestent dans la zone de froid en présence du frisson, des possibilités thermogénétiques bien supérieures à celles observées à la neutralité thermique. On voit ici que le muscle, par son activité de frisson elle-même, participe encore à cet effet calorigénique commandé par les hormones.

Ainsi, en dehors de leur action sur la thermogénèse sans frisson de l'animal adapté au froid, les hormones exercent-elles un effet de renforcement de la thermogénèse musculaire d'activité chez l'animal dont la régulation chimique dépend avant tout du frisson.

De toute façon, et sans nier la participation des autres organes, notamment du foie à la régulation chimique, il apparaît que le muscle est le siège principal de la thermogénèse de régulation, suivant diverses modalités et sous l'effet de commandes variées, tant nerveuses qu'hormonales.

Il ne paraît pas possible d'opposer les combustions de la régulation chimique à celles d'autres activités telles que l'exercice musculaire, d'après les variations isolées de tel ou tel métabolite. Le quotient respiratoire présente des modifications aussi difficiles à interpréter en fonction de la ventilation que celles de l'exercice musculaire. La lactacidémie, selon Hart and Heroux (1954) s'élèverait plus chez la souris dans l'exercice musculaire qu'au froid, pour une consommation d'oxygène élevée et équivalente.

Chez le chien, nous ne constatons pas de différence significative entre les deux activités, lorsque la secrétion médullo-surrénale est exclue. D'ailleurs, le caractère plus ou moins aérobie de l'utilisation des matériaux ne permet pas d'opposer le muscle à tel autre tissu, car selon ses modalités de contraction (tonus, frisson, secousses répétées) et la répartition plus ou moins étendue de son activité, cet organe peut présenter lui-même des régimes de fonctionnement très différents.

Certains auteurs tentent de relier la capacité thermogénétique des tissus à la teneur en cytochrome c (Drabkin, 1950) ou à leur activité cytochromoxydasique (Jansky, 1962). Il apparaît alors que le muscle squelettique en raison même de sa masse, représente plus de 70 pour cent de la capacité métabolique totale. Ce territoire offre des possibilités de variation de niveau métabolique élevées. Cette aptitude explique son rôle prééminent dans cette fonction de régulation chimique de la température. Le muscle assume la part la plus importante de cette régulation dont les organes viscéraux sont les bénéficiaires. En effet l'homéothermie leur permet justement d'échapper aux variations métaboliques étendues qui représentent la condition de l'organe poïkilotherme.

BIBLIOGRAPHIE

ADOLPH, E. F. and MOLNAR, G. W. (1946) Exchanges of heat and tolerances to cold in men exposed to outdoor weather. *Am. J. Physiol.* **146,** 507–537.

BARD, P. (1956) *Medical Physiol.*, Chap I, Mosby.

BRANDT, J. L., CASTELMAN, L., RUSKIN, H. D., GREENWALD, J. and KELLY, J. (1955) The effect of oral protein and glucose feeding on splanchnic blood flow and oxygen utilization in normal and cirrhotic subjects. *J. clin. Invest.* **34,** 1017–1025.

BRODY, S. (1945) *Bioenergetics and Growth.* Reinhold. Edit. New-York.

BROZEK, J. and GRANDE, F. (1956) Body composition and basal metabolism in man: correlation analysis versus physiological approach. *Human Biology* **27,** 22–31.

BURTON, A. C. and BRONK, D. W. (1937) The motor mechanism of shivering and of thermal muscular tone. *Am. J. Physiol.* **119,** 284.

CHATONNET, J. (1959) Données récentes sur la régulation thermique: Sur l'origine et les sources de la chaleur libérée dans la régulation chimique de la température. (Rapport à la 27ème Réunion de l'Association des Physiologistes, Marseille). *J. Physiol. (Paris)* **51,** 319–378.

CHATONNET, J. (1961) Thèse Sciences., Paris.

CHATONNET, J. (1951) Importance du frisson dans les capacités de thermogénèse du chien à moelle détruite. *C. R. Soc. Biol. (Paris)* **145,** 1538.

CHATONNET, J., TANCHE, M. et GUIEU, J. D. (1961) Action calorigénique de l'adrénaline et de la noradrénaline dans les conditions de thermogénèse maxima au froid. *J. Physiol. (Paris)* **53,** 296–298.

DEPOCAS, F. (1958) Chemical thermogenesis in the functionally eviscerated cold-acclimated Rat. *Can. J. Biochem. Physiol.* **36,** 691–699.

Doebeln, W. Von. (1956) Human standard and maximal metabolic rate in relation to fat free body mass. *Acta physiol scand.* **37,** Suppl. 126.

Dosekun, F., Grayson, J. and Mendel, D. (1960) The measurement of metabolic and vascular responses in liver and muscle with observations on their responses to insulin and glucose. *J. Physiol. (Lond.)* **150,** 581–606.

Drabkin, D. L. (1950) The distribution of the chromoproteins, hemoglobin, myoglobin and cytochrome C in the tissues of different species and the relationship of the total content of each chromoprotein to body mass. *J. biol. Chem.* **182,** 317–333.

Grosse-Brockoff, F. und Schoedel, W. (1943) Das Bild der akuten Unterkühlung im Tierexperiment. *Arch. exp. Path. Pharm.* **201,** 417–442.

Hammel, H. T., Wyndham, C. H. and Hardy, J. D. (1958) Heat Production and heat loss in the dog at 8–36° C. *Am. J. Physiol.* **194,** 99–108.

Hart, J. S. (1950) Interrelations of daily metabolic cycle, activity, and environmental temperature of mice. *Can. J. Res.* **28,** 297–307.

Hart, J. S. (1960) *Cold Injury,* 6th Conf. Josiah Macy Found., p. 284.

Hart, J. S. and Heroux O. (1954) Effect of low temperature and work on blood lactic acid in deer mice. *Am. J. Physiol.* **176,** 452–454.

Hegenauer, A. H. and Penrod, K. E. (1950) USAF Techn. Report 5912., Dayton.

Hemingway, A. and Hathaway, S. R. (1941) An investigation of the chemical temperature regulation. *Am. J. Physiol.* **134,** 596–602.

Heroux, O. and Saint-Pierre, J. (1957) Effect of cold acclimation on vascularization of ears, heart, liver and muscle of white rats. *Am. J. Physiol.* **188,** 163–168.

Heroux, O., Hart, J. S. and Depocas, F. (1956) Metabolism and muscle activity of anesthetized warm and cold acclimated rats on exposure to cold. *J. appl. Physiol.* **9,** 399–403.

Hsieh, A. C. and Carlson, L. D. (1957) Role of Adrenaline and Noradrenaline in chemical regulation of heat production. *Am. J. Physiol.* **190,** 243–246.

Iampietro, P. F., Vaughan, J. A., Goldman, R. F., Kreider, M. B. and Masucci, F. (1960.) Heat Production from shivering. *J. appl. Physiol.* **15,** 632–633.

Jansky, L., (1962) Maximal steady state metabolism and organ thermogenesis in mammals. In *Comparative Physiology of Temperature Regulation.* J. P. Hannon and E. Viereck (ed.), Arctic Aeromedical Laboratory, Forth Wainwright, Alaska, 175–201.

Jansky, L., and Hart, J. S. (1963) Participation of skeletal muscle and kidney during non shivering thermogenesis in cold acclimated rats. *Can. J. Biochem. Physiol.,* **41,** 953–964.

Kramer, K. and Reichel, H. (1944) Die Grenzen der chemischen Wärmeregulation. *Klin. Wschr.* **23,** 192–198.

Lefevre, J. et Auguet, A. (1933) La thermorégulation du travail. Rapport de ses courbes avec celles du repos. *Ann. Physiol. Physicochim. Biol.* **9,** 1103–1121.

Myers, J. D. (1947) The hepatic blood flow and splanchnic oxygen consumption in man. *J. clin. Invest.* **26,** 1130–1137.

Sellers, E. A., Scott, J. W. and Thomas, N. (1954) Electrical activity of skeletal muscle of normal and acclimatized rats on exposure to cold. *Am. J. Physiol.* **177,** 372–376.

Tanche, M. et Chatonnet, J. (1958) Sur l'influence d'un apport calorifique imposé à l'organisme (travail musculaire) sur les réactions thermorégulatrices au froid. *J. Physiol. (Paris)* **50,** 534–537.

Tanche, M., Chatonnet, J. et So-Satta. (1962) Influence de la secrétion thyroïdienne sur la marge de thermogénèse d'origine musculaire dans la lutte contre le froid. *C. R. Soc. Biol. (Paris)* **156,** 872–874.

Tanche, M., Chatonnet, J., Vial, J. et Schmidt, M. (1962) Sur les combustions dépendant de l'activité musculaire et de l'adrénaline au froid. *J. Physiol. (Paris)* **54,** 413–414.

Weiss, A. K. (1957) Tissue responses in the cold exposed rat. *Am. J. Physiol.* **188,** 430–434.

You, R. W. and Sellers, E. A. (1951) Increased oxygen consumption and succinoxidase activity of liver tissue after exposure of rats to cold. *Endocrinology* **49,** 374–378.

THE RESPONSES TO FINGER COOLING OF ALASKAN ESKIMOS AFTER NINE MONTHS OF URBAN LIFE IN A TEMPERATE CLIMATE

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Abstract – Three groups of subjects were studied: 4 Alaskan Eskimos who had lived under conditions similar to urban controls for 9 months; 5 mountaineers who had lived for several weeks under conditions of physical exertion and frequent peripheral cooling that would be extreme even for the Eskimo; 20 control subjects of mainly sedentary habitus. Subjects were tested under standardized conditions. The Eskimos were markedly superior to the other groups in tolerance to finger cooling both in 0° C water and −22° C air; there were no differences in response between mountaineers and controls. The advantage of the Eskimo in tolerance to finger cooling is attributed to a genetic cold adaptation or to a cold acclimatization that is other than seasonal.

Zusammenfassung – Drei Gruppen von Personen wurden untersucht: (a) 4 Eskimos aus Nordalaska, die 9 Monate lang unter den gleichen Bedingungen lebten wie die Kontrollpersonen, (b) 5 Bergsteiger, die mehrere Wochen lang unter Bedingungen gelebt hatten, die auch für Eskimos extrem waren, (c) 20 Personen (Laboratoriumspersonal). Alle Personen wurden unter standardisierten Bedingungen untersucht. Die Eskimos konnten besser als andere Personen die Abkühlung der Hände in Wasser von 0° C oder Luft von −22° C ertragen. Zwischen den Bergsteigern und Kontrollpersonen wurden keine Unterschiede beobachtet. Die grosse Toleranz der Eskimos wird über genetische Faktoren erklärt oder es ist eine Form der Kälteakklimatisation, die nicht jahreszeitenbedingt ist.

Résumé – Trois groupes de sujets ont été étudiés: 4 sujets Esquimaux qui vivaient neuf mois dans les conditions comparables à celles de témoins urbains; 5 montagnards qui vivaient plusieurs semaines dans des conditions d'effort maximum et de fréquents refroidissements periphériques qui seraient extrêmes même pour un Esquimau; 20 sujets témoins sédentaires. Les sujets dormaient durant la nuit au laboratoire et tous les essais furent faits dans les mêmes conditions. Les Esquimaux étaient très supérieurs, aux autres groupes en tolérance au refroidissement des doigts dans l'eau à 0° C ou dans l'air à −22° C il n'y avait pas de différence entre les réactions des témoins et celles des montagnards. La supériorité de l'Esquimau à résister au refroidissement des doigts doit être attribuée à un facteur génétique ou à une acclimatation au froid autre que saisonnière.

INTRODUCTION

There is considerable evidence that persons indigenous to Arctic regions maintain higher peripheral temperatures during cold exposure than do controls from the warmer zones (e.g. Hart *et al.*, 1962). It has not been possible, however, to

attribute these peripheral differences to genetic cold adaptation or to any other single factor. Most northern natives examined have lived for the time before the tests under conditions radically different from those for the so-called "controls". The latter have usually lived sedentary urban lives quite different from the physically demanding outdoor lives of the natives.

An opportunity was afforded to study the thermal responses to peripheral cooling of four young Eskimo men who returned to Alaska after nine months of an urban and essentially sedentary life at a boarding school in Oregon. They had subsisted on an ordinary mixed diet, had suffered no cold exposure for several months and had engaged in no manual work. In short, they had lived the life of typical "controls". The Eskimo group was compared with the groups described below, one of which was a control and the other of which had been engaged for several weeks in outdoor activities involving much greater physical demands and more frequent and severe cooling of the extremities than is usual even for the Eskimo. An essential fact in the comparisons is that all the subjects were tested after having slept overnight at the laboratory and under conditions that were otherwise standardized as far as possible.

Some of these data have been presented previously in a review article (Eagan, 1963).

MATERIALS AND METHODS

Subjects

The physical data on the subjects are given in Table 1. The weights are averages and ranges of "basal weights", that is, taken early in the morning with the subject nude, after urination or defecation and before ingestion of food or water. Surface area was estimated from the DuBois–Meek nomogram (Consolazio, Johnson and Marek, 1951).

The Eskimos were from the Alaskan villages of Anaktuvuk Pass and Point Barrow. In May 1962, on completion of their school year at Chemawa Indian

Table 1. Physical Data on Subjects

Group and no. of subjects	Age (yr)	Height (cm)	Weight (kg)	Surface area (m^2)
Eskimo (4)	20.0* (18–22)	163.9 (157–168)	60.8 (46–70)	1.64 (1.42–1.79)
Mountaineer (5)	27.6 (24–32)	180.1 (170–192)	73.2 (64–81)	1.92 (1.73–2.13)
Control (20)	29.7 (19–42)	179.1 (168–192)	76.6 (61–97)	1.97 (1.73–2.00)

* Mean and range.

School in Oregon they returned to Fairbanks, Alaska, by air. They were brought immediately to the Arctic Aeromedical Laboratory where they lived for the next 8–10 days. Meals were taken at the nearby military hospital cafeteria.

The mountaineer group consisted of the five male members of the 1962 Mt. McKinley expedition of the Alaska Alpine Club. In the course of the 45 days before the test they had crossed McKinley Park (Alaska) on foot to reach the base of the mountain, had then climbed to the summit and were returned by air from the base to the Park entrance. They then travelled by train to Fairbanks and were brought to the laboratory where they lived for three days (29 May to 1 June). There is a complication in reporting the weights on this group. On the first morning following their arrival the mean was 71.4 kg, on the second morning 72.7, and on the third 73.2; the last figure is the one listed in Table 1. It would appear that recovery from a state of relative dehydration took place.

The Control group was tested in May and July 1962. It consisted of the following: 19 USAF personnel of the laboratory staff — all of mainly sedentary habitus; one of the mountaineers who returned to the laboratory at the end of July and who was still in excellent physical condition.

Tests and Protocol

All tests except the one for physical fitness were done early in the morning. On the days before tests, subjects fasted from 19:00 h, arrived at the laboratory by 22:00 h and were in bed by 23:00 h. Room temperature was not controlled overnight, but it was never below 20° C and each person could choose the number of blankets for comfort.

At 06:30 h oral temperature was taken and metabolic rate measured using an open-circuit system. Expired air was collected in a Douglas bag for 10–15 min, a measured aliquot was analyzed for oxygen partial pressure on a Beckman C2 unit and the main part of the volume in the bag was then measured in a calibrated spirometer.

With the subject still in bed thermocouples of stranded copper-constantan were attached with waterproof plastic tape to the distal digital volar pads of the index fingers. The tips of each junction were placed 23 mm distal to a circumferential line 28 mm from the end of the finger. The hands were kept under the bed covers until finger temperatures were above 35° C. The subject then turned to a prone position and the two index fingers were immersed 28 mm in a stirred water bath at 0.0° C. The surface of the water was at bed level with the container in a position convenient to the subject. The duration of immersion was 10 min. Temperatures were measured continuously to the nearest 0.1° C on a Brown "Electronik" recording potentiometer. Pain was estimated by the subject at each minute according to a 5-unit scale explained by the investigator.

At the end of this test the subject arose, then dressed in his usual clothes with a heavy parka in addition. He moved to an adjoining room, thermocouples were

attached to the index and middle fingers of the left hand (at sites described previously) and the hand was inserted in a woollen glove with the index and middle "fingers" missing. The hand was held under the parka until finger temperatures were above 35° C. With the subject still seated the left hand was then inserted beneath a fan in a refrigerated box. The box temperature varied cyclically between −20° and −25° C (average −22° C) and the windchill factor was about 1100 kcal/m²/hr. The subject kept his hand in the box with the volar surface of the fingers exposed to the fan for 30 minutes unless either finger supercooled to −5° C or superficial freezing occurred. If either of these conditions was observed the hand was removed from the box and the duration of exposure recorded.

Table 2. Early Morning Metabolism and Oral Temperature

Group and no. of subjects	Energy States of subjects			
	Measurements per subject	Oral temperature (°C)	Basal metabolism	
			Heat Production (kcal/m²/hr)	BMR†(% from normal)
Eskimo (4)	6 to 8	36.21 (36.0–36.3)	42.5 (41.1–43.9)	+2 (−2 to +5)
Mountaineer (5)	2 to 3	36.19 (35.7–36.4)	36.5 (33.3–39.8)	−9 (−12 to 0)
Control (5)*	2	36.37 (36.1–36.6)	37.5 (34.1–39.5)	−5 (−14.to+2)

* Metabolism and oral temperature were measured on only 5 of the 20 control subjects.
† Related to Boothby–Sandiford normal values (Consolazio *et al*, 1951).

The treadmill test for physical fitness (Consolazio *et al.*, 1951) was done twice on each Eskimo and mountaineer but only once on most of the controls. The finger cooling tests in 0° C water and −22° C air were done once on each subject. The number of oral temperature and metabolism measurements on each subject is shown in Table 2. Each measurement represents a different test day for each subject. Hence the thermal responses of the fingers may be related to the average energy states for the group but not to the energy state of the particular subject on the day of his finger tests.

Metabolism and oral temperatures are reported for only five of the controls where the procedures described above apply. In fact, though, BMR was measured on all 20 of the control subjects using a Jones closed-circuit apparatus. These results as calculated by a technician showed high BMR's on the average with a range from −20 to +75 per cent of the Boothby–Sandiford standard values. The records were destroyed before they could be checked by the writer and hence the results are discarded as unreliable.

RESULTS

Table 1 shows that the Eskimos were both younger and smaller than the subjects of the other groups. A better match in these factors (age and body size) would contribute to the validity of conclusions regarding group differences in response to cooling.

*Table 3. Physical Fitness Scores**

Group and no. of subjects	Mean	Range
Eskimo (4)	53.8	22 to 78
Mountaineer (5)	81.4	76 to 88
Control (20)	35.5	19 to 89
Controls in 4 groups		
group 1 (5)	59.7	44 to 89
2 (5)	34.5	32 to 37
3 (5)	26.7	24 to 30
4 (5)	21.2	19 to 23

* Standards are: "poor" below 40; "average" 41 to 75; "good" 76 to 90; "superior" above 90 (Consolazio *et al.*, 1951).

Table 4. Thermal Responses to Finger Cooling

Group and no. of subjects	Average temperatures of fingers during immersion in 0° C water (°C)		Exposure to −22° C air
	At individual nadir	Average over 10 min	Tolerance factor* (units)
Eskimo (4)	2.41 ±0.78†	6.65 ±1.02	668.2±28.8
Mountaineer (5)	0.96 ±0.50	3.36 ±0.76	253.3±49.8
Control (20)	0.90 ±0.26	3.73 ±0.35	231.9±57.1
Eskimo (4)	2.41 ±0.78	6.65 ±1.02	668.2±28.8
Mountaineer and control (25)	0.91 ±0.22	3.66 ±0.31	236.2±46.4
Significance of Differences (P)			
Eskimo vs. Control	NS	<0.05	<0.001
Eskimo vs. Mountaineer	NS	<0.05	<0.001
Mountaineer vs. Control	NS	NS	NS
Eskimo vs. Mountaineer and control	NS	<0.01	<0.001

* Tolerance factor units = duration of cooling (minutes) x average finger temperature (°C) during exposure to air at −22° C with windchill about 1100 kcal/m²/hr.

† Standard error.

Table 2 shows no differences in oral temperature among the groups. There is an apparent difference in metabolism between the Eskimos and the other groups but the BMR column shows that this difference largely disappears when the age factor is brought in.

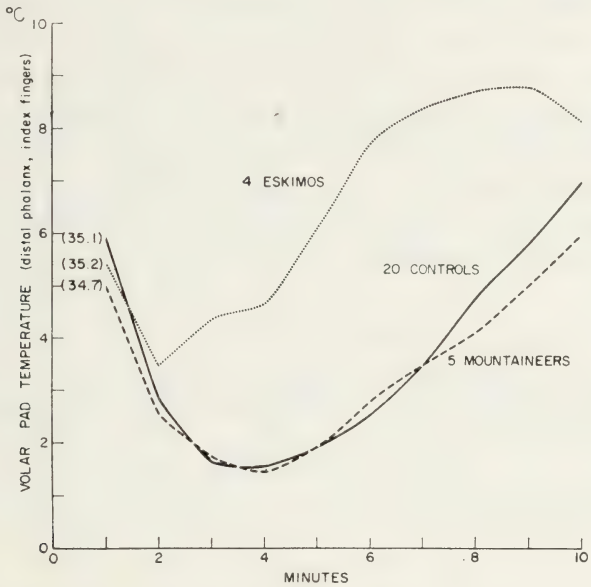

Fig. 1. Comparison of group averages of finger temperatures during immersion in 0° C water under standard test conditions. Pre-immersion finger temperatures are shown in brackets. Fingers were immersed at 0 min

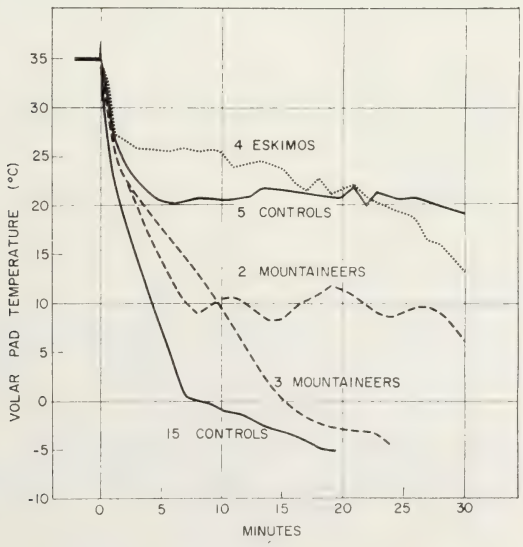

Fig. 2. Average finger temperatures during exposure to cold air (temperature approximately −22° C; windchill factor 1100 kcal/m^2/hr)

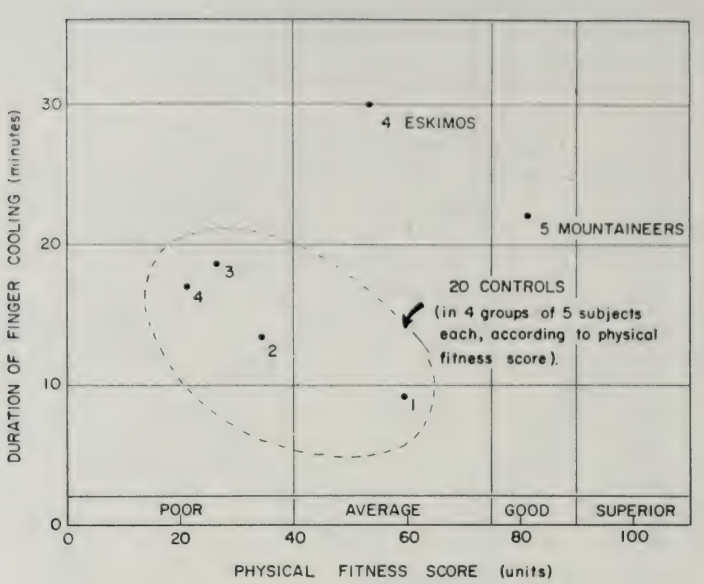

FIG. 3. Duration of finger cooling vs. physical fitness score

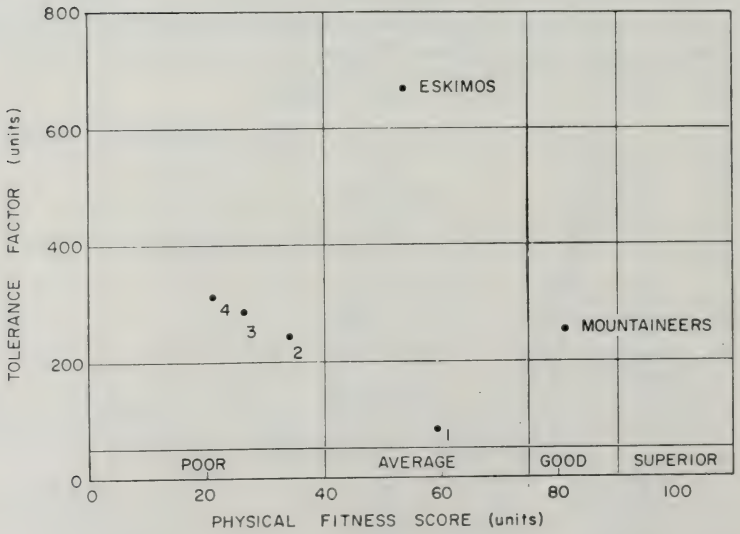

FIG. 4. Tolerance factor vs. physical fitness score. (Tolerance factor units = duration of cooling in minutes × average finger temperature during cooling in °C)

Table 3 shows physical fitness scores. The good performance of the mountaineers contrasts with the very poor showing for the controls. The score for the small Eskimo group is held down by the poor performance of one subject — the smallest man in the group.

Table 4 shows that the Eskimos withstood finger cooling better than the other groups whether in cold water or cold air. At individual nadir (minimum temperature for each subject) in the water cooling test there were no differences statistically, though it is near significance where the Eskimos are compared with the combined mountaineer and control groups. The superior resistance to finger cooling of the Eskimo over the 10 minutes of immersion is illustrated in Fig. 1.

Figure 2 shows that all of the Eskimos, 2 out of 5 mountaineers and 5 of 20 controls withstood 30 min of cooling. For all other subjects the exposure was ended because finger temperature reached $-5°$ C or superficial freezing was observed. The latter occurred in only four cases.

Figures 3 and 4 demonstrate a lack of relationship between level of physical fitness and resistance to cooling of the fingers in cold air.

Pain sensations were almost negligible for the Eskimos in both the water and air cooling tests. All mountaineer and control subjects experienced pain during water cooling though it was usually less for the mountaineers. Pain was usually experienced during air cooling when finger temperature was somewhat below 10° C.

DISCUSSION

The most significant finding in this study is that Eskimos living a sedentary urban life for several months in a mild climate still showed greater resistance to cooling of the extremities than did the other groups tested. To what factor may this greater tolerance be attributed?

It is obvious that physical fitness level is not a factor. This conclusion would seem to conflict with previous results from this laboratory (Adams and Heberling, 1958) where it was claimed that differences in peripheral temperature could be explained on the basis of levels of physical fitness. However, Adams and Heberling found higher resting metabolic rates in their subjects following physical training and it seems likely that these account for the higher peripheral temperatures. Osiba (1958) has shown that high physical activity combined with high protein intake can result in a sustained increase in basal metabolic rate.

It also appears obvious that recent prolonged exposure of the extremities to cold was not a factor. Otherwise the mountaineers should have shown the greatest resistance to cooling with the Eskimos and controls alike in their responses. This finding seems to conflict with the implication that many investigations have been made where various groups of subjects have been compared.

Differences in dietary regimen prior to the tests did not exist between the Eskimos and controls. Had the mountaineers been different from the controls in res-

ponses to finger cooling, this could possibly have been related to recent diet. In fact, there are no differences between these groups in spite of recent differences in diet — both in composition and in total calories consumed per day. The mountaineers consumed a great deal of pemmican while on the expedition and, of course, caloric intake had to match high physical activity.

Recent manual labour seemed not to be a factor, for the mountaineers had engaged in a great deal while it was negligible for the others.

When the early morning energy states of the groups are considered, the findings are not so conclusive. A questionable facet is the effect of age. It may be said that the Eskimos had a high basal metabolic rate, but was this so because they were Eskimo or only because they were younger? When the age factor is considered the Eskimo results are consistent with the Boothby-Sandiford standards. Both the mountaineers and controls had slightly depressed BMRs but not significantly so. It is possible that a small part of the advantage of the Eskimos during cold exposure was due to the metabolic rate factor.

It is concluded that the greater resistance to peripheral cooling of the Eskimo was mainly due to a genetic cold adaptation or to a cold acclimatization that was other than seasonal. Perhaps it is necessary to live in the cold natural environment for many years; perhaps one cold acclimatizes through the developmental years of childhood and early youth.

Some answers to the questions that remain many be obtained by investigating groups similar to these studied here but with subjects of like age and size.

ACKNOWLEDGEMENTS

The cooperation of the test subjects, especially of the mountaineers for whom technical arrangements were complicated, is gratefully acknowledged. Appreciation is also due; the staff of the Bureau of Indian Affairs at Fairbanks, Alaska and Captain John F. Watson for the arrangements to get the Eskimo subjects accomplished on short notice; Sgt. Paul Felts for technical assistance; Mrs. Frances Sheppard for assistance with the data.

REFERENCES

ADAMS, T. and E. J. HEBERLING (1958) Human physiological responses to a standardized cold stress as modified by physical fitness. *J. appl. Physiol.* **13,** 226–230.

CONSOLAZIO, C. F., JOHNSON, R. E. and MAREK, E. (1951) *Metabolic Methods.* C. V. Mosby, St. Louis.

EAGAN, C. J. (1963) Local vascular adaptations to cold in man. *Fed. Proc.* **22,** 947–952.

HART, J. S., SABEAN, H. B. HILDES, J. A., DEPOCAS, F., HAMMEL, H. T., ANDERSEN, K. L., IRVING, L. and FOY, G. (1962) Thermal and metabolic responses of coastal Eskimos during a cold night. *J. appl. Physiol.* **17,** 953–960.

OSIBA, S. (1958) Studies on the physiological variation in basal metabolism. *J. Physiol. Soc. Japan* **20,** 1004–1014 (in Japanese with English summary).

LUTTE CONTRE LE FROID ET ADAPTATION RAPIDE AUX CONDITIONS DE PLONGÉES DANS DES EAUX FROIDES—KERGUELEN

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Abstract — During a biological oceanographic expedition to Kerguelen, in which deep water diving was used extensively, special precautions were taken against the effect of cold. In addition to insulation of the body by rubber suits, measures had to be taken to increase the blood circulation and to reduce the cooling of the inhaled air. The measures were necessary for the first dives but could later be omitted. Training seems responsible for this adaptation which is discussed in detail.

Zusammenfassung — Während einer Expedition für Meeresbiologie in Kerguelen, bei der mit Freitauchgeräten gearbeitet werden musste, waren besondere Massnahmen getroffen worden, um die Kälte erträglich zu machen. Über die Isolierung des Körpers mit Gummianzügen hinaus hatten die Massnahmen zum Ziel, den Blutkreislauf zu beschleunigen und die Abkühlung der eingeatmeten Luft einzuschränken. Die Anwendung dieser Massnahmen konnte später vernachlässigt werden. Die Art der vorliegenden Adaptation wird diskutiert.

Résumé — Durant une campagne d'océanographie biologique au cours de laquelle des plongées en scaphandre autonome ont été pratiquées intensivement, des précautions ont été prises pour rendre supportable le froid et ses effets. Outre l'isolement du corps par des combinaisons de caoutchouc, les procédés indiqués ici favorisaient la circulation sanguine et diminuaient le refroidissement de l'air respiré issu des scaphandres. L'emploi de ces procédés, utile lors des premières sorties, a pu être négligé assez fréquemment ensuite. Un certain entrainement semble responsable de ce fait, comme cela se produit dans des activités mettant en jeu des dépenses d'énergie supportables par l'organisme. La nature de cette adaptation est discutée.

INTRODUCTION

Pour réaliser un programme d'étude de biotopes marins infralittoraux, des plongées avec scaphandre autonome se sont déroulées à Kerguelen, dans la Baie du Morbihan, du 23 décembre, 1962 au 5 février, 1963; un peu plus tôt, du 17 au 19 décembre, quelques plongées avaient eu lieu à l'ile de la Possession dans l'archipel de Crozet. Notre groupe comprenait un biologiste et un coéquipier; un cinéaste a participé temporairement à quelques plongées. Les observations suivantes concernent les deux premières personnes. Celles-ci ont passé 53 hr 10 min dans l'eau, entre la surface et 15 m de profondeur, au cours de 59 hr de plongées.

CONDITIONS PASSÉES ET CONTEMPORAINES

Avant de tirer les enseignements relatifs à l'influence de l'état physique, affronté à l'agression que devait supporter le corps, il convient d'indiquer les conditions corporelles antérieures à la période mentionnée, conditions ayant une incidence sur l'adaptation observée.

Au cours des mois précédents, l'un des plongeurs, A. Tanguy, avait mené une vie active, tandis que l'autre, P. Grua, avait été principalement occupé à des travaux d'intérieur avec un régime de dépenses énergétiques restreint, et présentait donc un état physique relativement engourdi.

Les jours précédent immédiatement l'arrivée sur place avaient été passés sur le navire; nous étions passés rapidement du climat tropical d'été de l'Ile de La Réunion au secteur subantarctique. L'inactivité, les malaises ressentis inévitablement sur un bateau, avaient diminué la tonicité corporelle des sujets. Nous éprouvions d'ailleurs le besoin de nous couvrir considérablement de vêtements en face de la fraîcheur nouvelle de l'air.

En débarquant à Crozet, nous avons trouvé une eau dont la température était de l'ordre de 4,5° C. Puis à Kerguelen, cette température était voisine de 7,4° C, dans les eaux fréquentées la première semaine. La température de l'air sous abri, relevée à Port-Aux-Français, était en moyenne pour cette semaine de 6,9° C, et la vitesse moyenne du vent au sol 8,2 m/sec.

Les caractéristiques moyennes intéressant l'ensemble de la période de plongées à Kerguelen se situent comme suit:

– Dates	23–31. XII. 62	1–15. I. 63	16–31. I. 63	1–4. II. 63	Moyenne générale 23. XII. 62–4. II. 63
– T° moyenne de l' air sous abri, °C	7,2°	6,4°	7,2°	7,0°	6,9°
– Vent moyen au sol, m/sec	8,29	11,49	9,61	7,23	9,76

Températures extrêmes: °C	2,2° moyenne du 7. I. 11.3° moyenne du 30. XII.	Chûtes de neige, 3 fois au niveau de la mer.
Vents extrêmes: m/s	2.4 moyenne du 27. XII. 16.8 moyenne du 13. I.	

La nébulosité est restée à une valeur élevée, la saison a été généralement considérée comme défavorable aux diverses disciplines nécessitant des sorties, comparativement aux conditions météorologiques habituelles d'été. Les journées ensoleillées sont intervenus vers la fin de Janvier seulement.

La température de l'eau de mer variait selon les lieux, l'agitation de la mer, la profondeur, entre 4,5° C et 8,5° C. L'eau superficielle à Port-Aux-Français, d'après les indications sujettes à caution du marégraphe, était donnée pour 7,5° C environ.

L'isolement thermique, procuré par les combinaisons de néoprène utilisées, diminue avec l'écrasement subit par le caoutchouc du fait de la pression en profondeur. Ainsi, dans une eau à 7° C, un séjour de 3 hr n'était pas désagréable en surface, tandis que des frissons apparaissaient après 40 min d'immersion à 15 m.

PROCÉDÉS UTILISÉS OU PRÉVUS POUR LUTTER CONTRE LE FROID

L'entretien de la chaleur comporte d'une part un réchauffement actif et apport extérieur de chaleur supplémentaire, d'autre part un isolement passif. Le refroidissement est causé par l'eau ambiante comme par l'air respiré; ces deux cas sont envisagés. Afin de ne pas être démunis devant les effets du froid, différents procédés avaient été prévus, selon l'expérience acquise durant les plongées d'hiver en Bretagne.

En ce qui concerne les plongeurs eux-mêmes, il convenait d'abord de stimuler les processus physiologiques de thermogenèse: pendant les premiers jours tout au moins, mise en forme physique par des mouvements et exercices musculaires, accompagnée de la consommation de préparation pharmaceutique polyvitaminée; préalablement aux plongées, port de sous-vêtements triboélectriques épais, dont l'effet ne parait pas un simple argument publicitaire puisqu'il devient pénible de les porter plus de quelques heures consécutives; au moment de l'équipement, la friction au gant de crin a été très bénéfique, suivie de l'application externe d'un révulsif pour sportifs. Ce dernier procédé détermine une vasodilatation superficielle qui prévient l'engourdissement cutané et ralentit le refroidissement des extrémités; ce conditionnement occasionne, certes, une déperdition de chaleur qui serait préjudiciable au bilan thermique global si elle devait se prolonger longuement mais sur une durée de quelques dizaines de minutes la déperdition était inférieure à la réserve métabolique produisant la chaleur. En effet, pendant le temps des immersions avec scaphandre, la consommation d'air ne peut être massive, l'activité physique est limitée, et la production de chaleur ne peut avoir une origine musculaire.

Si ces précautions n'avaient pas été appliquées, la réaction de thermogenèse aurait été moins vive et rapide, et le seuil des frissons en-deçà duquel nous étions généralement en fin de plongées aurait apparu beaucoup plus tôt. En même temps se serait manifestée la chute d'efficacité et de précision dans le travail immergé qui est concomitante du refroidissement.

L'isolement passif des plongeurs consistait dans la superposition de deux combinaisons de néoprène mousse dont l'épaisseur totale se situait entre 6 et 9 mm selon le cas. Une cagoule, des botillons et des gants de néoprène de 4 mm complétait la protection. Seules la bouche et la moitié des joues n'étaient pas recouvertes.

L'air respiré, pénétrant à l'intérieur du corps, est capable, malgré sa faible chaleur spécifique, d'occasionner une irritation de la gorge et de refroidir l'organisme.

En plus de la fraîcheur due à l'ambiance, la détente de l'air comprimé contenu dans les bouteilles abaisse sa température.

Un isolement passif était assuré par une feuille de néoprène mousse entourant étroitement les bouteilles. Une enveloppe de toile à voile cousue protégeait la fragilité de ce caoutchouc.

Le réchauffement, d'autre part, pouvait être assuré de deux façons : les scaphandres chargés d'air comprimé étaient placés contre un radiateur durant 8 à 10 hr et transportés jusqu'au lieu de plongée à l'abri du vent froid. Un autre moyen avait été prévu : des sachets de gel pour camping, vendus dans les grands magasins, permettent d'accumuler du froid ou de la chaleur selon qu'ils ont été au préalable placés au réfrigérateur ou au bain-marie ; nous pouvions placer ces sachets, réchauffés, entre les bouteilles métalliques des scaphandres et leur protection isolante de néoprène. Nous n'avons pas fait usage de ces sachets.

LE PHENOMENE D'ADAPTATION

Le travail fixé, réparti entre les classements au laboratoire non chauffé et les activités extérieures de plongées, a été poursuivi sur un rythme rapide tant que le programme n'a pas été sensiblement couvert. Ensuite, l'horaire a été un peu assoupli vers la fin du séjour.

Pendant près de la première moitié du séjour notre appétit aux repas m'a paru considérable, sans élection particulière pour tel aliment, puis il a diminué quelque peu ensuite. Dans le même temps nous avons ressenti un besoin de sommeil, attribuable à l'adaptation organique autant qu'à la dépense énergétique. D'autre part, dans la période suivante nous éprouvions moins le besoin de porter des vêtements chauds dans la vie journalière, et les couvertures mises la nuit sur les lits ont été dédoublées.

Si l'on considère le temps passé dans l'eau, cette durée est passée de 36 min en moyenne pour les 30 premières plongées, à 73 min en moyenne pour les 29 suivantes. Ces valeurs sont significatives, alors que la température des diverses eaux fréquentées s'est élevée d'un degré tout au plus, et que dans la seconde partie nous allions travailler plus souvent en profondeur où le froid se manifeste plus sensiblement.

Nous avons toujours remarqué que les conditions météorologiques ont une incidence immédiate, quoiqu'indirecte, sur la résistance au froid et sur l'état psychique *vis-à-vis* de celui-ci. Ainsi, par jours venteux, quand le ciel était couvert de nuages et plus encore quand la brume noyait l'horizon, lorsque tombait la pluie ou la neige, et que la mer était agitée, nous nous sentions frileux et nos dispositions morales étaient peu dynamiques avant les plongées. Par contre, lorsque le temps était beau, même si la température de l'eau était identique, nous n'étions pas tentés de recourir à tous les procédés décrits précédemment. L'influence de l'ensoleillement sur la tonicité corporelle est connue, bien sûr. Cet effet était pour nous toujours sensible ;

toutefois, après quelques temps, de l'ordre de 3 à 4 semaines, il nous était plus aisé d'outrepasser cette aversion à se déshabiller et se changer au froid.

Par ailleurs, l'usage du tabac, peu avant les plongées, tend à diminuer la réactivité face au froid. Après quelques semaines, l'effet de la fumée a paru nettement négligeable, sinon nul.

Progressivement, nous en sommes arrivés à négliger à peu près toutes les mesures préventives contre les refroidissements: peu à peu ont disparu l'emploi des vitamines, du gant de crin, du révulsif sportif, du sous-vêtement triboélectrique, du réchauffement des bouteilles de scaphandre. Nous n'avons conservé que l'isolement par néoprène.

INTERPRÉTATION ET CONCLUSION

Les distinctions relevées précédemment ont été moins nettes au sujet de Tanguy que pour Grua qui a eu un niveau d'activité physique sensiblement moindre dans les mois et les semaines précédant la mission. Tanguy s'est révélé plus à même de réagir dans la phase générale d'adaptation, comme au moment de chaque plongée du début. La forme d'handicap relevé chez Grua s'est amenuisée progressivement, avec un décalage dans le temps par rapport à Tanguy.

A l'issue de cette campagne de plongées à Kerguelen, nous n'avons pas éprouvé de fatigue ou d'asthénie par surmenage. L'état général était au contraire plus euphorique qu'au début du séjour.

L'adaptation observée tient, semble-t-il, à deux causes: une mobilisation des processus de thermogenèse et de thermorégulation, stimulée par certains moyens utilisés; un nettoyage de l'organisme, comme lors d'un entraînement sportif, facilitant le jeu des processus ci-dessus. L'importance d'un bon équilibre physique et d'une vie saine est à souligner, conditionnant cette adaptation rapide et la résistance au froid.

L'effort physique et physiologique demandé a obtenu une réponse positive sans pénalisations secondaires.

BIBLIOGRAPHIE

Arnest, R. (1959) Lettre adressée au LT. P. Linaweaver, Experimental Diving Unit, U.S. Navy, Washington D.C., 17 Avril 1959. p. 2.

Dowling, G. B. (1962) Scuba diving in the Arctic. Navy Mine Defense Laboratory, U.S.A., Rep. 167. p. 12.

Fane, F. D. (1959a) Skin diving in polar Waters. *Polar. Rec.*, **9**, 433–435; (1959b) Skin diving in polar seas. *U.S. Naval Institute Proceedings*, **85**, 65–71.

Grua, P. (1963a) Plongées aux Iles St. Paul et Nlle. Amsterdam-Plongées en eaux froides. *C. R. 1er Sympos. Biol. Antarct., Paris. Sept. 1962, Hermann Paris*, (sous presse);
(1963b) Etude de biotopes marins infralittoraux à Kerguelen. Compte-rendu d'activité. T.A.A.F., Paris, 23: (sous presse)

Lourmais, L. (1961) Communications personnelles.

Neushul, M. (1961) Diving in Antarctic waters. *Polar Rec.* **10,** 353–358.

Shumway, G., et Beagles, J. A. (1959) Arctic SCUBA Diving, 1958. U.S. Navy Electronic Laboratory, Rep. 916.

Tanguy, A. (1963) Les problèmes techniques de la plongée en mers froides. Fichier Techn Comité Rég. Bretagne, Fédér. Fraç. Etude Sports S-Marins. Brest, Juillet, p. 3.

Météorologie Nationale. Port-Aux-Français, Kerguelen. Communications personnelles

FIGHT AGAINST COLD IN ARCTIC NATIVES

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THE Eskimo race is composed of a few individuals who live isolated from the rest of the world, in arid and extremely cold regions. The Eskimos have survived many centuries by no other means than those found in nature. Their survival has always depended on adequate protection against cold and sufficient food. They have solved these problems and have remained happy people. Their clothing, their food, their physiological adaptation and their mental attitude have given them the means of resisting the extreme conditions of the Arctic.

THE TREATMENT OF FROSTBITE

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Rapid Thawing Temperatures Employed by Various Workers. Results Compared with Slow Thawing

Authors	Animals	Time of immersion, mins.	Water temperatures (°C) giving:			
			Best results	Some improvement	No improvement	Further damage
Finneran and Shumacker, 1950	Mouse	2	42	38	50	–
Entin and Baxter, 1952	Rat	2	42–45	35–37	–	55
Fuhrman and Fuhrman, 1957	Rat	2	42	38 48 (slight)	–	–
D'Amato and Covino, 1958	Rabbit	*ca.* 20	42–45	–	–	–
Fuhrman and Crismon, 1947	Rabbit	2	42	–	–	–
Ariev, 1939	Rabbit	–	40–45	–	–	–

THE prognosis of severe frostbite is greatly improved by rapid thawing, preferably by stirred hot water. Animal experiments summarized in the table show the best results when the water is between 42° C and 45° C. The upper limit seems to be 49° C. Recent clinical studies (Mills *et al.*, 1960–61) confirm the value of rapid thawing.

Providing a camp is sufficiently stable to permit enough hot water to be prepared, and evacuation facilities guarantee the prevention of re-freezing or infection, the method may be used, even in the absence of a thermometer, by controlling the water temperature by a normal hand.

The sensations in a normal hand alter from "warm" below 43° C, through "hot" or "very hot" up to 45° C, "pain" at 46° C and "severe pain" above 47° C. A more

detailed sensation scale enabled 16 subjects standing in snow to maintain water at the correct temperature for treatment by rapid thawing (Nelms and Waddell, 1964).

REFERENCES

MILLS, W. J. Jr. and WHALEY, R. (1960) Frost-bite: Experience with rapid rewarming and ultrasonic therapy (Part 1). *Alaska Medicine* **21,** 1–4.

MILLS, W. J. Jr. and WHALEY, R. and FISH, W. (1960) Frost-bite: Experience with rapid rewarming and ultrasonic therapy (Part 2). *Alaska Medicine* **2.**

MILLS, W. J. Jr, WHALEY, R. and FISH, W. (1961) Frost-bite: Experience with rapid rewarming and ultrasonic therapy (Part 3). *Alaska Medicine* **3,** 28–36.

NELMS, J. D. and WADDELL, J. L. (1964) A temperature sensation scale for the first aid treatment of frostbite. *Int. J. Biometeor.* **7,** 283–290.

INFLUENCE OF THE CENTRAL ARCTIC AND ANTARCTIC CLIMATE ON MAN

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Abstract — Comparative physiological studies were carried out among the personnel of several research expeditions in the Central Arctic and in the Antarctic and polar station Cape Chelyuskin from 1957 to 1959. These investigations showed certain physiological changes in the body during acclimatization. They concerned the nervous and cardiovascular system, the development of an acclimatization hypovitaminosis (C and B_1) and the increase of BMR. These reactions were more pronounced in the Antarctic than the Arctic because of the more extreme climate. Re-acclimatization lasts 1–2 months after return from the Arctic and 2–$2^1/_2$ months after return from the Antarctic.

Zusammenfassung — Vergleichende physiologische Untersuchungen wurden an Mitgliedern von Forschungsexpeditionen in der Zentralarktis, in der Antarktis und der Polarstation Cape Chelyuskin von 1957–59 durchgeführt. Die Untersuschungen zeigten physiologische Veränderungen während der Akklimatisationsperiode im Polarklima. Sie betrafen hauptsächlich das Nerven- und Herzkreislaufsystem, aber auch die Entwicklung einer Akklimatisations-Hypervitaminose (C und B_1) und eine Erhöhung des Grundumsatzes. Diese Veränderungen waren in dem extremen Klima der Antarktis ausgeprägter als in dem der Arktis. In der Regel dauert die Reakklimatisation nach der Rückkehr von der Arktis 1–2 Monate und nach Rückkehr von der Antarktis 2–$2^1/_2$ Monate.

Résumé — L'auteur a fait des études comparatives parmi le personnel de toutes les expéditions scientifiques dans l'Arctique central (station dérivant), dans l'Antarctique (Station Mirny, Oasis «Pionniers» et «Banger») ainsi qu'à la station polaire du Cap Chelyuskin (1954 à 1959). Ces observations démontrent la présence de certaines modifications physiologiques de l'organisme humain durant la période d'acclimatation aux conditions polaires. Ces modifications concernent en particulier les systèmes nerveux et cardiovasculaire, le développement d'une hypovitaminose d'acclimatation (vitamines C et B_1) et l'intensification du métabolisme basal. Ces changements sont plus prononcés dans l'Antarctique en raison de l'inclémence plus prononcée du climat des ces régions. En règle générale, la réacclimatation se fait progressivement et dure 1 à 2 mois pour les hommes rentrant de l'Arctique, 2 à $2^1/_2$ mois pour ceux revenant de l'Antarctique.

For some years the problem of man's adaptation to new natural conditions has acquired especial significance — not only theoretical but also practical. This fact is connected with the rapid growth of development and population in Zapolyarye and with the organization of numerous expeditions to Antarctica.

Our studies were carried out at the drift scientific research station North Pole-4 (May 1954–April 1955), during the First Soviet Antarctic Expedition (December 1955–March 1957) and at the polar station, Chelyuskin Cape (November 1958–

April 1959). The observations were carried out from the beginning of the preparation for departure, on the way, during the expedition, on the way back and, finally, after returning home for 6–8 weeks, and in some cases over a period of several years.

At the drift station, 13 persons were systematically under observation, in Antarctica 25 persons at Mirny Observatory, 11 persons at Pionerskaya Station and 76 persons at Chelyuskin Cape. Thus, 125 persons were under observation. Of this number only 14 persons were women, (workers at Chelyuskin Cape station).

Depending on age, the observed persons were divided into three groups: 58 persons were 18 to 30 years old; 39 persons 31 to 40 years old and 28 persons were over 40.

Fifty-four persons were experienced winterers who had worked in the Arctic for more than three years, 20 persons had had experience in the north for 6 months to 3 years and 51 persons were exposed to the polar climate for the first time.

The aim of our work was to study the reaction of a healthy person to the climatic effects of the severest regions on the globe, Central Arctic and Antarctica, and to give a comparative estimation of the acclimatization process in these regions.

There is no necessity to give a detailed account of the extremely uncomfortable climates of the Arctic and Antarctica. The irritating effect of these climates depends on the contrasting seasonal changes of the radiation balance, low mean annual temperature, great variations of air pressure, high degree of weather severity and peculiarities of the daily and seasonal natural rhythm.

A comparison of the Arctic and Antarctic climates reveals the greater severity of the latter, even in the region of Mirny, which is situated 14° further from the South Pole than North Pole-4 station from the North Pole at the end of drifting. If the coefficient of the weather severity at North Pole-4 was 3.5, at Mirny it was 8.7 and in the region of Pionerskaya station 11.0. While in Greenland at the latitude, corresponding to that of Mirny, even bushes grow, on the islands situated close to Mirny, only lichens and mosses are rarely found; on the rocks inland there is no vegetation.

The greater weather severity in Antarctica is determined to a considerable degree (especially in the region of Mirny) by extraordinarily strong winds. The creation of a new physiological equilibrium in winterers in Antarctica was also hampered by disrhythm due to the seasonal prevalence being contrary to that in the northern hemisphere. The intensive ultraviolet radiation to which man is exposed in Antarctica in summer has a considerable significance. In January, the warmest month, each cm^2 of the horizontal surface receives 700 cal. In the Soviet Union the same quantity of heat is received on the Volgogradskije steppes in the region of Kiev. But as the reflectivity of ice and snow is extremely high, 90 per cent of all rays falling on the surface (including ultraviolet rays), return again to the atmosphere. Thus, a man in Antarctica receives twice as much ultraviolet radiation as an inhabitant of the southern regions of the Soviet Union.

In studying the acclimatization process, we first paid attention to the state of the nervous system of the winterers. With this aim, investigations of higher ner-

vous activity according to the method worked out by the Institute of Therapeutics, Academy of Medical Sciences of the U.S.S.R., were carried out regularly, seasonal variations of daily periodicity of the body temperature were observed and electro skin resistance was measured.

In a considerable number of the polar explorers we observed the development of functional nervous diseases, which were expressed in sleep disorders, irritability, abnormal fatigue, headaches and cardiac shooting pain. These reactions were especially severe during the polar night. Sleep disorders of various kinds were observed in 90 out of 125 winterers, including all who were wintering for the first time. One third of the observed persons were troubled with certain unpleasant symptoms and even periods of cardiac pain. Forty-eight persons complained of frequent headaches. All these nervous disorders became reduced during acclimatization. Seasonal variations of daily periodicity of the body temperature indicate reorganization of physiological functions in the body and the creation of a new equilibrium. In winter the body temperature of all winterers was lower than in summer. It was noted that in winter the night phase became longer, in summer the day phase.

Special consideration was given to physiological changes in the cardiovascular system, which, according to K. M. Bykov, "perhaps, more than the others takes part in creating conditions which provide a quick reorganization of tissue vital activity under changing conditions of existence of the organism as a whole".

We observed the level of the arterial tension, pulse rate, measured the skin temperature, carried out oscillography and cold tests. The acclimatization of almost all winterers was accompanied by the development of a hypotension. The lowering of the arterial vascular tension took place gradually and reached its minimum level during the polar night. At the drift station the new level of the arterial tension was lower than the initial one, on an average by 16 mm Hg (both for systolic and diastolic pressure). Only two persons had a lowering of the arterial tension of less than 10 mm Hg. In Antarctica, the lowering of the arterial tension was much more considerable being 20 to 40 mm Hg. Only three persons showed no appreciable changes.

A cold test was carried out regularly on 47 winterers at Chelyuskin Cape, rarely more than once a month. With the vasopressor reaction the raising of the arterial tension was found to be higher, reaching 50 mm Hg (both systolic and diastolic). During the cold test maximum hypertention was observed at the height of the polar night that probably testified to the increasing reaction of the vascular system.

Certain changes in the pulse were observed in the Arctic: with the beginning of the polar night the frequency of the cardiac systole became appreciably less. At Mirny Station most of the observed winterers had no appreciable change of the pulse rate.

During the process of acclimatization in man when studying the skin temperature of the forehead, breast and back of the hand, we expected to learn not only about the character of the surface vascular reaction, but also about the dynamics of the exchanged heat. The winterers' skin temperature lowered from the first

weeks of their life in the Arctic or Antarctica, reaching the minimal level in winter. However, beginning with the 6 to 8-month life in the polar climate, the skin temperature gradually increased. The old timers of the North had a skin temperature of the covered parts of the body (breast) which exceeded the normal.

The dynamics of the skin temperature are, probably, a partial expression of adaptation of man to the cold climate, which is carried out by the cardiovascular system as the leading factor in physical thermoregulation. Contraction of peripheral bloodflow, leading to the reduction of heat loss is characteristic of the first period of adaptation. The rise of skin temperature after 6–8 months of living in the polar climate is, probably, connected with the gradual increase of heat production. The second period of acclimatization is probably, completed by establishing a new ratio between heat production and heat loss, adequate for severe conditions of the polar climate. The period of full adaptation then begins.

Acclimatization of men at Pionerskaya Station, situated 2,750 m above sea level and 400 m from Mirny was more difficult. There, at a high altitude, the severe climate creates particularly unfavourable conditions for the life and activity of man.

All 11 men at Pionerskaya during the first period suffered from the same nervous disturbances as those of Mirny, but to a greater extent. Tachycardia developed, the pulse rate at rest was 84 to 116/min. The slightest physical effort caused tachycardia and the pulse rate increased up to 140/min. Hypotensive reactions and lowering of the body temperature were very marked. All the wintering men were short-winded, but gradually improved.

During recent years great attention has been paid to the study of the vitamin balance of men living in the North and its changes in the process of acclimatization. The programme of our studies included the determination of ascorbic and pyraminic acid in urine of wintering men by the mg per hour method. Pyraminic acid was regarded as a sign of B_1 content in the body. During the 6-month period 54 men were examined in order to determine the quantity of vitamins in the urine, when they got about 4000 kcal/day with 50 mg of vitamin C and about 2 mg of vitamin B_1. After carrying out the control determination of vitamin content in urine, vitaminization of 24 men, which was conducted for 6 months was commenced. All were given 200 mg of ascorbic acid and 5 mg of vitamin B_1 daily in addition to the vitamins they received with food. In the middle of the dark winter time, the content of ascorbic acid in the urine of those who were not given additional vitamins, reached a minimum level — 0.18 mg which is 30 per cent of standard level. Then, gradually, the content of ascorbic acid increased to 0.26 mg.

With additional vitaminizing, in a month the content of ascorbic acid in the urine increased by more than half in comparison with those who were not vitaminized. After 5 months the ascorbic acid content in the urine nearly reached the lower boundary of standard level.

The content of ascorbic acid in the urine is directly dependent on the period of residence in the Arctic regions. The greatest deficit was noted among those who lived in the Far North for up to half a year. When this period is increased the de-

ficit is reduced. The highest level of ascorbic acid is found among the natives of the northern regions.

Determination of the pyroracemic acid in urine displayed its surplus content, that shows shortage of vitamin B_1. Among people living in the Far North for up to half a year the quantity of pyroracemic acid in urine, during the period of observation, exceeded 1.3, 1.5 times the standard level. Only old timers of the North had a pyroracemic acid content that was near the standard level. When the polar nights ceased, the content of pyroracemic acid became normal (even without additional vitaminization). Additional 5 mg of vitamin B_1 daily led to a normalization of the content of pyroracemic acid after 2-months vitaminization.

Vitaminization of polar explorers noticeably improved their general state of health. Men, receiving additional vitamins, had less reduction of arterial pressure, and the pulse rate remained almost normal.

The reason for the development of the observed C and B_1 hypovitaminosis is the increase of adrenaline production, the rise of dissociation of mediators that develop in the process of adaptation to the cold climate.

Hyperglycemia found among polar explorers is considered as indirect evidence of increased adrenaline production. Increased production of adrenaline and the intensification of dissociation of mediators lead to a higher requirement of vitamins C and B_1; these are necessary for the reduction of mediators from the initial products of their oxidation.

When there is no additional vitaminization the activity of reduction of mediators goes down and hypofunction of the autonomic nervous system develops. Reduction of arterial pressure, bradycardia, reduced appetite, and increased fatiguability in acclimatized persons may be considered to result from reduced response of the autonomic nervous system.

Evidence of the connection between hypofunction of the autonomic nervous system and "acclimatization hypovitaminosis" is the difference in reduction of arterial pressure and reduced pulse rate, which was observed in the group of additionally vitaminized and non-vitaminized men.

Our observations show that the administration of 200 mg of ascorbic acid per day was insufficient since the content of it in urine, even after polar nights, was not normal. However, the additional dose of 5 mg of vitamin B_1 per day led to a quick normalization of pyroracemic acid in the urine. This may be regarded as evidence of a lower utilization of vitamin B_1 in the process of acclimatization.

On the basis of analyses of the above mentioned physiological shifts, it is possible to regard the acclimatization of men in the polar regions as a process, consisting of three periods and to reveal some of the underlying mechanisms:

Period I. Irritating effects of climate on the one hand, leads to appearance of functional nervous disturbances, on the other hand, to "acclimatization hypovitaminosis", and hypotonus of the autonomic nervous system. Various neurotic reactions, physiological movements on the part of hemodynamics, increase of diuresis, shortness of breath are typical of this period.

Period II. Decrease of load on thermoregulating functions of cardiovascular system. Gradual rising of skin temperature as a sign of increasing heat loss.

Period III. Establishing of a new and firm balance in the heat production–heat loss system. Smoothing of neurotic reactions, some decrease of hypofunction of the autonomic nervous system, establishing of skin temperature of the covered parts of a body, at a level that considerably exceeds the standard.

There is no striking difference in the character of adaptational changes that are developing in the time of acclimatization of a man in the Central Arctic and Antarctica. In the severe climate of Antarctica the period of adaptation is longer than in the Arctic.

Re-acclimatization proceeds quietly, without any pathological reaction and lasts for 1–2 months after the return from the Arctic, and 2–2.5 months after the return from Antarctica.

PSYCHOPATHOLOGIE ET CLIMAT POLAIRE

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Abstract — The psychopathological problems related to life in polar regions particularly during the winter season are unsolved. A distinction between caucasians and natives has to be made. In the polar environment 2 types of parameter can be considered: (a) meteorological conditions; (b) social conditions. Our studies have considered both parameters. The results of several investigations carried out during the French Polar expeditions are reported.

Zusammenfassung — Die psychopathologischen Probleme, die mit dem Leben im Polargebiet verbunden sind, besonders bei der Überwinterung, sind noch nicht abgeklärt. Unterschiede zwischen Kaukasiern und Eingeborenen müssen gemacht werden. Zwei Parameter lassen sich unterscheiden: (a) die meteorologischen Bedingungen, (b) die sozialen Bedingungen. Die Ergebnisse von einigen Untersuchungen während der französischen Polarexpeditionen werden berichtet.

Résumé — Le seul point non résolu actuellement en expéditions polaires est celui des problèmes psychopathologiques posés par la vie en pays polaires et plus particulièrement en hivernage, bien qu'une note spéciale puisse être faite en ce qui concerne les blancs et les indigènes de l'Arctique. Dans l'environnement polaire deux ordres de paramètres sont à distinguer. Les uns sont d'ordre climatométéorologique stricts, et les autres d'ordre social. C'est évidemment aux premiers que nous nous adresserons bien que les seconds en découlent directement et y soient liés étroitement. Nous évoquerons ici les quelques essais tentés par les Expéditions Polaires Françaises.

NOTRE intention est d'exposer quelques faits concernant les rapports pouvant exister entre les conditions climatiques antarctiques et les problèmes biologiques; ce dernier terme étant pris dans un sens très large. Etant médecin, nous ne traiterons que de problèmes humains, c'est dire que nous limiterons considérablement le sujet.

Compte tenu des conditions dans lesquelles se déroulent actuellement les hivernages foloures, il n'y a pas de problèmes pathologiques somatiques spécifiques de la vie sous de tels climats. La seule restriction que nous apporterons à cette constatation négative concerne les gelures et nous en dirons ceci:

— Les gelures ne sont pas l'apanage des séjours en régions polaires, les deux guerres mondiales pour ne citer que celle-ci furent fertiles en lésions de ce type.

— La prévention de telles atteintes est plus intéressante que leurs soins. En effet, un équipement bien étudié s'il est intelligemment utilisé, doit mettre les sujets à l'abri de gelures graves dans les conditions que nous pourrions appeler polaires banales. En d'autres termes apprendre aux hommes à se servir de vêtements spéciaux, leur apprendre à ne s'exposer qu'à bon escient est le meilleur garant

d'une protection efficace contre les gelures. Sans vouloir adopter une attitude étroitement dogmatique, je crois que nous pouvons dire que ne sont pas gelés les individus qui savent ne pas se mettre en situation d'être gelés.

Nous ne voudrions pas insister plus sur le rôle du type de la personnalité individuelle dans la survenue d'une gelure, si ce n'est pour préciser que cette notion que certains qualifieraient de psycho-somatique va nous fournir la transition pour aborder le point suivant.

En effet si nous avons dit qu'il n'existait pas de pathologie somatique d'hivernage, nous avons volontairement simplifié et donc faussé l'expression : nous avons voulu dire qu'il n'existait pas de maladie survenant spécialement dans ce cadre ; le terme maladie étant pris ici dans le sens qu'il pouvait avoir à la fin du 19e siècle pendant l'ère pastorienne et, au début de ce siècle, la maladie étant alors l'atteinte somatique d'origine organique et des faits objectivement constatables. La médecine récente (essentiellement celle des USA) s'est penchée d'une part sur les problèmes des troubles fonctionnels c'est-à-dire des perturbations ressenties par le sujet et vécues par lui comme pathologiques sans que des signes objectifs de lésions organiques puissent être constatés par un observateur. Cette médecine s'est penchée d'autre part sur les causes de certaines maladies dont l'expression organique n'est que la traduction ou la conclusion de perturbations psychiques profondes. Cette conception psycho-génétique de lésions somatiques est à la base des théories de la médecine psycho-somatique. Si cette conception parait aussi intéressante philosophiquement (monisme ou dualisme) que discutable biologiquement et pratiquement, il n'en demeure pas moins qu'elle ne peut être négligée puisque ses adeptes ont tendance à vouloir étendre à presque tous la pathologie médico-chirurgicale. Ces quelques mots n'étant pas destinés à exposer le problème complexe des rapports entre médecine somatique et médecine psychique, mais simplement à préciser quelque peu certains termes, nous aborderons directement le problème des troubles psycho-somatiques en hivernage polaire.

Depuis de nombreuses années les rapports professionnels dont les médecins retour annuel en Terre Adélie font régulièrement état d'un certain nombre de troubles constatés chez les hivernants.

(a) troubles du sommeil, essentiellement insomnies dont se plaignent beaucoup de sujets, sujets qui ne consulteront jamais lors des périodes d'hypersomnie reposante qui viennent souvent alterner avec les périodes insomniaques.

(b) céphalées : sans caractère précis, sans horaire ni localisation fixes isolés, sans les signes d'accompagnement qui pourraient faire porter le diagnostique de migraines ; céphalées d'évolution brève remarquablement sensibles à la thérapeutique banale par l'acide acetyl salicylique.

(c) *Asthénie* (thèse du Dr. Nègre) : il est habituel de voir s'installer après quelques semaines ou moins d'hivernage un état de fatigue plus ou moins prononcé allant de la simple lassitude ou de l'incapacité à prolonger un effort jusqu'à l'asthénie profonde entraînant parfois le repos au lit.

Ces trois symptômes que nous avons choisis de citer comme étant les plus fré-

quents mais non les seuls, ont un point commun : ils n'ont rien d'objectifs donc de vérifiable, de mesurable et ceci rend leur étude extrêmement difficile. Nous allons essayer de préciser à leur propos quelques faits.

La situation en hivernage tire son originalité des conditions météorologiques. Pour nous le mot hivernage signifie long séjour d'un groupe humain plus ou moins restreint dans une région où le climat froid interdit toute relation extérieure directe avec d'autres groupes humains. En d'autres termes un groupe est isolé (restriction faite des liaisons radios) et donc en quelque sorte exclus. Les données géographiques et météorologiques sont responsables de cette situation globale d'isolement, elles sont donc indirectement responsables des troubles observés chez ces êtres humains.

Nous avons très superficiellement envisagé les troubles fonctionnels accusés par ces sujets. Envisageons maintenant la personnalité de tels sujets. Ce qui caractérise la situation d'hivernage est ce que les psychiatres nomment la « frustration », conséquence forcée de l'isolement.

— Frustration matérielle d'abord,

— Manque de liberté ensuite, certains impératifs dûs au climat ne pouvant en aucun cas être réfutés, le plus formel étant l'impossibilité de se séparer du groupe jusqu'à l'arrivée de la relève.

— Frustration affective et sexuelle enfin : les attachements extérieurs passés et présents devant désormais se manifester télégraphiquement. Au total en hivernage, l'individu est condamné à son groupe et, de la même façon, l'équipe est condamnée à ses hommes.

Comment ces hommes théoriquement sains de corps et d'esprit vont réagir face à cette situation d'exception, difficile non du fait direct de la météorologie mais de son fait indirect. Bien sûr ils vont tenter de s'adapter, ils vont utiliser pour ce faire un certain nombre d'apprentissages datant de leur enfance ou jeunesse et ayant fait leur preuve. Les mécanismes de défense qu'ils se sont forgés au cours de leur existence vont entrer en action pour tenter de maintenir un équilibre. Ce n'est que lorsque ces systèmes défensifs de la personnalité se trouveront dépassés par les éléments perturbateurs de la situation extraordinaire, que les troubles apparaîtront ; en d'autres termes les sujets doués de défense efficace sauront en cas de besoin jeter en quelque sorte un peu de lest, ce qui leur permettra de maintenir l'équilibre de leur « moi ».

Tandis que les sujets mal adaptés se laisseront déborder et n'arriveront jamais à trouver dans ce monde nouveau qu'est un hivernage, l'harmonie par tous. En fait nous rejoignons le problème maintenant classique de la réaction à un stress.

Ici, le stress s'il est physique du fait des conditions climatiques dures, est surtout psychique du fait de la conséquence de celle-ci c'est-à-dire de la frustration. Nous considérons donc l'isolement de l'hivernage comme une privation, un sevrage. La réaction inconsciente à un tel procédé est l'agressivité : celle-ci va devoir être utilisée. Il est bien des façons de liquider cette force, mais seul certaines nous intéressent ici. L'agressivité au lieu d'être projetée à l'extérieur, peut choisir l'individu

lui-même comme objet et s'attaquer à son propre corps. Ceci est un des grands principes de la médecine psycho-somatique et nous la retrouvons ici pour expliquer certains symptômes constatés chez nos sujets en hivernage. Dans ce groupe étroit où toute agressivité clairement extériorisée est très perturbée donc très mal acceptée par le groupe lui-même qui s'inquiète devant tout signe d'atteinte à son unité, dans ce groupe étroit chaque individu ressent inconsciemment l'interdit qui pèse sur toutes les manifestations nettement agressives vis-à-vis des autres participants. Il n'est donc pas étonnant que, conséquence de la frustration, l'agressivité, privée de ses objets habituels, se retourne contre le sujet et s'attaque à son corps, ce qui se traduira par le symptôme somatique.

Soulignons à ce propos deux faits importants à nos yeux.

(1.) Nos sujets sont des volontaires — ceci nous force à nous demander pour quelles raisons ils ont de bon gré choisi de vivre cette situation frustrante, que nous ne développerons pas ici.

— ceci les force à se sentir responsables de leur jugement. Or rien n'est plus difficile à supporter pour une personnalité fragile que d'assumer sa responsabilité. La maladie même dans ses formes minimes (mal de tête) soulage la responsabilité suivant la schéma simple: j'ai eu tort — maintenant je souffre donc j'expie mon erreur, donc je me pardonne. A ce propos nous ne voulons pas entrer plus profondément dans l'explication des conditions névrotiques, mais nous signalerons seulement que le caractère sadomasochiste de certaines motivations au départ se retrouve dans les modes de réactions pendant l'hivernage. Au total, pour certains, la maladie représente une façon de résoudre leurs problèmes personnels, cela fait partie de ce que l'on appelle le bénéfice secondaire de la maladie et ceci nous amène au deuxième fait. Dans le symptôme morbide, le sujet exprime son agressivité contre lui-même mais aussi contre les autres. En effet dans un groupe aussi étroit (le nôtre ne comptait pas 20 hommes) une défection de l'un perturbe le fonctionnement de l'ensemble; le travail non fait par le malade doit être rattrapé par ses collègues. Quelle meilleure façon de faire souffrir les compagnons que de leur imposer votre propre tâche! quelle meilleure façon de faire sentir au groupe son agressivité que de l'amputer d'un de ses membres, que de s'en désolidariser. Quel plaisir d'inquiéter les camarades, de savoir qu'on leur manque, de se faire plaindre, de se faire cajoler, de recevoir enfin des preuves d'attachement: le copain serviable qui apporte le petit déjeûner jusqu'au lit du malade n'évoque-t-il pas la présence rassurante de la mère protectrice lors des maladies d'enfance.

(2.) A propos d'enfance il faut aussi établir un rapprochement entre cette symptomatologie fonctionelle d'hivernage et l'immense pathologie utilisée par les enfants qui refusent d'aller en classe. Je crois qu'il existe des similitudes entre ces deux situations enfance et hivernage. Toutes deux sont des situations de dépendance auxquelles il est difficile d'échapper par des moyens licites. Dépendance vis-à-vis d'un petit cadre social (la famille dans un cas, l'équipe dans l'autre) dépendance vis-à-vis du leader et des différentes personnalités marquantes du groupe. Un bon mode de fuite devant une situation que l'on ne peut pas rejeter puisqu'elle s'im-

pose est le comportement — maladie: ainsi les enfants construisent-ils pour éviter l'école des histoires pseudo-pathologiques parfois admirables. Bien des absences scolaires pour «indigestion» sont probablement plus ou moins sciemment préparées. Peut-être pouvons-nous nous permettre un parallèle entre ces surcharges alimentaires infantiles et utilitaires et certaines absorptions démesurées de nourriture ou surtout de boissons alcoolisées rencontrées fréquemment chez nos «héros polaires». Les buts visés, les moyens mis en jeux, les résultats obtenus sont identiques: le sujet est «malade» c'est-à-dire qu'il vit la situation en malade. La responsabilité qu'il a de son vécu morbide ne peut qu'augmenter sa culpabilité de satisfaire son agressivité vis-à-vis de lui-même et par là même contribuer à le combler. Nous ne nous pencherons pas plus sur l'interprétation psychanalitique de tels comportements et n'iront pas jusqu'à dire que l'hivernage pour certains représente une regression au stade oral du développement libidinal.

(3.) Il faut pour terminer ce problème signaler qu'il est pratiquement impossible au médecin de déceler avec certitude dans les troubles invoqués par les sujets ce qui est réellement ressenti comme pathologique par l'individu et ce qui est construit consciemment pour obtenir un bénéfice immédiat. Dans de tels domaines, la bonne foi n'existe pas, pas plus que la mauvaise foi; la distinction entre les «troubles vrais» et les troubles simulés est tentante mais elle ne correspond guère à la réalité: en effet, on doit considérer comme normal le fait même de simuler dans le sens où elle traduit une tentative d'adaptation sur un mode pathologique.

La seule méthode d'exploration qui pourrait permettre de préciser la genèse des troubles accusés par les sujets, d'établir un rapport entre le symptôme exprimé et le contenu psychodynamique qu'il dissimule mais libère sous cette forme déviée, est l'abord analeptique. Celui-ci ne peut exister que dans le cadre de la relation spéciale qui existe entre le thérapeute analyste et le sujet analysé. On conçoit qu'une telle relation avec tout ce qu'elle implique formellement ne puisse se concevoir dans le cadre d'un hivernage. En admettant même qu'une telle étude en profondeur du psychisme de chaque hivernant puisse être réalisée, éclairant ainsi les motivations inconscientes de leurs symptômes, elle n'en permettrait pas pour autant la cure ou la prévention. Nous avons dit que ces manifestations pathologiques somatiques représentaient pour le sujet une méthode de défense et il ne saurait être question dans la situation d'hivernage d'entreprendre la destruction puis la reconstruction des mécanismes profonds d'une personnalité. Seule une psychothérapie superficielle de soutien est de mise en de telles circonstances et on ne peut attendre d'elle que des renseignements scientifiques et des résultats thérapeutiques très limités.

Toutes ces données paraissent peut-être obscures et surtout bien théoriques aussi allons-nous terminer par l'exposé de quelques constatations pratiques.

Nous avons eu la possibilité il y a peu d'années d'hiverner en Terre Adélie en temps avec un psychiatre. L'équipe comprenait au total 18 hommes lesquels vécurent totalement isolés pendant 10 mois $^1/_2$. Durant tout le séjour, le médecin observa et consigna les comportements individuels et collectifs. Il nota aussi les

troubles dont se plaignaient les hivernants et les consultations qu'entraînaient ces symptômes. Quelques faits ressortent de cette étude.

(1.) La moyenne des consultations journalières est de l'ordre de 2. Ce chiffre peut paraître élevé; si l'on considère qu'il s'agissait de 18 hommes jeunes (le plus âgé n'avait pas 40 ans) ayant subi au départ une visite médicale rigoureuse, exposés à des conditions climatiques sévères certes, mais pas extraordinaires, séjournant dans une atmosphère pure très pauvre en microbes. Nous voyons deux explications à cette demande médicale importante; la première: les sujets ayant un médecin sur place, à leur service, l'utilisaient au maximum; consultèrent pour des troubles absolument mineurs dont ils n'eussent parlé à personne dans des conditions normales. La visite dans le local médical était une occasion d'intéresser quelqu'un à soi-même, de parler en étant à peu près sûr d'être écouté, ce qui est rare et appréciable dans de tels groupes.

La deuxième raison de ces multiples consultations nous vous l'avons exposée tout-à-l'heure: la maladie a bien des avantages et dans une société étroitement organisée, il n'y a pas de maladie efficace sans bénédiction médicale.

(2.) Si nous étudions la répartition des troubles dans le temps tout au long de l'année, nous constatons que de mois en mois leur chiffre varie peu.

Le total des consultations de Février, c'est-à-dire au début de l'hivernage ou fin de l'été n'est pas sensiblement différent du total enregistré au cours de chaque mois d'hiver, n'est pas sensiblement différent du total enregistré en Novembre, c'est-à-dire à la fin de l'hivernage au retour des beaux jours.

Si à l'intérieur de chaque mois nous étudions la répartition des troubles, nous constatons que les périodes de très mauvais temps (tempête de blizzard pendant plusieurs jours) ne sont pas marquées par plus d'incidents pathologiques que les périodes de beau temps permettant une activité extérieure. Autrement dit les conditions climatiques locales journalières (température, vent, pression atmosphérique, insolation) n'influencent pas apparamment la survenue des troubles.

Ce qui revient à conclure que dans une base polaire telle que celle que nous exploitons en Terre Adélie, les conditions météorologiques ne conditionnent pas directement l'apparition de symptômes morbides. Elles agissent indirectement en imposant la situation vitale qui est confinement dans l'isolement: cette vie, en petit groupe exclu de la grande société, d'un certain nombre d'individus de même sexe, de niveaux socio-culturels différents, ne peut être que source de conflits. Le groupe ayant assez à faire pour maintenir son existence au milieu des rivalités qui ne manquent pas de se créer entre les sous-groupes obligatoirement formés, ne peut se permettre d'accepter les décharges agressives individuelles qui l'atteindraient lui-même. Et l'on peut dire que l'individu est amené inconsciemment par la morale collective à se sacrifier à son équipe en orientant vers lui-même l'agressivité qu'il aurait spontanément libérée contre ses compagnons. Dans de telles situations, la maladie de l'individu peut-être une arme efficace utilisée par une petite société pour se protéger et demeurer intacte malgré les combats perpetuels qui se livrent en son sein.

NUTRITION ET CLIMAT POLAIRE

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Abstract — A polar environment entails a number of physical climatic, physiological and psycho-sociological factors. This combination is not uniform, depending on the place, surroundings, and type of life considered. A certain amount of experimental data should be retained at the onset. These results of experimental investigations that have been carried out in the field or in the laboratory, will enable one to establish certain theoretical precepts as far as nutrition in a polar climate is concerned. The overall result of these investigations is to establish the most suitable type of food ration for sedentary occupations, or expeditions during the winter season, or mechanized or non-mechanized long-distance expeditions, or simply in the case of survival.

Zusammenfassung — Man muss unter Polarumwelt die Anzahl physischer, klimatischer, physiologischer und sozialpsychologischer Faktoren verstehen. Diese Gesamtheit ist nicht einheitlich, sondern hängt von dem Ort, dem Milieu und der Lebensweise ab. Eine gewisse Zahl experimenteller Angaben sollen am Anfang festgehalten werden. Die Ergebnisse der Versuche, die sowohl draussen, als auch im Laboratorium gemacht worden sind, werden die Aufstellung theoretischer Vorschriften für die Ernährung im Polarklima gestatten. Die Aufstellung der Nahrungsration hängt davon ab, ob es sich um Individuen mit einer sitzenden Beschäftigung, um Überwinterungsexpeditionen, um kurzdauernde Expeditionen, mechanisiert oder nicht, oder schliesslich darum handelt zu überleben.

Résumé — Par environnement polaire, il faut entendre un certain nombre de concepts physiques, climatiques, physiologiques et psycho-sociologiques. Cet ensemble n'est pas univoque selon les lieux, milieux et types de vie envisagés. Un certain nombre de données expérimentales doivent être retenues au départ. Résultats d'*expérimentations* faites sur le terrain ou en laboratoires, elles vont permettre l'établissement des précepts théoriques en ce qui concerne la nutrition en climat polaire. De cet ensemble résulte l'établissement pratique de la *ration* alimentaire se rapportant soit aux sédentaires implantés, soit aux *expéditions* d'hivernage, soit aux expéditions de raids, mécanisés ou non, soit aux cas de *survie*.

DÉFINITION DE L'AMBIANCE POLAIRE

(1) *Géographie:* On peut considérer qu'il y a lieu d'envisager un aspect nutritionnel spécial dans les régions de caractère polaire plutôt que dans celles qualifiées de subpolaires, bien que comme nous le verrons les travaux modernes mettent toutes la note sur le caractère assez banal de l'alimentation au froid. En fait les problèmes lorsqu'ils existent ne se trouvent posés que dans certaines régions de caractère déterminé où la vie menée par les hommes est une vie polaire. Par extrapolation du reste

on peut accepter ces données comme valables à tous groupes d'hommes ayant à vivre au froid dans des conditions difficiles comme c'est le cas par exemple dans certaines circonstances de guerre.

C'est donc l'ensemble des données géographiques, sociologiques et climatologiques qui va déterminer pour nous le cadre polaire dans lequel nous allons envisager rapidement les problèmes nutritionnels.

Dans l'Arctique on considère comme régions polaires les zones géographiques situées au nord de la limite extrême de la végétation arborescente. C'est le cas de certaines zones du Canada, de l'Alaska, de l'U.R.S.S., de la Finlande, de la Suède et de la Norvège. Il faut y ajouter le Groenland, le Spitzberg et les terres situées au nord du passage du nord-ouest et du passage du nord-est. Quelques cas de vie humaine se rencontrent encore sur la glace du pôle nord, dans des stations périodiquement habitées comme les îles flottantes américaines ou russes.

Pour l'Antarctique c'est plus simple, le continent Antarctique représente en gros la région polaire. On peut y ajouter les zones des îles de la péninsule antarctique et de la Terre de Feu et les îles subantarctiques dont certaines ont des caractéristiques polaires (Heard Island par exemple).

(2) *Sociologie:* 3 types d'individus vivent en régions polaires:

– Les membres d'expéditions vivant dans des stations, des bateaux ou participant à des raids.

– Les indigènes Esquimaux, Indiens, Lapons, Aléoutes, indigènes de Sibérie etc. plus ou moins disséminés selon les zones et plus ou moins en contact avec la vie civilisée et le remaniement social qu'elle apporte.

– Les blancs de l'Arctique, sédentaires ou fonctionnaires dont le mode de vie est souvent différent, les fonctionnaires apportant avec eux les habitudes et les besoins urbains, au contraire certaines populations sédentaires blanches comme celles de la Norvège par exemple vivant essentiellement de leurs ressources propres issues de la culture, de l'élevage et de la pêche.

Il est évident que devant des types sociaux et éthniques aussi différents, on ne peut généraliser ni les agressions ni les données alimentaires. Dans certains cas comme dans les stations d'hivernage, on doit tenir compte de problèmes spéciaux comme ceux de la conservation d'aliments pour une année ou bien les difficultés psychologiques résultant de la vie en commun dans un petit groupe isolé dans un environnement difficile. Les raids peuvent entraîner des dépenses d'énergie intervenant sur les besoins globaux en calories et ils peuvent aussi faire envisager des solutions très différentes a donner à la ration alimentaire selon qu'il s'agit de déplacements en véhicules ou de raids à pieds, traîneaux à chiens ou man-hauling.

Les notions de carence et de déséquilibre alimentaire vont se retrouver plus ou moins dans ces différents types de population selon les impératifs de vie dûs au cadre polaire auquel ils pourront être soumis.

(3) *Climatologie:* C'est dire que ces éléments retentissant sur les données diététiques vont dépasser largement le cadre qui pourrait résulter des seules données climatologiques encore que celles-ci soient extrêmement différentes selon les régions

auxquelles on s'adresse, le mode de vie des individus qui y séjournent et dont la protection par des techniques extérieures est elle aussi extrêmement variable.

Du point de vue climatologique, on peut considérer qu'une région est polaire lorsque la température moyenne pendant le mois le plus chaud est inférieure à 10° C. Donc climat rude et froid, hiver prolongé, comptant une période d'obscurité et apparation tardive et pour une courte période du printemps et de l'été.

La température extérieure basse n'est pas le seul élément agressif. La déperdition thermique est fonction de 3 facteurs climatiques: la température extérieure, la vitesse du vent, le degré hygrométrique de l'air. Le vent augmente dans des proportions considérables la déperdition thermique totale. Les mesures que nous avons faites en Terre Adélie avec un appareil à déperdition très simple nous ont par exemple donné les chiffres suivants:

Temps de refroidissement d'un litre d'eau de 37° C à 0° C:

par une température extérieure de moins 1° C,
si pas de vent, 1 hr 28 min
si vent de 7 m/sec; 59 min

par une température extérieure de moins 12° C,
si pas de vent, 1 hr 8 min
si vent de 10 m/sec; 36 min

LES DONNÉES EXPÉRIMENTALES ET D'ÉTUDES

(1) *Besoins caloriques globaux:* Le Comité des Besoins Caloriques (FAO, 1950) recommande les corrections suivantes:

En prenant pour base 10° C il convient d'augmenter de 5 pour cent les besoins en calories pour 10° C d'abaissement de la température. Mais c'est là raisonner dans l'absolu car dans la pratique tout dépend de la surface de corps exposée au froid, de la protection des vêtements, du nombre d'heures passées hors d'un habitat chauffé.

Les nombreuses études touchant ce domaine (Scholander *et al.* 1950; Burton et Edholm 1955; Rodahl, 1960) semblent indiquer que les indigènes et les blancs vivant dans l'Arctique ne sont pas exposés à un froid tel que leur métabolisme doive s'accroître dans une mesure appréciable. Dans ces conditions ils ne doivent avoir aucune raison d'augmenter la consommation de nourriture.

Malgré des études contradictoires (Balke *et al.*, 1944; Johnson et Kark, 1946–1947; Rodahl, 1949; Meehan, 1955) ne trouvent pas de différence notable du métabolisme de base chez les blancs ou les indigènes vivant au froid acclimatés ou non. Les différences notées sont certainement dûes au port de vêtements lourds (Gray, Consolazio et Kark, 1951).

Les besoins globaux en calories ont été diversement appréciés et la tendance actuelle est nettement à la baisse par rapport à celle des dernières années.

Johnson et Kark (1946) ont étudié des groupes d'hommes vivant à moins 40° C et ayant à leur disposition une très large ration dans laquelle ils pouvaient puiser à volonté. Le chiffre moyen consommé se situait autour de 4900 kcal par homme et par jour.

D'autres chiffres issus d'études faites sur le terrain:

Expédition Musk-Ox	4400 kcal/jour
Expédition Byrd (1939–1941)	5400 kcal/jour
Expédition Scott	4800 kcal/jour
Militaires de Ford Churchill (Swain *et al.*, 1949)	5600 kcal/jour
Premières expéditions polaires françaises	5000 kcal/jour
Mineurs du Spitzberg (ABS)	4580 kcal/jour

Or la consommation moyenne des esquimaux se situe autour de: 2800 kcal (Hoygaard, 1941) 3.100 kcal (Drury *et al.*, 1956) celle des trappeurs européens autour de 3000 kcal (Rodahl, 1960).

On a donc examiné les choses d'un peu plus près. Un groupe de jeunes aviateurs et un group de soldats d'infanterie ont été soumis à une série d'enquêtes nutritionnelles assorties, d'examens cliniques, physiologiques et biochimiques détaillés pendant les 4 saisons de l'année en Alaska de 1950 à 1952. L'enquête a montré que la consommation était de 3000 à 3200 kcal/jour.

Durant l'AGI à Little America V dans l'Antarctique un travail de Milan et Rodahl (1961) a montré qu'une consommation de 4000 kcal entraînait une augmentation de poids de 4 kg chez les sujets séjournant 1 an dans l'Antarctique. L'Expédition Glaciologique Internationale au Groenland avait prévu des rations de raid d'environ 4700 à 4800 kcal. Il s'est avéré que les sujets ne consommaient en moyenne que 85 pour cent de la ration et ce, sans perte de poids notable.

De nombreux faits sont venus confirmer ces données. On peut donc s'arrêter aux valeurs suivantes:

— Ration calorique normale pour les sujets sédentaires, c'est-à-dire environ par jour.	3000 kcal
— Ration énergétiquement supérieure pour les raids sans dépasser sauf si travail intense.	4000 kcal

(2) *Les besoins en différents types d'aliments* — L'école de Chicago, les expériences de Mitchell *et al.*, 1946, et Mitchell et Edman 1951, tendent à prouver qu'en climat froid la prédominance doit être donnée aux aliments riches en graisse qui sont plus efficaces que les hydrates de carbone, eux-mêmes supérieurs aux protides.

Au Canada, Johnson et Kark (1946) et Johnson *et al.*, (1949) expérimentent différents types de rations et celle qui semble être la meilleure au froid correspond à 121 g de protides, 276 g de lipides, 390 g de glucides.

Refutant l'idée de faim de graisses, Hildmann (1943) notait déjà sur un bataillon de skieurs allemands, qu'au froid les hommes refusaient les graisses et les viandes.

Les différents types d'études effectuées en Alaska et sur le personnel US dans l'Antarctique ne semblent pas montrer que les quantités de graisses réellement absorbées aient été aussi importantes qu'on le prévoyait.

En conclusion, si les lipides sont évidemment un excellent aliment au froid, il ne faut quand même pas qu'elles dépassent un pourcentage énergétique de 35 à 40 pour cent avec par exemple 10 à 15 pour cent pour les protides et 50 à 55 pour cent pour les glucides. Exemple:

Ration de 3000 kcal environ		*Ration de 4000 kcal environ*	
Protides	100 g	Protides	110 g
Lipides	110 g	Lipides	150 g
Glucides	450 g	Glucides	600 g

(3) *Les besoins spéciaux:* En ce qui concerne les vitamines, deux questions se posent: d'une part celle des carences par absorption de doses insuffisantes de vitamines par rapport au taux habituel, d'autre part celle d'une protection supplémentaire obtenue par surdosage, c'est-à-dire par absorption de grandes quantités de vitamines à des doses considérablement plus fortes que les taux habituels.

En régions froides toutes les études faites soit chez les Esquimaux, soit chez les trappeurs, soit chez des militaires, n'ont jamais montré de symptômes de carence pour des cas où l'absorption de vitamine C était pourtant particulièrement basse (Hoygaard et Mehren, 1931; Rodahl, 1958). Rien de net non plus avec la vitamine A. Par contre carence possible avec insuffisance d'apports en facteur B.

Les données actuelles ne permettent pas de supposer que les besoins de l'homme en vitamines soient nettement plus élevés en milieu polaire et subpolaire. Pour ce qui est de la vitamine C, les voyageurs de l'Arctique, les trappeurs et les Esquimaux peuvent subsister en consommant une nourriture comprenant moins de 15 mg par jour d'acide ascorbique sans présenter de signes de carence. Mais on sait qu'il est possible de prévenir et même de guérir le scorbut par un régime exclusivement carné (Stefansson 1918).

Quant aux effets de surdosage ils ont été chez l'homme une déception totale par rapport à ce que l'on avait cru apercevoir chez l'animal (Glickmann, *et al.*, 1946; Keys, 1947).

Aucune donnée spécifique actuellement connu ne laisse supposer que les régions polaires diffèrent des climats tempérés en ce qui concerne les besoins en sels minéraux dans l'alimentation humaine.

Les besoins en liquide sont probablement augmentés et ce d'autant plus qu'il peut y avoir perte d'eau par sudation. Notons enfin que l'alcool n'est pas reconnu comme utile dans la lutte contre le froid.

LES DONNÉES EMPIRIQUES

(1) *Autres impératifs:* La vie en régions polaires peut entraîner certains impératifs qui n'ont aucun rapport avec les données diététiques théoriques ni même avec la physiologie. Cela tient à ce que l'homme vivant dans ces environements spéciaux subit des contraintes de tous ordres qui influent directement ou indirectement sur son alimentation. L'indigène mange essentiellement ce qu'il peut se procurer, le trappeur ou le voyageur de l'Arctique ce qu'il peut emporter ou trouver sur place, l'hivernant d'une station ce qu'il a pu stocker, l'explorateur en raid, là encore, ce dont il dispose. Et dans chaque cas vont intervenir une série d'autres paramètres qui sont souvent impératifs: possibilités et formes de conservation, possibilités et facilités de préparation de cuisson, de transport, poids, volume, etc.... Ajoutons-y les problèmes psychologiques qui ne seront pas sans rapport avec l'appétit et la digestion; autant d'impératifs qui bien souvent sont primordiaux quant à la consommation d'une ration polaire pour laquelle on sera obligé d'adapter des principes théoriques de diététique aux contraintes climatiques, sociales et géographiques.

(2) *Expériences pratiques:* On peut considérer qu'un certain nombre de faits empiriques peuvent aussi être retenus des expériences pratiques (ou tout simplement de «l'expérience») faites par des sujets ayant vécu en pays polaires. C'est là une donnée qui nous semble tout aussi importante que les précepts scientifiques des diététiciens.

On peut reprendre l'expérience de Stefansson (1918): après avoir vécu 7 ans en Arctique avec un régime exclusivement carné (viande et poisson) il n'avait présenté aucune tare viscérale. Devant l'étonnement et l'incrédulité générale il reprit avec Andersen durant 1 an sous climat des Etats-Unis ce régime et aucun trouble métabolique ne fut noté.

On sait aussi que la consommation de viande et abats entraîne une protection certaine contre le scorbut. Ceci avait été péremptoirement prouvé lors de l'hivernage de la «Belgica» dans l'Antarctique. Amundsen, qui faisait partie de ce groupe, devant les dégâts réalisés par le scorbut dans l'équipage, sortit de son mutisme pour recommander d'aller chercher des phoques et d'en consommer abondamment. Ce conseil permis aux hivernants de retrouver la santé.

Certains explorateurs polaires ayant à vivre dans des conditions climatiques dures et sans possibilité de confort (raids à pieds et sous la tente) ont constaté un besoin en aliments liquides. Ils ne désiraient pas un steack pommes frites, objet de leur rêve habituel, mais une soupe épaisse concentrée et grasse ou un bol de chocolat bien dense sucré et enrichi en farine. Des petits repas fréquents leurs semblaient aussi une bonne chose.

Enfin, notion capitale en toute diététique, la question du goût. Elle est primordiale; il faut tenir compte des habitudes culinaires individuelles et ethniques. Nous avons constaté aux Expéditions Polaires Françaises que la liste des aliments préférés par ordre décroissant lors de référendums anglo-saxons correspondait à peu près au désir des Français mais à l'envers.

Deux essais que nous fîmes au Groenland furent démonstratifs. Une des premières expéditions polaires françaises fut dotée d'une alimentation très rationnelle mais composée essentiellement de plats sucrés, flocons d'avoine, miel, jus de fruit etc.... Le résultat fut catastrophique, les sujets ne consommant pas leurs rations et le moral du groupe et le travail s'en ressentirent. Récemment, au contraire, une expédition internationale au Groenland à laquelle participaient des Allemands, des Danois, des Français et des Suisses fut un succès sur ce plan en raison de l'étude minutieuse des rations, qui fut faite dans leur choix et dans leur variété.

Quant aux hivernages chacun sait qu'ils influencent fortement le psychisme des sujets. Un de leur plaisir demeure les repas et en tous cas leur susceptibilité dans ce domaine est exacerbée. C'est pourquoi un cuisinier de métier est emmené dans les Expéditions Polaires Françaises et les aliments sont choisis avec d'autres soucis que ceux relevant uniquement de la diététique.

LES RATIONS ALIMENTAIRES

Il peut sembler paradoxal que les conclusions théoriques auxquelles nous arrivons après analyse des travaux soient aussi banales: l'alimentation au froid ne diffère guère en théorie de l'alimentation en climat tempéré. Ceci ne doit cependant pas nous étonner. En effet, si, chez le rat soumis à une ambiance de plus 5° C (conditions extrêmement rigoureuses pour lui) on constate une augmentation importante de son métabolisme avec absorption plus grande de nourriture, intensification du métabolisme cellulaire, de la vascularisation des tissus musculaires et de l'activité de la thyroïde, augmentation des besoins en acide ascorbique et accroissement des glandes surrénales, il n'en est pas de même chez l'homme et ceci probablement parce que le stress n'est jamais aussi important. Il apparait donc que les indigènes ou les blancs vivant en pays polaires ne sont pas soumis à un froid suffisamment vif pour entraîner l'augmentation marquée du métabolisme que l'on constate chez les rats exposés à une température de + 5° C. En l'absence d'un tel accroissement du métabolisme, il ne peut y avoir aucune raison de consommer une nourriture plus abondante ni pour la nécessité de vivre en milieu froid, ni pour celle de s'acclimater à une température peu élevée. Lors des diverses expériences on n'a pas non plus constaté une augmentation nette des besoins en vitamine C de l'homme placé dans un milieu à basse température.

(1) Alimentation des Sédentaires

(a) *Les Blancs* séjournant dans l'Arctique doivent avoir une alimentation très proche de celle qu'ils ont en pays tempéré, sans présenter de surcharge ni qualitative ni quantitative. Elle doit être variée et apporter les différentes catégories d'aliments suivant les normes de l'alimentation équilibrée. L'apport le plus grand devra être prévu en ce qui concerne les aliments frais. Ainsi conçue, l'alimentation

apporte une dose suffisante de vitamines pour qu'il n'y ait jamais à craindre d'avitaminose.

(b) En ce qui concerne *les Indigènes* les mesures à prévoir en matière d'approvisionnement sont extrêmement variables selon les contrées et les contacts avec les populations blanches. Nous pouvons retenir les données récentes suivantes, mises en relief à la Conférence sur la Médecine et la Santé Publique dans les régions arctiques et antarctiques tenue à Genève par l'OMS du 28 août au 1 septembre, 1962.

Au Groenland, le régime alimentaire varie selon les saisons; les heures de repas sont irrégulières, de même que les possibilités d'approvisionnement. Parmi les denrées disponibles figurent la chair de divers poissons, mammifères ou oiseaux, les oeufs de poisson et quelques légumes ou baies. Les populations de l'Arctique se nourrissent encore dans une très large mesure de produits locaux: toutefois, les aliments importés sont de plus en plus utilisés.

Des enquêtes alimentaires régulières sont difficiles à mener, mais certaines études détaillées ont été faites au Groenland entre 1937 et 1952. Elles ont fait apparaître des fluctuations marquées de la consommation selon les saisons, les chiffres les plus bas correspondant d'habitude aux mois de février–avril. Précédemment, il avait été noté que près de 90 pour cent des calories étaient fournies par la viande de phoques récemment tués et par diverses viandes fraîches ou conservées, le reste venant des légumes et des herbes locales. La consommation de sel était faible, surtout en hiver. Le régime était riche en vitamines A et D, mais pauvre en acide ascorbique pendant l'hiver.

Des travaux plus récents mettent en évidence des différences considérables, quant aux aliments consommés, entre les agglomérations et les «comptoirs». Le poisson et la viande sont beaucoup plus abondants dans les «comptoirs» et par conséquent plus utilisés dans l'alimentation, alors que le pain et la farine viennent en tête dans les agglomérations. De toute manière, si la plupart des éléments nutritifs sont absorbés en quantités plus ou moins suffisantes, les rations de fer et de calcium laissent le plus souvent à désirer. On importe maintenant dans ces régions de la farine enrichie contenant du calcium, de la thiamine, de la riboflavine et du fer.

Des enquêtes alimentaires portant au total sur 1800 indiens et esquimaux ont été menées dans 11 villages de l'Alaska. Il en ressort que les intéressés achètent une partie de leur nourriture et que 60 pour cent des calories absorbées proviennent de denrées importées. Pour le reste, ils mangent surtout de l'élan, du caribou, du poisson, du phoque ou du morse, selon la situation du village. Les matières grasses d'origine locale ne fournissent que 4 pour cent des calories. La principale source d'acide ascorbique est constituée par des baies et des légumes ramassés en quantités variables. On a observé à peu près partout les mêmes pratiques et habitudes alimentaires. Soixante pour cent des enfants de moins de 2 ans ne sont pas nourris au sein, le lait concentré étant l'aliment le plus employé. L'introduction de suppléments dans le régime des nourrissons intervient plus tard qu'aux Etats-Unis.

La ration de calories des enfants plus âgés et des adultes reste inférieure aux normes courantes, même si l'on tient compte des différences de taille. Le pourcentage moyen de calories provenant des lipides est à peu près le même qu'aux Etats-Unis. Pour tous les âges, les protéines fournissent une grande proportion des calories, allant de 19 à 30 pour cent. Il y a assez peu de variations saisonnières à cet égard. En revanche, pour le calcium et le fer, on a noté des fluctuations marquées, les chiffres s'élevant avec la consommation de poisson entier. Les rations de vitamines varient suivant les saisons; elles sont en général satisfaisantes, sauf pour l'acide ascorbique qui, l'hiver, n'est absorbé qu'en très faibles quantités dans certains villages.

Dans les conditions actuelles, il n'est probablement pas possible aux Indiens et aux Esquimaux de se nourrir uniquement de denrées locales. Cependant, ils doivent être encouragés à utiliser ces denrées au maximum. L'emploi de produits importés modifie les habitudes alimentaires et risque d'avoir des conséquences défavorables pour la nutrition; aussi paraît-il nécessaire d'organiser, à titre préventif, l'éducation nutritionnelle des populations intéressées.

Il faudrait entreprendre parmi les populations indigènes des études nutritionnelles visant à déterminer les répercussions sur la santé de l'évolution actuelle des régimes et des habitudes alimentaires, ainsi que les facteurs qui provoquent les changements enregistrés.

Les recommandations relatives aux besoins en principes nutritifs se fondent souvent sur des connaissances fragmentaires. Des enquêtes concernant les rapports entre le régime alimentaire des populations arctiques et leur état de santé permettraient peut-être de faire plus de lumière sur ce problème complexe.

(2) L'Alimentation en Station d'Hivernage

On envisage une alimentation de conserves stockées qui doit répondre aux qualités suivantes:

— bonne conservation: le séjour pouvant durer plusieurs années, les transports nombreux et sous des climats différents impliquent une sélection rigoureuse dans le choix et le mode de conservation;

— variété de goût et variété de mode de conservation (produits secs, salés, déshydratés ou sous vide);

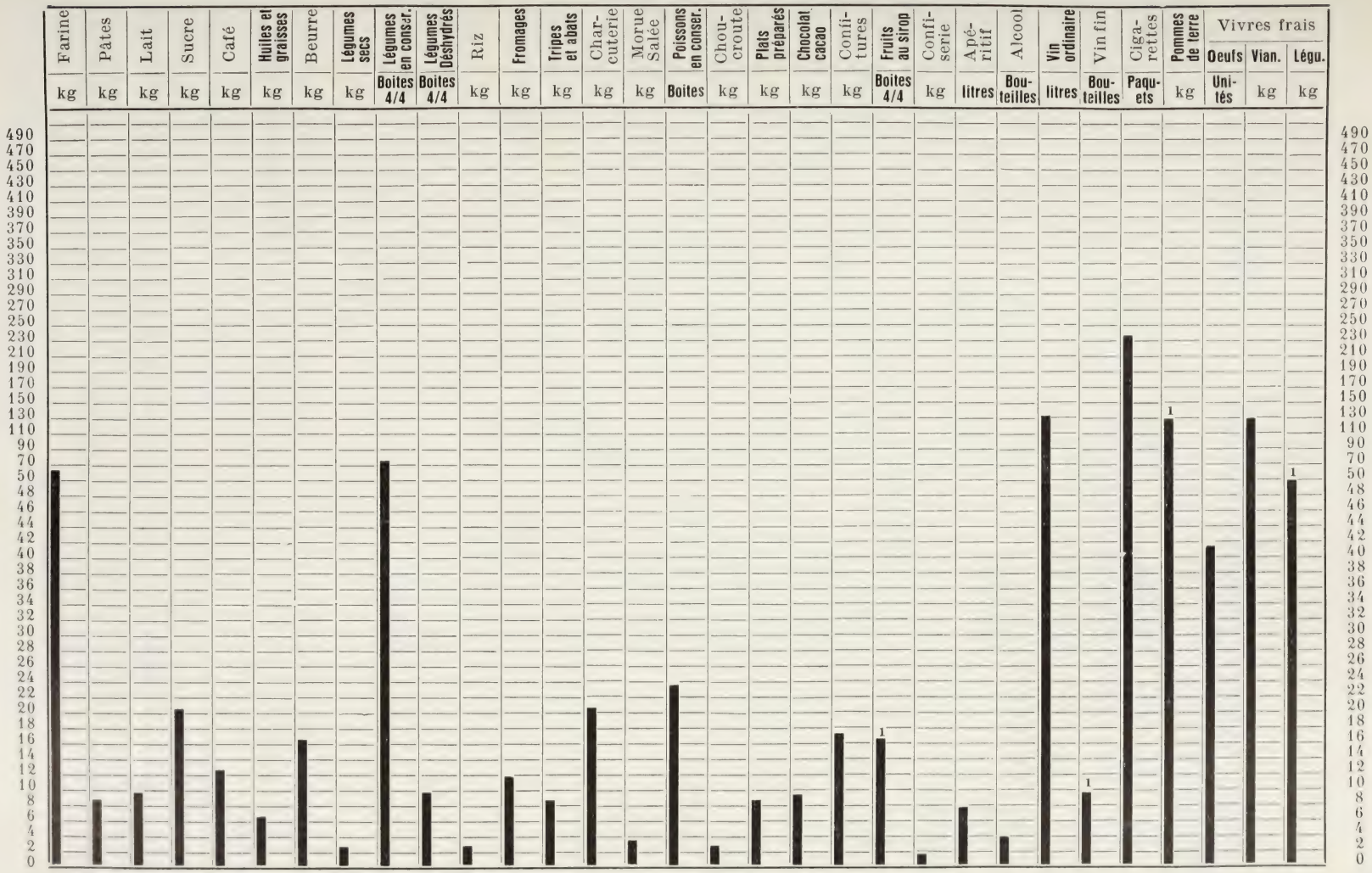
— bonne qualité des produits: non seulement en ce qui concerne les propriétés alimentaires, mais aussi dans le domaine culinaire;

— apport de tous les genres alimentaires; produits laitiers, viandes, légumes, fruits, etc.

Cette alimentation doit donc fournir tous les éléments nécessaires à une nutrition rationnelle.

Il suffit de posséder un stock suffisant de produits conservés et dont les variétés des mets permettront la préparation de repas agréables. Il n'est pas inutile d'insister sur la nécessité d'une excellente organisation culinaire au cours d'un hiver-

Tableau 1. Consommation moyenne 1 homme/année. Hivernages en Terre Adélie — 1960 à 1964



(1) Quantité consommée égale à la quantité emportée. ▬ 1960

Tableau 2.

a) Composition des repas:

	1er jour :	2ème jour :
Petit déjeuner:	Thé	
	Lait	
	Nescafé	
	Ovomaltine	
	Crème de marrons	dito
	Beurre	
	Sucre	
	Biscuits	
Casse croûte:	Lait	
	Figues, raisins secs	
	Rillettes	
	Biscuits	dito
	Soda orange	
	Confiture de pêches	
Déjeuner:	Maquereaux	Pâté
	Poulet en gelée	Veau Marengo
	Munster	Macédoine légumes
	Biscuits	Munster
	Caramels	Biscuits
		Caramels
Diner:	Potage légumes	Crème de champignons
	Corned-beef	Noix de porc
	Munster	Soma
	Biscuits	Munster
	Caramels	Biscuits
		Caramels

nage polaire. Le rendement en travail des hivernants sera en partie fonction de cette organisation, d'autant plus si l'on tient compte des facteurs psychologiques inhérents à tout hivernage. C'est pourquoi, dès qu'une expédition comprend un nombre suffisant de participants, nous considérons qu'elle doit posséder un cuisinier de métier.

Il est parfois possible de trouver une alimentation fraîche en utilisant les ressources locales. En Terre Adélie nous avons consommé avec plaisir la chair, la cervelle et le foie de phoque, les pectoraux de Manchot et de Skua, le Damier du Cap et quelques poissons.

Voir tableau 1 ci-joint — consommation moyenne 1 homme/1 an en Terre Adélie.

b) Composition de la Ration

Désignation	Poids g	Calories g	Protides g	Lipides g	Glucides g
Biscuits	720	2.977	79,2	64,8	519,4
Sucre	300	1.200	0	0	300
Beurre	400	3.044	3,2	336	2
Nescafé	50	160	0	0	40
Thé	25	—	—	—	—
Lait concentré	330	1.142	33	33	178,2
Ovomaltine	400	1.512	80	8	280
Soda orange	300	800	0	0	200
Crème de marrons	350	1.893	12	105	200
Figues, raisins secs	300	915	6	1,8	219
Caramels	150	600	0	0	150
Confitures de pêches	500	1.415	2,5	0,5	350
Potage 6 légumes	150	580	50	20	50
Crème de champignons	150	580	50	20	50
Munster	480	1.372	86,4	105,6	19,2
Rillettes	420	1.308	100	100	2
Poulet en gelée	720	1.400	145,5	90,7	0,6
Filets maquereaux	125	243	27	15	0
Pâté	140	433	33	33	1
Veau Marengo	440	600	46	13	75
Macédoine légumes	500	430	25	10	60
Soma	150	533	12	0,6	120
Noix de porc	450	1.760	100	150	2,5
Corned-beef	340	1.083	100	75	2
TOTAL	7890	25 980	990	1182	2821

Ouvre-boites	50
Papier hygiénique	25
Allumettes	50
	8015

(3) Alimentation en Raid

Elle doit répondre à certains impératifs:

— poids réduit; cela signifie donc un fort pouvoir calorique des aliments utilisés;
— volume réduit: il en résulte parfois la nécessité d'utiliser des produits en poudre, en granulés ou concentrés;
— peu d'exigences de cuisson, le combustible étant rare, et facilité de préparation;
— facilité d'ingestion et de digestion;
— variété de goût;

— conservation en milieu et emballage appropriés (solidité, imperméabilité et légéreté).

Ces impératifs sont du reste fort variables selon qu'il s'agit de raids mécanisés ou de raids à pieds ou en traîneaux à chiens.

Dans le premier cas, les problèmes de poids et volume sont peu impératifs. On va donc utiliser des rations faites de conserves classiques, variées et dans leur emballage d'origine. On confectionnera des caissettes de vivres correspondant aux besoins (par exemple 3 ou 4 hommes/2 jours) et en prévoyant des menus variés. Il suffira d'ajouter un certain nombre de rations de survie légères pour aider en cas de survie (Tableau 2).

A pieds au contraire (comme c'était le cas il y a quelques années dans toutes les expéditions polaires et comme c'est parfois encore le cas) il faut tenir le plus grand cas des paramètres poids et volume. D'où, nécessité d'aliments concentrés si possible liquéfiables. En premier lieu se pose la question du Pemmican. Cet aliment préparé à partir de viande, de graisses et de farines et présenté sous une forme sèche et compacte possède de gros avantages; il se dilue aisément et permet l'obtention d'une soupe épaisse, vite préparée et sans nécessité de cuisson; il se conserve remarquablement bien; enfin, son goût plaît à beaucoup d'individus en particulier à tous ceux qui aiment peu les mets sucrés. On peut lui adjoindre de nombreux produits tels la poudre de pomme de terre, les pâtes et les flocons d'avoine. Le pemmican est actuellement discrédité dans certains pays; on lui reproche son goût et surtout son pourcentage élevé en protides. Cependant, si le reste de la ration apporte les éléments nécessaires et si le pemmican n'est pas donné en trop grandes quantités, nous pensons qu'il reste un aliment très intéressant dans les rations en climat froid.

Nous donnons ci-dessous en documentation la composition de quelques types de pemmican:

Pemmican Bovril:

Humidité	10,7%
Protides	48,12%
Lipides	36,76%

Pemmican Beauvais (viande, riz, légumes et graisses):

Protides	25,6%
Lipides	45,2%
Glucides	11,8%

Pemmican Harris (Byrd 1939–41) (céréales, foie et viande de boeuf, légumes, huile):

Protides	27,2%
Lipides	41,6%
Glucides	20,4%

Pemmican Coman (Byrd 1939-41) (graisses, foie de boeuf, haricots, lait en poudre, pois, pommes de terre):

Protides	21,5%
Lipides	42%
Glucides	29,5%

Pemmican Mapleton (noix, cacahuètes, soja, oignons, céleri, etc.):

Protides	17,9%
Lipides	53%
Glucides	14,2%

Nous pensons qu'il est nécessaire que les rations soient conditionnées à l'avance et une fois pour toutes. Si l'on adopte le modèle «deux hommes un jour», par exemple, il est inutile d'y revenir par la suite en ouvrant, complétant ou modifiant les rations choisies. Tous les produits nécessaires doivent se trouver à l'avance dans un paquet conditionné avant le départ de l'expédition. L'emballage sera du reste

Tableau 3. Ration de raid à pieds — traîneaux à chiens en Terre Adélie

Aliments	Poids	Protides	Lipides	Glucides	Calories	Vitamines						
						C	B1	B2	PP	Pro A	A	D
	g	g	g	g	g	mg	mg	mg	mg	mg	mg	mg
Pemmican	150	60	60	15	840							
Biscuits secs	200	22	18	144	820	—	0,20	0,16	1,2	—	—	—
Beurre	100	0,8	84	0,5	761	+	+	+	+	1	1,3	0,003
Sucre de canne	100	0	0	100	400	—	—	—	—	—	—	—
Poudre de lait	80	20	22,4	29,6	400	6	0,24	0,8	1,2	+	+	0,0008
Poudre de pomme terre	100	8	0	85	372	10	0,12	0,10	2,5	+	—	—
Chocolat	50	3,5	12	32	250	—	0,015	—	—	—	—	0,001
Fruits secs	100	2	0,6	73	300	—	0,06	—	—	0,1	—	—
Confiture compacte	100	0,5	0,1	85	350	var	+	+	+	+	—	—
Ovomaltine	100	15	10	60	400							
	1080	131,8	207,1	624,1	4893							

Rapport calories poids = 4,53

Café ou thé en poudre
Boissons parfumées (citron, orange . . .)
Eléments vitaminiques et minéraux

fait en profitant des progrès et acquisitions de la technique moderne du conditionnement.

Il est possible de donner une certaine variété aux rations en les composant avec des aliments différents mais ayant les mêmes propriétés et en créant différents modèles de rations, toutes étant calquées sur le même type. Ceci n'impliquera par la suite aucune perturbation dans la distribution, mais permettra de satisfaire des goûts différents.

Il existe une autre manière d'envisager les rations de raids. Elle consiste à choisir quelques produits simples, par exemple: lait, biscuits, flocons d'avoine, sucre et à emporter un sac de chaque produit. Ce système simple présente deux inconvénients: d'une part, le risque de perdre l'un des produits dans sa totalité; d'autre part, la difficulté d'apprécier la quantité à utiliser chaque jour afin de garder suffisamment de réserves pour toute la durée du déplacement.

C'est pourquoi nous précisons la ration complète d'un seul type, conditionnée à l'avance et présentant une gamme de variétés (Tableau 3).

Certaines variantes peuvent être apportées dans cette ration:

— pâtes, farines de céréales, flocons d'avoine ou riz précuit à la place de pommes de terre;

— lard à la place de beurre;

— utilisation de toutes les variétés de fruits secs ou de fruits oléagineux;

— signalons que, si la viande fumée peut être employée dans les rations car elle reste agréable à consommer et se conserve bien, il n'en est pas de même pour le fromage qui est inutilisable au froid.

(4) Alimentation en Survie

Dans le cas de la survie, les données théoriques concernant une alimentation rationnelle et équilibrée ne nous préoccupent pas. Seul compte l'apport calorique qui permettra au sujet d'attendre les secours ou de rejoindre une zone de sécurité. Nous savons que l'élément de base en matière de survie est le facteur psychologique. Celui qui ne veut pas mourir, qui veut «en sortir» a cent fois plus de ressources possibles que celui dont le tonus psychique ne tient pas. On connaît dans ce domaine des exemples caractéristiques qu'il n'y a pas lieu de rapporter ici, mais qui sont suffisamment éloquents pour montrer les possibilités physiologiques d'un homme dont le moral «tient».

Nous concevions jadis aux Expéditions Polaires Françaises des rations de survie assez fortes.

Par exemple:	Pemmican	250 g
	Flocons d'avoine	100 g
	Poudre de lait	100 g
	Sucre	100 g
	soit	550 g pour 2.700 kcal.

La tendance actuelle est plutôt de concevoir des unités de 1.000 cal.

Par exemple:	Pemmican	100
	Aliment de survie «Mont-Blanc»	100
	Sucre	50

fournies en nombre déterminé suivant le cas et utilisable soit à raison d'une par jour si attente sur place sans effort, soit 2 par jour si déplacement.

Dans tous les cas, il est évidemment nécessaire de prévoir un combustible permettant la fabrication d'eau à partir de la glace.

BIBLIOGRAPHIE

Balke, B., Cremer H., Kramer K. et Reichel H. (1944) *Klin. Wschr.* **23,** 204–210.

Burton, A. C. and Edholm, O. G. (1955) *Man in a Cold Environment*, Edward Arnold London.

Committee on calorie requirements (1950) Calorie Requirements. Food and Agriculture Organization of the United Nations, FAO Nutritional Studies No. 5, Rome.

Drury, H. F., Hall, M., Glisczinski, R. and Spence, J. (1956) Nutritional Survey at Anaktuvuk Pass, Arctic Aeromedical Lab. Fort Wainwright, Alaska. Technical Note 57–17.

Glickman, N., Keeton, R. W., Mitchell, H. H. and Fahnestock, M. K. (1946) *Am. J. Physiol.* **146,** 538–558.

Gray, E., Consolazio, F. C. and Kark, R. M. (1951) *J. appl. Physiol* **4,** 270–275.

Hildmann E., Praktische Kältefragen. Gebirgssanitätsschule St. Johann, 23 et 24 September 1943.

Hoygaard, A., (1941) Studies on the Nutrition and Physio-Pathology of Eskimos. Det Norske Videnskaps-Akademis Skrifter, Mat.-Naturvid. Kmasse no. 9.

Hoygaard, A., and Mehren, M. (1931). Ajungilak eller Groenland pa tvers. Gyldendal, Oslo.

Johnson, R. E. and Kark, R. M. (1946a) Feeding Problems in Man as Related to Environment. Quartermaster Food and Container Institute, Chicago.

Johnson, R. E. and Kark, R. M. (1946b) An analysis of US and Canadian rations trials and surveys. Harward Fatigue Laboratory, Chicago, 74.

Johnson, R. E. and Kark, R. M., (1947) *Science* **105,** 378–379.

Johnson, R. E., Crowley, L. V., Toth, F., Koehn, C. J., Monahan, E. P., Lalanne, G. C., Parrott, E. M., Krzywicki, H. J. and Mancilla, A. (1949) Nutrition Surveys on Troops, Alaska, Winter 1948–1949, Medical Nutrition Laboratory, Report No. 59.

Keys A. (1947) *Nutr. Rev.* **5,** 129–131.

Milan, F. A. and Rodahl, K. (1961) *J. Nutr.* **75,** 152–156.

Mitchell, H. H. and Edman, M. (1951) Nutrition and Climatic Stress. Charles C. Thomas, Springfield, Illinois.

Mitchell, H. H., Glickman. N., Lambert, E. H. Keeton, R. W. and Fahnestock M. K. (1946) *Am. J. Physiol.* **146,** 84–96.

Rivolier, J. (1955) *Ann. Nutr.* Al. 3 1–43.

Rivolier, J. (1956) *Bull. Soc. Sci. Hyg.* **Al.** 7–8–9: 1–15.

Rivolier J. (1960) *Bull. Soc. Sci. Hyg.* **Al.** 1–2–3: 11–23.

Rodahl, K. (1949) A Dietary Survey Among Norwegian Trappers in Northeast Greenland. Norsk Polarinstitutts Skrifter, no. 91.

RODAHL, K. (1952) *J. Nutr.* **48**, 359–368.

RODAHL, K. (1958) *Human Acclimatization to Cold.* Trans. Fifth Conference on Cold Injury, Josiah Macy, Jr. Foundation, New York.

RODAHL, K. (1960) Nutritional Requirements Under Arctic Conditions. Norsk Polarinstitutts Skrifter No. 118, Oslo.

SCHOLANDER, P. F., WALTERS, V., HOCK, R. and IRVING, L. (1950) *Biol. Bull.* **99**, 225–236.

STEFANSSON, (1918) *J. Am. Med. Ass.* **71**, 1715.

SWAIN, H. L., TOTH, F. M. Q, CONSOLAZIO, F. C., FITZPATRICK, W. H., ALLEN, D. I. and KOEHN, C. J. (1949) *J. Nutr.* **38**, 63–72.

MÉCANISMES CENTRAUX ET RÉFLEXES DE LA THERMORÉGULATION AU FROID

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Abstract – It can be assumed that cold exposure lowers the threshold of excitability to temperature. This assumption is supported by some observations: change of the cerebral temperature threshold to release shivering depends on the mean skin temperature; shivering that follows lowering of the central temperature leads to an increase or maintenance of the surface temperature. A change of the heat balance is caused by the intake of water, or by the action of vasodilators. Direct application of cold to the hypothalamic region releases cold defence reactions. The central thermodetector can be suppressed either by coagulation or by means of drugs while the nervous reflex mechanisms persist.

Zusammenfassung – Man kann annehmen, dass in der Kälte die Erregungsschwelle für zentrale Reaktionen tiefer liegt. Dies wird durch Beobachtungen gestützt: Die Verschiebung der Temperaturschwelle im Gehirn für die Auslösung von Zittern ist abhängig von der mittleren Hauttemperatur; Zitternauslösung bei der Senkung der Zentraltemperatur führt zu einer Erhöhung oder Erhaltung der Oberflächentemperaturen. Diese Änderung des Wärmegleichgewichts erfolgt entweder durch Aufnahme von kaltem Wasser oder gefässerweiternden Mitteln. Auch die direkte Kälteeinwirkung im Bereich des Hypothalamus löst die Kälteabwehrmechanismen aus. Der zentrale Thermodetektor kann durch Medikamente oder Koagulation ausgeschaltet werden, während die nervösen Reflexmechanismen erhalten bleiben.

Résumé – On peut imaginer que l'exposition au froid abaisse le seuil des réactions d'origine centrale. L'autonomie de celle-ci est mise en évidence grâce à une série d'arguments : décalage du seuil des températures cérébrales où le frisson thermique se déclenche en fonction de la température cutanée moyenne, apparition d'un frisson lors d'un abaissement de la température centrale accompagnée d'une élévation ou d'un maintien des températures superficielles, déséquilibre réalisé soit par ingestion d'eau froide, soit par action de vasodilatateurs. La stimulation froide portée directement et localisée dans la région hypothalamique provoque des réactions de lutte contre le froid. Enfin il est possible de supprimer électivement soit par coagulation soit par action pharmacodynamique le thermodétecteur central, tout en laissant persister les mécanismes nerveux réflexes.

La caractéristique principale de l'homéothermie est l'adaptation permanente de la production de chaleur propre à l'animal aux pertes variables en fonction de la température ambiante.

Le système nerveux est responsable de cette adaptation qui trouve son effet le plus spectaculaire dans la lutte contre le froid. Chez le Chien, la lutte contre le

froid se manifeste principalement par l'apparition du frisson thermique : fonctionnement particulier du muscle avec faible rendement et fort dégagement de chaleur.

En suivant le schéma admis pour les réactions de lutte contre le chaud, on peut imaginer deux mécanismes possibles dans le déclenchement des réactions de l'animal exposé au froid.

(a) L'abaissement de la température externe sollicite les thermorécepteurs périphériques et ceux-ci sont à l'origine de l'apparition du frisson ainsi déclenché par voie réflexe.

(b) L'abaissement de la température interne, notamment de la température du sang, peut mettre en jeu directement des formations centrales commandant l'activité musculaire spécifique.

Jusqu'à ces dernières années, la plupart des auteurs modernes défendaient une *conception uniciste*, faisant de la réaction réflexe le seul mode de mise en jeu des moyens de lutte contre le froid. Hensel (1952) s'appuie notamment sur un certain nombre d'arguments d'observations et de faits expérimentaux.

La réaction de l'animal ou du sujet exposé au froid aboutit toujours à une élévation de sa température centrale (Jurgensen 1868, Frederico, 1882 ; Lefevre, 1898; Koenig, 1943; Metz, 1948; Horvath *et al.* 1956; Hardy, 1958).

Les tentatives d'abaissement de la température interne par ingestion d'eau glacée (Pinson and Adolph 1942 ; Carlson 1954) ne permettent pas de constater d'augmentation de la production de chaleur. L'élimination de la sensibilité périphérique chez le malade paraplégique (Franke et Gessler, 1925) ou par immersion dans un bain riche en CO_2 (Liljestrand et Magnus 1922; Golwitzer-Meier, 1937) semble supprimer les réactions de lutte contre le froid malgré un abaissement de 1° C de la température rectale.

Après refroidissement sous anesthésie, l'immersion de l'animal hypothermique dans un bain chaud supprime immédiatement le frisson (Kramer et Reichel, 1944; Penrod, 1949).

Tout ceci met en évidence l'importance de l'intégrité des récepteurs superficiels, mais de plus les expériences de refroidissement du sang circulant notamment au niveau de la circulation cérébrale (Brendel, 1960; Semenov *et al.* 1960) ou les expériences de refroidissement direct de l'hypothalamus par sonde (Strom, 1950; Kruger, *et al.* 1959; Freeman et Davis, 1959) aboutissaient à des résultats décevants et permettaient de nier toute sensibilité centrale au froid. On pouvait alors présenter le déclenchement des réactions de lutte contre le froid de la façon suivante (Hensel, 1952).

Seule la régulation réflexe déclenche les réactions thermogénétiques, la régulation d'origine centrale ayant uniquement un effet inhibiteur sur la thermogénèse de réchauffement et n'intervenant que lorsque la température centrale s'élève. Selon cette interprétation, la thermorégulation contre le froid provient d'un équilibre entre deux stimulations opposées : périphérique au froid pour déclencher la réaction,

interne au chaud, pour la limiter. L'animal placé en ambiance froide réagit par mise en jeu des récepteurs cutanés (réaction «réflexe»); de ce fait il élève sa température centrale, ce qui entraîne l'arrêt du frisson (régulation centrale). Si l'exposition au froid se prolonge, survient une baisse secondaire de la température centrale qui libère les réactions thermogénétiques et le cycle recommence.

Cependant, les multiples expériences sur lesquelles se fonde cette conception sont passibles d'un certain nombre de critiques, soit que l'évolution des températures centrales ait été jugée par l'enregistrement des températures rectales et non des températures cérébrales, soit que ces expériences aient été effectuées chez l'animal anesthésié qu'on ne peut considérer comme normal en ce qui concerne les réactions thermorégulatrices.

Une théorie similaire est toutefois développée par Benzinger. (1962). Elle est basée sur des expériences effectuées chez l'homme par calorimétrie et détection des températures craniennes.

Si la conception d'une régulation au froid par voie réflexe est indiscutable, bien des auteurs depuis la fin du siècle dernier signalaient de plus la *possibilité d'un mode de déclenchement «central»* (Richet 1893; Magne, 1920).

En effet du point de vue théorique, la constance de la température centrale étant le résultat de l'adaptation de la thermogénèse à l'intensité de la déperdition, on comprend mal comment une information contingente et complexe comme la sensibilité thermique périphérique serait capable de renseigner l'organisme sur la quantité de chaleur perdue effectivement et sur la production nécessaire à une régulation aussi bien adaptée.

La première idée qui vient à l'esprit est d'observer le comportement d'animaux éveillés, chez lesquels on peut abaisser la température centrale sans solliciter au passage les récepteurs thermiques superficiels. Sherrington, en 1924, plaçait l'arrière-train d'animaux dont la moelle avait été sectionnée en D1, dans l'eau glacée et observait du frisson dans la partie du corps non paralysée lorsque la température centrale s'était suffisamment abaissée. Pour répondre aux critiques faites à ces expériences, nous avons repris (Chatonnet et Tanche, 1956 a, b) le même protocole chez le chien éveillé, en prenant soin de maintenir les portions du corps ayant conservé leur innervation, à l'abri du refroidissement par un chauffage superficiel approprié et en enregistrant les températures cérébrales.

De cette façon le déclenchement du frisson ne peut être que le fait d'un abaissement de la température du sang, sans aucune sollicitation des récepteurs thermiques superficiels.

Inversement, sur cette préparation, il est facile d'obtenir une stimulation uniquement réflexe en réchauffant le train postérieur insensible afin de maintenir la température cérébrale au niveau habituel pendant que les récepteurs de la sensibilité thermique du train antérieur encore innervé, sont sollicités par application de glace.

Ce protocole expérimental nous a permis de confirmer les résultats de Sherrington, c'est-à-dire l'existence de deux modes de déclenchement de l'activité de frisson:

mode réflexe et mode «central». Dans ce dernier cas, le frisson apparaît dès la baisse de la température cérébrale alors que la température cutanée est maintenue très élevée.

Une autre technique d'abaissement électif de la température centrale peut également être utilisée: il s'agit d'un refroidissement appliqué non plus à la périphérie, mais au niveau des régions profondes de l'organisme. Carlson (1954) expose des hommes à des températures basses immédiatement après leur avoir fait ingérer de l'eau glacée et il mesure le temps nécessaire à l'apparition du frisson, en le comparant avec celui de sujets témoins. Le temps d'apparition du frisson est nettement raccourci chez les sujets ayant bu de l'eau glacée. Dans le même esprit (Chatonnet et Tanche, 1951) nous avons pratiqué des expériences similaires chez le chien, en provoquant l'abaissement de la température centrale par ingestion d'eau glacée, mais en maintenant les températures cutanées à des valeurs nettement supérieures à celles qui entraînent l'apparition du frisson. Dans ces conditions, dès la chute de la température cérébrale, on observe un frisson continu et généralisé à toute la musculature, réaction qui disparaît progressivement au fur et à mesure de la remontée de la température.

Rautenberg, Simon et Thauer (1963) récemment, pratiquent un refroidissement interne oesophagien chez le chien très légèrement anesthésié et observent l'influence des températures profondes et superficielles sur la consommation d'oxygène. Ils démontrent l'existence du stimulus central et affirment l'existence de structures sensibles au froid dans les parties profondes du corps.

Ainsi le simple abaissement de la température centrale est capable de déclencher des réactions thermogénétiques.

Le point de départ de ces réactions doit cependant être localisé. On est naturellement conduit à rechercher l'origine du stimulus au niveau des formations nerveuses commandant la réponse thermogénétique.

Si la plupart des expérimentateurs (Strom, 1950; Brendel, 1960) n'ont pu obtenir de résultat par perfusion cérébrale avec du sang refroidi, expérimentation choquante et nécessitant l'anesthésie, d'autres auteurs ont recherché l'existence de ces formations nerveuses par des expériences de stimulation électrique locale des centres nerveux. Seuls Anderson (1951) et Akert et Kesselring (1951), par cette méthode non spécifique ont pu mettre en évidence des réaction thermogénétiques par excitation du plancher du troisième ventricule.

Nous avons alors entrepris (Chatonnet, Tanche et Cabanac, 1960) un certain nombre d'expériences consistant dans un premier temps à implanter aseptiquement (par la méthode stéréotaxique) une thermode dans le crâne des animaux. Cette thermode est une sonde à détente gazeuse produisant un refroidissement localisé dans les structures nerveuses voisines du lieu d'implantation. Dans un deuxième temps, après réveil de l'animal et les jours suivants, nous pouvons refroidir de façon transitoire des régions bien déterminées de l'encéphale. On fait plusieurs séries d'épreuves de refroidissement de courte durée alternant avec des réchauffements spontanés ou provoqués.

Dans ces conditions, nous avons noté une corrélation très étroite entre l'évolution des températures cérébrales et l'activité électrique des muscles. Cette dernière présente un renforcement lors de l'abaissement de la température cérébrale bien que les températures superficielles restent constantes. Les meilleurs résultats obtenus correspondent aux cas où la pointe de la thermode était localisée dans la région moyenne de l'hypothalamus. Il suffit d'une faible variation de la température au voisinage de la sonde pour déclencher les réponses, mais les résultats ne nous permettent pas encore de juger de la nature du stimulus thermique adéquat (variation de température ou seuil).

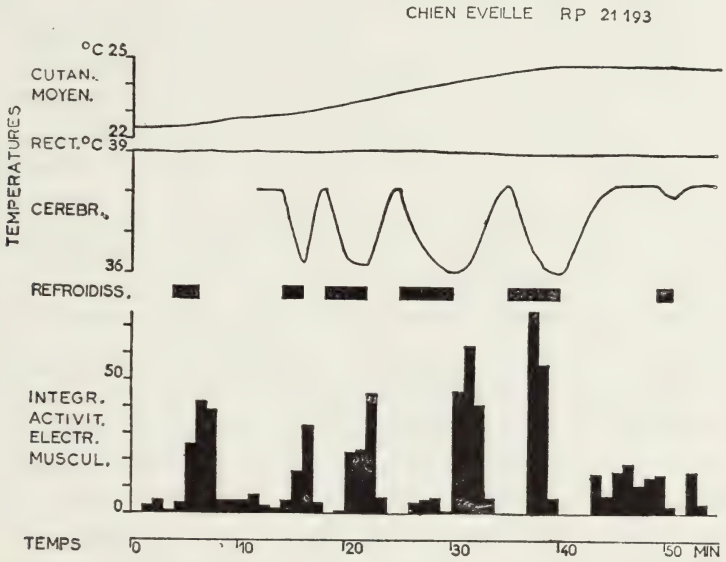

Fig. 1. Exemples de réponses à des stimulations répétées pour des températures cutanées constantes ou même s'élevant

Quoiqu'il en soit, le refroidissement local de certaines structures encéphaliques est capable de déclencher des réactions thermogénétiques du type frisson.

A la même époque d'ailleurs, Hammel, Hardy et Fusco (1960) ont obtenu exactement les mêmes résultats par une méthode similaire.

Toutes ces observations ont ainsi mis en évidence l'existence de structures encéphaliques responsables d'une régulation thermique d'origine centrale. Cependant, la régulation d'origine périphérique est indiscutable. Une question se pose alors: les centres nerveux commandant les réactions thermogénétiques, dans l'un et l'autre cas, sont-ils les mêmes?

Pour répondre à cette question (Tanche, Chatonnet et Cabanac, 1960) nous avons pratiqué sur un premier lot d'animaux des sections du tronc cérébral à différents niveaux. Les animaux sont ensuite suivis pendant tout le temps de leur survie.

Un certain nombre de sections dans la région méso-diencéphalique font apparaître un trouble que différentes épreuves permettent de caractériser. En ambiance chaude, ces animaux présentent une température centrale instable; par contre, en

ambiance froide, ils manifestent des réactions de frisson amenant en général une élévation thermique. On peut interpréter ces faits comme l'indice de l'absence chez ces animaux, de réactions d'origine centrale (absence de régulation en ambiance à la température de neutralité thermique), alors que les réactions prenant leur origine dans les thermo-récepteurs superficiels sont encore capables de se produire (remontée de la température centrale en ambiance froide, consécutive à l'apparition du frisson).

Si l'on fait ingérer de l'eau glacée aux animaux préparés de cette manière tout en les maintenant en ambiance thermique élevée, on observe un abaissement intense et prolongé de leur température centrale sans aucune réaction de calorification ni aucune remontée de température comme on l'observerait chez l'animal normal.

Les mesures de métabolismes effectuées avant et après la lésion et rapportées à différents paramètres tels que: température superficielle moyenne ou différence entre température superficielle et température ambiante (déperdition), indiquent qu'après l'intervention, la calorification n'est plus adaptée à la déperdition, mais seulement à l'intensité de la stimulation superficielle.

Ainsi, par des lésions appropriées du tronc cérébral, il est possible de dissocier chez le chien les deux modes de régulation.

Un nouvel argument en faveur de cette possibilité de dissociation nous a été apporté par l'observation du déclenchement des réactions thermorégulatrices chez le chien nouveau-né (Tanche et al, 1961). Différents tests nous ont permis de montrer qu'il existe un décalage dans l'apparition des réactions d'origine périphérique et celles d'origine centrale au cours du développement post-natal chez le Chien.

Pour essayer de localiser les formations nerveuses responsables de la régulation « centrale », nous avons effectué (Tanche, Chatonnet et Cabanac, 1962) sur un deuxième lot d'animaux, des coagulations très limitées de formations diencéphaliques. Les électrodes sont introduites par la méthode stéréotaxique adaptée à l'encéphale du Chien après mise au point d'un système de repérage utilisant la radiographie du crâne. De cette manière il nous a été possible d'obtenir les mêmes résultats que lors des expériences précédentes. Le trouble mis ainsi en évidence peut ne pas apparaître à une observation grossière ne tenant compte que de l'évolution des températures lors des épreuves de froid. Il s'agit d'un trouble plus qualitatif que quantitatif et seule une analyse assez fine permet de le déceler. Ce trouble résulte de l'exclusion d'une formation topographiquement distincte de l'appareil nerveux assurant les réponses réflexes. Cette formation serait située au niveau de l'hypothalamus.

En résumé on peut mettre en évidence, chez le chien normal et éveillé, des réactions thermogénétiques résultant directement de l'abaissement de la température centrale et de façon plus précise, de la température cérébrale.

Le thermodétecteur central ainsi caractérisé est distinct des formations nerveuses assurant les réponses aux stimulations froides périphériques.

Thauer cependant, pose le problème de la signification physiologique d'une sensibilité centrale puisque toutes les expériences précédentes inversent le gradient de

température à l'intérieur du corps, et ne reproduisent pas la répartition des températures chez un homéotherme exposé au froid, c'est-à-dire les conditions physioloques.

Mais même dans les conditions respectant un gradient normal, plusieurs observations parlent en faveur d'un contrôle central.

Cannon et al. (1929) avaient déjà constaté que les animaux sympathectomisés frissonnaient davantage au froid. Chez ces animaux les récepteurs superficiels sont à une température supérieure à la normale donc moins sollicités. S'il n'existait pas de sensibilité interne le frisson devrait être atténué. De même, Cannon et Keatinge (1960) étudiant le comportement des sujets gras et maigres dans l'eau froide, montre que les sujets maigres qui ont une déperdition thermique plus importante, augmentent plus leur métabolisme que les sujets gras, pour une stimulation périphérique équivalente; de plus, dans ce même type d'expériences, une augmentation plus importante du métabolisme est notée quand la température rectale baisse (Keatinge 1960).

Dans des conditions respectant le sens normal du gradient thermique, on peut réaliser un décalage des températures superficielles par divers moyens et tenter ainsi de réduire l'information d'origine périphérique. Nous avons ainsi considéré le comportement du chien à moelle épinière détruite chez lequel le contrôle vasomoteur est supprimé, en comparant ce comportement à celui de l'animal normal (Chatonnet et Tanche, 1957 a, b). La mesure des échanges respiratoires lors de l'exposition au froid nous a montré que la thermogénèse est plus élevée chez le même animal après mutilation nerveuse, pour une même température extérieure. Il faut remarquer de plus que la stimulation périphérique est réduite dans ce cas à un territoire restreint du fait de l'anesthésie de la majeure partie de la surface cutanée.

A l'aide de moyens pharmacodynamiques, nous avons en outre réalisé (Chatonnet et Tanche, 1956 c) chez le chien normal des expériences de même type en créant une vasodilatation superficielle par un vasodilatateur puissant: la Tolazoline. Après injection intra-veineuse de ce produit, l'animal étant maintenu en ambiance chaude, on constate une baisse rapide de la température cérébrale en même temps qu'apparaît un frisson intense qui ne cesse que lorsque la température cérébrale est revenue à son niveau initial. La déperdition accrue par vasodilatation crée une baisse de la température cérébrale; cette baisse est capable de mettre en jeu les réactions thermogénétiques sans que les récepteurs thermiques superficiels soient sollicités.

Ces résultats nous amènent à admettre que la thermogénèse s'adapte directement à la déperdition, celle-ci étant conditionnée par la différence entre la température superficielle et la température ambiante ($T_S - T_A$) et non par la valeur de la température superficielle moyenne (T_S), ce qui devrait être le cas dans une régulation de type purement «réflexe». Si le comportement de l'animal à moelle épinière détruite semble en accord avec cette conception, nous avons recherché chez l'animal normal l'évolution de la calorification en fonction de ces deux paramétres

(T_S-T_A) et T_S et la corrélation qu'elle pouvait présenter avec eux. On s'aperçoit alors que la corrélation existe entre la calorification et la déperdition alors qu'elle n'existe pas entre la calorification et la température superficielle moyenne. (Fig. 2) Il est difficile de concevoir cette soumission de la régulation à la déperdition autrement que par l'intermédiaire d'une sensibilité centrale. Un argument supplémen-

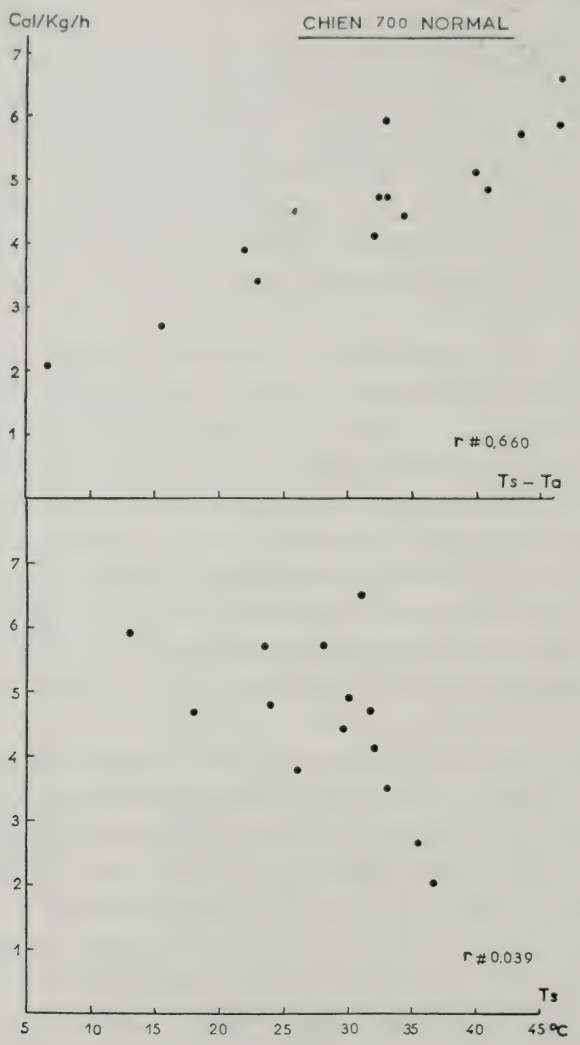

FIG. 2. Dans la partie supérieure, la corrélation entre la calorification et un facteur lié à la déperdition.
En dessous, absence de corrélation entre la calorification et la température superficielle moyenne

taire avait été apporté en 1946 par Burton qui constatait des réactions thermogénétiques sans aucune sensation de froid, chez des pilotes revêtus de combinaisons chauffantes en ambiance thermique froide, et ceci, dès que leur température centrale s'abaissait.

Enfin l'existence d'un contrôle de type «central» explique certains cas particuliers. Si on impose un apport calorifique (sous forme de travail musculaire) à un animal exposé au froid, la quantité de chaleur produite en supplément s'intègre dans la production normale de lutte contre le froid, alors que la stimulation froide n'a pas varié (Tanche et Chatonnet 1958) (Fig. 3).

De même chez le rat acclimaté au chaud, Hart (1958) observe une substitution de la thermogénèse de travail à celle de réchauffement due au frisson.

Il reste un dernier problème à résoudre, c'est celui de l'enchaînement normal des réactions de l'animal ou du sujet exposé au froid: dans ces conditions, on sait que

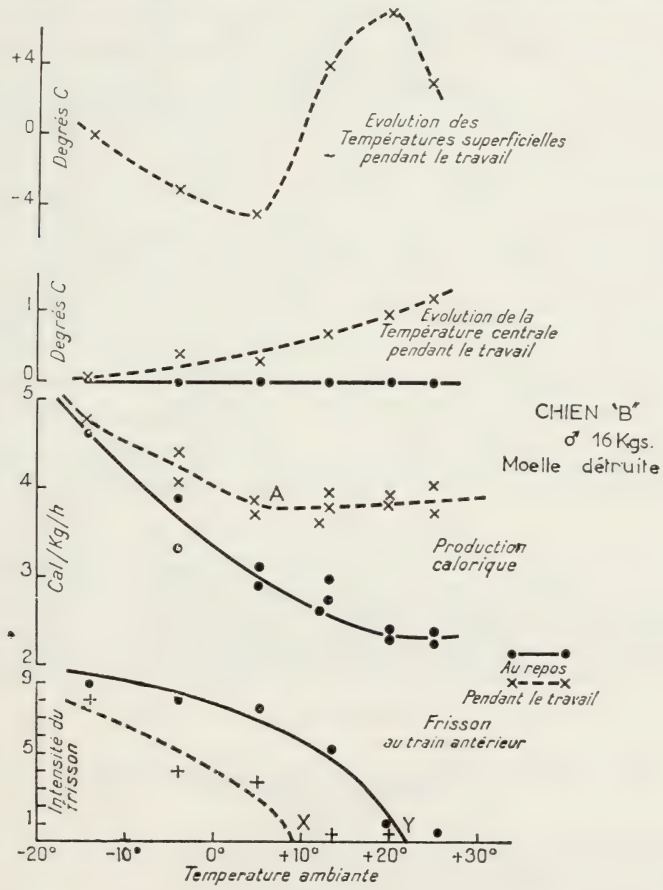

Fig. 3. La production calorifique due au travail musculaire s'ajoute à la dépense basale mais s'intègre dans la thermogénèse de lutte contre le froid en se substituant aux réactions de frisson dont le seuil d'apparition est décalé de telle sorte que la température centrale au froid reste à sa valeur normale. (Tanche et Chatonnet, 1958)

la température centrale s'élève, réaction interprétée d'ordinaire comme résultant de la régulation réflexe et excluant toute mise en jeu centrale des réactions thermogénétiques. Quelle serait alors la signification d'une sensibilité centrale qui resterait ainsi à l'abri de toute sollicitation?

Si les sensibilités superficielles et centrales sont capables de déclencher indépendamment des réactions thermogénétiques comme nous venons de le voir, on peut penser qu'elles sont liées l'une à l'autre et s'influencent respectivement. Nous avons cherché à établir le rôle respectif des températures superficielles et cérébrales dans leur capacité à mettre en jeu la thermorégulation. Chez le Chien, nous avons fait varier les températures interne et superficielle l'une par rapport à l'autre en prenant pour indice de mise en jeu, l'apparition du frisson jugé par l'inspection ou l'enregistrement électrique. On groupe les résultats sur un graphique en portant en ordonnée les températures cérébrales et en abcisse la température superficielle moyenne. Si la température cutanée moyenne est seule en cause, la courbe seuil d'apparition du frisson doit être une droite perpendiculaire à l'axe des températures cutanées. De même, si seule la température centrale est responsable des réactions, la courbe seuil doit être une droite perpendiculaire à l'axe des températures cérébrales.

Or, au cours de nos expériences, nous avons obtenu une courbe d'allure hyperbolique indiquant qu'il existe des interrelations indiscutables entre sensibilités centrale et périphérique et que le frisson apparaît même si les températures varient en sens inverse. Il n'existe pas un seuil propre à chaque modalité de stimulation, mais un seuil commun reliant ces deux variables selon une fonction complexe.

Si l'on se réfère chez l'animal normal exposé au froid à la courbe seuil d'apparition des réactions de frisson, on voit que l'abaissement rapide des températures superficielles déplace le seuil des réactions «centrales» vers un niveau de température plus élevé et les réactions ainsi déclenchées se poursuivront tant que ce seuil n'est pas atteint.

Suivant cette conception, les deux modalités centrale et superficielle de déclenchement des réactions thermogénétiques conjuguent leurs effets même dans cette réaction élémentaire; que l'une de ces deux modalités vienne à disparaître, on constatera un déficit thermorégulateur dans des circonstances définies.

BIBLIOGRAPHIE

AKERT, K., et KESSELRING, F. (1951) *Helv. physiol pharmacol. Acta* **9,** 290–295.
ANDERSON, A. (1957) *Acta Physiol. scand,* **41,** 90–100.
BENZINGER, TH. (1962) *Proc. Intern. Union Physiol. Sc. Leiden,* Vol 1 Part 1 415–438.
BRENDEL, W. (1960) *Pflüger's Arch. ges. Physiol,* **270,** 607, 628, 648.
BURTON, A. C. (1946) *Fed. Proc.* **5,** 344.
CANNON, P., and KEATINGE, W. R. (1960) *J. Physiol. (Lond.)* **154,** 329–344.
CANNON, W. B., NEWTON, H. P., BRIGHT, E. M., MENKIN, V. and MOORE, R. M. (1929) *Am. J. Physiol.* **89,** 84–107.
CARLSON, L. D. (1954) *Proc. Soc. exp. Biol. (N. Y.)* **85,** 303.
CHATONNET, J., et TANCHE, M. (1956a) *J. Physiol. (Paris)* **48,** 439–442.
CHATONNET, J. and TANCHE, M. (1956b) *Symposium über Temperatur-Regulation* Bad Nauheim.
CHATONNET, J. et TANCHE, M. (1956c) *C. R. Soc. Biol. (Paris)* **150,** 1558–1560.
CHATONNET, J. et TANCHE, M. (1957a) *C. R. Soc. Biol. (Paris)* **151,** 1533–1535.

Chatonnet, J. et Tanche, M. (1957b) *J. Physiol.* (Paris,) **49,** 89–91.
Chatonnet, J., Tanche, M., et Cabanac, M. (1960) *J. Physiol. (Paris).* **52,** 48–49.
Franke, C. and Gessler, H. (1925) *Pflügers Arch. ges. Physiol.* **207,** 376–389.
Fredericq, L. (1882) *Arch. Biol.* **3,** 687.
Freemen, W. J. and Davis, D. D. (1959) *Am. J. Physiol.* **197,** 145–148.
Gollwitzer-Meier, K. (1937) *Klin. Wschr.* **16,** 1418–1421.
Hammel, H. T., Hardy, J. D. and Fusco, M. M. (1960) *Am. J. Physiol.* **198,** 481–486.
Hardy, J. D. (1947) *Fed. Proc.* **6,** 122.
Hart, J. S. (1958) *Cold Injury.* Josiah Macy Foundation. New. York. p. 271.
Hensel (1952) *Ergebn. Physiol.* **47,** 166–368.
Horvath, S. M., Spurr, G. B., Hutt, B. K. and Hamilton, L. H. (1956) *J. appl. Physiol.* **8,** 595.
Jurgensen, Th. (1868) *Dtsch. Arch. Klin. Med.* **4,** 110.
Keatinge, W. R. (1960) *J. Physiol. (Lond.)* **153,** 46 P.
Koenig, F. H. (1943) *Pflügers Arch. ges. Physiol.* **246,** 693–708.
Kramer, K. and Reichel, H. (1944) *Klin. Wschr.* **23,** 192.
Kruger, F. J., Kundt, H. W., Hensel, H. and Brück, K. (1959) *Pflügers Arch. ges. Physis.* **269,** 240–247.
Lefevre, J. (1898) *Arch. Physiol.* **30,** 1.
Liljestrand, G. and Magnus, R. (1922) *Pflügers Arch. ges. Physiol.* **193,** 527–554.
Magne, H. (1919–20) *J. Physiol. Gen.* **18,** 527.
Metz, B. (1949) Thèse Médecine Strasbourg.
Penrod, K. E. (1949) *Am. J. Physiol.* **157,** 436–444.
Pinson, E. A. and Adolph, E. F. (1962) *Am. J. Physiol.* **136,** 105–114.
Rautenberg, W., Simon, E. and Thauer, R. (1963) *Pflügers Arch. ges. Physiol.* **277,** 214–230.
Richet, Ch. (1893) *Arch. Physiol.* **5,** 312.
Semenov, N. V., Chetverikova, G. A., Konstantinova, T. I. (1960) *Bjull. Eksper Biol. Med. S. S. S. R.* **49,** 35.
Sherrington, C. S. (1924) *J. Physiol. (Lond.)* **58,** 405–424.
Ström, G. (1950) *Acta physiol. scand.* **21,** 271–277.
Tanche, M. et Chatonnet, J. (1958) *J. Physiol. (Paris.)* **50,** 534–537.
Tanche, M., Chatonnet, J. et Cabanac, M. (1960) *C. R. Soc. Biol. (Paris)* **154,** 2305–2307.
Tanche, M., Chatonnet, J. et Cabanac, M. (1962) *Proc. Inter. Union Physiol. Sc. Leiden,* no. 484.
Tanche, M., Chatonnet, J., Cabanac, M. et Elkaim, P. (1961) *C. R. Soc. Biol. (Paris)* **155,** 1669–1672.
Thauer, R. (1959–61) *Physiol. Abteilung Kerckhoff Institut (Dtsch.)* **IV** p. 95.

PHYSIOLOGICAL ACCLIMATIZATION DURING THE FOURTH JAPANESE ANTARCTIC EXPEDITION (1959–1961)

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Abstract – Physiological investigations were made on members of the Fourth Japanese Antarctic Expedition (1959–61). The following results were obtained: (a) body weight of the members increased during the winter (May to August); (b) blood pressure was slightly lower in the winter as compared with the values in Tokyo or on the ship; (c) oral temperature was slightly lower in persons adapted to cold indoor living; (d) decrease in the number of neutrophil polymorphs in the blood occurred during the winter; (e) 17-ketosteroid excretion in the urine was higher in winter than in autumn (March); (f) diurnal fluctuations of the number of eosinophils in the blood, and 17-ketosteroids, sodium and potassium in the urine of the wintering persons showed similar patterns as in Tokyo, although irregular fluctuations were found in non-wintering men.

Zusammenfassung – Physiologische Untersuchungen an den Mitgliedern der 4. japanischen Antarktis-Expedition 1959–61 ergaben folgende Ergebnisse: (a) Das Körpergewicht stieg während des antarktischen Winters von Mai bis August maximal an; (b) der Blutdruck war etwas niedriger als in Tokyo oder auf dem Schiff; (c) die Mundtemperatur war bei akklimatisierten Personen etwas niedriger als in Tokyo; (d) die neutrophilen Leukozyten im Blut verminderten sich während des Winters; (e) die 17-Ketosteroid-Ausscheidung war im Winter höher als im Herbst; (f) die Tagesperiodik der eosinophilen Zellen im Blut und der 17-KS, Natrium-und Kalium-Ausscheidung im Harn war bei den Personen, die in der Antarktis überwinterten, wie in Tokyo, dagegen war die Periodik gestört bei Personen die nicht überwinterten.

Résumé – Une étude physiologique des sujets qui ont hiverné de la IVe Recherche-Expédition Antarctique Japonaise a été faite. (a) Le poids a augmenté pendant l'hiver. (b) La pression artérielle a été un peu plus basse qu'à bord du Soya ou à Tokyo. (c) Il semble que la température du corps (orale) soit un peu descendue quand les sujets se sont adaptés à la vie de l'intérieur de la base polaire (température basse des pièces). (d) Le nombre des éosinocytes polymorphes circulatoires a diminué pendant l'hiver. (e) La quantité de l'excrétion urinaire de 17-CS était plus élevée en hiver (septembre) qu'en automne (mars) dans la zone antarctique. (f) La fluctuation diurne du pourcentage des éosinocytes circulatoires, de 17-CS urinaire et de sodium et potassium urinaires des hivernants antarctiques a montré une ligne courbe analogue à celle observée à Tokyo, tandis que la courbe de ceux qui n'ont pas passé l'hiver en zone antarctique montre une fluctuation irrégulière.

THE Japanese Antarctic Research Expedition Program started in November 1956, in conjunction with the International Geophysical Year Program. At that time, Japan had no experience of Antarctic expeditions except for one party, led by Lieutenant N. Shirase, 1910–1912, and there was no information about life in

Antarctica. The Medical Branch of the Japanese National Antarctic Committee was formed to discuss medical problems in the Antarctica and to select members for the expedition by strict physical and mental examinations. This Medical Branch suggested that two physiological research programs should be carried out in the Antarctic: (1) studies on acclimatization to the cold environment, and (2) observations on 24-hr rhythms of the body. The Japanese Antarctic Expedition, however, had no authorized medical and physiological research in the program, and the number of wintering members was so limited that no physiologist to examine these problems could be included. The only doctor in the wintering party had to care for the physical and mental health of the members and to improve the living conditions of the base and had little time for research. However, some physiological investigations were made by the doctor in spite of many difficulties.

MATERIALS AND METHODS

The Soya, the ship of the Japanese Antarctic expedition, left Tokyo on 30 November 1959. She called at Singapore and Cape Town on the way to the Antarctic, and arrived at the fast ice of Lützow-Holm Bay near the Japanese Antarctic Station Syowa Base at the beginning of January 1960. Fifteen men, aged 23 to 41 (average age 31), stayed at Syowa Base from January 1960 to January 1961. During this one year period body weight, blood pressure, body temperature (oral), blood cell counts, urinary 17-ketosteroid excretion, and sodium and potassium in the urine were determined periodically. The investigation of diurnal fluctuations of blood eosinophil counts, 17-ketosteroids, sodium and potassium in the urine were also performed on the Soya on 14 members of the Third Expedition, who had just spent a winter at the Syowa Base, and on another 9 men simultaneously.

Sodium and potassium were estimated by a flame photometer, and hydrochloric acid was added to the urine which was transported in cold storage for the 17-ketosteroid determination.

Syowa Base: Syowa Base is situated on the rock of East Ongul Island about 5 km from the continental coast (69°00′S latitude and 39°35′E longitude). The minimum air temperature observed at Syowa Base in 1960 was −40° C at the end of July. Average air temperature in 1960 was −11.9° C ranging in monthly mean temperature from −0.8° C in Jan. to −22.4° C in September. There were many windy days and the mean velocity of wind in 1960 was 5.9 m/s. Permanent buildings were set up of which the indoor temperature was maintained at about 10° C in the daytime using a warm air furnace.

Average food intake at the Base was approximately 3500 cal containing about 100 g protein, 50 g fat, and necessary quantities of minerals and vitamins per man per day. Water was obtained from different sources such as ice from icebergs, drifting snow, and puddles in sea ice. It was proved by chemical analysis that the water obtained from these sources was sufficiently pure for drinking and cooking.

PHYSIOLOGICAL ACCLIMATIZATION

Body Weight

All members in the base showed a gradual increase of body weight as a result of subcutaneous fat deposition for insulation against cold. The maximum body weight was seen in winter, and a temporary weight loss was noticed when a member went on a trip or did hard outdoor work.

Blood Pressure

The systolic blood pressure was slightly lower in the winter as compared with the value in Tokyo or on the Soya. It seemed that this lowering of blood pressure was due to the inactivity during the winter.

This finding was supported by studies of Dr. Ogata during the voyage of the First Expedition and by Dr. Muto during the winter of the Third Expedition. Their studies revealed that the basal metabolic rate varied with changes of air temperature during the voyage showing a resemblance to the seasonal variation in Japan, i.e. an increase in winter and a decrease in summer, but in the winter period at the base the basal metabolic rate was slightly lower than in summer.

It is likely that the inactive and monotonous life in the dark mid-winter season is the cause of the lower basal metabolic rate and blood pressure.

Body Temperature

By measuring the basal body temperature (oral) of the same five men from Nov. 1959 (Indian Ocean) to March 1960 (at Syowa Base), a slight decrease was seen when they had become adapted to cold indoor living.

Blood Cell Counts

There was a decrease in the number of circulating neutrophil polymorphs in the winter period, although erythrocyte counts did not change markedly at Syowa Base. In Japan a slight increase in the leucocyte count was found in the winter. The decrease in the number of neutrophil polymorphs in the Antarctic was probably due partly to the absence of pathogenic microorganisms.

Urinary Excretions of 17-ketosteroids and Electrolytes

In wintering members there was a greater excretion of sodium and potassium than in non-wintering men, and this increased excretion corresponded to the increase of the 24-hr urine.

The 17-ketosteroid excretion was higher in the winter (September) than in the autumn (March), similar to the seasonal variation in Japan.

The range of diurnal fluctuations in percentage of circulating eosinophils and 17-ketosteroids and electrolytes in the urine in the wintering members was less than that in non-wintering men. The diurnal fluctuations in the percentage of circulating eosinophils, urinary 17-ketosteroids, sodium and potassium in the wintering members showed a similar pattern to that in Tokyo, although irregular fluctuations were found in non-wintering men.

ESSAI DE RECHERCHE D'UN DÉTERMINISME DES COMPORTEMENTS HUMAINS DANS UN ENVIRONNEMENT AUSTRAL

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Au cours de travaux effectués pendant la campagne 1960–1962 à l'Ile de la Nouvelle-Amsterdam (Terres Australes et Antarctiques Françaises) nous avons montré qu'une corrélation stochastique relative existait entre la pression atmosphérique et la conductance électrique de la peau. Comme corollaire de ce concept il découle qu'il existe une corrélation négative entre l'émotivité et la pression atmosphérique: les dépressions atmosphériques déterminent une hypoémotivité jusqu'à un certain degré. Cette assertion est confirmée par une étude conjointe de l'excitabilité neuromusculaire. Nos conclusions sur le plan psychothérapique sont les suivantes: les médecins de Missions isolées dans des environnements d'exception au point de vue climatique doivent être avertis de l'influence dans certain cas de ce paramètre climatique sur l'émotivité des individus, principal déterminant des comportements au sein de leurs groupes, et envisager éventuellement de mettre en oeuvre une diététique de l'émotivité. D'une manière plus générale les hypothalamiques (indolents, psychasthéniques) pourraient heureusement bénéficier des cures en des lieux de haute pression atmosphérique habituelle (niveau de la mer), alors que les hyperthalamiques (hyperémotifs, dystoniques, hystériques) devraient bénéficier de cures de repos en moyenne altitude (2000 mètres).

RELATIONS ENTRE LA PHYSIOLOGIE DES ALGUES ET LES FACTEURS ATMOSPHÉRIQUES

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Abstract – The physiology of marine algae is influenced by atmospheric factors although these plants are aquatic. The different cycles observed in nature (seasonal, diurnal, lunar, solar) often show physiological variations with similar periodicities. The study of these cycles in subantarctic algae is important especially if they are to be used commercially.

Zusammenfassung – Die Physiologie der Algen ist von atmosphärischen Bedingungen abhängig, obwohl sie im Wasser wachsen. Die verschiedenen in der Natur vorkommenden Periodiken (Tag-Nacht, jahreszeitlich, lunar und solar) haben oft physiologische Veränderungen von ähnlicher Periodizität zur Folge. Das Studium dieser physiologischen Periodiken bei Algen der Subarktis ist besonders wichtig, wenn sie industriell verwendet werden.

Résumé – La physiologie des algues est conditionnée par les facteurs météorologiques d'une façon certaine, bien que ces plantes soient essentiellement aquatiques. Le métabolisme cellulaire en particulier est directement affecté par ces facteurs, et son étude en fonction des diverses périodes de l'année pour un même matériel, le met bien en évidence Par ailleurs, des observations ont montré qu'il pouvait y avoir un certain synchronisme entre les phénomènes ionosphériques et le développement de grandes algues brunes comme les Laminaires. Ces deux faits ne peuvent être ignorés dès qu'il s'agit de prévoir une exploitation de certaines grandes algues brunes sub-antarctiques comme les Durvilléa et Macrocystis.

Les caractéristiques physico-chimiques et dynamiques de la mer conditionnent la physiologie des végétaux marins qui y vivent. La température, la salinité, le pH, l'agitation de l'eau sont parmi les principaux facteurs influents, ainsi que la lumière (plus ou mois modifiée en qualité lors de son passage dans l'eau) qui détermine une répartition verticale des algues en fonction de leurs exigences *vis-à-vis* de l'intensité totale et des diverses radiations élémentaires.

Or, parmi ces facteurs, certains sont directement liés aux conditions atmosphériques (température, luminosité, agitation de la mer), et cette influence est particulièrement nette sur les algues benthiques de l'étage littoral soumises à une émersion de durée variable à chaque marée, au cours de laquelle ces végétaux doivent supporter la dessiccation active par le vent, l'ensoleillement, la désalure due aux pluies, les variations de température plus accusées que celles de la mer.

L'étagement vertical de la végétation marine sur les côtes à marées résulte en grande partie de ce facteur humectation, lui-même lié aux marées, donc à rythme lunaire. Les algues, en effet, se répartissent en fonction de leurs caractéristiques physiologiques (sténohalines, sténothermes, euryalines, eurythermes) et se disposent alors en ceintures parallèles au niveau de l'eau, matérialisant autant de niveaux différents d'humectation. Par conséquent, bien que vivant généralement dans la mer, les algues marines sont, en partie, sous la dépendance des facteurs atmosphériques.

Comme certains facteurs météorologiques, atmosphériques ou cosmiques, présentent des rythmes de périodicité variée, la comparaison entre ces rythmes connus et les manifestations vitales des algues est particulièrement profitable. L'étude des phénomènes biologiques rythmés est un des principaux thèmes de la recherche actuelle (Baillaud, 1958a, b) et de nombreux colloques font périodiquement le point. Il n'est donc pas question d'envisager le sujet dans son ensemble, mais seulement de montrer que des études importantes restent à faire pour les algues.

1. Le rythme le plus apparent est sans doute celui des saisons qui s'observe, en particulier, dans les périodes de reproduction de diverses espèces. Ce rythme saisonnier est en relation étroite avec les variations de température et d'éclairement, comme le montrent les récentes notions de photo et thermo-périodisme. La température et la lumière interviennent d'abord par leur intensité globale, déterminant une intensité maximale, minimale, optimale pour chaque espèce d'algue. En outre, le rythme de ces facteurs (alternance lumière/obscurité pour le photo-périodisme; température relativement haute/température relativement basse pour le thermo-périodisme) conditionne certaines phases du développement comme la floraison pour les Phanérogames. Pour les algues, quelques faits semblent s'y rapporter parmi lesquels nous rappellerons (Levring, 1957) *Ulothrix flacca* (petite Chlorophycée filamenteuse) dont les cultures fournissent en jour long des gamètes; le Zygote ne se développe pas dans ces conditions.

En jour court, des Zoospores sont libérées et germent immédiatement. Ceci peut expliquer la présence seulement au printemps de cette algue sous forme d'une ceinture bien marquée dans les eaux nordiques. En même temps qu'elles peuvent sans doute expliquer de façon semblable la présence saisonnière de certaines autres algues, ces études donneront peut-être la solution de certains cas de parthénogénèse géographique. Pour les algues antarctiques, en outre, le rythme lumière-obscurité est tout à fait remarquable avec la longue nuit au cours de laquelle certaines algues semblent, non seulement continuer à se développer, mais aussi devenir fertiles (comme c'est le cas de *Phyllogigas* sans doute, car Neushul (1963) n'a récolté qu'un exemplaire en été). Sous la neige et la glace de mer, la luminosité est très réduite; d'intéressants problèmes sont à analyser et ces notions doivent rester présentes à l'esprit mais l'expérimentation ne manque certes pas de difficultés.

Ce rythme annuel saisonnier se manifeste nettement aussi pour les principales substances cellulaires des algues, problèmes que Haug et Jensen (1954) ont bien

étudié par des dosages micro-chimiques réalisés au cours de l'année. Pour les Laminaires, par exemple, grandes algues brunes d'importance industrielle certaine, ils montrent qu'en Norvège « le pourcentage en acide alginique » (quantité d'acide alginique dans 100 g de matière sèche) est maximal de Mars à Juin et minimal de Septembre à Octobre. Par contre, le pourcentage en laminarine, substance de réserve (exprimé de la même façon en fonction de la matière sèche) présente une variation complémentaire de celle de l'acide alginique, avec un maximum de Septembre à Novembre, et une quasi absence de Février à Juin. Rappelons, avec les auteurs, que les périodes de valeurs maximales ne correspondent pas nécessairement au moment où les populations fournissent la plus grande quantité en valeur absolue de ces constituants car, d'une part, la matière sèche moyenne d'une algue varie suivant la saison et, d'autre part, le rapport matière sèche/poids frais également. La teneur moyenne par algue (exprimée en grammes d'acide alginique pour la matière sèche moyenne d'une algue) a un maximum en été et non au printemps comme le pourcentage maximal ci-dessus. En outre, il semble qu'en se référant au poids frais, la quantité d'acide alginique soit plus ou moins constante au cours de l'année, les variations apparentes étant dues à celles d'autres produits métaboliques (les protéines principalement). *Par conséquent, certains constituants cellulaires tout au moins varient avec les saisons.* Ces problèmes doivent être étudiés avant d'entreprendre toute exploitation industrielle d'algues marines; c'est dans ce but que des récoltes et observations méthodiques pour deux espèces *(Durvillea* et *Macrocystis)* ont été entreprises au cours de la dernière campagne à Kerguelen.* Moss et Naylor (1954) ont déjà montré pour *Durvillea willana* et *D. Antarctica* de Nouvelle-Zelande que des exemplaires récoltés le même jour et en un même lieu mettent en évidence des différences d'acide alginique, d'une part entre les différentes parties d'une même plante, et d'autre part entre des régions morphologiquement comparables à divers stades de développement.

2. Un deuxième rythme très fréquent chez les plantes supérieures *(rythme journalier)* mérite d'être recherché chez les algues. Le volume des noyaux, la fréquence de leurs divisions, la perméabilité cytoplasmique et de nombreux autres phénomènes physiologiques souvent intra-cellulaires comme la variation du pH cellulaire, seraient à périodicité diurne (Baillaud, 1958 a, b).

3. Le rythme lunaire a pu être détecté plus ou moins nettement à propos de la périodicité d'émission des gamètes chez certaines algues, comme la *dictyota dichotoma* ou *Halicystis parvula* (Feldmann, 1957). Pour cette dernière, des analyses sur plusieurs années ont montré que l'entrée en reproduction était conditionnée par la température (18 à 20° optimale), mais les facteurs réglant le rythme bi-mensuel d'émission qui est simultané pour tous les individus de provenance différente ne sont toujours pas connus (Abelard et Feldmann, 1958). Les émissions de gamètes

* Je tiens à exprimer mon amicale reconnaissance au Dr. Reneau qui a bien voulu se charger, en plus de son service médical, de la poursuite de ce travail, pendant toute la durée de l'hivernage.

pour *Halimeda* possèderaient aussi ce même cycle (Beth, 1962). S'il est particulièrement intéressant de retrouver ce rythme dans les organismes relativement simples, nos connaissances sont loin d'être précises quant à sa détermination. Rappelons enfin que les marées conditionnent, par l'intermédiaire du facteur humectation, la répartition verticale de la végétation dans l'étage médio-littoral.

4. Un rythme d'une période de onze ans a été mis en évidence par Walker, (1956) en étudiant les Laminaires des côtes d'Ecosse. En utilisant des photos aériennes stéréoscopiques, et compte tenu des autres données, obtenues par échantillonnages systématiques en de nombreux points, cet auteur a déterminé des changements dans la quantité de la végétation observant un maximum en 1947 et un minimum en 1953. En outre, des variations dans l'importance relative des trois espèces de Laminaires existent. Les chiffres exprimant le poids frais moyen de ces algues en kg par mètre carré sont dans un rapport voisin de 1 à 5 ($13{,}4 \times 0{,}54$ en 1947; $2{,}8 \times 0{,}54$ en 1953). De semblables études méritent d'être entreprises dans les eaux sub-antarctiques, où les *Macrocystis* parfaitement repérables sur photographie aérienne seraient un bon matériel. De plus, ces données ne manquent pas d'intérêt pour l'utilisation industrielle de ces algues et leur vérification est souhaitable. Outre la durée de la période, *la prédominance des composantes exogènes ou endogènes* est aussi un critère de classification des rythmes.* Sans envisager en détail le problème de leur déterminisme, disons seulement que, pour certains d'entre eux, le mécanisme régulateur d'ordre intra-cellulaire pourrait être dû aux *variations périodiques de la structure des colloïdes* (Bunning, 1958).

De nombreuses recherches algologiques restent à réaliser, pour lesquelles les stations sub-antarctiques et antarctiques réunissent souvent d'excellentes conditions. En effet, ces lieux non encore perturbés par les activités humaines, possèdent en outre, généralement, des enregistrements de nombreux facteurs atmosphèriques. La comparaison entre les variations du plus grand nombre possible d'entre eux et les manifestations physiologiques des algues serait sans doute révélatrice, mais nécessite certes l'installation de laboratoires bien adaptés à ce travail. Ces études peuvent, avec profit, être menées simultanément avec celles de la physiologie humaine ou toute autre expérience parallèle, telle que l'analyse de réactions de solutions colloïdales réalisée à Kerguelen en 1961 (Pruche). Nous ne pouvons que souhaiter la mise au point d'un programme général et organisé de physiologie pour ces régions.

BIBLIOGRAPHIE

Abelard, C. et Feldmann, J. (1958) Influence de la température sur la formation des gamètes d'Halicystis parvula Schmitz. *Soc. Phys. France Bull.* **4**, 10–11.

Baillaud, L. (1958a) Introduction à la notion de rythme endogène. *Bull. Soc. Nist. Nat. Doubs* **18**, 16–23.

* D'aprés Baillaud (1958a), un rythme est exogène s'il se manifeste et se synchronise obligatoirement avec des conditions externes à fluctuations périodiques. Il est endogène s'il peut se manifester ou se maintenir dans des conditions externes uniformes . . .

Baillaud, L. (1958b) Rythmes endogènes et rythmes exogènes, notamment chez les végétaux. *Année biologique* **34,** 299–329.

Beth, K. (1962) Reproductive phases in populations of Halimeda in the Bay of Naples. *Publ. Staz. Zool. Napoli,* 32 supl. 515–534.

Bunning, E. (1958) Mécanisme physiologique et importance biologique de la périodicité diurne endogène. *Bull. Soc. Fr. Physiol. Végét.* **4,** 42–44.

Feldmann, J. (1957) La reproduction des algues marines dans ses rapports avec leur situation géographique. *Année Biol.* **33,** 49–56.

Haug, A. and Jensen, A. (1954) Seasonal variations in the chemical composition of Alaria esculenta, Laminaria saccharina, Laminaria hyperborea and Laminaria digitata from Northern Norway. *Rep. Norw. Inst. Seawed Res.,* **4,** 1–14.

Levring, T. (1957) Some modern aspects of growth and reproduction in marine algae in different regions. *Année Biol.* **33,** 57–65.

Moss, B. and Naylor, M. (1954) The chemical composition of the two New Zealand species of Durvillea. *Trans. roy. Soc. N. Zeal.* **81,** 473–478.

Neushul, M. (1963) Reproductive morphology of antarctic kelps. *Botanica marina* **5,** 19–24.

Pruche, Y. (1961) Aptitude au climat et régulation thermique. *T. A. A. F.* **17,** 4–20.

Walker, F. T. (1956) The Laminaria cycle. *Rev. Alg.* **2,** 179–181.

WATER BATH STUDIES OF MAMMALS FROM SEVERAL ECOLOGICAL AREAS*

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Abstract – Water bath (25° C) experiments on *C. lateralis C. spilosoma M. auratus* and *D. ordi* demonstrate differences in the capacities of these animals to tolerate a severe cold stress. The *lateralis* and *spilosoma* had a greater capacity for shivering. The *lateralis* had a greater ability to limit heat loss by peripheral vasoconstriction. The principal method of combating cold available to ordi and auratus was preferential cooling of peripheral tissues.

Zusammenfassung – *C. lateralis C. spilosoma M. auratus* und *D. ordi* zeigten unterschiedliche Kälteempfindlichkeiten im Wasserbadexperiment (25° C). *Lateralis* und *spilosoma* hatten grössere Kapazität für Muskelzittern. *Lateralis* verhinderte den Wärmeverlust am besten durch periphere Gefässverengung. Die Kälteabwehr in ordi und auratus beruhte hauptsächlich auf der schnelleren Abkühlung der äusseren Gewebe.

Résumé – *C. lateralis C. spilosoma M. auratus* et *D. ordi* démontrent différentes sensibilités au froid dans l'expérience à l'eau (25° C). *Lateralis* et *spilosoma* démontrent une plus grande capacité de frisson. *Lateralis* limitait la perte de chaleur par striction des vaisseaux sanguins peripheriques. La principale méthode de combattre le froid repose avant tout sur une possibilité plus rapide de rafraîchissement des tissus extérieurs.

BEHAVIOR patterns and insulative values of fur are recognized as being primary factors in determining tolerance of animals to thermal stress (Burton and Edholm, 1955; Irving and Krog, 1954; Prosser and Brown, 1961). Few studies have explored physiological differences which may be important in determining the transfer or conservation of body heat. Physiological capacity may be of great importance in determining the survival of a given species at extremes in the thermal environment, for instance: when the limits of protection by insulation and behavior have been surpassed, physiological capacity would determine survival. Regarding physiological capacity there is evidence of species differences in temperature regulation, zone of thermal neutrality, tolerance for hypothermia and cooling of peripheral tissues (Hannon and Viereck, 1955; Kayser, 1961; Prosser and Brown, 1961). Additional information is needed in these areas, particularly with respect to physiological capacity of animals from various ecological groups. The water bath is a

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useful tool for describing transfer and conservation of body heat in response to thermal stress because environmental factors, such as radiant heat, air velocity, fluctuating air temperature and humidity are not involved. (Wilber, 1957).

MATERIALS AND METHODS

The animals studied include three hibernators from different ecological areas and a non-hibernator. *Citellus spilosoma marginatus* inhabit warm regions (mean air temperature – summer, 24° C; winter, 3° C) at elevations of 1500 to 2000 m. *Citellus lateralis lateralis* inhabit cool regions (mean air temperature – summer, 13° C; winter, – 7° C) at elevations of 2600 to 4300 m. *Mesocrecitus auratus*, Asian ancestory, were purchased from a pet shop. The fourth species, *Dipodomys ordi*, are nocturnal non-hibernators and inhabit the same areas as spilosoma in New Mexico.

All animals had been in the laboratory for 1 to 12 months prior to the studies. Periodic body weight measurements to the nearest 0.5 g indicated they were in good health: mean body weight 231 g (7.01 S.E.) lateralis; 132 g (4.58 S.E.) spilosoma; 118 g (2.99 S.E.) auratus; 68 g (3.68 S.E.) ordi. The swim chamber ($33 \times 33 \times 25.5$ cm) was constructed from 1.2 cm lucite. A rubber gasket fitted to a groove on the top edge of the chamber insured an airtight seal when the lid was fastened to the chamber with adjustable vise grip clamps. One side of the chamber was fitted with a drain outlet, while the lid was fitted with four outlets for temperature probes and an oxygen source. A wire-mesh bag attached to the underside of the lid filled with soda lime provided absorption of carbon dioxide. A heating element of 110 v, 300 w resistance wire in a coiled aluminum tube was inserted through the drain outlet. Cooling was effected by immersion of the swim chamber in a 100 l water tank which provided constant temperatures $\pm 0.4°$ C. Metabolic rate determinations were made by measuring oxygen consumption with a spirometer sensitive to 0.6 cm^3. All rectal and water temperature measurements were made with thermistor probes.

Three series of water immersion experiments were conducted: (1) free swimming, (2) confined, and (3) dead animals for a total of 96 water bath experiments on 14 lateralis, 10 spilosoma, 8 ordi and 4 auratus. Repetitive exposure to cold water did not effect acclimatization as reported by Adolph and Richmond (1956). The protocol for the free swimming experiments of 30 min duration was as follows: weigh animals, measure rectal temperature, place in water at time zero, and at 10 min intervals the animals were removed from the water for 1 – 2 min for rectal temperature measurements. Metabolic rate measurements were made during the second 10 min swim period. The series on confined and dead animals involved placing the animals in a cone of one centimeter mesh wire and immersing to the head in water. Rectal temperature determinations of dead animals were made at two minute intervals for the first 10 min and at 5 min intervals for the last 20 min.

Short term experiments of 2, 4, 6, 8, and 10 min duration were conducted on swimming animals. In this series the animal was removed from the bath at the specified times: 2, 4, 6, 8, and 10 min, and rectal temperature was recorded. Three animals of each species were tested for each time interval and a given animal was subjected to no more than one swim per day.

Several assumptions have been made to facilitate interpretation of the data: (1) Heat loss from the head which was above the water in all experiments was negligible. (2) Heat loss from the respiratory tract was negligible. (3) The skin temperature was constant, and equal to the bath temperature; therefore, the insulation value of the fur was lost. (4) The specific heat of the tissues was 0.83. (5) A respiratory quotient of 0.90 was assumed. (6) Surface area (SA) calculations were made with the formula: $SA = Weight^{0.73}$. (7) Mean body temperature (MBT) was calculated as follows: $MBT = 0.8\ Tr + 0.1\ Ts$ (Burton, 1955). (8) The initial (IBH) and final body heat (FBH) values were determined by multiplying the MBT by the specific heat of tissues and body weight. (9) Body heat loss (BHL) was determined by the difference between IBH and FBH. (10) Total heat loss (THL) was equal to BHL plus metabolic heat (M).

RESULTS

The changes in rectal temperature while swimming describe 25° C water as a severe cold stress for all animals studied, 30° C as a moderate cold stress for *C. lateralis* and *C. spilosoma*, 33° C bath as a neutral temperature for *C. lateralis* and *C. spilosoma* but a moderate cold stress for *M. auratus* and *D. ordi*. The 36° C water bath represents a moderate heat stress for *C. lateralis* and *C. spilosoma*. (Figs. 1, 2, 3, 4).

The responses of the animals to severe cold , 25° C water, are of major interest. The greatest heat loss was during the first few minutes of the cold water exposure

Table 1. Mean Metabolic Rate of Animals in Waterbath (kcal/hr/m²)

Animal species	Free swimming animals			Confined animals
	25°C	30°C	33°C	25° C
C. lateralis	13.6	11.8	12.9	14.6
	*(2.65)	(2.28)	(0.74)	(3.38)
C. spilosoma	10.1	10.7	10.8	11.2
	(1.79)	(2.67)	(2.63)	(1.40)
M. auratus	12.2	10.9	11.2	4.03
	(0.89)	(1.23)	(0.73)	(0.67)
D. ordi	8.73	6.52	9.9	5.10
	(1.26)	(1.24)	(0.52)	(1.69)

* (One standard deviation)

(Figs. 1, 2, 3). The lateralis had least change in rectal temperature because of higher metabolic rates (Table 1). The experiments conducted for 2, 4, 6, 8 and 10 min intervals demonstrate that maximum rate of heat loss for all animals occurs during

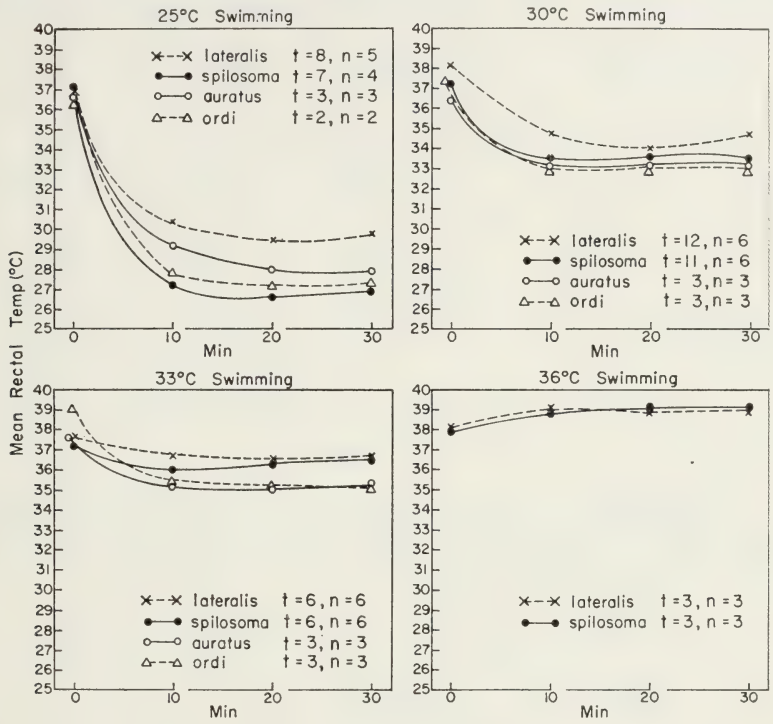

FIG. 1. Mean rectal temperature of animals swimming in water baths (t = number of swim trials; n = number of animals)

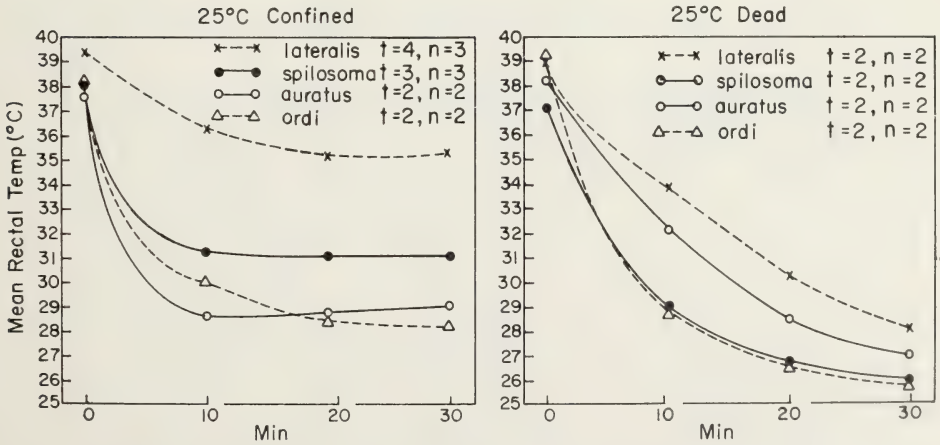

FIG. 2. Mean rectal temperature of confined living and dead animals after 10, 20 and 30 min immersion in water (t = number of trials; n = number of animals)

Table 2. Mean Total Heat Loss of Animals in 25° C Water 30 Min (kcal/hr/m²)

	Species			
	Lateralis	Spilosoma	Auratus	Ordi
Swimming	20.9 *(1.5)	19.2 (1.68)	19.5 (1.21)	15.1 (0.94)
Confined	18.8 (1.80)	16.7 (2.71)	11.4 (1.56)	12.1 (1.11)
Dead	11.3 (0.87)	9.32 (0.00)	9.41 (0.10)	9.1 (0.91)
Swimming minus dead	9.6	9.9	10.1	6.0
Confined minus dead	7.5	7.4	2.0	3.0

* (Standard deviation)

the first 2 min of the exposure. The difference between the dead and swimming animals demonstrates the facilitation of heat loss by the blood circulation at least during the first 4 to 5 min (Fig. 3, Table 2).

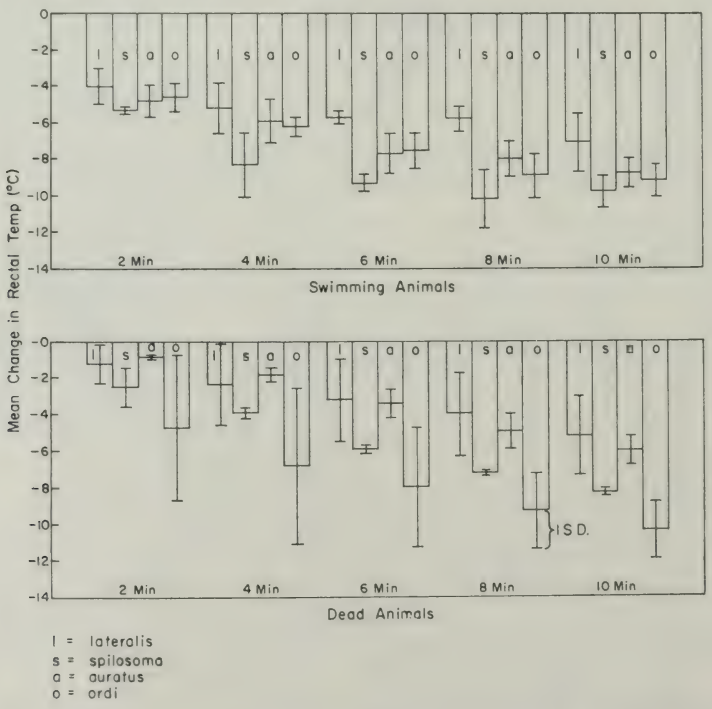

FIG. 3. Mean change in rectal temperature of swimming and dead animals after short term immersion in water (3 animals of each species at each time interval)

There was no visual evidence of shivering when the animals were swimming but shivering began within 1 min after the animals were removed from the water as evidenced by visual observation and handling of the animals. The capacity for shivering was an important factor in determining the extent of heat loss of the animals confined during immersion (Figs. 5, 6). When confined, the lateralis and

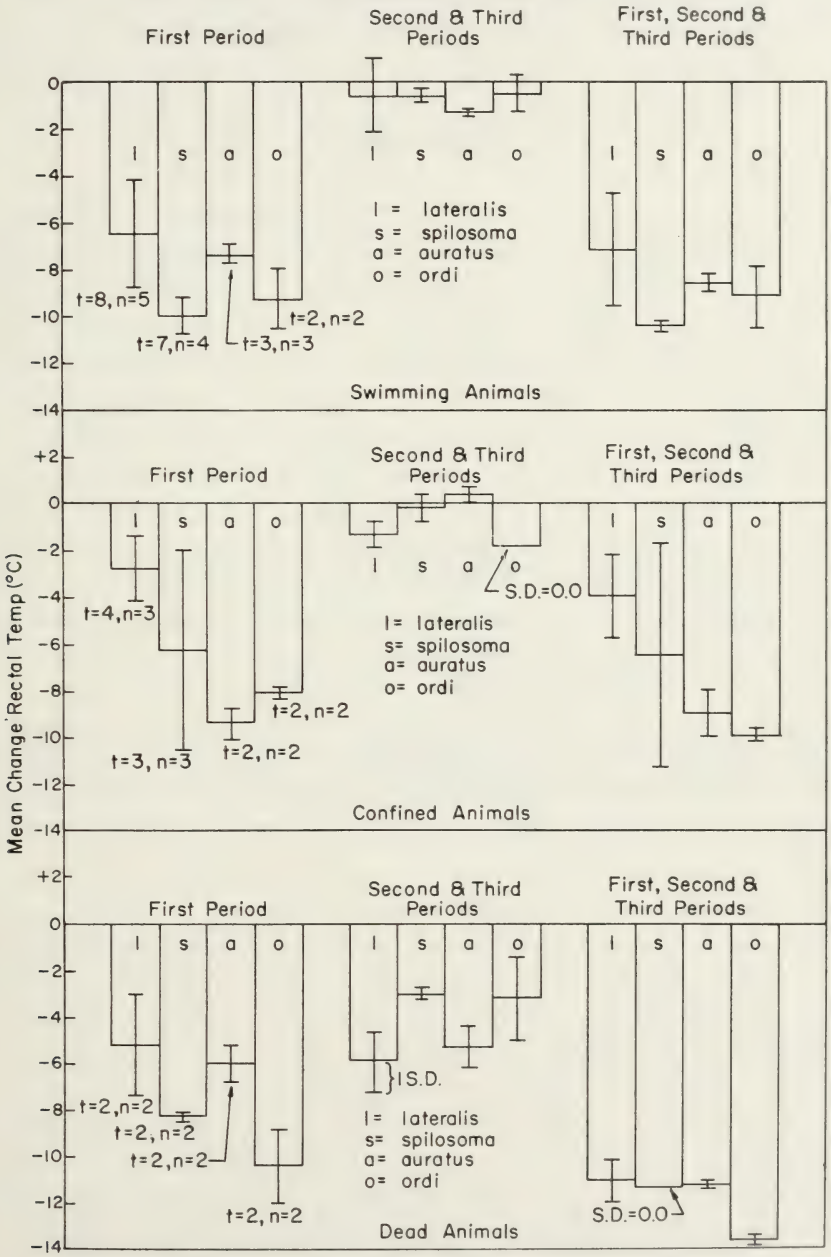

FIG. 4. Mean change in rectal temperature of animals during three swim periods of 10 minutes duration in 25° C water
(t = number of swim trials; n = number of animals)

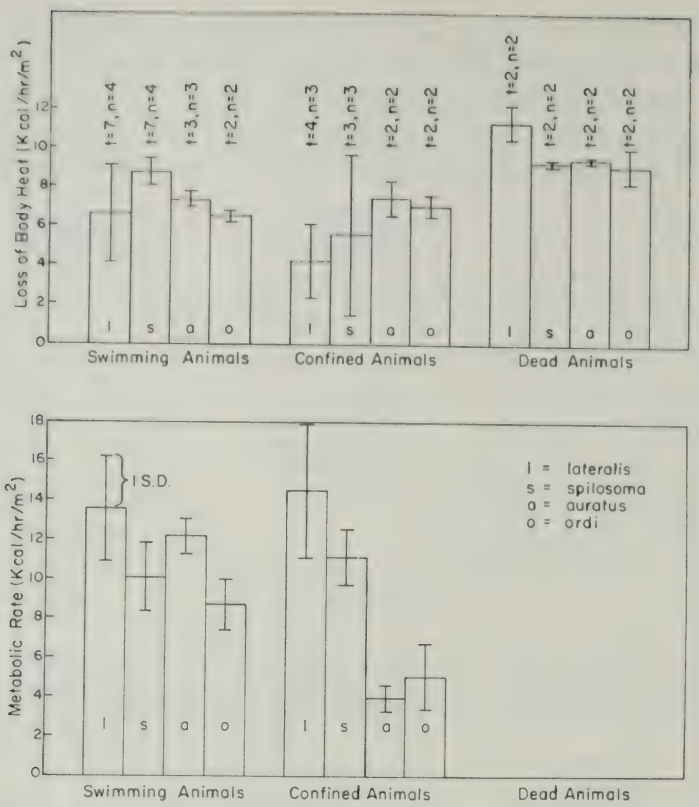

FIG. 5. Body heat loss and metabolic rate during 30 min immersion in 25° C water
(t = number of swim trials; n = number of animals)

spilosoma were able to maintain core temperature by a high metabolic rate but the auratus and ordi were unable to prevent lowering of rectal temperature, partic-

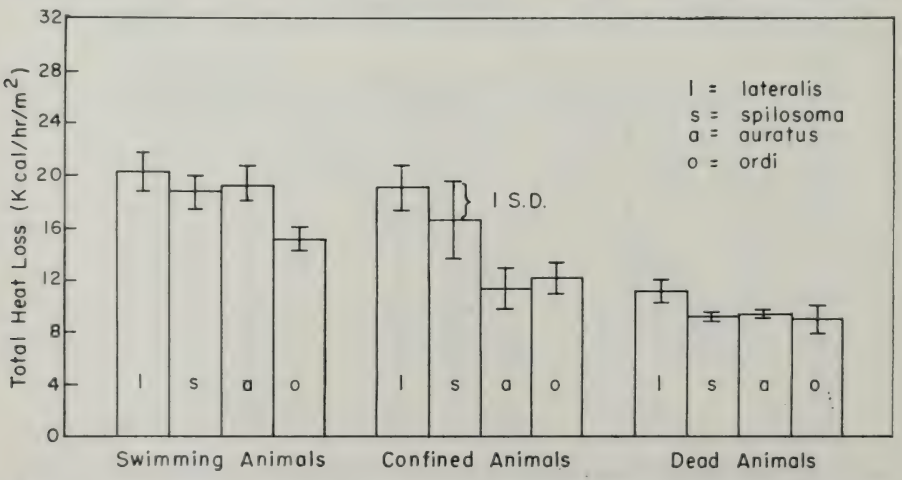

FIG. 6. Total heat loss of animals during 30 min immersion in 25° C water (kcal/hr/m²)

ularly during the first ten-minute-swim period (Fig. 4). The metabolic rates of the confined animals confirm the visual evidence of shivering by lateralis and spilosoma (Table 1). Shivering, an important mechanism for rewarming during arousal from hibernation, is apparently well developed in lateralis and spilosoma.

Two additional points to be noted are: (1) Differences in body weight did not effect differences in the heat loss of the dead animals over a 30-min period (Fig. 6, Table 2) (2) The live animals were in or near thermal balance during the last two swim periods (Fig. 4).

DISCUSSION

These water bath studies permit comparison of the capacity of animals to respond to thermal stress by shivering, increased gross activity and vasomotor activity. The curves in Figs. 1 and 2 are similar and asymptotic. The bath temperature, body mass and form, and initial body temperature appear to be major factors in determining the extent of the drop in body temperature which occurs within the first 2 min. The capacity of animals to increase metabolic rate under hypothermic conditions was important in determining the shape of the curve after the first few minutes. All animals had the highest activity during the first few minutes of submersion and became docile and easy to handle after 10 min in the water.

There are several points of interest regarding the heat loss of animals during 30-min immersion in 25° C water. The swimming lateralis, spilosoma, and auratus (Fig. 6) had very similar total heat loss (THL) ($p = 0.2-0.7$). When confined, the lateralis and spilosoma had much greater THL than auratus and ordi (Fig. 5) ($p = 0.01-0.05$) primarily because of a greater metabolic rate (Table 1, Fig. 5). The auratus and ordi have limited capacity for shivering when compared to lateralis and spilosoma. Hypothermia was undoubtedly an important factor in limiting the metabolic rate of free swimming and confined ordi. The THL of spilosoma and lateralis were similar when confined and when swimming (Fig. 6, Table 2); however, as a result of shivering, the confined animals had less lowering of rectal temperature during the first swim period (Fig. 4). Shivering was more effective than swimming in maintaining core temperature, presumably because the metabolic rate was higher when shivering (Horvath *et al.*, 1956). The capacity of auratus and ordi to resist lowering of body temperature when in 25° C water is limited, as evidenced by the similarity of the THL of confined and dead animals (Table 2).

The second and third periods of swimming and confined animals represent steady state conditions (Fig. 4). During this thermal balance, total heat loss (THL) is equal to M plus BHL and is the sum of heat conductance through tissues and heat transferred by the circulation of blood from the warmer core to the cooler periphery. The data collected on dead animals provides information regarding the rate of heat loss by tissue conductance. The thermal gradients within dead and live confined animals are undoubtedly different; however, by assuming that the conductance of heat through live and dead tissues is similar at a given rectal to water

bath temperature gradient, it is possible to estimate the amount of heat transferred by tissue conductance, and to estimate the amount of heat transferred by circulation of blood.

In Table 3 we have compared the rate of heat transfer of the swimming, confined, and dead animals. The rate of heat transfer per unit surface area for dead animals of each species, given in Table 3, was the rate which occurred over the mean tem-

Table 3. Mean Heat Loss of Animals in 25° C Water during Second and Third Periods (kcal/hr/m²)

	1 Total heat Loss swim.	2 Total heat loss confined	3 Heat loss dead animals		1 less 3a	2 less 3b
			a Swim.	b Confined		
Species and Range °C						
C. lateralis Swimming 33.0–28.0 Confined 37.5–32.3	14.5	19.7	8.5	14.9	6.0	4.8
C. spilosoma Swimming 28.5–26.0 Confined 33.8–29.3	10.8	11.4	3.8	17.8	7.0	–6.4
M. auratus Swimming 29.4–27.2 Confined 29.7–28.0	13.8	3.6	5.6	18.5	8.2	–14.9
D. ordi Swimming 28.7–26.6 Confined 30.2–27.9	9.1	6.9	4.9	10.3	4.2	–3.4

perature gradient (mean rectal less water bath temperature) existing during the steady state condition of the second and third swim periods. For instance, the rectal temperature of swimming lateralis during the second and third swim periods ranged from 28.0 to 33.0° C; therefore, the heat loss of the dead animals, 8.5 kcal/hr/m², in this temperature range is given in Table 3 and compared with the rate of THL of the swimming animals. The heat loss for all animals while swimming was greater than the heat loss of dead animals: lateralis, 40 per cent greater; spilosoma, 65 per cent; auratus, 60 per cent; and ordi, 46 per cent. These differences are related to the volume of blood flow to the skin. Blood flow accounted for 6.0 and 4.2 kcal/hr/m² heat loss in lateralis and ordi while blood flow was effective in losing 7.0 and 8.2 kcal/hr/m² in spilosoma and auratus.

When considering the THL of confined and dead animals over the same temperature gradient, it is of interest to note that blood flow accounted for 20 per cent

of the heat loss of the confined lateralis. The greater heat loss of dead animals as compared to confined animals of the spilosoma, auratus, and ordi species must be explained by differences in the thermal gradients of the dead and confined animals. In a dead animal the thermal gradient is nearly equal throughout the body, whereas in a live animal peripheral tissues cool to a lower temperature than in the dead animal. With a given BHL greater peripheral cooling means less heat is lost from the core, or in other words, there is heat loss from the periphery in preference to heat loss from the core. Estimation of the extent to which preferential cooling occurs in lateralis is not possible from the data available. That preferential peripheral cooling is very important is evidenced by heat loss of confined animals being 80 per cent, auratus, 34 per cent, spilosoma, and 33 per cent, ordi, less than heat loss of dead animals of the same species.

In summary, the major contribution of these water bath studies has been to point out physiological mechanisms which are operative in determining the tolerance of a given species to a given environmental stress. The *C. lateralis* and *C. spilosoma* responded to cold water primarily by increasing metabolic rate. The spilosoma were effective in limiting cooling of the core by cooling peripheral tissues. The *M. auratus* and *D. ordi* have limited capacity for shivering but confined auratus demonstrated conservation of body heat by peripheral cooling. It is dangerous at this time to say that any given physiological response is responsible for survival of a given species in a given environment. However, capacity for shivering and peripheral cooling are important physiological mechanisms in determining the capacity of animals to tolerate short term cold stress.

REFERENCES

Adolph, E. F. and Richmond, J. (1956) Adaptation to cold in golden hamster and ground squirrel measured chiefly by rates of body cooling. *J. appl. Physiol.* **9**, 53 – 58.

Burton, A. C. and Edholm, O. G. (1955) *Man in a Cold Environment.* Monographs of the Physiological Society, No. 2. Edward Arnold, London, p. 23.

Hannon, J. P. and Viereck, E. (ed.) (1955) Proceedings, Symposia on Arctic Biology and Medicine, II. Comparative Physiology of Temperature Regulation, Arctic Aeromedical Laboratory, Fort Wainwright, Alaska.

Horvath, S. M., Spurr, G. B., Hutt, B. K. and Hamilton, L. H. (1956) Metabolic cost of shivering. *J. appl. Physiol.* **8**, 595 – 602.

Irving, L. and Krog, J. (1954) Temperature of skin in the arctic as a regulator of heat. *J. appl. Physiol.* **7**, 355 – 364.

Kayser, C. (1961) *The Physiology of Natural Hibernation.* International series of monographs on pure and applied biology. Pergamon Press, London, p. 109.

Prosser, E. L. and Brown, F. A. (ed.) (1961) *Comparative Animal Physiology.* W. B. Saunders, Philadelphia, London.

Wilber, C. G. (1957) Influence of temperature on performance in guinea pigs. *Amer. J. Physiol.* **190**, 457 – 458.

LICHEN ECOLOGY AND MICROCLIMATE STUDIES AT CAPE HALLETT, ANTARCTICA*

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Abstract – Microclimate studies were made in the Antarctic, in the vicinity of Hallett Station (72°18′ S, 170°18′ E) where the vegetation consisted of 12.8 per cent green algae, 2.4 per cent mosses and 0.2 per cent lichens. Continuous measurements of the rock surface temperature, air temperature and R.H. 60 cm above the ground were recorded from November 1962 to January 1963. At times dark rock surface temperature increased to over 32° C while air temperature did not exceed 8° C. Temperature changes on lichen covered rocks frequently varied as much as 40° C over a 24-hr period. Relative humidity was very variable but in general was low and almost never exceeded the dew point. Moisture was available for plants in a short period following snow fall or in certain localities from melting of standing ice. A comparison of the climatic pattern of Hallett Station with that of Point Barrow, Alaska, shows much similarity yet there are no flowering plants.

Zusammenfassung – Das Mikroklima wurde in der Antarktis in der Nähe von Hallett Station (72°18′S, 170°18′ 0) mit einer Vegetationsdecke von 12,8% Grünalgen, 2,4% Moosen und 0,2% Flechten untersucht. Fortlaufende Messungen der Oberflächentemperaturen von Steinen, der Lufttemperatur und rel. Feuchte 60 cm über dem Boden wurden von November 1962 bis Januar 1963 vorgenommen. Die Oberflächentemperaturen von dunklen Steinen waren zeitweilig über 32° C, während die Lufttemperatur zur gleichen Zeit nicht über 8° C stieg. Mit Flechten bedeckte Steine wiesen häufig 40° C auf während 24 Stunden. Die R.F. schwankte sehr, war in der Regel niedrig und überschritt den Taupunkt fast niemals. Wasser stand den Pflanzen nur kurze Zeit nach einem Schneefall oder als Schmelzwasser von Eis zur Verfügung. Ein Vergleich des Klimas von Hallett Station mit dem von Point Barrow, Alaska, zeigt grosse Ähnlichkeit, dennoch fehlen in Hallett blühende Pflanzen.

Résumé – Des études microclimatiques furent effectuées dans une aire du Cape Hallett, Antarctic, dans le voisinage de Hallett Station (72°18′ S, 170°18′ E) où la couverture végétale consiste en 12.8 pour cent d'algues vertes, 2.4 pour cent, de mousses et 0.2 pour cent de lichens. Températures de la surface de la roche, température de l'air, et humidités relatives 60 cm au-dessus de la terre furent enregistrées de novembre 1962 à janvier 1963. Les températures de la surface de la roche sombre ont parfois excédé 32° C au milieu de l'été tandis que les températures de l'air n'excédèrent pas 8° C. Le changement de température sur les roches couvertes par du lichen a varié fréquemment jusqu'à 40° C

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pendant une période de 24 heures. L'humidité relative été très variable mais généralment basse et n'a presque jamais excédé le point de rosée. La moiteur été utile pour les plantes dans une période courte, suivant la tombée de la neige ou la fusion de la glace dans quelques localités. Une comparaison du type climatique de Hallett Station avec celle de Point Barrow, Alaska, indique une grande similitude mais les plantes fleurissant sont dans une position défavorable à Hallett.

ECOLOGICAL aspects of lichen and other vegetation have been under investigation for two austral summers at Cape Hallett, near Hallett Station, Antarctica, as part of a 3-year program. This research was supported by the U.S. Antarctic Research Program Office, National Science Foundation Grants G-19586 and G-23803. During the second season, automatic equipment was employed to continuously record microclimatic factors.

Hallett Station, a joint United States and New Zealand base, is located on the northern end of the west coast of the Ross Sea at 72° 18′ S lat., 170° 18′ E long. (Fig. 1). The study area, indicated by the black rectangle in Fig. 1, is on the more or less level rocky-gravel base of Cape Hallett, approximately 3.5 m above sea level in a South Polar skua nesting area near a large Adelie penguin rookery. This Cape, co-

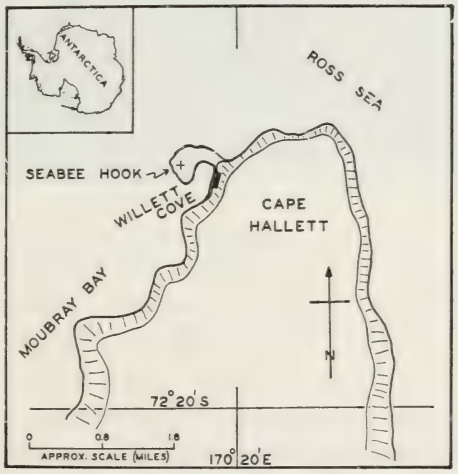


FIG. 1. Cape Hallett indicating study area (black rectangle), Hallett Station (X) is on Seabee Hook. Insert map: Antarctica with arrow locating Cape Hallett

vered for the most part by permanent highland ice, rises steeply from the gravel base to a height of about 300 meters and is the headland of Hallett Peninsula, the north-south oriented extension of the Admiralty Mountain Range. The study area is snowfree during late spring and summer except during periods of snowfall which occur approximately one day a week throughout the season. Rain has never been recorded at this station.

Hallett Station weather records have been kept to date since the beginning of operation in 1957, but only the IGY years have been published (Benes, 1959; U.S. Weather Bureau, 1962). The annual mean temperature for this 6-year period (per-

sonal communication, U.S. Weather Bureau, Polar Research Project) is −15.5° C, the highest recorded temperature is +8.3° C (January 1959) and the lowest is −45.8° C (August 1959). The annual mean equivalent precipitation is recorded as 19.7 cm of water but this is probably higher than that resulting from actual snowfall because of difficulties of excluding blown snow. The average wind velocity is 3.5 m/sec.

The microclimate equipment used was arranged in four approximate stations in an area where the vegetation cover consisted of 12.8 per cent green algae, 2.4

FIG. 2. View of two microclimate stations. The one in the foreground has the recorder cover opened. The humidity-sensing elements are in the white weather boxes, the thermocouple wires are attached to rocks between the recorders and the weather boxes

per cent mosses, and 0.2 per cent lichens. Each station included a fine (30 gage) thermocouple wire sensor attached with transparent cement directly to the surface of a lichen-bearing rock, a resistance relative humidity sensing element (Hydrodynamic, Inc.) and a mechanical thermograph; the latter two units were mounted in a weather station box 60 cm above ground level. At each station rock surface temperature and air relative humidity were continuously measured on dual channel Westronics strip recorders operating on generated power (Fig. 2). The air temperature was recorded by a clock-driven thermograph.

Microclimate information was obtained for a three-month period: November 1962 through January 1963. As was expected, rock surface temperatures had a greater amplitude of variation than did the 60 cm air temperatures. Dark rocks, at times during late summer, had surface temperatures exceeding 32° C, while at the same time the 60 cm air temperatures did not exceed 8° C, and the official station temperatures did not exceed 5° C. In Table 1, data of representative days are presented for comparison of these three temperature regimens. The recorded data

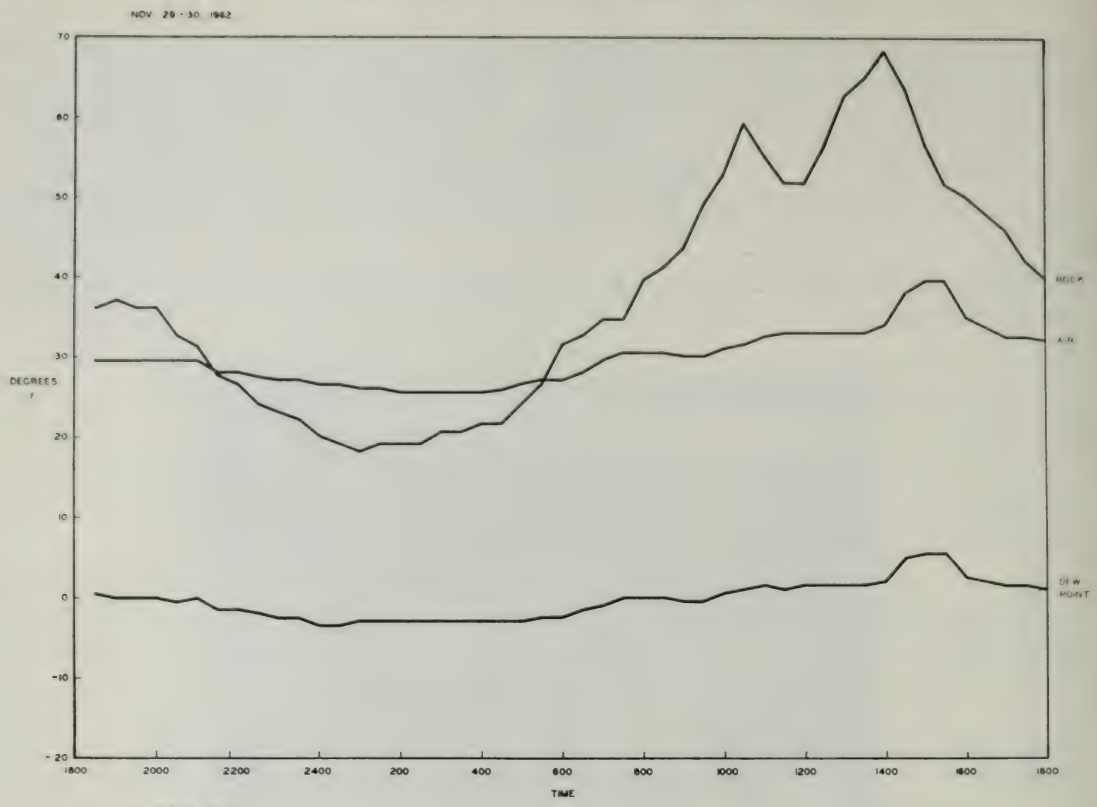
Table 1. Comparative Temperature in Degrees Celsius for Selected Days. All Cloudy with Mild Wind (up to 4 m/sec) except for 24–25 December when Winds Were as High as 15 m/sec

Date	Maximum			Minimum			Mean = $\frac{\text{Max}+\text{Min}}{2}$		
	Base air	Air	Rock	Base air	Air	Rock	Base air	Air	Rock
29–30 Nov. 1962 19:00–18:00 n Snow: Trace	+1	+4	+20	−6	−5	−8	−3	−1	+6
11–12 Dec. 1962 17:00–17:00 n Snow: None	+1	+3	+21	−8	−7	−3	−3	−2	+9
24–25 Dec. 1962 18:00–18:00 n Snow: 11.9 cm	−1	0	+2	−5	−6	−2	−3	−3	0
2–3 Jan. 1963 18:00–17:00 n Snow: None	+3	+5	+30	−6	−3	−2	−2	+1	+14
30–31 Jan. 1963 16:00–16:00 n Snow: None	0	+4	+12	−4	−6	−4	−2	+1	+ 4

Base air = Official base temperatures taken at 1.8 m above ground.
Air = From 4 stations 0.6 m above ground.
Rock = From 4 stations on dark rock surfaces, ground level.

for one of the four field stations on each of the five days (see Table 1), using half-hourly readings, are presented graphically in Figs. 3–7. Except for 24–25 December, during which period a severe blizzard was occurring, the other days were normal cloudy days. It is noteworthy that the amplitude of change of temperatures during a 24-hr period was always greater for the rock surfaces than for the air. It is also noteworthy that during most of the season, the rock surface temperatures were usually lower than the air temperatures in the mid-nighttime hours when the sun was behind the surrounding mountains. During the few mid-January weeks the rock surface temperatures were consistently higher than air temperatures at all hours, indicating residual ground heat. While Benes (1960) does not have data for sub-surface "soil" temperatures in January, his December data show considerable heating at the 10 cm level and Pryor (1962) presents data showing high temperatures of the "soil" surface for two days in December. Temperature changes on lichen-covered rocks frequently varied as much as 40° C in a 24-hour period. Starting at the end of December, the ground was warm enough for water to accumulate locally as a result of melt and run-off snow on the Cape or fallen snow in the study area.

The measured relative humidities were quite low, usually less than 20 per cent at mid-day and less than 50 per cent at mid-night. Only rarely was the dew point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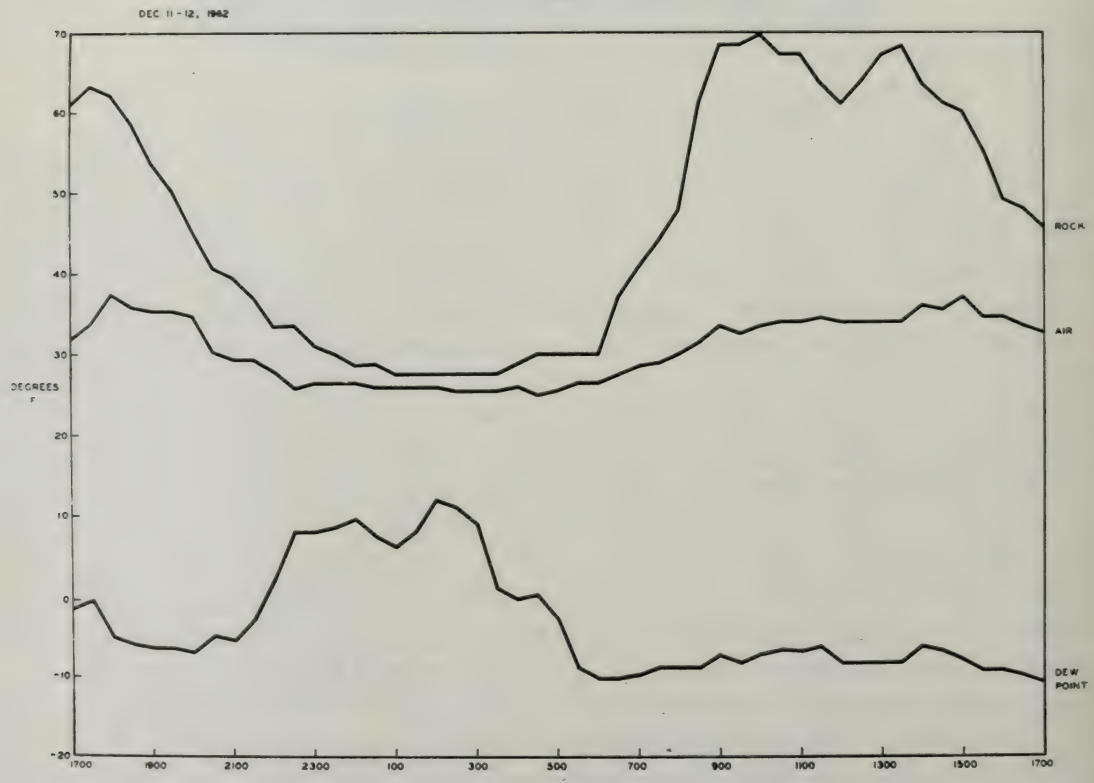
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DEGREES F
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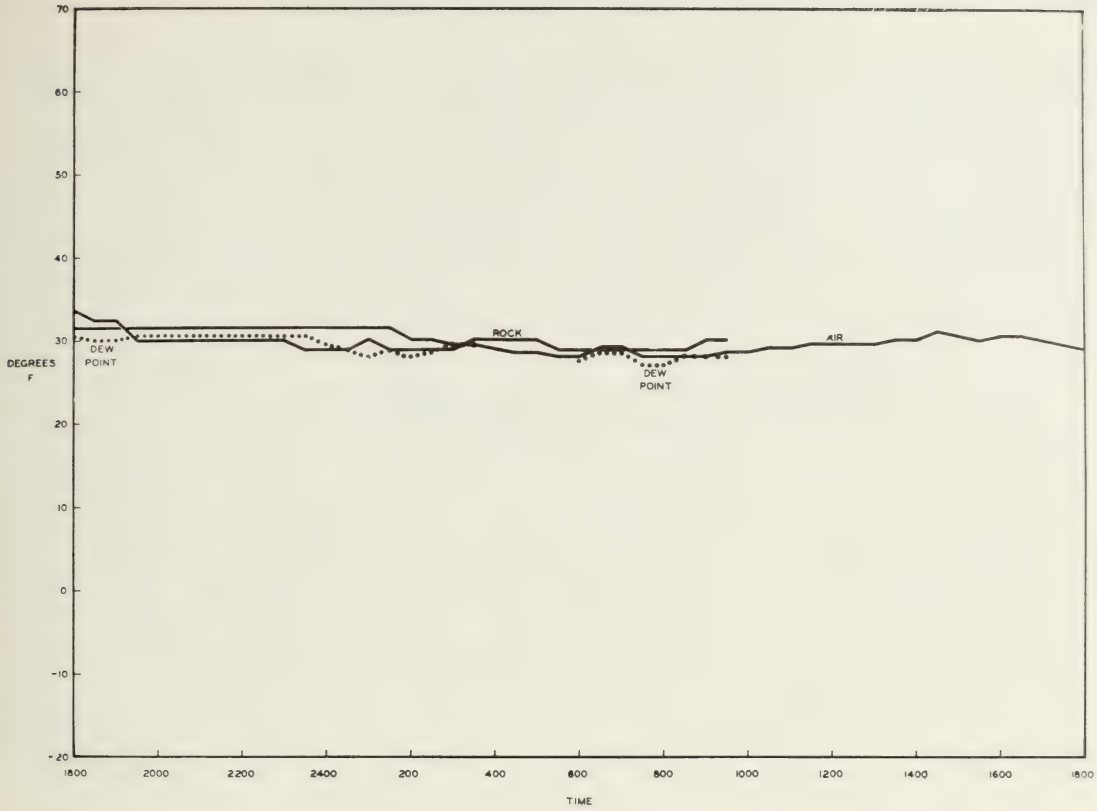

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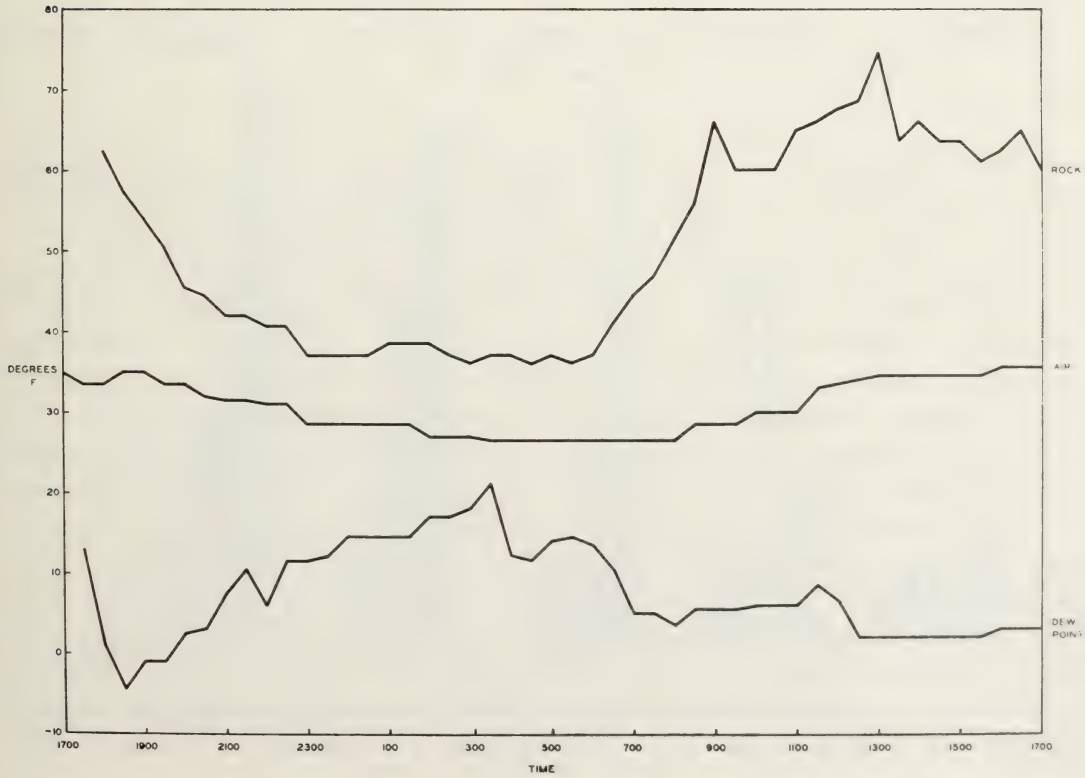

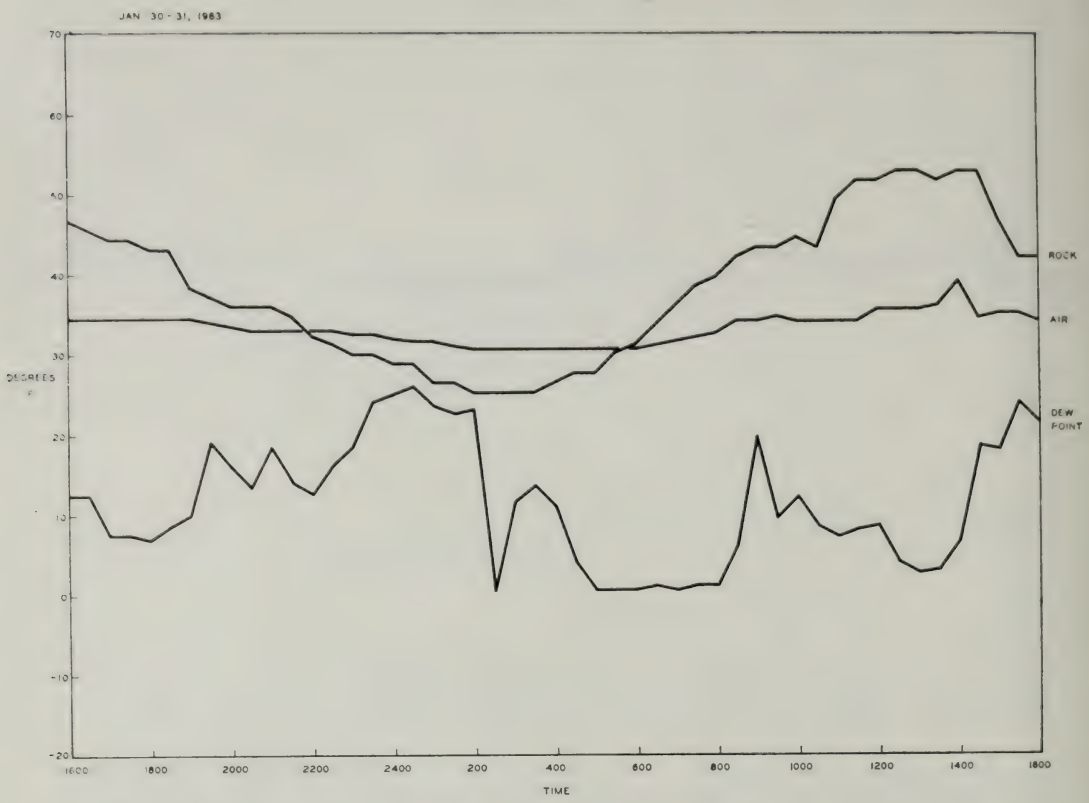

FIGS. 3–7. Microclimate data for individual stations based on half-hourly readings

reached on the rock surfaces or in the 60 cm air layer. This would indicate that atmospheric moisture is only available to vegetation in the form of water from melted snow since the dew point was seldom reached and frost was never observed.

It seemed, after mapping the vegetational distribution (Rudolph, 1963), that the pattern was primarily determined by availability of water. During the 1962–1963 season, weekly moisture content determinations were made of a sheet-like green alga, *Prasiola crispa;* a moss, *Bryum argentium* and three species of lichens: *Parmelia coreyi, Xanthoria mawsoni* and *Polycauliona pulvinata.* It was noted in the first season that the algae and mosses occupied the wettest habitats and that the lichens were found in the dryer ones. The overall pattern of moisture content during the eleven weeks of measurements in the second season (Fig. 8) quantifies this earlier observation. During weeks E (9 December) and G (23 December), indicated by S in Fig. 8, measurements were taken just after snowfalls of 7 and 12 cm and subsequent meltings. It is significant that all plants except *Polycauliona* were higher in moisture content at this time than at previous normal periods. The lack of increase in moisture content of *Polycauliona* can be explained by its habit of growing on the upper surface of smooth rocks blown free of snow. Thus, there was

no snow available for melting after the storms, and, as indicated by Fig. 8 the effect on this lichen was really a drying one. The other two lichen species grow on the leeward sides of rocks, in depressions in rock surfaces, or in spaces between two rocks, and thus have relatively moister and more protected microhabitats. During the weeks H–K (23 December through 20 January), standing and running water occurred in parts of the study area. The algae and moss were high in moisture content during this period since they grew exclusively in these wet areas. The case of *Parmelia* is interesting because during the weeks I and J (30 December and 6 January), the moisture content was high as a result of water running in washes, the exclusive habitat for the *Parmelia*. At other times these washes were relatively dry. Comparison of moisture availability with type of vegetation cover indicated that there is good correlation.

A striking feature of Antarctic vegetation is the lack of flowering plants except for two species in the most northerly part of the Antarctic Peninsula (Skottsberg, 1954). This is in strong contrast to the Arctic where numerous species of flowering plants occur as far north as there is land and even on some ice islands floating in the Arctic Ocean (Polunin, 1959). A climatic comparison of Point Barrow, Alaska (U.S. Weather Bureau, 1959) with Hallett Station is presented in Fig. 9. The annual temperature pattern is remarkably similar. The rainfall equivalents are not as similar but yet are not too dissimilar especially taking into account the difficulty

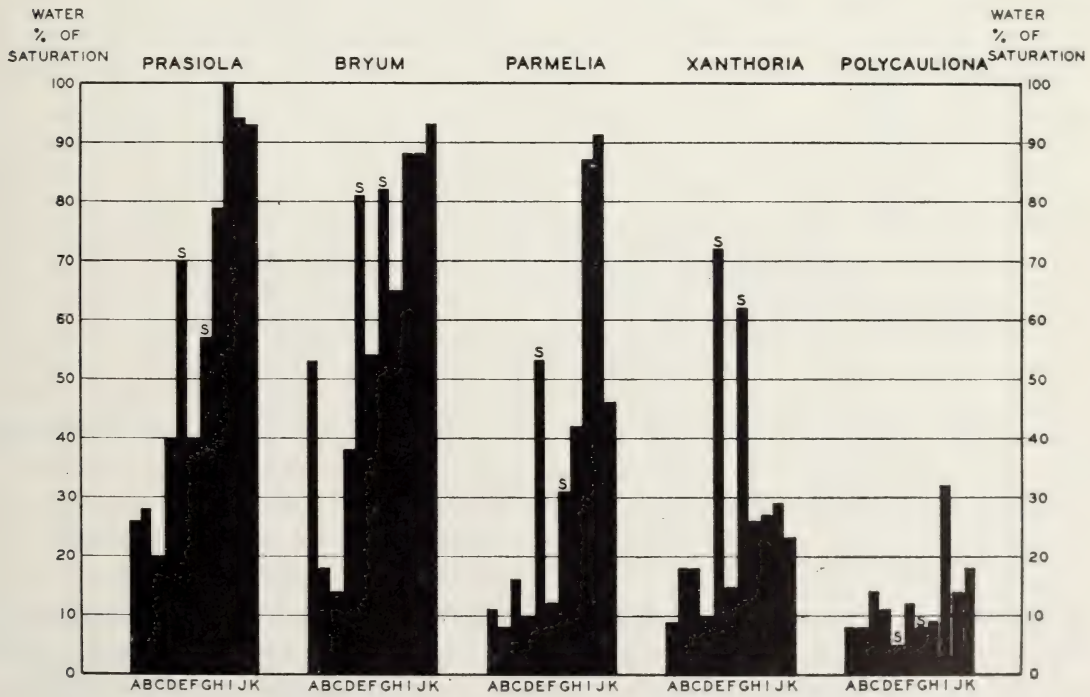

FIG. 8. Weekly moisture content of selected plants as percent of possible saturation for an eleven week period, 4 November, 1962–19 January, 1963

of obtaining accurate snowfall measurements. Point Barrow fits into the Köppen tundra climatic category and does have a wet tundra vegetation with many flowering plants, while Cape Hallett does not fit the tundra climatic classification because no monthly mean exceeds 0° C; however, it does have a dry tundra-like cryptogamic vegetation.

An attempt to grow several types of flowering plant seeds in the Hallett study area "soil" resulted in failure of any to germinate. When seeds were planted in the same

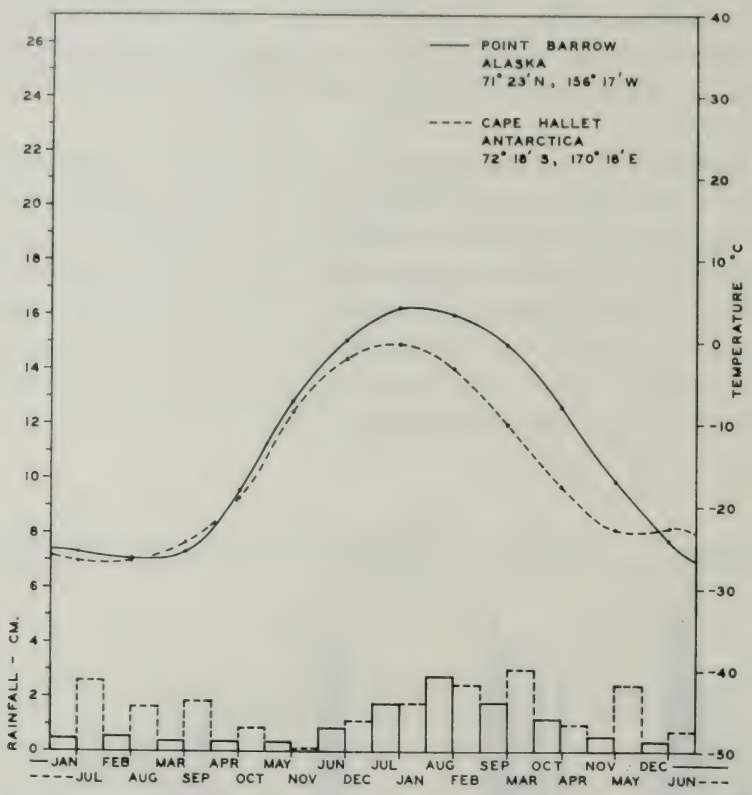

FIG. 9. Average monthly temperatures and precipitation for Point Barrow (10 years) and Hallett Station (6 years)

"soil" in the laboratory at Hallett, they grew well and flowered. It would thus seem that lack of minerals is not a limiting factor for flowering plant growth. The question that needs answering is: what are the factors in the environment which limit growth of flowering plants at Cape Hallett where moderate coastal Antarctic climate prevails? Lack of available ground moisture can be ruled out for at least some of the places at Hallett judging from the results of the moisture studies shown in Fig. 8. The situation resulting from the drying effect of the atmosphere which usually is low in moisture upon exposed plant parts, especially those that protrude above the snow cover as indicated by *Polycauliona* in Fig. 8, is an important consideration. Temperature limitations are perhaps more important because from the

climatic data it becomes apparent that there are never days at Hallett with temperatures constantly above freezing. However, the microclimatic data show that at ground level on rock surfaces there are a few days with temperatures always above freezing. Pryor (1962), in his measurements of sub-surface temperatures, found that on the days he measured there were always some below-freezing temperatures; he also points out that the permafrost is near the surface (15–20 cm). It would thus appear that temperature is probably the most critical factor limiting growth of flowering plants at Hallett for several reasons. While mature plants often are able to withstand freezing temperatures, seedlings are much less resistant and with decreased metabolic rates resulting from low temperatures, seedling growth (Bliss, 1962) would be severely curtailed. Freezing temperatures are present in the air and sub-surface every day of the year at Hallett, creating a condition strongly deterrent to seed germination. Bliss (1958) indicates than in shallowly-thawed soils, seed germination is very low. Then too, the very short duration of a possible growing season at Hallett would make flowering plant growth unlikely unless evergreen plants were present which like the algae, mosses and lichens, could take advantage of any favorable periods no matter how short for growth and reproduction. The possible natural introduction of seeds into the Ross Sea sector of Antarctica would not seem impossible since Grissitt *et al.* (1960, 1961) have shown that insects which are larger than most small seeds can be blown in the upper atmosphere toward the Antarctic continent.

In conclusion, it can be said, even with the partial analysis thus far made of the microclimatic data, that the plants growing at Cape Hallett are exposed to extreme and rapid fluctuations of temperatures and available moisture. These fluctuations are not apparent from the normal macroclimatic information. Rock surface temperatures have a greater daily amplitude of variation than do air layers 60 cm above the rocks, and there is a temperature inversion at night during much but not all of the summer. The availability of moisture as water in microhabitats is strongly correlated with specific types of vegetation and the lack of flowering plants can be best explained by the prevalence of below-freezing temperatures on every day throughout the year. Much about the interesting distribution of vegetation in the Antarctic remains to be explained. Further studies of microclimate can, it is hoped, help to illuminate the relationships between these plants and their inhospitable environment.

REFERENCES

Benes, N. S. (1959) Inside Antarctica No. 4: The Hallett story. *Weatherwise* **12,** 200–205.

Benes, N. S., (1960) Soil temperatures at Cape Hallett, Antarctica, 1958. *Monthly Weather Rev.* **88,** 223–227.

Bliss, L. C. (1958) Seed germination in arctic and alpine species. *Arctic* **11,** 180–188.

Bliss, L. C. (1962) Adaptations of arctic and alpine plants to environmental conditions. Arctic **15,** 117–144.

GRESSITT, J. L., LEECH, R. E., LEECH, T. S., SEDLACEK, J., and WISE, K. A. J. (1961) Trapping of air-borne insects in the Antarctic area (Part 2). *Pacific Insects* **3,** 559–562.

GRESSITT, J. L. LEECH, R. E., and O'BRIEN, C. W. (1960) Trapping of air-borne insects in the Antarctic area. *Pacific Insects* **2,** 245–250.

POLUNIN, N. (1959) *Circumpolar Arctic Flora.* Clarendon Press, Oxford, pp. 514.

PRYOR, M. E. (1962) Some environmental features of Hallett Station, Antarctica, with special references to soil arthropods. *Pacific Insects* **4,** 681–728.

RUDOLPH, E. D. (1963) A vegetation map and report of Hallett Station, Antarctica. *Ecology* **44,** 558–586.

SKOTTSBERG, C. (1954) Antarctic flowering plants. *Botan. Tidsskr.* **51,** 330–338.

U. S. Weather Bureau (1959) World weather records 1941–1950. Government Printing Office, Washington, D. C. 803 p.

U. S. Weather Bureau (1962) Climatological data for Antarctic stations July 1957–December 1958, number 1. Government Printing Office, Washington, D. C. pp. 314.

AERIAL TRANSPORT OF INSECTS IN POLAR AREAS, PARTICULARLY IN THE ANTARCTIC

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In the North Polar area winds carry insects in various directions, including far northward. There have been occasional records of insects such as aphids found alive on glaciers on Spitzbergen. These were certainly blown great distances from their normal habitats. Certain butterflies seen occasionally in northern Greenland are said to be blown there periodically, but are not known to breed there. In the Antarctic area, wind directions are generally unfavourable for transport of insects from temperate to polar areas, because of the prevailing south winds on the ice cap and the westerlies revolving around the continent. However, during recent experiments in trapping insects from planes and ships and on land, a number of specimens have been captured. Only a few have been found on the continent, but several have been collected from planes and ships well south of 60° South Latitude. A spider was found on the continent at 77° S. A butterfly was found at 71° S. South of New Zealand and Australia at times numerous insects of various groups have been found. On and near the Antarctic continent springtails (Collembola) of Antarctic origins have been trapped. This and other evidence, such as colonization of recently deglaciated areas, and isolated populations, indicate that wind transport is the primary method of insect dispersal in Antarctica. The same means probably account for colonization of the continent and of subantarctic islands, at least by part of the fauna.

BIOMETEOROLOGICAL OBSERVATIONS ON MAN, ANIMALS AND PLANTS DURING THE SOUTH AFRICAN NATIONAL ANTARCTIC EXPEDITION AND AT MARION ISLAND

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TEMPERATURE and in some cases also humidity values were given for various heights at different places inside the station buildings during the South African National Antarctic Expedition. A comparison of these data with data for outside wind speeds and temperatures showed that the inside temperatures are greatly affected by the wind speeds. There is a difference in clothing worn before and after winter as men seem to be better acclimatized after winter. Persons spending more hours during the day outside also seem to be better acclimatized than those spending more time inside. The microclimate of lichens on rocks was mentioned. Data were given on the migration of birds and seals in relationship to climate conditions. Finally, a summary on the climate of the Marion Islands and the breeding cycles of birds and seals was presented.

INFLUENCE OF CLIMATIC FACTORS ON THE MIGRATION OF THE EMPEROR PENGUINS *Aptenodytes forsteri* OF CAPE GEOLOGY, ANTARCTICA

J. PREVOST

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THE emperor penguins of Cape Geology occupy successively 5 different sites in their zone of reproduction during the annual cycle. It follows that the entire colony follows a similar itinerary, approximately the same each year, during their 9-month stay on the coast. The choice of each one of these sites depends on certain closely connected biological and climatic factors. The breaking up of drift-ice plays an important part. It depends on the action of the winds, tides and currents and is more likely to occur at certain periods than others. The sensitivity of the birds to its effects depends on the phase of the reproductive cycle; when carrying an egg or a chick between their flippers they cannot escape by walking or swimming to regions with no autumn breaking up of the ice. The wind also has a direct influence on the birds. Sites which are most exposed to wind may be favoured during certain periods, e.g. incubation and the first stage of rearing but avoided during others, e.g. the second stage of rearing. Finally, solar radiation whether acting directly on the birds or on the ice seems to be an important factor in determining the site for the final stage of the reproductive cycle.

SUMMARY REPORT — COMPTE RENDU

J. RIVOLIER

GÉNÉRALITÉS

Avant le Congrès nous avions préparé un programme de travail suffisamment large pour pouvoir intéresser des gens venus d'horizons différents mais rassemblés sur les deux concepts «biométéorologie et polaire». Le découpage suivant avait été prévu:

A. Technologie et Données Bioclimatologiques et Biométéorologiques:

(1°) Appareils de mesure et possibilités d'investigation bioclimatologiques
(2°) Données biométéorologiques
(3°) Corrélations bioclimatologiques

B. Physiologie Humaine:

(1°) Les Blancs de l'Arctique
(2°) Les Indigènes de l'extrême Nord et Sud
(3°) Adaptation en expéditions polaires
(4°) Mécanismes d'adaptation

C. Pathologie Humaine

(1°) Accidents dus au froid
(2°) Psychopathologie
(3°) Autres pathologies
(4°) Survie
(5°) Hygiène

D. Biologie Animale:

(1°) Physiologie
(2°) Ecologie
(3°) Autres corrélations

E. Biologie Végétale:

(1°) Physiologie
(2°) Ecologie
(3°) Autres corrélations

F. Recherches Futures — Coordination — Cooperation

PARTICIPANTS

Ont participé à notre Section de façon continue ou discontinue ou en envoyant un article à lire par un collègue, les personnes suivantes:
MM. Aubert, Bach, Bessuges, Blatteis, Borghorst, Bost, Chaffee, Chatonnet, Cour, Davies, Delepine, Dubief, Eagan, Goldsmith, Gressitt, Grisollet, Grua, Havlicek, Kita, La Grange, Leblanc, Lorius, Markov, Meisus, Nelms, Paleev, Perrier, Prevost, Pryor, Ragotzkie, Renbourn, Riedesel, Rivolier, Rudolph, Schreiber, Tanche, Wagner, Watanabe, Wilson.

COMPTE — RENDU GÉNÉRAL

La section polaire et antarctique groupa les activités de 10 à 30 personnes selon les jours.

Nous avons rencontré certaines difficultés pour les raisons suivantes:

Le président était Français et la moitié des participants au moins parlaient Anglais mais ceci put être arrangé au mieux que possible en faisant des deux côtés des efforts suffisants et en particulier grâce à l'aide du Dr. Leblanc qui est Canadien et qui nous a beaucoup aidé.

Une autre difficulté tenait à la dispersion des activités et des spécialités des participants: médecins, physiologistes, géophysiciens, météorologistes, zoologistes, phytologistes etc., et tous les sujets ne furent pas toujours intéressants pour chacun des participants en raison de ces spécialités (il n'y avait pas homogénéisation par spécialisation, mais seulement du point de vue biométéorologique).

Une autre difficulté tenait à ce que certains des participants étaient des chercheurs polaires et d'autres des hommes de laboratoire et qu'en fin de compte ils n'avaient pas les mêmes points de vue et les mêmes buts.

Enfin nous avons eu à parler d'un trop grand nombre de sujets et de sujets trop différents.

Matériellement nous avons séparé la section chaque jour selon les cadres suivants:

Technologie et appareillage et dans cette partie nous avons discuté de problèmes d'appareillages nécessaires pour l'étude de l'environnement polaire selon un point de vue biologique et nous avons découvert aisément, chose dont nous nous doutions déjà, qu'il n'est pas possible d'utiliser directement les données météorologiques brutes. Nous pensons qu'il y a une nécessité absolue d'avoir une optique spéciale comme par exemple de faire certaines mesures ou certaines manières dans un certain endroit et d'avoir très souvent un appareil spécial comme par exemple pour l'observation de la déperdition thermique. Il apparut aussi que nous désirons en savoir plus sur les microclimats que sur les climats régionaux. Après les exposés de certains d'entre nous, nous pouvions conclure que nous sommes très pauvres dans l'Antarctique quant à la connaissance de l'environnement biométéorologiques, que cet

environnement présente en outre des caractères spéciaux incluant certains paramètres tout-à-fait spécifiques des régions polaires.

La seconde session s'occupait des problèmes de physiologie humaine en relation avec la bioclimatologie polaire.

Nous entendîmes d'intéressants rapports sur certains aspects de la thermorégulation et nous avons reçu des informations à propos de certaines réponses métaboliques ou biologiques ou de certaines conséquences en rapport avec la vie dans les régions polaires.

En fait la plupart des sujets discutés se rapportaient à l'étude ou aux tentatives de recherches de preuves d'un mécanisme d'adaptation au froid chez les sujets vivant dans cette partie du globe. Si, comme il a été dit durant cette session, nous pouvons trouver quelques expérimentations montrant qu'il y a réellement un acclimatement périphérique au froid et particulièrement chez les indigènes, une fois de plus nous n'avons pas trouvé de preuves indiscutables d'un acclimatement général au froid des sujets vivant dans l'Antarctique. En particulier tous les rapports d'expédition que nous avons entendus ne sont pas concluants sur ce sujet.

La 3ème session était en rapport avec les phénomènes pathologiques en relation avec l'environnement biologique polaire. Malheureusement nous n'avons pas eu suffisamment de rapports sur ce sujet pour faire un tour d'horizon complet mais deux points furent mis en relief:

- premièrement la possibilité de noter certains troubles avec en particulier des modifications cardio-vasculaires lorsque certains phénomènes météorologiques ont lieu.
- deuxièmement la grande difficulté d'apprécier les réactions psycho-somatiques et psychiques des hivernants en corrélation avec les phénomènes climato-météorologiques, car en effet le stress le plus important provient de l'environnement psychologique d'un petit groupe d'hommes vivant ensemble un an séparés du monde.

Nous entendîmes un intéressant rapport à propos de certaines modifications des réactions émotives en corrélation avec la conductivité de la peau qui est elle-même parait-il en corrélation avec la pression atmosphérique.

Une autre session était dévolue à la biologie des animaux et des plantes. Il semble que la plupart des problèmes rencontrés par les biologistes soient aussi importants que ceux rencontrés par les médecins et les physiologistes dans les régions polaires et que, dans la plupart des cas, il y a lieu de connaître mieux les caractéristiques des environnements par des études de micro-climats, ces micro-climats étant encore plus petits que ceux qui intéressent la biologie humaine. Lorsque l'on étudie les déplacements, la physiologie, de certains oiseaux ou manchots, ou la biologie de certains lichens, il est nécessaire de connaître en détail les éléments climatiques intervenant sur ces phénomènes et il semble déjà que certains travaux montrent que certains phénomènes biologiques sont directement en corrélation avec certains paramètres climatiques ou météorologiques.

Durant la dernière session nous avons essayé ensemble de préciser et de définir quelles sortes de mesures et avec quel type d'appareil semblent les meilleures pour étudier les phénomènes biologiques en relation avec les phénomènes biométéorologiques. Nous avons essayé aussi, en définissant ces appareils, d'obtenir l'emploi du même matériel marquant les mêmes unités par tous les biologistes polaires, car il semble y avoir une nécessité absolue de pouvoir comparer les résultats issus de différents points des régions polaires. Enfin il a été émis le souhait que des programmes communs ou semblables soient effectués dans les différents endroits de recherches de l'Antarctique. Les biologistes dans l'Antarctique ne sont malheureusement pas arrivés au point des géophysiciens avec des programmes communs, des mesures communes et des dépouillements mondiaux. Nous pensons qu'ils sont en retard sur ce plan et qu'il est temps maintenant pour eux de coopérer selon un point de vue international.

ECOLOGICAL CLIMATOGRAPHY

Chairmen: H. Boyko and H. Gaussen

INTRODUCTION

H. BOYKO

In opening this meeting of our Working Group, I have the great honour and pleasure in greeting not only many old friends, but also many new coworkers prepared to disseminate the various ways and methods devised through our work in the past, and to add to them new methods of Ecological Climatography, methods which, we hope, will open new vistas in this scientific field.

Although "Ecological Climatography" is a new branch of science, it has already lead to many qualitative as well as quantitative climate indicators.

Its methods could be successfully applied to determining the complex climate concept for certain regions, as well as to identify certain single climatic factors.

Several climate maps have already been made on the basis of these new methods, and at our last two Congresses, a number of instructive examples were presented also for the determination of single climatic factors.

In all, about 22 different methods were enumerated (Boyko, 1958).

In addition to the findings of biological climate indicators, these methods also open the way to the solution of various *other* geophysical problems beyond the purely climatological ones, and, at the same time, of certain biological problems also.

The geophysical problems, apart from those of climatology, include many on hydrology, hydro-engineering, soil science, and the erosion complex, all of which are closely connected with the climatic features and, in most cases, even decisively dependent on them.

It could be proved that all biocoenoses, and particularly all vegetation units have a high indicator value which also applies, although to a far lesser degree, to certain plant species and, in certain cases such as, for instance, when determining the wind factor or flood heights, even to single plant individuals.

We must, therefore, deal in our working groups with plants or animals as indicators, not only from the purely meteorological point of view, but also in regard to some other geophysical fields which are usually separated from meteorology and climatology proper.

This applies particularly to hydrology and its application in large hydro-engineering projects.

It may, therefore, be an advantage to define these various and frequently overlapping lines of research in which Ecological Climatography pays an important and sometimes even a dominating role:

We understand the concept of *Ecological Climatography* as the study of living beings or groups of living beings (plant communities or biocoenoses) as qualitative

or quantitative indicators of climate, or of climatic factors and factor complexes.

An analogous definition may be given for "Ecological Hydrology" and "Ecological Pedology".

Ecological Hydrology is the study of living beings or groups of living beings (plant communities or biocoenoses) as qualitative or quantitative indicators of water sources and their various features. Such features may be, for instance, amount or distribution of rainfall, depth or quality of groundwater, etc.

Ecological Pedology is the study of living beings or groups of living beings (plant communities or biocoenoses) as qualitative or quantitative indicators of single soil factors or factor complexes.

"*Erosion Ecology*" also belongs to this last group of studies, combining biological and pedological investigations.

Since the water sources as well as the soil properties of any place are, to a great extent, dependent on climatic factors, all three lines of research overlap in regard to precipitation and evaporation, the IE-factor (i.e. insolation-exposure factor), the various erosion factors, etc.

Those three lines, together with the studies of biological indicators of geological features, may therefore be called "*Ecological Geophysics*", the definition of which is analogously expressed as "the study of living beings or groups of living beings as qualitative or quantitative indicators of geophysical factors or factor complexes".

These definitions will have to be put up for discussion and all suggestions will be most welcome.

Our Committee will have to discuss also the best way to propagate the knowledge gained and accumulated hereto, and to introduce the methods into the work of as many field workers as possible. The more comparable data we receive from various climatic regions, the sounder, of course, will be the scientific basis for practical application and drawing of conclusions.

The aspects in this direction are very diverse and international cooperation on all the various investigations will materially enrich our knowledge.

The significance of international cooperation, even in such single investigations, may perhaps best be explained by one example. By studying the impact of the IE-factor on plant-distribution, I found for instance, that the topographical distribution of the Mediterranean plant species Spartium junceum, can be used on its border regions to advantage as a climatic indicator, although quite generally single species are far less suited for this than plant communities.

During my journey in various countries, I found the following IE-data for Spartium junceum:

In the Mediterranean parts of France, Italy and Turkey, I found this plant in the lower altitudes to have a wide IE-amplitude. Thus, for instance, I found it in Southern France near Carcassonne at 250 m altitude on horizontal sites, and also on not too steep northern slopes. At 300 m, the extreme was already reached at 5° North, a sign that here we are already near to its northern borderline. The real

extreme IE-data of this was found by me in London and on the journey between Ankara and Istanbul. There I could not find individuals other than those growing on steep slopes with an exposure of 35–40° South.

The other extreme is to be found in Northern Israel on Mt. Atzmon, where it grows only on northern slopes with a similar steep inclination.

These few points indicate primarily three or four points respectively on the border of a distinct climate region, which we may call the Spartium junceum climate; secondly they outline the ecological and geographical distribution of this species.

If we succeed in organizing international team work, investigating this IE-amplitude along the whole borderline of such a specific species, comparing the data with existing meteorological data, then we shall have made progress in various directions; namely in the direction of climatology, plant-geography, plant-physiology regarding heat or drought tolerance or both, and the exact indicator value of a specific species, in this case of Spartium junceum also for other applications such as forestry or agriculture.

I hope that we shall be able to propose international working groups on specific plant-species and/or plant-communities, either during our present meetings or at the next Botanical Congress in 1964 in Edinburgh, where I have been invited to lecture on this subject.

Furthermore, several other working groups are due to be proposed during our meetings, and I hope that the activities of all participants in our field will succeed in leading to practical steps and in an ever increasing interest by succeeding generations of scientists.

We, here, are the pioneers of new ways in science. Pioneering work is science is fraught with difficulties as is any pioneering work in any other field. However, we can already see the gradual general recognition and also the beginning of moral and financial support of special agencies of UNO and the large foundations.

The reason is clear. This support goes hand in hand with the growing recognition that the contribution of these new branches of Science of Ecological Climatography in particular, and Ecological Geophysics in general, are most valuable contributions to the progress of our knowledge. One can already see that the results of these new lines of research are expected to be of global impact for the many diverse activities of humanity as a whole.

REFERENCES

Boyko, H. (1958) Report of the International Committee for Ecological Climatography of I. S. B. B. (for the period 1956 and 1957) by the Chairman.

I. S. B. B., II, Part VII., Section Alb (submitted to the *First Bioclimatological Congress*, Vienna, Austria, September 1957).

SOME NEW METHODS IN ECOLOGICAL CLIMATOGRAPHY AND ECOLOGICAL HYDROLOGY

H. BOYKO

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Abstract – A number of new methods are presented for carrying out research work in these fields, as well as examples of practical applications: (a) a vegetation map of the Huleh region in Israel, worked out as the basis of a large hydro-engineering scheme; (b) examples of quantitative indications of groundwater fluctuations in oases by investigating the vegetation cover as the most exact indicator; and an example showing the determination of the yearly water influx into these oases of Wadi Araba, in order to achieve a scientific basis for recognizing the potential of these oases for settlements and land use in general without endangering the natural equilibrium; (c) plant sociological records showing the erratic features of desert climate and the various adaptations of plant species to this important "Factor of Erratics".

Zusammenfassung – Beispiele für die Anwendung neuer Methoden in der ökologischen Klimatographie und Hydrologie werden vorgetragen: (a) Die Ausarbeitung einer Vegetationskarte des Huleh Gebietes in Israel als Grundlage für ein grosses bewässerungstechnisches Programm; (b) die Untersuchung der Vegetationsdecke als genauester Indikator für Grundwasserbewegungen in Oasen und ein Beispiel für die Bestimmung des jährlichen Wasserzustroms in die Oasen von Wadi Araba, um eine wissenschaftliche Grundlage zu schaffen zur Erfassung der Potentiale dieser Oasen für Siedlungen und Landgewinnung, ohne das natürliche Gleichgewicht zu gefährden; (c) pflanzensoziologische Bestimmungen, die die unregelmässigen Eigenarten des Wüstenklimas und die verschiedenen Anpassungsvorgänge von Pflanzenarten an den wichtigen "Faktor der Unregelmässigkeit" zeigen.

Résumé – On présente ici des exemples d'utilisation de méthodes nouvelles en climatographie et en hydrologie écologiques. Il s'agit: (a) De l'établissement d'une carte de la végétation de la région d'Huleh en Israël comme élément de base d'un vaste programme d'irrigation. (b) De l'étude de la couverture végétale comme étant l'indicateur le plus exact des variations du niveau de la nappe phréatique dans les oasis. On prend pour exemple les afflux annuels d'eau dans les oasis de Wadi Araba. On tente par là d'apporter une base scientifique pour déterminer le potentiel de ces oasis dans l'établissement de nouveaux habitants et dans l'utilisation de leur sol sans, pour autant, mettre en danger leur équilibre naturel. (c) De la détermination géobotanique des associations végétales du désert, associations qui montrent les conditions d'irrégularité du climat désertique et les différents processus d'adaptation des plantes aux principaux «facteurs erratiques».

THIS paper is intended to present some examples of the overlapping functions of ecological climatography with "Ecological Hydrology" and certain other branches of "Ecological Geophysics". It is intended also to present some aspects of their practical applicability.

The former Papyrus swamps of the Huleh Lake in Israel may serve as one example. There, the basic plant-sociological investigations and the study of the relations between the various plant communities and the water-level were carried out by me in the years 1937–1952. During the final months of my work, in 1952, I had the valuable help of my assistants, A. Abraham and E. Rawitz.

I determined the zonations themselves and their border-lines by quantitative plant-sociological records, i.e. in each square "abundance" and "dominance" were recorded separately, and numbers and size of the individuals were given. These border-lines, which had been sketched by me earlier, were completely visible from two opposing hills because of their very different colours, so we could use a theodolite for exact mapping. In this region, an important hydro-engineering work was at that time in the planning stage with the aim of converting the greater part of the swamps into agricultural lands and, thereby, gaining considerable amounts of fresh water for other purposes.

From the vegetation map of the Huleh Lake region, it is possible to see how these methods can help the engineers with economic calculations. Since all the plant associations occurring on the map are restricted to certain vertical zonations above the groundwater level, and since each of these plant associations is a good indicator of the best agricultural utilization, it is relatively easy by this work to determine the economic optimal level to which the groundwater should be lowered by the hydro-engineering work. The relation of the plant communities to the water level of the lake is represented by vegetation profiles. For each water level, the most suitable areas for the various kinds of crops are easily determined as a result of this kind of vegetation mapping and on the predetermined relationship of the wild plant communities to the water level.

It is, for instance, seen from the map and the Vegetation Profiles that after lowering the water-level by 50 cm, the whole area of the *Panicetum geniculatae* would be occupied by a *Cynodontetum dactyli*, in the natural vegetational succession which could be used, without irrigation, for maize, durrha, etc., and after a lowering by 200 cm, we can count on an arable area of about 16,000 dunams (4000 acres), suitable for numerous crops if non-irrigated, and, of course, many more species if irrigated.

The investigations in the Huleh swamps also gave us the basic information for another and very important side of the hydro-engineering planning. It can be shown that the vegetation there indicated a much higher amount of yearly water influx than the engineers had in mind. I estimated this amount in the years 1937–1952 at ten times as high as the amount on which the engineers based their technical calculations, which were reached mainly through rain gauges, run-off measurements and other mechanical devices, and on Thornthwaite's formula for evapotranspiration which results in approximately the same amount of water loss to the air as on an open water surface. This may be the applicable figure to a wheat field, but it is certainly misleading in the case of forests and likewise of a high and dense swamp vegetation. My estimate was specifically based on a closer investig-

ation of the *Papyretum*, covering most of the area, and the *Typhetum angustatae*, as well as on the fluctuations of the border-lines of the various plant communities.

I further discovered that more than one-third of the whole area of the *Cyperetum Papyri* was not rooted in the ground but floating, and I found, as an excellent indicator for this, the accompanying plant species, *Polygonum acuminatum* and *P. senegalense*, whereas the *Cyperetum Papyri* growing on dry ground was characterized by the fern, *Dryopteris Thelypteris*. I proposed therefore an exact measurement by installing lysimeters in the midst of the most important plant associations for measuring the evapotranspiration. The history of actual events is of practical interest. For budgetary reasons, no lysimeters were installed as they would have cost a few hundred pounds. Furthermore, a primitive vegetation map, which in many sections did not even concur with the facts, was used. It had been prepared by botanists without an ecological approach and without an adequate experience or training in the hydrological and hydro-engineering fields. The result was that the whole scheme—when it had already reached a very advanced stage—had to be changed as had been predicted, causing high financial losses running into millions of pounds.

Other new methods have been devised in order to determine the yearly minimum amount of the water influx into oases. A proposal in this direction made by the author at a symposium of the International Union of Biological Sciences and at the UNESCO—Turkey Symposium (Ankara, 1952) was carried out by the Hydrological Service of the Ministry of Agriculture, Israel, at Yotvata in Wadi Arava from 1960 on.

My proposal was to set up lysimeters in each of the main plant communities and to measure the actual water requirements of each zone. Having achieved these figures, they would indicate the minimum water influx into this oasis. In the Hydrological Service, under the direction of Dr. W. Stern, an automatic evapotranspirometer was invented and after having received the necessary financial support from an American fund, it was constructed and built in accordance with my advice. Thus by measuring the evapotranspiration of the main vegetation zone, the yearly influx into the near-surface groundwater was found to be 20,000,000 m^3 as a minimum in Yotvata during a particularly dry year (1961), whereas the plant-sociological records of the years with higher precipitation indicated six times as large an amount of water influx or 120,000,000 m^3 yearly in the years 1949–1951. These great fluctuations correspond with the erratic precipitation figures measured in various parts of the Negev.

Excellent indicators of these fluctuations may be found by plant-sociological records around Tels and small hills where the topographical distribution of annual plant species is decisively determined by the IE factor (Insolation–Exposure factor).

A good indication of the yearly fluctuation of precipitation in Israel is given by the height of *Avena barbata*, *Avena sterilis* and *Avena Wiestii*, and as it is generally well known, by the development of certain crops, particularly of barley. A barley field of the Beduins with 30 cm high crops indicates at 900 to 1000 m altitude

(near Rosh Rimon) a precipitation of about 225 to 250 mm, as happened in the rainy season 1949–1950. The same rainfall amount is indicated by a height of 40 cm of barley in 600 m altitude near Abde: the difference of about 25 per cent is caused mainly by higher temperatures at lower altitudes and by the additional run-off.

Factually the amount of rainfall is, in most cases, not of such great importance as its timely distribution. Therefore, here too, the plants give us another very distinct conception of the rainfall that is determined from the rain-gauges using millimeters as a yardstick. The only drawback is that we are not yet sufficiently accustomed to the biological concept, and it is to be hoped that our work will gradually strengthen our ability to think in these biological norms, at least in addition to the others.

A new line of research in the fields of Ecological Climatography is given by investigations on "the Factor of Erratics".

THE FACTOR OF ERRATICS

The development in growth of annual plant species and their yearly distributional movements according to these meteorological fluctuations are of particular significance in regard to their indicator value for those desert areas where precipitation is the main limiting factor. The erratic feature of precipitation, however, leads to the fact that this decisive "Factor of Erratics" has not yet received the necessary scientific attention which it deserves. Surprisingly many plant species are adapted to the extreme irregularities caused by this factor. Even in regions where whole years can pass without a drop of rain, quite a number of plant species survive, and they are enabled to do so by very different kinds of adaptations.

Some of these ways are enumerated here:

Generally a strong control of transpiration is to be presumed in probably all cases, and in many of them this has already been proved by physiological studies.

PARTICULAR TYPES OF PLANT ADAPTATION TO THE FACTOR OF ERRATICS

1. *The Anabasis articulata type:* Succulence of leaves, or stems, or both, supplies, only in few cases, effective determination means. This type is represented in Israel by the species *Anabasis articulata* (Forsk.) Moq-Tand, *Carraluma (Boucerosia) Aaronis* Hart., and a few others.

2. *The Erodium hirtum type.* Tubers or bulbs may be of additional help in some not very frequent cases of real desert plants, to overcome a dry period longer than usual. *Erodium hirtum* (Forsk.) Willd. belongs to this group.

3. *The desert annuals type.* Almost all therophytes of arid zones belong potentially to this group, for which the characteristic of an extremely short but complete life cycle of the single individual is the main feature. In many cases the rapid

development from germination to fruit bearing and seed dispersion is completed in less than one month. A typical representative of this group is *Aaronsohnia Faktorovskyi* Warburg et Eig.

4. *Longevity of seeds.* The generally well known extreme longevity of seeds of desert plant species is an important adaptation of desert plants in their struggle for survival. The seeds may rest for many decades without losing their viability and will, after an erratic rainfall or flooding, germinate and grow with surprisingly strong vitality. There are, however, also other types of adaptation to the Factor of Erratics which are less known or even completely unknown up to now as such, and of which we should like to record some examples.

5. *The Poa sinaica type.* This grass (*Poa sinaica* Steud.) lives with its fibrous root system in rock crevices which serve as a kind of water bottle retaining the water for a relatively long time after rainfall. If there is not enough rain, then the habitus of this species is like a low moss cushion without flowering and fruiting stems. In rainy years, however, the grass grows to a height of 30 to 40 cm or higher, flowering richly and fruiting, and thus securing the seeds for later and possibly luckier generations.

6. *The desert Acacia type.* These Acacias have deep and widespread root systems, part of which reach into the subterranean, erratically filled watercourses beneath the surface of Wadi-beds and similar places where sudden floods occur. If there is no water or moisture in these subterranean watercourses for a long time, then part of the leaves or all leaves are shed, and the trees appear to be dead. However, they revive very soon when the subterranean water supply recurs and the development of their leaves, as well as the changing of colour and density—from fresh and dense green to grey leaflessness — of their crowns, present us a measurable and easily comparable indicator of the *seasonal* hydrological conditions. Species of a type which simply adapt their transpiration surface to the erratically changing water sources, are not restricted to the Acacia species. Thus, for instance, almost all *Lycium Europaem* L. individuals of the normally evergreen plants in the Wadi of Beersheva seemed to be dead and leafless after the almost 10 month long dry period in 1962, and quickly became fresh and dark green again when adequate rainfall set in. According to the data of the Government Meteorological Service of Israel, that year was the driest in the last 40 years. This figure 40 years supplies an important basis for the estimate of climatic extremes in the regions of the distribution area of this species.

7. A similar effect of reduction of transpiration, nutrition requirements, etc., is achieved by *dwarfing.* On the Hammada plains of the southern Negev, only a few single perennial individuals with relatively large root systems are to be found per hectare, and these individuals do not develop to more than 2 cm in height with a coverage of about 1 cm^2 only. I found on a square of 100 by 100 m in the Hammada near Ein Fukra in April 1949, only two such individuals of *Anabasis articulata* (Forsk.) Moq.-Tand. (whose normal height is about 60 cm with a basal area of about half a square metre). Furthermore, I found one individual of *Erodium*

glaucophyllum (L.) L'Her. and two of *Erodium hirtum* (Forsk.) Willd. The latter has thick roots, and, in addition, substantial tubers. These tubers can be used as a welcome food supply in the desert, even when the green parts of the plant are not higher than 1–2 cm.

8. Other types particularly to the Factor of Erratics are the *Panicum turgidum* type, a high grass with deep-going roots, or the *Calotropis procera* type with divaricated and also deep-reaching roots. Both easily survive a rainless period of nine months.

9. The *Haloxylon persicum* type has two kinds of roots, a deep-reaching one, probably reaching 20 m or more and, as its other water supplier, a dense layer of adventive roots, closely filling the layer from 5 to 70 cm depth below the surface of the desert dunes which are its natural habitat from the Arabian deserts to the Central Asiatic sand deserts east of the Aral Sea. It thus extends its distribution almost from the region of the global maximal July isotherm to the minimal January isotherm. *Haloxylon persicum* is one of the very few desert trees and it utilizes in this way the "subterranean dew" which is a frequent phenomenon, particularly in the more continental parts of the deserts, where the temperature differences between day and night are very great. *Haloxylon salicornicum* (Moq.) Bge., although growing in erosion channels even in an almost absolute desert climate with only 20 mm yearly rainfall e.g. in Eilat, is more of the type of *Calotropis*.

10. A particularly interesting type adapted to the very erratic features of the saharo-sindian region is *Juncus arabicus*. This species can endure almost a whole year rainfall and without any contact with groundwater. This plant develops roots leading almost vertically downward to about 2 m. They number about twice the number of the 1–2 m high, stiff, knitting-needle-like leaves and fruiting stems standing almost vertically upwards from the ground. The relative transpirating surface of leaves and stems is therefore reduced to a minimum, whereas most of the roots are fleshy and evenly 1–4 mm thick down to their deepest end, and serve as water containers for a long period if necessary. In addition to these fleshy roots there are other finer and more densely branched roots too, particularly in the upper soil layer to 30 cm depth, in order to catch every drop when one of the erratic rainfalls occurs, and particularly in order to use the "subterranean dew" in the upper soil layer.

This plant is seemingly one of the best adapted species to the "Factor of Erratics" because it grows lusciously in swamps, or when its roots reach the ground water, but on the other hand it easily survives great fluctuations of the latter by drastically restricting its number of leaves, if necessary. When, however, rainfall again wets the soil or the ground water rises, then the roots develop a particularly high number of sucker roots in order to utilise these erratic water sources to the utmost. I once counted 420 and, another time, even 525 sucker roots/cm^2, which is perhaps the highest number ever counted. The extraordinary adaptability of this plant species is also to be seen by its particularly wide ecological amplitude with regard to salinity.

I combined experiments on these lines with studies of natural stands and found that many desert species can be used satisfactorily as quantitative indicators of hydrological conditions simply by comparing the number of green leaves of old individuals, their maximum height, and similar characteristics. If we mark the same individuals, count the green leaves and measure them, or if we have the possibility of comparing plants of hydrologically different habitat, then we have hydrological yardsticks in these plants not easily equalled in their indicator value by mechanical instruments. In different habitats, I mean for instance, different heights of the soil surface above the groundwater level in vegetational zonations in oases, etc., the reason for the high value of biological yardsticks lies in that the mechanical instruments can be used only on a specific spot, whereas the biological yardsticks have a general validity for the whole area and maybe even beyond it. The best system, therefore, would be the combination of both methods through the teamwork of hydrologists, meteorologists and plant ecologists, for these methods would complement one another in reaching an ideally complete investigation.

AU SUJET DES BIOCLIMATS

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Abstract — Formulas, indices, quotients have no global value because the determining factor changes with the countries. The most simple method is the graphic representation of the two essential factors (heat and humidity) month by month during the year. Humidity is not only rainfall but also atmospheric humidity which is very important for the vegetation. In the countries where there is a dry period, the number of dry days during the dry period is apt to give figures of good value. This method was used in the maps of the mediterranean climatic zones in the world, published in 1963 by UNESCO–FAO. The use of colours in these maps is explained. For the axeric countries i.e. for those without a dry season, a method is given for the establishment of subdivisions. The mountain climates are to be studied in a particular manner. Their general feature is the low temperature of the night. A comparison of bioclimatic maps with vegetation maps will be of great value.

Zusammenfassung — Formeln, Indizien und Quotienten können keinesfalls für die gesamte Erde passen, da nach den Gebieten der determinierende Faktor variiert. Eine ausreichende Darstellung der im Laufe eines Jahres herrschenden Bedingungen ergibt die graphische Darstellung der beiden wichtigsten Faktoren, d. h. der Temperatur und Feuchtigkeit (Niederschläge und atmosphärische Feuchtigkeit). Bei Ländern mit Dürre-Perioden wird die Zahl der trockenen Tage während der Dürre-Periode angegeben. Dies Verfahren wurde bei den von UNESCO–FAO 1963 veröffentlichten Karten angewandt. In Ländern ohne Dürre-Periode wird eine Methode zur Abbildung eventuellen Unterteilungen angegeben. Es muss auch auf die Klimate der Bergländer hingewiesen werden, da hier die nächtliche Abkühlung besonders gross ist.

Résumé — Les formules, indices et quotients définis empiriquement ne peuvent jamais s'appliquer à la terre entière, car les facteurs déterminants changent de région à région. Une représentation complète des conditions ayant régné durant une année fournit la courbe des deux éléments principaux, c'est à dire de la température et de l'humidité (précipitations et humidité atmosphérique). On indique le nombre de jours sans précipitations pour les régions présentant une saison sèche. L'UNESCO et la FAO ont utilisé le même procédé pour l'établissement des cartes que ces institutions internationales ont publiées en 1963. Pour les pays sans saison sèche, on indique une méthode permettant la représentation de sub-divisions éventuelles.

J'ai déjà eu l'occasion de parler de l'insuffisance des méthodes qui prétendent représenter les types climatiques par des rapports ou des formules diverses.

S'il s'agit des bioclimats, il est bien évident qu'une formule valable au Sahara donne l'importance maximale à l'humidité, une formule valable au Groenland donne l'importance maximale à la chaleur. La même formule sera difficilement bonne dans les deux cas.

En collaboration avec Bagnouls (1954), j'ai précisé graphiquement la notion d'*indice xérothermique* que j'avais définie au Congrès international de Lisbonne en 1949. La classification des climats, d'après les graphiques ombrothermiques, que j'avais exposée au Congrès international de Botanique à Paris, en 1954, s'est révélée très féconde et Walter a reconnu l'intérêt de cette méthode et a publié tout un Atlas des divers pays du monde.

LES PAYS Á PERIODE SÉCHE

Les courbes «ombrothermiques» permettent de définir l'hyperxéricité d'un mois si on utilise la relation $P_{mm} < T$ C°, la xéricité si on utilise $P < 2T$ et l'hypoxéricité si on utilise $P < 3\ T$.

La relation générale $P < 2T$ est arbitraire mais il n'y a pas de vérité en ces questions. Dans les mêmes conditions, une plante souffre de la sécheresse, alors que sa voisine la supporte bien. Une plante de climat très humide pourra souffrir de la sécheresse si $P < 3T$, alors que des plantes xérophiles pourront attendre la valeur $P < T$ pour manifester leur souffrance. La relation $P < 2T$ est en moyenne la meilleure.

D'autre part, les valeurs de P et de T publiées par les Services météorologiques ne correspondent pas, de façon précise, à celles qui ont de l'importance pour les plantes; et, comme disait justement Walter (1954) après ma communication: «. . . les valeurs climatiques ne donnent qu'une idée très grossière des facteurs extérieurs agissant sur les plantes. On ne devrait donc pas se donner beaucoup de peine pour établir avec une grande précision des formules climatiques, mais donner des évaluations beaucoup plus simplement . . .».

Malgré l'avantage des courbes ombrothermiques que Walter appelle «climogrammes»*, il faut remarquer qu'elles reposent uniquement sur les valeurs des températures et des précipitations, sans tenir compte de l'humidité atmosphérique, facteur souvent très important.

Pour corriger ce défaut, on peut, par l'emploi de l'indice xérothermique, compter le nombre de jours secs durant la période sèche ($P < 2T$).

Cette méthode a été utilisée par le Comité d'experts UNESCO-FAO dans une publication consacrée aux bioclimats de type méditerranéen dans le monde (1963). Une grande carte à 1/5 000 000 du Maroc à l'Indus, de petites cartes à 1/10 000 d'Australie du Sud, Afrique du Sud, Amérique du Sud, Amérique du Nord, accompagnent une notice explicative, publiée en Français ou en Anglais où on y trouve l'explication détaillée de la méthode.

Les mêmes experts préparent des cartes de végétation du bassin méditerranéen à la même échelle; ce qui fera ressortir les ressemblances et les différences. Ces

* Cet auteur a ajouté des renseignements supplémentaires sur la période de gel, ce qui est une indication précieuse.

dernières seront dues, soit à l'imperfection de la carte bioclimatique, soit à l'influence d'autres facteurs; de toutes façons, elles seront riches en enseignements.

En pays tropicaux, Meher-Homji (1960-1964) a fait une étude poussée des conditions climatiques. Une période humide, à faible précipitation, peut donner des conditions différentes d'une période humide à forte précipitation. La précipitation moyenne annuelle reprend son intérêt car elle représente à peu près la précipitation durant la période humide. Elle reprend son intérêt pour caractériser la période humide, mais non pour caractériser l'année.*

PAYS AXÉRIQUES

Tout ce qui vient d'être dit concerne les pays où existe une période de sécheresse, mais ne permet pas de donner beaucoup de renseignements sur les pays où l'indice xérothermique est nul: équatoriaux ou tempérés.

Les courbes ombrothermiques représentent toujours les facteurs, précipitation et température, mais ne vont pas plus loin et ne peuvent pas par leur croisement permettre d'indiquer des mois défavorables à la végétation.

En régime équatorial, on peut dire qu'il n'y a pas une suite de jours défavorables à la végétation. Mais la moyenne annuelle des précipitations prend de la valeur, alors qu'elle est très fallacieuse aux pays tropicaux où la saison sèche coupe l'année en deux parties (parfois trois) très différentes. Par la méthode de $P < 3T$, on peut, dans certains climats, faire apparaître une (ou plusieurs) périodes où les plantes habituées à une grande humidité peuvent souffrir d'une subsécheresse. On pourra ainsi définir un climat subéquatorial qui fera la transition vers les climats tropicaux.

En régime tempéré, $P < 3R$ fait apparaître aussi des parties où les plantes peuvent un peu souffrir de sécheresse, mais ces pays sont essentiellement les pays où le froid et la durée de la couverture de neige prennent de l'importance.

La question a déjà été évoquée à propos des climats steppiques où aux mois secs ont été ajoutés les mois de gelée.

La période défavorable à la végétation n'est plus ici une période sèche; c'est une période froide et la notion de gel devient fondamentale, ainsi que celle de couverture neigeuse qui en atténue les effets.

LES CLIMATS DE MONTAGNE

Ces climats présentent une grave difficulté de représentation cartographique et devraient être traités à grande échelle car ils varient fortement sur de petites surfaces.

* Pour la période humide on peut définir le subhumide: $3T < P < 4T$, l'humide: $4T < P < 5T$, le surhumide $5T < P$.

Un climat tropical pourra etre caractérisé par son *indice xerothermique* x et un *indice hygrothermique* y, nombre de jours humides ($4T < P < 5T$) durant la periode humide.

Ils sont caractérisés par le refroidissement nocturne, facteur fondamental dans la biologie des plantes, et par la durée de la couverture neigeuse.

Ces caractères communs n'empêchent pas une grande variété. Depuis longtemps, j'ai insisté, pour nos pays, sur la distinction fondamentale entre *oronérothères* à été sec et *orohygrothères* à été humide qui sépare, par exemple, l'Atlas des Alpes centrales.

Les premiers ont deux périodes défavorables à la végétation : l'hiver sous la neige ou le froid, l'été sous la sécheresse. Les seconds ont une période défavorable : l'hiver où neige et froid ont une longue durée.

Mais il faut distinguer d'autres types :

Les montagnes des hautes latitudes n'ont pas entre le jour et la nuit le même contraste de température que les montagnes plus raprochées de l'équateur. Elles ont parfois une très longue durée d'enneigement, d'autres fois des neiges faibles mais des froids très rigoureux.

Les montagnes équatoriales ont des conditions très particulières. Les saisons peu marquées donnent une faible variation en altitude de la limite inférieure des neiges. Si on appelle alpin, l'étage sans arbres, il a un large développement dans les pays tempérés car la couverture neigeuse de la période des jours courts s'étale sur une grande amplitude d'altitudes. En pays équatorial, les arbres peuvent s'approcher des neiges éternelles si le climat est assez humide et l'étage alpin peut être très réduit ; mais le froid nocturne reste le facteur déterminant pour les végétaux de haute altitude.

Certaines régions très sèches des Andes, bien que non génées par la neige, peuvent présenter en altitude une large amplitude de l'étage alpin.

Dans toutes les régions montagneuses, les variations locales sont très grandes et il est difficile de donner des règles générales.

LES PAYS VOISINS DU CERCLE POLAIRE

Dans les pays tropicaux, la moyenne annuelle des précipitations donne une idée fausse du climat et il faut séparer une période sèche et une période humide ; de même, dans les pays qui s'approchent des cercles polaires, les moyennes annuelles doivent être interprêtées et il faut séparer une saison froide et une saison tempérée.

Si la saison froide est très neigeuse, cette neige fond lors du réchauffement et la saison tempérée profite de la pluviosité totale annuelle. Durant la période neigeuse, les plantes sont relativement protégées contre des froids très rigoureux et certaines végètent sous la couverture de neige.

Si la saison froide est peu neigeuse, les plantes ne sont pas protégées et subissent des températures qui peuvent être très basses et la flore ne trouve de l'humidité que durant la période tempérée.

Si cette période est sèche les plantes peuvent souffrir de la sécheresse. Si le sol est gelé en profondeur, les plantes à racines profondes sont exclues, ce qui donne son originalité au paysage végétal.

APPLICATION CARTOGRAPHIQUE

Les cartes publiées par UNESCO-FAO ont utilisé les couleurs analogues à celles dont j'ai préconisé l'emploi pour les cartes de végétion, en 1949, à Lisbonne. Voici un tableau valable pour le monde entier:

Pour les pays à grande sécheresse: désertiques et subdésertiques, couleurs rouges et orangées.

Pour les pays tropicaux à alternance de saison sèche et de saison humide et de température moyenne élevée, un fond rouge orangé avec des bandes verticales bleues indiquant l'importance de la période pluvieuse. On a ainsi des bandes alternantes violettes (bleu sur rouge) et rouge-orangé, de largeur proportionnelle à la durée de chaque période. Quand il y a deux saison sèches, les bandes sont obliques.

Pour les pays équatoriaux, la couleur est violette (rouge + bleu).

Pour les pays tempérés chauds, le fond est jaune et peut être surchargé de rouge pour les parties plus chaudes, ou de bleu pour les parties plus froides. Quand il y a alternance nette d'une saison humide et d'une saison sèche, on peut utiliser des bandes verticales vertes (bleu sur jaune) et jaunes. S'il y a bixérisme, les bandes seront obliques.

Pour les parties tempérées axériques, on utilise une teinte plate verte (bleu sur jaune).

Pour les pays tempérés froids, au moins un mois de l'année à température moyenne inférieure à 0°, on le représente par un ligné lâche oblique et noir, sur un fond de couleur correspondant à la représentation de l'humidité: orangé, jaune, vert bleu.

Pour les pays très froids de haute montagne, un croisillé noir se superposera à du violet rose (bleu + rose forte lumière), puis à du blanc pour les hauts sommets qui sont couverts de neige.

Pour les pays à alternance de période très froide et d'une période tempérée, comme c'est le cas près du cercle polaire, sur un fond représentant la précipitation annuelle qui n'est utilisée que pendant la période tiède, on mettra des bandes verticales de croisillé noir proportionnels à la longueur de la période où la température moyenne mensuelle est inférieure à 0°.

Inutile de dire que des couleurs de transition peuvent exister quand on entre dans plus de détails.

Remarquons qu'il est plus aisé de colorier des cartes bioclimatiques que des cartes de végétation. Il est facile d'alterner sec et humide, ou froid et chaud, pour le climat alors que beaucoup de plantes, les arbres par exemple, existent pendant toute l'année.

EN CONCLUSION

A l'échelle mondiale, et c'est la seule qui a été envisagée ici, je crois que les méthodes proposées et qui ont déjà été appliquées, donnent des résultats satisfaisants. Il y a lieu d'insister sur le fait que ces méthodes ont été soumises à l'épreuve de l'impression.

Il est facile de critiquer et la critique est utile mais elle n'est réellement valable que si on apporte des cartes meilleures. La science doit être un perpétuel progrès et il est nécessaire qu'une oeuvre plus récente soit un progrès sur les publications antérieures.

Je ne veux pas dire qu'il n'y a pas d'erreurs et de défauts dans les cartes publiées. La documentation fut souvent très insuffisante. Je parle des principes de la méthode et j'espère que la critique portera sur des inexactitudes et non sur la méthode employée.

Les cartes bioclimatiques ont utilisé uniquement les données météorologiques et la connaissance du milieu physique. Leur confrontation avec les cartes de la végétation en préparation sera, je l'espère, très fructueuse. Elle permettra de corriger des inexactitudes de la carte bioclimatique et, d'autre part, éclairera le rôle des bioclimats dans la répartition des types de végétation, ce qui précisera leur écologie.

ANNEXE

Classification des climats proposée par H. Gaussen
et utilisée dans les cartes bioclimatiques éditées par UNESCO-FAO en 1963

t = température moyenne du mois le plus froid.

I. Climats chauds, tempérés chauds et tempérés quand $t > 0°$

II. Climats froids et tempérés froids si $t < 0°$

III. Climat glacial si tous les mois de l'année ont une température moyenne $< 0°$

1. Climats chauds, tempérés chauds et tempérés

I A. *Climat désertique.* Dans les diagrammes, la courbe thermique est toujours au-dessus de l'ombrique.

(P_{mm} = précipitation d'un mois; T °C température moyenne d'un mois).

A a. $P < T$ toute l'année: désert hyperxérique

A b. $P < 2T$ toute l'année: désert xérique.

x = Indice xérothermique: nombre de jours biologiquement secs durant la période sèche définie par $P < 2T$.

Si on dispose de l'indice xérothermique A a correspond à $x > 355$; A b correspond à $300 < x < 355$ } $x > 300$

I B. *Climat subdésertique.* 9 à 10 mois secs.

B a. Subdésertique accentué	$250 < x < 300$	$200 < x < 300$
B b. Subdésertique atténué	$200 < x < 250$	

I C. *Climat méditerranéen.* 1 à 8 mois secs pendant la période des jours longs; $t < 15°$.

C a. xérothermoméditerranéen	En $150 < x < 200$	$0 < x < 200$
C b. thermoméditerranéen	En $100 < x < 150$	
C c. mesoméditerranéen	$40 < x < 100$	
C d. subméditerranéen, transition	Sub $90 < x < 40$	

I D. *Climat tropical.* 1 à 8 mois secs pendant la période des jours courts, $t > 10°$.

D a. thermotropical : $t > 15°$
D b. mésotropical : $t < 15°$
Dans D a et D b, on peut distinguer un type

accentué	$150 < x < 200$
moyen	$100 < x < 150$
atténué	$40 < x < 100$
transition	$1 < x < 40$

D c. Climat bixérique, à deux périodes sèches. On additionne x_1 et x_2 de chaque période pour avoir x.

En plus de l'indication de «x» qui correspond à la saison sèche il sera bon d'utiliser aussi «y» qui définit la saison humide,

I E. *Climat axérique.* Pas de mois sec, $x = 0$

E a. axérique chaud équatorial	$t > 20°$	
E b. axérique chaud subéquatorial	$15° < t < 20°$	
E c. axérique tempéré chaud	$10° < t < 15°$. On peut utiliser	$P < 3T$
E d. axérique tempéré moyen	$0° < t < 10°$	id.

E c passe à C d
D c est en général entre C et D
A est en général entre C et D

II. Climats froids et tempérés froids

II A. *Climat désertique froid.* Les mois secs + mois de gel de 11 à 12 mois.
II B. *Climat subdésertique froid.* Le total est de 9 à 10 mois.
II C. *Climat steppique froid.* Le total est de 5 à 8 mois. La sécheresse se produit pendant les jours longs. C'est la transition de I C vers les climats froids.

II D. *Climat de jours longs humides et jours courts secs et froids.* C'est un climat où la période de gel coïncide avec la période de sécheresse. On ne peut pas l'appeler tropical puisque t est $< 0°$. On le trouve en Himalaya.

II E. *Climat subaxérique froid.* Il y au moins 1 mois sec et le total sec + gel est de 2 à 4 mois.

II F. *Climat axérique.* C'est le climat tempéré froid. Par la courbe $P < 3T$, on peut y faire apparaître de la subsécheresse. On aura:

F a. tempéré froid subsec.
F b. tempéré froid avec moins de 4 mois de gel.
F c. froid avec plus de 4 mois de gel.

Tenir compte de la quantité de neige de l'hiver qui fond au printemps et modifie la courbe ombrique.

III. Climat glacial

Tous les mois de l'année ont une moyenne $< 0°$. C'est un climat de hautes montagnes. On peut y distinguer:
III a. Jours longs secs
III b. Jours longs humides
III c. Hautes montagnes équatoriales.

RAINFALL PATTERNS WITHIN THE TROPICS

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Abstract – The appreciable variation of rainfall within the tropics, both on an areal and a temporal scale, makes this element in need of special study. This paper endeavors to present some simple statistical techniques that enable an investigator to prepare probability maps of annual monthly totals, the onset of rains, and average maximum daily falls.

Zusammenfassung – Die ziemlich starken Niederschlagsschwankungen in den Tropen, die sowohl räumlich als zeitlich auftreten können, lassen eine besondere Untersuchung als erforderlich erscheinen. Dieser Artikel will einige einfache statistische Methoden mitteilen, die es dem Meteorologen möglich machen, prognostische Karten der jährlichen und monatlichen Niederschlagsmengen neben solchen des Anfangs der Regenzeit und des mittleren täglichen Maximalniederschlags herzustellen.

Résumé – Le problème de la variation appreciable de la pluie aux tropiques, en rapport avec la superficie où elle tombe et sa durée, mérite d'être soumis à un étude particulière. Cet article essaye de présenter quelques méthodes statistiques simples qui permettront à l'investigateur de préparer ses cartes de probabilité du total annuel et mensuel, celles du commencement des pluies, et celles de la chute quotidienne maximale moyenne.

WITHIN the tropics, except in areas where the elevation significantly changes the pattern, the temperature is always sufficient for plant growth. The climate element of greatest agricultural significance, therefore, is moisture, its availability or non-availability.

ANNUAL RAINFALL

In the tropics some regions have a sufficiency of rain throughout the year, but much of these regions is sparsely populated (Amazon and Congo Basins) and is of little agricultural importance at present. Much of the area has only a marginal amount of rainfall and year to year variations can prove disastrous. Annual rainfall amounts at tropical stations show a very marked variability, greater than that found within temperate regions. For example, in East Africa many stations have recorded maximum annual rainfalls of more than four times the minimum.

Because of the great variability of annual totals at a station it is essential, for agricultural and hydrological purposes, to introduce a factor taking account of the rainfall reliability. It can be shown that most of the values at a station fit some

simple mathematical distribution and by identifying these the probability of receiving certain annual amounts can be calculated.

This paper covers two tropical areas, namely, East Africa and Central America, with a general summary for Africa.

THE DISTRIBUTION OF ANNUAL RAINFALL TOTALS

It has been general practice for many years to assume that annual totals of rainfall, at a station, are normally distributed. This has, no doubt, stemmed from the detailed investigation of the Padua, Italy, data made by Conrad and Pollak.

Padua has one of the largest series of rainfall figures available, over 220 years, and a thorough analysis showed that there was no significant departure from normality of the distribution, both for the complete run of years and for chosen samples. This very interesting piece of work has, however, been used to its limit and beyond. The folly of this practice is patently obvious — it is an example of extrapolation from a sample of one.

Owing to the assumption of normality in all cases discrepancies have arisen between original estimates (statistical forecasts) and observation and it is quite clear that many stations in an area should be tested before any assumptions are made.

STATISTICAL ANALYSIS

For most rainfall data the set of figures available presents a run of no more than about 80 years; Padua with over 200 years is an exception. This limitation means that only three tests for normality can be applied, namely, the Cornu criterion, the skewness test and the χ^2 test, out of which the first two were used.

During the course of the analysis each station's extreme value, maximum or minimum showing greatest deviation from the mean, was tested against the Chauvenet criterion.

RESULTS

In East Africa 298 stations were tested, in Central America 156 and in the rest of Africa 132. The resulting distributions are listed below.

	Total	Normal	Non-normal
East Africa	298	269	29
Central America	147	128	19
Africa	132	109	23
Totals	577	506	71

It must be mentioned that 10 suspect readings have been removed prior to the calculations. It is interesting to note that with annual totals of below about 250 mm the chance of non-normality increases from about 12 to 50 per cent.

MONTHLY TOTALS

Although it is necessary to analyze the annual totals of rainfall to obtain the overall picture of precipitation conditions, it is clear that some smaller interval is needed so as to give an idea of the seasonal distribution of the rainfall. For this reason attention was next focused on the monthly totals with the same aim, namely, to find suitable, simple types of distributions that could be used to calculate probability levels with reasonable reliability. It is very definitely desirable to propound a general rule and not one that is applicable only to certain areas, for the latter method increases the work and makes comprehension of the basic pattern difficult, if not impossible.

Experience shows that the mean monthly rainfall, even when obtained from many years of records, gives no reliable indication of the distribution of the totals that arise. The basic fact behind the discrepancy is that the frequency distributions of monthly rainfall are markedly skew, the mean being greater than the median.

Experiments showed that the use of a square-root transformation was worthy of consideration and this was applied to all months for about 200 tropical stations (2400 station-months).

RESULTS OF MONTHLY ANALYSIS

It was realized that, owing to the very marked skewness associated with small means, there would be a limit below which it would not be expected that a square root transfer would prove powerful enough. This lower limit is not suggested to be when the square root mean is below 4 mm, equivalent to an arithmetic mean of about 20 mm.

With this criterion applied 2181 station-months were available, and of these 1966 were square root normal (90 per cent).

The extremely heavy rainfall of November 1935, in Panama affected 10 stations; the rain totals in that month were such as would be statistically forecast only once in over 1000 years.

With a knowledge of the type of distribution patterns it is a straightforward matter to calculate probability levels for map purposes. It is the decision of the investigator as to whether the probability or the amount is held constant for any one map.

ONSET OF THE RAINS

It is realized that the amount of rainfall is not the only important factor of precipitation patterns, distribution being equally significant. This led to the next investigation, how to assess a rainy season and how to introduce the factor of time in such a way as to make the result tractable to the normal statistical processes.

The shortest period generally available is one day and the first, obvious, approach is to consider the distribution of daily amounts throughout the year. This method is quite laborious and, as shown by the slide no. 1 for Nairobi, not very rewarding. It indicates that, even with a number of years of records the pattern is still too chaotic to allow simple statistical analysis.

Finally, a method using pentads (5 day periods) was derived in which if a 3 pentad periods had more than 1.5 in. of rain and no more than one of the pentads had less than 0.5 in. then the centre pentad was classed as "wet". It was possible to identify not only the average rainfall patterns associated with the Equatorial Trough, but also the probability of occurrence and reliability. This was extended to identification of the extra-monsoon rains at the East Africa coast and the moist incursion into western Tanganyika.

The isochrones of maximum intensity in pentads were then mapped and the average data of maximum onset of the rains could be interpolated. As both the mean and standard devistions were known the isochrones for any probability level could be mapped.

CUMULATIVE CURVES OF RAINFALL, AMOUNT VS. TIME

If over a period of years the daily falls are classified according to frequency of occurrence within a certain amount interval it is possible to construct a table showing percentage occasions.

Originally, for East Africa, stations representative of the main rainfall regimes were chosen and the cumulative curves constructed. It was most surprising to find that, within the sampling error, the curves were identical. As each month at a station showed the same curve the distribution remained true for the annual pattern. Investigations in Central America and a few test cases in other regions have produced the same curve. This curve can be of great use in deriving certain rainfall parameters, for example:

(a) Daily Amounts – Average Yearly Maximum

Given a station with an annual rainfall of 40 in. falling in 100 days, what is the average yearly maximum fall in one day?

From the graph 99 per cent occurrence gives about 92 per cent of the amount so that the final 1 per cent yields 8 per cent of the total; that is, for this example, one day will produce $40 \times 0.08 = 3.2$ in.

This is then the average maximum daily fall.

Note that 50 of the rain days will give only about 4 in. (10 per cent) rain and it takes 86 days to contribute 50 per cent of the rain.

(b) Extreme Falls

In (a) we calculated the average yearly maximum for a certain station, what are the likely 2-year and 5-year maxima?

As the station figures denote, in 2 years 80 in. fall on 200 days. One day is 0.5 per cent of this total and corresponds to 5 per cent amount, or 4 in. This figure is the average 2-year daily maximum.

For the 5 years maximum, we note that 200 in. fell on 500 days during 5 years. so that 1 day is 0.2 per cent. This corresponds to approximately 2½ per cent amount, or 5 in. Thus 5 in. is the 5-year daily maximum. It must be realized that inaccuracies can be introduced with very small factors of a percent owing to the difficulty of reading from the graph. However, the method is mentioned as a quick, easy way of obtaining information on the frequency distribution of rainfall amounts and it is hoped that the method will be tested in other countries.

SEASONAL DISEASES AND BIOCLIMATOLOGICAL CLASSIFICATION

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Abstract – In a ten-year survey, the annual sequence of peak months of the seven infectious diseases under consideration (typhoid fever, poliomyelitis, diphtheria, scarlet fever, measles, whooping cough, and cerebrospinal meningitis) display a regular pattern which, in analogy with the phaenology and ecology, might be termed a "sequence of peaks". This sequence of peaks of the various infectious diseases in the different climatic zones reflects the interdependence between the predilection of the occurrence of these diseases and the special seasonal climatic conditions obtaining in a given zone. The different pattern of the sequence of peaks of these diseases in the various climatic zones may be used as a basis for the drawing-up of a bioclimatological classification. Thus they may be regarded as representing an essential element in the theory of the ecology of man as an ubiquitous globe-dweller. The concept of an "indifferent zone" of the incidence of infectious diseases on the earth is no longer tenable.

Zusammenfassung – In einem Überblick über 10 Jahre zeigt die jährliche Aufeinanderfolge der Monate mit Häufungsgipfeln der sieben betrachteten Infektionskrankheiten (Typhus, Poliomyelitis, Diphterie, Scharlach, Masern, Keuchhusten und Meningitis) einen regelmäßigen Ablauf, der, in Analogie zum Erscheinungsbild und zur Ökologie, als „Aufeinanderfolge der Häufungsgipfel" bezeichnet werden soll. Diese Aufeinanderfolge der Gipfel der verschiedenen Infektionskrankheiten in den einzelnen Klimazonen zeigt den Zusammenhang zwischen der Neigung zum Auftreten dieser Krankheiten und den spezifischen jahreszeitlichen klimatischen Bedingungen in der betrachteten Klimazone. Die unterschiedliche Form der Aufeinanderfolge der Häufungsstellen dieser Krankheiten in den einzelnen Klimazonen können als Ausgangspunkt für die Aufstellung einer bioklimatischen Einteilung benutzt werden. Sie stellen so gleichsam ein wesentliches Element in der Theorie der Ökologie des Menschen als allgegenwärtiger Bewohner der Erde dar. Die Auffassung von einer „indifferenten Zone" des zufälligen Vorkommens infektiöser Krankheiten auf der Erde ist nicht länger haltbar.

Résumé – Au cours de 10 ans, la succession des mois présentant un accroissement subit de 7 maladies infectieuses (fièvre typhoide, poliomyélite, diphtérie, fièvre scarlatine, rougeole, coqueluche et méningite), présente une régularité qui, comme la phénologie et l'écologie, peut être dénommée «succession de pointes». Cette succession dans les dites maladies infectieuses s'étend aux diverses zones climatiques et présente une interdépendance entre l'apparition de ces maladies et les conditions climatiques particulières à chaque zone. Les différentes formes que prend la succession des pointes d'apparition de la maladie peuvent être utilisées comme point de départ d'une répartition bioclimatologique des dites maladies. Elles représentent également un élément important dans la théorie écologique de l'homme comme habitant de la terre entière. L'idée d'une «zone indifférente» dans la répartition des maladies infectieuses ne peut être retenue plus longtemps.

CONSIDERING the wide thermal differences between summer and winter, and the resulting marked summer and winter peaks in the incidence of various infectious diseases, B. de Rudder 30 years ago, subdivided the globe into three climatic zones: a northern zone, a southern zone, and an "indifferent zone" near the equator.

The lack of adequate information on epidemiological phenomena from the countries listed under the "indifferent zone" may have motivated de Rudder's classification. Meanwhile more data have been gathered in these countries, and it seems no longer justified to speak of a uniform "indifferent zone".

In a geomedical analysis of the prevalence of cerebrospinal meningitis in Africa, I have found evidence that, south of the Sahara, epidemics of this disease coincide with the dry season. Subsequent studies by Gans and independently made investigations by B. D. Owusu, have established that the fluctuations observed in measles epidemics in these regions are related to the cycle of dry and rainy seasons.

These findings have proved that the concept of seasonal diseases is applicable not only to the development of infectious diseases in relationship to the thermal situation within an annual cycle, but also to the fluctuations in diseases in the tropical zone where these fluctuations are brought about by the cycle of dry rainy seasons rather than by temperature conditions.

In our effort to classify the bioclimate of man, we are thus in a position to widen the scope of bioclimatological classification by taking into account not only thermal seasons but also hygric seasons. Therefore, we can no longer speak of an "indifferent zone" of our globe. Even a region with 11 or 12 months of extremely high air humidity can no longer be classified as "indifferent" as this extreme degree of humidity, which sets its apart from the other climatic regions, can exert a specific influence on human diseases.

Nevertheless, if we want to prove the existence of a biotropic effect, it will be necessary to ascertain that the frequency rate of certain diseases in the course of the year is in keeping with measurable climatic characteristics of the given region: (1) the latitudinally differing length of solar radiation, (2) the fluctuations of air temperature in the course of the year, and (3) the seasonal distribution of rainfall.

In the tropics, where only minor variations of the mean air temperature during the course of a year are measurable, the incidence of parasitic diseases of man and animal are interrelated on the cyclic incidence of rainy and dry seasons.

When drawing up his tabulation of seasonal diseases, B. de Rudder differentiated between diseases showing a summer peak and others showing a peak in the winter or early spring. His differentation was based on studies of diseases in the temperate zone only. Yet he established the fact that the peak incidences of infectious diseases are definitely ruled by certain seasons, the manifest peaks of the various diseases following a set pattern. This pattern may be called a "sequence of peaks", which is characteristic for each climatic zone.

Determination of such a sequence is another step toward a bioclimatological classification.

The sequence of peak months of infectious diseases representing the annual maximum of cases over a period of ten years has been determined for seven of the most prevalent infectious diseases in the different Central European countries. The sequence shows a regular pattern, as if it were controlled by a time factor,

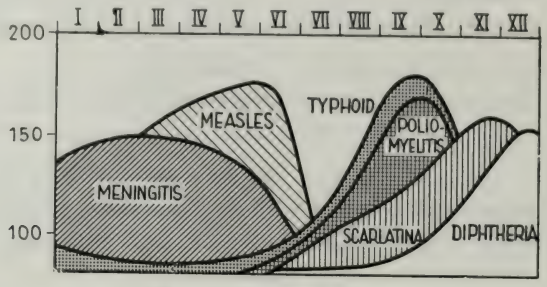

FIG. 1. Central Europe
Countries of the warm-temperate zone

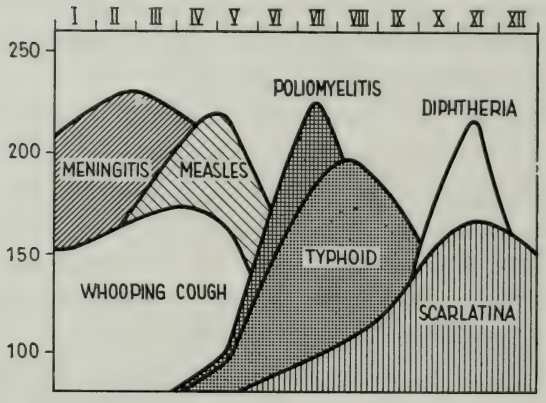

FIG. 2. Northern hemisphere

suggesting a seasonally conditioned sequence of peaks, as shown in Fig. 1 for Central Europe.

The countries of the *cool-temperate zone of the northern hemisphere* show a specific sequence of peaks, year after year the cerebrospinal meningitis peak being followed by the measles peak, which is in turn followed by the whooping cough peak. Following in the course of the year the typhoid fever peak appears in late summer, preceding the poliomyelitis peak, which is in turn followed by the scarlet fever peak, preceding the diphtheria peak.

The seven infectious diseases also demonstrate a sequence of peaks in the countries of the *warm-temperate zone of the northern hemisphere*; however, the predilection of the incidence of the individual infectious diseases occurs *earlier* in the course of the year than in the countries of the cool-temperate zone. The peak

of poliomyelitis arises before the peak of typhoid fever, the peak of diphtheria before the scarlatina peak (Fig. 2).

If we compare this sequence of peaks with its counterpart for the *warm-temperate zone of the southern hemisphere* (Fig. 3), we find further evidence that this pattern of the seasonal incidence of infectious diseases is closely related to the climatic conditions. The peaks of the infectious diseases prevalent in the northern hemisphere during the winter and into the spring (Fig. 1) are paralled by a nearly identical sequence in the countries of the southern hemisphere during their winter season, that is, from April to October. Here we find the same phenomenon that the poliomyelitis peak is invariably followed by the typhoid fever peak.

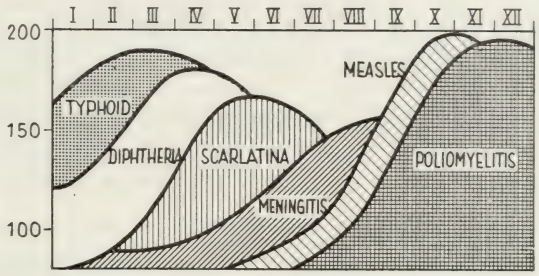

Fig. 3. Southern hemisphere

Evidence has been produced for some West African countries which range to the *tropical zone*, that the peak incidence of cerebrospinal meningitis precedes the measles peak, the occurrence of epidemics of meningitis invariably being linked to the uninterrupted dry season of several months duration.

For further studies, it will be necessary to investigate the relationship between seasons and peaks of infectious diseases in the countries of *the fringe tropics*, that is, a region characterized by *three* annual seasons: (1) a cool and dry winter, (2) a dry and hot spring, and (3) a slightly cooler, but wet and sultry summer. Here, we speak of the Indian type of annual temperature trend, which is found not only in India, especially on the Deccan Plateau, but also in the Sudan, the Kalahari Desert, the Philippines, Northern Australia, Mexico, and other countries of the fringe tropics.

The coincidence of the peaks of some infectious diseases and the dry season or the rainy season suggests that it is no longer justified to speak of an "indifferent zone" for seasonal diseases. It is considered highly desirable to include the tropics in such pathogeographic studies so as to be able to evaluate the findings in a bioclimatological classification designed to establish the principles of human ecology.

RESEARCH WORK ON THE ANNUAL PERIODICAL RHYTHM OF PLANT COMMUNITIES AND ITS METHODS IN HUNGARY

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Abstract – Research work on the annual periodical rhythm of plant communities has been done in Hungary, as in other countries, by phytophenological surveys. Systematic studies were initiated in 1952 by collecting data of the various ecological requirements of plant communities. The method of investigation thus developed is discussed in detail. Observations of plant communities and meteorological factors were carried out concurrently. Data are evaluated from the point of view, of the whole community and represented schematically.

Zusammenfassung – Forschungsarbeiten über den jährlichen periodischen Rhythmus von Pflanzengemeinschaften wurden in Ungarn wie in anderen Ländern in Form von pflanzenphänologischen Übersichten ausgeführt. Systematische Untersuchungen begannen 1952, indem Unterlagen über die ökologischen Bedingungen von Pflanzengemeinschaften gesammelt wurden. Die dabei entwickelte Untersuchungsmethode wird ausführlich besprochen. Die Beobachtungen an den Pflanzengemeinschaften und der meteorologischen Faktoren wurden gleichzeitig vorgenommen. Alle Messungen wurden in Hinsicht auf Gemeinschaften ausgewertet und schematisch dargestellt.

Résumé – Des recherches concernant le rythme périodique annuel d'associations végétales, recherches basées sur des confrontations phénologiques, ont été effectuées en Hongrie et dans d'autres pays. Les recherches systématiques ont débuté en 1952. On a, dès cette date, recueilli des renseignements concernant les conditions écologiques d'existence des dites associations. On discute ici la méthode mise au point à cet effet. On a entrepris simultanément des observations phénologiques et météorologiques. Toutes les mesures et observations furent compilées en fonction des diverses associations végétales et rapportées schématiquement.

RESEARCH work on the annual periodical rhythm of plant associations has been carried out in Hungary, as in other countries, by phytophenological surveys. In 1951 when the department for Agricultural Meteorology of the National Meteorological Institute was established, it became possible to set up a central organization for the phenological network. Two hundred observation posts were established for the observation of wild grass species, trees and shrubs. Intructions were issued to these stations to assure uniform methods of observation. At present this work is carried out by the Department of Agriculture Biometrics of the National Meteorological Institute. The chief work consists of the phenological evaluation of cultivated plant varieties.

Parallel with the development of the phytocoenological view, attention was focused more and more on the study of vegetation instead of plant species. The corresponding work on microclimate was started by R. Soó in 1929 in Hungary in the region of Lake Balaton. The microclimatic features of the individual plant associations have been elucidated during the past three decades in a number of fragmentary studies.

When studying the annual periodical rhythm of plant associations the various aspects of the individual associations are analysed. Hereby the levels of the plant associations related to time are regarded as aspects which in the same biocoenosis under the given vital conditions follow each other periodically in the various stages of the vegetation period. The phase of these levels, their character (habit of life and ecological requirements of the species involved) and duration are a function of the meteorological changes.

Investigation and utilization of meteorological factors in research work on aspects run along two lines:

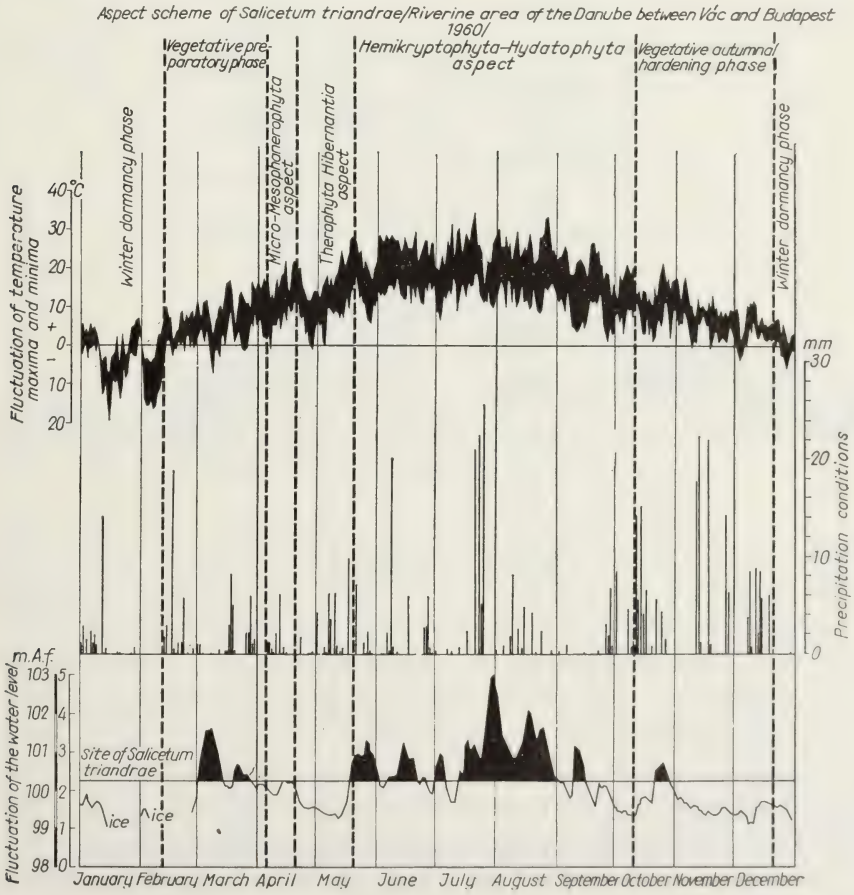

FIG. 1. Aspect scheme I. Aspect scheme of *Salicetum triandrae* (Riverine area of the Danube between Vác and Budapest, 1960)

(1) Macro- and mesoclimatic conditions are recorded at standard meteorological stations.

(2) For special problems microclimatic research work is conducted. Measurements of the other significant factors, e.g. light, radiation, evaporation and respiration, wind conditions, are still not entirely up-to-date.

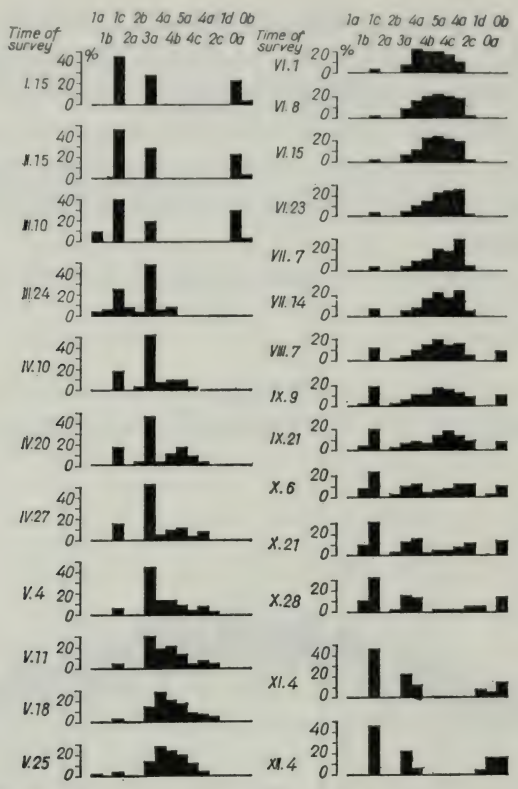

FIG. 2. Distribution of the aspect values of *Salicetum triandrae* according to the several "chronologic transects" (1960)

According to our method, degree of ontogeny in the plant species characteristic of the associations is observed at 3- to 7-day intervals. The grades used in the phytophenological methods are used, but evaluated from the point of view of the dynamics of the whole association. Whatever time level the association is investigated in, its species are not of identical value for the phenological aspect. There are so-called "characteristic species of the aspect" which at the given time level reach their highest degree of ontogeny (flowering) from the viewpoint of the periodical rhythm. Some species in the time sector examined are in the stage of preparation (sprout, basal leaf, tillering, shooting, etc.) or in the stage of withdrawal (ripening, defoliation, shedding of seed, wilting). These grades, depending on their distance in periodical development from the highest aspect value (flowering recorded as 5) are designated with the scores 1 to 4. Degrees of ontogeny occupying the same

position from the viewpoint of the phenological aspect are distinguished from each other by the addition of letters (4a, 4b, 4c, etc.).

Literature generally separates time levels according to seasons (spring, late spring, early summer, summer, autumnal aspect). In most studies the apparent winter dormancy phase in neglected. In our investigations, complementing the field studies with experimental ecological methods under laboratory conditions, e.g. elimination of cold winter phase, fixed light or heat effect, we endeavoured to obtain data on the features of the winter dormancy phase of the analysed plant associations.

For illustrative representation of the individual time levels the horizontal-vertical quadratic map of *Alyochin*, while for the representation of the underground parts the widely used root diagram was employed (Fig. 1). The composition of this representation by time levels stabilizes the periodical changes of the aspect as the squares of a film.

Evaluation of surveys. The aspect-values surveyed are tabulated and condensed in groups taking into account the florescence of the species involved in the associa-

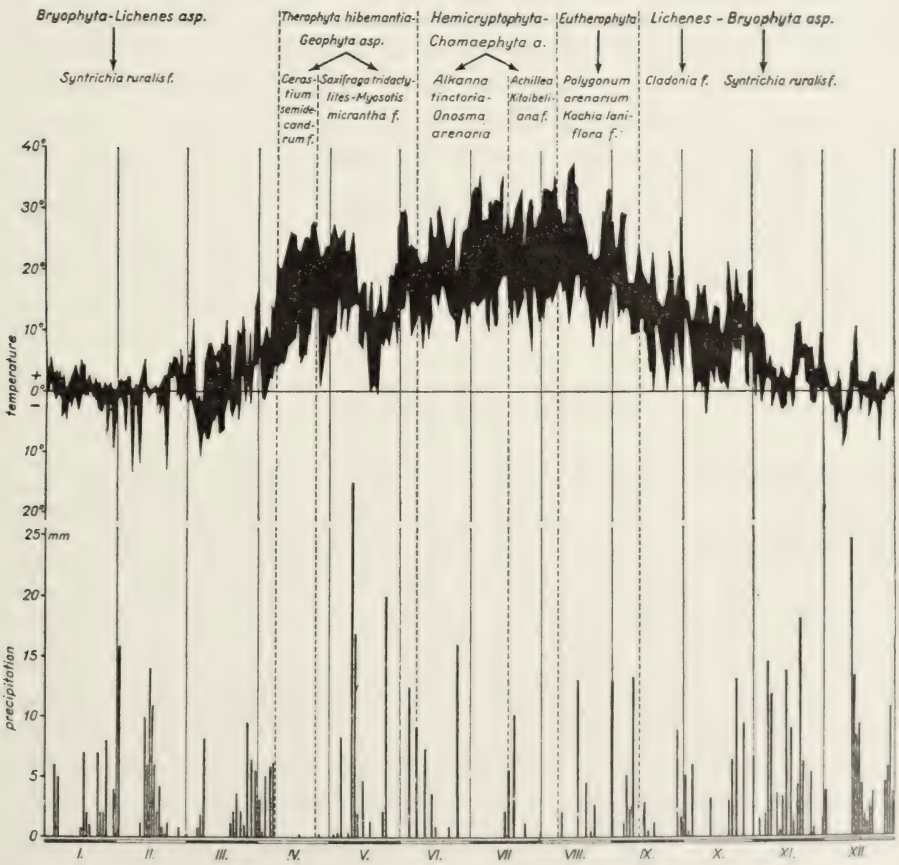

FIG. 3. Aspect scheme II. Aspect scheme of *Festucetum vaginatae danubiale* in the environment of Vácrátót in 1952

tion. The aspect scheme characteristic of the annual period is constructed on the basis of the overall table (aspect scheme I, II in Figs. 2 and 3).

In naming the aspects Raunkiaer's life habits of plant species in flowering, characteristic of the aspect, are used. Within the aspects the phases are separated by constant plant species appearing in masses and flowering in certain phases of the aspect.

In the complex diagram representing the annual periodical rhythm of the individual plant communities the aspects and their phases are shown as a function of time and compared with the rhythm of meteorological factors and of other important factors of the habitat.

VEGETATION MAPS AS CLIMATIC RECORDS

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Abstract — The high value of vegetation maps as climate indicators is demonstrated by various examples. Three main types of vegetation maps are discussed: (1) aclimatic Vegetation Maps: they are without reference to climatic aspects. (2) Quasi-climatic Vegetation Maps: although based (like Type 1.) more or less exclusively on phyto-coenoses, they reveal climatic features, but only by implication. (3) Climatic Vegetation Maps: they represent a systematic coordination of vegetation and climate and climatic boundaries and harmonize with vegetational boundaries.

Zusammenfassung — Der grosse Wert von Vegetationskarten als Klimaindikatoren wird an verschiedenen Beispielen demonstriert. Drei Haupttypen der Vegetationskarten werden diskutiert: (1) a-klimatische (2) quasi-klimatische, und (3) klimatische Vegetationskarten. Letztere stellen eine systematische Einordnung von Vegetation mit Klima dar und die Klimagrenzen harmonisieren mit den Vegetationsgrenzen.

Résumé — On démontre par de nombreux exemples la grande valeur qu'ont les cartes de la végétation utilisées comme indicateurs du climat. On discute trois types principaux de cartes de la végétation: (1) des cartes sans rapport aucun avec les aspects climatiques, (2) des cartes para-climatiques, c'est à dire basées essentiellement sur la phytocénose, mais tenant compte de certains éléments du climat et (3) des cartes climatiques de la végétation. Ces dernières cherchent à harmoniser systématiquement la végétation et le climat. Les limites de l'une et de l'autre y coïncident parfaitement.

INTRODUCTION: THE ELEMENTS

The geographical distribution of biota on earth depends on the character of the organism, the character of the environment and the evolution of both the organism and the environment. It depends therefore on four complex variables. The character of a plant species is very complex. Of its many facets, tolerance is perhaps the most significant one concerning the geographical distribution of species. The tolerance of a species is its genetically controlled ability to tolerate a certain amplitude of environmental conditions. Every species has its own tolerance which may or may not differ appreciably from the tolerance of the next species. The matter is complicated in that tolerance must be considered with regard to each individual aspect of the environment separately. For instance, a species may be able to tolerate a wide range of temperature, yet be very narrow in its tolerance of the soil acidity (pH); even a small change in the pH may make it impossible for such a species to survive. The problem is rendered still more complex by the fact that

the tolerance of a species varies with each ontogenetic phase. Thus, climatic conditions may be optimum during the germination phase but at a later phase, these same conditions may be quite harmful. For instance, the lowest temperature which *Pinus cembra* can tolerate in January is $-47°$ C, but in July its minimum temperature is $-7°$ C (Walter, 1951, p. 57).

But the species are not scattered through the landscape in haphazard fashion. Rather are they grouped into recurring combinations which are termed phytocenoses or plant communities.

One of the reasons for the rapidly spreading use of vegetation maps is the recognition that phytocenoses are valuable indicators of site qualities.

The high degree of accuracy in revealing the site qualities of the landscape has made the various phytocenoses of the vegetation the most valuable indicators of the biological potential of all sites. Therefore, vegetation maps increase in value with the growing understanding of the relations between plant communities and their environment.

Late in the 19th century, Schimper (1898) made a major effort to coordinate the geographical distribution of climates and vegetation types. His forests, grasslands and deserts expressed wet, periodically wet, and dry climates respectively, and his views were widely accepted. Later, Clements (1916) went so far as to say that the climate controls the vegetation to such an extent that within the region of a given climate all types of vegetation evolve toward a uniform climax. Today, the close relations between climate and vegetation are expressed, inter alia, by such terms as savanna climate, rainforest climate, tundra climate, steppe climate. In all these instances, the climate is characterized by the vegetation. The reverse happens, too, and such terms as cloud forests, alpine meadows, etc. imply a forest vegetation where clouds and fog prevail, and meadows of a climatic type characterized by a short, cool growing season, ample moisture, long snow cover, etc.

This broad and unspecified use of the term climate may be quite adequate in some cases and misleading in others. The climate, as all features of the environment, is highly complex and very difficult to describe in exact terms. Its major components are temperature, precipitation (both rain and snow), and wind. Atmospheric humidity, direct and diffuse insolation and a host of other factors, contribute to the complexity. These features vary with the seasons from continual high intensity to total absence as, for instance, in the case of insolation; northern Nigeria and northern Greenland illustrate some of the extremes. But the seasonal variation of a climatic factor assumes a new character when viewed in combination with others. Thus climatic conditions even within a given latitude may be almost totally unlike. A comparison of the climate at Oran (Algeria) with that at Tokyo (Japan) in the same latitude illustrates this: Oran experiences its rainfall maximum during the winter and has pronounced summer drought, whereas the rainfall maximum at Tokyo occurs during the summer with no dry period in any season. The contrast in the vegetation is startling.

Individual climatic factors may be used to illustrate the geographical distribution of phytocenoses. But this approach must needs be vague because often it is not feasible to establish such an individual factor. For example, temperature is often so elusive that any "official" observations made in a standard instrument shelter are meaningless.

Individual climatic factors must be employed with great care and caution if they are to be related to the geographical distribution of species or entire phytocenoses. Nevertheless, individual climatic factors have been used repeatedly to explain phytocenotic changes. Thus, Köppen (1931) used the arctic timberline to determine the boundary between his D and E climates. In northern Russia, he found this coincided with the 10° C isotherm of July.

Troll (1943) noted sharp vegetation boundaries in the high Andes of Peru where the temperature rises above 0° C during the day and drops below 0° C at night every day for most months of the year. This is a temperature condition outside the range of tolerance of most species and as a result, where this type of climate sets in, the relatively rich vegetation of lower altitudes changes abruptly to much impoverished phytocenoses of widely spaced cushion plants, dwarf shrubs and very tough bunch grasses.

In a similar fashion, an increase in the annual precipitation is illustrated by the increasingly luxurious character of the vegetation. A traveller, journeying from eastern New Mexico to eastern Tennessee along the 36th parallel will observe an impressive change from a few grass species of short stature to one of the tallest and richest forest types anywhere in the middle latitudes.

The effectiveness of exposure to sunlight depends on inclination and on latitude (See Boyko's IE-Factor (1947). In arctic regions, the vegetation on a south-facing slope benefits from the increased intensity of insolation and the resulting higher temperatures; it is therefore richer than on the northern slopes. However, in the Front Range of the Rocky Mountains in Colorado, the southern exposure means a poorer vegetation: shrub and grass as compared with the forests on the north-facing slopes. Here the insolation on the southern slopes is more powerful due to the lower latitude; the heating and hence drying effect produces semi-arid conditions whereas the cooler and hence moister northern slopes retain enough moisture to support forests.

In equatorial regions, there is usually little difference between northern and southern slopes with regard to insolation because the amounts of energy received is alike on both sides.

The moisture conditions of mountainous regions are not only dependent on altitude but also on exposure to rain-bearing winds. The starkest contrasts are produced where steady sea winds blow throughout the year more or less in the same direction. This is particularly true of the tradewind belts. In the outer tropics, where normally a rainy season alternates with a pronounced dry season, the tradewinds deposit heavy rain on the windward side of the mountains. Such orographic rainfall is, of course, relatively independent of the seasons. In the

high elevations, vegetation will be about the same on both sides of the mountains because ample moisture is available. But in the lower altitudes, as for instance in Jamaica, the mountains bear a dense tropical rain forest on their northeastern flanks while the southwestern foothills are covered with strongly xeromorph communities, rich in cacti.

Even wind as an individual climatic factor can sometimes find expression in the vegetation. However, this is only the case, when it is so strong and persistent that it inhibits tree growth in areas where the available heat and precipitation are ample to support forest communities. The best known examples are the Hebrides, Shetland, Kerguelen and similar islands that face frequent and severe storms.

THE TYPES OF VEGETATION MAPS

The number of correlations in the distribution of climate and vegetation might well lead one to believe that everywhere climate and vegetation are so closely coordinated that a vegetation map and a climatic map are essentially identical. This, however, need not be the case.

Both climate and vegetation are very complex and each can therefore be described in a variety of ways. Climatic maps cannot present all climatic features individually. They are usually based on only one or two features, more or less ignoring all others. A great variety of such climatic maps is published in the Atlas of American Agriculture (Baker, 1923). It happens often therefore that a change in vegetation is brought about by climatic features which are not recorded on the map. If, for instance, a climatic map is based on mean annual temperatures and mean annual precipitation, and the vegetation of two areas differs because of a difference in the seasonal distribution of rainfall, then a vegetation map cannot agree with the climatic map. Any other climatic cause may result in vegetational changes; yet this climatic map would not reveal them. In this case, parallels between the climatic map and a vegetation map can exist only where the vegetation changes because of changes in the mean annual temperature or precipitation.

The complexity of the climate finds its counterpart in the complexity of the vegetation. The floristic composition, the structure and all other features of phytocenoses are susceptible to change because of altered climatic conditions. But it is not feasible to predict with certainty just which feature will change for which reason. It may now be one and then another.

An important item which prevents vegetation maps and climatic maps from being alike is the reaction of vegetation to changes in the soil. The climate may be uniform over large areas but within such climatic regions several soil types may occur side by side. The conclusion seems inevitable that vegetation maps and climatic maps are unlikely to agree and that, due to more frequent changes in the soil, vegetation maps tend to be more complex than climatic maps.

The evidence is contradictory. On the one hand, climatic types seem to imply vegetation types and climatic changes seem invaribly to produce changes in the

vegetation. On the other hand, vegetation maps cannot reasonably be expected to agree with climatic maps unless, quite by chance, the latter are based on the particular climatic factor that affects the particular feature of the vegetation shown on the map.

The apparent dilemma disappears with the realization that there is no need for a mirror-like agreement between vegetation maps and climatic maps. It is enough that vegetation maps reveal climatic differences. Within one vegetation map the effects of different climatic factors may be revealed by different phytocenoses. The task is not to produce a climatic map which will faithfully reflect a vegetation map. It is rather to interpret the vegetation map in such a manner that observable climatic effects on the vegetation can be clearly discerned, whatever they may be.

In a sense, the inclusion of climatic features in mapping vegetation is a step in the direction toward mapping biogeocenoses, as in the case of vegetation–soil combinations. But such is the complexity of both vegetation and its environment, that such a first step implies but a small advance. Essentially, most such maps are vegetation maps with some added information.

The consideration of vegetation maps as a climatic record reveals three types of vegetation maps. The difference between them lies in the degree of coordination between vegetation and climate. The three types are (1) aclimatic, (2) quasi-climatic, and (3) climatic vegetation maps.

ACLIMATIC VEGETATION MAPS

The first type, the aclimatic vegetation maps, are prepared without any reference to any aspect of climate and they reveal none, whether directly or by implication.

QUASI-CLIMATIC VEGETATION MAPS

As in the case of aclimatic vegetation maps, the quasi-climatic vegetation maps, too, are based more or less exclusively on phytocenoses. But whether the vegetation consists of substitute communities or of phytocenoses of the real or potential natural vegetation, it is important to understand that climatic data were not taken into account during the preparation of the map.

Unlike the aclimatic vegetation maps, however, the quasi-climatic vegetation maps do reveal climatic features. They do this incidentally and by implication. They may do so in one part of the map and not in another, and they may reveal the effects of different climatic factors in different parts of the map. While it may not be the purpose of the vegetation map to show these climatic features, the reader is nevertheless enabled to glean climatic relationships from such a vegetation map. Quasi-climatic vegetation maps are therefore genuine climatic records to a varying degree and in preparing such maps, it is often difficult to foresee how much climatic information will be revealed by the vegetation.

The complexity of climatic conditions in areas with appreciable local relief was pointed out above. It is therefore not surprising that vegetation maps of mountainous areas are almost necessarily quasi-climatic in character. Altitudinal vegetation belts are well known everywhere, as are the contrasting conditions on north and south facing slopes. The effect of the differences in altitude and exposure is a matter of degree. At one extreme stand high mountains of alpine character with bold contrasts in climate and hence in vegetation. As altitudes get lower and the slopes gentler, the contrasts in climate and vegetation become more modest and the boundaries become blurred until at last, in gently rolling plains, the differences fade into the finest phenological nuances.

In areas with considerable local relief, climatic conditions may change frequently and within short distances. This is equally true of the mosaic of plant communities. Quasi-climatic vegetation maps are therefore relatively independent of the map scale where the relief is reasonably bold. In studying the aclimatic vegetation maps, it became clear that little or no relief was quite the rule, especially on maps of large scale. But this must not be interpreted to mean that a large scale necessarily implies an aclimatic character of the vegetation map. A good illustration is the map of the foothills of the Harz Mountains near Bad Harzburg by Tüxen (1954). This map is done at the scale of 1:10,000 and is based on the classification of vegetation by Braun-Blanquet.

Tüxen's legend contains no indication whatever of the interrelations between the distribution of phytocenoses and the local climate. To establish such interrelations, the reader is obliged to deduce them from the map where his success will be proportional to his experience and knowledge of local circumstances. Or else, he must refer to the text which accompanies the map. Not everybody is so familiar with the climate of the northern Harz foothills, the prevailing wind directions, etc., that he can get the full benefit of the map without consulting the text. The map is therefore not independent. It may, of course, be argued that such independence was not intended, that the map was expected to be accompanied by the text. But as it was the stated purpose of the author to study the vegetation as an expression of the complex local climate (Tüxen, 1954, p. 456), at least the more relevant observations might have been extended from the text to the map, thereby greatly enriching the latter. In other words, an expanded legend could have made this vegetation map a climatic record of more immediate usefulness, and this could have been done with relative ease since Tüxen's text contains the necessary data in a well ordered presentation.

The attempt to achieve such immediate usefulness was crowned with more success on the second example of a quasi-climatic vegetation map. This is the vegetation map of the Nanga Parbat group in the northwestern Himalayas at 1:50,000 (Troll, 1939). Although the scale is much smaller than that of the Harz map, this is not a matter of concern. Troll's map differs from Tüxen's map in two basic respects: the classification of vegetation is different and climatic correlations with the vegetation are incorporated into the legend. Many of the subdivisions of a major

vegetation belt are directly related to exposure but such is the contrast between northern and southern slopes that some phytocenoses can climb more than 1000 m higher on the sunny south side than in the shadier north, e.g. the *Artemisia* community.

Not all phytocenoses on this map are related to the climate, some definitely to the substratum. In some instances, the rockiness of the slopes is more significant than the exposure, as in the case of the little Pistacia trees which occur on both north and south facing slopes of the hot arid valleys below 2000 m. Like Tüxen's map of the Harz foothills, Troll's map of the Nanga Parbat is a good climatic record in a limited way, but with the added advantage of a more interpretive legend.

A last example of the quasi-climatic vegetation maps may be selected from the smaller scale maps. The vegetation map of Central Asia at 1:1,000,000 (Lavrenko and Rodin, 1956) comes in seventeen sheets, and the Tashkent sheet (K-42) may serve to illustrate a different method. On this map, a large number of phytocenoses is spread over a terrain which ranges in elevation from less than 200 m along the Syr Darya to over 4500 m. There is great uniformity in the lowlands and an increasing complexity with growing altitude. Both altitudinal zonation and exposure contrasts are clearly noticeable on the map. In essence, therefore, the scale has little effect on vegetation maps as climatic records.

Of the three quasi-climatic vegetation maps discussed above, the maps of Central Asia and of the Harz foothills are closer to each other in character than to the map of the Nanga Parbat, because they show the relations between climatic types and the distribution of phytocenoses mostly by implication. In order to appreciate fully what these relations are and how they function, it is necessary either to consult a text or else become familiar with the peculiarities of the local climates. On the Nanga Parbat map, on the other hand, the legend points out more of the crucial aspects of the climate and the resulting vegetation. This, then, leads to the conclusion that the manner of expressing the relationships between vegetation and climate is more significant than the scale in analysing a vegetation map as a climatic record.

CLIMATIC VEGETATION MAPS

The third and last type of vegetation maps is the climatic vegetation map. It is the most interesting type from the point of view of Ecological Climatography because it comes closer than either of the others to achieve a true climatic record with the help of vegetation.

The climatic vegetation map represents a systematic coordination of vegetation and climate. This means that throughout the area of the map, this coordination is applied to all types of vegetation and climate without exception. On the aclimatic maps, the vegetation is not coordinated with the climate. On quasi-climatic vegetation maps, some or even many relations between vegetation and climate are shown either directly or, more often, they are implied. But this rarely, if ever, inclu-

des all phytocenoses. On the other hand, the climatic vegetation maps are so organized that climatic boundaries harmonize with vegetational boundaries.

In the following paragraphs, the climatic vegetation map will be discussed with the help of four examples, each of which is quite different from the others. The discussion will begin with the map of the smallest scale and proceed to progressively larges scales.

The first example is the vegetation map of Guatemala at the scale of 1 : 1,000,000 (Holdridge, 1959). It presents one of the simplest and clearest methods of correlating vegetation and climate and the key to the method is given with the legend of the map. The reader is thus enabled to study the distribution of vegetation types throughout the country and, simultaneously, appreciate the climatic conditions that prevail in each vegetation type.

Holdridge has simply drawn three sets of parallel lines, inclined to one another at an angle of 60 degrees. One set represents mean annual precipitation in millimeters. All lines are equidistant but the values progress geometrically thus: 125, 250, 500, 1000, 2000, 4000, and 8000 mm. Another set shows mean annual temperatures in degrees centigrade: 0, 3, 6, 12 and 24° C. Finally, the third set of parallels follows almost inevitably, signifying evapotranspiration values thus: 0.25, 0.50, 1, 2, 4, 8 and 16. The over-all effect is that of a triangular honey comb in which each hexagon contains a specific type of vegetation because it finds itself at the intersection of given temperatures, precipitation and evapotranspiration. At its right and left sides, the drawing is flanked by latitudinal zones and altitudinal belts respectively. These zones and belts are so spaced as to harmonize with the main drawing. In this manner every vegetation type is at once coordinated with temperature, precipitation, evapotranspiration, latitude and altitude.

The second example shall be the vegetation map of Portugal at 1 : 500,000 (Pina, Manique and Albuquerque, 1952). The country is divided into a considerable number of "phytoclimatic" zones where each zone is presented as being characterized by a given type of climate and also by certain dominant plant species.

The climatic zones of Portugal are arranged in seven altitudinal groups, e.g. basal, submontane, montane etc. to alpine (!), and each of these groups consists of one to fifteen more restricted climatic types such as Atlantic or Mediterranean. The number of types in a group declines with increasing elevation above sea level. The phytoclimates are arranged in tabular form so as to facilitate the coordination of the local types with the altitudinal zones. The individual types may be combined so that such a combination presumably embodies the characteristics of all constituent types or implies a transition. In another table the climatic types are coordinated with characteristic tree species. A climatic type may have only one such characteristic species or as many as ten. For instance, the submediterranean climate corresponds to a forest vegetation of *Olea oleaster*, two pine species: *Pinus pinea* and *P. pinaster* and five oak species: *Quercus Ilex*, *Q. faginea*, *Q. lusitanica*, *Q. Mirbeckii* and *Q. canariensis*.

The third example of a climatic vegetation map is the Perpignan sheet of the vegetation map of France at the scale of 1 : 200,000 by Gaussen (1948). On this map, quite a different approach has been employed, based on the use and manipulation of color. Gaussen understood that to show both vegetation and climate meant to show more than is usually done on one map. Yet, the ways and means to show anything on a map are limited and Gaussen searched for a more economical method of using his limited means. He discovered that colors are used in order to create contrasts between the items shown on a map so that the reader might distinguish these more readily. This seemed a wasteful manner of using color and Gaussen greatly enlarged the scope of his map by giving colors a definite meaning. Suffice it so say that Gaussen arranges his colors according to the spectrum and with them describes climatic conditions. The red end of the spectrum corresponds to hot and dry conditions whereas the blue and black end signifies cold and humid conditions. In an elaborate system, Gaussen establishes the degree of dry or humid by the number of dry or humid months in the year, and the character of each month by the number of dry or humid days. All are clearly defined.

As in the cases of Holdridge and Pina, Gaussen observes that given climates go hand in hand with certain types of vegetation. He speaks, therefore, of plant climates naming, however, the plant quite specifically. For instance, on the map of Perpignan, a part of the area is shown in blue. Blue is close to the cool and humid end of the spectrum which, in this case (Perpignan) coincides with a natural forest vegetation of beech *(Fagus silvatica)*. Gaussen, therefore, speaks of a beech climate, characterized by cool summers, cold winters, ample precipitation in all seasons, fog, snow cover in winter, etc. Other climates are described in the same manner.

In addition to the main map, there is a series of smaller scale inset maps of the same area. Of these, two present the potential natural vegetation and a combination of precipitation and temperatures respectively. These inset maps, therefore, represent an additional feature correlating vegetation and climate in the mapped area. Gaussen's genius for organization and his vivid imagination have led him to produce a vegetation map which is so rich in information that it has never been surpassed. The basis of this wealth, however, is Gaussen's manner of showing vegetation and climate simultaneously, thus making his vegetation map very much a climatic record as well. Recently, the same principles were applied on a vegetation map of Tunisia at the scale of 1 : 1,000,000 (Gaussen and Vernet, 1958).

The final example of a climatic vegetation map is the map of Leonberg at a scale of 1 : 50,000 (Ellenberg and Zeller, 1951). This is, of course, a rather large scale and as indicated on the map, the manuscript was prepared on base maps at 1:25,000. When the scale is as large as this, it is no longer feasible to use ordinary meteorological data to describe the climate. The area is too small and the climatic differences within short distances are not recorded by the weather service in such detail that climate and vegetation can be correlated. Therefore the authors of the Leonberg map used the vegetation and its development through the seasons to gain the full appreciation of the climatic variations of their area. This phenological appro-

ach resulted in climatic types which are not based on quantitative data as in the case of Holdridge's map of Guatemala. They are relative to one another and can be used in their present form only in southwestern Germany. But the method in itself and as employed by Ellenberg and Zeller proved to be eminently successful.

An inset map, centered on Leonberg, shows the distribution of climates in southwestern Germany so that the area of the main map is integrated into the larger region surrounding it. The climatic types are based on phenological observations and are, therefore, quite literally "plant climates."

Ellenberg and Zeller enriched their map of Leonberg by introducing symbols for slopes, the critical features being the angle of inclination (steep or gentle) and the exposures toward north and south respectively. Other symbols mark the areas which are especially exposed to wind or protected from it during the growing season.

In spite of all this detail, the Leonberg map might not have succeeded as well as it did, had its authors not introduced edaphic information as well. In fact, the authors refer to their map as a "plant-site map" and, of course, the climate is only one of the various site qualities, albeit a major one. However, the map is a climatic record which, perhaps more than most vegetation maps, has been a major success in its practical application to local agriculture.

The discussion of various examples of aclimatic, quasi-climatic and climatic vegetation maps leaves no doubt that many vegetation maps are genuine climatic records. The examples have revealed a variety of methods for establishing such records but the important fact is now that there is indeed a variety of available methods and not just one. Considering the complexity of vegetation and of climate, a choice in methods means that the preparation of vegetation maps as a climatic record can be adapted to the purpose of the map. The greater the choice, the finer can the adaptation to a purpose be. Thus, for instance, there is a choice between arbitrarily fixed quantitative values on one hand, perhaps applicable over large areas, and relative values on the other, such as phenological ones, applicable only in a limited region, but with greater detail and meaning.

Two observations therefore stand out: (1) vegetation maps can be significant climatic records, and (2) a flexible approach permits their applicability to a wide variety of purposes.

One more point requires comment. A consideration of climates has led to some questions regarding their classification. Thus Garnier (Fosberg, Garnier and Küchler, 1961) takes the point of view that a classification of climates must be based exclusively on climatic criteria and that the classifier must not be influenced by vegetation as was Köppen, for example. This is not only a valid argument but one which is perhaps more logical and in many instances more useful, especially in an era when aeronautics are an integral part of civilization.

There is, however, another consideration, quite as fundamental as the foregoing. This is the effect of climate on agriculture, silviculture, range management and related forms of land-use. Even though aviation is now a part, if not indeed a symbol

of our civilization, agriculture remains man's most basic and essential activity, and there is every indication that this will continue to be so for generations to come.

The growing usefulness of vegetation maps goes hand in hand with a growing need for research in which the main problems concern the relations between phytocenoses and their sites of occurrence. World maps of vegetation and of climate must necessarily be drawn on a small scale and this applies even to maps of individual continents. On such small scale maps all features are so generalized that the chief purpose of the map can be little more than to present a broad view of the main features and the major characteristics of their distribution. This is valuable in itself, especially from a didactic point of view.

As the scale grows and more detail can be shown on the maps, new problems arise. The limitations of the small scale map change. If it revealed but a few items of world-wide significance, so the large scale map shows in detail the features and problems of local significance. Indeed, a large-scale map may be focussed on problems that do not exist elsewhere. In order to get the greatest benefit from a vegetation map for all aspects of land-use and land management (which includes planning), the map scale should be large. This permits a sharp focus on specific relations and problems with specific results. Such problems include the relations of the character and distribution of phytocenoses and their individual phases with the peculiarities of the microclimate. However, the larger the map scale, i.e. the more detailed the study, the more difficult it is to separate the various factors of a holocenotic environment. In the progress of research, such problems may find a solution. The solution may not be applicable over an area much larger than that of the map, but the method may lead to new solutions elsewhere and one success promotes another.

In the meantime, vegetation maps reveal the character, extent and distribution of phytocenoses in the landscape and, at least for those concerned with land-use, the climatic vegetation map remains one of the most realistic climatic records available today.

REFERENCES

Baker, O. E. (1923) Atlas of American agriculture. United States Department of Agriculture, Washington, D. C.

Boyko, H. (1947) On the role of plants as quantitative climate indicators and the Geo-ecological Law of distribution. *J. Ecol.* **35,** 138–157.

Clements, F., E. (1916) Plant Succession. Carnegie Institution of Washington. Publication No. 242.

Ellenberg, H. and Zeller, O., (1951) Die Pflanzenstandortskarte des Kreises Leonberg. 1:50,000. *Forsch. Sitzungsbericht der Akademie für Raumforschung und Landesplanung,* Band II. Hannover.

Fosberg, F. R., Garnier, B. J., and Küchler, A. W., (1961) Delimitation of the Humid Tropics. *Geographical Rev.* **51,** 333–347.

Gaussen, H. (1948) Carte de la végétation de la France, feuille Perpignan. 1:200,000. Service de la carte de la végétation de la France, Toulouse.

Gaussen, H., (1953) A proposed ecological vegetation map. *Surveying and Mapping* **13,** 168–173.

Gaussen, H., and Vernet, A. (1958) Carte internationale du tapis végétal, feuille Tunis-Sfax. 1 : 1,000,000. Service de la carte de la végétation de la France, Toulouse.

Holdridge, L. R. (1959) Mapa ecológico de Guatemala con la clave de classificación de vegetales de mundo. 1 : 1,000,000. Instituto interamericano de ciencias agricolas. San José, Costa Rica.

Köppen, W. (1931) *Grundriss der Klimakunde*. Walter de Gruyter, Berlin.

Lavrenko, E. M. and Rodin, L. E. (1956) Vegetation map of Central Asia. 1 : 1,000,000. Geobotanical Institute, Academy of Sciences of the U. S. S. R., Leningrad.

Schimper, A. F. W. (1898) *Pflanzengeographie auf physiologischer Grundlage*. Gustav Fischer Verlag, Jena.

Troll, C. (1939) Vegetationskarte der Nanga Parbat Gruppe (Nordwest-Himalaja). 1 : 50,000. *Wissensch. Veröffentlichungen des Deutschen Museums für Länderkunde, N. S.*, No. 7. Leipzig.

Troll, C., (1943) Die Frostwechselhäufigkeit in den Luft- und Bodenklimaten der Erde. *Meteor. Z.* **60,** 161–171.

Tüxen, R. (1954) Über die räumliche, durch Relief und Gestein bedingte Ordnung der natürlichen Waldgesellschaften am nördlichen Rande des Harzes. *Vegetatio,* **5–6,** 454–478.

Walter, H. (1951) *Grundlagen der Pflanzenverbreitung,* Teil I: *Standortslehre*. Verlag Eugen Ulmer, Stuttgart.

PROPOSAL FOR AN IDEAL CONTINENT OF PLANT RHYTHM

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Abstract — The author proposes a diagrammatic picture of an Ideal Continent of Plant Rhythm and natural Plant Communities over the surface of the earth. The basic theoretical consideration is: on a system of Cartesian axes, segments in proportion to the increasing values of solar radiation on the abscissae, and segments in proportion to the available moisture on the ordinates are described. Each point, determined in this way, will correspond to a theoretical plant community. In order to show the areas of natural plant communities in a single diagram, the author proposes to make an equilateral triangle on the base of which, from A to B, are the increasing values of solar radiation, and on the upright from D to the vertex C, the increasing values of the available moisture. These values will determine the formation of points corresponding to natural plant communities. The natural plant communities are placed on this Ideal Continent according to their respective rhythms, and separate entities are distributed according to their ecological needs. For every mutation of the ecological conditions of a station in one direction a plant migration in the opposite direction is possible.

Zusammenfassung — Der Verfasser schlägt die graphische Darstellung eines Idealkontinents über den Rhythmus der Planzen und der natürlichen Pflanzenformationen auf dem Erdglobus vor. Wenn in einem System kartesianischer Achsen Kreisabschnitte (Segmente) angebracht werden, die auf den Abszissen im Verhältnis zu den zunehmenden Werten der Sonnenbestrahlung und auf den Ordinaten solche, die im Verhältnis zur vorhandenen Feuchtigkeit stehen, so wird jedem so bestimmten Punkt eine theoretische Pflanzenformation entsprechen. Um die von den natürlichen pflanzlichen Formationen bezeichneten Flächen in einer Figur zusammen zu fassen, dient ein gleichschenkliges Dreieck, auf dessen Basis von A in Richtung B die steigenden Werte der Sonnenbestrahlung angegeben sind und in der Höhe von D in Richtung auf den Scheitelpunkt C die steigenden Werte der vorhandenen Feuchtigkeit. Die obengenannten Werte ermöglichen die Bildung von Punkten, die den natürlichen pflanzlichen Formationen entsprechen. Auf diesem Idealkontinent verteilen sich nicht nur die natürlichen Pflanzenformationen je nach dem betreffenden Rhythmus, sondern auch die einzelnen Individuen je nach den betreffenden ökologischen Bedürfnissen. Für jede Veränderung der ökologischen Bedingungen eines Ortes in einem bestimmten Sinn ist eine Wanderung der Pflanzen in entgegengesetzter Richtung möglich.

Résumé — L'auteur propose ici la représentation graphique, sur un Continent Idéal du Rythme des plantes et des associations végétales sur la surface du globe. Le schéma théorique fondamental est le suivant: si nous portons, en abscisse d'un système d'axes cartésiens des segments proportionnels aux valeurs croissantes de la radiation solaire, et en ordonnée des segments proportionnels à l'humidité disponible, une formation végétale théorique déterminée correspondra à chacun des points ainsi determiné. Pour indiquer les zones occupées par les associations végétales, l'auteur propose un triangle équilatéral, sur la base duquel l'on portera, dans un graphique, de A à B, les valeurs croissantes de la radia-

tion solaire, tandis que l'on reportera sur la hauteur de D au sommet C, les valeurs croissantes de l'humidité disponible. Ces valeurs déterminent des points correspondant à des associations végétales naturelles et nous pourrons remarquer que les déserts froids se concentreront en direction de A, et les déserts chauds en direction de B. La forêt équatoriale se rencontrera au voisinage de C. Toute autre association végétale se placera dans les zones intermédiaires. Les associations végétales naturelles se répartissent donc, dans ce Continent Idéal du Rythme, selon leur propre rythme chaque espèce ayant ses propres exigences écologiques et selon les limites de sa propre tolérance. A chaque changement dans une direction déterminée des conditions écologiques d'un milieu il se produit une migration de la végétation dans la direction inverse.

I WOULD like to propose, in this brief paper, the diagram of an ideal continent of rhythm in which the various plant communities and their rhythmic manifestations may be ideally represented.

At the first International Bioclimatological Congress held in Vienna in 1957, I hinted at the conceptions which I consider as being fundamental for the interpretation of rhythm in the manifestations of plant life.

I must premise first of all the distinction between specific or endogenous rhythm, belonging to separate individuals, and collective season rhythm, belonging to plant communities.

Every plant has its specific rhythm; when and where the surrounding conditions are most favourable the specific rhythm manifests itself and corresponds to the phenological one; when and where the surrounding conditions disturb it the phenological rhythm does not correspond to the specific one.

On the other hand, even a community, like every living thing, reacts to its surrounding conditions with the biophysical resultant of all the conditions undergone in the past, going back in time.

The physiognomy of a community and its rhythmic mutation is therefore the first unitary expression of the whole community.

In its turn synphenology is able to give a shape to this succession of happenings, as an expression of the rhythm imposed by external factors.

Where the conditions of the surroundings, especially the climatic ones, dominate, and I am referring to those regions in which more or less severe conditions of life prevail, there well-defined collective seasonal rhythms manifest themselves.

Where such conditions may be attenuated then the collective seasonal rhythms are attenuated as well and the specific rhythms appear.

Where the surrounding conditions are the most favourable the whole collective seasonal rhythm disappears to give place to a continuous manifestation of the multiplicity of the specific rhythms.

This is valid not only for different places but sometimes for the same place in the progress of time. Suffice it to remember the sub-Mediterranean surroundings; even if those factors which regulate the seasonal rhythm at the onset of the spring, and the temperature factor is then pre-eminent, in the course of time this rhythm almost disappears in the innumerable specific rhythms and continues until new factors –

when perhaps there is a scarcity of water – impose a fresh seasonal rhythm in the autumn.

How is this distribution of rhythm over the surface of the terrestrial Globe to be represented?

The fundamental, theoretical scheme which I propose is the following.

If, on a system of Cartesian axes, we place on the abscissae, segments proportionate to the increasing values of solar radiation and on the ordinates, segments proportionate to the available moisture, each point determined in this way will correspond to a theoretical plant community with the indication of the respective biological rhythm.

If we take into consideration then, only those points which correspond to actual surrounding conditions, we will see that they dispose themselves in our diagram in areas which correspond to natural plant communities actually distributed over the surface of the terrestrial globe and which also correspond to their respective biological rhythm.

It is possible to foresee at once that the positions of these areas in the diagram will either show, in accordance with certain modalities, the prevalence of the physical surrounding conditions with its consequent mechanical action tending to a general levelling of the phenomenon owing to which it moves from the differentiated towards the homogeneous and from the complex towards the simple, from the prevalence of the specific rhythms to the collective seasonal rhythms, or else they will show the prevalence of the typical phenomenon of the life in one particular environment which allows of their free manifestation, so that it moves from one homogeneous system to an always more differentiated one, and the seasonal rhythm is dissolved in the innumerable specific rhythms.

If I wish to include, in a single diagram, the above-mentioned areas I employ a triangle with these characteristics.

Let there be an equilateral triangle on the base of which, from A to B are shown the increasing values of total solar radiation and on the vertical from D towards the vertex C are shown the increasing values of the available moisture. These values will cause the formation of points corresponding to natural plant communities and we will see that towards A cold deserts will become more numerous; towards B, the hot ones and towards C we will find the equatorial rain forests. In the intermediate areas will lie all the other plant communities. To make my conception clearer it may be useful to refer to previous geobotanic research work, undertaken for the purpose of recognizing the distribution of natural plant communities according to their surrounding conditions.

For the sake of brevity I will confine myself to quoting only a few examples, drawn from the Climatic Kingdoms of Vegetation of Köppen (1901, 1923).

In the *kingdom of megatherm plants* the greatest wealth of the species is shown in the innumerable specific rhythms of each separate entity. This is still more evident in the equatorial rain forests which, in my diagram, would be placed at the vertex of the triangle.

Instead, in the *kingdom of the xerophile plants* the rhythm is conditioned strictly by the rainfall and therefore the period of quiescence lasts for most of the year, sometimes even longer, through drought. Its communities would be placed near angle B.

In the *kingdom of the mesothermic plants*, or temperate climates, with a slightly colder winter, or even colder still but with a mild summer or a form between the two, the rhythm passes gradually from summer quiescence in the first case, to the winter one in the second and to one with two seasons of quiescence in the third.

Finally in the *kingdom of the microthermic plants*, or the temperate region, where there may be spring, summer and autumn rains, and the covering of snow lies for a more or less long period during the winter, the collective seasonal rhythm is well defined and the communities tend always towards angle A.

The collective seasonal rhythm in the *kingdom of the echisthothermic plants* or cold climates, is still more evident. The rhythm is collective and of brief duration, and these communities tend still more towards angle A. Thus in the *kingdom of perennial cold* the rhythmic manifestation is very brief, and in some cases only occasional and caused by Kryoplancton; this one is placed even closer still to angle A.

Besides these very summary examples of the rhythms in the various vegetable kingdoms, which have been suggested by Köppen, (1901, 1923) (475) a glance at the classification of plant communities suggested by Brockman-Jerosch and Rübel (1912) and revised by Vierhapper (1918) for the purpose of gathering other examples, may be opportune.

Let us begin with woods Lignosa. The rain forests (*Pluvisilvae* and *Pluvifruticeta*), are extremely rich in vegetable entities in which the specific rhythm is very evident. Even in the Lauraceae forests (*Laurisilvae*) it is possible to have a very evident specific rhythm. A collective seasonal rhythm, observed by Schimper, appears in the monsoon forests, which should be dealt with separately.

In the stiff-leaved, hard-wood forests (*Durisilvae* and *Durifruticeta*), winter and spring are favourable to vegetable development, while the seasonal rhythm is to some extent marked by summer dryness. Nevertheless sometimes even in the summer the whole rhythm demonstration does not always cease completely.

Something quite different happens in the winter forests (*Hiemisilvae* and *Hiemifruticeta*) in which the quiescence and winter aspect are to be seen during the summer, through which the rhythm is collective and seasonal but is caused by the dry season. The opposite happens in the summer forests (*Aestilignosa* and *Aestifruticeta*), in which the collective seasonal rhythm is dictated by the dry cold during the winter.

In the needle-leaf woods (*Aciculisilvae* and *Aciculifruticeta*) only a few arboreal entities have a noticeable rhythm of leaves, for example the *Larix decidua*. It must be remembered, however, that the rhythm, which is not physiognomic but physiologic, is clearly indicated by the growth rings in the resinous entities and that

the anthesic phenomenon is always very evident although often of a paleo-rhythmic character.

If we wish to introduce the above-mentioned woodland communities into the diagram which I have suggested, for the purpose of showing the Ideal Rhythm Continent, we must imagine that the first two would fall gradually from the vertex while the third and the fourth would move towards the side C – B and the fifth towards the side C – A.

Instead in the bush formation of Ericaceae (*Ericifruticeta*), the presence of mycorrhiza complicates the interpretation of the phenological rhythm; in fact, in a way, the specific rhythm seems to be separate from the collective seasonal one causing phenoses.

Let us now glance at the meadows. The savannahs, with their numerous varieties, in the actual inter-tropical regions, have their own physiognomy which is mostly regulated by one period of rest and dryness only. Nevertheless it is very difficult here to make a schematic classification of their rhythm since the various savannahs have different rhythms. The only thing that can be said is that the change from less favourable climatic conditions to more favourable ones is evident and that the collective seasonal rhythm of these may partly disappear. The presence of a permanent water course may cause the sudden shift of the collective seasonal rhythm. The same may happen, where there is regular flooding from a distant catchment basin when a sudden collective rhythm may be observed.

On the Steppe (*Sicciprata*) the rhythm is dominated by two seasons and, contrary to what we have observed for the savannahs, it has two vegetable renewals during the year instead of only one. On the Pasture-lands of the high mountains (*Frigidiprata*), the rhythm is collective and seasonal and strictly bound up with the climatic conditions.

Here too we could imagine the first two communities tending towards the side C – B, and the third towards the side C – A.

In the marshes the rhythm seems very often influenced by one factor alone – solar radiation, but in salt marshes it may happen that during the summer there is a transition to surrounding conditions like those of the *sebchas* with a desert environment.

With regard to the deserts it is necessary to distinguish the hot deserts (*Siccissimideserta*), where rain may not fall for two or even more years, and the manifestation of rhythm differs according to whether we are dealing with the therophytes or bushes or succulents. These last may keep apart, or at least appear to do so, from the aridity, displaying a specific rhythm of their own.

In the cold deserts (*Frigidideserta*), it is solar radiation which controls the collective seasonal rhythm.

These deserts should be placed respectively as follows: the *Siccissimideserta* towards angle B and the *Frigidideserta* towards angle A.

After this summary and certainly imperfect description of examples for the purpose of demonstrating the Ideal Continent of Plant Rhythm which I propose,

it will not have escaped the observation of some that, like all syntheses, it is an abstraction and that in certain cases reality may contradict it. Nevertheless the diagram which I propose seems to me to be valid as a logical synthesis of the phenomenon and of its fluctuations over the surface of the terrestrial Globe.

Undoubtedly some communities, such as for example, those of the Ericaceae and the marshes, should be disposed in an irregular way in the triangle of the Ideal Continent, and this because other factors intervene besides those of solar radiation and availability of water, factors which it is not possible to take into consideration in a synthesis such as this.

To conclude I would like to draw a few more conclusions from the diagram of the Ideal Continent:

First, the natural communities of plants distribute themselves in this continent in relation to their respective exigencies.

Second, the separate entities distribute themselves each within the limits of their own tolerance.

Third, for every mutation in the ecological conditions of a station in one particular direction a plant migration in the opposite direction is possible.

In whatever way this synthesis of mine may be judged one thing that seems to me to emerge here also is that "reality is not diffuse and dispersive; on the contrary it is aggregative, ordered, structural . . . " (Smuts).

REFERENCES

KÖPPEN W. (1901) Klassification der Klimate. *Hettners Geogr. Z.* **6,** S. 106.

KÖPPEN W. (1923) *Die Klimate der Erde.* Berlin und Leipzig.

BROCKMANN-JEROSCH H. and RÜBEL E. (1912) *Die Einteilung der Pflanzengesellschaften nach ökologisch-physiognomischen Gesichtspunkten.* Leipzig.

VIERHAPPER, F. (1918) Zur Kritik und Klärung einiger pflanzengeographischer Begriffe und Bezeichungen. *Verhandl. Zool. Bot. Ges. Wien.*

ANOMALIE DANS L'APPARITION DES GELÉES PRINTANIÉRES EN SERBIE

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Abstract – During the night from 8 to 9 June 1962 heavy frost caused damage of vines in a vineyard in Vladimirovac near Belgrade. This vineyard with sandy soil shows a wavelike surface formation. Frost damaged vines were only found at the bottom of the troughs while the plants on top of the crests were unaffected. The difference in height between the crests and the troughs was only 0.5 to 1.0 m.

Zusammenfassung – In der Nacht vom 8. auf 9. Juni 1962 erfroren bei starkem Nachtfrost Weinreben in Vladimirovac, im Nordosten von Belgrad in einem grossen Plantagenweinberg, der auf Sandboden mit wellenartiger Bodenformation angelegt ist. Erfrorene Reben standen nur in den Geländeniederungen, die Reben auf den Wellenhöhen blieben unbeschädigt. Der Unterschied zwischen Wellental und Wellenhöhe betrug stellenweise nur 0,5 bis 1,0 m.

Résumé – Dans la nuit du 8 au 9 juin 1962, une forte gelée printanière sévit en Serbie. Elle causa le gel de la vigne à Vladimirovac, au nord-est de Belgrade . On y trouve un grand vignoble planté sur un sol sablonneux, ondulé. La gelée apparut dans les parties basses tandis que sur les crêtes, la vigne est restée indemne. Une différence d'altitude de 0,5 à 1 m entre les bas-fonds et les crêtes a suffit pour que l'on constate les différence notables mentionées plus haut.

INTRODUCTION

Les gelées printanières ont une importance spéciale pour la végétation, et avant tout pour les plantes sensibles. Si le printemps est tardif, et que toute la végétation se trouve encore dans le sommeil hivernal, les gelées printanières sont très peu nuisibles. Mais si les plantes se sont déjà éveillées par suite d'une période chaude et que commence leur période de végétation, une gelée printanière plus forte peut être particulièrement nuisible.

Selon la nature de son apparition la gelée printanière peut être advective ou radiative.

Gelées printanières advectives. Ces gelées ont des caractéristiques dynamiques et apparaissent durant l'advection de l'air froid. Dans notre région elles apparaissent le plus souvent durant les invasions des masses d'air froid du quadrant nord-ouest.

Gelées printanières radiatives. Les gelées printanières de cette sorte sont conditionnées par des facteurs locaux, et apparaissent durant un fort refroidissement de la surface du sol ou de la surface d'une couche de végétation, pendant un temps calme, serein et sec.

Il y a très souvent des gelées avec des caractéristiques mêlées, c'est à dire, qu'au début il y a invasion d'air froid, la température de l'air baisse brusquement et ensuite le temps devient serein et calme, et durant la nuit se produit un rayonnement fort et la température de la couche de l'air au voisinage du sol baisse au dessous de 0°.

L'intensité du rayonnement de la surface du sol et de l'air au voisinage du sol dépend du bilan thermique de la surface du sol et peut être calculé selon A. F. Tchudnowsky au moyen de l'équation suivante:

$$B = K + P + T$$

dans laquelle B est le rayonnement effectif de la surface du sol, K la réception de la chaleur de l'air par l'échange turbulent, P la réception de la chaleur des couches du sol plus profondes par transport d'une parcelle à l'autre, T le gain de chaleur causé par la condensation, d'environ 600 kcal/g de l'eau condensée par la rosée ou d'environ 680 kcal/g de formation de gelée blanche.

Le rayonnement effectif de la surface du sol dépend beaucoup du relief du sol, de la répartition des surfaces de forêts et de la proximité de l'eau. Les formes concaves du sol sont très favorables pour la formation des gelées printanières et aussi de la formation de gelée blanche sur une végétation basse.

Le vent qui cause la turbulence de l'air dans les couches au voisinage du sol, amoindrit en relation avec sa force la possibilité de rayonnement et des gelées radiatives.

En tout cas le refroidissement du sol et l'abaissement nocturne de la température dans la couche de l'air au voisinage du sol est fonction de l'intensité du rayonnement. Mais ce processus est d'autant plus marqué que:

– la nuit et plus claire – le ciel plus découvert et sans nuages,

– l'air est plus sec – parce que la vapeur d'eau, contenue dans l'air absorbe dans l'atmosphère les rayons profonds de la chaleur émis par le sol et l'air se chauffe ainsi,

– l'air est plus calme – parce qu'un air calme se refroidit au contact du sol froid plus vite, que l'air se déplaçant au voisinage du sol.

DATES MOYENNES ET EXTRÊMES DE L'APPARITION DE LA GELÉE PRINTANIÉRE EN SERBIE

On estime comme jour de gelée printanière le jour avec minimum de la température de l'air sous 0° C. Ce minimum de la température se rapporte à une hauteur de 2 m au dessus de la surface du sol dans l'abri météorologique. D'habitude

ce sont les températures observées à 7 heures du matin durant l'observation météorologique du matin.

Sur la base des observations météorologiques durant la période 1925 à 1940 ont a calculé les dates moyennes et extrêmes de gelées printanières en Serbie pour quelques lieux. Dans cette étude au tableau 1 sont représentées les dates pour les stations météorologiques qui ont une période d'observations ininterrompue de 1925 à 1940.

Tableau 1. Dates moyennes et extrèmes de gelée printanière ($T_{min} < 0°$ C) en Serbie

Stations	Date moyenne	Date extrême
Senta	14.IV	6.V
Stari Becej	3.IV	4.V
Novi Sad(Forteresse à Petrovaradin)	28.III	19.IV
Vršac	2.IV	3.V
Koviljaca	4.IV	6.V
Beograd	28.III	3.V
Kragujevac	5.IV	6.V
Vrnjacka Banja	9.IV	6.V
Niš	5.IV	6.V

Ces données montrent que dans les années 1925 à 1940 les dates les plus attardées de l'apparition de la gelée printanière sont dans la première décade de mai.

Mais, ces minima de température ont été observés dans l'abri météorologique. Il est bien connu que au cours de certaines nuits il existe une grande différence entre les valeurs du minimum de la température à 5 cm et à 2 m au dessus de la surface du sol, c'est à dire le minimum de la température à 5 cm peut être plus bas qu'à 2 m. Ainsi il peut apparaitre, qu'à 5 cm au dessus du sol le minimum de la température soit sous 0°, et à 2 m au dessus de 0° C. Un exemple pour la nuit du 21 au 22 avril 1953 montre que le minimum de la température de l'air à l'Observatoire Météorologique de Beograd a été à 5 cm de −3,5° et à 2 m dans l'abri météorologique de 0,4°. Ainsi, cette nuit-là à l'Observatoire Météorologique de Beograd, sur une végétation basse (par exemple sur l'herbe) il y avait une forte, gelée blanche tandis qu'aux rameaux des arbres au dessus de 2 m elle n'existait pas.

De telles gelées printanières se sont produites en Serbie du 19 au 22 mai, 1952 et ont causé assez de dégâts aux jeunes plantes basses, comme par exemple: au maïs, pois, pommes de terre, à la vigne. Ces gelées ont été fréquentes aux positions basses des vallées, auprès des lits des fleuves Velika, Južna et Zapadna Morava, Toplica, Nišava, Timok et autres fleuves, et aussi en Vojvodina. Comme exemple sera représenté au tableau 2 les minima de la température de l'air à 5 cm et 2 m pour quelques stations de Serbie.

Tableau 2. Minima de la température de l'air à 5 cm et à 2 m (dans l'abri météorologique) au dessus du sol

Date	19 mai 1952		21 mai 1952		22 mai 1952	
Station / Hauteur de la mesure	5 cm	2 m	5 cm	2 m	5 cm	2 m
Palic	−2,5	2,2	−2,5	1,6	−0,4	2,6
Bački Petrovac	−2,0	0,0	−1,9	0,0	-2,0	1,1
Novi Sad (Rimski Šančevi)	−1,1	1,6	1,6	2,0	−1,1	1,0
Beograd	−1,0	3,7	2,1	4,9	−1,0	3,5
Sm. Palanka	−4,1	1,0	0,0	5,2	-4,5	0,7
Cuprija	–	−1,6	–	4,5	–	−0,8
Kruševac	–	0,0	–	3,4	–	−0,7
Čačak	–	–	–	3,6	–	−1,3
Kraljevo	–	0,4	–	3,4	–	−0,7
Vranje	–	−0,5	–	2,2	–	2,0
Zaječar	–	−1,1	–	3,4	–	−2,6

L'apparition de la gelée printanière (et de la gelée blanche) au commencement de la troisième décade de Mai dans notre région peut être considerée comme une certaine anomalie, mais avec laquelle il faut conter pour l'avenir de l'agriculture de notre pays.

Mais en 1962 les gelées printanières sont apparu encore plus tard du 7 au 9 juin, et ont causé beaucoup de dégâts aux plantes cultivées déjà assez développées.

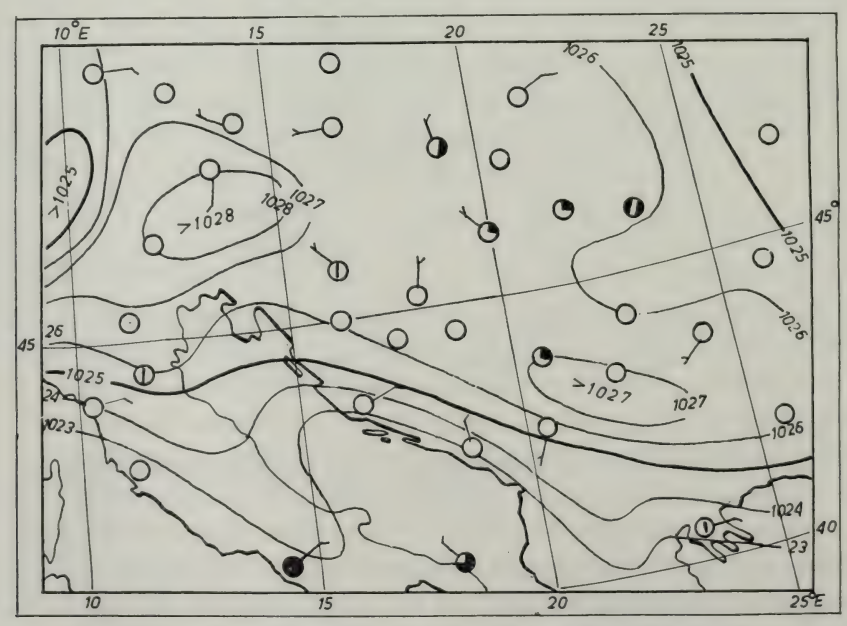

Fig 1. Situation météorologique le 9 juin 1962 à 01:00 h.

Les minima de la température de l'air à 5 cm de hauteur en beaucoup de stations ont été sous 0° C.

Cette dernière gelée printanière est apparue après une certaine invasion d'air froid du quadrant nord-ouest dans notre région. Après cette invasion il y a eu un temps calme et serein, et le rayonnement de la surface du sol durant la nuit a été intense, ce qui causa la baisse de la température de l'air sous 0° dans la couche d'air au voisinage du sol.

La situation météorologique générale du 9 juin, 1962 à 01 : 00 h est représentée à la Fig. 1.

De la Fig. 1 on voit qu'au milieu de l'Europe et la Péninsule Balcanique dans cette nuit il y avait un champ anticyclonique sans gradient situé environ à 1027 mb, ou 771,8 à 770,3 mm. Le temps était calme avec des vents faibles de différentes directions. Dans notre pays le temps a été surtout serein. Ces conditions météorologiques ont été très favorables pour le rayonnement intense de la surface du sol et le refroidissement de la couche de l'air au voisinage du sol sous 0°. Cela s'est produit en beaucoup de stations de Serbie, ainsi qu'on peut le voir au tableau 3.

Cette gelée printanière (gelée blanche) a été d'un caractère mixte, c'est à dire. une combinaison d'une gelée advective et radiative. Cette sorte de gelée peut être prévue avec succès par le Service météorologique synoptique.

Tableau 3. Minima de la température de l'air à 5 cm au dessus du sol le 9 juin 1962

Stations	Température (arrondie)	Stations	Température (arrondie)	Stations	Température (arrondie)
Palič	−1	Sombor	0	Kikinda	−2
Vrbas	0	Zrenjanin	−2	Rimski Šančevi	−1
Vršac	−1	Sr.Mitrovica	−2	Zemun Polje	−1
Vel. Gradište	−1	Žagubica	−2	Ćuprija	−1
Zaječar	0	Zlatibir	0	Sjenica	−4
Kuršumlija	0	Dimitrovgrad	0		

La répartition des minima de la température de l'air à 5 cm au voisinage du sol le 9 juin, 1962 est présentée à la Fig. 2.

Presque dans tout le Nord de la Serbie, à une partie de la Plaine de Panonie, les minima de la température ont été ou égaux ou inférieurs à 0°, ce qui a causé certains dégâts aux plantes cultivées basses sensibles.

Durant cette nuit entre le 8 et 9 juin, 1962, il y a eu une grave gelée de la vigne à Vladimirovac, près de Beograd vers le nord-est. On y trouve une grande plantation de vigne sur un sol de sable d'une forme ondulée. Cette forme du sol a été créée dans le passé quand le vent bien connu du Sud-est, appelé cochava a porté le sable mobile qui a formé des dunes de sable dans une direction normale à la direction

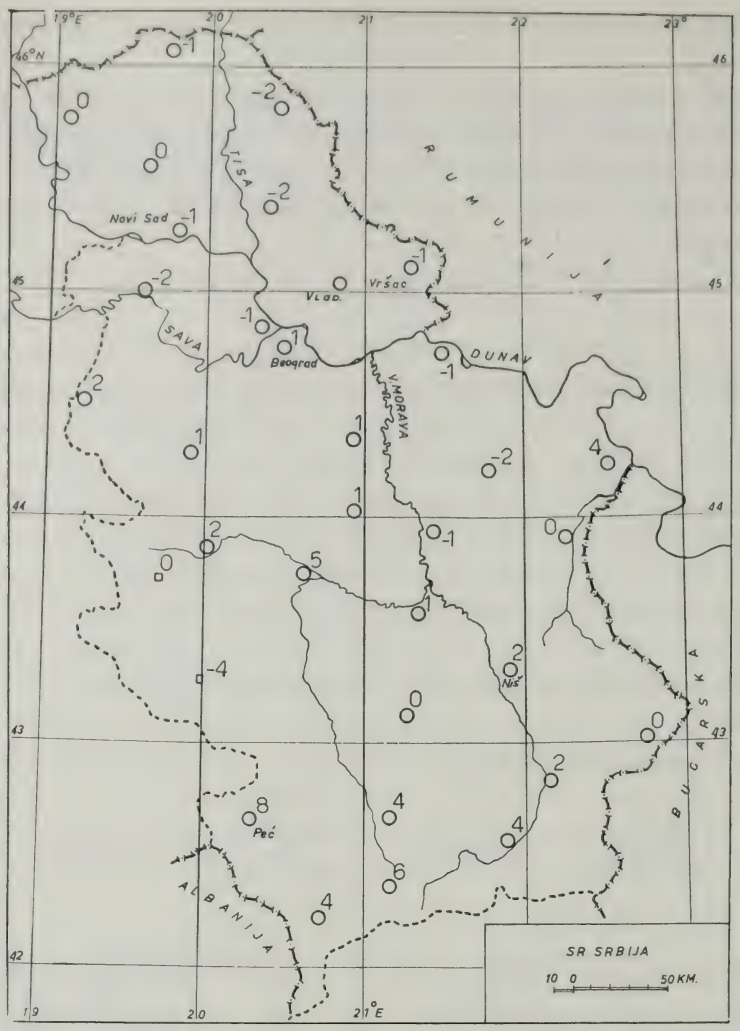

Fig 2. Minima de la température de l'air à 5 cm au dessus du sol le 9 juin 1962

du vent. Ce sable fut plus tard fixé au sol par la végétation et on y a planté des vignes et des vergers.

La gelée a sévi dans les dépressions, tandis qu'aux dos des ondulations les ceps sont restés intacts. En quelques lieux une différence de hauteur de 0,5 à 1 m entre le dos et le creux a été suffisante pour que la vigne reste intacte sur le dos, tandis qu'aux dépressions il y avait des dégâts assez grands et même complets.

Nous allons représenter ici encore quelques caractéristiques de la température de l'air en relation avec cette gelée du 9 juin 1962. Par exemple, le 8 juin dans les heures du soir la température de l'air dans l'abri météorologique a été assez haute, mais elle a baissé brusquement durant la nuit, et le 9 juin déjà aux heures du matin elle a promptement monté. Comme exemple on cite au tableau 4 la température de l'air dans l'abri météorologique à Vršac et Beograd.

Tableau 4. Température de l'air dans l'abri météorologique de 19:00 h le 8 juin à 07:00 h le 9 juin, 1962

Stations \ Heures	19	22	01	04	07
Vršac	11,2	5,0	3,0	2,4	7,4
Beograd	11,8	7,4	5,7	5,2	9,8

La variation de la température est mieux visible sur le graphique à la Fig. 3 où sont représentées les courbes de la température de l'air du tableau 4 à Vršac et Beograd (t_v et t_b).

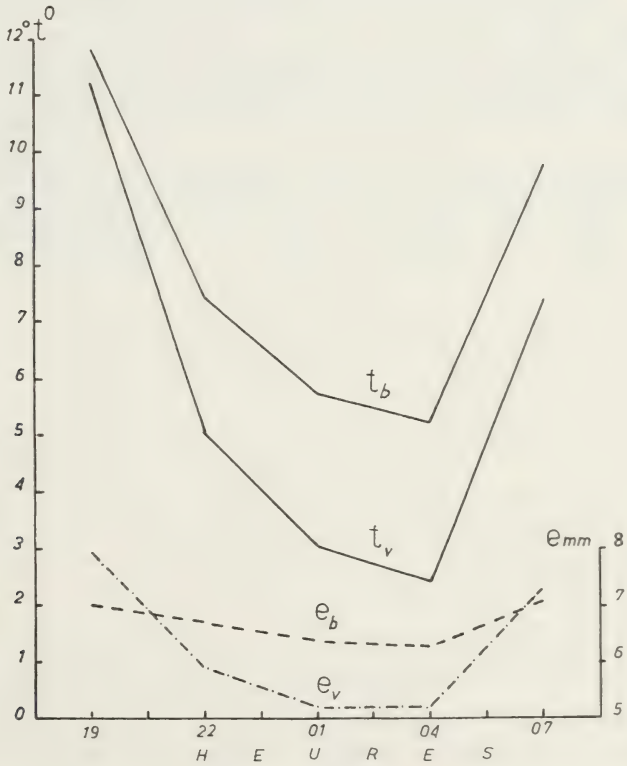

Fig 3. Courbes de la température de l'air et de la tension de vapeur d'eau dans l'abri météorologique de 19:00 à 07:00 h dans la nuit du 8 au 9 juin 1962. t_v-à Vršac t_b-à Beograd, e_v-à Vršac, e_b-à Beograd

Dans cette nuit le temps a été calme et serein. A côté de cela, l'air était assez pauvre en vapeur d'eau: Voici les données de la tension de vapeur d'eau à Vršac et Beograd, représentées au tableau 5.

La tension de vapeur d'eau, a donc été assez faible, spécialement à Vršac entre 01:00 et 04:00 h, et faisait 5,2 mm, ou 5,2 g de vapeur d'eau dans un mètre cube d'air. Selon les données de Belgrade, mesurées pour une longue période d'obser-

Tableau 5. Tension de vapeur d'eau en mm dans l'abri météorologique du 19 au 07:00 h dans la nuit du 8 au 9 juin 1962

Stations \ Heures	19	22	01	04	07
Vršac	7,9	5,9	5,2	5,2	7,3
Beograd	7,0	6,7	6,4	6,3	7,1

vations, la moyenne quotidienne de la tension de vapeur d'eau le 8 et 9 juin est 11,1 mm. Cela montre que ce jour-là éxistait dans l'air peu de vapeur d'eau et c'est pourquoi le rayonnement de la surface du sol a été tellement actif, et que l'air au voisinage du sol s'est refroidi au dessous de 0°. Cela a causé la formation de la gelée blanche.

A la Fig. 3 sont représentées aussi les courbes de la tension de vapeur d'eau à Vršac et Beograd (e_v et e_b) entre 19 et 07 h dans la nuit du 8 au 9 juin, 1962.

Sur la base des données montrées dans cette étude on peut tirer la conclusion suivante: En Serbie il faut compter avec des gelées printanières attardées même dans la première décade de juin. Cette règle vaut spécialement pour les localités situées dans les vallées et plaines et en général pour les terrains de forme concave.

INTRODUCTION TO PHYOCHOROLOGY OF NORDEN

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Abstract – The paper deals with the climatically conditioned forest yield potential in Norden. The relationships between the yield of the site in virgin stands and the climate of the site are examined by regression analytical computations.

Zusammenfassung – In dieser Arbeit wird das klimatisch bedingte forstliche Ertragspotential Nordens behandelt. Der Zusammenhang zwischen dem Ertrag des Standortes in Naturwald und dem Standortsklima wird mit Hilfe von regressionsanalytischen Berechnungen untersucht.

Résumé – L'ouvrage traite du rendement forestier potentiel du Nord contitionné par le climat. La relation entre le rendement de la station d'une forêt vierge et le climat de la station est examinée par l'analyse de la régressive.

PHYOCHOROLOGY is the science of the ecology and the geographic occurrence pattern of areal production. Its aim is to explain the different areal production factors, their importance, mutual relationship and the regional variation pattern. The duality of phyochorology is obvious: it analyses the production factors and opens, by synthesis, possibilities of regional comparisons.

In the present study the material refers to the conditions of the site – yield and climate. This means that the influence of outside factors affects the whole relationship, with an increased dispersion of data supporting the correlation as a result.

The plant physiological features of forest phyochorology point out that the climatic data of special interest are those primarily concerning light, temperature and water supply (Paterson, 1962). These factors were represented as far as the official international meteorological material admitted, in the formula for the CVP-index, invented by the author in 1956:

$\mathrm{CVP} = Tv \times N \times G \times E : Ta \times 12 \times 100$ (Tv = mean temperature of the warmest month; Ta = amplitude between the mean temperature values of the warmest and the coldest months of the year; N = mean annual precipitation; G = length of the growing season in number of days per year when the mean temperature amounts to or exceeds $+3°$ C, and at least two months with an average temperature each of more than $+10°$ C; in warm-temperate to tropical regions G = humid months with an index above 20 according to de Martonne's and Lauer's aridity index, $I = 12p : t + 10$; $E = 100 \times Rp : Rs$, where Rp represents radiation at the pole and Rs radiation at the latitude of the place under consideration, in both

cases with the use of Milankowith's figures for annual radiation at the earth's surface neglecting the atmosphere).

This formula has been given two slightly different forms in the recent investigation: first, the length of the growing season is expressed in days instead of months ($G : 360$), and second additional to the preceeding, the square root of N has also been tested, thus $CVP_1 = Tv \times \sqrt{N} \times G \times E : Tv \times 360 \times 100$.

The investigation of the phyochorology of Norden is built on forest yield data and meteorological data; there the influence of soil conductivity and stand composition has been tested in the statistical computations.

Yield data from 174 sample plots in Sweden are included in the study. Each plot contains an area of approximately 40×40 m. Data of lesser extent have been obtained from Denmark, Finland and Norway.

The Swedish yield data represent sites, with fully closed, natural stands. Due to the subjective choice of sites, however, the sample plots may not always be representative for average climatic conditions, but are better than normal edaphic ones, which may result in too high yield data. This seems to be the case especially in some parts of North Sweden.

Since the Swedish material is largest with respect to comprehensiveness and geographical distribution, it has been found suitable to use it exclusively in further compilations. The data from Denmark, Finland and Norway are used for comparison and for testing the conclusions drawn from the Swedish data.

The yield capacity of the site has been characterized by the mean increment per hectare per year, expressed in cubic metres stem wood over bark and above the stump. As the highest yield of even-aged, pure stand is recorded after natural thinning, or a thinning programme just preceding the natural mortality, mean increment in virgin stands may be considered a good expression of the yield capacity of a site (Carbonnier, 1962).

At the choice of sample plots it was necessary to get stands of Scots pine and mixed stands with Scots pine, at ages between 81 and 120 years. The measured yield of the sample plots does not include the depletion caused by natural thinning. According to recorded natural mortality in studies of naturally thinned check plots in permanent thinning experiments, an allowance could be given for natural mortality (*ibid.*, 1962).

At the statistical computations the material has been grouped in the age classes: 81–90 years, 91–100 years, 101–110 years, and 111–120 years.

The *meteorological material* is gathered from stations (107 in Denmark, 31 in Finland, 190 in Norway and 139 in Sweden) for which values concerning mean monthly temperature and mean monthly precipitation are available in meteorological tables.

The climate data for the sample plots have been computed according to the following method. For each sample plot two of the nearest climate stations are selected so that the line connecting the places passes through, or is very close to, the same plot. The location of the sample plot on the line and the values observed

at the climate stations are used for a computation of the temperature and precipitation values for the sample plot by interpolation.

The length of the growing season is computed by means of the climate diagram designed by Gaussen–Walter–Seljaninow. As a limiting value for computing the length of the growing season +7° C has been selected. This choice rests upon studies of the relationships between climate and the physiological variability of Scots pine by Langlet (1936). This worker found the best relationship with the number of days with +6° C and +8° C when comparing dry matter content and various temperature values. The length of growing season of the sample plots has been calculated according to the same method of interpolation used for temperature and precipitation. Two complete climate stations are selected on each side of the sample plot and with its connecting line passing through the plots. The growing season of each station is calculated to the elevation of the plot, and the difference between the values is divided on a linear scale and according to the location of the sample plot on the line. The question whether the decrease of the growing season by increasing altitude is based on a linear regression is of special interest. Langlet makes this assumption and finds that the growing season decreases 5 days per 100 m increase in altitude. Investigating some, meteorological stations in Norway, the author comes to the conclusion that the reduction of the growing season at increasing altitudes is not linear, but faster at low levels than at high levels (Table 1).

Table 1. Reduction in Number of Days of the Growing Season at Increasing Altitude within Various Zones

Zone	Increase in altitude per one day reduction of the growing season, m
0–100	8
100–300	15
300–500	20
500–600	24

(Paterson, 1962, p. 57)

A disturbing factor by calculating the growing season is the occurrence of dry and arid periods (definition see Paterson, 1962) within the area of investigation. By analysing the climate diagrams for all climate stations we find that drought periods occur during the growing season, even with arid spells as in Ulstad, Norway. The longest dry period recorded in Norden has the village of Lärdal at the innermost Sognefjord, where the drought begins in April and ends no earlier than July, i.e. a total of 108 days. An analysis of climatograms for some stations shows that even stations with very high precipitation suffer from dry periods during the growing season (Figs. 1–4).

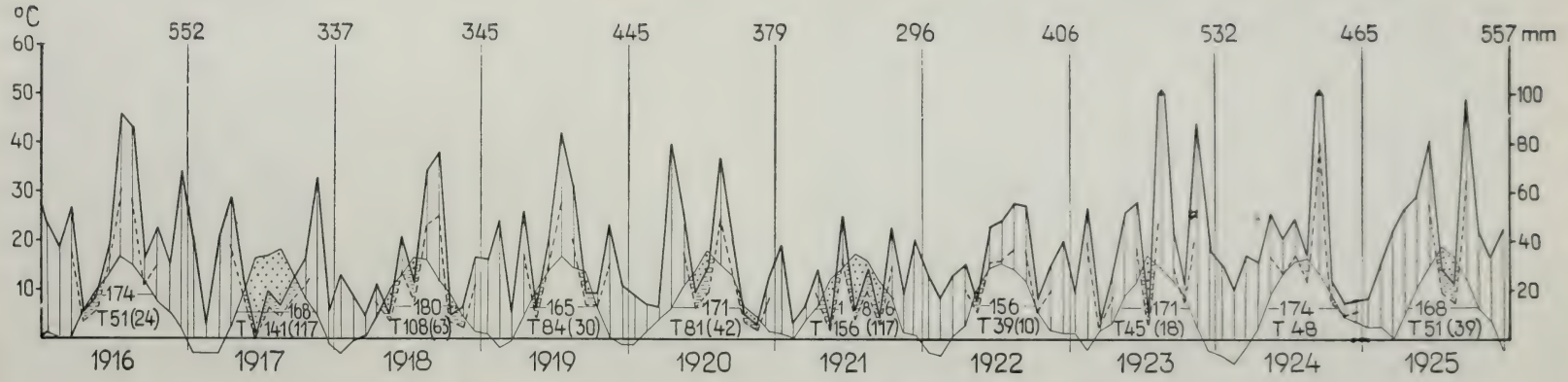

Fig. 1. Climatogram for Kalmar, Sweden, years 1916–1925

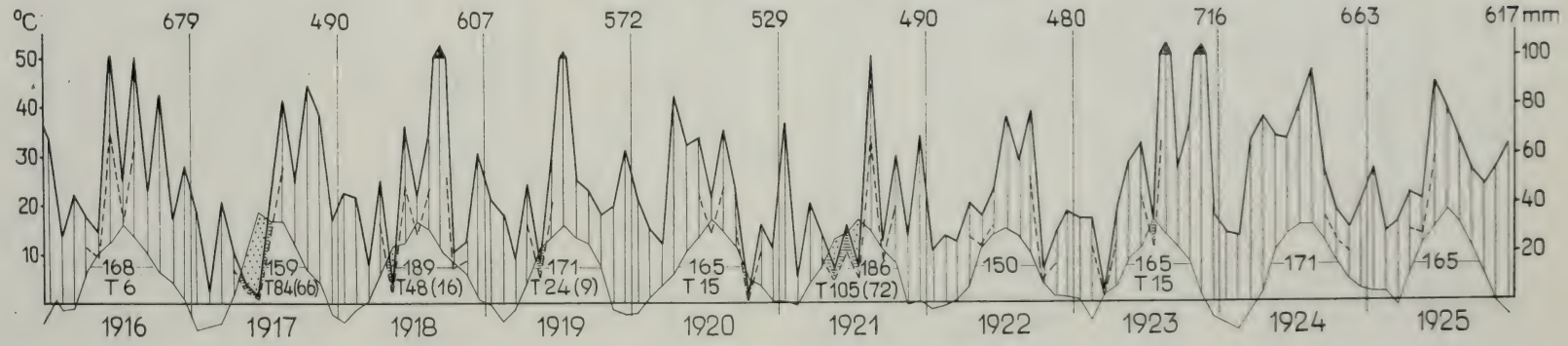

Fig. 2. Climatogram for Växjö, Sweden, years 1916–1925

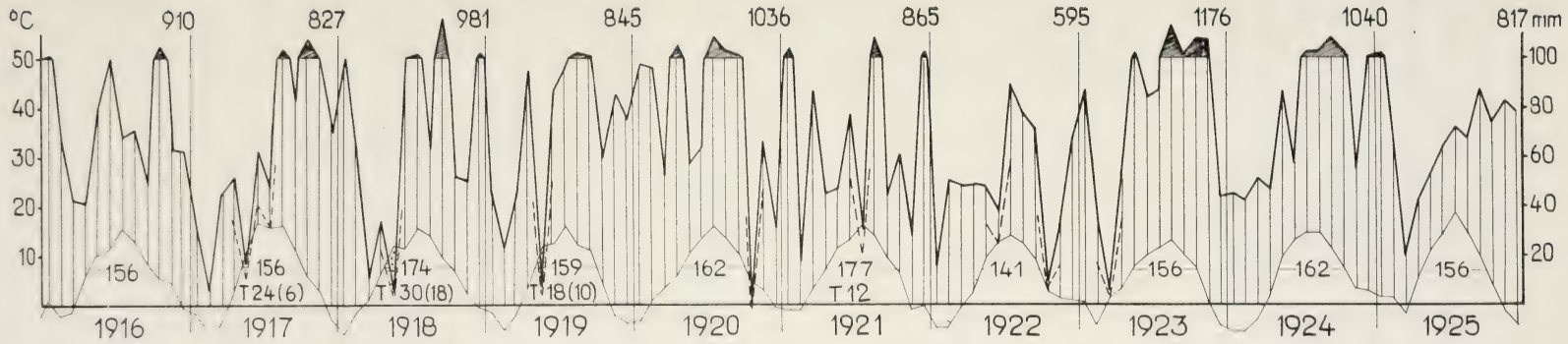

Fig. 3. Climatogram for Borås, Sweden, years 1916–1925.

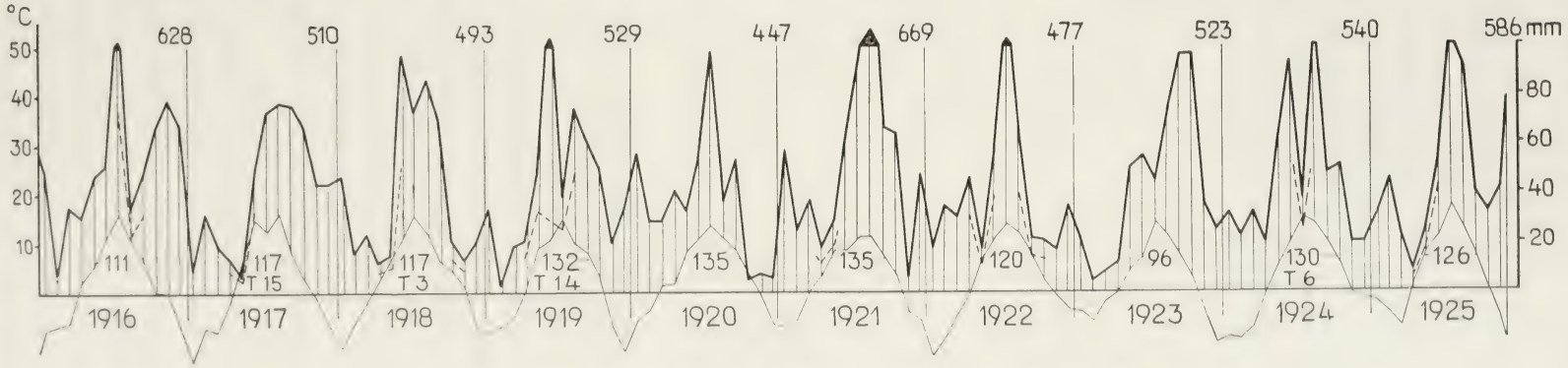

Fig. 4. Climatogram for Östersund, Sweden, years 1916–1925

The knowledge of the length of the drought period and its geographical location puts the relationship concerning the water management in forests in an informative light. The thermally determined growing season appears to be an insufficient definition of the time factor when included in a mathematical expression of the growth potential. A drought period during the growing season means a deficiency of precipitation in the forest. If this deficit is not compensated, the growth will be reduced, i.e. the yield lowered. The only possibility for the trees to satisfy their demand for water in a situation like this, is a supply of either capillary soil water or of a reserve of free soil water. To what extent such a supply exists is a question not only

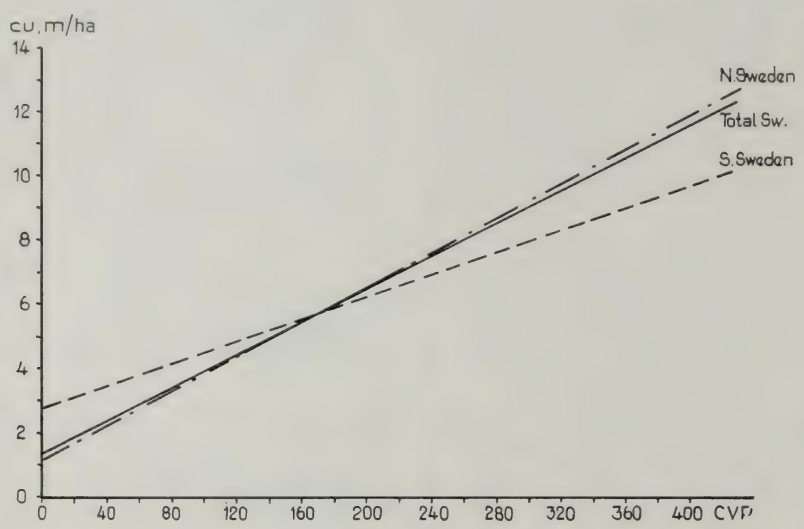

Fig. 5. Relationships between yield and CVP for southern and northern Sweden, respectively, and for the whole of the country

of precipitation before the drought but of soil conditions, topography, plant cover, etc. The rôle of the capillary moisture and the free water in the soil as drought period compensation, is a question that can be answered only by a surrender of the climatic basis of evaluation used when studying the mutual position of the ombrothermal curves, and a transition to a corresponding analysis of hygrothermal curves specially designed for the purpose. The hygro-thermal curves would then represent the combined influence of climate and edaphic conditions on the supply of water. To achieve this is to produce values for soil moisture, particularly in the root horizon, and its variation during the growing season.

As pointed out by the author in 1956 a precipitation too high in relation to temperature has a negative influence on the growth. This observation is made also in this investigation. It can be read from regression functions (Figs. 5 and 6) and from correlation computation. When other climate conditions are kept constant an increase in precipitation beyond a certain point effects reduced yield. A value of 600 mm seems to be the turning point in Norden (Patterson, 1962).

In a detail phyochorological investigation like this, we must expect an increased influence of edaphic factors in comparison with the interregional research method. To arrive at a practical useful index for the yield capacity of an individual site, attempts have been made to find an expression of the site factor feasible to incorporate with the CVP-index. Particularly one method has been tested, namely the one based on the procedure used by Hoagland and Burd for the measurement of the electric conductivity of the site (S). The sites lie mainly on moraine but a few are on sedimentary soils (25 sites). The soil profile is mostly podsolic, but brown soils are also represented to a minor extent.

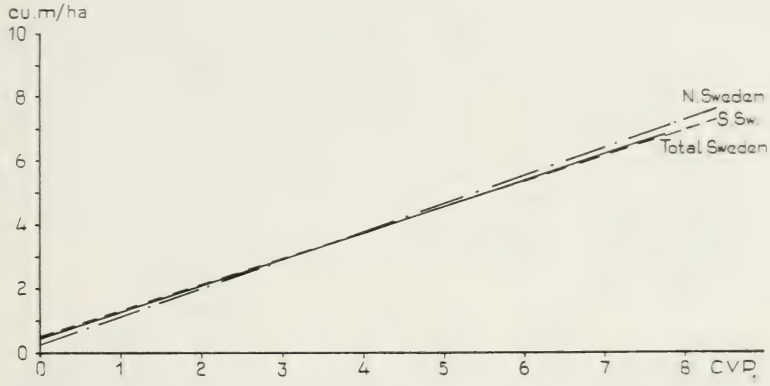

Fig. 6. Relationships between yield and CVP_1 for southern and northern Sweden, respectively, and for the whole of the country

By comparing the two relations, CVP-site yield and CVP$\times S$-site yield it appears that conductivity values below 0.5×10^{-2} ohm cm effect an improved fit, conductivity values of 0.8×10^{-2} and above give an impaired fit, whereas intermediate values have no distinct influence. The observations may be interpreted to mean that a nutrient concentration for conductivity values below 0.5×10^{-2} is too low for the trees to exploit the climatic bio-effect of its site. Equilibrium between the latter property and the supply of nutrients occurs at conductivity values between 0.5×10^{-2} and 0.8×10^{-2} whereas the bioclimatic effect is insufficient for the forest to utilize the good nutrient status of the sites at still higher conductivity values. Strengthened research efforts in this field are, however, necessary.

In our data on yield there is a weakness caused by the stand composition factor (Z). This influence has been elucidated in the statistical analysis. The portion of Scots pine of each sample plot is computed and entered as a new variable. The regression functions show that stand composition has an obvious influence on the mean increment.

THE STATISTICAL COMPUTATIONS

The statistical analysis has been carried out for the total material by means of a standard programme for regression analysis with the electronic computing machine, Facit EDB. The regression analysis has been supplemented by means of manual computations with both the total and the partial correlation coefficients up to third order. Totally 57 regression functions were obtained and found of value for a closer study of the dispersion (Person, 1962).

Only a few of all these functions can be discussed here and then only those which include terms with the strongest influence on the yield.

These are:

	dispersion of the function in per cent of the gross mean value
$y = 7.06 + 0.300Tv - 0.338Ta$	73.9
$y = 1.18 + 0.0257\ \mathrm{CVP}$	77.7
$y = 3.47 + 0.0204\ \mathrm{CVP} - 0.222\ Z$	73.1
$y = 3.027 + 0.0172\ \mathrm{CVP} + 0.7830\ \mathrm{S} - 0.0217\ Z$	71.7
$y = 0.443 + 0.814\ \mathrm{CVP}_1$	71.8
	($r = 0.70$)

Being most suited methodically, the last function was applied in the computation of the potential yield. The reason is that the CVP-(CVP_1)-index covers the mutually varying relationships of the composite factors to give them comparable expression. The best example is provided by the conditions prevailing at the boundaries of dry deserts and cold deserts. Although these areas are conditioned by entirely different minimum factors, precipitation and temperature, respectively, the CVP-index presents the same value for both boundaries, the climato-isophyte 25 (Paterson, 1956).

The relationship of the individual climate elements with the growth potential has been analysed for the total material (*ibid.*, 1962).

The total correlation coefficient of Tv (2), $r = 0.46$, represents a weak relationship. The partial correlation coefficient informs that Tv is strongly correlated with both Ta (3) and G (6):

$$r_{11\ 2.3} = 0.18 \qquad r_{11\ 2.6} = -0.08 \qquad \text{and} \quad r_{11\ 2.3.6} = 0.05$$

The temperature range and the growth potential are obviously correlated; $r_{11\ 3} = -0.66$. It is interesting that this correlation is considerably less influenced by Tv, $r_{11\ 3.2} = -0.56$, than the latter factor is correspondingly influenced by Ta according to the previous paragraph. Considerable influence is exerted by G on Ta since the correlation coefficient decreases to $r_{11\ 3.6} = -0.24$, if G is kept constant. Accessory correlation coefficients of the second and third order cannot impair the latter correlation to any appreciable extent.

FIG. 7. Map of the potential productivity of Norden's forests

Of all climate factors considered, precipitation has the weakest influence on the variation of yield, $r_{11\ 4} = 0.38$. The correlation coefficients of higher order show that precipitation is a variable dependent on temperature range and growing season to a considerably larger extent than the latter factors are dependent on precipitation.

The growing season shows a clear relationship with the growth potential, $r_{11\ 6} = 0.66$. This relationship is strongly influenced by Ta, $r_{11\ 6.3} = 0.20$, and weakly by Tv, $r_{11\ 6.2} = 0.53$. Precipitation has no pronounced influence.

THE POTENTIAL PRODUCTIVITY OF NORDEN'S FORESTS

Since the CVP-(CVP_1)-index is an expression of the climatic bio-effect it is possible to calculate the growth potential. The method was developed by the author in 1956. The map, Fig. 7, shows the climato-isophytes for both CVP and CVP_1 and the phyochores lying between. The result of the computation and comparisons with the official estimates of the mean annual increment and the annual depletion by felling operations is shown in Table 2.

Table 2. Comparison between Estimated Values of the Potential Productivity, Mean Annual Increment and Annual Depletion

Country	Potential productivity	Increment	Depletion 1957–58
	mill. m³		
Denmark	2.5	2	2
Finland	62.5	55	36*
Norway	20	16	9
Sweden	84	68	44†

*Mean value of the 1954 and 1957 estimates.
†Mean value of the 1954, 1957, and 1958 estimates.
(Paterson, 1962, p. 103)

The results obtained in this investigation lay stress upon the necessity for future detail phyochorological work to study the climatic and soil moisture conditions of the site, and at the same time to measure the physiologic manifestations of growth, such as length, height and radial growth. For this purpose the author has been given a grant to raise three phyochorological field stations in south Sweden. One station lies within a rather dry area (precipitation 464 mm), one within an area with very high precipitation (1000 mm), and the third one in a transitional position (593 mm). At the start of the growing season in 1964 all three stations will be in full operation and the following recording will be made: radial, height and

length growth of Norway spruce and Scots pine; soil moisture at a depth of 15 cm and 50 cm; soil temperature, precipitation, air temperature, relative humidity, solar radiation and thunder frequency.

The material will later on be analysed according to the regression analytic method here presented.

REFERENCES

Carbonnier, Ch. (1962) see Paterson, St. St. (1962, p. 45).

Langlet, O. (1936) Studier över tallens fysiologiska variabilitet och dess samband med klimatet. Ett bidrag till kännedomen om tallens ekotyper. (Studien über die physiologische Variabilität der Kiefer und deren Zusammenhang mit dem Klima. Beiträge zur Kenntnis der Ökotypen von *Pinus Silvestris* L.). *Meddelanden från Statens Skogsförsöksanstalt*, hf. 29, N:r 4, Stockholm.

Pardé, J. (1959) Retour sur l'Indice CVP de Paterson. *Revue Forestière Française*, No. 1, Janvier 1959.

Paterson, St. St. (1956) The forest area of the world and its potential productivity. Diss. Göteborg.

Paterson, St. St. (1962) Introduction to phyochorology of Norden. *Meddelanden från Statens Skogsförskningsinstitut*, **50,** No. 5, Stockholm.

Person, O. (1962) see Paterson, St. St. (1962), p. 69).

Weck, J. (1955) *Forstliche Zuwachs- und Ertragskunde*. Radebeul und Berlin.

COASTAL SANDDUNE VEGETATION IN RELATION TO WIND CLIMATE

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Abstract – Transpiration determinations were carried out on leaves of *Ammophila arenaria* on 2 to 3 typical days of each month for one year. The leaves were weighed before and after a 3-min exposure and the wind velocity and other meteorological factors were measured simultaneously. When wind velocities rose above 3 m/sec, transpiration rates were between 200 – 300 mg/g/hr. In the case of better water supply nearer the sea-shore, only velocities above 5 m/sec caused such low transpiration rates. The other factors did not interfere with this correlation between wind and transpiration, even when they appeared in distinct amplitudes, as: air temperatures from 22.5 to 32.1 °C; relative humidity from 60 to 66%; evaporation (Piche) from 0.75 to 1.02 cm^3/hr; cloudiness (0/8 to 3/8). When the other factors were favourable to the water balance of the plant, transpiration rates remained low, when wind velocities were high. High transpiration rates were accompanied by low wind velocities. There was a rapid reaction to strong winds which seems to be characteristic of drought resistant plants. The ability of the plant to open and shut its stomata rapidly seems to facilitate the increase of transpiration and gas-exchanges at calm moments, even in the dry and hot season.

Zusammenfassung – Während einer Exposition von 3 Min zwischen dem 1. und 2. Wiegen für Transpirationsmessungen von Blättern *(Ammophila arenaria)* wurde die Windgeschwindigkeit und andere meteorologische Faktoren gemessen, an 2–3 typischen Tagen in jedem Monat während eines Jahres. Die Auswertung ergab: Bei Windgeschwindigkeiten von mehr als 3 m/sek lag die Transpirationsrate zwischen 200 – 300 mg/g/hr. Bei besserer Wasserversorgung in der Nähe der Küste fand sich ein so niedriger Wasserverlust nur bei Windgeschwindigkeiten von über 5 m/sec. Andere Faktoren waren ohne Einfluss, selbst bei grösseren Abweichungen, z. B. Lufttemperatur 22,5–32,1° C, R. H. 60–66%, Evaparation (Piche) 0,75–1,02 cm^3/hr und Bewölkung 0,8 bis 3/8. Selbst wenn die anderen Faktoren für die Wasserbilanz der Pflanze günstig waren, blieben die Transpirationsraten niedrig solange die Windgeschwindigkeiten hoch waren. Hohe Transpirationsraten fanden sich immer bei niedrigen Windgeschwindigkeiten. Die Fähigkeit der Pflanze ihre Spaltöffnungen rasch zu öffnen und zu schliessen scheint die Transpiration und den Gasaustausch in jedem übrigen Moment zu erleichtern, selbst in der trockenen heissen Jahreszeit. Die rasche Reaktion bei starken Winden scheint eine charakteristische Eigenschaft von Pflanzen zu sein, die widerstandsfähig gegen Trockenheit sind.

Résumé – On a déterminé la transpiration de feuilles de *Ammophila arenaria* pour deux ou trois journées typiques de chacun des mois d'une année. Les dites feuilles furent pesées avant et après une période de trois minutes durant laquelle elles étaient exposées au milieu ambiant. Durant ce même laps de temps, on a en outre mesuré la vitesse du vent et d'autres éléments météorologiques. Si la vitesse du vent était supérieure à 3 m/sec, la transpiration était comprise entre 200 et 300 mg/g/hr. Dans le cas d'un meilleur approvisionnement en

eau de la plante, c'est à dire au bord de la mer, seuls des vents de plus de 5 m/sec ont provoqué une transpiration aussi faible. Les autres éléments météorologiques n'ont pas eu d'influence, même s'ils variaient dans des proportions appréciables telles que: température de l'air entre 22,5° et 32,1° C, humidité relative entre 60 et 66 pour cent, évaporation (Piche) entre 0,75 et 1,02 cm³/hr, nébulosité entre 0/8 et 3/8. Même si les autres éléments météorologiques étaient favorables au bilan hydrique de la plante, la transpiration en est restée faible tant que le vent était fort. Une forte transpiration n'apparût que par de faibles vents. La particularité de cette plante de fermer et d'ouvrir rapidement ses stomates semble favoriser la transpiration et les échanges gazeux par temps calme, même durant la saison sèche et chaude. Un réaction rapide aux vents violents semble être une propriété caractéristique des plantes résistantes à la sécheresse.

I WISH to summarize some points in the field of wind influence upon a vegetation which has to withstand high wind velocities during most days of the year, namely the vegetation of the sanddunes.

We in Israel, having an area of appr. 0.5 million acres of sanddunes which constitutes a quarter of the total area able to be developed by non-traditional methods, have begun to do research work in this field for the following reasons:

(1) A great deal of research work has already been done on the relation of vegetation to wind by such workers as Boyko, Nägeli, Stocker, Walter, Gäumann, Griepe and Yoschino. It seemed to us to be worthwhile investigating this relation in regard to sandbinding plants which live under extremely severe conditions, so as to arrive at a better understanding of what happens in this kind of plants.

(2) For sanddune fixation purposes, we are interested in finding those wild species of plants which are the most resistant to strong winds. These species can then be used specifically as good wind breaks, which is well known to be one of the most difficult problems of sanddune fixation and reclamation.

(3) The point is whether wild species develop special adaptions of growth under the influence of different wind frequencies or velocities. If we are able to determine these special forms, we can then use them as indicators of the wind climate of a certain area and this would be of more significance than pure meteorological data.

Does the sanddune vegetation react to wind influence like other types of vegetation or do sanddune species react in a specific way? The data of Martin and Clements who investigated the influence of wind upon Mesophytes, show that under the influence of high velocity-winds the total surface area of the leaves reaches only a quarter of the area of leaves which are not exposed to wind. The stems were half the normal height and the total weight of the dry material of the plant was only a third of the corresponding weight of Mesophytes living in still air, when all other microclimatic and edaphic conditions were the same.

Many investigations were made also to test wind influence on plant transpiration. The findings of these investigations were that as a whole the rate of transpiration increases with increasing wind velocity. After 6 weeks, three different lots of plants under continuous wind velocities of 5, 10 and 15 m.p.h. use water at rates about 20, 35 and 50 per cent respectively higher per unit area of leaf surface than control plants grown in still air. A wind velocity of no more than 2 m.p.h., when

occurring intermittently, increased the transpiration from 20 to 30 per cent. Higher velocities resulted in greater losses, increasing the transpiration rate up to 78 per cent and even to 138 per cent more than that of control plants.

If similar phenomena occurred in the sanddune species, we would find no plant life at all and we would not be able to introduce permanent vegetation in these areas, since besides the constant wind storms, most of the other conditions are most unfavourable to plant life. (a) Nutrients in the dune sand are very poor. (b) The sand has a low water-holding capacity. (c) The upper layer of the soil dries out very rapidly, since in the arid and many semi-arid regions, there are no rains from April to October. During this period, the sand becomes very hot and may attain a maximum of 45.7° whereas the air temperature attains only 32° at the same time. This means that plants in this area must be able to withstand relatively high ground temperatures. (d) Maximum evaporation in the air near the sea-shore attains 1.1 cm^3/hr which is quite high. (e) On the other hand, there is a favourable factor: the air humidity which varies between 50 and 60 per cent during most of the year. However, there are many days of the year in which the humidity is much less, because of desiccating eastern winds which are called by the Arabs: *Hamsins*. The word is derived from the number 50, as they believe that there are only 50 days of such eastern winds during the year. In reality, there are many more. Meteorological measurements conducted by the Israeli Meteorological Service during a period of ten consecutive years showed that almost half of all strong winds (above 6 Beaufort) or 44 km/hr) are eastern winds. These cause severe damage to plant and man and discomfort to animals. From these details, we see that there are many extreme conditions with which the sanddune plants are confronted. Hence, the question is how they are able to live at all in these severe conditions and how they react to the wind. Our topic in this paper is to deal only with the last question.

METHODS AND RESULTS

We tried to observe the wind influence upon the plant transpiration. Instead of laboratory measurements such as those of Martin and Clements, we detached leaves of the living plant (we used Marram grass, *Ammophila arenaria*) and determined the rate of transpiration by weighing the leaves near the mother plant, in the field, in the dunes, with Huber's torsion balance. The leaves, as is well known, are left exposed to wind and sun, for exactly 3 min. The loss of fresh weight which occurs during these 3 min indicates the rate of transpiration. During these 3 min wind velocity was measured by hand anemometer. Other microclimatical factors were measured at the same time, including evaporation by Piche, relative air humidity and air temperatures by a whirling hygrometer. Cloudiness data were taken from the nearest meteorological station at Haifa-harbour. These measurements were taken during 12 continuous months, on 2–3 typical days each month. Measurements were carried out at three stations, Sta. 1 with lower soil humidity than Sta. 2, both

of them 1 km distant from the sea-shore and Sta. 3. – on the sea-shore itself. The results in Table 1 include only wind velocities increasing 3 m/sec.

Table 1.

	Date	Hour	Wind m/sec	Transp. mg/g/hr	C°	Air hum. %	Piche cm³/hr	Cloudiness 0 – 8/8
	11.7	11.26	3.1	422	31	61	0.8	1/8
STA. 1	11.7	12.04	3.2	340	30.5	58.5	0.8	1/8
	28.8	11.18	7.1	200	31.5	73	0.8	0/8
	28.8	13.16	4.75	200	32.0	68	1.03	0/8
	13.11	10.39	5.0	296	22.5	40	0.44	4/8
STA. 2	12.7	13.50	3.0	630	32	57	1.2	2/8
	12.7	16.16	4.0	600	29	66	1.2	2/8
	28.8	12.18	4.4	450	33	68	0.75	0/8
	28.8	13.10	6.1	420	32	71	0.78	0/8
	28.8	15.32	5.0	348	31.5	73	1.2	0/8
		15.52	5.0	430	32.5	65.5	1.2	0/8
	28.8	13.52	5.0	454	32	62	1.2	0/8
	28.8	13.52	5.0	71.5	28	65	1.2	0/8
	28.8	13.52	5.5	622	24	68	0.77	1/8
	13.10	13.13	7.75	476		38		4/8
STA. 3	13.11	12.00						
	16.10	10.16	7.5	240	22.5	76	0.6	5/8

Strong winds are accompanied by low transpiration rates, weak winds by high transpiration rates, when other factors are approximately the same, an inverse phenomenon in comparison to mesophytes, already found by other investigators, Maximov and Stocker in relation to xerophytic desert plants, but not yet observed in relation to sanddune plants.

In Sta. 2 and 3, where soil water conditions were better and root systems more developed, we find similar phenomena, but the level of transpiration rates is generally higher. For instance: under maximum wind 7.75, transpiration is 476; under 3.0 m/sec wind, it is 630. At Sta. 3, transpiration is similar to Sta. 2 (7.5 m/sec wind with 240 -transpiration. As a rule, we may say, that plants having a better soil water regime are less required to withstand winds, as they are generally more independent of outside factors.

Though our data are based upon a great number of measurements, they are not sufficient to get conclusive results. More observations are necessary. In drawing attention to these interesting phenomena, we hope to encourage others to take part in similar investigations. Meanwhile we may however draw the following conclusions:

(1) The plants react to strong winds which might cause dangerous water losses. This seems to be true and characteristic during the hot season. On the other hand, when other microclimatical factors tend to assist the plant in the maintenance of its water balance, transpiration rates increase in spite of higher winds.

(2) The micro-climatical studies on plants' reaction to wind also show that this reaction is an extremely rapid one. Stomata close and open quickly, a phenomenon observed on xerophytes by Stocker (1948) who says that the stomata system is more hydroactive and more photoactive than that of the mesophytes. Also Nakyama and Kadenta (1948) found a similar phenomenon in xerophytic trees. Not only do xerophytes behave in this manner, but also plants with superficial roots and which suffer from water deficits, as Rachid and Rawitscher observed. Also Walter, Griepe and Gäumann write that in general, wind increases transpiration rates, but in xeromorphological species, the increase is to a lesser extent.

In connexion with these facts, we find ourselves confronted with another problem: if it is true that the plants withstand high wind velocities, especially during the hot season by reducing transpiration by the closing of the stomata, how can we explain the high physiological activity accomplished by these plants precisely during summer time? The closure of the stomata not only causes the interruption of transpiration, but the exchange of all other gases, too, including carbon-dioxide. This would mean the interruption of vegetative growth. The rapidity of closure and opening of the stomata perhaps explains this phenomenon: every calm moment is immediately used by the plant for increased gas-exchange and the total amount remains high in spite of the interruptions caused by strong winds. In spite of temporary reductions and decreases of the transpiration rates, the *total* amount of transpiration and other exchanges of gases is held at a relatively high level: the quick closure and opening of the stomata make this phenomenon possible. Perhaps it is worthwhile to add that other investigators too found this high physiological activity of sanddune plants during the hot summer season.

Would it be possible to find among sanddune species indicators for prevailing winds? It is superfluous to emphasize the difficulty of getting data about wind climate by meteorological measurements alone. Wind directions, wind forces and their frequencies change or are liable to change every minute. Measurements are done three times a day. It is generally admitted that when they have been done for at least 10 years, they represent valuable information. However, in wild areas there are not always meteorological stations. Therefore, if it would be possible to find relations between wind climate and some forms of growth of the vegetation, as it has been found for trees by Yoschino, this would be of high value. The plant as the living result of wind influence during many years, may perhaps furnish more reliable data than pure meteorological data. We began with this kind of observation recently and got the following indications:

1. The most clear indicators seem to be the rhizomes of *Phragmites communis*. These rhizomes creep from 40 to 50 m along the sand, always in the west–east direction. This is a form of migration. Now we know that the direction in which

a migrant moves is determined by the agent concerned. Migration tends to radiate in all directions from the parent group, as the result of the action of winds which blow from any quarter, but when there are constant winds, we have *linear migration*, a kind of induced migration, such as the migration of plants along water courses.

Since seeds never germinate in wild shifting sanddunes, the location of invaders with reference to the original home necessarily indicates the only direction of migration. Another sandplant which shows obvious linear migration is the sedge, *Carex arenaria.*

2. Another indication of prevailing winds we got through observation on the growth of *Ammophila arenaria* bushes. They are formed this way: a subterranean rhizome first produces stems. Additional rhizomes form with their stems a triangle whose borders seem to be influenced by prevailing winds always in a west-east direction. Now sand accumulates on the lea-side of the shrub. This enables strong development of new stems, as sand accumulation is very favourable for this plant. The new stems form mathematically straight lines, perpendicular to dominating winds.

3. A similar kind of growth we found in *Saccharum biflorum.* The sandy hillocks formed by this species are much higher than those formed by *Ammophila arenaria;* they reach 3.00–3.20 m, as against 0.75–1.10 m. The form of migration is similar to that of Marram Grass.

How may we use the data found in research work about wind and vegetation for solving practical problems of sanddune fixation?

(1) We use the wind resistant species for fixation-purposes: as we have already discussed its resistance to wind does not only mean the survival of a plant, its flexibility or ability to avoid the mechanical breaking of its aerial parts by wind. It is not only the ability to survive in a state of dormancy, but a capacity to grow and to develop a normal physiological activity, in spite of high wind velocities and other severe conditions. Species with those abilities may be used with success for fixation purposes, particularly as windbreaks. In consequence of the obtained data, the following species came into use: *Ammophila arenaria, Retama roetam, Calligonum comosum, Lotus creticus, Pennisetum asperifolium, Tamarix pseudopallassii.*

(2) By efficient windbreaks it is possible to modify the local environment and the total climatic complex may be greatly ameliorated. Without it, on the other hand, the surface of whole fields may be blown away and the soil deposited elsewhere. Both processes, the process of erosion and of deposition may cause severe damage.

Another question is how to exploit the wind for our own purposes? First of all in which direction is it advisable to plant the windbreaks? We first used the classical method: to plant the windbreaking plants in perpendicular lines to prevailing winds. More recently, we began to plant them parallel to the prevailing wind, in straight rows at 50 m intervals. The opposite frontier side was closed by a transversely planted line. What did happen? The wind blew the sand against the obstacles, the plants. These profited by the additional sand, grew more vigorously and form-

ed foredunes parallel to the wind. The wind continued to deepen the area between every two foredunes. We then closed off the area by new transverse lines in order to avoid too much outblowing of the deep areas. In this way, we obtained deep beds, into which it was possible to introduce more delicate plants, but more valuable as fodder plants with high palatibility, like *Agropyrum junceum*. This species profited from being well protected against the wind and from being nearer to ground water table. In this, way, we got plots on which it was possible to graze cattle. Exact weighing tests showed that a one year old calf increased its weight at the rate of 1 kg per day, when it was fed only on this grass, without any other food.

(3) Another method to avoid wind erosion was the direct sowing of seeds in rows perpendicular to prevailing wind. The outblowing of the seeds occurred till germination was protected by a special emulsion of bitumen.

WIND-SHAPED TREES AS INDICATORS OF MICRO AND LOCAL CLIMATIC WIND SITUATION

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Abstract – An attempt was made first to classify the wind-shaped trees. According to the results of studies that dealt with them in England, France, Germany, Japan, Switzerland and U.S.A., they are classified into the following four types. (1) Those whose trunk is vertical, but the branches are bent drastically to the leeward of the tree by prevailing winds during their growing period. (2) Those whose trunk is vertical, but the branches on the windward side of the tree are severed by the effects of strong winter wind carrying snow and frozen rain. (3) Those whose trunk and branches are deformed drastically by prevailing winds during their growing period. (4) Those whose trunk is declined by the occasional strong wind, but the shape of canopy is almost symmetrical. The results of investigation into the local distribution of the wind-shaped trees of type (2) mentioned above in the summit area, subalpine zone, of Mt. Neko and Mt. Azuma (Central Japan) were then presented. On the map showing their distribution, one can determine the micro- and local climatic situations of wind direction and wind velocity under the influence of the micro-topography of the area.

Zusammenfassung – Es wurde versucht, eine Klassifikation der windgeformten Bäume zu schaffen. Den in Deutschland, England, Frankreich, Japan, der Schweiz und den U.S.A. durchgeführten Untersuchungen zufolge unterscheidet man folgende vier Typen: (1) Bäume mit vertikalem Stamm und zur Leeseite hingebogene Zweigen, verursacht durch Winde während der Wachstumsperiode. (2) Bäume mit vertikalem Stamm, deren Zweige auf der Luvseite wie abgeschnitten erscheinen; verursacht durch Schnee- und Eisgebläse während des Winters. (3) Bäume, deren Stamm und Zweige durch die während der Wachstumsperiode wehenden Winde entsprechend der Hauptwindrichtung deformiert sind. (4) Bäume, deren Stamm sich zur Leeseite der jeweils stärksten Winde neigt, deren Kronen jedoch nicht sehr stark deformiert sind. Die Untersuchungsergebnisse über die lokale Verbreitung der windgeformten Bäume vom Typ (2) im subalpinen Gebiet des Mt. Neko und Mt. Azuma (Zentral-Japan) werden mitgeteilt. Die beigegebene Verbreitungskarte veranschaulicht die mikro- und lokalklimatische Situation der Windrichtung und -geschwindigkeit unter dem Einfluss der Mikrotopographie des Gebietes.

Résumé – Nous avons essayé tout d'abord de donner une classification des arbres déformés par le vent. Selon des investigations faites en Allemagne, en Angleterre, en France, au Japon, en Suisse et aux Etats-Unis on distingue les quatre types suivants: (1) Arbres au tronc vertical dont les branches sont courbées sous le vent par des vents soufflant pendant la période de végétation. (2) Arbres au tronc vertical dont les branches paraissent coupées du côté du vent. Cette déformation est due à l'action des vents chargés de neige et de la pluie gelée en hiver. (3) Arbres dont les troncs et les branches sont déformé par le vent prédominant durant la période de végétation. (4) Arbres dont le tronc a été penché par des vents spécialement forts sans que leur cime soit fortement déformée. Les résultats de nos recherches concernant la distribution locale des arbres déformés selon (2) dans la région

subapline du Mt. Neko et du Mt. Azuma (Japon central) seront communiqués. La carte de distribution montre la situation microclimatique de la direction et de la vitesse du vent sous l'influence de la microtopographie de la région.

INTRODUCTION

The wind distribution under the influence of microtopography shows very complicated characteristics from place to place. However, due to the difficulty of the instrumental observation at many points within a small area for long periods, little investigations into them have been made. Because of this difficulty, attempts have been made by climatologists to make clear the local distribution of the wind, using the wind-shaped trees as indicators of wind situation. This paper deals firstly with the classification of the wind-shaped trees, recording the results, and secondly with the wind situations deduced from their distribution in the summit area of the sub-alpine zone in Japan from the micro- and local climatological point of view.

CLASSIFICATION OF WIND-SHAPED TREES

According to the results of the investigations into the wind-shaped trees in the various parts of the world, they are classified into the following four types:

Type (1): *Those whose trunk is vertical, but the branches are bent drastically to the leeward of the tree by the prevailing winds during their growing period.* This type may beregarded as one of the type of "Windgepeitschte Bäume" described by Walter (1951). Only the conifers seem to conform to this type.

Typ (2): *Those whose trunk is vertical, but the branches are severed by the effects of stroneg winter wind carrying snow and frozen rain.* The effects, "storm pruning" seem to be caused by two cases: i.e.

(1) The snowflakes, frozen raindrops etc. carried by the prevailing winds adhere to the branches on the windward side of the trees and through it, the branches at the windward side are mechanically injured.

(2) Due to the low temperature, low humidity and icy blast caused by the strong winter winds at the windward side of the trees, the buds on the windward side are killed every year and consequently the branches on the windward side are absent. According to Walter (1951), this type is called "Windgescherte Bäume". The detailed studies by Lawrence (1939) showed this type of Douglas fir *(Pseudotsuga taxifolia)* in the western part of the Columbia River Gorge, was caused by the glaze storms in winter, which bring "silver thaw" or direct "storm pruning" effects.

Type (3): *Those whose trunk and branches are deformed drastically by the prevailing winds during their growing period.* This type was found most commonly in the windy parts of the world. The effects of the wind, however, have been cleared neither ecologically nor physiologically. It may be said that, in general, their physical and desiccation effects are most conspicuous and, by local conditions, the influences of salt-spray, sand particles, etc. are added. In the case of the relatively weak

degree of deformation, the trunks and the branches of the tree top are only bent leewards. When the wind is constantly very strong, they are deformed so as to take a creeping shape. According to Walter's classification, this type belongs to "Windgescherte Bäume", (Walter 1951).

The examples of this type were grouped climatologically into three. The first group consists of those in the regions facing the prevailing westerlies. The second group consists of those in the regions having strong local winds such as the up-valley winds. The third group consists of those on the coasts and in the inland areas where the strong winds blow constantly, probably under the influence of the circulation system plus the topographic situation:

The deciduous and the evergreen broad-leaved trees and conifers are found as this Type.

Type (4): *Those whose trunk is declined, but the shape of canopy is almost symmetrical.* This type was, in my opinion, caused by the occasional, disastrous strong winds, such as typhoons, because the directions of the inclined trunks in the restricted area have deviated greatly. The Japanese black pine *(Pinus Thunbergii)* in the coastal regions of the Pacific in Japan often show this type.

THE LOCAL DISTRIBUTION OF THE WIND-SHAPED TREES OF TYPE (2) ON MT. NEKO AND MT. AZUMA, JAPAN

By observing the wind-shaped trees of Type (2) mentioned above, an attempt was made to make the distribution map of the wind condition in the summit area of the sub-alpine zone in Central Japan and, from it, the characteristics of wind velocity and wind direction under the influence of micro-topography in the area were studied.

Preliminary Survey on the Characteristics of the Wind-shaped Trees in this Area

As a preliminary survey concerning the general characteristics of the wind-shaped trees in this area, the following results were obtained.

Figure 1 shows a wind-shaped tree of *Picea jezoensis* var. *hondoensis* on the SW slope (2160 m) of Mt. Azuma. Part *a* is the part severed by winter storms carrying snow and frozen rain. Part *b* is the part protected from winter storms, because of snow accumulation. In Part *b* there develop the branches densely on all sides. Part *c* shows a radius of these branches. Part *d* is the length of the branches at lee side of the tree over the mean surface of the snow accumulation in winter.

Choosing the trees of about 100 years old, Parts *a*, *b*, *c* and *d* were measured at the several points (Table 1). From this table, it can be seen that the range of Part *b* is 0.5–1.4 m. and that of Part *c* 1.4–2.0 m. On the other hand, Parts *a* and *d* vary greatly from point to point; i.e. the ranges of Parts *a* and *d* are 0.5–3.0 m and 0.3–1.7 m. This means that the local change of the wind condition is relatively greater than that of the snow accumulation.

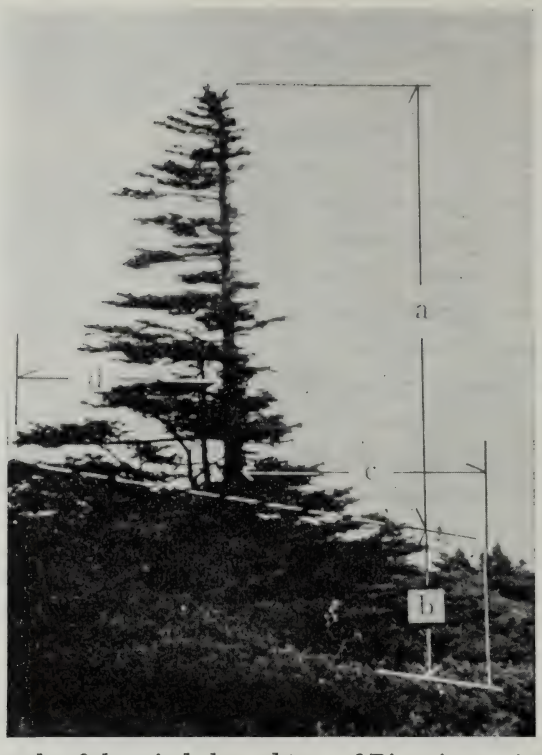

FIG. 1. An example of the wind-shaped tree of *Picea jezoensis* var. *hondoensis* on the slope (2160 m) of Mt. Azuma. The length of Parts *a*, *b*, *c* and *d* are given in Table 1.

Table 1. Shape of the Wind-shaped Trees on Mt. Neko and Mt. Azuma

Name of the tree	Observed point (Height) (m a. sea level)	Parts as are shown in Fig. 1				Note
		a	*b*	*c*	*d*	
Abies Veitchii	2025	1.2m	1.3m	2.0m	0.8m	between Parts *a* and *b* there is a part of trunk 0.2–0.4 m having no branches
Larix leptolepis	2020	1.2	1.3	1.8–2.0	0.9	
Abies Veitchii	2100	1.9	0.5–0.8	1.4	1.0	
Abies Veitchii	2145	2.2	1.4	1.5–2.0	1.0	
Picea jezoensis var. *hondoensis*	2160	3.0	1.2	2.5	1.7	Pictured in Fig. 1.
Abies Veitchii	2220	0.5	0.8–1.0	1.5–2.0	0.3	
Abies Veitchii	2260	2.2	1.0	1.5	1.2	
Abies Veitchii	2250	1.6	0.7	1.5–1.8	0.8	between Parts *a* and *b* there is a part of trunk, 0.3–0.5 m having no branches
Abies Veitchii	2045	3.0	0.8	1.5	1.5	

As indicators of wind conditions, it is desirable to observe the trees of certain species being about the same age. However, it was difficult to satisfy these conditions in the area at present under observation, because the distribution of these trees was scattered. Therefore, it was decided to observe all the "wind-shaped conifers" of about 100 years in this area, such as *Abies Veitchii*, *A. Mariesii*, *A. firma*, *A. homolepis*, *Picea jezoensis* var. *hondoensis*. The age of the trees was estimated by the diameter of trunk at the height 30–50 cm above the ground. (According to the measurements on the SW-slope of Mt. Azuma, 2120–2140 m, the relationship between diameter and the age of the trees obtained from tree-rings was found as shown in Table 2.)

Table 2. Relationship between the Age of Tree and the Diameter of Trunk at the Height 30–50 cm, above the Earth's Surface

Tree	A	B	C	D	E	F
Diameter	16.6	28.7	30.1	30.2	30.2	41.6 cm
Age	78	105	94	110	116	146 year

Observations

The geographical and climatological sketch of this area is firstly given here. The area studied locates around 36°35′ N, 138°25′ E; approximately 20 km south-east of Nagano City, Central Japan. In this area, there are two old volcanos, Mt. Neko (2195 m) and Mt. Azuma (2333 m) and the observations were limited to the slopes over 1900 m above sea level. This area belongs to the sub-alpine zone.

Although the climatological data for this area is not available, the observed records at the station on the southwestern foot (1301 m) can be obtained: mean yearly air temperature is 6.3°C, mean monthly air temperature in December, January, February and March −3.1, −6.7, 6.5 and −2.6° C respectively, and mean monthly snow depth 26, 58, 78 and 61 cm respectively. The important data for this type of wind-shaped trees i.e. the velocity of winds during snowfall, was obtained from the data observed at 10:00 h (local time) every day at the same station from autumn 1940 to spring 1947. They were averaged month by month; 3.1 (wind force) in January, 3.0 in February, 3.3 in March, 2.8 in April, 2.0 in May, 2.6 in November and 2.8 in December.

The field observations of the trees were made in August 1958, in July–September 1959 and in April 1960. In these observations, not only the measurement of the wind-shaped trees, but also the distribution of the lichen, *Usnea diffracta* and *U. longissima*, was investigated. The *Usnea* grows in general, on branches and trunks of the trees in foggy intermontane regions of Central Japan at elevations of about 1000 to 2500 m. Its distribution is uneven, however, from the effect of microcli-

matic wind conditions which apparently precluded its growth in windier, less humid areas. Therefore, it was considered that its distribution indicates the windless areas and that, compiling the distribution of the windless areas and of the windy areas revealed from the wind-shaped trees, the more detailed distribution of the wind conditions in the area can be drawn.

Results

In Fig. 2 the distribution of the wind-shaped trees and the areas, where no wind-shaped trees are seen and the *Usnea* is growing, are shown. From this figure, the

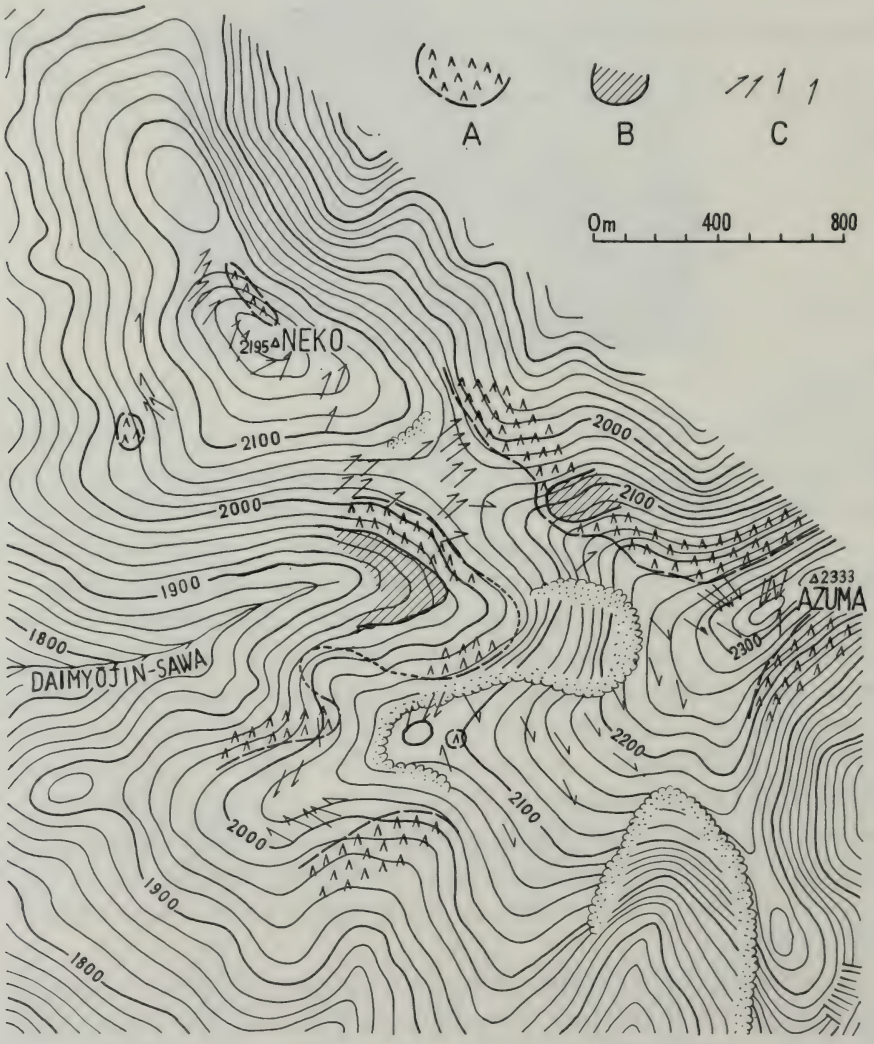

FIG. 2. The distribution of the wind-shaped trees, the symmetric trees and *Usnea* on the summit area of Mt. Azuma and Mt. Neko. A, the area, where the symmetric trees are found. B, the area, where Usnea are growing. C, the wind-shaped trees. Arrow shows the wind direction deduced from it.

following must be noted: The wind shaped trees are generally found in the area exposed to the wind at elevations over 2020 m. In some places they occurred in the area over 2000 m or 2050 m. On the narrow ridges at elevations of 2300–2340 m and of 2000–2030 m extending from the summit of Mt. Azuma in a SW-direction, a very interesting distribution can be seen; i.e. the trees just behind the ridge are deformed by the winds with a reverse direction to the prevailing wind. On the windward side of the ridge, the wind-shaped trees are seen on the slope from the ridge top to 40–70 m (vertical difference) below it. On the other hand, on the leeside of the ridge, they appeared on the slope from the ridge top to 20–70 m below it.

On the col-topography between Mt. Azuma and Mt. Neko, the wind-shaped trees are deformed clearly by the wind blowing through the col. Their distribution is restricted in the area from the col point to 30–40 m (vertical difference) below it. The local change of their deformation was observed at five points as shown in Fig. 3. The five points, S_1–S_5, were located from SW to NE, from the under part to the upper part of the slope facing to the prevailing winds. Their topographical situation and the other notes are given in Table 3.

From Fig. 3 and Table 3, it can be pointed out that the degree of the deformation of the trees is indicative of the wind conditions.

The distribution areas of the *Usnea* are found in the part (1920 to 1980 m) of the end of the small valley, Daimyôjinsawa, and the leeside slope of the ridge on

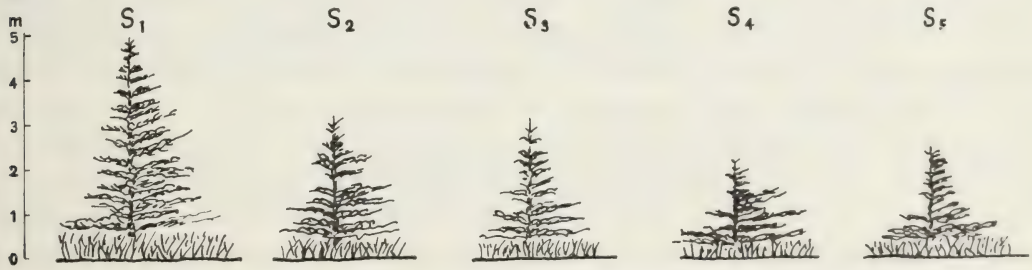

Fig. 3. The change of the form of the trees along the leeward slope (col-topography) between Mt. Neko and Mt. Azuma. The topographical conditions are shown in Table 3.

Table 3. Conditions of the Topography and the Wind at St. S_1–S_5.

Station	Height m a. sea level	Distance along the slope		Name of tree	Wind direction obs. on the wind-shap. tree	Wind condition estimated
S_1	2015	—	—	*Abies Mariesii*	—	weak wind
S_2	2030	S_1–S_2	50 m	*Abies Veitchii*	—	medium betw. S_1 and S_3
S_3	2040	S_2–S_3	65	*Abies Veitchii*	(S40°W)	strong wind
S_4	2044	S_3–S_4	30	*Abies Veitchii*	S40°W	the strongest wind
S_5	2050	S_4–S_5	85	*Abies Veitchii*	S40°W	strong, but weaker, than S_4

Mt. Azuma, extending in the NW-direction. It is supposed that, they grow only in these two small areas due to the high humidity caused by the weaker wind.

According to the observation made just after the strong winter monsoon conditions, which prevailed for two days, the state of the "silver thaw" were as follows: The state of adhesion of snow and ice was changed in accordance with the height above the ground, when we look at it on the individual trees, and also changed in general according to the height above sea level. On the windward side of the upper 2/3 of Part *a* (Fig. 1), the frozen snow (ice), which was composed of parts with a form of "torpedo", adhered closely and densely. The under 1/3 of Part *a* looked like a sugar-covered cake. The diameter and the length of each "torpedo" mentioned above, were 1–2 cm and 5–10 cm on the trees on the slope (2140–2250 m) of Mt. Azuma. On the other hand, they were about 0.5 cm and 3–4 cm respectively on the trees on the slope (2030 m). Part *b* was packed in ice. The depth of Part *b* was not even, but higher near the trunk. On the surface of snow accumulation at the leeward of these trees, severed leaves and twigs were observed. The length of the latter was 5 to 6 cm in general, but sometimes reached 20 cm. From this fact one can easily suppose the mechanical effects of the wind.

Microclimatic Wind Situation

The prevailing wind direction in winter at the 2000 m level in the free atmosphere over this area is westerly, based upon the pilot balloon observation at Nagano (36°40′N, 138°12′E). Therefore, the distribution of wind direction revealed in Fig. 3 can be regarded as a result of deflection caused by the micro-topography in this area.

The microclimatic wind situations are summarized as follows: the westerly winds pass through the col between Mt. Azuma and Mt. Neko with great force. On the ridges, the winds tend to blow over at right angles to the direction of the ridges. Behind the ridge, just below the ridge on the lee side, the almost reverse direction of the winds were found. The area, on which the winds are locally strengthened under the influence of microtopography, is from the col to 30–40 m (vertical difference) below it and from the ridge to 40–70 m below it on the windward slope and from the ridge to 20–70 m below it on the leeward slope.

REFERENCES*

BARSCH, D. (1965) (To be published in Freiburg, West Germany)

BAUER, W. (1952) Der Windfaktor im Obstbau. *Ber. dtsch. Wetterdienst U.S*-Zone **42,** 352–358.

BERNBECK, O. (1954) *Wind und physiologische Tiefgründigkeit.* Berlin. 100S.

BILLWILLER, J. R. (1914) Der Walliser Talwind. *Ann. Schweiz. Met. Zentr. Anst.* **50,** 7, 1–13.

FRÜH, J. (1902) Die Abbildung der vorherrschenden Winde durch die Pflanzenweld. *Jahrb. Geogr. Gesell. Zürich.* 1901–1902.

GAMS, H. (1927) Von den Follatères zur Dent de Morcles. *Beitr. geobotanisch. Landesaufn.* **15,** 760.

* The text of this paper had to be condensed for publication but the reference list was left complete for full information.

GAUSSEN, H. (1927) Le Pin à crochets dans les Pyrénées. *Bull. Soc. H. N. Toulouse.*

GEIGER, R. (1950) Das Klima der bodennahen Luftschicht. 176–177.

ISSLER, E. (1932) Die Buchenwälder der Hochvogesen. *Veröff. d. geobotanisch. Inst. Rübel in Zürich.* **8,** 464–489.

KAWADA, M. (1933) Shinrinseitaigaku kôgi. *Tokyo.* 99–106.

KIRA, T. *et al.* (1958): Yama no seitaikei. *Gendai seibutsugaku kôza* **5,** 231–269.

KRAUS, G. (1911) Boden und Klima auf kleinstem Raum. *Jena.* 1–184.

KRIVSKÝ L. (1958) Bestimmung der vorherrschenden Windrichtung aus Windfahnenbäumen. *Meteor. Rdsch.* **11,** 86–90.

LAWRENCE, D. B. (1939) Some features of the vegetation of the Columbia River Gorge with special reference to symmetry in forest trees. *Ecol. Monogr.* **9,** 217–257.

MARES, P. (1955) Phénomènes actuels de surface et l'équilibre du tapis végétal dans la région Méditerranéenne. *L'Année biolog.* **59,** 361–367.

MEIKLEJOHN, J. (1955) The local wind at Milfield, Northumberland. *Quart. J. Roy. Met. Soc.* **81,** 468–474.

MISAWA, K. (1951) Shokubutsu riyô no Jôhûko chôsa. (1) and (2). *Tenmon to Kishô* **17,** 132–137, 169–173.

OLIVER, J. (1960): Wind and vegetation in the Dale Peninsula. *Field Studies* **1,** 1–12.

RUNGE, F. (1955) Windgeformte Bäume und Sträucher und die von ihnen angezeigte Windrichtung. *Meteor. Rdsch.* **8,** 177–179.

RUNGE, F. (1957) Windgeformte Bäume an der italienischen Riviera. *Meteor. Rdsch.* **10,** 47–48.

RUNGE, F. (1958) Windgeformte Bäume in den Tälern der Zillertaler Alpen. *Meteor. Rdsch.* **11,** 28–30.

RUNGE, F. (1959) Windgeformte Bäume in den Tälern der Allgäuer Alpen. *Meteor. Rdsch.* **12,** 98–99.

SCHWEINFURTH, U. (1962) Mt. Egmont–Taranaki. Zugleich ein Beitrag zum Studium der vertikalen Anordnung der Vegetation in Neuseeland. *Erdkunde,* **16,** 34–48.

SEKIGUTI, T. (1951) Studies on local climatology (III). *Papers in Meteor. Geophy.* **2,** 168–179.

STAMP, L. D. (1950) *The Land of Britain. Its Use and Misuse. London.* 261–263.

TATEWAKI, M. (1953) Bomurintai no jukei. *Shokubutsu-seitai-gakkaihô* **2,** 162–169.

TROLL, C. (1955) Der Mount Rainier und das Mittlere Cascaden-Gebirge. *Erdkunde* **9,** 264–274.

TROLL, C. (1961) Klima und Pflanzenkleid der Erde in dreidimensionaler Sicht. *Naturw.* **48,** 332–348.

WALTER, H. (1951) *Einführung in die Phytologie.* III. *Grundlagen der Pflanzenverbreitung.* 493–498.

WEISCHET, W. (1951) Die Baumneigung als Hilfsmittel zur geographischen Bestimmung der klimatischen Windverhältnisse. *Erdkunde* **5,** 221–227.

WEISCHET, W. (1953) Zur systematischen Beobachtung von Baumkronendeformationen mit klimatologischer Zielsetzung. *Meteor. Rdsch.* **6,** 185–187.

WEISCHET, W. (1955) Die Geländeklimate der Niederrheinischen Bucht und ihrer Rahmenlandschaften. *Münch. Geogr.* Hefte **8,** 1–169.

WEISCHET, W. (1959) Geographische Beobachtungen auf einer Forschungsreise in Chile. *Erdkunde* **13,** 6–22.

WHITEHEAD, F. H. (1957) Wind as a factor in plant growth. Control of the Plant Environment. *Proc. Univ. Nottingham Fourth Easter School in Agri. Sci.* 1957, 84–94.

YAZAWA, T. (1953) Ôshima no kikôkeikan no ichirei. *Chigaku zasshi* **60,** 152–154.

YOSHINO, M. M. (1960) The local distribution of wind-shaped trees and Usnea as indicators of microclimates in the sub-alpine zone. *Chirigaku kenkyûhôkoku* **4,** 87–106.

YOSHINO, M. M. (1961) Shôkikô. *Tokyo,* 193–201.

YOSHINO, M. M. and YOSHINO, M. T. (1963) Lokalklima und Vegetation im Kirishima-Gebirge im südlichen Kyûshû, Japan. *Erdkunde* (To be published).

SUMMARY REPORT

H. BOYKO

THE final Programme of our Working Group was much larger than had been envisaged in the provisional printed programme.

Instead of seven, we had 14 lectures, dealing with living beings or communities, not only from the plant world as qualitative or quantitative climate indicators, or connected with studies based on bioclimatic research work.

New lines of research, many new methods and new data were presented.

The list of the lectures given in chronological order is as follows:

1. H. Boyko (Israel): Chairman's Address
2. S. S. Paterson (Sweden): Introduction to Phyochorology of Norden
3. H. Gaussen (France): Au sujet des Bioclimats
4. A. W. Küchler (U.S.A.): Vegetation Maps as Climatic Records
5. M. Milosavljević (Yugoslavia): Anomalie dans l'apparition des gelées printanniéres en Serbie
6. M. Yoshino (Japan): Wind-shaped Trees as Indicators of Microclimatic Wind Situation.
7. I. Kárpáti (Hungary): Research Work and Methods on the Annual periodical Rhythm of Plant Communities in Hungary.
8. H. Boyko (Israel): Some New Methods in Ecological Climatography and Ecological Hydrology.
9. D. Tsuriell (Israel): Coastal Sanddune Vegetation in Relation to Wind Climate
10. H. J. Jusatz (Germany): Seasonal Diseases and Bioclimatological Classification.
11. J. F. Griffiths (U.S.A.): Rainfall Altitude-Relations and its Ecological Significance in Kenya
12. A. Marcello (Italy): Proposal for an Ideal Continent of Plant Rhythm.
13. H. and E. Boyko (Israel): Climatic and other Geophysical Rules in Direct Irrigation with Highly Saline and Seawater (appears elsewhere).

I should like to particularly mention the *new lines of research* presented herein:

Paterson showed us new possibilities to use the growth of plants, particularly forest plants, as yardsticks.

Gaussen showed us his method of vegetation mapping which he introduced in 1947: "The Climatic Vegetation Maps".

Hugo and Elisabeth Boyko described examples of Ecological Hydrology and the climatic rules determining the use of highly saline and seawater for direct irrigation.

Jusatz demonstrated how human diseases could be evaluated as climatic indicators, and

Marcello put forward a proposal for an ideal continent of plant rhythm.

In addition all other lectures also brought new methods and many new data. The lectures were followed with lively discussions in which almost all of the 20 to 24 participants took part.

The diversity of the various lines and subjects of ecological climatography made it necessary to subdivide the future work of the Committee in order to stimulate a closer international co-operation in each field, and in this way simplify such co-operation.

It was therefore unanimously agreed that the following sub-committees be created and the Chairmen were elected.

Their task will be the pooling of scientific work in their respective fields, to stimulate the dissemination of the new methods, and in co-operation with others working on these lines — to organize international teamwork on specific, restricted subjects.

The proposed sub-committees and working groups are:

(1) Human Diseases as Climate Indicators (Chairman: H. J. Jusatz, Germany)
(2) Climate Vegetation Maps (Chairman: H. Gaussen, France)
(3) Ecological Hydrology and General Ecological Climatography (Chairman: H. Boyko, Israel)
(4) Tree-Ring Research (Chairman: W. G. McGinnies, U.S.A.)
(5) Phyochorology (Chairman: S. S. Paterson, Sweden)
(6) Crops as Climate Indicators (Chairman: A. Baltadori, Italy)
(7) Plants as Indicators of Wind-Data (Chairman: M. Yoshino, Japan)

The first textbook on Climatological Climatography sponsored by our Committee is already far advanced and will, we hope, appear in 1966.

In addition a working group has been proposed to work as a pooling centre for climate-classification and the preparation of an international agreement on adequate definitions, (This working group consists at present of Dr. Yoshino, Japan, and Dr. W. Undt, Austria.), and a Resolution Committee under the Chairmanship of Dr. W. A. Fairbairn, U.K.

In order to relieve the present Chairman of the Permanent Committee on Ecological Climatography from a large part of his work, Prof, H. Gaussen, France, was unanimously elected as Co-Chairman of the Committee as a whole.

Two motions were put before the Congress Forum and accepted during the Plenary Session on 7 September 1964.

"Motion 1 of the Working Group, Ecological Climatography"

"In view of the close connection of many studies of Ecological Climatography in general, and Ecological Hydrology in particular, with the global water problem, the Third Biometeorological Congress recommends the integration of such studies into the programme of the "*Water-Decade*" planned by UNESCO in co-operation with the other specialized agencies of the United National Organization."

"Motion 2 of the Working Group, Ecological Climatography"

"In view of the expressed opinion recorded at the first Plenary Session, that the subject of botany has not been sufficiently represented nor operative within the Society, it is suggested that a permanent committee of PHYTO-BIOMETEOROLOGY should now be formed in order to foster the use of meteorology in phytobiological research in such disciplines as botany, agriculture and forestry."

Resolution Committee:

signed: Hugo Boyko
W.A. Fairbairn
(Gt. Britain)
St. St. Paterson
(Sweden)
A. Baumgartner
(W. Germany)

BIOLOGICAL EFFECTS OF NATURAL IONIZATION

Chairmen: I. H. Kornblueh and A. P. Wehner

ACTION BIOLOGIQUE NON SPÉCIFIQUE DE L'AÉROIONISATION

M. C. DELEANU et T. FRITS

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Abstract – Experiments were undertaken on the role of moderate concentrations of air ions (5,000 to 20,000 ions/cm³) in different biological processes. Negative air ion therapy had favourable results in neurotic illness, gastric ulcer, bronchial asthma and skin disease and improved the performance of sportsmen. From the multiplicity of the effects it is concluded that the biological action of aeroionization is non-specific.

Zusammenfassung – Die Wirkung von mässigen Konzentrationen an Luftionen (5000–20 000 Ionen/cm³) auf verschiedene biologische Vorgänge wurde experimentell untersucht. Die Therapie mit negativen Ionen in mässigen Konzentrationen führte zu guten Ergebnissen bei Menschen in Fällen von neurotischen Zuständen, Ulkuskrankheit, Bronchialasthma, Hautkrankheiten und verbesserte die Leistung von Sportlern. Die Vielseitigkeit der Erfolge weist auf eine unspezifische Wirkung hin.

Résumé – On a par voie expérimentale, mis en évidence l'intervention des aéroions en concentrations modérées (5,000 – 20,000 petits ions par ml air) dans divers processus et fonctions biologiques, tels que: réactivations de plusieurs centres nerveux, motricité spontanée, trophicité de la muqueuse gastrique, anaphylaxie, stabilité colloïdale des protéines plasmatiques, ablation des surrénales, intoxications par solvants organiques etc. Chez l'homme, en appliquant l'aéroionothéraphie modérée négative (3,000–10,000 ions par ml d'air), on a obtenu des résultats favorables dans des états névrotiques, ulcères gastriques, asthme bronchique, affections cutanées, de même que l'augmentation du rendement chez les sportifs. La multiplicité des effets plaide pour la non-spécifité de l'action.

L'INFLUENCE des facteurs météorologiques et cosmiques en général sur l'organisme humain est depuis longtemps reconnue. Malgré cela, nous ne connaissons pas encore tous les éléments météorologiques agissant sur l'organisme, les systèmes fonctionnels qui en supportent l'action, et d'autant moins le mécanisme selon lequel l'effet des facteurs bioclimatiques est réalisé. C'est pourquoi nous estimons qu'une étude des données analytiques concernant l'influence des différents facteurs météorologiques, envisagés séparément, est indispensable. Dans ce but, nous nous sonnes proposé de suivre l'action des aéroions sur certaines fonctions non étudiées. Nous nous permettons de présenter, ci-dessous, les données obtenues.

MÉTHODE

Nous avons effectué des recherches expérimentales, aussi bien que des essais thérapeuthiques.

Les *concentrations ioniques* utilisées ont été d'un degré modéré: 5000–20,000 petits ions/cm³ d'air, ions émis par un générateur radioactif, dans les expériences sur l'animal; 3000–10,000 ions par cm³ air, produits par un *hydroaéroionisateur*, chez l'homme.

La durée de l'exposition: 40–120 min par jour chez l'animal; 15–50 min par jour chez l'homme.

RÉSULTATS

Bien que les objets de nos préoccupations semblent disparates, ils sont susceptibles d'être systématisés en vue d'éclairer *l'action biologique de l'aéroionisation* et d'étendre l'application de ce facteur dans la pratique médicale.

(1) En partant de l'observation que certains processus allérgiques et anaphylactiques présentent une amélioration dans des climats à taux ionique élevé, nous avons essayé d'analyser expérimentalement cette action. Le *choc anaphylactique* a été provoqué chez le cobaye (304 animaux) par du serum de boeuf. La dose létale d'antigène a été titrée sur les animaux du vivarium, dans lequel l'ionisation naturelle est basse. Les animaux traités par l'air ionisé ont survécu au choc anaphylactique dans une proportion de 40 pour cent. En revanche, les animaux témoins non traités n'ont survécu que dans une proportion de 4 pour cent (Comes, Deleanu et Papilian, 1962). Nos résultats viennent confirmer les données de Nekliudov et Kaufman (1953) et Téréhova (1955) qui ont obtenu également des résultats favorables dans le choc anaphylactique expérimental sous l'influence de l'aéroionothérapie.

(2) Nous avons poursuivi la durée de survie des *animaux* privés de leurs surrenales (60 rats). Les animaux soumis à l'aéroionothérapie ont survécu plus longtemps, 48 pour cent en moyenne, que les témoins surrénalectomisés mais non traités (Cupcea *et al.*, 1957). Remarquons que la hyperpotassémie surrénoprive n'a pas changé sous l'influence de l'aéroionothérapie.

(3) Des rats privés de leurs surrenales, présentant une dispnée marquée, ont été soumis à l'aéroionothérapie négative et la respiration a été enregistrée par la méthode pneumo-plétismographique (Cupcea *et al.*, 1956). Exception faite de la période finale, nous avons constaté un redressement de la réactivité des centres respiratoires vis-à-vis de l'accumulation du CO_2 et du déficit de O_2, tandis que les témoins ont perdu la sensibilité envers ces facteurs (Deleanu et Florea, 1960).

(4) La *stabilité colloïdale des protéines* plasmatiques — déterminée par les analyses au thymol et de Greenstedt — chez le lapin normal et chez le rat sans surrénales, a été plus élevée chez les animaux traités par les aéroions que chez les animaux non traités (Deleanu et Frits, 1961).

(5) En cas *d'intoxication par solvants organiques* (benzène et monochlorbenzène), nous avons constaté que les animaux (rats et souris) soumis à l'aéroionothérapie ont présenté dans un pourcentage plus réduit les phénomènes de déséquilibre corporel (réflexes de posture et de redressement) ainsi qu'une mortalité plus réduite, par rapport aux témoins intoxiqués mais non traités (Deleanu, Sirbu et Asgian, 1962).

(6) Nous avons suivi l'action de l'aéroionothérapie sur les *lésions pneumococciques* chez le cobaye, pendant 45 jours, par rapport aux témoins exposés à la même poussière de SiO_2, mais non traités. Les images microscopiques des poumons montrent que, sous l'influence de l'aéroionothérapie négative, les lésions ont un caractère plus bénin, localisées surtout dans l'interstice, représentées par des processus d'infiltration et à tendance de regression. En revanche, *l'aéroionisation positive* a favorisé l'extension des lésions pulmonaires, intéressant l'interstice et les alvéoles; l'évolution des lésions est, dans ce cas, plus grave, présentant une fibrose interstitielle et la diminution de la surface respiratoire (Frits, 1957).

(7) En partant du caractère météorotrope de certains symptômes de la maladie ulcéreuse, nous avons poursuivi l'influence de l'aéroionisation sur les processus trophiques de la muqueuse gastrique, processus troublés par voie expérimentale.

C'est ansi que nous avons provoqué des *ulcères gastriques* par *inanition* de 3 jours, chez 199 rats. La biopsie de l'estomac nous avait montré que 91–95 pour cent des animaux témoins ont présenté des lésions ulcéreuses sur la portion glandulaire de la muqueuse, lésions qui n'étaient présentes que dans 51 à 68 pour cent des animaux traités (Frits, Cupcea et Deleanu, 1957).

Dans une autre série d'expériences, *l'état distrophique* de la muqueuse gastrique a été provoqué à l'aide de *la réserpine* (2–4 mg par kg de poids par jour, administrée pendant 15–25 jours, par voie bucale), chez 145 rats. Les animaux témoins ont présenté des ulcérations gastriques dans une proportion de 83 pour cent, tandis que les animaux traités ne les ont présentées que dans une proportion de 45 pour cent. Par des doses plus élevées de réserpine (4–5 mg/kg, administrées pendant 22–26 jours, chez 93 rats), nous avons provoqué une *dilatation gastrique* accentuée avec retention alimentaire chez 70 pour cent des animaux non traités par les aéroions, et seulement chez 8 pour cent des animaux traités (Krueger and Purith, 1960a, b). Etant donné que la réserpine agit sur l'estomac par l'intermédiaire du système nerveux central (*hypothalamus*, *formation réticulaire* et *système limbique*) suggère l'idée que les aéroions agissent à ces niveaux.

(8) Les résultats favorables que nous avons obtenus dans l'ulcère gastrique expérimental, nous ont incité à appliquer un traitement semblable à 45 malades souffrant d'ulcères d'estomac et se trouvant dans la phase douloureuse. Chez plus de 2/3 des malades l'effet de l'aéroionothérapie a été favorable: *la douleur* s'est attenuée, disparaissant même en quelques jours. Les autres *symptômes digestifs* qui accompagnaient parfois la poussée douloureuse — vomissements, pyroses, constipation, ptialisme — ont également diminué. La disparition de la niche a été constatée à l'examen radiologique chez 9 malades. Les crises douloureuses saisonnières

habituelles de quelques-uns des malades ne se sont plus répétées (Neklindoff et Kaufman, 1935).

(9) Nous avons observé au cours du traitement de l'ulcère par aéroionothérapie que *le sommeil* des malades a été favorablement influencé, fait que d'autres auteurs ont aussi signalé. Nous avons traité plus de 150 *malades névrotiques* qui présentaient de l'*insomnie* comme symptôme principal. Les résultats ont été favorables pour presque 2/3 des malades: leur sommeil s'est amélioré en durée, profondeur et rapidité d'établissement. Les autres n'ont pas montré d'amélioration évidente et durable (Pislaru, Cupcea et Deleanu, 1958).

Quant au *mécanisme d'action des aéroions*, il existe sans doute beaucoup d'incertitudes. Celles-ci s'appliquent aussi bien à certaines des actions envisagées séparément, qu'aux effets sur l'organisme en général. Le problème des récepteurs de charges électriques et de la médiation et intégration de leurs effets est également sujet à de nombreuses discussions.

L'action locale directe des aéroions sur les mouvements vibratiles des cils de la trachée est maintenant reconnue (Krueger and Smith, 1960 a, b). On a également admis *l'hypothèse électro-humorale*, c'est à dire le transfère des charges électriques sur les colloïdes sanguins et tissulaires (Tchijevsky, 1960; Vassilieff, 1953).

Il semble toutefois que, dans l'organisme, le déroulement d'un certain nombre des effets observés a lieu par l'intermédiaire du système nerveux. Nos données plaident pour l'intervention des *secteurs nerveux* suivants dans l'action des aéroions: centres respiratoires bulbo-protubérantiels, formation réticulaire, allocortex et écorce cérébrale. L'effet favorable observé dans l'insomnie pourrait être produit par une action directe sur l'écorce cérébrale. Il serait cependant aussi possible que cette action ait lieu par l'intermédiaire de la formation réticulaire, voie par laquelle se produirait le changement du tonus cortical.

Il existe bien d'autres effets des aéroions que faute de données expérimentales concrètes, nous ne pouvons expliquer si ce n'est par une action primaire sur le système nerveux. Cela, ajouté à la multiplicité et à l'hétérogéneïté des effets de l'aéroionothérapie, nous permet de supposer que les aéroions ont une *action non spécifique* et qu'ils peuvent exciter divers récepteurs physiologiques et diverses structures de l'organisme.

BIBLIOGRAPHIE

Comes, V., Deleanu M. et Papilian V., Sglimbea M. B. et Toader A. (1962) (L'influence de l'aéroionisation artificielle sur les lésions pneumocociques chez le cobaye). *Igiena, Bucarest* **11,** 395–401. (roumain).

Cupcea S., Deleanu M. et Frits T. (1959) Experimentelle Untersuchungen über den Einfluss der Luftionisation auf patologische Veränderungen der Magenschleimhaut. *Acta biol. med. germ.* **31,** 407–416.

Cupcea S., Deleanu M., Frits T., Elges E. et Gruescu V. (1958) (Recherches sur l'action des aéroions sur la stabilité colloïdale des protéines plasmatiques chez l'animal normal et surrénoprivé). *Comunicarile Academiei R. P. R., Bucarest* **8,** 435–441 (roumain).

Cupcea S., Deleanu M., Frits T. et Gros E. (1957) (L'action de l'air ionisé sur les animaux surrénoprivés. Note I). *Communicarile Academiei R. P. R.* **7,** 143–149 (roumain).

Cupcea S., Deleanu M., Margineanu C. et Gros E. (1956) (Action de l'ionisation de l'air sur le choc anaphylactique chez le cobaye). *Comûnicarile Academiei R. P. R.* **6,** 611–616 (roumain).

Deleanu M., et Florea E. (1960) (Résultats de l'utilisation de l'aéroionothérapie dans la maladie ulcéreuse). *Clujul medical* **32,** 124–125 (roumain).

Deleanu M. et Frits T. (1961) Versuche über die Beteiligung des Nervensystems im biologischen Wirkungsmechanismus von ionisierter Luft. *Acta biol. med. germ.* **6,** 103–109.

Deleanu M., Sirbu A., Asgian B. (1962) Luftionen in der Behandlung von Schlaflosigkeit bei psychogenen, neurotischen Zuständen. *Dtsch. Gesundh.–Wes.* **17,** 1329–1331.

Frits T. (1957) (Une nouvelle méthode de pneumographie. Pneumopletismographie). *Comunicarile Academiei R. P. R.* **7,** 741–748 (roumain).

Frits T., Cupcea S., et Deleanu M. (1957) (L'action de l'air ionisé sur les animaux surrénoprivés. Note II.). *Communicarile Academiei R. P. R.* **7,** 567–572 (roumain).

Krueger A. P. et Smith R. F. (1960a) The biological mechanisms of air ion action. I. *J. gen. Physiol.* **43,** 533–540.

Krueger A. P. et Smith R. F. (1960b) The biological mechanisms air ion action. II. *J. gen. Physiol.* **44,** 269–276.

Nékliudoff V. N. et Kaufman S. V. (1935) Dans le recueil "L'air à charges unipolaires d'après la méthode de Dessauer et son action biologique", *Voronej* 97–104 (russe).

Pislaru V., Cupcea S. et Deleanu M. (1958) (Données expérimentales concernant l'influence de l'air ionisé dans certaines intoxications par des solvants organiques. Notes 1,2). *Igiena* **7,** 319–328 (roumain).

Tchijevsky A. L. (1960) (L'aéroionisation dans l'économie nationale). *Gosplanizdat, Moscou* (russe).

Vassilieff L. L. (1953) (Théorie et pratique du traitement par l'air ionisé) *Isd. Gos. Universiteta, Leningrad* (russe).

BIOLOGICAL AND HYGIENIC SIGNIFICANCE OF AIR IONIZATION

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Abstract — A study of *atmospheric ionization* at the *health resorts* and comparison of the results of these studies with the patients' well-being and their clinical symptoms have made it possible to regard ionization as a new bioclimatological factor. An investigation of the physiological action of *artificially ionized* air confirms the biological significance of air ionization. Physiological mechanisms involved in the action of air ionization have not as yet been precisely established. The main route of the ion action is considered to be the respiratory tract. The action of atmospheric ions through the skin is not excluded. The most complete study was that of the physiological action of negative ions widely used in therapeutic practice. Artificial air ionization may be used for the precipitation of *dust* and *microorganisms* in closed rooms. In an industrial establishment with powerful ion-formation sources, high ion concentrations may have an unfavourable effect on the organism.

Zusammenfassung — Das Studium der Ionisation der Atmosphäre in Kurorten und der Vergleich der Resultate mit dem Wohlbefinden der Patienten und den klinischen Symptomen haben es ermöglicht, die Luftionisation als neuen biometeorologischen Faktor zu berücksichtigen. Die Untersuchungen der physiologischen Wirkung von künstlich ionisierter Luft bestätigen die biologische Bedeutung der Luftionen. Die physiologischen Mechanismen, die bei der Wirkung der Luftionen beteiligt sind, sind noch nicht genau abgeklärt. Die Wirkungen gehen vom Respirationstrakt aus. Die Wirkung von atmosphärischen Ionen über die Haut kann nicht ausgeschlossen werden. Die gründlichsten Studien haben sich mit der Wirkung der negativen Ionen befasst, die viel in der Therapie eingesetzt werden. Künstliche Ionisation kann in geschlossenen Räumen auch zur Präzipitation von Staub und Bakterien verwendet werden. In Industriebetrieben, wo viele Ionen gebildet werden, können hohe Konzentrationen eine ungünstige Wirkung auf den Organismus haben.

Résumé — L'étude du degré d'ionisation de l'air des stations climatiques et la mise en parallèle des chiffres ainsi obtenus avec la sensation de bien-être des patients et avec les symptômes cliniques a permis de considérer l'ionisation de l'air comme un nouveau facteur biométéorologique. La recherche des effets physiologiques de l'air ionisé artificiellement corrobore l'importance biologique des ions de l'air. Les mécanismes physiologiques qui entrent en jeu lors de l'action des ions atmosphériques ne sont pas encore connus exactement. L'action des ions part en général des voies respiratoires. On ne peut pourtant exclure une absorption par voie cutanée. Les études les plus approfondies ont porté jusqu'ici sur les ions négatifs qui sont déjà fort utilisés en thérapie. L'ionisation artificielle peut également être utilisée à l'intérieur des locaux pour y provoquer la précipitation de poussières et de bactéries. Dans les locaux industriels où de nombreux ions prennent naissance, les hautes concentrations qui en résultent peuvent avoir un effet défavorable sur l'organisme.

Electric properties of the atmosphere attract increasing attention from medical workers and biologists. It is unnecessary to mention the causes provoking this interest as every year man comes into greater contact with various types of electric energy, including aero-electric processes, occurring in natural conditions, in industrial establishments and in the home.

The first attempts to determine the rôle played by atmospheric electricity in various manifestations of life on earth arose in the middle of the eighteenth century. From that time up to the end of the nineteenth century electric potential – electric field intensity of the atmosphere – was considered as the main factor determining the electric action of the atmosphere on the living organisms. A number of workers pointed to the connection between the electric state of the atmosphere and the plant development, animal behaviour, the general well-being and morbidity of human beings. It was established experimentally by Nollet, Lemonnier, Bertholon, Humboldt, Schübler, Lemschtöm, I. V. Michurin *et al.* that artificial air electrification stimulated the growth of seeds, development of plants, increased the height and weight of the animals, etc.

From the time of discovery of electroconductivity phenomena and air ionization in 1899 by Elster and Geitel, a question of the biological significance of atmospheric ions was posed. In the development of this subject considerable credit belongs to the Russian scientists (Sokolov, Vasiliev, Chernyavsky, Bulatov, Verigo *et al.*). As a result of much work by Russian and foreign scientists, there have now accumulated extensive experimental and clinical data confirming the biological significance of the natural and artificial air ionization.

A survey of the studies of *atmospheric ionization* at the *health resorts* is presented in a separate report, and points to the bioclimatological significance of atmospheric ionization; however, this problem requires further exhaustive study. It is of importance to widen systematic observations of atmospheric ionization at the health resorts and to ascertain the connection between its variations and the clinical manifestations in the patients, as well as the well-being of healthy individuals.

Parallel with this, laboratory experiments are necessary to prove the biological action of atmospheric ions. In these experiments it will be possible to obtain ions of the required concentration, mobility and polarity and to study their isolated action *per se* or in definite combinations with other meteorological factors. It is evident that under natural free atmospheric conditions it is extremely difficult to carry out such experiments, quite apart from the impossibility of studying the physiological action mechanisms of atmospheric ions. Already at the very beginning aeroionization problems developed. Therefore, it became necessary to conduct the experiments in an *artificially ionized medium*. This was investigated also by the desire to apply air ionization as a therapeutic factor outside of health resorts and independently of the season and local natural conditions.

In the U.S.S.R. such investigations were started in the twenties of this century. They were mainly directed by the ideas of A. P. Sokolov, who also developed the first original apparatus for artificial ionization of the air.

Chernyavsky, Sapozhnikova and others studied the effect of artificially ionized air on plants. But, notwithstanding a definite stimulating effect on the *growth of plants* and *inhibiting effect on bacteria* the results of these experiments found no practical application. During the last few years the interest in this question has been revived. Ritslide has studied the effect of negative air ionization on the growth of plants and on various seeds and obtained favourable results.

A number of investigations was carried out to study the possibility of applying artificially ionized air to *animal breeding* (Dolgikh, Skvortsov, and others), but they also found no practical use.

The attention of Soviet scientists was mainly concentrated on the physiological and therapeutic *effects of ionized air* on man and animals. In the thirties the principal investigations in this direction were carried out by Vasiliev and his associates, Bulatov, Kaufman, Obrosov *et al.* These investigations were considerably widened during the postwar period, since a number of new authors became engaged in this work (Faibushevich, Portnov, Minkh, Katsenovich, Siirde, Finogenov, Raudam *et al.*).

The results clearly indicated a physiological effect of gas ions and *hydroaeroions* obtained by atomization of water. This was established in clinical work and in numerous experiments on animals. Artificially ionized air has a definite effect on many body systems and functions. This effect could be positive or negative, depending on the ion concentration, their polarity, mobility and the duration of action. Of great significance are the characteristics of the individual, his "sensitivity" to aeroions, the functional balance in the action of various organs and systems, particularly the state of the vegetative nervous system. The reaction of different persons (both sick and healthy) to the action of aeroions varies: their responses are stronger, the greater the disturbances of some of the organic functions.

The physiological mechanism of the aeroion action has not as yet been definitely established. According to Vasiliev' s view, aeroions produce their effect through the respiratory route (reflexly, by stimulating the pulmonary receptors and humorally, penetrating through the walls of the pulmonary alveoli into the blood). The work of American scientists (Kornblueh) also points to the humoral route of action. However, some scientists hold that only ions of medium size penetrate into the lungs; whereas gaseous small ions, produced by the majority of the ion generators, act only on the upper respiratory tract (Kolodina, Janitzky *et al.*). Lately, on the basis of her experiments on animals, Skorobogatova denied the possibility of pulmonary electro-exchange and considered that the upper respiratory tract, mainly the nasopharynx, is the site of the ionized air action. In the process of inhalation of ionized air the mucous membranes of the nasal tract and trachea acquire an additional potential due to the formation of superficial charges on them.

The action of aeroions through the skin surface is not excluded and has been mentioned earlier by Sokolov and Kimura. At present this view is shared by Portnov and, especially, by Finogenov, who carried out special experimental inves-

tigations on this topic. It has been proven that the aeroionic flow penetrates through the skin surface and induces there a number of physical and chemical reactions. Finogenov also does not consider that alveoli are the site of aeroion action: their effect in respiration is limited to the stimulation of the nervous elements of mucosa of the mouth, nose and upper respiratory tracts. At the surface of mucosa walls there occurs an inductive electric charge, equal to the charge of aeroions, but of a reverse polarity.

The most thorough study was made of the physiological action of light negative ions and hydroaeroions, the bearers of negative electric charges. Both have a characteristic normalizing effect on the arterial hypertension, on the morphological composition and physico-chemical properties of the blood, tissue respiration, vitamin metabolism, as well as on the functional state of the central and peripheral nervous system. There is a distinct desensitizing and somnifacient effect of negative aeroionization. It was established that negative ions possessed the capacity to intensify the inhibiting process in the cerebral cortex, to activate tissue processes, to increase the body resistance to deficiency of oxygen or vitamins, chilling and to bacterial infection, to raise the tolerance to static and dynamic work and to retard somewhat the growth of tumor.

The majority of the authors hold that positive aeroions produce an unfavourable effect on the body and therefore only negatively ionized air is used at present in the therapeutic practice. However, individual investigators are in favour of using positive ions. A. N. Obrosov pointed out that in some cases positive and not negative ions should be supplied. Schulz connects the observed favourable therapeutic results with ions bearing positive electric charges with the initial state of the vegetative nervous system.

It should be indicated that the physiological and therapeutic effect of aeroionization was observed not only with the high ion concentrations used in the majority of the experiments (up to 1–1.5 million of light ions/cm^3 air), but also with the comparatively low ones, approaching those observed in natural atmospheric conditions. This indicates a certain similarity between the action of artificial and natural air ionization, thus confirming the biological significance of atmospheric ionization.

Some possible practical application of negative aero- or hydroaeroionization is recommended in the following conditions: hypertension, bronchial asthma, ozena, catarrhal states of the upper respiratory tracts of non-specific etiology, rheumatic affections of the cardiovascular system without active manifestations, atrophic rhinitis, aphthous stomatitis, erythema exudativa multiformis, neurodermatitis. Favourable results were obtained in the treatment of burns, trophic ulcers, lacerations, poliomyelitis, neuroses of various etiology, peptic ulcers, atherosclerosis, endarteritis, migraine, insomnia, morbid disturbances connected with the change of the climate and tonsillitis.

The following *negative responses* have been established: in cases of insufficiency of coronary circulation, marked vascular sclerosis with a tendency to cerebral and

cardiac spasms, affections of the kidneys and periods following cerebral hemorrhages and myocardial infection.

It was of importance to establish the optimal therapeutic doses of aeroions. American and some Soviet authors were in favour of using much lower doses than usually recommended in our manuals. It may be supposed that the same dose would act differently in aeroionization treatments of different duration and that the effect of large doses of aeroions in a few seances would differ from that obtained in treating with low doses for a prolonged period of time.

More precise data are required on the action of ions of different polarity which under certain conditions (ion concentration, exposure, body state, individual peculiarities) may give similar results. Of great interest is the study of the physiological action of bipolar ionization and possible optimal combinations between ions of different polarities.

Further investigations are necessary on the action of ions with different mobility and on the significance of their chemical nature. Undoubtedly, apart from the polarity, one should also take into consideration the ionic substrate, since not only the electric charge, but also the substance connected with it are the factors taking part in the aeroion action on the human organism as reported by Chernyavsky, Minkh, Tverskoy and Obrosov. According to Tverskoy, resistant negative ions largely represent oxygen and air vapor molecules. According to Martin during artificial aeroion formation with radioactive materials, negative ions are formed from oxygen atoms and molecules, leading to an activation of their oxidative properties. Positive ions are formed mainly from nitrogen molecules, and also from CO_2 and O_2. From the experiments of Krueger and Smith it follows that negative ions consist of oxygen molecules, whereas positive ones consist of carbon dioxide molecules.

Of great practical interest is the study of the effect produced by ionized air on the immunobiological reactivity of the body, on the controlling role of the CNS and some other body functions. The results of these investigations will permit a more intelligent application of ionized air in therapeutic practice.

Little is known about the hygienic significance of the natural and artificial air ionization. The majority of investigations conducted in our country concerns the state of air ionization under various environmental conditions in towns, homes and industrial establishments. Ionization recordings were usually made together with determinations of the state of those other physical and chemical factors usually taken into consideration in hygiene, when assessing the quality of the air.

As a result of these investigations a distinct difference was noted in the state of air ionization in towns and rural localities. In large industrial centres the number fo *small ions* is lower than in the country and usually varies within the range of 100–150/cm^3. However, the number of *heavy ions* increases and exceeds the number of small ions by a factor of 100–200 or more. Almost invariably, positive ions prevail in the air but to the same degree as in the rural localities.

In the crowded homes, apartments and public buildings, and where ventilation is inadequate, the concentration of small ions is 200 to 50/cm^3 as a result of ion uptake during the respiration process, contact with the body, clothes and due to raising of dust, serving as nuclei for condensation of light ions. The number of heavy ions under these conditions increases to several tens of thousands per cm^3 of air, exceeding 100 to 200 times the number of light ions in the polluted outdoor atmosphere. The polarity changes in enclosed premises without any strict regularity: mostly there is the usual predominance of the positive ions. The greatest ionization changes were observed at the time of the worst hygienic state of the air, as determined by the usual methods. The most sensitive and the most stable indicator of these correlations was the value of the heavy ions' prevalence over the light ones.

Thus, air ionization may be regarded as an indicator of the purity of the air. This was confirmed by a number of foreign authors.

Application of recorded data on air ionization for assessing the surrounding environmental conditions is of accessory significance in hygiene. The main interest is the problem of the effect produced by the changes of ionization on healthy individuals. As was demonstrated by observations in health resorts, sick persons react to changes occurring in the atmospheric ionization state. No convincing data in this respect were demonstrable in healthy persons. In any case there are but a few observations on the effect variations of ionization on the well-being of apparently healthy individuals. This does not permit us to draw decisive conclusions. Some authors answer this question in the affirmative, while others believe that the human organism has completely adapted itself to the considerably greater variations of air ion levels than those present in industrial towns and closed premises. In experiments with artificially ionized air it was impossible to find an answer to this question, since with rare exceptions, the available information was obtained from experiments with sick persons exposed to light ion levels tens or thousands of times greater than occur in natural atmospheric ionization. In the thirties interesting investigations on animals and healthy individuals were conducted under Kimura. These demonstrated that the air of rooms artificially devoid of ions caused some unfavourable symptoms in man but were easily eliminated by introduction of negative ions (500 to 2000/cm^3). Animals, kept in *deionized air* for prolonged periods of time did not perish, but a retardation of growth and reduction of blood phosphorus was noted. Recent experiments by A. M. Skorobogatova and Nedzel, with animals kept in deionized air, have definitely refuted the suggestion of the incompatibility of life in air devoid of ions.

The latter experiments are of no practical significance, since complete absence of atmospheric air ions occurs only under extremely rare conditions. It is much more important to determine the effect of slight changes in the number and character of the ions on the organism.

Such experiments were started in the U.S.S.R. during the last few years. Wail and Ivanov studied the effect on healthy adults exposed for 8 hr to unipolarly

ionized air in concentration of light ions of about 100,000/cm^3. They also investigated the effect of bipolarly ionized air, containing 4000 to 5000 negative and 5000 to 7000 positive ions/cm^3 at 24-hr exposure. It was established that inhalation of ionized air is not accompanied by any subjective sensations of "freshness" or by any unpleasant sensations in either the first or the second case. Some moderate physiological shifts were noted in these patients. They were more marked when the aeroionization seances were prescribed after mental or physical work, not after rest. Negative ions manifested their favourable effect both separately and in combination with the positive ones. Positive ions acted more favourably on the higher nervous activity.

Golovanova and Gracheva observed a group of children treated twice a day for 30 days with hydro-ionization at the concentration of negative ions of 2147/cm^3. There were no changes in the behaviour of these children, their appetite, sleep, pulse rate, respiration, arterial pressure and oxihemometry, and in anthropometric indices only a slight rise of the percentage of hemoglobin was noted. In another study, *weakened children* were subjected daily 2 to 4 hr of hydroionization for 2 years. As a result, there was a better physical development and a lesser incidence of catarrhal conditions of the upper respiratory tract as compared with the control group.

Ogleznev studied the effect of negative ions (80,000 to 100,000/cm^3) on adults after a night's sleep, or after work, in relation to fatigue. The seances lasted from 12 to 15 min. It was found that, aeroionization treatment had no effect on the rested persons, whereas tired individuals pointed to reduction of fatigue and to a sensation of "freshness" Objectively there was normalization of a number of functional cardiovascular and CNS indices. The same author tested the action of the positive ions in the concentration of 8000 to 12,000/cm^3 and noted no unfavourable effects on the body, except a reduction of excitation of the visual analyser and a slight rise of arterial blood pressure.

In natural conditions near a powerful fountain and in laboratory conditions, Dumansky has established that hydroionization treatment at a concentration of negative ions of 2000 to 3000/cm^3 of air did not cause any significant physiological shifts, whereas the concentrations of 8000 to 9000/cm^3 provoked rather marked shifts in the cardiovascular and respiratory systems.

Investigations in this direction are being continued. They should bring an answer to the question on the expediency of artificial air ionization in closed rooms. At present this problem has not as yet been solved, and, particularly in the U.S.A., where it was studied by many authors, there was no reliable physiological basis for employment of artificial ionization in air conditioning.

Artificial air ionization in closed rooms deserves attention as a factor which may be used for elimination of dust and microbes from the air. Former indications pointing to the possibility of precipitation of dust together with microbes from the air by means of aeroionization, were confirmed by the latest investigations of Sigal, Golovanova and others. The problem of the direct bactericidal action of artificially

ionized air is still unsolved. Shafir, Yaroshenko, Vashkov and others consider that gas ions and hydroions have no direct *bactericidal effect* on bacteria in the air and on various surfaces, whereas Chernyavsky and Barantsevich point to the action of ionized air on bacteria. Krueger, Smith and Go, as well as Polard stated that ionized air accelerates the death and decreases the toxicity of bacteria and viruses.

Parallel with defining the role of air ionization as a general hygienic factor, the significance of ionization from the point of view of occupational hygiene should also be ascertained. At many industrial establishments and in some therapeutic-diagnostic institutions there are powerful air ionization sources creating high ion concentrations not indifferent to the organism. Depending on ionization value and the chemical nature of the ions they may play a definite role in the etiology and pathology of occupational diseases. Considerable significance is attached to the greater penetration capacity of charged dust particles into the lungs (I. I. Livshitz and I. B. Shagan *et al.*). Ionization may also activate the chemica properties of industrial gases and thus intensify their toxic effect. Arising from use of atomic energy, the possibility of high ion concentrations in the shops increases considerably.

It is suggested that concentration of light ions of about 20,000–30,000/cm^3 of air acting daily upon the workers for many years may have an unfavourable effect on their health, especially if there is a prevalence of positive ions. Therefore, scientists are confronted with the question of bringing the quantitative and the qualitative characteristics of ionization to harmless levels. For this purpose specially charged screens may be used of opposite potential from that of the air; other methods may also be applied.

Air ionization also attracts attention in connection with the problems of aviation and space medicine. Examination of the hermetic personnel chambers of passenger planes demonstrated that the ionization state here is of occupational hygienic interest and air should be additionally supplied with negative ions. It is quite evident that in space flights, started in the U.S.S.R., the recording of ion concentration in space capsules is necessary. This factor should find reflection in the development of the most effective methods for supplying normal living conditions for man during the flight.

Artificial air ionization has found its application in textile, paper, rubber and other industries to eliminate the static electrical charges formed here.

Some data were accumulated on the prophylactic effect of the negative aero- and hydroaeroionization in pneumoconioses and other conditions, especially of allergic nature. In patients with silicosis who were exposed to hydroaeroionization there was a reduction of cough, dyspnea, chest pains and favourable shifts in the processes of oxidation and in the function of the upper respiratory tract (Sigal). Positive results of aeroionotherapy of miners were reported by Andrievskaya and Shulz.

Of considerable interest are investigations of Siirde and in the U.S.A. of Kueger and Smith. They demonstrated that negatively ionized air increases the ciliary

activity of the flickering epithelium of the trachea and the secretion of mucous glands and improves the tonus of smooth bronchial muscles promoting elimination of dust from the respiratory tract.

Negative ionization may also be applied to increase the physical endurance performance and the mental capacity. However, this opinion is not shared by all scientists.

The examples presented do not exhaust all the possibilities of practical application of aeroionization in hygiene and only touch upon the most important problems.

REFERENCES

Malysheva, I. N. (1960) The application of ionized air in stomatology. *Amer. J. phys. Med.* **39,** No. 3. Ann. of the All-Union Conference on Aero and Hydroionization, Tashkent, 1963.

Minkh, A. A. (1963) *Ionization of the Air and its Hygienic Importance.* Publishing House of Medical Literature, Moscow.

Minkh, A. A. (1961) Ionization of the air as a hygienic factor. *J. Hyg. Epidem.* (Praha) **5,** 479.

Vasiliev, L. Y. (1953) *Theory and Practice of Therapy with Ionized Air.* Leningrad University Press.

L'IONISATION ARTIFICIELLE DE L'AIR PAR ACTION ÉLECTRIQUE; PERSPECTIVES NOUVELLES

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Summary — The electric corona discharge has been known as the richest and most versatile source of ions. Unfortunately, unavoidable by-production of chemical compounds, and poor knowledge of ion distribution around emitting electrodes, have largely hampered the design and practical use of electrical ionizers. Mathematical computations and model measurements, now allow us to forecast the distribution of ion density at a distance from electrode arrangements of various shapes. It has been shown that sufficient ion concentrations can be achieved in the centre of a room by inconspicuous ionizers of slender shape and insignificant bulk, which can easily be located in corners or recesses, as fluorescent tubes are. Besides, neutral molecules of unwanted chemical compounds, like ozone or nitrogen oxides, can be readily eliminated by an aerodynamical counterflow which prevents them from entering the adjacent space. This flow, however, is so gentle that it cannot be harmful or even be felt in the treatment zone. Theory shows that it cannot impede the flight of small ions, either. Precipitation of airborne dust particles takes place inside the ionizer, and the walls and furniture are not stained by precipitated dirt. It is thought that this new type of ionizer will be preferred to the antiquated and ill-looking "spiders", while providing more reliable physical background for both experimental work and treatment practice.

Zusammenfassung — Die Koronaentladung, eine selbständige Gasentladung in der Umgebung der Oberfläche von elektrisch hochgespannten Drähten oder Spitzen nach Überschreiten einer gewissen Feldstärke, ist eine sehr bekannte und ergiebige Ionenquelle. Die gleichzeitige Erzeugung ungewünschter chemischer Bindungen und die Unwissenheit hinsichtlicht der Ionenverteilung im Raum wirkten hemmend auf die Anwendung dieses Verfahrens zur Anreicherung der Luft mit Ionen. In den letzten zwei Jahren wurden theoretische und experimentelle Untersuchungen der Ionisierungsvorgänge in der Luft unternommen, deren Ergebnisse es gestatten, die Ionenverteilung im Raum bei verschiedenen Elektrodenanordnungen vorauszusehen. Eine ausreichende Ionendichte kann im Zentrum eines Raumes erzielt werden, auch wenn die Entladeelektroden an den Wänden angebracht sind. Die neutralen Moleküle der schädlichen chemischen Bindungen können somit auf der Erzeugungsstelle aufgesogen werden mit gleichzeitiger Verhinderung der unangenehmen Bestäubung des Raumes. Es besteht somit die Möglichkeit zur Herstellung von Luftionisationsgeräten mit bekannter und reproduzierbarer Ionisation für Ärzte, Biologen und Forscher, die eine künstliche Ionenanreicherung der Luft wünschen.

Résumé -- L'effluve électrique ou « effet couronne » est la source d'ions la plus abondante et la plus universelle. Deux raisons ont cependant freiné son emploi dans le domaine de l'aéroionisation: l'ignorance à peu près totale de la façon dont les ions se répartissent dans l'espace et la production de composés chimiques indésirables. Une étude théorique et une expérimentation rigoureuse, permettent maintenant de prévoir l'action dans l'espace d'un

ioniseur et d'éliminer au départ les composés parasites sans gêner la migration des ions vers les zones utiles. Il a été montré en particulier qu'une concentration d'ions suffisante peut être obtenue dans le centre d'une salle au moyen d'ioniseurs discrétement placés près des parois, une aspiration locale retirant de la zone même de production les composés parasites. Cette disposition évite accessoirement la précipitation désagréable des poussières dans l'ensemble de la salle, celle-ci se produisant exclusivement dans la région des ioniseurs. D'une facon plus générale, des appareils aéroioniseurs «propres», fonctionnant dans des conditions définies et reproductibles, peuvent être maintenant étudiés et construits pour répondre aux besoins du médecin, du biologiste, du «technicien d'ambiance» et de tous les chercheurs qui doivent accroître artificiellement le degré d'ionisation de l'air.

L'effluve électrique ou *effet couronne* est la source d'ions la plus abondante et la plus aisément réglable. Elle peut donner aussi bien des ions positifs que négatifs, mais, dans tous les cas, il est facile d'être assuré qu'une seule sorte d'ions est présente dans la région d'expérimentation ce qui facilite grandement l'interprétation. On peut également, si on le désire, avoir simultanément des *ions positifs et négatifs*, en proportion *réglable*. En ce qui concerne *les densités d'ions réalisables*, elles peuvent être extrêmement élevées. Dans un champ électrique de 1000 V/cm avec une densité de courant de 0,01 μamp/cm^2, valeurs très facilement obtenues avec un effluveur alimenté par un générateur de haute tension continue (80 à 100 kv) de faible puissance (100 W), on a une densité d'ions supérieure à 10^7/cm^3, chiffre qui surpasse par un facteur 1000 ou 10 000 la densité de petits ions usuellement présente dans l'air pur de la campagne.

Depuis plusieurs décades, des aéroioniseurs électriques ont été préconisés et construits. On peut faire remonter leur début à la «douche électrique» ou «franklinisation» pratiquée au début du siècle dans les cabinets médicaux à l'aide de générateurs électrostatiques à influence, où la source de haute tension était reliée à des pointes effluvantes suspendues au-dessus du patient. Ce type d'ioniseur n'a pas cessé d'être utilisé depuis et seule la vieille machine électrostatique a disparu, remplacée d'abord par des systèmes à redresseurs puis, plus récemment, par de nouveaux générateurs électrostatiques bien adaptés au but poursuivi. Dans son grand ouvrage paru en 1960 «L'aéroionisation dans l'économie», le Pr. Tchijevsky décrit un grand nombre d'installations de ce genre où des ioniseurs à nombreuses pointes, qu'il désigne sous le nom de «*lustres effluvants*», sont suspendus au plafond des pièces où a lieu le traitement et sont reliés à une source de haute tension de 30 à 80 kv. Dans certaines variantes, l'effluveur se trouve derrière un grillage isolant et les ions sont entrainés vers le local à traiter par un courant d'air produit par un ventilateur placé derrière l'ioniseur.

Il est manifeste que ce système d'ioniseur, malgré ses éminentes qualités, n'a pas rallié jusqu'ici l'unanimité des expérimentateurs et des médecins, comme cela est attesté par la multiplicité des systèmes concurrents, fondés sur la radioactivité les rayonnements ultra-violets, etc.

Les raisons de cette hésitation devant l'ioniseur électrique sont connues. D'une part, il n'existait pas, jusqu'à présent, de méthode scientifique pour prévoir la

distribution de la densité d'ions créée dans l'espace par un ioniseur électrique. Dans chaque cas, on était obligé de s'en remettre entièrement à l'expérience et à des mesures longues et délicates, dont on connaît l'incertitude. D'autre part – et c'est probablement là une difficulté essentielle – l'ioniseur électrique était connu pour produire en quantités plus ou moins grandes, non seulement des ions, mais aussi des composés chimiques dérivés des constituants de l'air, avant tout de l'ozone et de l'oxydes d'azote. Il est très possible, comme l'ont affirmé certains auteurs, qu'un aéroioniseur bien réglé ne produise ces composés qu'en proportions trop faibles pour être dangereuses. Ceci, néanmoins, n'est pas entièrement démontré. Par ailleurs, la notion de «niveau dangereux» est sans cesse sujette à révision et, dans le cas de l'ozone, une tendance à la sévérité se fait jour au point que, dans certains pays comme les Etats-Unis, le taux d'ozone autorisé n'excède pas la dose naturelle habituellement présente à l'air libre. Enfin, du point de vue scientifique, il est indispensable de pouvoir séparer les effets des ions de ceux d'autres facteurs, physiques ou chimiques. Quand on sait la prodigieuse sensibilité des organismes à des doses moléculaires de certains composés chimiques, il est évident que l'on doit éliminer au maximum toutes les molécules étrangères qui viendraient superposer leurs effets à celui des ions, si l'on veut opérer de façon scientifique et avoir des résultats dont l'interprétation soit simple. Aussi, même si la proportion d'ozone et d'oxydes d'azote demeure réellement sans danger, il est évident qu'il faut éliminer au maximum ces facteurs parasites, surtout dans la période actuelle, où l'on cherche avant tout à déterminer scientifiquement l'effet propre des ions sur les fonctions vitales.

La possibilité d'une prévision théorique des densités ioniques en même temps que l'élimination des composés chimiques produits par l'effluve est donnée par les recherches qui ont été conduites depuis trois ans au laboratoire d'Electrostatique de la Faculté des Sciences de Grenoble par le Pr. N. J. Félici et ses collaborateurs. Le Pr. Félici s'est posé le problème de prévoir par le calcul la distribution du potentiel, du champ électrique et de la densité de charge (ou densité d'ions) dans un champ électrique ionisé, comme celui qui existe dans les précipitateurs électrostatiques de fumées. Ce problème, essentiel pour des applications industrielles de la plus haute importance, comme précisément la précipitation électrostatique, n'avait pas reçu jusqu'ici de solution satisfaisante, sauf dans des cas très simples, comme celui de l'ioniseur à fil dans l'axe d'un cylindre, traité par Townsend (1914).

En s'aidant d'un caculateur électronique, le Pr. Félici est parvenu à une description générale des propriétés mathématiques des champs ionisés ainsi qu'à des formules et des abaques pratiques qui permettent des calculs numériques suffisamment approchés. Il est impossible de donner ici même un aperçu de ces développements mathématiques, je ne puis que renvoyer aux notes qui ont paru dans les Comptes-Rendus de l'Académie des Sciences de Paris (Felici, 1962a, b, 1963) et à l'article, beaucoup plus détaillé, publié par le périodique britannique «Direct Current» (Felici, 1959). D'une façon extrêmement schématique, voici les résultats de l'étude mathématique qui nous intéressent directement.

La distribution des ions dans l'espace dépend d'une façon très compliquée de la figure exacte de l'effluve produite par l'ioniseur, et pas seulement de la différence de potentiel et du courant d'ionisation. Cependant, si la densité d'ionisation sur l'électrode ionisante est suffisamment forte et que l'on se trouve à une distance assez grande, la distribution du potentiel, du champ et de la charge devient très proche de certaines solutions relativement plus simples du problème, dont la détermination par le calcul électronique est possible. Ces solutions ont été nommées par le Pr. Félici «solutions saturées» ou «solutions asymptotiques». Un grand nombre d'entre elles, pour des figures géométriques simples de l'électrode réceptrice (angles, plans parallèles) ont été numériquement calculées.

On peut se faire une idée de ce que sont les solutions saturées en se référant au seul cas simple connu jusqu'ici, celui du fil dans l'axe d'un cylindre, qui correspond au problème résolu par J.S. Townsend et aux premiers précipitateurs de Cottrell. Si $\dot{I}$ est le courant d'ionisation, l la longueur commune du fil et du cylindre, K la mobilité des ions, E le champ électrique, Townsend à montré que $E^2 = (2\dot{I}/Kl) + + C/r^2$, C étant une constante qui dépend des autres données (diamètre du fil, etc.). Si $\dot{I}$ est grand ou le fil très mince, C est très petit, de telle sorte qu'a une distance r importante, E devient constant et égal à $\sqrt{2\dot{I}/Kl}$. C'est là l'exemple le plus simple d'une solution saturée ou asymptotique, qui devient très différente à grande distance de la solution valable lorsque $\dot{I}$ est nul (ici $\sqrt{C}/r$) et qui se substitue pratiquement à cette dernière dès que $\dot{I}$ est notable.

Des résultats similaires peuvent être obtenus dans tous les cas, quoique impossibles à représenter par des formules aussi simples. A titre d'exemple nous citerons le cas d'un angle dièdre conducteur dans lequel est tendu, parallèlement à son arête, un fil fin ionisant.

Cette disposition est susceptible de remplacer avantageusement les «araignées» de la franklinisation dont la présence dans un local est inesthétique et gênante, désagréable en cas de contact fortuit, dangereuse si une étincelle venait mettre le feu à des vapeurs inflammables et déplaisante en raison de la précipitation des poussières dans toute la pièce et sur le mobilier.

La théorie mathématique et le calcul électronique montrent que, dans le cas qui nous occupe, à une distance du fil grande par rapport à l'espace qui le sépare de l'arête du dièdre, la solution asymptotique peut se représenter de façon assez simple. Dans la réalité, les faces du dièdre seront les parois d'une pièce ou d'un local, de telle sorte que nous nous intéresserons spécialement aux angles dièdres rentrant de 90°, de 120° et également de 180°. Ce dernier cas correspond au fil tendu à faible distance du plafond, parallèlement à lui.

Dans tous ces cas, le potentiel de la solution asymptotique est de la forme $V = r^n f(\theta)$, n étant un exposant négatif, r la distance à l'arête et θ un angle polaire pris à partir des faces ou du plan bissecteur. En conséquence, le champ E sera en r^{n-1} et la densité de charge (qui donne la densité d'ions) en r^{n-2}, sa valeur précise étant $\varrho = (1/4\pi)\, r^{n-2}\, [n^2 f(\theta) + f''(\theta)]$. Le calcul montre que la fonction $n^2 f(\theta) + f''(\theta)$ varie assez peu avec θ (de 30 pour cent en plus ou en moins par

exemple) de telle sorte qu'il est suffisant de supposer en première approximation que ϱ ne dépend que de r.

Le calcul donne les valeurs de n pour les différents angles. Les voici: pour 90° $n = -0{,}86$, pour 120° $n = -0{,}60$, pour 180° $n = -0{,}32$. Si le champ n'était pas du tout ionisé, les exposants seraient beaucoup plus grands en valeur absolue, soit respectivement -2, $-1{,}5-1$. En passant du potenciel au champ nous voyons que le champ ionisé dans un dièdre conducteur de 90° décroîtra comme $r^{-1,86}$ et au voisinage d'un plan conducteur comme $r^{-1,32}$. Cette loi de décroissance est valable tant que r est grand par rapport à la distance du fil ionisant à l'arête et doit être remplacée par une autre quand r est d'environ le double de cette distance.

Si nous considérons maintenant le champ de vitesses aérodynamiques dû à une aspiration de l'air le long de l'arête du dièdre, ce champ est dans tous les cas de l'ordre de r^{-1}, de sorte que le rapport de la vitesse des ions à celle de l'air varie comme $r^{-0,86}$ pour 90° et $r^{-0,32}$ pour 180°. Si nous voulons qu'une aspiration de l'air le long de l'arête ne gêne en rien la pénétration des ions, il faut que, au centre de la salle d'expérience, la vitesse des ions soit par exemple 10 fois la vitesse de l'air. Au voisinage du fil ionisant, ce rapport des vitesses sera nécessairement plus grand mais nous pouvons montrer qu'il sera parfaitement réalisable: en admettant un rapport des distances de 20, il atteindra respectivement $10\times(20)^{0,86} = 130$ et $10\times(20)^{0,32} = 26$. Si l'on considère comme suffisant que l'air se déplace à 10 cm/sec pour qu'il entraîne sûrement les produits indésirables, la vitesse des ions devra donc atteindre 1300 cm/sec ou 260 cm/sec. De telles vitesses sont aisément réalisables: elles demandent des champs électriques de l'ordre de 1000 v/cm.

Au voisinage du fil, le champ est donné grossièrement par la formule de J. S. Towsend $E = \sqrt{2\dot{I}/Kl}$ ce qui donne le débit linéique nécessaire $\dot{I}/l$. Pour 1000 v/cm, on trouve environ 50 μamp par mètre. La tension nécessaire pour entretenir ce courant d'effluve dépend de la distance du fil aux parois; pour des distance raisonnables (10 à 20 cm) elle est de l'ordre de 50 à 90 kv.

En ce qui concerne la densité d'ions, elle varie comme $r^{-2,86}$ pour un angle rentrant de 90°, c'est-à-dire qu'un rapport des distances de 20 se traduit par un rapport des densités de 5500. Avec les chiffres précédents, la densité de charge est de l'ordre de 0,03 UES ou 10^8 ions/cm^3 à une dizaine de cm du fil; divisé par 5500, cela fait plus de 10^4 ions/cm^3. On obtient ainsi très facilement des densités supérieures aux densités naturelles dans l'air pur de la campagne. Si l'on désire des chiffres 10 ou 50 fois plus forts il est facile d'y parvenir en augmentant le débit linéique et la tension, en plaçant le fil plus loin des parois, et surtout en adoptant un angle de 180° (fil parallèle au plafond) car la décroissance du champ et de la densité est alors beaucoup plus lente. Dans ces conditions on pourra traîter efficacement des volumes extrêmement importants.

Le calcul montre par ailleurs que la plupart des poussières flottant dans l'air prendront dans le champ ionisé des vitesses plus faibles que celle du champ aérodynamique; elles viendront donc se précipiter dans l'appareil ioniseur et non sur le mobilier et les parois de la salle. Ajoutons que le débit d'air nécessaire pour assurer

la vitesse de 10 cm/sec est comparable à celui d'une ventilation moyenne: renouvellement complet de l'air d'une salle plusieurs fois par heure. Il sera naturellement avantageux de faire passer cet air à travers une paroi poreuse en forme de gouttière, située derrière le fil ionisant, moyennant une dépression suffisante.

Les travaux précédents, orientés surtout vers le problème de l'ionisation «collective» à l'échelle de la salle, apportent aussi une contribution précieuse à l'étude de l'ioniseur «individuel», dont l'action est limitée à une zone de traitement relativement restreinte.

Quel que soit leur type, ces ioniseurs nécessitent bien entendu pour leur alimentation une source de haute tension continue, commode et inoffensive. Les nouveaux générateurs électrostatiques, apparus sur le marché voici quelques années (Felici, 1959; Morel, 1961), se prêtent bien à cet usage en raison des tension élevées qu'ils permettent d'obtenir sous un petit volume, dans des conditions d'innocuité absolument totale.

Ainsi, l'ioniseur électrique doit permettre de résoudre les problèmes posés par le médecin, le biologiste, le chercheur qui doit accroître artificiellement le degré d'ionisation de l'air, et peut être un jour par le technicien qui ajoutera ce degré d'ionisation aux facteurs « d'ambiance » que ses installations contrôlent déjà. Une étude technologique, entreprise à la suite de ces travaux de base par une société industrielle spécialisée dans la construction des générateurs électrostatiques et dans les applications du champ électrique, conduira dans un proche avenir à la réalisation d'aéroioniseurs à action locale ou étendue. Il est d'ores et déjà souhaitable qu'une collaboration avec les utilisateurs s'établisse, pour préciser les besoins et pour orienter dans le sens voulu le choix des caractéristiques à retenir.

BIBLIOGRAPHIE

Felici, N. J. (1962a) Singularités du champ électrique ionisé. *C. R. Acad. Sci. (Paris)* **255,** 1703–1705.

Felici, N. J. (1962b) Solutions singularières et regulières de l'équations des champs électriques ionisés. *C. R. Acad. Sci. (Paris)* **255,** 3377–3379.

Felici, N. J. (1963) Conditions aux limites et déterminations des solutions regulières de l'équations du champ électrique ionisé. *C. R. Acad. Sci. (Paris)* **256,** 3254–3256.

Felici, N. J. (1964) Recent advances in the analysis of DC ionized electric fields. *Direct Current* **8,**

Felici, N. J. (1959) Recent developments and future trends in electrostatic generation *Direct Current* **4.**

Morel, R. (1961) Une technique nouvelle issue d'une Science oubliée: l'Electrostatique *Ingenieurs et Techniciens,* Nos 147 et 148, Octobre et Novembre 1961.

Townsend, J. S. (1914): *Phil. Mag.* **28,** 83.

AEROSOL IONIZER AND ITS APPLICATION IN MEDICINE

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Abstract – An aerosol ionizer working on the principle of a pulverizer has been constructed. Using it to spray water or aqueous solutions of medicaments with oxygen or compressed air, it is possible to produce electroaerosols suitable for inhalation. Aerosols are, at will, given a negative, positive or bipolar charge by electrostatic induction. It was observed that negatively charged electroaerosols obtained by spraying water with oxygen exert a normalizing effect on the mucous membrane of the respiratory tract: ciliary activity is intensified, blood vessels either contract or widen, temperature and pH of mucus becomes normal. Inhalation of negative electroaerosols obtained by spraying water with oxygen increases oxyhemoglobin to a greater extent than inhalation of oxygen alone. Electroaerosols obtained by spraying with oxygen can with success be applied in the treatment of allergic rhinopathy, bronchial asthma, atrophic rhinitis and ozaena.

Zusammenfassung – Es wurde ein auf dem Prinzip eines Pulverisators arbeitender Aerosolionisator konstruiert, der durch Zerstäubung von Wasser oder Wasserlösungen von Medikamenten mit Hilfe des Sauerstoffs oder der Pressluft die zum Inhalieren geeigneten Elektroaerosole erzeugt. Den Aerosolen wird mittels elektrostatischer Induktion nach Belieben eine negative, positive oder bipolare Ladung gegeben. Es wurde beobachtet, daß negativ geladene Elektroaerosole, die bei der Zerstäubung des Wassers mit Sauerstoff erzeugt worden sind, auf die Schleimhäute des Atmungstraktes eine normaliesierende Wirkung ausüben: die Aktivität des Wimperepithels steigt, die Blutadern ziehen sich zusammen oder erweitern sich, die Temperatur und pH des Nasensekrets werden normal. Die Inhalation von negativen Elektroaerosolen, die bei der Zerstäubung des Wassers mit Sauerstoff erhalten werden, steigert den Oxyhaemoglobingehalt im Blute mehr als nur das Einatmen von Sauerstoff. Die durch Zerstäubung von Wasser erhaltenen Elektroaerosole kann man mit gutem Erfolg bei der ärztlichen Behandlung von allergischer Rhinopathie, des Bronchialasthmas, der atrophischen Rhinitis und Ozaena benutzen.

Résumé – On a construit un ionisateur d'aérosols fonctionnant selon le principe du pulvérisateur. En pulverisant ainsi, à l'aide d'oxygène ou d'air comprimé, de l'eau ou des solutions aqueuses de médicaments il est possible d'engendrer des électro-aérosols propres à l'inhalation. On donne à volonté, aux aérosols une charge négative, positive ou bipolaire par le moyen d'une induction électrostatique. On a observé que les électroaérosols chargés négativement, obtenus en pulvérisant de l'eau à l'aide d'oxygène, produisent un effet normalisant sur les muqueuses des voies respiratoires: l'activité des cils de l'épithélium s'accroît, les vaisseaux sanguins se rétrécissent ou s'élargissent, la température et le pH de la secrétion nasale se normalisent. L'inhalation d'électroaérosols négatifs, obtenus en pulvérisant de l'eau à l'aide d'oxygène, augmente davantage le taux de l'oxyhémoglobine du sang que l'inhalation d'oxygène seul. Les électroaérosols, obtenus par voie de

pulvérisation d'eau à l'aide d'oxygène, peuvent être utilisés avec succès dans le traitement de la rhinopathie allergique, de l'asthme bronchial, de la rhinite atrophique et de l'ozéna.

By *aerosols* in medicine we mean particles of the solutions of medicaments sprayed in the air for the purpose of inhalation and having a size of 0.2 μ to 10μ. Spraying is usually carried out by means of a sprayer with the help of compressed air from a compressor, oxygen from an oxygen balloon or a special ultrasonic device.

In the dispersed spraying of water or of aqueous solutions of medicaments one obtains, as a result of the balloelectric effect, an almost symmetric bipolar electrification of particles of aerosols, i.e. an almost equal number of positive and negative elementary charges per cubic centimetre of air.

In non-symmetrical electrification one obtains the preponderance of charges of that polarity which coincides with the polarity of the minutest droplets (Natanson, 1955). Electroaerosols represent an air-dispersed system whose particles have only a unipolar charge, i.e. a positive or a negative one.

For a number of years members of the Chair of General Physics of Tartu State University have been working at the problem of how, with the help of comparatively simple devices, it would be possible to produce electroaerosols that can be applied to inhalation therapy in medicine. As a result of these efforts different designs of ionizers have been worked out, such as a steam inhalation ionizer (Reinet, 1959) and various types of aerosol ionizers, which have found application in medical practice up to the present time. Reinet and Tammet, 1958; Siirde and Reinet, 1959; Raudam *et al.*, 1959; 1960; Raudam and Reinet, 1960; Reinet, 1960; Reinet and Siirde, 1960; Reinet, Susi and Tamm, 1960; Siirde and Prüller, 1963).

Below we shall deal with one type of a device termed an *oxygen ionizer* of aerosols (Reinet and Siirde, 1960).

An oxygen ionizer of aerosols is intended for the production of electrically charged aerosols of the solutions of medicaments in the air enriched by oxygen. The design of the device makes it possible to detach the spraying chamber from the device for its disinfection. The sprayer of medicaments represents a pulverizer of the Bergson–Barkovsky type (Siirde and Prüller, 1963). Above the nozzle of the pulverizer is mounted an electrode which is given the voltage appropriate to earthed nozzles (Fig. 1.).

On the surface of the liquid in the nozzle one induces a charge the polarity of which is contrary to the polarity of the voltage of the electrode.

When the medicament is being sprayed, each droplet which is torn away from the surface of the medicament retains a charge of the same polarity as the charge on the surface of the liquid.

Electrically charged droplets while striking an obstacle (the interior wall of the body of the sprayer) are broken up into still smaller ones as a result of which electroaerosols are produced with a charge which may amount to 10^7 elementary charges/cm^3. Compressed air or oxygen which passes from the spraying chamber

into the inhalation mask or a small porcelain cylinder (to be inhaled by the patient through the mouth or the nose) carries with it electroaerosols.

The physiological effect of negatively charged electroaerosols was investigated by us regarding the changes which they produced in the activity of the ciliated epithelium of the isolated oesophagus of a frog and in several physiological indices in men.

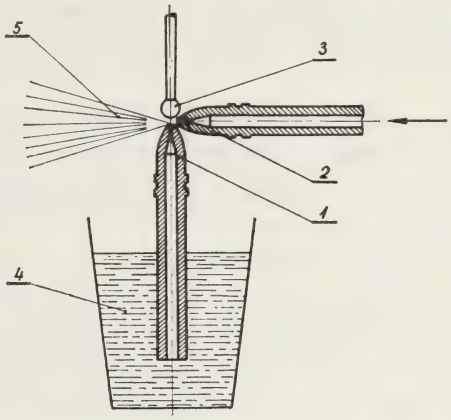

Fig. 1. The working-scheme of the aerosol ionizer. 1 — nozzle for medicament 2 — nozzle for oxygen or compressed air 3 — electrode 4 — medicament 5 — electroaerosol

Changes in the *activity of the ciliated epithelium* were judged by the rate of movement of a plug, placed on the mucous membrane of the isolated oesophagus, between two definite points before and after the spraying of electroaerosols on the mucous membrane for one minute. The oesophagus slit was held lengthwise at a distance of 10 to 15 cm from the ionizer. Experiments showed that negatively charged electroaerosols speed up the movement of the cilia of the ciliated epithelium, but positively charged electroaerosols slow it down, (Siirde, 1957, 1959) results of our experiments are in agreement with observations conducted by Krueger and Smith (1957) on the isolated trachea of a rabbit.

The activity of the ciliated epithelium was also observed for the effect produced by some medicaments on the mucous membrane of an isolated oesophagus of a frog when the medicaments were sprayed in the form of aerosols and electroaerosols. The following kinds of medicaments were used: novocain solutions (0.25–1 per cent), penicillin solutions (100,000 and 200,000 units per 10 cm^3 of distilled water), urethan solution (0.5 per cent) and piped, as well as distilled, water.

The experiments showed that in the majority of cases the above solutions of medicaments, when given in the form of aerosols, retarded the movement of the cilia of the ciliated epithelium; when these aerosols, however, were negatively charged, they speeded up the movement of the cilia in spite of the fact that the above mentioned solutions contain substances causing retardation of activity. Hence it is possible to conclude that in the treatment of the respiratory tract electroaerosols are to be preferred to aerosols.

The physiological effect of electroaerosols was also observed in men after a 5-min period of inhalation of approximately 150 milliards of elementary charges, which also served as a séance of treatment. The observations of physiological changes were carried out 5–10 min after inhalation.

Plethysmography of the mucous membrane of the nose of men showed that in inflammation and allergy the negatively charged electroaerosols made the distended blood vessels of the mucous membrane of the nose contract, but in atrophic rhinitis and ozaena the same electroaerosols made the contracted blood-vessels of the nose distend.

Results of rhino-anemometric observations on the passage of air through the nose after the inhalation of negative electroaerosols were similar to the results of plethysmography: in the case of oedema of the mucous membrane of the nose, breathing through the nose became easier.

Observations of the changes in the temperature of the upper respiratory tract showed that in a normal condition the temperature of the mucous membrane of the nose (on an average 32° C) may increase by 1° C under the effect of the negatively charged electroaerosols; however, at the same time the temperature of the skin (on the chest and on the legs), may go down. In pathological conditions (such as catarrh, allergy, ozaena) changes in the temperature of the mucous membrane of the nose and of the skin proceed in the same direction—there occurs either a simultaneous rise or a simultaneous fall.

Studies of the pH of the mucus of the nose showed that the reaction of pH of the mucus from a healthy nose is almost neutral or slightly alkaline (pH is 7.10–7.20), but in pathological conditions (catarrh of the nose, allergy, ozaena) the reaction of pH is more alkaline (pH rises up to 7.60–7.80). Negatively charged electroaerosols may bring about changes in the reaction of the mucus from the nose; the direction of the changes depends on the type of aerosols applied: distilled water for instance, reduces the alkaline reaction. In the course of treatment an improvement in the clinical picture is accompanied by a reduction in the alkaline reaction of the nose and the approach of pH to the neutral reaction.

Our observations on the oxyhemoglobin content in the blood (carried out by means of the Kreps oxyhemometer of the design 0–38) demonstrated the dependence of the oxyhemoglobin content on the type of ions used: as a rule, aeroions slightly raise the oxyhemoglobin content in the blood, but sometimes even reduce it (below 96 per cent); hydroions, however, raise the oxyhemoglobin content to a greater degree. The degree of saturation of oxyhemoglobin in the blood rises most of all (even up to 99.3 per cent) when electroaerosols are inhaled which have been obtained by spraying with oxygen – it is higher than when oxygen alone is inhaled. Hence one can draw the conclusion that inhalation of electroaerosols obtained by spraying with oxygen is indicated for removing any oxygen deficiency in the organism.

Negatively charged electroaerosols obtained by spraying with oxygen were used by us in the years 1958–1961 in the treatment of 524 patients, the majority of whom

were suffering from ozaena (205 cases), bronchial asthma (94 cases) and vasomotor disturbances, chiefly from allergic rhinopathy (75 cases); the rest of the patients were suffering from atrophic rhinitis, severe and chronic inflammatory processes in the respiratory tract. Séances of treatment were given 1–2 times a day in the course of 2–3 weeks. Our observations showed that treatment with electroaerosols proved to be more effective in asthma, allergic rhinopathy and ozaena—about three-fourths of the total number of patients showed a greater or smaller degree of improvement of their clinical picture. In relapses the treatment was repeated, which again gave positive results.

The observations described testify to the normalizing effect of negative electroaerosols on the organism, which justifies their much wider application in medical practice.

REFERENCES

Elkin, I. I., and Eidelstein, S. I. (1955) Aerozoli antibiotikov, ih polucheniye i klinicheskoye primeneniye. Moskva, 1955. *Aerosols of Antibiotics, Their Receipt, and Clinical Application.*

Krueger, A. P. and Smith, R. F. (1957) *Proc. Soc. exp. Biol. (N. Y.)* **96,** 807–809.

Natanson, G. L. (1955) Elektrizatsiya pri raspylenii zhidkostei. *Doktotskaya dissertatsiya, Fiz.-him. institut im.* L. J. Karpova, Moskva 1955. (Electrization at the atomization of liquids. Thesis for the doctorate).

Prüller, P. and Reinet, J. (1961) Fizicheskoye obosnovanye razlichiya fiziologicheskogo deistviya aerozolei i elektroaerozolei. Trudy po meditsine IV. *Uchonye zapiski Tartuskogo gos. universiteta, Tartu,* **112,** 7–14. (Physical substantiation of the difference of the physiological influence of aerosols and electroaerosols. Studies in Medicine. IV. *Proc. of Tartu State University.*

Raudam, E. J. and Reinet, J. J. (1960) O primenenii gidroaeroionov aerozolei i elektroaerozolei u trakheotomirovannykh bolnykh s diagnozom poliomielita. Vsesoyuznaya konferentsiya po aero- i gidroaeroionizatsii. Tezisy dokladov, Medgiz UzSSR, Tashkent, 106–107. On the use of the hydroaeroions of aerosols and electro-aerosols in tracheotomized poliomyelitis patients. All-union conference on aero- and hydroaeroionization. Theses of the reports.

Raudam, E., Reinet, J. Tikk, A. and Veldi, A. (1959) Ob ispolzovanii aerozolei i elektroaerozolei u trakheotomirovannykh bolnykh poliomielitom. Nauchnaya konferentsiya meditsinskogo fakulteta Tartuskogo gos. universiteta 1959 g. Tezisy dokladov. Tartu, 7–8 (na estonskom yazyke). On the use of aerosols and electro-aerosols in tracheotomized poliomyelitis patients. Scientific conference of the medical department of Tartu State University. Theses of the reports (in Estonian).

Raudam, E. J., Reinet, J. J., Tikk, A. A., Veldi, A. T. and Tamm, E. I. (1960) O primenenii aerozolei i elektroaerozolei v ostroi stadii poliomielita, osobenno u podvergshikhsya trakheotomii bolnykh. *Zhurnal Nevropatologii i psihiatrii imeni S. S. Korsakova,* **60,** 1428–1434. On the use of aerosols and electro-aerosols at the acute stage of poliomyelitis, especially in the patients subjected to tracheotomy. *J. Neuro-Pathology and Psychiatry* named after S. S. Korsakov.

Reinet, J. J. (1959) O novykh aeroionizatorakh, skonstruirovannykh v laboratorii aeroionizatsii Tartuskogo gosudarstvennogo universiteta. *Voprosy kurortologii* V. Riga, 31–35. On new air ionizers constructed at the laboratory of ionization of Tartu State University. *Problems of Spa Treatment* V.

Reinet, J. J. (1960) Novye aerozol- i aeroionizatory uspeshno primenyaemye v meditsinskoi praktike v Tartuskikh klinikakh. Vsesoyuznaya konferentsiya po aero- i gidroaeroionizatsii.

Tezisy dokladov. Medgiz UzSSR Tashkent 140–141. New aerosol and air ionizers used with success in medical practice at Tartu clinics. All-union conference on aero- and hydroaeroionization. Theses of the reports.

Reinet, J. J. and Tammet, H. J. (1958) Avtorskoye svidetelstvo No. 129636 na izobreteniye "Aerozol-ionizator" ot 24 noyabrya 1958 g. Patent No. 129636 of 24 November 1958 for the invention of "aerosol-ionizer".

Reinet, J. J. and Siirde, E. K. (1960) Kislorodnyi aerosol-ionizator i nekotorye nablyudeniya pri ego primenenii v meditsine. Vsesoyuznaja konferentsiya po aero- i gidroaeroionizatsii. Tezisy dokladov. Medgiz UzSSR, Tashkent, 147–148. Oxygen aerosol-ionizer and some observations on its application in medicine. All-union conference on aero- and hydroaeroionization. Theses of the reports.

Reinet, J. J., Susi, A. K. and Tamm, E. I. (1960) Avtorskoye svidetelstvo No. 131456 na izobreteniye "Generator aerozolei dlya apparatov iskusstvennogo dyhaniya intratrakhealnym metodom" (Opublikovano v byulletene izobretennii No. 17 ot 7 yanvarya 1960 g.). Patent No. 131456 for the invention of "the generator of aerosols used in the apparatus of artificial respiration by the intratracheal method" (Published in the bulletin of inventions No. 17 of 7 January 1960).

Siirde, E. (1957) O nekotorykh fiziologicheskikh pokazaniyakh vozdeistviya otrisatelnykh i polozhitelnykh ionov. Nauchnaya sessiya Tartuskogo gos. universiteta. Tezisy dokladov. Tartu, 66–67 (na estonskom yazyke). On some physiological indices of the influence of negative and positive ions. Scientific conference at Tartu State University. Theses of the reports (in Estonian).

Siirde, E. K. (1959) O nekotorykh fiziologicheskikh pokazetelyakh vozdeistviya otritsatelnykh i polozhitelnykh aeroionov i gidroionov. *Voprosy kurortologii* V. Riga, 215–220. On some physiological indices of the influence of negative and positive aero- and hydroions. *Problems of Spa Treatment* V.

Siirde, E. and Reinet, J. (1959) O kislorodnom aerozol-ionizatore i nekotorykh fiziologicheskikh pokazatelyakh pri primenenii ionizirovannogo kisloroda. Nauchnaya konferentsiya meditsinskogo fakulteta Tartuskogo gosudarstvennogo universiteta. Tezisy dokladov, Tartu, 1959, 4–5. On oxygen aerosol-ionizers and some physiological indices of the use of ionized oxygen. Scientific conference of the medical department of Tartu State University. Theses of the reports.

Siirde, E. K. and Prüller, P. K. (1960) Aerozolionizator i sravnitelnye nablyudeniya o deistvii aerozolei i elektroaerozolei na aktivnost mertsatelnogo epitelya pishchevoda ljagushki. Vsesoyuznaya konferentsiya po aero- i gidroaeroionizatsii. *Tezisy dokladov. Medgiz UzSSR. Tashkent* 64–65. Aerosol ionizers and comparative observations of the effect of aerosols and electro-aerosols on the activity of the ciliated epithelium of the oesophagus of the frog. All-union conference on aero- and hydroaeroionization. Theses of the reports.

Siirde, E. K. and Prüller, P. K. (1963) O primenenii aerozolei i elektroaerozolei v otorinolaringologii. Vestnik otorinolarigologii. *Medgiz, Moskva*, **2**, 3–10. On the application of aerosols and electro-aerosols in otorhinolaryngology. *The Herald of Otorhinolaryngology.*

ON THE METHODS OF COUNTING AIR IONS

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Abstract – It is expedient to earth the outer cover of an air ion counter. In this case the neutral terminal of a sensitive electrometer gets a voltage. If the neutral terminal is earthed, the electrometer should be connected with the inner cover by a coupling capacitor. The disturbing influence of voltage fluctuations is removed by a balanced bridge scheme. In the case of a sensitive electrometer the ionic current may be measured by voltage drops arising on the resistor shunting the electrometer. It is even better to compensate the ion current by the current passing through a high resistance, by maintaining the input voltage of the electrometer in the vicinity of zero. The most essential parts of the structure of a counter are its insulators, which must be protected from the direct action of outside air and the precipitation of aerosol particles. The parts surrounding the insulators must have a voltage equivalent to that of the inner cover. An attempt has been made to meet these requirements in constructing a portable ion counter fed by alternating current. The indicating instrument mounted on the switch-board directly shows the ion concentration. Changes in ion density can be automatically registered by means of a recording external millivoltmeter connected with the counter.

Zusammenfassung – Es ist zweckmäßig, das äußere Meßkondensatorrohr des Aeroionenzählers zu erden. In diesem Falle wird man der Nullklemme des empfindlichen Elektrometers die entsprechende Spannung geben. Wenn die Nullklemme geerdet ist, muß der Elektrometer mittels eines Trennungskondensators mit dem inneren Meßkondensatorrohr verbunden sein. Die störende Wirkung der Speisespannungsschwankungen wird mittels der Brückenschaltung beseitigt. Im Falle der Anwendung des empfindlichen Elektrometers ist es möglich, den Ionenstrom nach dem Spannungsabfall an den Enden des Hochohmwiderstandes zu messen. Noch besser würde es sein, den Ionenstrom mit einem durch Hochohmwiderstand geleiteten Strom zu kompensieren und die Eingangsspannung des Elektrometers dabei nahe der Nullinie zu halten. Die wichtigsten Bestandteile des Zählers sind die Isolatoren, die gegen die direkte Wirkung seitens der äußeren Luft und der Sedimentation der Aerosolteilchen geschützt sein müssen. Die den Isolator umfassenden Details sollten eine gleiche Spannung zu der des inneren Meßkondensatorrohrs haben. Unter Berücksichtigung aller dieser Gesichtspunkte wurde ein tragbarer, vom Wechselstromnetz gespeister Ionenzähler konstruiert. Das Meßgerät an der Vorderplatte zeigt direkt die Ionenkonzentration an. Der Ionisationsverlauf kann dabei mittels eines äußeren selbstschreibenden Millivoltmeters automatisch registriert werden.

Résumé – Il est rationnel de mettre à la terre le revêtement extérieur du condensateur de mesure des aéroions. Dans ce cas, on donne une tension à la borne-zéro de l'électromètre.

La borne-zéro étant mise à terre, l'électromètre doit être lié au revêtement intérieur par un condensateur de séparation.

L'influence perturbatrice des variations de la tension d'alimentation est éliminée par un montage en pont.

En cas d'utilisation d'un électromètre sensible, il est possible de mesurer le courant ionique d'après la chute de tension de la résistance ohmique élevée. Il est mieux encore de compenser le courant d'ions par un courant dirigé à travers la résistance ohmique élevée, en maintenant la tension d'entrée de l'électromètre près de zéro.

Les détails les plus importants du compteur sont les isolateurs qui doivent être protégés contre l'influence directe de l'air extérieur et de la sédimentation des particules d'aérosols. Les détails avoisinant les isolateurs doivent avoir la même tension que le revêtement intérieur du condensateur de mesure.

En tenant compte de toutes ces exigences, on a construit un compteur d'ions portatif, alimenté par le secteur en courant alternatif. L'appareil de mesure relié à la plaque avant indique directement la concentration des ions. Il est possible d'enregistrer automatiquement les variations de l'ionisation a l'aide d'un millivoltmètre enregistreur.

THE measurement of the density of air ions in different conditions is a complicated physical and technical problem, and explains why very many papers have been devoted to the problem of constructing ion counters. In spite of this fact, the properties of the existing counters do not adequately meet the actual requirements. The excessive size of the constructed devices, their complicated and troublesome handling, and their poor reliability must be regarded as their most important drawbacks, and these are revealed particularly clearly when the charge density of electroaerosols is to be measured.

Hence we set ourselves the task of constructing a reliable multiple-purpose counter of small size which can easily be handled and used in carrying out research into bio-climatological and geophysical problems as well as those of artificial aeroionization.

THE DESIGN OF THE COUNTER

In most counters of air ions the outer cover of the cylindrical measuring condenser gets a voltage and the inner cover is connected with an electrometer the neutral terminal of which has been earthed. This measuring method—the charging method—is however, not quite appropriately named as the charge on the measuring condenser actually decreases in the course of the measuring process. For these reasons the design to be described has been designated by us as that of the earthed inner cover. The drawback of counters with an earthed inner cover is the end-effect (Lenard and Ramsauer 1910; Itiwara, 1931; Scholz, 1931; Israel, 1932; Siksna, 1950), which can essentially distort the results of measurement. Various electrostatic safeguards have been used to remove the end-effect (Swann, 1914; Reimers, 1940; Yunker, 1940; Komarov, 1961), but they render the structure of such counters more complicated. Electrostatic safeguards may produce disturbing side-effects. Thus, for instance, in the case of the Swann safeguard, which has found the widest application (Swann, 1914; Gish, 1932), the cross-section of the air current entering the condenser widens, rendering the air current turbulent with a lower volumetric velocity than with a tube of uniform cross-section (Schlichting, 1959). In the case of a counter with a Swann safeguard the conditions

necessary for the study of the spectrum of the ion mobilities have not been fulfilled (Tammet, 1960). This fact has interfered with the determination of the ion mobilities by means of a counter provided with a Swann safeguard (Scholz, 1935). One of the principal defects of electrostatic safeguards is the diminished reliability of the counter on account of the strong electric field arising in connection with an electrostatic safeguard, and this is of particular importance in the case of counters of heavy ions.

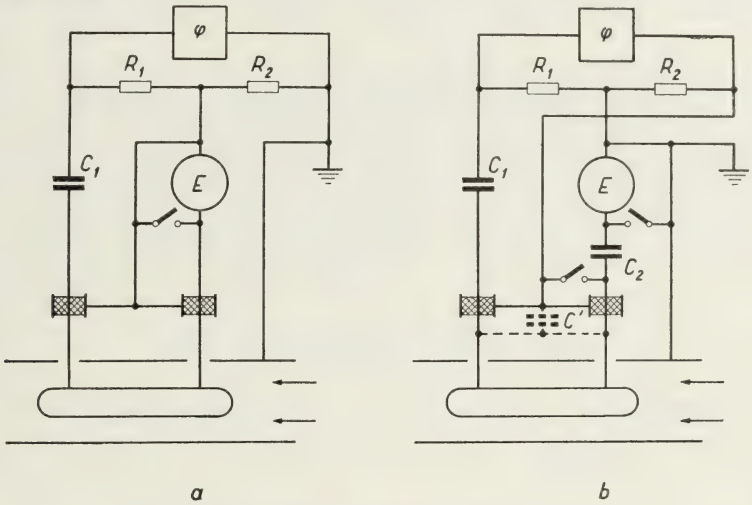

Fig. 1. The designs for a counter of air ions

In some counters of older types (Ebert, 1901; Gerdien, 1905) the scheme of an earthed outer cover is used along with an earthed neutral terminal (the discharging method). Such a scheme, however, is rarely applied nowadays owing to its low sensitivity and the resulting long measuring time.

The end-effect can also be avoided in counters with an earthed outer cover if a sensitive electrometer is used (McClelland and Kennedy, 1912; Weger, 1935). The defects of the scheme with an earthed outer cover, however, are the complexity and the parasitic capacity of the measuring condenser.

The scheme with an earthed outer cover where the neutral terminal of the electrometer has a voltage equivalent to that of the inner cover is best (Lenard and Ramsauer 1910, Baranov, 1925; Israel, 1931; Nolan and Nolan, 1935; Gubichev, 1955; Reinet, 1958, 1959). Such a scheme differs from that with an earthed inner cover only in the choice of its earthing point.

In the case of a design with an earthed cover and a sensitive electrometer, the end-effect can easily be avoided. Experience shows that the giving of voltage to the neutral terminal of the electrometer does not bring about any insurmountable technical difficulties (Baranov and Kravchenko, 1934; Weiss and Steinmauer, 1937; Schaffhauser, 1952; Reinet, 1959). The greater complexity of the structure of the counter resulting from the insulation of the electrometer is compensated by a greater simplicity of the structure of the measuring condenser.

The neutral terminal of the electrometer can also be earthed in a counter with an earthed outer cover and a sensitive electrometer if the inner cover is connected with the electrometer through a special coupling capacitor (Tammet, 1962 b).

It is necessary that the feed voltage of the measuring condenser in a counter with sensitive electrometer should have a high stability. The difficulties that may arise may be overcome by means of a bridge scheme with an auxiliary capacitor (Erikson, 1921; Komarov, Kuz'menko and Seredkin, 1961; Reinet, 1962), in which the fluctuations in the voltage of the feedsource do not affect the measuring results.

The designs of the counters recommended by us are shown in Fig. 1. In Fig. 1a arms of the bridge layout, which are balanced for possible changes in the voltage, are formed by the capacity of the measuring condenser C, the capacity of the compensating condenser C_1 and the resistances R_1 and R_2. In Fig. 1b the coupling capacitor C_2 has been introduced, which makes it possible to earth the neutral terminal of the electrometer. This arrangement is desirable in the case of a particularly high voltage of the measuring condenser. In the case of the scheme with a coupling capacitor, changes in the feed voltage can exert an influence on the readings of the electrometer only through the capacity C' of the insulators. In the scheme under consideration this influence is neutralized by the balanced bridge network formed by the capacities C' and C_1 and the resistances R_1 and R_2.

THE MEASUREMENT OF THE ION CURRENT

The convenience of handling the counter and the precision of measurement depend on the method of measuring the ionic current precipitated on the inner cover.

As a rule, voltage decrease $\Delta\varphi$ in a measuring condensor with an insulated inner cover is recorded in the course of a given period of time denoted by Δt and the current is calculated from the ratio $I = C_0\Delta\varphi/\Delta t$, where C_0 is the total capacity of the insulated system. The periodic grounding of the electrometer is performed either by hand or by a mechanism. If the measuring results are recorded automatically (Langevin and Moulin, 1907; Saks, 1956), one obtains a disconnected recording curve, which is not always to be recommended. The method of the condenser voltage decrease resembles the method of compensation with care of a current induced above capacity (Nolan and Nolan, 1935; Thellier, 1936). An advantage of the compensation methods is their greater degree of precision.

In the case of the shunting resistor method (Nordmann, 1904) the power of the current can be calculated from the ratio of the voltage of the electrometer to the resistance connected in parallel to the electrometer. An advantage of this method is the possibility of steady recording, as it is not necessary to carry out the commutations. By contrast, in the design with a coupling capacitor, the measuring condenser has to be recharged from time to time, short-circuiting the input of

the electrometer during those periods. The current indicator functioning by the method of a shunting resistor has a somewhat greater inertia than the indicator operating by the method with the decreasing condensor voltage, but the high sensitivity of modern electrometers makes it possible to reduce inertia adequately for usual measurements. The shunting resistor method resembles the method of compensation with the current passing through the resistor, in which case the electrometer is used as a null indicator. Vacuum tube electrometers and dynamic electrometers make it possible to perform compensation automatically by means of an electrical feedback.

Of electrometers, the dynamic ones are the most satisfactory, for the direct reading and the possibility of simple automatic recording facilitate the handling of the counter. Vacuum tube electrometers with a conductive input have also been used (Schaffhauser, 1952), but their degree of sensitivity and especially that of stability are considerably lower. Of mechanical electrometers, the Lindemann type of electrometers have shown themselves most expedient (our model СГ – 1 М resembles them).

THE STRUCTURE OF INSULATORS

Amongst the most essential units of the measuring condensor of a counter are the insulators of the inner cover, and the quality of insulation is the most critical factor in guaranteeing the reliability of a counter. The number of insulators ought to be kept at the minimum. Experience shows that the inner cover of a measuring condenser of average size can be fixed securely enough by means of two insulators.

The parts on which an insulator rests should have the same voltage as the inner cover, otherwise leakage current is inevitable, causing essential errors in measurements (Israel, 1931). It is necessary to use double insulators. They may be constructed with one metal interlayer (Langevin and Moulin, 1907; Gockel 1917; Nolan and Nolan, 1935; Reinet, 1958, 1959). There is an additional advantage in mounting the insulators in a separate tube insulated from the outer cover and having a voltage equivalent to that of the inner cover (Reinet, 1962). To avoid the errors which may arise with the polarization of the insulators due to a change in the voltage of the measuring condenser, it is necessary to shield the surface of an insulator from the electric field. It is required to shield not only the insulators bearing the inner cover but also all other insulators as the charges on their surfaces may affect the readings of the electrometer by electrostatic induction.

The surfaces of the insulators must be protected from the direct effect of a current of outside air, or else the aerosol particles may precipitate on the surface of the insulator and destroy the insulation. Insulators must be mounted above the measuring condensor so that gravity will not aid the precipitation of aerosol particles. The choice of the material of an insulator is of great importance. Fluoroplast (Teflon) has proved to be the best material for insulators for its electrical properties and dampproofness, but the unsatisfactory mechanical properties do not

permit of using it everywhere. Another kind of insulating material is polystyrene, which is mechanically durable, lends itself easily to processing and is not inferior to amber in electrical properties.

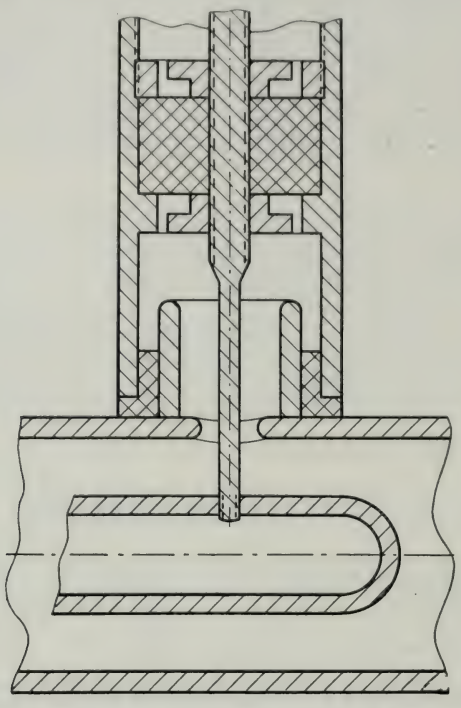

FIG. 2. Structure of the insulator of the inner cover of the measuring condenser

A design for a set of insulators fulfilling the above-mentioned requirements is given in Fig. 2. The insulator is mounted in a tube insulated from the outer cover and having a voltage equivalent to that of the inner cover.

DESCRIPTION OF THE PORTABLE COUNTER

The general requirements touched upon above have been taken into account in the construction of a multiple-purpose counter. This counter (size $53 \times 33 \times 24$ cm) is fed by alternating current. The limiting range of mobility can be selected in the region of $0.0009 - 2.6$ cm^2/v. There are five regions with a linear scale for the measurement of the ion concentration, the concentrations corresponding to swing being 1000–10,000,000 e/cm^3. In the case of higher concentrations measurement would be interfered with by the electric field of the space charge of the air in the condenser (Siksna and Metnieks, 1953; Tammet, 1962a). The ion concentration is read directly on the scale of the indicating instrument. The counter can be connected with any type of recording millivoltmeter by means of which the course of the ion concentration in time can be steadily recorded.

The basis of the design of the counter is represented in Fig. 1a. The measuring condenser is cylindrical, the radius of the inner cover being 1 cm and that of the outer cover 1.95 cm. The length of the inner cover with hemispherical ends is 40 cm; the effective capacity of the condenser is 30.4 cm. At the end of the condenser where air enters it, the outer cover is 6 cm longer than the inner cover to avoid the end-effect. The inner cover is fixed on two insulators the structure of which resembles the one shown in Fig. 2. Connection with the electrometer has been effected through one insulator block, a cylindrical multicover compensating capacitor C_1 with an air dielectric mounted in the upper end of the other insulator block. The capacity of the compensating condenser has been chosen so as to be equivalent to the effective capacity of the counter. A rectifier with a simple vacuum tube stabilizer supplies the voltage. In order to decrease disturbing voltages, capacitors with a capacity of 0.1 μF have been connected in parallel to resistances R_1 and R_2. The voltage of a measuring condenser can be regulated within the limits of 1 v–300 v, roughly by means of a potential switch, and more precisely with the help of a potentiometer. The indicating instrument indicates voltage value and limiting range of mobility. The polarity of the ions to be measured is selected by means of a switch which, at the same time, performs the interchange of the output terminals of the electrometer.

The air-current is sucked through the measuring condenser by means of a ventilator provided with a synchronous motor. A rotameter is used to measure the volumetric velocity of the air current. The nominal volumetric velocity is 1000 cm^3/sec. When heavy ions are measured, the volumetric velocity is reduced to 100 cm^3/sec.

The actuating device of the electrometer is a dynamic condenser. The alternating signal obtained from it is amplified by means of a multistage vacuum tube amplifier 95 dB. The amplified signal is detected in the synchronous ring detector. The detected direct voltage is smoothed and is transmitted to the vacant terminal of the high-ohmage resistor connected with the inner cover. Polarity and the factor of voltage division is so chosen as to give rise to negative feedback with a depth of 30 dB. The electrometer regulates the current passing through the resistor so that the voltage on the input of the dynamic condenser would be in the vicinity of zero. To carry out the function of regulation, it is necessary that the dynamic condenser should have a low cue voltage not exceeding 5 mv. The current of the ions precipitated on the inner cover is compensated by the current passing through the resistor which is equivalent to the ratio of voltage applied to the resistor to resistance. The voltage applied to the resistor is measured with an indicating instrument the readings of which are proportional to ion density.

To change the sensitivity of the counter, high-ohmage resistances are exchanged by a region switch. In the most sensitive region the current corresponding to swing is 1.6×10^{-13} amp. When using resistance 10^{12} Ω, the voltage drop necessary to compensate the ion current is 0.16 v. For higher levels of measurement the voltage drop remains the same, only resistance value being changed. The inertia of

the counter can be regulated by means of filters to be inserted in the feedback circuit. To reduce disturbances, the time constant chosen for the most sensitive region is 50 sec, for other regions the time constant is smaller.

The stability of the zero point of the electrometer depends on the quality of the dynamic condenser. We have used dynamic condensers constructed by O. Saks. Using such electrometers the drift of the zero point within 6 hr does not exceed 1 per cent of the most sensitive region of the counter. In measurements of longer duration the zero point has to be checked periodically and, if need be, it has to be adjusted.

Since the neutral terminal of the electrometer has been given the voltage of the measuring condenser, the electrometer together with its amplifier must be well insulated from the ground. At the suggestion of V. Reeben, another synchronous detector has been used to connect the external measuring instrument with the electrometer. This detector has been insulated from the amplifier by means of transformers. As both the synchronous detectors have the same structure, the outer self-recording measuring instrument has been given a voltage proportional to the ion concentration. The outer measuring instrument can be earthed, which, however, does not interfere with measurements.

REFERENCES

BARANOV, V. I. (1925) Vliyanye medlennykh ionov na izmerenye elementov atmosfernogo elektrichestva. *Zhurn. russk. fiz.-khim. obshch-va, chast' fiz.* **57,** 151–170. The effect of large ions on the measuring of the elements of atmospheric electricity.

BARANOV, V. I. and KRAVCHENKO, M. D. (1934) O bystrykh izmenelyakh ionizatsii vozdukha. *Zhurn. geofiz.* **4,** 379–385. On quick changes in air ionization.

EBERT, H. (1901) Aspirationsapparat zur Bestimmung des Ionengehalts der Atmosphäre. *Phys. Z.* **2,** 662–664.

ERIKSON, H. (1921) The change of mobility of the positive ions in air with age. *Phys. Rev.* **18,** 100–101.

GERDIEN, H. (1905) Demonstration eines Apparates zur absoluten Messung der elektrischen Leitfähigkeit der Luft. *Phys. Z.* **6,** 800–801.

GISH, O. H. (1932) Systematic errors in measurements of ionic content and the conductivity of the air. *Gerl. Beitr. Geophys.* **35,** 1–5.

GOCKEL, A. (1917) Luftelektrische Beobachtungen im Schweizerischen Mittelland, im Jura und in den Alpen. Neue Denkschr. *Schweiz. Naturf. Ges.* **54,** 1–75.

GUBICHEV, V. A. (1955) Izmereniye ionnogo spektra v vozdukhe g. *Rostova n/D. Uch. zap. Rostovsk. n/D. un-ta.* **32,** 183–189. Measurement of the ionic spectrum in the atmospheric air at Rostov.

ISRAEL, H. (1931) Zur Theorie und Methodik der Grössenbestimmung von Luftionen. *Gerl. Beitr. Geophys.* **31,** 173–216.

ISRAEL, H. (1932) Zum Problem der Randstörungen bei Ionenmessungen. *Gerl. Beitr. Geophys.* **35,** 341–348.

ITIWARA, Y. (1931) Zur Methodik der Ionenzählung in der freien Atmosphäre. *Phys. Z.* **32,** 97–106.

KOMAROV, N. N. (1961) Metody i nekotorye rezul'taty izmereniya ionizatsionnogo sostoyaniya

svobodnoi atmosfery. Sb. Issl. oblakov, osadkov i grozovogo elektrichestva, AN SSSR, Moskva, 259–265. Methods and some results of the measurements of the ionic condition of the free atmosphere.

Komarov, N. N. Kuz'menko, M. D. and Seredkin, A. A. (1961) Schetchik atmosfernykh ionov. *Izv. AN SSSR, ser. geofiz.* No. 12, 1875–1881. The counter of air ions.

Langevin, M. P. and Moulin, M. (1907) Electromètre enregistreur des ions de l'atmosphère. *Radium* **4,** 218–223.

Lenard, P. and Ramsauer, C. (1910) Über Bildung grosser Elektrizitätsträger. *Sitzungsber. Heidelberger Akad. Math.-Naturwiss. Kl. Abh.* **32,** 3–31.

McClelland J. A. and Kennedy, H. (1912) The large ions in the atmosphere. *Proc. Roy. Irish Acad.* A **30,** 72–91.

Nolan, J. J. and Nolan, P. J. (1935) A new method for counting atmospheric ions and determining their mobilities. *Proc. roy. Irish Acad.* A **42,** 15–19.

Nordmann, Ch. (1904) Enregistrement continu de l'ionisation gazeuse et de la radioactivité par les méthodes de déperdition. *C. R. Acad. Sci.* (Paris) **138,** 1596–1599.

Reimers, H. (1940) Messungen der kleinen Ionen der Luft mit einem neuen Messgerät. Dissertation Universität Berlin.

Reinet, J. J. (1958) Novaya apparature i methodika dlya opredeleniya plotnosti aero- i gidroionov v atmosfere. *Uch. zap. Tartuskogo gos. un-ta, vyp.* **59,** 41–67. New apparatus and methods for determining the density of aero- and hydroions in the atmosphere.

Reinet, J. J. (1959) Novaya apparatura i metodika dlya opredeleniya plotnosti aero- i gidroionov v atmosfere. *Voprosy kurortologii* **5,** 45–52. New apparatus and methods for determining the density of aero- and hydroions in the atmosphere.

Reinet, J. J. (1959b) Schetchik aero- i gidroionov. *Biull. izobr.* No. 11, 27–27. The counter of aero- and hydroions.

Reinet, J. J. (1962) Spektrometr atmosfernykh ionov. *Biull. izobr.* No. 11, 62–62. The spectrometer of air ions.

Saks, O. (1956) Automaatne fotograafiline ioonide loendaja. *Tartu Riikliku Ülikooli toimetised* **42,** 84–93. The automatic photographic counter of ions (in Estonian).

Schaffhauser, J. (1952) Messung von kurzperiodigen Schwankungen der Luftionisation. *Arch. Met. Geoph. Biokl.* A **5,** 179–186.

Schlichting, H. (1959) Entstehung der Turbulenz. *Handb. d. Phys.* VIII/1. Springer Verlag, Berlin–Göttingen–Heidelberg.

Scholz, J. (1931) Gegenfelduntersuchungen und Beweglichkeitsmessung kleiner Ionen. *Gerl. Beitr. Geophys.* **29,** 226–238.

Scholz, J. (1935) Luftelektrische Messungen auf Franz-Joseph-Lands während der II internationalem Polarjahres 1932–1933. *Tr. Arkticheskogo instituta* **16,** 5–169.

Siksna, R. (1950) Measurements of large ions in the atmospheric air at Uppsala. *Arch. Geophys.* **1,** 483–518.

Siksna, R. and Metnieks, A. (1933) Aufladung eines isolierten Rohrs bei Durchströmen von ionisierter Luft und Adsorption der Ionen. *Z. angew. Phys.* **5,** 454–461.

Swann, W. I. G. (1914) On certain new atmospheric-electric instruments and methods. *Terr. magn.* **19,** 171–185.

Tammet, H. F. (1960) K teorii aspiratsionnykh schetchikov aeroionov. *Izv. AN SSSR, ser. geofiz.* No. 8, 1263–1270. On the theory of the aspirating counter of air ions.

Tammet, H. F. (1962a) Iskazhayushchie effekty v aspiratsionnykh schetchikakh aeroionov. *Izv. AN SSSR, ser. geofiz.* No. 6, 845–853. Disturbing effects in the aspirating counters of air ions.

Tammet, H. F. (1962b) Schetchik aeroionov. *Biull. izobr.* No. 20, 60–61. The counter of air ions.

Thellier, O. (1936) Mesure de la conductibilité électrique de l'air à Paris. *Ann. l'Inst. Phys. Globe l'Univ. Paris* **14,** 71–76.

Weger, N. (1935) Eine Verbesserung der Methodik der Kleinionen-Zählung. *Phys. Z.* **36**, 15–20.

Weiss, R. und Steimauer, R. (1937) Messungen der Luftionen in Innsbruck. *Gerl. Beitr. Geophys.* **50**, 238–251.

Yunker, E. A. (1940) The mobility spectrum of atmospheric ions. *Terr. Magn.* **45**, 127–132.

PASSIVE TECHNIQUE, ION-THERAPY AND AIR-HYGIENIC ION-CONDITIONING WITHOUT THE USE OF ION-GENERATORS

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STRAY-FIELDS from surface charge, space charge and personal potential can be reduced and controlled, the content of dust can be reduced, and other precautions can be taken to maintain a favourable content of ions in a person's inhaled air. The principles of the technique will be described and the experiences obtained with this method in Denmark since 1956 will be mentioned.

Passive technique has been valuable as a therapeutic resource and as a hygienic measure.

SUMMARY REPORT

I. H. KORNBLUEH

THE interesting papers by Bach: "Passive technique, ion therapy and air hygienic ion conditioning", Morel: "A 'clean' electrical ion generator", and Wehner: "Preliminary results with electro-aerosol therapy in respiratory ailments" stimulated a lively discussion spread over three sessions. Appreciation of the difficult problems facing individual investigators was stressed by a number of speakers. Lack of reliable and standardized instruments and inadequate technique appear to be still the most frequent causes of failures. Especially informative were the opinions on the port of entry into the body of air ions and electro-aerosols. Schaefer, Bonnevie, Bach, Felici, Neuberger, Wehner and others analyzed the role of the respiratory tract as the primary recipient of charged gaseous and corpuscular aerosols. Wehner referred to Eichborn's theory according to which, during exposure to electric space charges, a current forms along the surface of the skin to the ground inducing a secondary current in the subcutaneous tissues. In Eichborn's opinion no electric charges enter the body through the skin due to the low transversal conductivity of the integument. Quoting Bisa, Wehner mentioned that under normal conditions, the electric charge acts primarily through the lungs. However, Bisa was able to demonstrate that the exhaled air of subjects exposed to electro-aerosols but breathing electrically neutral air became charged apparently by the electric action through the skin. German investigators, as early as 1924, have noted a reduction of the systolic blood pressure in persons whose face and body were treated with ultraviolet light. Protection of the face by appropriate masks eliminated this effect. Here, of course, the relatively large amount of ozone, the unavoidable by-product of ultraviolet emitters, and not only ionization, could have been the precipitating agent (Kornblueh).

Felici commented on the difference between static electricity and air ions and stated that some ion action through the skin cannot be excluded. Captain Schreiber pointed to the localized effects of tribo-electricity. Deloraine confirmed this stressing the pain relieving quality of textiles made from polyvinyl chloride fibres on contact with the skin. Deloraine's statements, based on a broad personal experience and supported by the findings of French investigators, shed new light on the theories of percutaneous pathways of negative static electricity.

Methods of ion generation, ion metering and physics of air ions and aerosols took up a good part of the evening session. In the opinion of Robinson continuous outdoor ion counts broaden the value of routine meteorological observations. Robinson found a characteristic increase of positive ion levels in advance of the

Near East "Chamsin", hours before meteorological instruments commenced to register the impending weather changes.

The following day, Schaefer stressed the need for more information on the modus agendi of air ions to facilitate the incorporation of this medium into the therapeutic armamentarium. Captain Schreiber reported briefly on the results of a joint study with Canellas and Madame Gourmel at the Centre de Recherches Climatologiques de Pau. A passagere lymphopenia was observed in rabbits exposed to negatively ionized air. Sluggish behavior and activity of mammals kept in an atmosphere of very low ion density and an increased appetite and activity on exposure to high concentrations of bi-polar air ions are the preliminary results of experiments conducted by Vad. An animated exchange of ideas on the influence of radioactive substances in building materials on indoor ion levels and the possible effects of other factors of the physical environment terminated the third and last meeting of this Section.

In spite of the absence of Russian and Roumanian authors the results of these sessions point to a steadily growing interest in the field of aeroionization and electroaerosols and a far better understanding of the basic technical and biological principles.

CHEMICAL TESTS IN BIOMETEOROLOGICAL RESEARCH

Chairman: G. Piccardi

WECHSELNDE GEFRIERBEREITSCHAFT KLEINER WASSERMENGEN IM VERGLEICH MIT ÄNDERUNGEN DES LUFTDRUCKS UND DER SONNENAKTIVITÄT

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Abstract – In agreement with previous findings, from 1956 to 1962 it was found that the freezing of small samples of chilled water to – 6° and – 7° C depends on changes of the air pressure at sea level. Such changes of air pressure are positively correlated with changes in the intensity of some components of cosmic radiation. The expected phase shift to the right occurred again in 1962 while approaching the sun spot minimum. A relationship between the extreme values of freezing of the water and the relative sun spot numbers (Wolf's numbers) is suggested. With increasing numbers of spots this relationship lost its significance. The freezing values could be temporarily increased, particularly in March 1963, through covering the water samples with various materials.

Zusammenfassung – In Übereinstimmung mit früheren Versuchsergebnissen konnte in den Jahren 1956 bis 1962 nachgewiesen werden, daß das Gefrieren kleiner, auf – 6°, später auf – 7° C unterkühlter Wasserproben im Zusammenhang mit Änderungen des Bodenluftdrucks steht. Diese Luftdruckänderungen korrelieren ihrerseits mit Intensitätsänderungen einiger Komponenten der kosmischen Strahlung. Die mit der Annäherung an das Sonnenflecken-Minimum bei den Extremwerten des Luftdrucks in der Umgebung der Tage mit maximalem und minimalem Wassergefrieren erwartete Phasenverschiebung nach „rechts" ist im Jahre 1962 wieder eingetreten. Beziehungen zwischen den Extremwerten des Wassergefrierens und den Sonnenflecken-Relativzahlen (Wolf'sche Zahlen) sind angedeutet. Mit abnehmender Fleckenzahl veränderten sich jedoch die Zusammenhänge und verloren auch an Deutlichkeit. Durch Überdecken der Wasserproben mit verschiedenen Materialien konnten die Gefrierzahlen zeitweilig, besonders im März 1963, erhöht werden.

Résumé – En corrélation avec les résultats obtenus lors d'essais antérieurs, on a pu démontrer au cours des années 1956 à 1962 que la congélation à – 6°, puis à – 7° C de petites quantités d'eau surgelée est en relation avec les fluctuations de la pression atmosphérique au sol. Ces fluctuations de la pression correspondent de leur côté à des variations d'intensité de quelques composantes du rayonnement cosmique. Le décalage attendu vers la «droite» de la dite phase s'est produit en 1962 avec l'approche du minimum de l'activité solaire. Ainsi, les jours présentant des maximums et des minimums de la congélation de l'eau se rencontrent au voisinage des variations extrêmes de la pression. On démontre en outre une relation entre les valeurs extrêmes de la congélation de l'eau et des chiffres relatifs des taches solaires (nombre de Wolf). Avec la diminution du nombre de taches solaires, les dites relations se sont pourtant modifiées et ont perdu de leur signification. En recouvrant les échantillons d'écrans de diverses matières, on a pu relever par moments les valeurs définissant la congélation, surtout en mars 1963.

Wasser ist die Grundlage jeglichen Lebens. Es läßt sich leicht auf einige Grade unter den Gefrierpunkt abkühlen, ohne in jedem Falle zu kristallisieren. Es lag deshalb nahe, Wasser in labilem, unterkühltem Zustand als empfindliches und zugleich verhältnismäßig einfaches Testobjekt für jene unbekannten Agentien zu benutzen, die sich als Ursache meteorobiologischer Reaktionen bisher noch der endgültigen Bestimmung entziehen.

Bortels hat 1956 über Versuche berichtet, die bestätigten, daß kleine Proben destillierten Wassers bei $-6°$ C in 24 Stunden mehr oder weniger zahlreich gefrieren je nachdem, ob bald danach der Luftdruck im statistischen Mittel steigt oder fällt. Diese Versuche zeigten aber außerdem, daß sich die zugehörigen Extremwerte der interdiurnen Luftdruckänderungen in Nähe des Sonnenflecken-Minimums 1953/54 im Mittel etwa einen Tag später einstellten als im Zeitraum von 1951/52. Ob diese Phasenverschiebung mit Annäherung an das nächste Sonnenflecken-Minimum wiederkehren würde, also eine gesetzmäßige Beziehung vorliegt, sollte durch Fortsetzung der Versuchsreihe geprüft werden, worüber nebst einigen weiteren Beobachtungen im folgenden berichtet wird. Die Untersuchungen sind noch nicht abgeschlossen.

METHODIK

Jeweils 5 ml destillierten Wassers mit etwa 5 g Glasstaub je Liter als Träger wirksamer Gefrierkerne in 50 ml fassenden Erlenmeyerkolben mit übergreifendem Deckel, beide aus Jenaer Geräteglas Nr. 20, wurden in einem konstant gekühlten Kellerraum des sehr massiv gebauten, aus drei Geschossen bestehenden Institutsgebäudes in Berlin – Dahlem bei $-6° \pm 0{,}5°$ C, ab September 1962 bei $-7° \pm 0{,}5°$ C aufgestellt. In unregelmäßigen Abständen bis zu mehreren Monaten wurden die Kolben neu beschickt, wobei die oben angegebene Menge des verwendeten Glasstaubs nicht immer eingehalten wurde. Vergleichsuntersuchungen auf dem Dachboden desselben Gebäudes sind in Aussicht genommen.

Zunächst waren nur 50, ab 1959 100 und ab Februar 1963 400 Kolben im Versuch, die fortlaufend numeriert und zu jeweils 100 in einem hölzernen Kasten mit bzw. ab Anfang 1963 ohne Deckel aus Hartfaserplatten in Zehnerreihen ohne nennenswerte Bewegungsmöglichkeit nach den Seiten zusammengefaßt stets an genau festgelegten Orten standen. Auf Einschmelzen des Wassers in Ampullen wurde ab Oktober 1957 verzichtet, nachdem sich herausgestellt hatte, daß sich dadurch an den Beziehungen zum Luftdruck nichts änderte, dieser selbst also als auslösendes Agens unmittelbar nicht in Betracht kommt (Bortels, 1956).

Täglich um etwa 12^h mittags wurden die Kästen nacheinander aus dem Kühlraum in einen warmen Raum gebracht, die gefrorenen Wasserproben gezählt und notiert, in einem Wasserbad bei etwa $+50°$ C aufgetaut und die Kästen dann sofort wieder an den bestimmten Platz zurückgestellt. Die gefrorenen Proben wurden absichtlich nicht auf über $+70°$ C erhitzt, um die für das Gefrieren maßgebliche Molekülassoziation nicht zu zerstören. Eine auf diese Weise in den Gefrierprozen-

ten stets enthaltene Anzahl von Dauergefrierern wurde in Kauf genommen, weil es interessierte, wann diese Dauergefrierreihen unterbrochen, ihre Molekülassoziationen also spontan zerstört wurden.

Als meteorologischer Indikator wurde für diese Untersuchungen zunächst wieder der Bodenluftdruck verwendet. Aus den zu den meteorologischen Terminen 00^h, 03^h, ...21^h (Weltzeit) in Berlin–Dahlem (Institut für Meteorologie und Geophysik der Freien Universität Berlin) gemessenen Werten wurden die Luftdruck-Tagesmittel berechnet, die als Grundlage für den weiteren Rechnungsgang dienten. Als solarer Indikator wurde die jeweilige Relativzahl der Sonnenflecken (Wolf'sche Zahl) zu den Gefriermaxima und -minima in Beziehung gesetzt.

ERGEBNISSE

Der Bodenluftdruck als meteorologischer Indikator

Die Kurven der mittleren interdiurnen Luftdruckänderungen in der Umgebung der Stichtage mit relativen Maxima und Minima der Gefrierprozente für die Zeit von Oktober 1956 bis einschließlich Dezember 1962 sind nach Jahren geordnet in

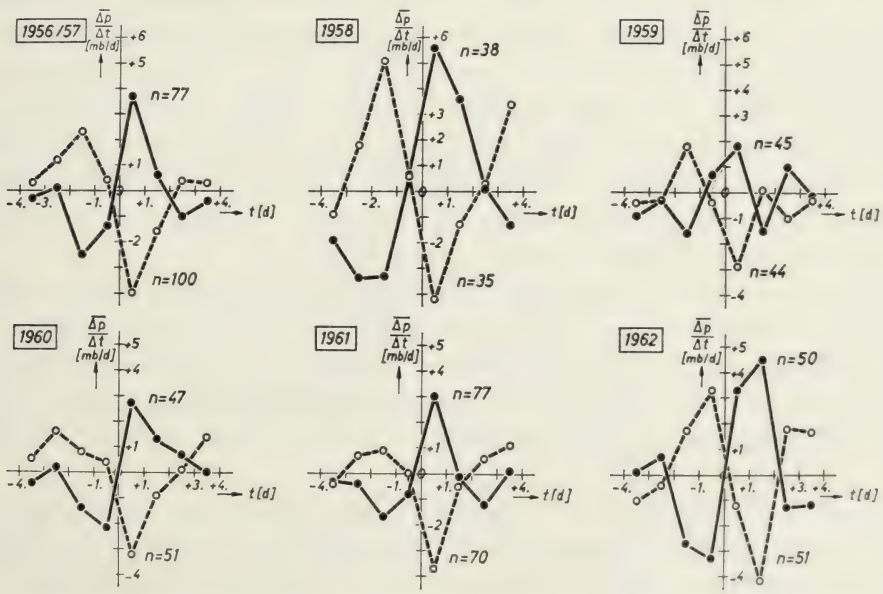

Abb. 1. Mittlere interdiurne Luftdruckänderungen in der Umgebung der Stichtage mit Maxima (●——) und Minima (○ - - -) des Wassergefrierens. Berlin–Dahlem, 1956–1962

Abb. 1 dargestellt. Dabei wurde das letzte Viertel des Jahres 1956 mit dem Jahr 1957 vereinigt. Das Verfahren der Synchronisation des Verlaufs der mittleren interdiurnen Luftdruckänderungen um die Stichtage mit Maxima bzw. Minima des

Gefrierens ist auch schon früher verwendet worden (Bortels, 1954, 1956). In Übereinstimmung mit den damaligen Ergebnissen folgte in allen Jahren auf Gefrier-Maxima im statistischen Mittel Luftdruck-Anstieg und auf Gefrier-Minima Luftdruck-Fall. Die Amplituden des maximalen Anstiegs bzw. Falls sind allerdings in den einzelnen Jahren unterschiedlich. Die jeweils größten Maximalamplituden traten sowohl für die Stichtage „Maxima" als auch für die Stichtage „Minima" des Wassergefrierens im Jahre 1958 auf, die jeweils kleinsten Amplituden in den Jahren 1959 und 1960. In diesen beiden Jahren waren auch die Beziehungen biologischer Reaktionen, wie z. B. der Phytophthora-Befallsstärke an Tomaten (Bortels, Massfelder und Wedler, 1964), zu Luftdruckänderungen gestört. Meteorologisch-geophysikalisch zeichnete sich das Jahr 1959 einmal durch relativ zahlreiche und langdauernde antizyklonale Wetterlagen aus und zum anderen durch starke erdmagnetische Störungen, deren Maximum als Folge des letzten Sonnenflecken-Maximums 1957–58 im Jahre 1960 erreicht wurde.

Mit Annäherung an das für 1964–65 erwartete nächste Sonnenflecken-Minimum nahmen die Maximalamplituden der interdiurnen Luftdruckänderungen in den Jahren 1961 und 1962, wenn auch langsam, wieder zu. Gleichzeitig aber verschoben sich für die Stichtage „Gefrier-Maxima" das Maximum und für die Stichtage „Gefrier-Minimum" das Minimum der interdiurnen Luftdruckdifferenz-Kurven im Jahre 1962 um 24 Stunden nach „rechts". Die auf Grund frührerer Untersuchungsergebnisse (Bortels, 1956) für die Zeit vor dem nächsten Sonnenflecken-Minimum erwartete Phasenverschiebung nach „rechts" ist damit tatsächlich wieder eingetreten. Synchronisiert man statt der interdiurnen Luftdruckänderungen die Tagesmittel des Bodenluftdrucks in der Umgebung der Stichtage „Maxima" bzw. „Minima" des Wassergerfrierens (Abb. 2), so zeigt sich, daß tatsächlich in allen sechs hier untersuchten Jahren die Gefrier-Maxima mit Luftdruck-Minima und die Gefrier-Minima mit Luftdruck-Maxima koinzidieren.

Die maximalen Amplituden in der Umgebung der Stichtage traten bei den mittleren Luftdruckgängen ebenso wie bei den mittleren interdiurnen Luftdruckänderungen im Jahre 1958 auf, die minimalen Amplituden dagegen im Jahre 1959. Entsprechend dem Verlauf der interdiurnen Luftdruckänderungen deutet sich auch für die Luftdruckgänge im Jahre 1962 eine „Rechts"-Verschiebung der Extremwerte an.

Auf spezielle Signifikanzberechnungen für die gefundenen und in den Abbildungen dargestellten Korrelationen wurde verzichtet, weil die Überzufälligkeit der Koinzidenzen zwischen den Extremwerten der Wassergefrierhäufigkeit und des Luftdrucks allein durch die Wiederholung der in je sechs voneinander unabhängigen Jahreskollektiven gewonnenen Beziehungen hinreichend bewiesen wird.

Durch die bisher beschriebenen Untersuchungsergebnisse zur Frage der Beziehungen des Wassergefrierens zum Luftdruck wird natürlich die schon mehrfach, auch bei dem Versuchsobjekt des unterkühlten Wassers experimentell gesicherte Feststellung, daß der Luftdruck oder seine Änderung selbst zunächst nur einen Indikator und nicht den primär auslösenden Faktor darstellen, keinesfalls umge-

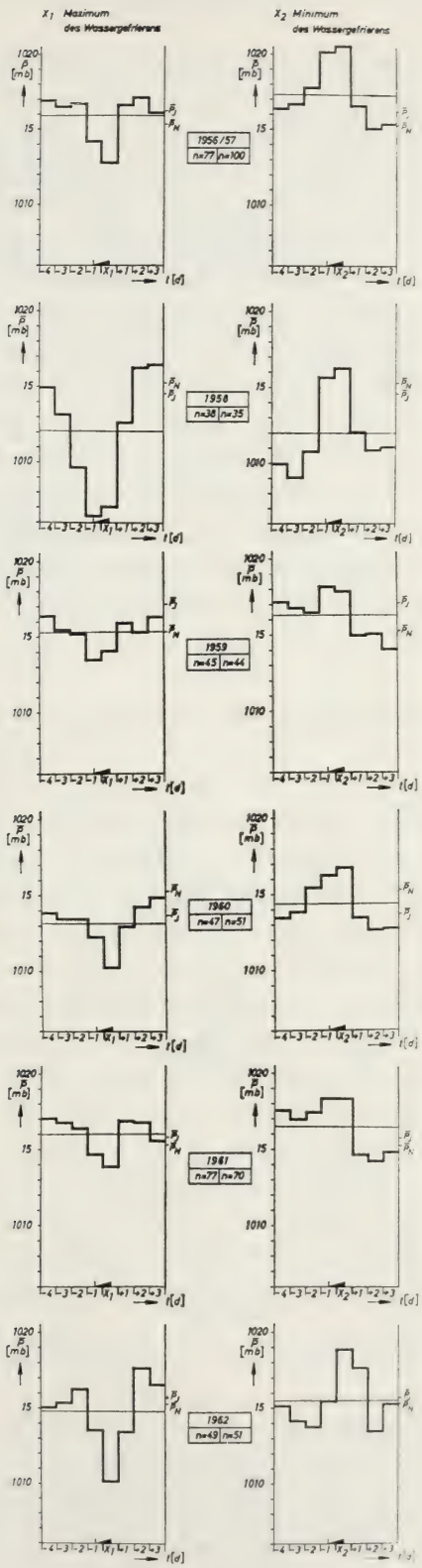

Abb. 2. Mittlerer Luftdruckverlauf $[p(t)]$ in der Umgebung der Stichtage mit Maxima (x_1) und Minima (x_2) des Wassergefrierens. Die Markierung auf der Abszisse gibt die Zeit des Gefriervorganges an. Berlin–Dahlem, 1956–1962

stoßen. Eine als Ursache für die aufgezeigten Korrelationen angenommene Strahlung könnte aber z. B. durch die an der Station über dem Erdboden lagernde Luftmasse – ausgedrückt durch den Bodenluftdruck – so beeinflußt werden, daß sie bei niedrigem Luftdruck relativ viele und bei hohem Luftdruck relativ wenige Wasserproben gefrieren läßt. Demnach müßte es sich um eine Strahlung handeln, die parallel zu den Änderungen des Bodenluftdrucks genügend starken Intensitätsänderungen unterworfen wäre. Man könnte an die sogenannte kosmische Strahlung denken, deren Gesamtintensität einem Luftdruckeffekt unterliegt. Dieser erscheint jedoch verglichen mit der beobachteten Wirkung zu klein. Dagegen wäre es durchaus denkbar, daß eine für das Testobjekt besonders wirksame Komponente der primären kosmischen Strahlung oder ihrer Folgeprodukte tatsächlich stärkere Intensitätsschwankungen infolge von Luftdruckänderungen aufweist. Kürzlich hat *Rochester* (1962) berichtet, daß die Intensität der μ-Mesonen-Strahlung am Erdboden mit fallendem Luftdruck deutlich zu-, mit steigendem dagegen deutlich abnimmt. Umgekehrt wurden auch Luftdruckänderungen in der Folge von Strahlungsausbrüchen auf der Sonne schon verschiedentlich nachgewiesen (Koppe, 1951).

DIE SONNENFLECKEN-RELATIVZAHLEN ALS SOLARER INDIKATOR

Die Sonnenflecken-Relativzahlen stellen bekanntlich ein Maß für die Aktivität der Sonne dar. Die Vorgänge, die sich dabei im einzelnen auf der Sonne in der Umgebung der Sonnenflecken abspielen, sind sehr komplexer Natur. Die bei diesen Vorgängen emittierten Korpuskular- und elektromagnetischen Wellensstrahlungen können zu verschiedenen Zeiten trotz gleicher Sonnenflecken-Relativzahlen qualitativ und quantitativ verschiedene Werte haben. Das heißt, die Vorgänge, die sich zu zwei verschiedenen Zeiten bei gleichen Flecken-Relativzahlen auf der Sonne abspielen, sind nicht unbedingt in allen Teilen miteinander identisch.

Synchronisiert man die Sonnenflecken-Relativzahlen und ihre interdiurnen Änderungen um die Stichtage „Maxima“ und „Minima“ des Wassergefrierens in den einzelnen untersuchten Jahren 1956–57 bis 1962 und berechnet über die interdiurnen Änderungen die zugehörigen Medianwerte, so ergeben sich die in den Abb. 3 und 4 dargestellten Kurven. Insgesamt zeigen diese keinen so durchgehend einheitlichen Verlauf wie diejenigen des Bodenluftdrucks und seiner interdiurnen Änderungen im gleichen Zeitraum. Ihr Verlauf ist vielmehr mit dem Sonnenfleckenzyklus veränderlich.

Die Kurven für die beiden Jahre des letzten Sonnenflecken-Maximums 1957 und 1958 sind einander am ähnlichsten. In der Umgebung der Stichtage „Maxima“ fallen bei den interdiurnen Änderungen der Relativzahlen die Maxima im Kurvenverlauf drei Tage vor der Mitte der Gefrierzeit (00^h des Tages x) und die relativen Minima zwei Tage davor auf. Gleichheit im Verlauf besteht also erst im zweiten Differenzenquotienten. Bei den Stichtagen „Minima“ tritt an denselben Tagen umgekehrt zuerst ein Minimum und dann ein Maximum auf. Betrachtet man dazu

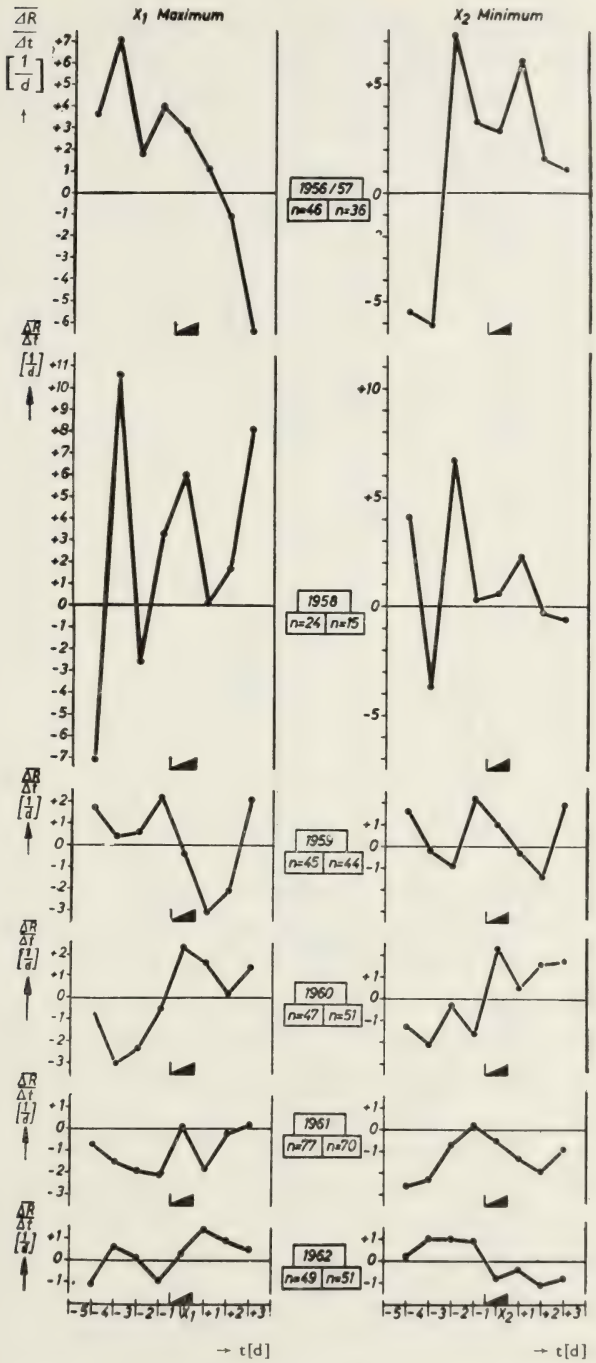

Abb. 3. Mittlere interdiurne Änderungen der Sonnenflecken-Relativzahlen (ΔR) in der Umgebung der Stichtage mit Maxima (x_1) und Minima (x_2) des Wassergefrierens. Berechnung nach der Medianwertmethode. Die Markierung auf der Abszisse gibt die Zeit des Gefriervorganges an. Berlin–Dahlem, 1956–1962

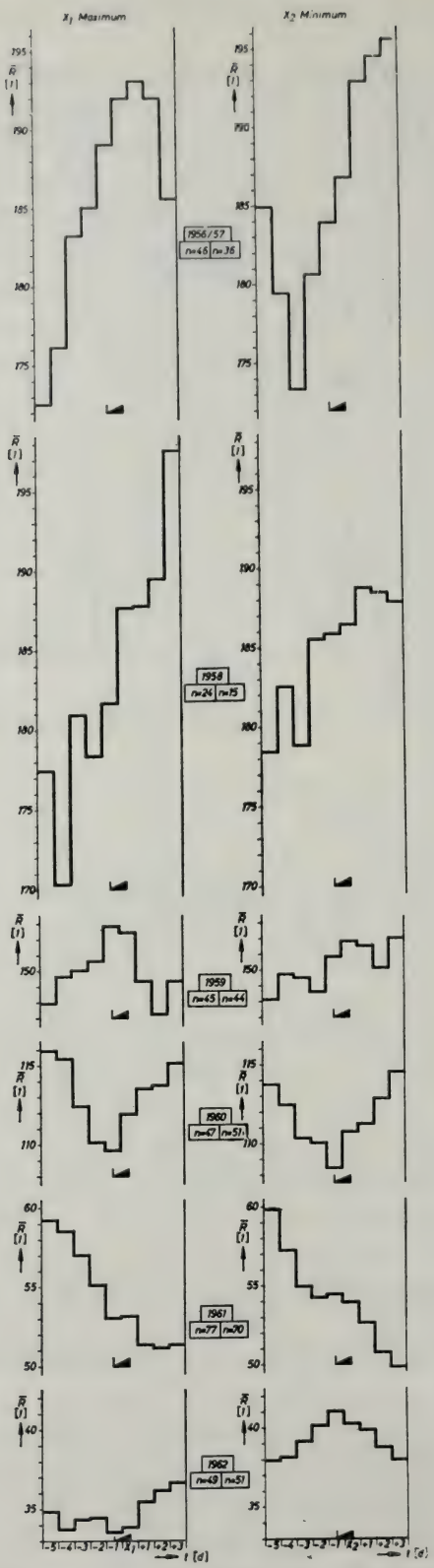

Abb. 4. Mittlere Sonnenflecken-Relativzahlen ($\bar{R}$) in der Umgebung der Stichtage mit Maxima (x_1) und Minima (x_2) des Wassergefrierens. Berechnung nach der Medianwertmethode. Die Markierung auf der Abszisse gibt die Zeit des Gefriervorganges an. Berlin–Dahlem, 1956–1962

den Verlauf der Sonnenflecken-Relativzahlen selbst in der Umgebung der Stichtage „Minima", so zeigt sich in beiden Jahren 2,5 Tage vor der Mitte der Gefrierzeit ein ausgeprägtes Minimum der Fleckenzahl, das auch in den beiden folgenden Jahren 1959 und 1960 wieder vorhanden ist, sich allerdings in jedem der beiden Jahre einen Tag näher an die Mitte der Gefrierzeit heranschiebt („Rechts"-Verschiebung). 1961 ist dieses Minimum dann 1,5 Tage vor der Mitte der Gefrierzeit noch angedeutet und verschwindet im Jahre 1962 ganz. In diesem letzten Jahre des Untersuchungszeitraumes ist mit der größten Annäherung an das für 1964–65 erwartete nächste Sonnenflecken-Minimum gleichzeitig auch der niedrigste Gesamtpegel der Sonnenflecken-Relativzahlen erreicht. Entsprechend diesem Trend vom Maximum der Sonnenaktivität zum Minimum nehmen auch die Amplituden der interdiurnen Änderungen der Sonnenflecken-Relativzahlen von 1958 bis 1962 ab. Das relativ stärkste Fallen hat dabei das Jahr 1961 aufzuweisen, dessen interdiurne Änderungen für beide Stichtage fast ausschließlich negative Werte besitzen.

Ob Monatsmittelwerte der Prozentzahlen gefrorener Wasserproben einen dem Sonnenflecken-Zyklus entsprechenden Gang aufweisen, wie es schon einmal vermutet wurde (Bortels, 1956) und wie es für die Calciumphosphat-Fällungsreaktion (Bortels, 1954) wahrscheinlich, für die Wismutoxychlorid-Fällung nach *Piccardi* (1962) bestimmt zutrifft, ist bei der Art der bisherigen Versuchsdurchführung mit z. B. nicht genau dosierten Mengen Glasstaubs vorläufig nicht zu entscheiden. Immerhin mußte die Gefriertemperatur ab September 1962 von $-6°$ auf $-7°$ C erniedrigt werden, um überhaupt noch genügend hohe Gefrierzahlen zu erreichen.

Auch die Sonnenflecken-Relativzahlen sind hier nur als ein Indikator für ein im einzelnen sehr komplexes Geschehen auf der Sonne aufzufassen. So wird man bei Annahme eines kausalen Zusammenhanges der solaren Aktivität mit der Auslösung des hier untersuchten Wassergefrierens nach den vorliegenden Ergebnissen möglicherweise nicht mit einer physikalischen Größe allein als Ursache der Gefrierzahlschwankungen auskommen. Die Ergebnisse widersprechen andererseits nicht der nach den Untersuchungen mit dem Bodenluftdruck als Indikator und der Modifizierung der Versuchsbedingungen durch Metallabdeckungen aufgestellten Strahlungshypothese.

Bei früheren Untersuchungen wurde bereits darauf hingewiesen, daß mit einer Veränderlichkeit gewisser physikalischer, chemischer und biologischer Reaktionen in den verschiedenen Phasen des Sonnenfleckenzyklus zu rechnen ist (Bortels, 1954; Piccardi, 1962; Takata, 1951). Um Ergebnisse derartiger Untersuchungen miteinander vergleichen zu können, ist es demnach offensichtlich sehr wichtig zu wissen, in welcher Phase des Zyklus sie gewonnen wurden.

ÜBERDECKUNGSVERSUCHE

Daß überhaupt eine von oben kommende Strahlung als wirksames Agens in Betracht zu ziehen ist, geht außer aus früheren Versuchsergebnissen auch aus folgenden hervor: Die Wasserproben wurden zur Hälfte – und zwar jeweils 100 in

einem Kasten gemeinsam – während einer Reihe von Tagen seit Anfang 1963 mit verschiedenen Materialien überdeckt. Ein Temperaturstau unter diesen Bedeckungen war nicht zu befürchten und ist auch nicht eingetreten, weil die Auflagen in ausreichendem Abstand über den Kölbchen gehalten wurden und ein Umwälzer (neuerdings zwei) für ständige Durchmischung der Luft in dem gesamten Kühlraum sorgte. In jedem Falle, gleichgültig ob das Material aus 45 mm dicken Eisplatten, aus 0,1 mm Kupferblech oder aus 0,03 mm Aluminiumfolie bestand, wurde unter

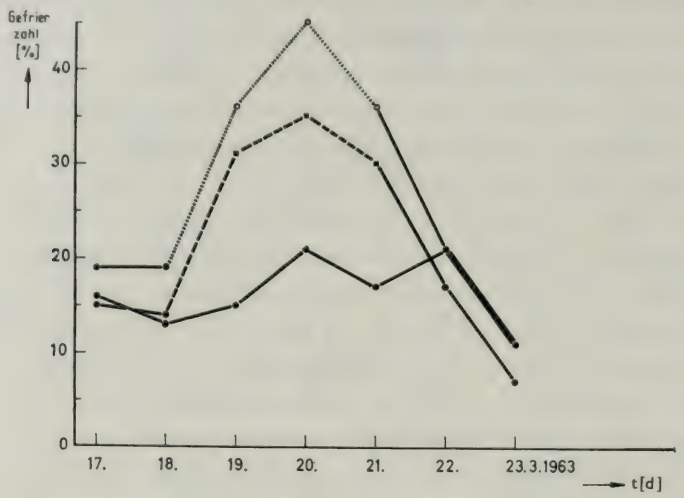

Abb. 5. Einfluß einer Bedeckung mit Kupferfolie von 0,10 mm (■- - -) und mit Aluminiumfolie von 0,03 mm (○ · · ·) im Vergleich zu „unbedeckt" (●——) auf das Gefrieren der Wasserproben. Berlin-Dahlem, 1963

diesen Bedeckungen die Zahl der in 24 Stunden gefrorenen Wasserproben erhöht, wenn die Gefrierzahlen ohne Bedeckung schon verhältnismäßig groß waren. Am stärksten wirksam in dieser Richtung war das Metall, ganz besonders die dünne Aluminiumfolie Abb. 5). Moriyama (1962) hat kürzlich berichtet, daß die Wirkung seines „X-Agens", vergleichbar oder identisch mit den hier untersuchten Wetteragentien, mit γ-Strahlen interferiert, aber ebenfalls nur dann, wenn sich das „X-Agens" selbst sehr stark bemerkbar macht.

Die im März und Ende August 1963 eindeutig fördernde Wirkung der Metallbedeckungen auf das Gefrieren des Wassers war in den übrigen Monaten dieses Jahres schwächer und zeitweilig sogar in eine hemmende Wirkung umgewandelt. Das Maximum der verstärkenden Gefrierwirkung scheint demnach mit den jährlichen Extremwerten der Wismutoxychlorid-Fällungsreaktion nach Piccardi (1962) sowie mit den extrem streifigen Calciumphosphat-Fällungen zeitlich zusammenzufallen (Bortels, 1954).

Zum Schluß sei eine interessante Beobachtung noch kurz erwähnt: Eine Harzer Wetterregel, die einen der Anlässe zu diesen und den voraufgegangenen Untersuchungen über das Gefrieren des Wassers gab und auf die wir freundlicherweise von Herrn Dr. Zeumer, Braunschweig, hingewiesen wurden, besagt, daß im Winter

bei Temperaturen unter 0° C die schnellfließenden, von Terrasse zu Terrasse springenden Bäche im Harz zunächst nur oberflächlich ganz oder teilweise, plötzlich aber innerhalb eines Tages vom Bachgrund her völlig zufrieren, so daß dann das Wasser über das schon länger vorhandene Oberflächeneis hinwegfließt. Diese Grundeisbildung soll mit Sicherheit unmittelbar vor einem Wetterumschwung von Frostwetter zu Tauwetter eintreten, also vermutlich bei fallendem Luftdruck. Wir konnten zwar in den geschilderten Versuchen und unter den gegebenen örtlichen Verhältnissen feststellen, daß die Zahl der gefrierenden Wasserproben im statistischen Mittel bei fallendem Luftdruck, besonders unter Metall oder Eis, zunahm, jedoch dürfte diese Feststellung für eine Deutung der genannten Wetterregel noch nicht ganz ausreichen. Vielleicht wird es bei Fortsetzung der Versuche gelingen, die noch offenen Fragen zu beantworten und auch auf diese Weise zur wissenschaftlichen Deutung von Wetterregeln und zur Klärung meteorobiologischer Probleme beizutragen.

LITERATUR

Bortels, H. (1954) Zwei einfache Model meteorobiologischer Reaktionen in ihren Beziehungen zu Luftdruckänderungen und zur Solaraktivität. *Arch. Meteor. Geoph. Biokl.* B **5**, 234–257,

Bortels, H. (1956) Das Gefrieren unterkühlten Wassers in Beziehung zu interdiurnen Luftdruckänderungen und zur Solaraktivität. *Arch. Meteor. Geoph. Biokl.* B **7**, 270–276.

Bortels, H., Massfeller, D. u. Wedler, E. (1964) Schwankungen der Befallsstärke von *Phytophthora infestans* (Mont.) de Bary an Tomatenpflanzen im Vergleich mit Änderungen des Luftdrucks. *Phytopath. Z.* **50**, 69–79.

Koppe, H. (1951) Sonnenaktivität, Großwetter und wetterbezogene Reaktionen. *Ann. Meteor.* **4**, 87–96.

Moriyama, H. (1962) Studies on X-Agent. XXIV. Special Attitude of Kaolin Suspension toward X-Agent. *Yokohama Med. Bull.* **13**, 355–362.

Piccardi, G. (1962) *The Chemical Basis of Medical Climatology.* Charles C. Thomas, Springfield, Illinois.

Rochester, G. D. (1962) Cosmic Rays and Meteorology. *Quart. J. roy. Meteor. Soc.* **88**, 369–381.

Takata, M. (1951) Über eine neue, biologisch wirksame Komponente der Sonnenstrahlung. Beitrag zu einer experimentellen Grundlage der Heliobiologie. *Arch. Meteor. Geoph. Biokl.* B **2**, 487–508.

EFFETS DIURNES DANS LES TESTS PHYSICO-CHIMIQUES DE PICCARDI ET DANS LA PRÉCIPITATION DU CARBONATE DE CALCIUM EN SOLUTIONS DILUÉES

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Abstract – A very significant diurnal effect is shown upon some of the chemical tests resulting from differential precipitation by hydrolysis of bismuth oxychloride, made in Florence by G. Piccardi and in Brussels by the author. Various electrochemical methods have been applied to study the lack of reproductibility of the "induction period" in the precipitation of calcium carbonate in dilute solutions. This work has shown the influence of external factors able to impose a diurnal fluctuation. In fact, conductivity measurements made after mixing the reagents, at constant temperature and under controlled atmospheric conditions of pure nitrogen, have shown fluctuations both in the initial values and in time – variations, bound to conditions of the day and hour at which the experiments were made. This method could be used to register nearly continuously the effect of external factors on a precipitation reaction by absolute measurements, carried out in constant conditions of temperature, mixing and atmosphere that exclude any variability brought by these well-known factors.

Zusammenfassung – Ein signifikanter „Stunden-Effekt" zeigt sich bei verschiedenen Fällungsreaktionen von Wismutoxychlorid, die gleichzeitig in Florenz durch G. Piccardi und in Brüssel durch den Autor gemacht wurden. Untersuchungen mit verschiedenen elektrochemischen Methoden über die Reproduzierbarkeit der „Latenz-Zeit" in Fällungsreaktionen von Kalziumkarbonat in verdünnen Lösungen haben gezeigt, dass diese „Latenz-Zeit" von äusseren Faktoren beeinflusst wird, die täglich einwirken. Besonders die Leitfähigkeit nach der automatischen Mischung von den Reagenzen im Thermostat und in 100% N_2 zeigt Schwankungen, sowohl der ursprünglichen Werte, als auch der Leitfähigkeit Zeit-Änderungen. Die Methode eignet sich also für kontinuierliche Registrierung der Wirkung von äusseren Faktoren auf eine Fällungsreaktion durch absolute Messungen unter konstanten Bedingungen für Mischungsweise und Atmosphäre.

Résumé – Un effet diurne très significatif a été mis en évidence sur certains tests différentiels de précipitation par hydrolyse de l'oxychlorure de bismuth, effectués soit à Florence par G. Piccardi, soit à Bruxelles par l'auteur. Par ailleurs, une étude, par diverses méthodes électrochimiques, du manque de reproductibilité du «temps d'induction» que présente la précipitation du carbonate de calcium en solutions diluées, a montré l'effet de facteurs d'origine extérieure, produisant une fluctuation diurne : les conductivités mesurées *après* mélange des réactifs, par pipette automatique, en thermostat et sous atmosphère d'azote pur, présentent des fluctuations des valeurs initiales et des variations de conductivité en fonction du temps, liées aux conditions du jour et de l'heure de l'essai. Cette méthode s'avère donc adéquate pour enregistrer de façon quasi continue les effets de facteurs d'origine extérieure sur une réaction de précipitation, par des *mesures absolues*. Elle peut permettre à la fois la recherche par corrélation des facteurs inconnus prédominants, et l'étude du mécanisme de leurs effets sur la germination et la croissance d'un précipité.

On sait que les tests différentiels de précipitation de l'oxychlorure de bismuth, proposés par G. Piccardi, et pratiqués systématiquement depuis plus de dix ans à l'Université de Florence et à l'Université de Bruxelles, ont mis en évidence des fluctuations de longues périodes, d'origine cosmique.

L'existence d'une *variation séculaire*, en corrélation statistiquement assurée avec l'activité solaire, et d'une *variation annuelle*, reliée au mouvement de la terre dans la galaxie, ne font actuellement plus aucun doute.

Ces grandes fluctuations apparaissent avec évidence sur les différents tests (F, D, P) pratiqués quotidiennement *à la même heure*, à une échelle statistique, par l'observation d'un effect positif (=accélération) ou négatif d'un traitement différentiel (activation de l'eau ou écran) sur la sédimentation de dix couples de précipités formés par hydrolyse (Piccardi, 1960a; Capel-Boute, 1960a).

Il est apparu dès le début des observations que le même test pratiqué à des heures différentes de la journée ne donne pas des résultats identiques, quoique l'allure des fluctuations de longue période puisse rester remarquablement semblable (pour exemple: test P) (Piccardi, 1960b).

Nous avons montré précédemment (Capel-Boute, 1955) que les coefficients de corrélation calculés sur les moyennes *mensuelles* des résultats des tests F et D effectués à Florence le matin à 8:30 h et l'après-midi à 14 : 30 h (de mars 1951 à juin 1954 – période de décroissance d'activité solaire) étaient significatifs.

$$F(\text{a.m.})/F(\text{p.m.}): \quad \varrho = 0{,}45 \quad \text{avec } P = 0{,}01$$

$$D(\text{a.m})/D(\text{p.m.}): \quad \varrho = 0{,}89 \quad \text{avec } P = 10^{-10}$$

Mais on a constaté aussi que la corrélation était bien meilleure pour le test D, effectué à l'intérieur d'une chambre faradisée en cuivre de 0,1 mm, que pour le test F. L'enceinte protectrice assure donc nettement des résultats plus constants au cours de la journée.

Ce fait est confirmé aussi par les observations que nous avons faites en août et septembre 1958 (période de maximum de l'activité solaire) sur les quatre tests F, D', P_N, et P_A à midi et à minuit (Capel-Boute, 1960a). Aussi bien les courbes de fluctuations que les résultats moyens sont assez différents selon l'heure, *sauf pour le seul test D'* pratiqué sous un simple écran horizontal de cuivre de 0,1 mm.

Nous en avions conclu, *sous toutes réserves, pour cette brève période** (quoiqu'il s'agisse de 1100 précipitations différentielles comparées pour chaque test) que «*les facteurs influençant les précipitations différemment à midi et à minuit ne passent pas un écran de cuivre de 0.1 mm*».

Une analyse de la variance à 2 critères («jour» et «heure»), effectuée récemment sur ces mêmes données quotidiennes (Capel-Boute, 1963) (cf. tableau 1–3e période) confirme que l'*effet jour* n'apparaît significativement que sur les *tests D'* (effet de

* Nous n'avons eu connaissance que plus tard des résultats des observations effectuées à midi et minuit par Melle U. Mayer à Tübingen (Piccardi, 1961a).

l'*activation* sous *écran*) et P_A (effet de l'*écran* sur l'eau *activée*) qui mettent en jeu à la fois les phénomènes d'activation et d'écran, tandis que l'*effet heure* est prédominant et *hautement significatif* sur le test P_N lorsque l'effet d'*écran* est observé sur l'hydrolyse par l'eau *normale*.

Aucun de ces effets n'apparaît assez systématiquement *pendant cette période* sur le test F pour être concluant, malgré les courbes des moyennes péréquatées par décades bien distinctes pour midi et minuit.

Cependant les données recueillies du 25 février au 19 juillet 1957 sur le même *test F*, pratiqué successivement par des méthodes différentes entre 9:30 h et 12:00 h, (Capel-Boute, 1960b), nous ont permis de faire également une analyse de la variance à 2 critères («jour» et «méthode *ou* heure») en considérant deux périodes distinctes, sensiblement de même durée que celle considérée précédemment (Capel-Boute, 1963). (cf. tableau I–1e et 2e période).

On constate que cette fois l'effet «méthode ou heure» (ces deux paramètres sont ici systématiquement confondus) apparaît *très significativement* surtout à la seconde période. L'effet *jour* apparaît également, devenant même *trés significatif* à la deuxième période.

On voit donc qu'il existe aussi un *effet de la période d'observation* sur les conclusions d'une telle analyse. Nous avons fréquemment insisté (Capel-Boute, 1960, 1962, et I. S. B. 1960) sur les réserves que la variabilité des facteurs de l'ambiance, notamment selon les périodes du cycle solaire considérées, impose à toutes conclusion d'*observations peu prolongées*, même si le *nombre* d'observations est statistiquement suffisant pour conclure à des effets très significatifs.

Ces analyses de la variance démontrent néanmoins formellement, que la *grande variabilité selon le jour et l'heure* des résultats des tests de Piccardi n'est pas simplement l'effet du hasard, c'est à dire d'une dispersion incohérente propre à la méthode, sur laquelle seules des fluctuations de longues périodes d'origine cosmique, révélées par des moyennes mensuelles ou annuelles, pourraient être mises en évidence.

Piccardi a d'ailleurs montré (Piccardi, 1961b) que le test F pratiqué toutes les 15 minutes de 6h à 12h, du 15 au 18 février, 1961, avait accusé remarquablement l'éclipse de soleil du 15 février 61, tandis qu'aucun effet significatif n'était observé sur le test D.

L'existence d'un effet «heure», plus ou moins saillant, semble-t-il, selon les jours et les tests considérés, justifie donc une étude de la variation diurne, en relation avec celle de tous les facteurs de rayonnement du soleil.

Les analyses de la variance précédentes (tableau I–3e période) peuvent indiquer aussi qu'une *réaction de précipitation pratiquée sans écran* et *sans activation* de l'eau pourrait être plus sensible aux facteurs de la variation diurne, tandis que la même réaction pratiquée sous écran ou avec de l'eau activée pourrait être plus sensible à d'autres facteurs.

Dans ce cas, les résultats d'une *mesure absolue* sur une simple réaction de précipitation seraient plus aisément interprétables en fonction de la variation diurne

Tableau 1. Tests de Piccardi à Bruxelles

Périodes d'observations →	25.2 au 30.4.57	1.5 au 19.7.57	28.7 au 5.10.58	28.7 au 5.10.1958
Sources de variations ↓	$j = 57$ jours $i = 6$ méthodes (à heures differ.)	$j = 68$ jours $i = 6$ méthodes (à heures différ.)	$j = 60$ jours $i = 2$ heures différentes (méth. mélangeur)	$j = 60$ jours $i = 2$ heures différentes (méthode mélangeur)
$X_j = 2$ critères	F (effet activation sans écran) = test F		F	P_N (effet écran sans activation)
1 observation/cellule	1. Manuelle 9 h 30 2. Mélangeur 12 h 3. Pipettes (Hg) 1° 11 h 4. d° d° 2° 11 h 15 5. d° (M) 1° 11 h 6. d° d° 2° 11 h 15		1. Midi 2. Minuit	1. Midi 2. Minuit
Nombre d'observations	$N = 57 \times 6 = 342$	$N = 68 \times 6 = 408$	$N = 60 \times 2 = 120$	$N = 60 \times 2 = 120$
i effet méthode ou effet heure	5 *4,73* 0,01 —	5 *10,21* 0,01 —	1 1,23 — >	1 *9,20* 0,01 —
j effet jour	56 *1,36* 0,1 0,05	67 *1,96* 0,01	59 0,52 — >	59 1,03 — >
ji interaction méthode/jour ou heure	280 —	335 —	59 —	
$X_{ji} = 2$ critères 1 observation/cellule	↑ Degrés de liberté ↑ ↑ Variables F (soulignées quand l'effet est significatif) ↑ Niveaux de probabilités pour RH_0 (rejet de l'hypoth. nulle Ho = effet significatif) ↑ Niveaux de probabilités pour AH_0 (acceptation de H_0 = pas d'effet >)		D' (effet activ. avec écran) 1. Midi 2. Minuit	P_A (effet écran avec activation) 1. Midi 2. Minuit
Nombre d'observations			$N = 60 \times 2 = 120$	$N = 60 \times 2 = 120$
i effet heure			1 0,61 — >	1 *3,20* 0,1 0,05
j effet jour			59 *1,66* 0,05	59 *1,81* 0,05 0,01
ji interaction heure/jour			59 —	—
	N.B. Les tetst F et D' enregistrent la fréquence d'un effet positif (accélération de la sédimentation) dû à l'activation de l'eau			N.B. tests P_N et P_A = fréquence d'un effet positif de l'écran

de facteurs extérieurs, qu'un test différentiel, et plus facile à enregistrer de façon continue ou par des essais rapidement successifs.

Cependant, dans un ordre de phénomènes aussi sensibles que la germination et l'évolution d'un précipité, on peut craindre, par la mise en oeuvre d'un moyen d'observation enregistrable, d'exercer précisément sur les phénomènes un effet ordinateur masquant ceux des facteurs recherchés.

Tel pouvait être le cas dans des *mesures de conductivité de la solution* qui exigent la présence, dans la cellule de réaction d'électrodes de platine platiné de grande surface active, et l'application d'un champ électromagnétique de basse fréquence.

Nous avons eu l'occasion de lever cette objection dans le cadre d'un travail de fin d'études, fait dans notre laboratoire par. R. Van Winnendael (1963) (Capel-Boute, 1963), pour étudier par la même technique le manque de reproductibilité dans la précipitation du carbonate de calcium observé par P. Godrie (1961).

On sait les incertitudes auxquelles donnent lieu les titrages conductométriques dans les réactions de précipitation, selon les conditions de formation du précipité, et aussi, fréquemment, par suite de l'existence d'un «temps d'induction» après le mélange des réactifs, considéré habituellement comme un «temps de latence» nécessaire à la germination du précipité.

La mesure de la conductivité en fonction du temps, après le mélange des réactifs, doit permettre en principe de déterminer ces « temps d'induction », variables selon les concentrations et les conditions expérimentales, par la longueur d'un « palier », pendant lequel la conductivité du mélange évolue très peu. Ensuite, la conductivité de la solution diminue habituellement plus ou moins rapidement, par suite de la disparition des ions formant le précipité.

En étudiant ainsi la précipitation du carbonate de calcium en solutions très diluées ($0{,}75.10^{-3}$ M en ions réagissants, selon la réaction $CaCl_2 + CO_3Na_2 = 2NaCl + CO_3Ca$) nous avons obtenu des courbes d'allures très différentes, aussi bien lorsque les réactifs étaient mélangés manuellement d'un seul coup, en béchers ouverts, comme dans la méthode manuelle des tests de Piccardi, que lorsque le mélange était effectué de façon plus standardisée par pipettes automatiques. (Capel-Boute, 1960b) (Fig 1.).

Dans tous les cas, certaines courbes présentaient l'allure normale d'un «palier d'induction» suivi d'une décroissance plus ou moins rapide de la conductivité (type I–ex: 019), tandis que sur d'autres le palier disparaissait plus ou moins complètement (type II–ex: 013). Mais plus singulières étaient des courbes sans aucune variation notable de la conductivité semblant présenter un «temps d'induction» infini (type III–ex: 012), ou même une période d'accroissement de la conductivité (type IV–ex: 014).

Nous nous sommes assurés que de telles anomalies n'étaient pas le résultat de variations de la température, ou de pollutions par l'atmosphère, en opérant en thermostat à 20° C ± 0,1° C et avec de nouvelles solutions, préparées à partir d'eau bidistillée, et désaérées en atmosphère d'azote.

Nous avons, en effet, constaté que la conductivité de la solution de carbonate de soude était particulièrement sensible à la présence de traces d'anhydride carbonique dans l'atmosphère.

La pipette automatique et la cellule de réaction étaient maintenues en atmosphère d'azote, comme le montre la Fig. 2, qui schématise la technique expérimentale.

La cellule de mesure de la conductivité et les électrodes de verre sensibles au pH et au pNa de la solution n'étaient introduites qu'immédiatement *après* le mélange des réactifs, pour suivre l'évolution des concentrations des ions en solution au cours de la précipitation.

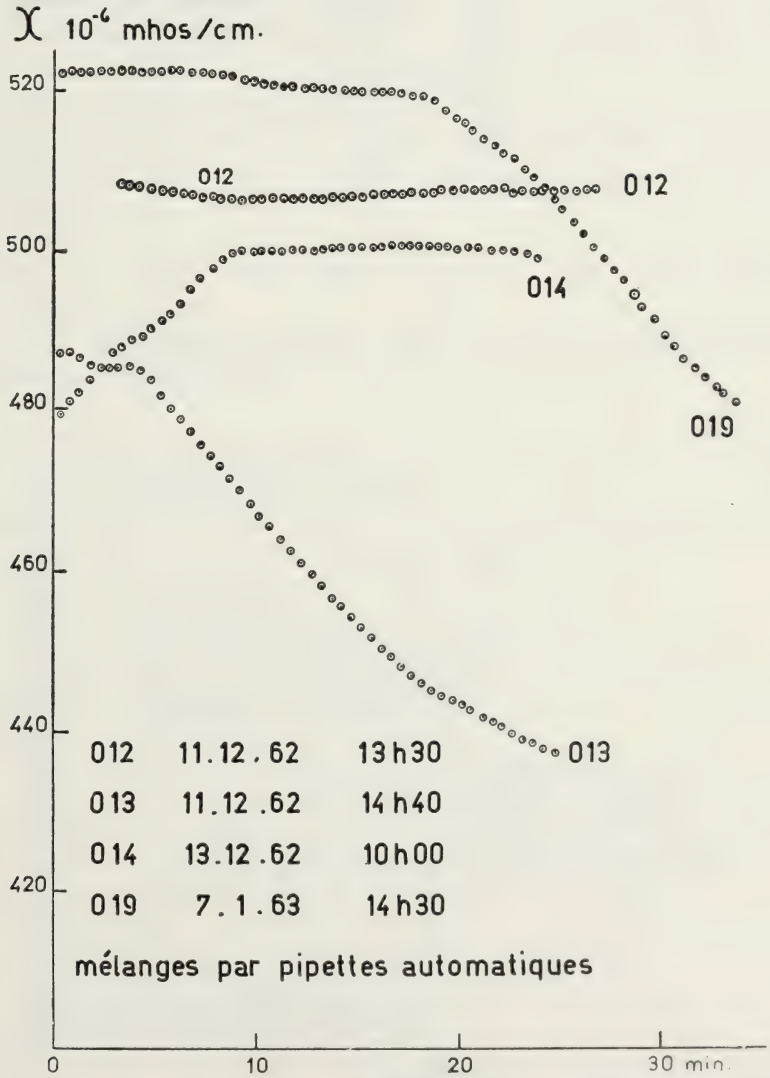


Fig. 1. Types différents de courbes d'évolution de la conductivité en fonction du temps dans un mélange stoechiométrique de chlorure de calcium et carbonate de soude – $1{,}25 \cdot 10^{-3}$ M effectué par pipette automatique

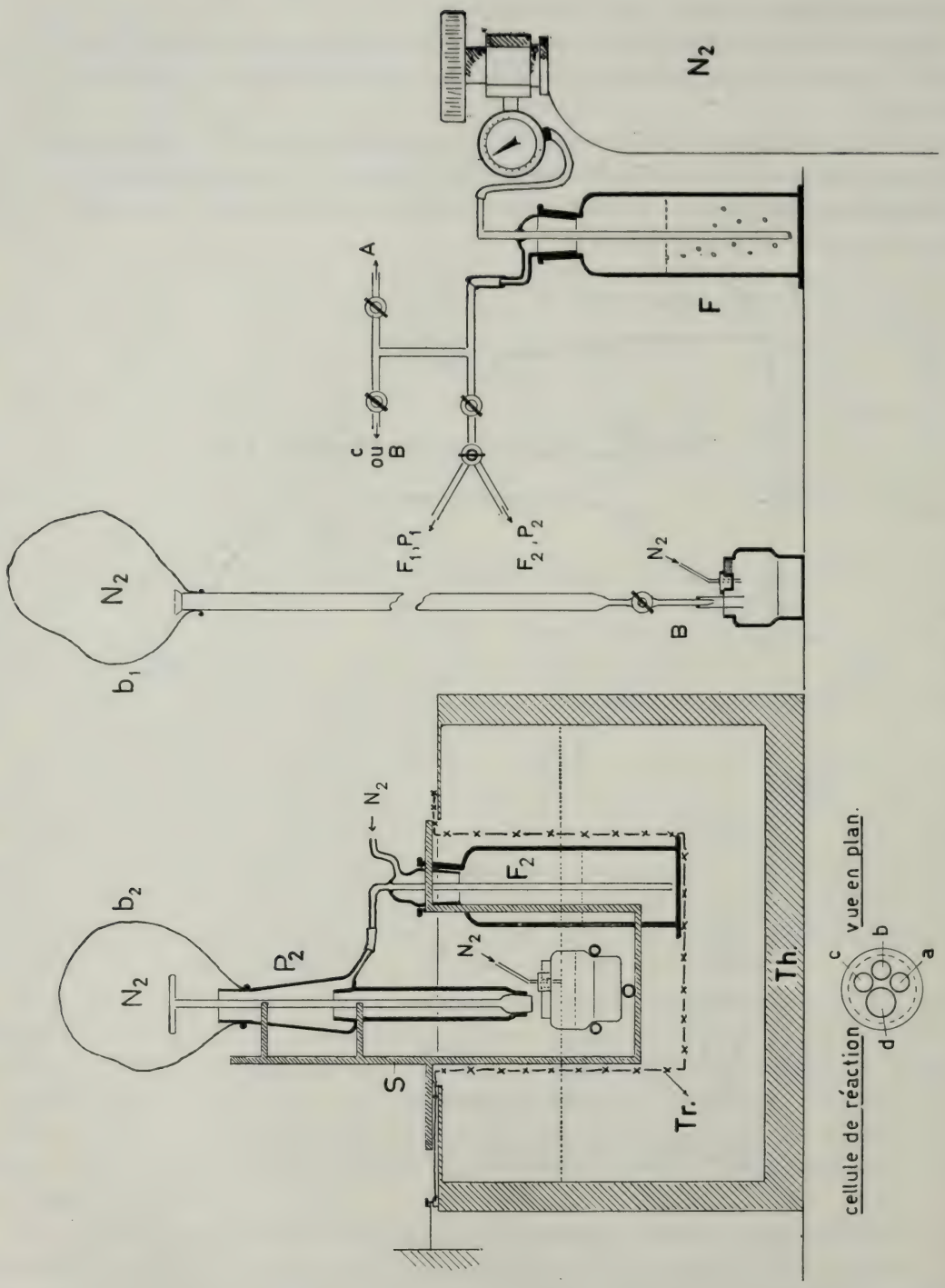

N2
F
A
c
ou
B
F1, P1
F2, P2
N2
B
N2
b1
N2
b2
P2
N2
F2
N2
S
Tr.
Th.
cellule de réaction
vue en plan.
c
b
a
d

Fig. 2.

Dans ces conditions expérimentales beaucoup plus rigoureuses, nous avons obtenu une meilleure reproductibilité des valeurs de départ $\varkappa_0$ de la conductivité, mesurée immédiatement après le mélange, mais l'*évolution de la conductivité* en *fonction du temps* présente encore les *types de courbes différents*, se succédant parfois, comme nous l'avions déjà observé dans les premiers essais manuels, dans un *ordre chronologique* remarquable pour une suite d'essais successifs au cours d'une même journée. (Fig. 3 a, b, c, d).

En solution très diluée on voit que les courbes plates ou à conductivité croissante (types III et IV) se présentent seulement en début de matinée ou fin d'après-midi les jours sereins (3a) mais plus fréquemment et à toutes heures les jours variables (3c et 3d), tandis que les courbes à paliers courts ou sans paliers (types I et II) caractérisent le milieu de la journée les jours sereins (3a et 3b), avec successivement des pentes croissantes, puis décroissantes.

Un effet «heure» apparaît ainsi, particulièrement régulier et continu, semble-t-il, pour des observations effectuées par des journées *ensoleillées* à ciel *sans nuages*, telles que celles du 24/4/63 et du 8/5/63. Les figures 4 présentent, en fonction de l'heure de la précipitation:

- d'une part, la conductivité initiale $\varkappa_0$ du mélange des réactifs ($CaCl_2 + CO_3Na_2$),
- d'autre part, les diminutions de conductivité $-\Delta\varkappa$ relevées sur les courbes après 10 min et après 20 min.

Fig. 2. Technique des précipitations effectuées en thermostat (20° C ± 0,1° C) par pipette automatique sous atmosphère d'azote

F flacon de garde à eau distillée
B burette à eau distillée désaérée par barbotage de N_2
F_1 flacon de $CaCl_2$ désaéré par barbotage de N_2 } hors thermostat,
P_1 pipette automatique de 5 ml pour dito } non représentés
F_2 flacon de CO_3Na_2 désaéré par barbotage de N_2
P_2 pipette automatique de 25 ml pour CO_3Na_2
S support mobile permettant de reculer la pipette *après* mélange pour introduction des électrodes de mesure
C cellule réactionnelle placée dans le thermostat après introduction par *b* de 5 ml de solution de $CaCl_2$ et 20 ml d'eau distillée
a emplacement de l'électrode de verre pour mesure du pH
b emplacement de l'électrode de verre de référence sensible aux ions sodium (pNa)
c arrivée d'azote pur (ou emplacement éventuel pour électrode de référence à KCl saturé pour les étalonnages du pNa)
d emplacement de la cellule plongeante pour mesures de la conductivité
b_1, b_2 ballonets de protection par l'azote
A mise à l'air libre pour le refoulement des trop-pleins des pipettes automatiques
Tr treillis de cuivre mis à la terre avec
Th cuve métallique du thermostat

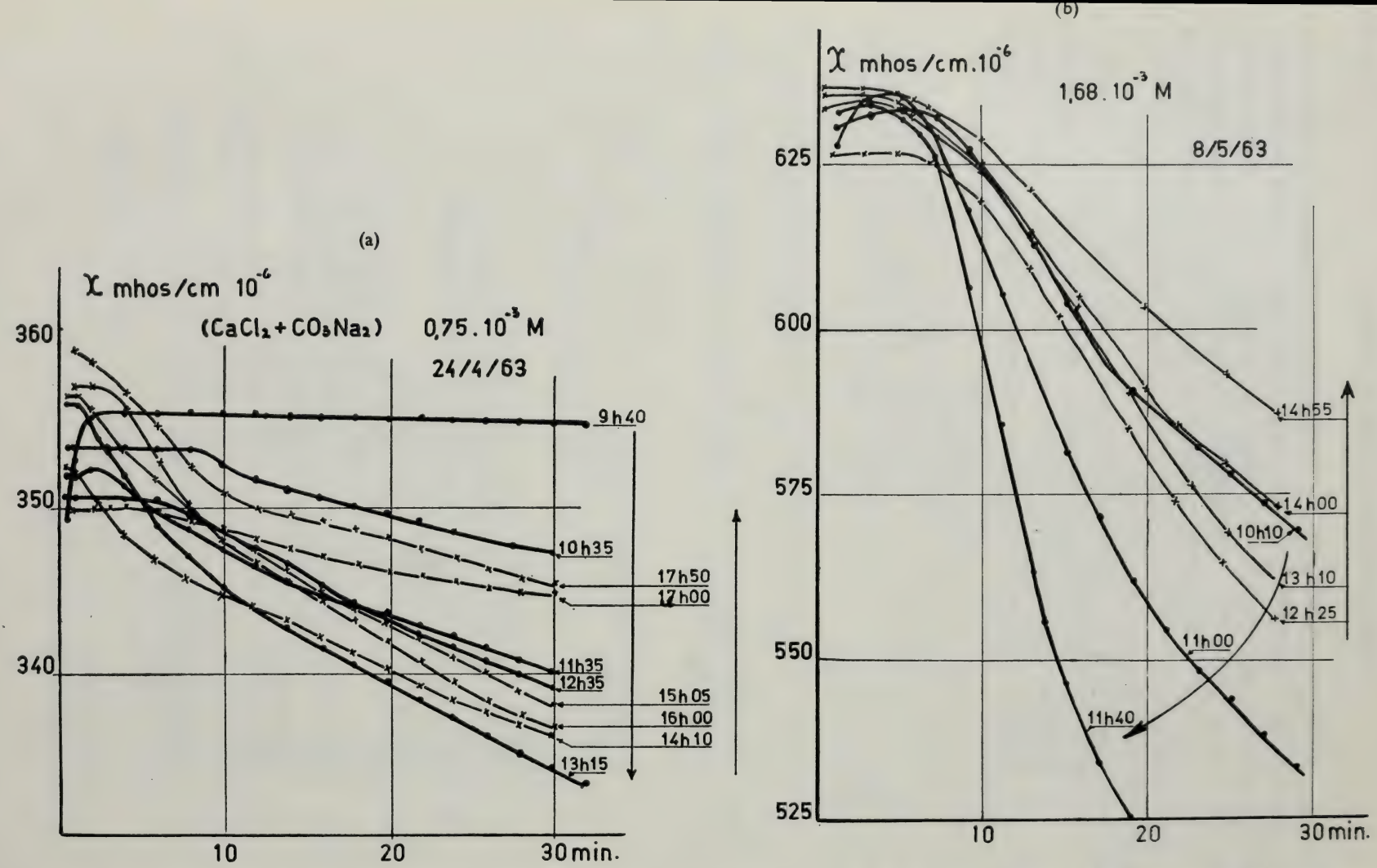
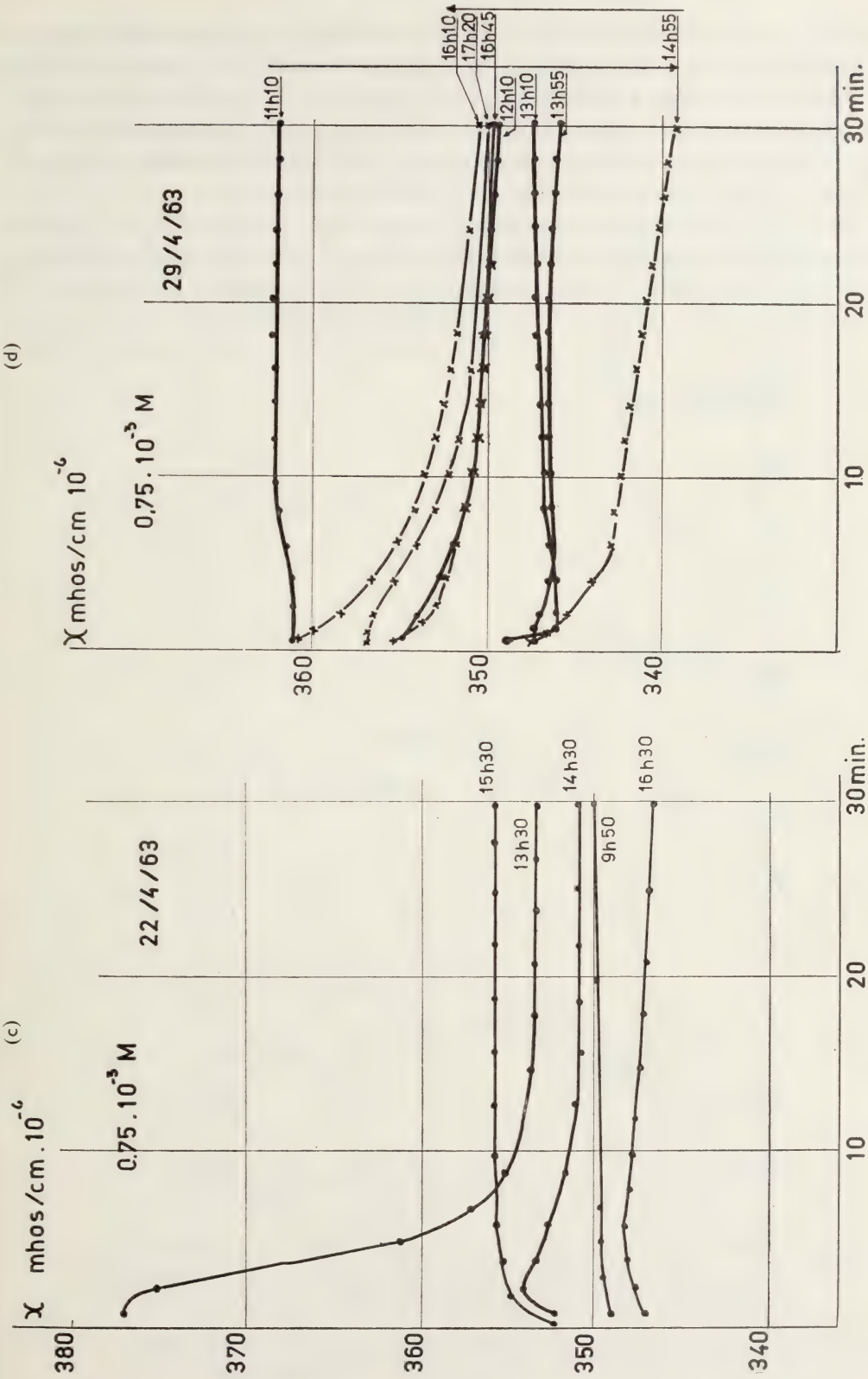


FIG. 3 a, b, c, d. Evolution en fonction du temps de la conductivité mesurée dans un mélange stoechiométrique de chlorure de calcium et carbonate de soude (mélange par pipette automatique en thermostat à 20° C ±0,1° C–sous atmosphère d'azote)

(a) concentration $0{,}75 \cdot 10^{-3}$ M le 24/4/63 } jours sereins à ciel
(b) concentration $1{,}68 \cdot 10^{-3}$ M le 8/5/63 } sans nuages



(c) concentration $0,75 \cdot 10^{-3}$ M le 22/4/63 } jours à temps variable
(d) concentration $0,75 \cdot 10^{-3}$ M le 29/4/63 } et ciel nuageux

On voit que l'*amplitude des variations de conductivité* $-\Delta\varkappa$ peut régulièrement croître et décroître au cours des journées claires (4a et 4b). Cette fluctuation diurne pouvant être trois à quatre fois plus importante dans la solution la plus concentrée et continuant à s'accuser entre 10 et 20 min après le mélange. Les fluctuations de la conductivité initiale, dans ces deux cas, sont beaucoup moins importantes et ne semblent pas présenter une allure diurne régulière.

Par contre, les jours à temps variable (Fig. 4 c et d) présentent une variation plus importante, en fonction de l'heure des essais, de la *conductivité initiale* $\varkappa_0$ mais une diminution quasi négligeable entre 10 et 20 min après le mélange.

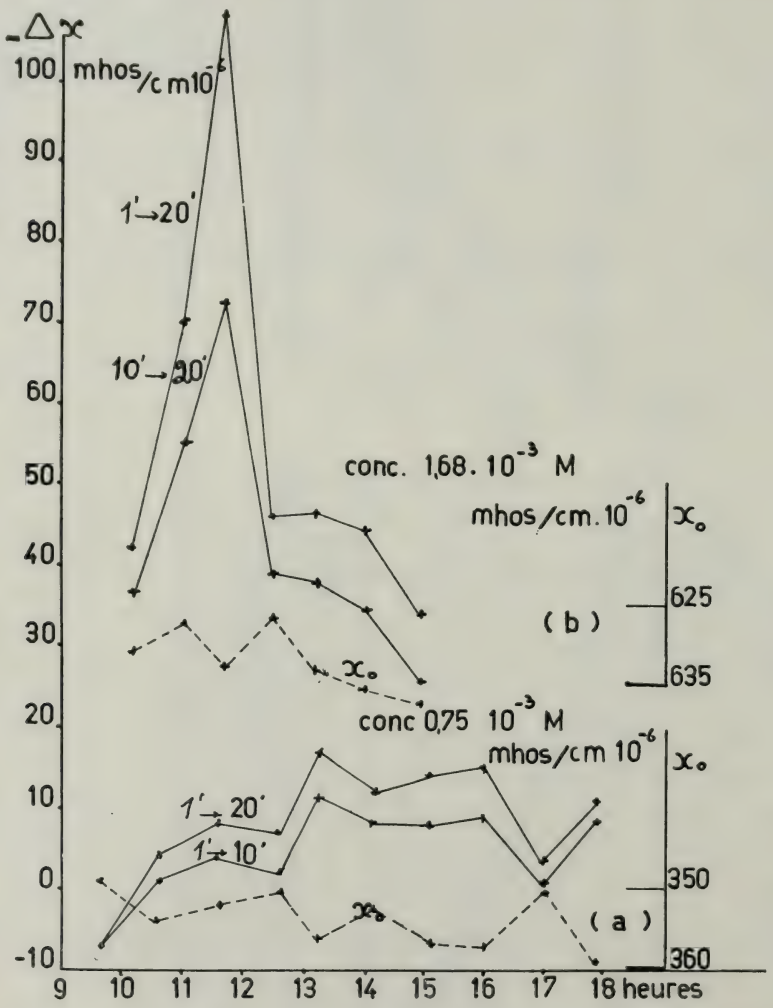
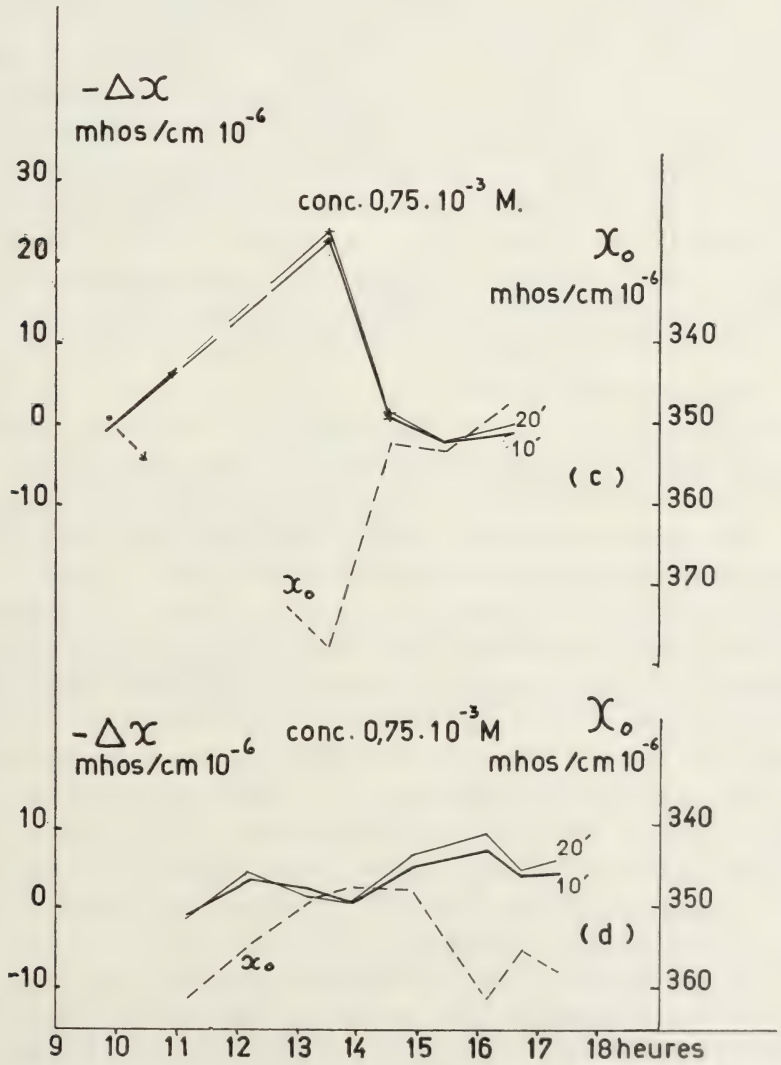


Fig. 4 a, b, c, d Conductivités initiales $\varkappa_0$ (échelle à droite) et abaissement de conductivité $-\Delta\varkappa$ (échelle à gauche) après 10 et 20 min. dans des mélanges stoechiométriques de chlorure de calcium et carbonate de soude

(a) concentration $0{,}75 \cdot 10^{-3}$ M le 24/4/63 } jours sereins à ciel
(b) concentration $1{,}68 \cdot 10^{-3}$ M le 8/5/63 } sans nuages

Les mesures électrochimiques du pH de la solution faites simultanément, et divers titrages conductométriques, ont permis de démontrer (van Winnendael, 1963) que la conductivité initiale est inférieure à celle des ions mis en présence dans le mélange des réactifs et correspond à la formation, *dès l'instant du mélange*, d'une *population d'embryons de germes hétérogènes*, quoiqu'aucun précipité ne soit visible dans ces solutions très diluées.

Dans ces conditions, selon notre hypothèse, les différents types de courbes observés peuvent s'interpréter aisément comme suit : la population initiale d'embryons formés au moment du mélange présente une distribution statistique variable de leurs grosseurs, selon les concentrations, les conditions du mélange et les facteurs extérieurs influençant la *germination* du précipité.



(c) concentration $0{,}75 \cdot 10^{-3}$ M le 22/4/63 } jours à temps variable
(d) concentration $0{,}75 \cdot 10^{-3}$ M le 29/4/63 } et ciel nuageux

Si le taux de germination est élevé, avec formation d'un grand nombre de petits embryons thermodynamiquement instables, ceux-ci ayant tendance à se redissoudre en ions, la conductivité peut augmenter momentanément (type IV) ou rester plus ou moins longtemps stable (type III et «paliers» du type I), si cet accroissement d'ions en solution est compensé par le phénomène opposé de la croissance des germes stables, aux dépens des ions de la solution.

Cette *croissance* des germes, qui entraîne la diminution plus ou moins rapide de la conductivité (courbes du type II et partie décroissante des courbes du type I), est donc fonction simultanément

(1°) du nombre d'embryons formés à l'instant du mélange et de la répartition initiale de leurs grosseurs,

(2°) de divers facteurs de la croissance (concentration, température, état des ions en solution, structure du solvant, inhibiteurs, etc.).

Les courbes de $\varkappa_0$ et $-\Delta\varkappa$ montrent que les deux phénomènes semblent plus ou moins influencés, selon les jours, par les facteurs extérieurs de la variation diurne, et confirment l'hypothèse précédente, si on remarque que les *taux de germination* les plus élevés (minimum de $\varkappa_0$) semblent bien correspondre, en solutions très diluées, à des diminutions moins rapides de la conductivité par croissance (minimum de $-\Delta\varkappa$) (Fig. 4 a, c, d).

L'ensemble d'essais d'orientation effectués par cette méthode est évidemment encore insuffisant pour justifier une analyse plus poussée de la nature des facteurs liés à cette fluctuation diurne, les facteurs «*température*» et «*pollution par l'atmosphère*» étant cependant déjà *exclus*.

Mais il est ainsi démontré qu'une telle technique de mesure pourrait aisément:

(1°) *servir de base à une méthode automatique d'enregistrement quasi continu pour la recherche des facteurs extérieurs en cause:* une étude systématique permettra la choix de la température et d'une concentration optima des réactifs, permettant le mieux de mettre en évidence les fluctuations de $\varkappa_0$ et $-\Delta\varkappa$ pour une suite ininterrompue de précipitations, effectuées à des intervalles de temps de quelques minutes, le rinçage des électrodes en solutions diluées étant aisé. De tels enregistrements comparés à ceux de toutes les variables géophysiques communément enrégistrées doivent permettre l'identification des causes prédominantes des fluctuations observées. Ils peuvent être effectués également pour des précipitations sous des écrans divers et comparés notamment aux variations diurnes des champs électromagnétiques de très basses fréquences observées par H. Koenig (1959, 1962) et à celles de divers phénomènes biologiques (Haine, 1956, 1962, 1963).

(2°) *cette technique permettrait d'étudier et d'interpréter l'action de ces facteurs sur les réactions de précipitation:* notamment, l'application de la même méthode à l'observation de précipitations par hydrolyse (au moyen d'eau traitée ou non par différentes actions physiques), telles que la précipitation de l'oxychlorure de bismuth en solutions diluées, permettrait d'interpréter les effets des facteurs extérieurs observés dans les tests différentiels de Piccardi et le mécanisme de leurs fluctuations, diurne, annuelle et séculaire.

(3) la même technique permettrait, par des essais successifs, en nombre suffisant, d' *analyser les causes du manque de reproductibilité d'un grand nombre de réactions chimiques ou de tests cliniques, basés sur* des réactions de précipitation ou de floculation (Capel-Boute, 1963)

BIBLIOGRAPHIE

Capel-Boute, C. (1955) De la non-reproductibilité de certains processus physico-chimiques. *Industr. Chim. Belge* **4,** 365–380.

Capel-Boute C. (1960a) Observations sur les tests de Piccardi effectués à Bruxelles de 1950 à 1958. *Symposium International sur les Relations entre phénomènes solaires et terrestres en chimie-physique et en biologie* Presses Académiques Européennes, Bruxelles.

Capel-Boute C. (1963) Facteurs de l'ambiance et expérimentation statistique. Communication au Xème Convegno della Salute, Ferrare, 25–26 mai (à paraître dans les Comptes Rendus, Ed. Artioli, Modène).

Capel-Boute C. (1960b) Méthode des pipettes automatiques. *ibid.* p. 71–95.

Capel-Boute C. (1960c) *ibid.* et (1962) Tests chimiques et tests cliniques dans l'étude des facteurs géophysiques de l'ambiance. *C.R. du IXe Convegno della Salute*; Ed. Artioli, Modène.

Godrie P. (1961) Thèse, Faculté des Sciences, Bruxelles.

Haine E. (1956) Mitt. Biolog. Bundesanstalt Berlin-Dahlem Nr. 85, et Communications aux IX et Xèmes Convegni della Salute, Ferrare (1962 et 1963).

I. S. B. (1960) Discussions à la réunion conjointe des groupes de travail «Tests chimiques», «Ionisation de l'air», «Etat physicochimique du sang», «Aerosols» à la 2ème réunion de la I. S. B. à Londres.

Koenig H. (1959) Z. *angew. Phys.* **11,** 264, et Communication au IXe Convegno della Salute, Ferrare, 1962.

Piccardi G. (1960a) Exposé introductif. Les tests chimiques. Une hypothèse solaire. *Symposium Intern. Relations entre phénomènes solaires et terrestres en chimie-physique et en biologie.* Presses Académiques Européennes Bruxelles.

Piccardi G. (1960b) *Les tests chimiques. ibid.* p. 45.

Piccardi G. (1961a) *The Chemical Basis of Medical Climatology*, Ch. C. Thomas, Springfield, Illinois, p. 57.

Piccardi G. (1961b) The chemical tests and the solar eclipse of February 15, 1961. *Symposium on Solar Seeing*, Rome, 20–25/2/1961.

Van Winnendael R. (1963) Travail de fin d'études. Faculté des Sciences Appliquées, Bruxelles.

SUMMARY REPORT

G. PICCARDI

THE following six points on the agenda were discussed:

1st – Activity of the Committee

2nd – Plans for the IQSY

3rd – Relations with other international organizations

4th – Plans for the development of the research

5th – Re-organization of the committee

6th – News and discussions.

ACTIVITY OF THE COMMITTEE

Introduction

The permanent Committee for the study of the chemical tests in general biometeorology and cosmic biometeorology held a meeting for the third time since its organization in 1957. The present capacity of the committee is that of developping a branch of science which not only is developping very fast but which is also becoming very important and taking on a much larger scope. In fact the observations made with the chemical tests of Prof. Piccardi which were the reason for the organization of the 13th working group, pointed out a *general method* of research, applicable to the most varied phenomena presenting fluctuation in time.

The applications of this method in many different branches of science such as physical chemistry, biochemistry, biology, biophysics and microbiology, open the way to the study of new relations with the sciences observing the external environment: astrophysics, geophysics and meteorology.

During the last three years a large number of such applications were developed, meaning an important increase in the activity of the committee. All this justifies the necessity for a reform of the structure of the committee. Since it was first set up, the committee has lost three of its important members, the loss of whom is much regretted: Professor Berg and Dr. Cauer died and Dr. Holzapfel retired prematurely because of illness. It is, therefore, necessary to reorganize the committee into a more numerous organization responding better to the extension if its present objectives.

PUBLICATIONS ON NUMERICAL DATA

After the meeting in London, we devoted ourselves to the publication of all the data gathered in Florence since 1951. The undertaking was rather ponderous as we had to gather and publish 38,000 daily numerical data. They were grouped in a first volume including respectively the data of 10 years, from 1951 to 1960, followed by two volumes including, respectively, the data of 1961 and 1962. In this way we were able to make well organized numerical data available to all those who are interested in statistical studies.

Since we did not have any funds available, printing expenses were covered by the Institute of Physical Chemistry of the University of Florence.

We also wished to publish the data gathered at the Free University of Brussels by Mme Capel-Boute, since 1952 and the data gathered during the International Geophysical Year and then gathered by the World Geophysical Cooperation in the Southern and Northern hemisphere (Tromso, Genoa, Trieste, Libreville, Leopoldville, Fort Dauphin, Kerguelen, New Amsterdam, Sapporo, Kumamoto, King Baldovin Base – Antarctic) but were not able as yet to do so. It is a pity that it is so because we are going into the new IQSY without having been able to publish or analyse completely the data obtained during the geophysical year for the maximum of solar activity (AGI). In fact, the comparison of these data with the large number of geophysical, astrophysical and meteorological observations gathered during the period of the maximum solar activity, could have supplied us with a better description and, perhaps, an interpretation of the conditions in which the different spots of the globe are located from the point of view of physics and chemistry and biology.

DIRECTIONS OF RESEARCH

We have come to such a point in which research must follow four different directions corresponding to clearly distinct methodologies.

Routine Experiments

These experiments made with the method of chemical tests are presently standardized and mechanized and must give us information on the space situation in different places, with regard to time: their role is essentially geophysical. Similar experiments will be carried out in Florence and Brussels and repeated in other places, notably during the IQSY in 1964–1965.

Physical–Chemical Research

This research deals with the mechanism of physical–chemical phenomena, non-organic and organic ones, submitted to natural or artificial external actions. Research concerns especially the structure of the liquids, interphase phenomena, cine-

tics of the heterogeneous chemical reactions. The role of this research is essentially physical-chemical; such research was already started at the University of Florence and Brussels.

Biological Research

This research concerns the response of the biological systems submitted to natural and artifical external actions, considered along with the response of the chemical tests: the role of this research is essentially biological, that is, to supply biology with a method to allow this science to surmount difficulties deriving from the interference of external factors on the systems studied in the laboratory. The results obtained up to the present in Florence, Pavia, Berlin, Munich, Vienna, Sapporo, the Grotto of Caudano, the Glacier of The Giant (Mont Blanc) have been more than satisfactory. Recently, collaborative studies were organized between the Institute of Physical chemistry of the University of Florence and the Blutstation of the University of Vienna (Klinik für Hautkrankheiten, Prof. Wiedmann). Physical chemical research as well as physiological will be carried out at the same time with the collaboration of the Interdisciplinary Center of Research and Study of Environmental Factors (C.I.R.E.F.A. – Free University of Brussels) and the Laboratory of General Pathology and Therapy of the University of Liège Prof. M. Bacq) by Mme Capel-Boute and Dr. Henrotte.

Statistical Research on the Numerical Data Gathered

The analysis of the fluctuations observed and the research on the correlations made with different statistical methods between the physical-chemical data or biological data and the meteorological geophysical and astrophysical data gathered is particularly useful when, as in the case of the method of chemical tests, it can be based on a number of observations amounting to several thousands.

Statistical studies were started in 1954 in Florence, Fribourg, Cologne, Trieste, Graz and Brussels and are now developing on more material and taking advantage of the new means offered by electronic calculating machines. Through the IBM Scientific Center in Florence we were able to get comparisons between the chemical data gathered in Florence (already published) from 1951 to 1961 and the International Solar Data (R- Wolf's number, H-floculi, Ca-floculi, filaments, Cp-magnetic character) published during the same period of time. This statistical study has confirmed correlations that were highly significant between the chemical data and purely astrophysical (R, H-Fl, Ca-Fl fil) solar data. The above research is continuing.

Plans for the IQSY

During the meeting of the Committee for IQSY held in Rome, steps were taken towards the organization of a chain of observation posts for the chemical tests. This chain is to be located along the 70th meridian W, from the Antarctic to the

Arctic. We have informed about it the National Center for Atmospheric Research, Boulder, Colorado, U.S.A. where research on chemical tests have been carried out for two years. It would also be desirable to set up a station for routine observations in the State of N.Y.

We also hope to be able to resume observations during the IQSY in Kerguelen, New Amsterdam and, if possible, in Terre Adélie (Antarctic) with the help of the French scientific organizations (National Meteorology and T.A.A.F.).

Experiments in Tromso will be resumed by the Nordlysobservatoriet where there is a complete installation available at 70° North latitude. Research on the chemical tests is also planned in Israel. Experiments with a standard biological test are planned to take place in the same places where the chemical tests are carried out. Some suggestions on the above were given by Prof. A. L. Tchijevsky during a meeting of the 10th Health Convention held in Ferrara in May 1963; these suggestions were then passed on to the working group.

Relations between the Committee and other International Organizations

During the COSPAR meeting held in Florence in 1961 we proposed to create a working group for *Space Chemistry*. Following our request and upon our repeated pressures, IUPAC submitted the above proposal officially during the plenary meeting of COSPAR on May 14, 1963 in Warsaw. IUPAC was represented by Prof. Kemula who was able to have a working group for *Physics and Chemistry in the Near Space* organized. Also a working group for biology in the Near Space was organized. We are now waiting for the developments of the situation. COSPAR will hold a meeting in Florence in May of 1964 with all the working groups.

The above three points of the agenda were submitted for discussion during the meetings of September 2nd and 3rd.

DISCUSSION

1. Regarding the difficulties found in the publication of the data, M. Welder suggested to look into the possibility of using the publishing setup of his „Institut für Meteorologie und Geophysik der Freien Universität Berlin“ to make sure that the next publication will contain all the data gathered up to today and put together at the Institute of Physical Chemistry of the University of Florence.

2. Regarding routine observations to be made during the IQSY, Mme Capel-Boute said that due to the interruption of the Belgian expedition in the Antarctic it will not be possible to resume observations at the Base of King Baldovin in 1964.

Mr. Bost suggested to resume observations at Kerguelen and New Amsterdam in 1964 and he hopes to be able to organize something like it to take place in Terre Adélie for 1965.

Regarding the Equatorial Zone, Mme Capel-Boute said that the experiments carried out from 1957 to 1961 in Leopoldville will not, very likely, be resumed but that the possibility of transferring the material to another equatorial station is taken into consideration.

Mr. Bost said he will contact la Météorologie National Française in order to look into the possibility of a meeting of coordination to take place in Paris during the first week in April 1964 about the organization of the observations for the IQSY.

3. About the working group for Physics and Chemistry in the Near Space, it appears necessary to resume immediately contacts with COSPAR to make sure that the activity of this group may not be directed entirely towards chemistry in the High Atmosphere but also towards studying the effects of space actions in the biosphere from the chemical point of view. It also appears necessary to resume contacts with the working group for biology in the Near Space.

PLANS FOR THE DEVELOPMENT OF PHYSICAL CHEMICAL RESEARCH

The group agreed on the decision that IQSY routine observations must be made with the same technique as the previous AGI observations.

On the other hand, all other useful observations are left up to each one to make.

Professor Piccardi is trying to have a center for experimental research on chemical and biological tests created in Italy.

In Brussels, routine observations were again tranferred from the Royal Observatory of Belgium where they were carried out since August 1st, 1957, to the university of Brussels where they can now be made along with other physical chemical research within the Centre Interdisciplinaire de Recherches et Études des Facteurs de l'Ambiance (C.I.R.E.F.A.).

REORGANIZATION OF THE COMMITTEE

Having noted the numerical deficiency of the Committee for the Studies of Chemical Tests, it was decided to make additions to the same, appointing, as members of the committee, only those scientists who were involved and are still actively involved as well as experimentally, in the problem of fluctuations of physical chemical and biological phenomena.

The following people were suggested for the new committee:

1. Piccardi	President	Florence (Italy)
2. Capel-Boute	Secretary	Brussels (Belgium)

and, in alphabetical order:

3. Bortels	Berlin (Germany)

4.	Bost	Paris (France)
5.	Brezowsky	Bad Tölz (Germany)
6.	Haine	Bonn (Germany)
7.	Henrotte	Liege (Belgium)
8.	Hummel	Freiburg (Germany)
9.	Itoh	Sapphoro (Japan)
10.	Koenig	Munich (Germany)
11.	Lossnitzer	Fribourg (Germany)
12.	Moriyama	Kyoto (Japan)
13.	Neuwirth	Fribourg (Germany)
14.	Ogata	Kumamoto (Japan)
15.	Pichotka	Bonn (Germany)
16.	Ranscht-Froemsdorff	Freiburg (Germany)
17.	Takata	Tokyo (Japan)
18.	Tarczy-Hornoch	Sopron (Hungary)
19.	Tchijevsky	Moscow (U.S.S.R.)
20.	Vassy	Paris (France)
21.	Vering	Vienna (Austria)
22.	Wedler	Berlin (Germany)

The people not present will be notified.

It was deemed necessary to give the working group a more clear name and one more in harmony with the expansion of its objectives. The following name was suggested:

Committee for the Studies of the Fluctuations of Physical Chemical and Biological Phenomena.

NEWS

The following news was given to the group, texts for which will be published in their entirety:

G. Piccardi: "Correlations between Chemical Tests and Solar data".

C. Capel-Boute: "Diurnal effects on Physical-chemical tests of Piccardi and on the precipitation of calcium carbonate diluted in solution.

H. Bortels, D. Massfeller, E. Wedler: „Wechselnde Gefrierbereitschaft kleiner Wassermengen im Vergleich mit Änderungen des Luftdrucks und der Sonnenaktivität".

Discussion dealt with the variability of certain correlations with regard to the period of the solar cycle. Mme Capel-Boute pointed out the significant correlations but also found opposite correlations between the observations of the chemical tests in Brussels and Florence, during the minimum solar activity on one hand and during the maximum solar activity on the other.

Bortels and *Wedler* added supplementary information about research now

being made on relations between the experiments on water freezing and sun spots (Wolf's number R) magnetic perturbations and the Atmospherics (10 Kc/sec).

Piccardi brought to the general attention that the correlation coefficients between the chemical tests and the solar astrophysical data point out clearly a diurnal effect. It was also shown that correlations with the magnetic character are always less good than those with data of solar physics.

Undt gave information on the recording conditions of e.l.f. (extremely low frequencies) in Vienna and their relation with the fluctuations of the electrical atmospheric potential.

Wedler presented an hypothesis on the interpretation of the annual variation of test "D" of Piccardi, independently from latitude presenting a maximum in February and March on the basis of present knowledge of solar wind (permanent emission of solar plasma)

Bost Gave details on the mechanism of captivation and deviation of ionized particles of solar origin in the magnetic terrestrial field.

Ranscht said that the observations made on the diurnal variation of the title of a thiosulphate solution were continued. The fluctuations observed seem to be of a different type, the succession of which seems to be in relation with the variations of the atmospherical electrical potential.

Piccardi informed on the observations made on the diurnal variation of the pH of distilled agitated water by Bordi and Papeschi in Florence.

RESOLUTIONS

Le Groupe de travail pour les «test chimiques» tenant compte de l'extension de ses objectifs, a jugé nécessaire des réformes de structure. Il a décidé de faire appel à diverses personnes activement intéressées au problème général des fluctuations de certains phénoménes physico-chimiques et biologiques, et , en particulier, aux textes chimiques et biologiques sensibles aux facteurs de l'ambiance.

Il propose de remplacer la dénomination actuelle du groupe par celle de «Comité d'étude des fluctuations de phénomènes physicochimiques et biologiques».

Il a été rendu compte des résultats de l'ensemble des observations de longue durée recueillies à ce jour, par les tests chimiques de Piccardi, Ainsi que par les tests de congélation de l'eau de Bortels.

D'autre part, des observations nouvelles sur les variations diurnes de grandeurs absolues observées dans la précipitation du carbonate de calcium, le pH de l'eau distillée agitée, et le titre d'une solution de thiosulfate ont été signalées.

Les projets d'observations systématiques pour l'Année Internationale du Soleil Calme (IQSY) ont été établis et seront précisés au cours d'une réunion projetée à Paris, la première semaine d'Avril 1964.

Le Comité a décidé, que la création d'un groupe de travail pour la Physique et la Chimie, et d'un groupe de travail pour la Biologie de l'Espace Proche au sein du COSPAR, exige la prise de contact avec ces organismes.

On peut dégager des communications et discussions présentées à ce congrés les conclusions suivantes:

(1) Les observations physico-chimiques de longue durée s'étendant actuellement sur une période dépassant celle d'un cycle solaire undécennal, étudiées statistiquement par l'Institut Scientifique de calcul IBM à Florence ont confirmé indubitablement l'existence d'une relation hautement significative entre l'activité Solaire et certains processus physico-chimiques dans la biosphère.

(2) Il a été montré que des relations non causales existent entre la fréquence de congélation de l'eau et l'allure moyenne de la pression barométrique. Ces relations évoluent cependant d'une année à l'autre, et cette variation des corrélations observées en fonction des périodes du cycle solaire, apparaît un fait analogue a celui déjà établi sur les tests chimiques, à savoir la variabilité des effets des facteurs extérieurs sur la période du cycle solaire et la latitude.

(3) Des essais d'orientation ont montré l'existence de relations entre les fluctuations des divers tests chimiques et de tests biologiques.

(4) Tant dans le domaine Physico-chimique que biologique de nouvelles méthodes d'observations sont développées pour permettre une analyse plus poussée de la nature des facteurs physiques extérieurs qui sont à l'origine des fluctuations observées, soit périodiques (séculaires, annuelles, ou diurnes) soit sporadiques.

Il est de plus en plus évident que l'étude des fluctuations rythmiques et des perturbations par l'activité solaire révélées par des test chimiques inorganiques, pourra aider à l'étude des rythmes biologiques, et des mécanismes d'agression par les facteurs perturbateurs de l'ambiance.

INSTRUMENTATION, TERMINOLOGY AND CLASSIFICATIONS

Chairman: J. F. Griffiths

THE DESIGN OF A THERMO-HYGRO-SIMULATOR FOR BIOMETEOROLOGICAL APPLICATION

F. BUCKENS

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THE copper sphere (associated with Davos) which has its temperature regulated to 37° C, measures modes of thermal exchange with the environment which differ significantly from those operating for living organisms, as no account is taken of the effect of perspiration. In the tropics, the Davos instrument daily registers temperatures rising to the level of "fever-heat".

An improvement, which includes provision for evaporative cooling, leads to a more satisfactory simulation of physiological thermal exchange. The rate of water loss, as well as the energy input to maintain a minimum temperature of about 37° C, can be measured.

Two systems have been used : in one a hollow porous sphere is filled with water at 37° C under variable pressure, electrical heating being used to control temperatures between a minimum of 36.5° C and a maximum of 37.5° C. Difficulties in adjusting the porosity, and others arising from the thermal inertia of the system, lead to a second design based on the wet and dry-bulb psychrometer. An aluminium cylinder, heated to 36.5° C is covered with a thin sheet of felt whose moisture content is governed by the use of a contact maximum thermometer.

Experiments have been conducted in constant and variable conditions and comparison made with published data on physiological response. Results are promising and have pointed to possible ways of improving this, apparently new, instrument.

EINE NEUE METHODE ZUR ERFASSUNG DER BODENFEUCHTE UNTER ANWENDUNG RADIOAKTIVER ISOTOPE

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Abstract – The method developed by us uses a solid source of gamma-radiation (60 Co, 137 Cs) placed in the ground. The layers above the source screen the gamma-radiation emanating from it; the magnitude of this screening depends on the water content of the layer. A counter-tube connected to an impulse counting device serves as an indicator. During 1960–62 the method was tested for the three depths of 10 cm, 20 cm and 60 cm, and the results compared with those from the classical method which employs drilling (soil cores). Repeated calibrations with a radio-active source revealed a maximum error of about 1 per cent by weight. In comparing the results so far obtained by the new method, a number of advantages were found: non-interference with the factor to be measured, economy of labour, the possibility of automatic recording and accuracy of measurement. The establishment of a network of soil-moisture measuring stations utilizing the "gammascopic" method is strongly recommended. In doing so, ^{60}Co should be used in the deepest layers (50 cm) and ^{137}Cs at other depths. The source should possess a strength of 10–20 mC.

Zusammenfassung – Die von uns entwickelte Methode arbeitet mit fest in den Boden eingesetzten Gammaquellen (^{60}Co, ^{137}Cs). Die über dem Präparat befindliche Erdschicht schirmt abhängig vom Grad ihres Wassergehaltes die von der Strahlenquelle ausgehende Gammastrahlung verschieden stark ab. Als Indikator dient ein Zählrohr mit angeschlossenem Impulszählgerät. In den Jahren 1960–1962 wurde die Methode in den 3 Lagerungstiefen 10, 20 und 50 cm erprobt und die Ergebnisse mit denen der klassischen Bohrmethode verglichen. Die regelmässig durchgeführten Eichungen (mit einem radioaktiven Eichpräparat) ergaben einen praktischen maximalen Fehler von 1 Gew. %. In Auswertung der bisherigen Ergebnisse der entwickelten gammaskopischen Methode konnte eine Reihe von Hinweisen gegeben werden, so wurde auf den geringen Arbeitsaufwand, das Nichtzerstören des Messfeldes, die Möglichkeit einer automatischen Registrierung sowie die Messgenauigkeit hingewiesen. Dringend empfohlen wird die Errichtung eines Netzes von Bodenfeuchte-Mess-Stationen, wobei die Anwendung der gammaskopischen Methode ratsam erscheint. Dabei sollte vorwiegend in den niederen Schichten ^{137}Cs und in den tieferen Schichten (50 cm) ^{60}Co verwendet werden. Die Präparate sollten dabei eine Stärke von 10–20 mC haben.

Résumé – La méthode que nous avons développée utilise une source solide de rayonnement gamma (^{60}Co, ^{137}Cs) placée dans le sol. Les strates situées au-dessus de la source en atténuent le rayonnement. L'ampleur de cette diminution dépend de la teneur en eau des dites strates. Un compteur connecté à un détecteur sert d'indicateur. On a contrôlé cette méthode de 1960 à 1962 pour trois niveaux (10, 20 et 30 cm) et comparé les résultats

ainsi obtenus à ceux de la méthode classique consistant à déssécher des échantillons. Des étalonnages répétés effectués avec d'autres sources de rayonnement ont montré que les erreurs ne dépassent pas 1 pour cent. En tenant compte des résultats obtenus, on peut concéder divers avantages à la nouvelle méthode: par d'interférences avec le facteur mesuré, économie de travail, possibilité d'enregistrement automatique et précision des mesures. On recommande vivement la création d'un réseau de stations utilisant la méthode «gammascopique». Le ^{60}Co doit être utilisé pour le niveau le plus bas (50 cm), le ^{137}Cs aux autres niveaux. La source doit avoir une puissance d'émission de 10 à 20 mC.

DEFINITION UND BISHERIGE MESSMETHODEN

Nicht nur die Luft-, sondern auch die Bodenfeuchte spielt in der Landwirtschaft eine große Rolle. Die Entwicklung der Pflanze hängt maßgeblich von den Wasserverhältnissen im Boden ab. Ramsauer (1955) versteht unter dem Begriff Bodenfeuchte alles Bodenwasser in tropfbarer Form, das den Bodenkräften (Abhäsion, Kapillarität) noch ausgesetzt ist. Das Grundwasser wird bei ihm nicht zur Bodenfeuchte gerechnet, da es die spannungsfreien Boden- und Gesteinhohlräume zusammenhängend ausfüllt und nur dem Ruhedruck des Wassers folgt. Die von Raumsauer definierte Bodenfeuchte kann aber nicht völlig befriedigen und läßt sich auch nicht eindeutig feststellen, da man das lediglich unter dem Schwereeinfluß stehende Bodenwasser bei den Messungen nicht ausschalten kann. Deshalb verstehen wir unter Bodenfeuchte alles Wasser (einschließlich des „toten" Wassers), das im Augenblick einer Bodenprobeentnahme aus einer definierten Tiefe den Pflanzen zur Verfügung steht.

Tritt z. B. das Grundwasser in 70–80 cm Tiefe auf, so wird es bei einer bis 100 cm Tiefe reichenden Bodenprobe enthalten sein. Wir erfassen also bei einer Bodenfeuchtemessung sowohl das festgehaltene Haftwasser als auch das in Bewegung befindliche Sickerwasser.

Bekanntlich ist die Bodenfeuchte eine wichtige Größe der Wasserhaushaltsgleichung. Hesse (1956, 1958) hat ausführlich über die Erfassung der Komponenten der Wasserhaushaltsgleichung berichtet.

Die meist benutzte Methode zur Erfassung der Bodenfeuchte ist die klassische Bohrmethode, die durch Bodenprobenentnahme aus verschiedenen Tiefen und Bestimmung des Frisch- und Trockengewichtes der Proben den Wassergehalt des Bodens in Gewichtsprozenten Trockensubstanz auf direktem Wege zu bestimmen erlaubt. Man erfaßt also mit dieser Methode das zum Zeitpunkt der Messung enthaltene, sowohl kapillar festgehaltene, als auch absickernde Wasser. Für Vergleichszwecke ist es oft von Vorteil, die Gewichtsprozente in Volumenprozente umzurechnen. Wenn auch die Bohrmethode wegen der direkten Erfassung des Wassergehaltes als Vergleichs- und Eichmethode öfters benutzt wird, so darf man doch nicht übersehen, daß sie mit mehreren Fehlern (Verdunstung bei der Probenentnahme, Ungenauigkeit bei der Tiefenbestimmung, schwierige Probenentnahme bei sandigen Böden und besonders im Winter, Durchlöchern des Bodens, so daß

nie an der gleichen Stelle wieder eine Probe entnommen werden kann, etc.) behaftet ist.

Einige weitere Methoden zur Erfassung der Bodenfeuchte sind bekannt geworden. So empfehlen Reeker (1954), Fleischhauer-Binz (1949) und Stocker und Kausch (1952) das Tensiometer als Bodenfeuchtemesser. Das Wärmeleitvermögen in Abhängigkeit vom Bodenwassergehalt benutzten Albrecht (1932) und Herzog (1951–52), um eine Aussage über die Änderung der Bodenfeuchte zu machen.

In der Literatur nehmen die elektrischen Methoden zur Bestimmung der Bodenfeuchte einen breiten Raum ein. So bestimmt man die Bodenfeuchte entweder durch Erfassung der elektrischen Leitfähigkeit oder durch Messung der Dielektrizitätskonstante. Bouyoucos (1940) erfaßte die Bodenfeuchte mit Hilfe von Elektroden in einem Gipsblock. Baier (1952) und Person (1952) weisen aber auf erhebliche Mängel dieser Methode hin. Auch die Verwendung von Nylon, wie Bouyoucos (1954) vorschlägt, birgt Fehlerquellen in sich. Weitere Untersuchungen wurden u. a. von Danilin (1956), Höschele (1957), Buschmann (1956), Linder und Lötschert (1958), Vilkner (1957, 1959) Plater (1955) bekannt. Alle elektrischen Bodenfeuchtemessungen weisen aber oft erhebliche experimentelle Fehler auf, so daß eine netzmäßige Erfassung des Wassergehaltes des Bodens mit diesen Methoden nicht ratsam erscheint.

MESSMETHODEN UNTER ANWENDUNG RADIOAKTIVER ISOTOPE

In den letzten 10–15 Jahren hat man unter Verwendung radioaktiver Isotope Methoden zur Erfassung der Bodenfeuchte entwickelt. So mißt man entweder die Rückstreuung von schnellen Neutronen an den im Boden vorhandenen Wasserstoffatomen (Belcher, Cuyhendall und Sack (1950), Van Bavel, Underwood und Swanson (1956), Unger (1963)) oder die vom Wassergehalt abhängige Größe der Durchdringung von Gammastrahlen (Danilin, 1955; Korobotschkin, 1958). Unger (1963) hat auch die Gammastrahlen-Rückstreuung benutzt, um solche Messungen auszuführen. Mit Hilfe eines Szintillators oder eines Neutronenzählrohres erfaßt man die thermischen Neutronen, deren Anzahl vom Gesamtwasserstoffgehalt des Bodens abhängig ist. Allerdings ist dabei der Anteil der thermischen Neutronen, die durch den Wasserstoff der organischen Substanzen des Bodens entstehen, gering gegenüber dem des Wassergehaltes, so daß sich auch in stark humushaltiger Erde der meßbare Intensitätsanstieg langsamer Neutronen durch eine Befeuchtung des Bodens sehr deutlich bemerkbar macht. Stewart und Taylor (1957) weisen auf die Bodenfeuchtemessung mit der Neutronendiffusionsmethode hin. Auch Mortier, Boodt und Leenherr (1959) berichten über das Auflösungsvermögen dieser Methode für Feuchtebestimmungen im Boden und schlagen vor, das Auflösungsvermögen mit Hilfe eines Zusatzmoderators zu verbessern. Die Diskussion über diese Methode ist noch im vollen Gang. Für eine netzmäßige Erfassung der Bodenfeuchte scheint der hohe experimentelle Aufwand nicht gerechtfertigt zu sein.

Um die Bodenfeuchte netzmäßig zu erfassen, hat Noack eine Theorie der gammaskopischen Erdbodenfeuchtemessung entwickelt. Bringt man zwischen Strahlungsquelle (radioaktives Präparat) und den Detektor (Zählrohr, Szintillator) eine Absorberschicht (in unserem Falle eine Erdbodenschicht), so tritt eine deutliche Schwächung der Strahlungsintensität am Detektor auf. Die Schwächung der ursprünglichen Strahlung wird dabei durch verschiedenartigste Effekte hervorgerufen:

(a) Photoelektrische Absorption an Hüllenelektronen (oder an Kernen)
(b) Elastische und unelastische (Compton-) Streuung an Hüllenelektronen (oder an Kernen)
(c) Paarbildung.

ENTWICKELTE METHODE UND ERGEBNISSE

Das Prinzip der von uns entwickelten Methode der Bodenfeuchtebestimmung beruht auf der variablen Abschirmwirkung des Bodens für Gammastrahlung.

Man versenkt eine radioaktive Strahlungsquelle einige dm tief in den Boden. Die über dem Präparat liegende Bodenschicht schirmt je nach dem Grad ihrer Feuchtigkeit die Strahlung verschieden stark ab. Dabei bedingt eine hohe Bodenfeuchte eine hohe Abschirmwirkung, d. h. eine geringe Strahlendurchlässigkeit. Ein Geiger-Müller-Zählrohr, das sich senkrecht über dem Präparat an der Bodenoberfläche befindet, gestattet mit Hilfe eines Impulszählgerätes die Messung der Intensität der Strahlung in der beschriebenen Richtung.

Seit Anfang 1960 arbeitet unser Institut mit der Methode der Bodenfeuchtebestimmung mittels Radioisotopen. Auf dem Observatoriumsgelände wurden zu diesem Zweck ein ^{60}Co-Präparat (3 mC) 50 cm tief, ein ^{137}Cs-Präparat (20 mC) 20 cm tief und seit Herbst 1961 ein ^{137}Cs-Präparat (13 mC) 10 cm tief unter Rasen gebracht (Abb. 1). Die Präparate wurden vor dem Versenken in Metallbehälter eingeschlossen, die durch ihre besondere Form die Strahlung auf die Bodensenkrechte beschränken sollen.

Bei den Messungen ergaben sich Änderungen der Impulsrate auf Grund von Änderungen der Bodenfeuchtigkeit, die weit oberhalb des statistischen Schwankungsbereiches von Gamma-Messungen liegen. Allerdings sind zur Einhaltung der wahren Signifikanz der Abhängigkeit von Impulsrate und Bodenfeuchtigkeit drei Punkte zu berücksichtigen, die bei unseren Messungen Beachtung fanden:

(1) Um den Meßeffekt deutlich von statistischen Schwankungen abzugrenzen, muß bei jeder Einzelmessung eine möglichst große Anzahl von Impulsen erfaßt werden, was bei relativ schwachen Präparaten eine größere Zählzeit (z. B. 15 Min) bedingt.
(2) Um die Temperaturabhängigkeit der Indikation der Strahlung mittels Zählrohr auszuschalten, muß das Zählrohr thermostiert werden, da bei Freilandversuchen große Temperaturschwankungen auftreten.
(3) Zur Ausschaltung eines Meßfehlers infolge von Spannungsschwankungen an der Meßeinrichtung muß vor und nach jeder Messung mit einem Vergleichs-

präparat geeicht werden, um einen Bezugswert zu schaffen. Bei unseren Versuchen wurde ein ^{60}Co-Vergleichspräparat (20 μC) direkt an der Bodenoberfläche verwandt.

Vergleiche zwischen der Bodenfeuchte nach der Bohrmethode und der Methode der radioaktiven Durchstrahlung ergaben einen einwandfreien funktionellen Zusammenhang, vornehmlich für die beiden Cs-Präparate.

Ein Eichpräparat ^{60}Co (20 μC) diente zur Ausschaltung des Meßfehlers infolge von Spannungsschwankungen am Impulszählgerät. Nach jeder Messung wurde

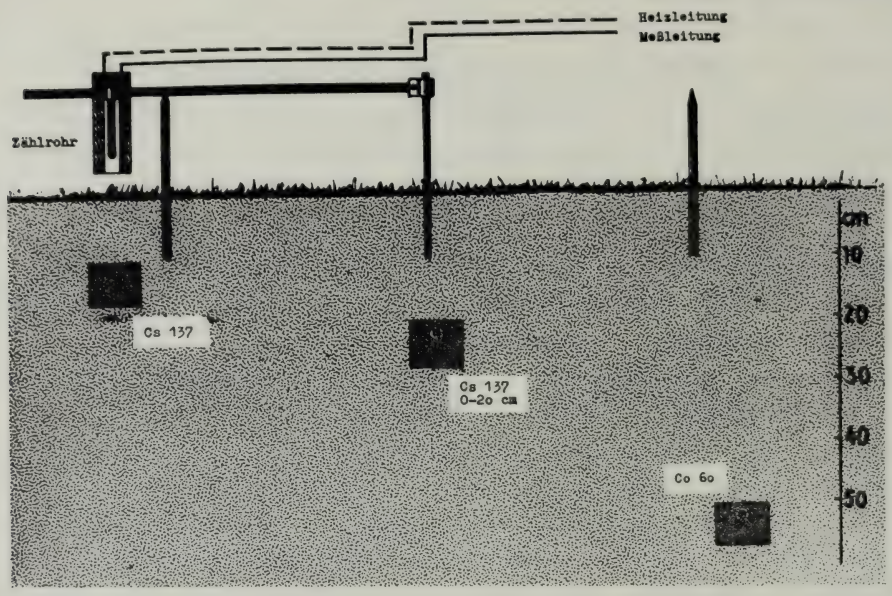

Abb. 1. Schematische Darstellung der Versuchsanlage

aus diesem Grunde eine Eichmessung vorgenommen. Das Zerfallsschema des ^{60}Co zeigt anschließend an einem β^--Übergang zwei kaskadenförmig aufeinanderfolgende Gammalinien, bevor der Grundzustand des Nachfolgekerns ^{60}Ni erreicht wird. Die auftretende β^--Strahlung ist energiearm und hat in Aluminium nur eine Reichweite von 0,35 mm. Das Präparat wirkt also nach außen praktisch als reiner Gammastrahler.

Sehr Ähnliches zeigt das Schema des ^{137}Cs-Zerfalls: energiearme β^--Strahlung und nachfolgende Gamma-Emission.

Der Vorteil von ^{137}Cs ist seine größere Halbwertszeit ($T_1/_2 = 27$a), weil darum eine Korrektur des Standardwertes weniger häufig nötig ist als bei ^{60}Co ($T_1/_2 = 5{,}1$a).

Die Schwächung der Intensität der Gammastrahlung hängt nicht linear mit der Dicke der durchstrahlten Schicht zusammen, sondern folgt einer Exponentialfunktion. Da Gammaquanten bei einem Stoß ihre Energie abgeben, ist die Gesamt-

intensität der durchgehenden Strahlung von der Wahrscheinlichkeit der Anzahl der Stöße in der Schicht abhängig, d. h. eine Funktion der Dicke und der Dichte der Absorberschicht. Abbildung 2 zeigt Prozente der Impulsrate bei ^{137}Cs und ^{60}Co bei einem mit 10, 20 und 30 mm Wasser durchfeuchteten Boden. Deutlich ist zu

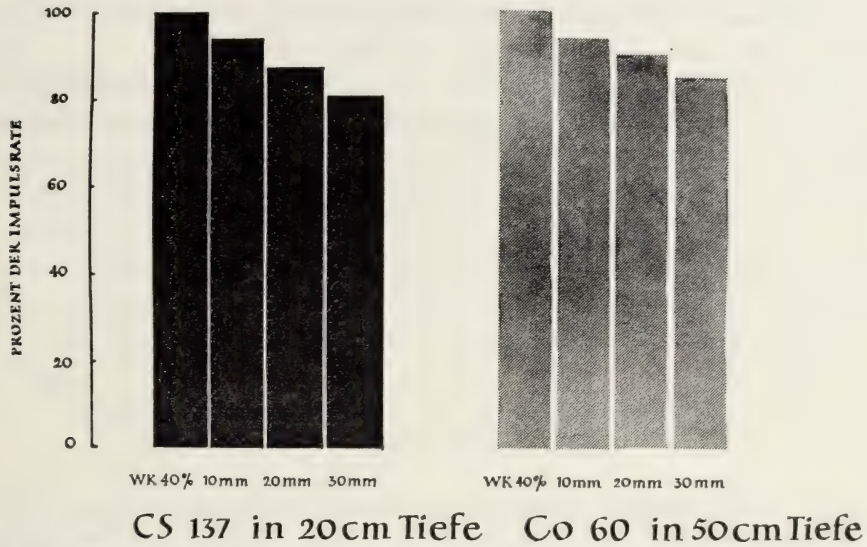

Abb. 2. Impulsrate über ^{137}Cs und ^{60}Co in Prozent vom Ausgangswert bei stufenweiser künstlicher Befeuchtung

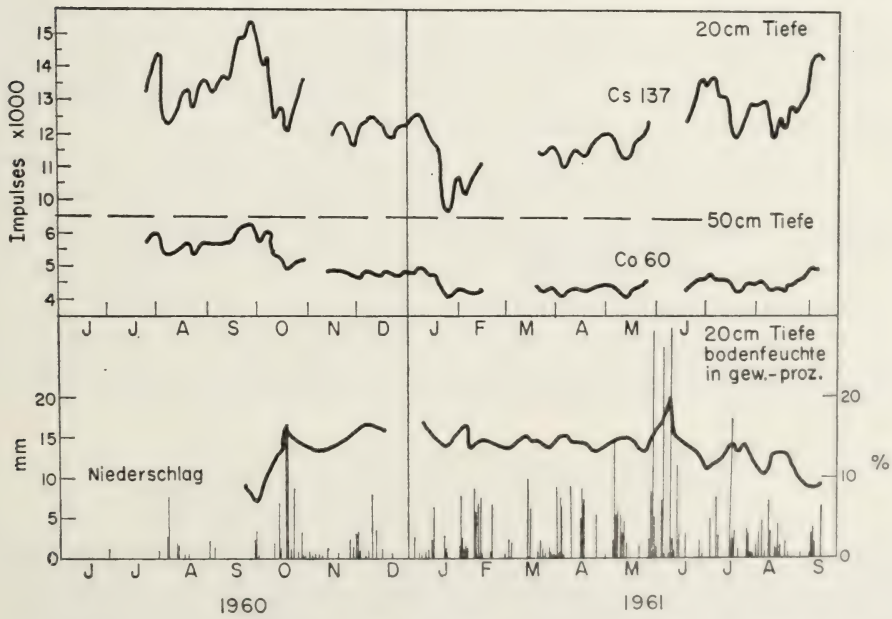

Abb. 3. Impulsrate über ^{137}Cs (20 cm Tiefe) und ^{60}Co (50 cm Tiefe) im Vergleich zu Niederschlag und Bodenfeuchte nach der Bohrmethode (20 cm Tiefe) vom Juli 1960 bis September 1961 unter Rasen

erkennen, daß mit zunehmender Durchfeuchtung des Bodens, also mit hoher Bodenfeuchte, die Impulsrate absinkt. Diese Gesetzmäßigkeit kann für die Anwendung radioaktiver Isotope zu Bodenfeuchtemessungen benutzt werden.

Da zwischen der Erfassung der Bodenfeuchte nach der Bohrmethode Vergleichsmöglichkeiten mit der Methode der radioaktiven Durchstrahlung und der damit gemessenen Zählrate bestehen, können auch Beziehungen zwischen der Feuchte in Gewichtsprozenten und der Impulsrate hergestellt werden.

Abbildung 3 zeigt die Meßergebnisse der Änderungen der Impulsrate für ^{137}Cs ni 20 cm Tiefe und ^{60}Co in 50 cm Tiefe sowie der Bodenfeuchte (Gewichtsprozente)

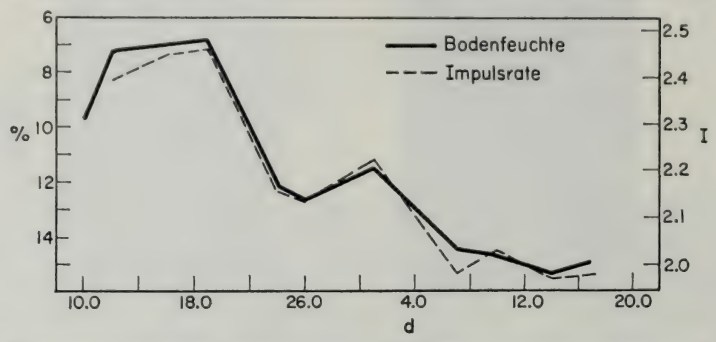

Abb. 4. Eichvergleich von Bodenfeuchte in Gewichtsprozenten nach der Bohrmethode und relativer Impulsrate über ^{137}Cs (13 mC) für die Bodenschicht 0 – 10 cm vom 10. Oktober bis 17. November 1961

in 20 cm Tiefe. Außerdem ist der Niederschlag eingetragen worden. Die Übereinstimmung von Maxima und Minima der einzelnen Kurvenzüge ist sehr überzeugend. Damit sind die beiden Meßmethoden eindeutig vergleichbar. Ein wichtige Frage ist dabei noch die Festlegung der Tiefe und die Intensität der einzubringenden radioaktiven Präparate, denn davon hängt die Empfindlichkeit ab.

Da gute Vergleichsmöglichkeiten der Erfassung der Bodenfeuchte zwischen der Bohrmethode und der von uns entwickelten Methode bestehen, wurden in den Jahren 1960 bis 1962 zahlreiche Vergleichsmessungen durchgeführt. In Abbildung 4 ist zu erkennen, daß für die Zeit vom 10. Okt. –17. Nov. 1961 eine sehr gute Übereinstimmung der Bodenfeuchtewerte beider Methoden besteht.

Da die Untersuchungen noch nicht abgeschlossen sind, werden später in einer ausführlichen Publikation die gesamten Meßergebnisse bekanntgegeben.

AUSWERTUNG DER BISHERIGEN ERGEBNISSE

(1) Die gammaskopische Methode gestattet die Bestimmung der Erdbodenfeuchte mit wesentlich geringerem Arbeitsaufwand als die Bohrmethode.

(2) Bei Anwendung dieser Methode wird das Meßfeld nicht gestört, so daß kontinuierliche Meßreihen über einen langen Zeitraum hin am gleichen Ort aufgenommen werden können.

(3) Die Möglichkeit einer automatischen Registrierung ist vorhanden, muß aber noch praktisch erprobt werden.

(4) Nach Errichtung der Anlage ist die Handhabung der Messungen leicht und die Wartung nicht aufwendig.

(5) Die Genauigkeit der Ergebnisse steht der der Bohrmethode nicht nach (absoluter Fehler um 1 Gew. %) und wird nur von der Neutronendiffusionsmethode übertroffen.

(6) Die Errichtung eines Netzes von Bodenfeuchtestationen wird dringend empfohlen. Die Verwendung der beschriebenen gammaskopischen Methode scheint ratsam. Dabei sollte vorwiegend mit dem Präparat ^{137}Cs gearbeitet werden, zumindest in den Schichten bis 50 cm Tiefe. ^{60}Co bietet für Messung dickerer Schichten den Vorteil der größeren Härte der Gammastrahlung.

(7) Die verwendeten Präparate sollten eine Stärke von 10 bis 20 mC haben. Strahlungsschädigungen kommen dabei laut Untersuchungen der Strahlenschutzkommission an unserer Meßanlage auch bei täglicher Messung für das Personal nicht in Frage.

LITERATUR

Albrecht, F. (1932) Ein Meßgerät für die Messung des Wärmeumsatzes im Erdboden. *Meteor. Z.* **49,** 294–299.

Baier, W. (1952) Elektrische Methoden zur Messung der Bodenfeuchte. *Ber. dtsch. Wetterd. i. d. US-Zone,* 32.

Van Bavel, C. H. M., Underwood, N. und Swanson, R. W. (1956) Messung der Bodenfeuchtigkeit durch Neutronenbremsung. *Soil Sci.* **82,** 29–41.

Belcher, D. J., Cuyhendall, T. R. und Sack, H. S. (1950) Die Messung der Bodenfeuchte und Dichte durch Aussendung von Neutronen und Gammastrahlen. U. S. Civil Aeronautics Adminstr. Techn. Development Report No. 127.

Bouyoucos, G. J. (1940) Eine elektrische Widerstandsmethode zur laufenden Messung der Bodenfeuchte unter Feldbedingungen. *Techn. Bull.* 172.

Bouyoucos, G. J. (1954) Neue Nylonkörper für die Messung der Bodenfeuchte im Freiland. *Highway Res. Abstr.* **24.**

Buschmann, H. (1956) Die Bestimmung der Bodenfeuchte mit einer V2A-Stahl-Plexiglaselektrode. *Z. Pflanzenernähr., Düngung u. Bodenkd.* **72,** 239–248.

Danilin, A. J. (1955) Messung der Bodenfeuchtigkeit mit Hilfe von Gamma-Strahlen. *Bodenkunde,* Nr 7.

Danilin, A. J. (1956) Bestimmung der Bodenfeuchtigkeit zwischen zwei in Glaswolle eingebetteten und in den Boden eingelassenen Kohleelektroden. *Meteorologii i Gidrologii, Leningrad* **7.**

Fleischhauer-Binz, E. (1949) Die Messung von Bodensaugkräften mit Tensiometern. *Planta* **37,** 565–594.

Herzog, F. (1951) Bodenfeuchtemessung durch Wärmeleitfähigkeitsbestimmung. *Jahresber., Abh. Badischen Landeswetterdienst.*

Hesse, W. (1956) Der Wasserhaushalt von Kulturpflanzen. *Geofis. pura appl.* **34,** 253–259.

Hesse, W. (1958) Einfluß des Wärme- und Wasserhaushaltes auf das Pflanzenwachstum. *Ber. d. Dt. Wetterd.* Nr. 51.

Höschele, K. (1951) Untersuchungen zur Methode der elektrischen Bodenfeuchtemessung. *Veröff. Inst. Physik u. Meteorol. d. Landw. Hochschule, Stuttgart-Hohenheim.*

Korobotschkin, J. W. (1958) Eine Möglichkeit zur Erforschung der Bodenfeuchtigkeit und -dichte mittels Gammastrahlen verschiedener Energie. *Ber. Allunions-landw. Lenin-Akad.* **23,** Nr 9.

Linder, R. und Lötschert, W. (1958) Eine neue Elektrode zur Bestimmung der physiologisch wirksamen Bodenfeuchtigkeit. *Z. Pflanzenernähr., Düngung u. Bodenkd.* **82,** 33–37.

Mortier, P., Boodt, M. de und Leenherr, L. de (1959): Über das Auflösungsvermögen der Neutronendiffusionsmethode für Feuchtigkeitsbestimmung im Boden. *Z. Pflanzenernähr., Düngung u. Bodenkd.* **87,** 244–250.

Person, H. (1952) Über elektrische Messungen der Bodenfeuchte. *Ber. dtsch. Wetterd. i. d. US-Zone* **32,** 1952.

Plater, de C. V. (1955) Ein tragbares Bodenfeuchtigkeitsmeßgerät vom Kapazitätstyp. *Soil Sci.* **80,** 391–395.

Ramsauer, B. (1955) Agrarmeteorologie und Kulturtechnik. *Wetter u. Leben* **7,** 236–240.

Reeker, R., (1954) Das Bodentensiometer, ein Feuchtigkeitsmesser. *Gartenwelt.* **3,** 46.

Stewart, G. L. und Taylor, S. A. (1957) Erfahrungen mit der Bodenfeuchtemessung mittels Neutronendiffusionsmethode. *Soil Sci.* **83,** 151–158.

Stocker, O. und Kausch, W. (1952) Bodenfeuchte und Tensiometermessung. *Ber. d. dtsch. Wetterd. i. d. US-Zone* **32.**

Unger, K. (1963) Experimentelle Untersuchungen mit Hilfe von ionisierenden Strahlen und Neutronen zur Bestimmung der witterungsbedingten Wachstumsintensität von Kulturpflanzen am natürlichen Standort. *Veröff. d. Inst. f. Agrarmeteorologie d. Karl-Marx-Univ. Leipzig,* Bd II,

Vilkner, H. (1957) Über die Erdbodenfeuchtigkeit und ihre Messung mittels elektrischer Kapazität. *Z. Meteor.* **11,** 49–58.

Vilkner, H. (1959) Erdbodenfeuchtigkeitsmessung mittels elektrischer Leitfähigkeit. *Z. Meteor.* **13,** 163–177.

REMARQUES SUR L'EMPLOI DES MEMBRANES À MICROPORES POUR LE CAPTAGE D'ÉCHANTILLONS D'AÉROSOLS À DISPERSIONS TRÈS FINE

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Abstract – The efficiency of a relatively thin micro-pore filter of mean pore diameter $2\bar{R} = 1.8\mu$, for the sampling of a dispersion of very small aerosol particles (mean dimensions $2\bar{r} = 0.05\mu$ to 0.20μ) has been measured. The results show that when $\bar{r} \ll \bar{R}$ filtration with a micro-pore filter takes place somewhat as with a fibre filter. Accordingly for sampling dispersed aerosols of small or very small particles, a rather thicker micro-pore filter and a reduced speed of flow are preferred.

Zusammenfassung – Es wurde die Brauchbarkeit eines verhältnismäßig dünnen feinporigen Filters mit einem mittleren Porendurchmesser $2\ \bar{R} = 1{,}8\ \mu$ für die Untersuchung der Verteilung sehr kleiner Aerosolpartikel (mittlere Größe $2\ \bar{r} = 0{,}05\ \mu$ bis $0{,}20\ \mu$) gemessen. Die Ergebnisse zeigen, daß, wenn $\bar{r} \ll R$, die Filtrierung mit einem kleinporigen Filter ungefähr so verläuft wie mit einem Faserfilter. Für die Untersuchung der Verteilung von Aerosolen kleiner oder sehr kleiner Teilchen wird ein etwas dickerer kleinporiger Filter bei verringerter Strömungsgeschwindigkeit bevorzugt.

Résumé – Nous avons mesuré l'efficacité d'un filtre à micropores, relativement mince, aux pores de dimension moyenne $2\bar{R} = 1{,}8\ \mu$, pour des aérosoles de dispersion très fine soit d'une dimension moyenne des particules $2\bar{r} = 0{,}05 - 0{,}20\ \mu$. Les résultats démontrent que, pour un filtre à micropores, la filtration s'accomplit à condition que $\bar{r} \ll \bar{R}$, c'est à dire de manière un peu analogue à celle des filtres à fibres. C'est pourquoi nous préférons employer, pour le captage d'échantillons d'aérosols à dispersion fine et très fine, des filtres à micropores plus épais et des vitesses de circulation du gaz plus réduites.

INTRODUCTION

De nos jours, l'emploi de membranes à micropores (Millipore filtre) se répand de plus en plus pour le captage d'échantillons d'aérosols atmosphériques. Cependant, on suppose dans la plupart des cas que l'efficacité de ces membranes est «absolue», et que les particules ne sont interceptées qu'à la surface du filtre. Jusqu'à présent, nous ne possédons que très peu de reférences bibliographiques sur les limites des dimensions de particules et sur les conditions dans lesquelles ce principe est valable. Fitzgerald et Detwiler (1957), plus tard Walkenhorst (1959) et de nos jours Megaw et Wiffen (1963) se sont occupé de ce problème. Tandis que les premiers de

ces auteurs avaient constaté que les membranes à micropores de fabrication américaine avaient une efficacité minimum ($r = 0{,}01\ \mu$), le second auteur n'a pas même réussi à reproduire les résultats obtenus par les deux premiers. Megaw et Wiffen n'ont pas trouvé d'efficacité minimum ($r = 0{,}01\ \mu$). Il y a plusieurs années déjà, nous nous sommes mis nous-mêmes à étudier le mécanisme de filtration des filtres de cette espèce; les résultats de nos études démontrent que la filtration d'aérosols au moyen de membranes à micropores ressemble un peu à la filtration au moyen de filtres à fibres, à condition que les dimensions des particules d'aérosols soient sensiblement inférieures à celles des pores de ces filtres.

RÉSULTATS EXPÉRIMENTAUX

Nous avons mesuré les rapports $E = E\ (q)$ et $E = E\ (r)$ pour les filtres modèles, c'est à dire les rapports déterminant l'efficacité du filtre E en fonction de la vitesse de circulation du gaz q et des dimensions des particules d'aérosols r. Ces résultats ne sont évidemment valables qu'à condition que $R \gg r$ (R étant le rayon des pores, r le rayon des particules d'aérosols). Nous nous sommes servi de filtres relativement minces ($\sim 100\ \mu$), pour que leur efficacité respective présente une dispersion de valeurs facilement mesurable. C'est pourquoi il n'est pas possible d'interpréter

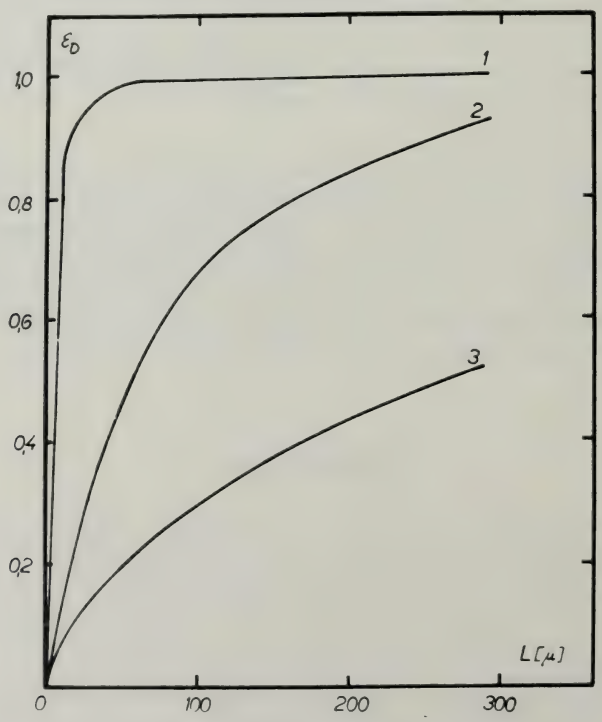

Fig. 1. Courbes du rapport $E = E$ (L)
(1 pour $q = 1$ cm/sec, 2 pour $q = 10$ cm/sec 3 pour $q = 50$ cm/sec)

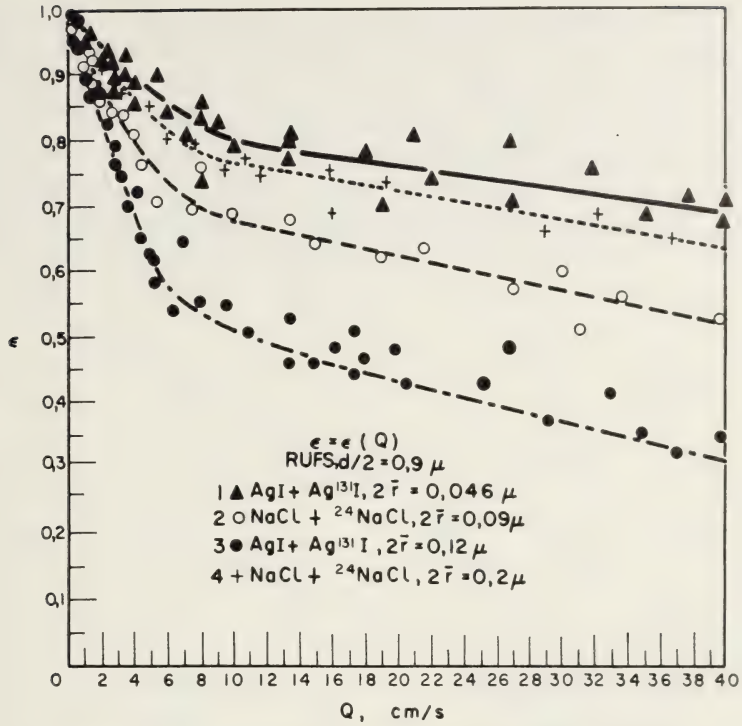

FIG. 2. Courbes du rapport $E = E(q)$ à $10^{-4} \leqslant Stk \leqslant 1$; $10^{-4} \leqslant Re \leqslant 10^{-2}$

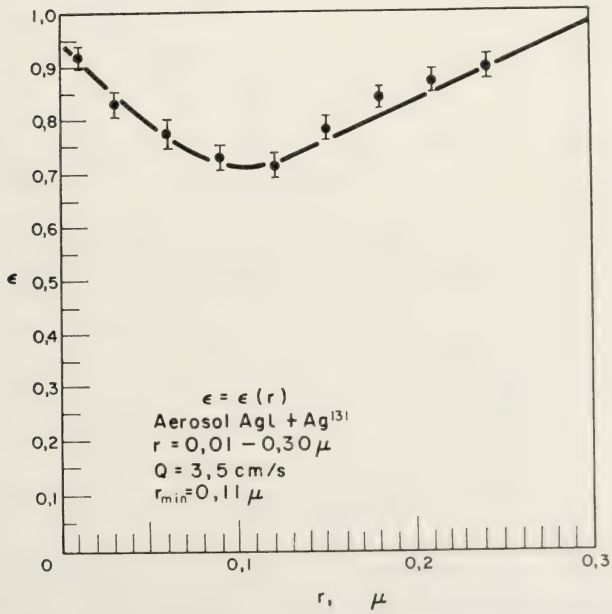

FIG. 3. Courbes de rapport $E = E(r)$ à $Re = 2.10^{-3}$; $10^{-4} \leqslant Stk \leqslant 10^{-6}$

les résultats obtenus comme si l'efficacité des filtres, pour le cas de $r \ll R$, pourrait être même inférieure à 50 pour cent. Il est toujours possible d'augmenter l'efficacité en augmentant l'épaisseur du filtre (Fig. 1). Ces résultats, obtenus sur des filtres-types ne font que démontrer un peu la similitude des mécanismes de filtration chez les deux sortes de filtres: à micropores et à fibres. La figure 2 représente les courbes des rapports $E = E(q)$ pour le filtre à micropores aux pores de dimension moyenne $2R = 1{,}8\ \mu$ et pour les aérosols à grosseur moyenne des particules $2r = 0{,}05 - 0{,}20\mu$.

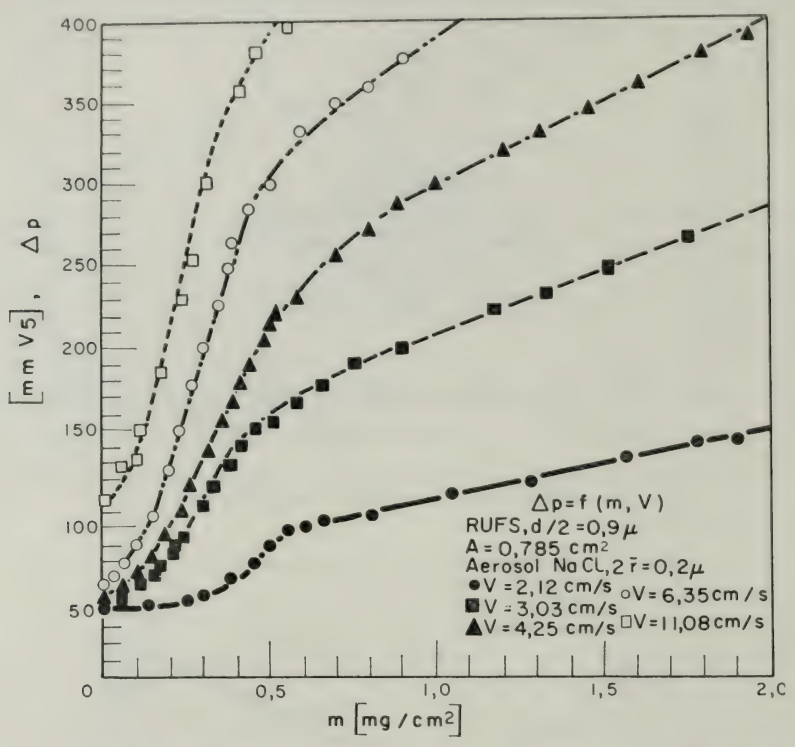

FIG. 4. Courbes d'«encrassement» du filtre à micropores, la fonction $\Delta p = f(m, q)$

La figure 3 donne le rapport $E = E(r)$ pour un filtre à micropores de la même espèce. Enfin, à la Fig. 4, nous pouvons observer l'allure du soit-disant «encrassement» des filtres à micropores, c'est à dire de la croissance de la chute de pression Δp en fonction de la quantité d'aérosol amassé sur la surface-unité de 1 cm² (m) et de la vitesse de circulation du gaz (q).

DISCUSSION

Les exemples cités démontrent que, comme pour les filtres à fibres, l'efficacité est fonction de la vitesse de circulation du gaz aussi bien que de la grosseur des particules d'aérosol capté. En nous servant d'un filtre à micropores pour capter des

aérosols dont la grosseur moyenne de particules est inférieure ou de beaucoup inférieure à la dimension moyenne des pores, ce filtre agit par toute sa structure interne qui se rapproche un peu de la structure des filtres à microfibres. L'échantillon n'est pas capté seulement par la surface du filtre, mais s'accumule aussi à l'intérieur, de sorte que nous avons la possibilité de régler son efficacité en modifiant l'épaisseur du filtre et la vitesse de passage du gaz.

Or, lorsque nous nous servons de filtres à micropores pour le captage d'échantillons d'aérosols à dispersion fine et très fine, et si nous ne pouvons pas nous servir

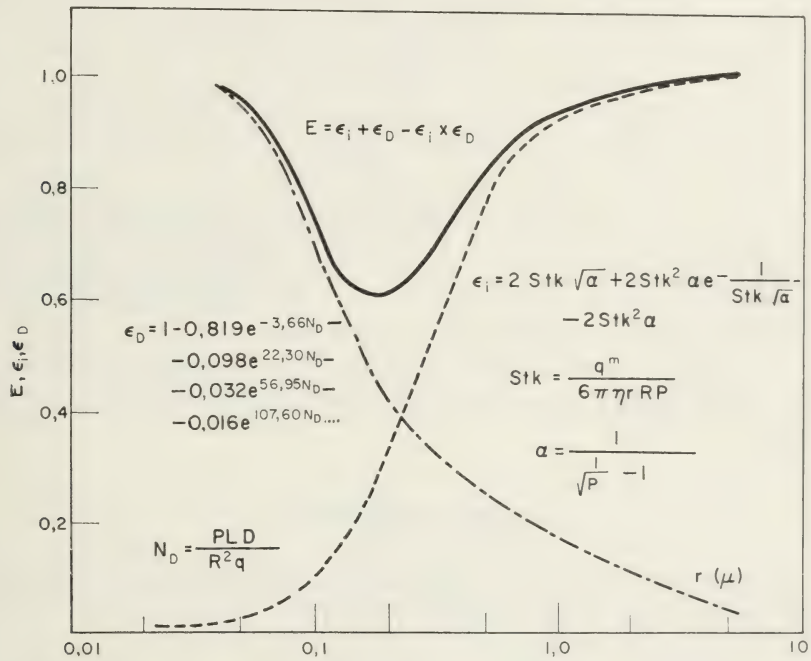

FIG. 5. L'efficacité totale (E) et les efficacités partielles (ε_i, ε_D) d'un filtre à micropores. (P signifie la porosité du filtre, L est son épaisseur, D le coefficient de diffusion des particules, m est la matière d'une particule, η le coefficient de viscosité dynamique du gaz, R le rayon des pores)

de filtres dont les pores ont des dimensions comparables à la grosseur des particules d'aérosols, nous employons des filtres à épaisseur plus importante et aspirons le gaz à une vitesse relativement réduite, par exemple jusqu'à 2 cm/sec. Dans ces circonstances, l'augmentation de la chute de pression au cours de l'encrassement du filtre à micropores est sensiblement moins accentuée pour les petites vitesses de circulation du gaz (Fig. 4).

L'efficacité totale E est donnée par deux efficacités partielles ε_i et ε_D où ε_i est l'efficacité de surface et ε_D celle de la diffusion. L'efficacité totale est exprimée

ensuite par

$$E = \varepsilon_i + \varepsilon_D - \varepsilon_i \times \varepsilon_D \tag{1}$$

$$\varepsilon_i = 2.\ Stk.\ \sqrt{\alpha} + 2(Stk)^2\alpha \exp(-1/Stk,\ \sqrt{\alpha}) - 2(Stk)^2\alpha \tag{2}$$

$$\varepsilon_0 = 1 - 0\cdot 819 \exp(-3.66\ N_D) - 0\cdot 098 \exp(-22.30\ N_D)$$
$$- 0.032 \exp(-56.95\ N_D) - 0.016 \exp(-107.60 N_D) \tag{3}$$

$$Stk = \frac{qm}{6\ \pi\eta\ rRP}$$

$$\alpha = \frac{1}{\frac{1}{\sqrt{P}} - 1}$$

$$N_D = \frac{PLD}{R^2 q}$$

L'efficacité totale et les efficacités partielles, comme fonctions de r, sont reproduites à la fig. 5. L'efficacité ε_i est expliquée par des équations de Townsend (1899), Gormley (1938), Gormley et Kennedy (1949) et Twomey (1962). L'efficacité ε_D et expliquée par l'équation développée par nous-même.

Nous avons détaillé les résultats expérimentaux et théoriques dans les travaux Spurný, Pich (1963, 1964), où nous avons essayé de trouver quelques explications du phénomène.

BIBLIOGRAPHIE

FITZGERALD, J. J. and DETWILLER, G. G. (1957) Optimum Particle size for penetration through the millipore Filter. *A. M. A. Arch. Industr. Health* **13,** 3–8.

GORMLEY, P. G. (1938) see Twomey (1962)

GORMLEY, P. G. and KENNEDY, M. (1949) see TWOMEY (1962)

MEGAW, W. J. and WIFFEN, R. D. (1963) The Efficiency of membrane filters. *Int. J. Air Wat. Poll.* **7,** 501–509.

SPURNY, K. and PICH, J. (1963) Analytical methods for determination of aerosols with help of membrane filters. VI. On the mechanism of membrane ultrafilter action. *Collection Czechoslov. Chem. Commun.* **38,** 2886–2894.

SPURNY, K. and PICH, J. (1964) The separation of aerosols particles by means of membrane filters by diffusion and inertial impaction. *Int. J. Air. Wat. Poll.* **8,** 306–310.

TOWNSEND, J. S. (1899) see Twomey (1962)

TWOMEY, S. (1962) Equations for the decay by diffusion of particles in an aerosol flowing through circular and rectangular channels. *Bulletin de l'Observatoire du Puy de Dôme* **62,** 173–180.

WALKENHORST, W. (1959) Aerosolfiltration mit Membranfiltern im Teilchengrössenbereich unterhalb 0,1 Mikron. *Staub* **19,** 69–72.

ÜBER DIE VERWENDUNG VON FOLIENWÄRMESTROMMESSERN IN DER BIOMETEOROLOGIE

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Abstract – The physical basis underlying the principle of the heat flux meter (the Lustig and Cammerer plastic-film type), its construction, its calibration, its advantages over other thermal methods, and the conditions under which it can be used, are discussed. The method is suitable for the measurement of heat exchange in stationary and moving gaseous, liquid or solid media. The average error of the method is at most ± 5 per cent depending on the magnitude of the resistance to heat flow. The method is suitable to apply in biometeorology wherever quantitative information on the density of heat flux is required for the investigation of problems involving energy.

The following applications are discussed.

(1) Measurement of heat loss from the body surface of man and indications of the peripheral blood flow.
(2) Instantaneous measurement of cooling power as determined by the Davos frigorimeter.
(3) Measurement of the latent heat of vaporisation to evaluate the potential evaporation from wet surfaces, (with practical tests using the Piche evaporimeter).

Zusammenfassung – Es werden die physikalischen Grundlagen des Wärmestrommesserprinzips (Folien-Wärmestrommesser nach Lustig-Cammerer), Herstellung, Eichung, Vorteile des Messverfahren gegenüber anderen thermischen Meßmethoden sowie die Voraussetzungen der Anwendbarkeit erörtert. Das Verfahren eignet sich zur Bestimmung des Wärmeaustausches in ruhenden wie strömenden gasförmigen, flüssigen oder festen Medien. Der mittlere Fehler der Meßmethode beträgt je nach der Größe des Wärmeaustauschwiderstandes maximal $\pm 5\%$. Der Einsatz der Meßmethode ist in der Bioklimatologie überall dort angebracht, wo quantitative Angaben der Wärmestromdichte für das Verständnis energetischer Probleme erforderlich sind. Folgende Anwendungsmöglichkeiten werden erörtert:

(1) Wärmeabgabemessungen der Körperoberfläche des Menschen sowie zur Kennzeichnung der pheripheren Durchblutung.
(2) Bestimmung von Momentanwerten der Abkühlungsgröße des Davoser Frigorimeters.
(3) Bestimmung der latenten Verdampfungswärme zur Kennzeichnung der potentiellen Verdunstung feuchter Oberflächen mit praktischer Erprobung bei dem Piche-Evaporimeter.

Résumé – On discute ici les bases physiques qui constituent le principe de l'appreil de mesure des flux de chaleur (films de plastique du type Lustig et Cammerer). On en donne la construction, l'étalonnage, les avantages par rapport à d'autres méthodes thermiques et les conditions dans lesquelles ils peuvent être utilisés. Cette méthode permet de mesurer les échanges de chaleur en milieux gazeux, liquides et solides. l'erreur moyenne en est de ± 5

pour cent au maximum selon la résistance du milieu aux échanges thermiques. Cette méthode peut être appliquée en biométéorologie partout où des informations quantitatives de la densité des flux de chaleur sont nécessaires aux recherches énergétiques. On discute en outre les applications suivantes:

(1) mesure des pertes de chaleur à la surface du corps humain et indication du courant sanguin périphérique,
(2) mesure intantannée du pouvoir réfrigérant déterminé par le frigorimètre de Davos,
(3) mesure de la chaleur d'évaporation latente afin d'évaluer l'évaporation potentielle des surfaces humides (avec essais pratiques basés sur l'évaporomètre de Piche).

ALLGEMEINE ÜBERLEGUNGEN UND PROBLEMSTELLUNG

Die Kennzeichnung der an den Aufnahmeorganen des Menschen angreifenden dynamischen Größen der atmosphärischen Umwelt im *absoluten, energetischen Maß* hat Carl Dorno 1942 als Hauptaufgabe der biometeorologischen Forschung hingestellt. Nur so könne der Physiologie die Frage untersuchen, wie die angreifenden Kräfte im gegebenen Falle vom Organismus qualitativ und quantitativ beantwortet werden. Bezüglich der thermischen Faktoren des Klimas sind enge Korrelationen mit zahlreichen physiologischen Funktionen seit jeher bekannt. Es sei in diesem Zusammenhang nur an das Erkältungsproblem, die Fragen des Temperaturempfindens, verschiedene reaktionsdiagnostische Methoden zur Feststellung der Kälte- und Wärmeempfindlichkeit des Menschen sowie an die termischen Behandlungsmethoden der physikalischen Therapie und Balneologie erinnert. Quantitative Angaben des Wärmeaustausches der Körperoberfläche sind für das Verständnis der Thermoregulation des menschlichen Wärmehaushaltes unerläßlich.

Haut- und Kerntemperaturmessungen allein geben bekanntlich kein klares und widerspruchloses Bild der energetisch-dynamischen Probleme der Körpertemperaturregelung. Von medizinischer Seite ist hierauf wiederholt verwiesen worden (Aschoff, 1958). Ähnliche Überlegungen gelten auch für Untersuchungen über die Bedingungen der Pflanzenentwicklung in Abhängigkeit von der Lufttemperatur (vergl. Budyko, 1958).

Die in der Literatur für medizinische Zwecke beschriebenen thermischen Meßverfahren gehen im wesentlichen auf die Arbeiten von Hensel (1951) und Aschoff (1944) zurück.

In der Praxis haben folgende Methoden Bedeutung erlangt.

(1) *Kalorimetrische Meßverfahren* (Aschoff, 1944; Hensel, 1951).

(2) *Hautwärmeleitmessungen* nach dem Prinzip des geheizten Thermoelementes (Hensel und Bender, 1956) bzw. geheizter NTC-Widerstände (Eitner, 1958).

(3) Das *Temperaturgradientenmeßverfahren* nach der sog. „Hilfswandmethode" (Hencky, 1919, Schmidt, 1923).

Das zuletzt genannte Verfahren wurde von Lustig und Cammerer (1955) wesentlich verbessert und empfindlicher gestaltet und in Form der sog. *Folienwärmestrommesser* auch für physiologische Zwecke empfohlen.

DIE PHYSIKALISCHEN GRUNDLAGEN DES WÄRMESTROM-MESSVERFAHRENS

Das Wärmestrommeßprinzip wird bekanntlich in der Technik zur Bestimmung des Wärmedurchganges von Baumaterialien, Kühlwänden, beheizten Behältern u. ä. angewandt (s. Cammerer, 1952). Auf die wärmeabgebende Fläche bringt man eine „Hilfswand", bestehend aus einer dünnen Glas-, Gummi- oder Korkscheibe der Stärke d und der Wärmeleitzahl λ und bestimmt thermo- oder widerstandselektrisch die sich zwischen Ober- und Unterseite der Schicht einstellende Temperaturdifferenz $(\vartheta_1 - \vartheta_2)$. Die durch die Schicht hindurchgehende Wärmestromdichte q genügt dann der Beziehung

$$q = \frac{\lambda}{d}(\vartheta_1 - \vartheta_2) \quad (\mathrm{cal/cm^2sec})$$

Als Hilfswand dienen dünne PVC-Folien der Stärke 0,1 bis 0,5 mm oder Schichten aus mit Kunstharz (Araldit – *Ciba* – Basel) verstärktem Glasgewebe. Die Thermosäule wird aus Konstantanband (0,7 bzw. $1{,}4 \times 0{,}04$ mm² Querschnitt) um die Schicht gewickelt und jeweils zur Hälfte galvanisch verkupfert. Die Eichung erfolgt mit dem in der Wärme- und Kältschutztechnik eingeführten Plattenapparat von Poensgen (s. Cammerer, 1962), gegebenenfalls unter Verwendung von Zusatz- und Randheizungen. Unter der Voraussetzung, daß der von der Heizplatte ausgehende Wärmestrom die Kühlplatte an allen Stellen verlustlos durchströmt, ist die Wärmestromdichte q der elektromotorischen Kraft der Thermosäule U des auf der Heizplatte befestigten Wärmestrommessers proportional. Es gilt somit

$$q = k \cdot U$$

q (cal/cm²sec), U (v). Aus dieser Beziehung ergibt sich dann die Eichkonstante k (cal/cm²sec.v).

Das *Wärmestrommesserprinzip* ist aus noch näher zu erörternden Gründen für biometeorologische Zwecke vielseitig verwendbar. Es erfüllt folgende Forderungen:

(a) kontinuierliche Registriermöglichkeit der Meßgröße
(b) hohe Empfindlichkeit
(c) schnelle Einstellgeschwindigkeit
(d) Unabhängigkeit von äußeren Störungen
(e) einfache Handhabung und Auswertung
(f) geringe Störung der physiologischen Bedingungen
(g) Anwendbarkeit an beliebigen Körperstellen und unter verschiedenen physikalischen Bedingungen.

Der praktische Wert des Wärmestrommeßverfahrens besteht darin, daß man in einfacher Weise quantitative Angaben im absoluten, energetischen Maß über die Größe des Wärmeentzuges trockener (Leitung, Konvektion, Strahlung), wie auch feuchter Wärmeträger (Leitung, Konvektion, Strahlung, Verdunstung) erhält.

Damit übertreffen Messungen dieser Art die verschiedenen Meßmethoden zur Bestimmung des vertikalen Temperatur- und Feuchtegradienten zur Berechnung der Wärmeaustauschvorgänge wesentlich. Wärmeabgabemessungen dieser Art sind nicht nur in ruhenden sondern auch in strömenden Medien ohne die besondere Kenntnis der sonst jeweils gesondert zu ermittelnden Koeffizienten des Energie- und Stoffaustausches möglich. Der geringen Stärke der Folie zufolge erfolgt die Bestimmung des Temperaturgradienten stets im sog. „Grenzschichtbereich", in dem bekanntlich der Wärmetransport allein durch molekulare Wärmeleitung erfolgt. Die vom Wärmestrommesser angezeigte Wärmestromdichte ist also auch bei Windeinfluß der Temperaturdifferenz in der Schicht verhältnisgleich.

Die instrumentellen Anforderungen (Punkt- oder Linienschreiber mit elektronischer Verstärkung) sind nicht größer als bei den sonst üblichen thermoelektrischen Meßverfahren. Die praktische Handhabung wird im Gegenteil noch dadurch vereinfacht, daß die Kontrolle der Basistemperatur wegfällt. Bei Verwendung von Registrier- und Integrationsgeräten lassen sich die Meßwerte für beliebige Zeitintervalle einfach auswerten.

Das Folienwärmstrommeßverfahren ist unter folgenden Voraussetzungen anwendbar.

(1) Durch das Aufbringen der Hilfswand mit dem Wärmedurchgangswiderstand $R_F = d/\lambda$ darf der Gesamtwärmeübergangswiderstand R_G nicht wesentlich erhöht werden. R_G setzt sich bei Messungen an der Körperoberfläche aus den beiden Teilwiderständen R_K (Wärmestrom Körperkern – Oberfläche) und R_L (Wärmestrom Körperoberfläche – Umgebung) zusammen.

$$R_G = R_K + R_L$$

Der Wärmestrommesser ist deshalb fest mit der wärmeabgebenden Fläche zu verbinden, um zusätzliche Wärmeübergangswiderstände (Luftpolster) zu vermeiden. Bewährt hat sich für diesen Zweck doppelseitig klebender Kautschukfilm (Tesaprint) von 50 μ Stärke.

(2) Die Oberflächeneigenschaften des Wärmestrommessers hinsichtlich Strahlungsumsatz und Rauhigkeit sollen sich von denen der umgebenden, unbedeckten Fläche nicht wesentlich unterscheiden.

(3) Die Wärmekapazität des Wärmestrommessers soll möglichst gering sein.

Der mittlere Fehler der Messung (Warmbt, 1961) beträgt selbst unter ungünstigen Bedingungen maximal $\pm 5\%$.

WÄRMEABGABEMESSUNGEN DER KÖRPEROBERFLÄCHE

Das Wärmestrommeßverfahren erlaubt die Bestimmung der Wärmestromdichte an beliebigen Körperstellen und unter verschiedenen Umgebungsbedingungen (Fig. 1). Derartige Angaben sind für Fragen des Temperaturempfindens bedeutungsvoll. Nicht die Hauttemperatur, sondern die dem Körper entzogene oder zuge-

führte thermische Energie ist als die primäre Ursache des thermischen Empfindens anzusehen. Wärmestrommessungen lassen sich mit feuchtigkeitsbeständigen Wärmestrommessern aus Kunstharz(Araldit) in einfacher Weise in wässerigen oder breiigen Bademedien durchführen.

Bei der großen Empfindlichkeit des Wärmestrommeßverfahrens haben wir nach Ausschaltung der an der Oberfläche der Wärmestrommesser stets wirksamen Mikroturbulenz der Luft durchblutungsbedingte Änderungen des zur Peripherie gerichteten Wärmestromes gemessen. Zur Ausschaltung störender äußerer thermischer Einflüsse haben wir anfangs auf der Oberfläche der Wärmestrommesser Dämm-

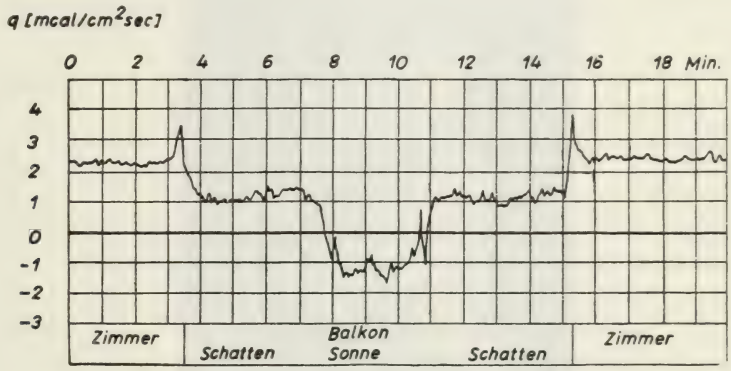

Fig. 1. Wärmestrommessung an der Stirn im Zimmer und im Freien Lufttemperatur: Zimmer 26,0°, Balkon 29,3° C.

schichten aus Kunststoffschaum (Moltopren) angebracht. Dieses Material hat den Nachteil, daß der Wärmedurchgangswiderstand Haut — Luft erhöht und daß damit auch die physiologischen Bedingungen der Wärmeabgabe an der Meßstelle stark verändert werden. Wesentlich geeigneter hierfür erwiesen sich kleine, luftdichtverschlossene Hohlkörper in Kapselform aus Kunststoff (Glasgewebe mit Araldit). Mit diesem Verfahren lassen sich Wärmestrommesser mit genügender mechanischer Festigkeit herstellen, die nicht zuletzt auch den bei medizinischer Verwendung zu beachtenden hygienischen Forderungen genügen.

Zur Objektivierung peripherer Durchblutungsänderungen wurden vergleichende Untersuchungen der Wärmeabgabe mit dem Folienwärmestrommesser (K) in der von uns abgeänderten Form (Fig. 2) und dem von Hensel entwickelten Meßkopf zur Bestimmung der Wärmeleitzahl der Haut (Fluvograph) durchgeführt. Für die vergleichenden Untersuchungen haben wir den von Hensel für die Bestimmung der Hautdurchblutung mit dem Wärmeleitmesser vorgeschlagenen Drosselungstest (arterielle Sperre mit nachfolgender reaktiver Hyperämie) gewählt.

Die Meßköpfe waren auf der Innenfläche von Daumen und Mittelfinger mit Heftpflaster befestigt und die Oberseiten des Hautwärmeleitmessers mit einem Wattepolster abgedeckt, um störende thermische Einwirkungen des Außenraumes auszuschalten. An dem Oberarm befand sich eine Blutdruckmanschette.

Diese wurde mit einem Druck von 200 mm QS aufgeblasen und 5 min in diesem Zustand belassen. Die Aufzeichnung zwischen λ und q erfolgte gleichzeitig mit zwei Linienschreiben. Wie aus Fig. 3 hervorgeht, zeigen beide Kurvenläufe eine weitgehende Übereinstimmung hinsichtlich Amplitude und Frequenz. Eine Aus-

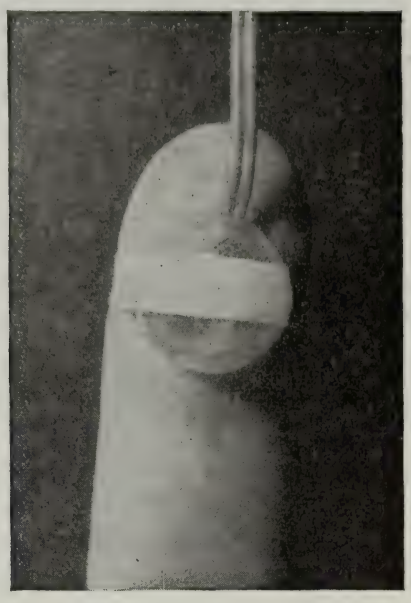

Fig. 2. Folienwärmestrommesser nach Warmbt-Cammerer für durchblutungsbedingte Wärmestrommessungen, an der Fingerkuppe befestigt

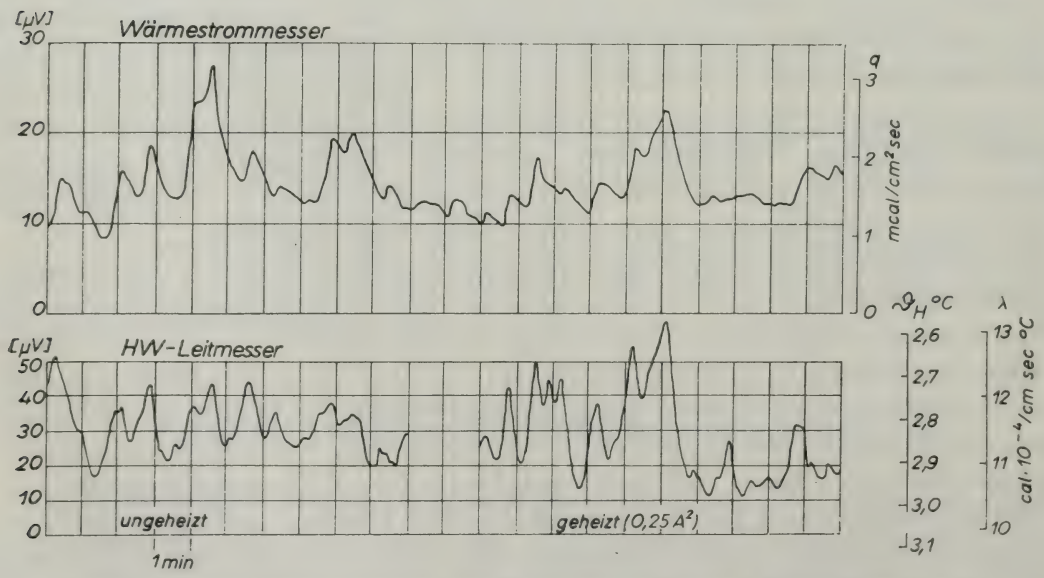

Fig. 3. Parallelregistrierung von Wärmeströmdichte q (Zeigefinger) und Wärmeleitzahl der Haut λ (Daumen) an der linken Hand

wertung der Registrierungen der Wärmestromdichte läßt einen quasilinearen Zusammenhang zwischen q und λ erkennen. Hieraus folgt, daß durchblutungsbedingte Variationen der Wärmestromdichte mit dem Wärmestrommeßverfahren im Prinzip nachweisbar sind.

MOMENTANWERTE DER ABKÜHLUNGSGRÖSSE

Für die Kennzeichnung der thermischen Wirkung des Klimas leisten Wärmestrommessungen der Körperoberfläche in Verbindung mit Meßwerten der Abkühlungsgröße physikalischer Modellkörper (z. B. Davoser Frigorimeter) wertvolle

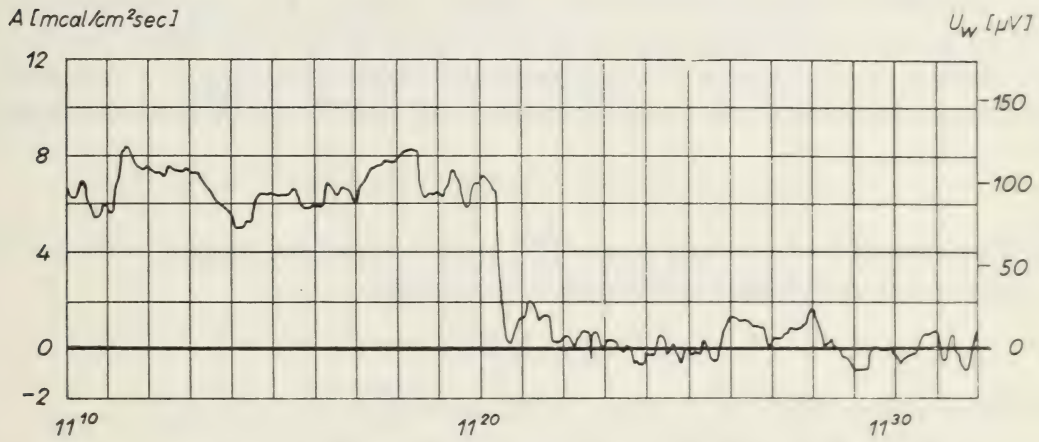

Fig. 4. Abkühlungsgröße (Frigorimeter) gemessen mit ringförmigem Wärmestrommesser; Kugel ab 11 Uhr 20 von der Sonne beschienen; Registrierung mit Linienschreiber

Dienste. Die Forderung nach wirkungsbezogenen Momentanwerten der Abkühlungsgröße ist mit dem Wärmestrom-Meßverfahren in einfacher Weise zu verwirklichen. Wir haben auf der Frigorimeterkugel einen ringförmigen Folienwärmestrommesser in Meridianebene befestigt bzw. in die Oberfläche der Kugel eingelassen und die Abkühlungsgröße direkt bestimmt. Auf diese Weise ergeben sich nicht nur Meßwerte der „*Abkühlungs-*", sondern auch der „*Überwärmungsgröße*" (nach Thams, 1962) (Fig. 4). Das Gerät ist damit ohne Änderung der physikalischen Konstanten auch in warmen Klimaten einsatzfähig (Warmbt, 1965).

Das Frigorimeter läßt sich ferner in dieser Form auch für raumklimatische Untersuchungen, wie z. B. über die Auswirkungen von Heizungs- und Lüftungseffekten verwenden. Die Kennzeichnung des Raumklimas durch Meßwerte der meteorologischen Elemente erfordert oft einen hohen Aufwand von Meßgeräten. Für biometeorologische Fragestellungen ist es jedoch vielfach zweckmäßiger, die komplexe Wirkung der thermischen Komponente des Klimas am lebenden Objekt

oder am Modellkörper direkt zu ermitteln, als Schlußfolgerungen indirekt aus den Meßwerten der meteorologischen Größen zu ziehen.

DIE BESTIMMUNG DER LATENTEN VERDAMPFUNGSWÄRME

Wir haben mit Folienwärmestrommessern nicht nur die Wärmeabgabe trokkener, sondern auch feuchter Oberflächen bestimmt. Bei Kenntnis der Größe der wärmeabgebenden Fläche F (cm²) und der Dauer der Befeuchtung t_V (sec) läßt sich die *Verdunstung* W (ml) aus der latenten Verdampfungswärme V (cal) in folgender Weise direkt ermitteln. Ein Wärmestrommesser ($F = 10$ cm²), dessen Oberfläche mit einem saugfähigen Gewirkstück bedeckt ist, wurde auf dem Meßkopf des Strömungskalorimeters nach Hensel befestigt. Die Kalorimetertemperatur ist größer als die Lufttemperatur. Von der trockenen, beheizten Oberfläche wird Wärme durch Leitung (L), Konvektion (C) und Strahlung (S) abgegeben. Die Wärmestromdichte ($L+C+S$), gemessen mit dem Folienwärmestrommesser, sei

$$q_t = k \cdot U_t$$

Die Wärmestromdichte der mit Wasser (W) befeuchteten Oberfläche ($L+C+S+V$) sei dagegen bei unveränderter Kalorimetertemperatur

$$q_f = k \cdot U_f$$

Die Wärmestromdichte der latenten Verdampfungswärme ist somit

$$q_f - q_t = k(U_f - U_t) = q_V$$

Da andererseits $V = q_V \cdot F \cdot t_V$ (cal) ist und

die Beziehung gilt $V = W \cdot r$

(r = Verdampfungswärme des Wassers (cal/ml)) ergibt sich

$$W = \frac{q_V \cdot F \cdot t_V}{r} \text{ (ml)}$$

oder

$$W = \frac{k(U_f - U_t) \cdot F \cdot t_V}{r} \text{ (ml)}$$

Sofern die Befeuchtung der Meßfläche mit abgemessenen Werten W erfolgt, läßt sich der Eichfaktor k aus den anderen Größen wie folgt bestimmen.

$$k = \frac{r \cdot W}{(U_f - U_t) F \cdot t_v} \quad (\text{mcal/cm}^2 \text{ sec} \cdot \mu V)$$

Hieraus folgt, daß man den Wärmestrommesser auf diese Weise auch ohne den Plattenapparat von Poensgen eichen kann. Ein Registrierbeispiel der trockenen und feuchten Wärmeabgabe zeigt Fig. 5.

Die Bedeutung, die der thermodynamischen Seite der Verdunstung zukommt, legt es nahe, die für die Verdunstung benötigte latente Verdampfungswärme V des Wassers auch für praktische Meßverfahren zur Ermittlung von W zu verwenden. Die Bestimmung der *Verdunstung* mit Wärmestrommessern aufgrund der latenten *Verdampfungswärme* haben wir bei dem *Piche-Evaporimeter* sowie bei

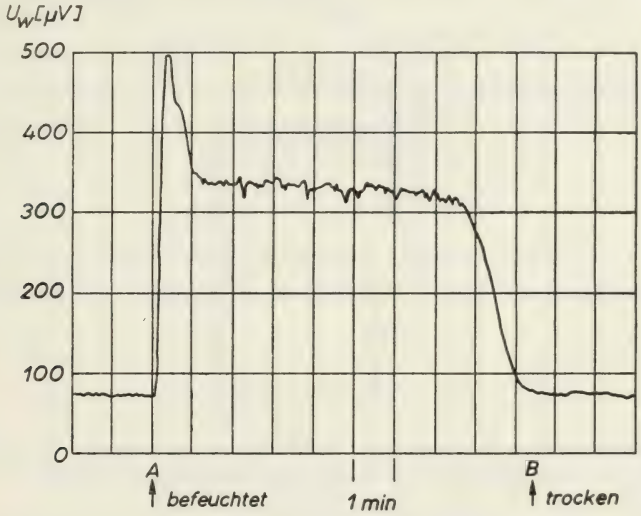

Fig. 5. Wärmestromregistrierung einer feuchten Oberfläche, belüftet mit $v = 2{,}4$ m/sec.

einem einfachen *Verdunstungsmesser* eigener Konstruktion erprobt. Der Vorteil eines derartigen Meßverfahrens besteht darin, daß man die latente Verdampfungswärme V aufgrund der Wärmebilanzgleichung

$$V = L + S + B \text{ (cal)}$$

mit dem Wärmestrommeßverfahren direkt messen kann und nicht, wie sonst allgemein üblich, aus den einzelnen Gliedern der Energiebilanzgleichung berechnet.

Da sich die Thermospannungen leicht registrieren und auch integrieren lassen, erhält man auf diese Weise Mittelwerte wie auch Momentanwerte der potentiellen Verdunstung. Das Meßverfahren erlaubt außerdem auch die Bestimmung der Verdunstungswirksamkeit nach Givoni und Belding (1962) sowie Wärmeabgabemessung beheizter Probekörper mit feuchten Oberflächen (wie z. B. der Klimasonde von Riedel, 1958, des Sweating Cylinders von Givoni und Belding, 1962 oder der feuchten Abkühlungsgröße des Davoser Frigorimeters).

Die Kenntnis der Verdunstungswirksamkeit J_V ist vor allen Dingen für bekleidungsphysiologische Untersuchungen zur Ermittlung des aktuellen Kühleffektes

(Q_V) befeuchteter oder mit Schweiß benetzter Gewebeauflagen von Bedeutung

$$J_V = \frac{Q_V}{W \cdot r} \quad (\%)$$

Die Größe Q_V läßt sich mit dem Wärmestrommesser direkt bestimmen und in Beziehung zur potentiellen Verdunstung $V = W \cdot r$ setzen. Es ist ferner möglich, Wärmestrommesser in die Oberfläche der Probekörper einzulassen und die feuchte Wärmeabgabe direkt zu ermitteln.

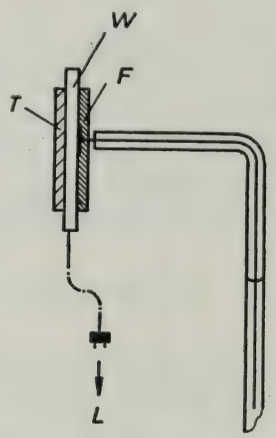

Fig. 6. Schematischer Aufbau des Verdungstungsmessers; W = Wärmestrommesser, T = trockene –, F = feuchte Fließpapierauflage, L = Zuleitung Linienschreiber

Wir haben die Erprobung der Wärmestrommesser für Verdunstungsmessungen in längeren Versuchsreihen durchgeführt und die latente Verdampfungswärme $V = W \cdot r$ sowie die Wärmestromdichte q_v direkt bestimmt und beide Energiegrößen miteinander in Beziehung gesetzt. Die physikalischen Versuchsbedingungen wurden durch Variation der Luft- und Umgebungstemperatur, der Luftfeuchtigkeit und Luftbewegung modifiziert. Die Linearität der Beziehung $q_V \sim W$ ist stets erfüllt und es läßt sich Verdunstung W (ml) aus den q_V-Werten direkt ermitteln.

Für das in Fig. 6 dargestellte Meßprinzip lautet die Energiebilanzgleichung der feuchten Schicht

$$(L_T + L_F) + (S_T + S_F) + B + V = 0$$

Da man zweckmäßigerweise die Energieströme auf die Einheit der Projektionsfläche bezieht, wird bei allen Energieströmen, die von beiden Seiten (T und F) kommen, die Summe dieser beiden Energieströme genommen. Die für die Verdunstung benötigte Verdampfungswärme wird, wenn man die Wärmeleitung aus dem Körperinnern B infolge der geringen Wärmekapazität des Systems und den Energiestrom durch die Zuleitungen außer Betracht läßt, durch $(L_T + L_F) + (S_T + S_F)$ gedeckt.

Für die Verdunstung $W = 0{,}1$ ml/h beträgt bei einer Fläche von $F = 7{,}1$ cm² die Wärmestromdichte q_V

$$q_V = \frac{W \cdot r}{F \cdot t}$$

$$q_V = \frac{0{,}1 \cdot 590 \cdot 10^3}{7{,}1 \cdot 3600}$$

$$q_V = 2{,}3 \qquad (\text{mcal/cm}^2\ \text{sec})$$

Der von dem Wärmestrommesser gemessene Anteil $L_T + S_T$ ist

$$q_{W1} = 1{,}1 \qquad (\text{mcal/cm}^2\ \text{sec})$$

Der von der Luft der feuchten Oberfläche direkt zugeführte Anteil $L_F + S_F$ beträgt infolgedessen

$$q_{W2} = 2{,}3 - 1{,}1$$

$$q_{w_2} = 1{,}2 \quad \text{mcal/cm}^2\ \text{sec}$$

Daraus folgt, daß die Wärmeübertragungswidersände zu beiden Seiten des feuchten Blättchens angenähert von gleicher Größenordnung sind.

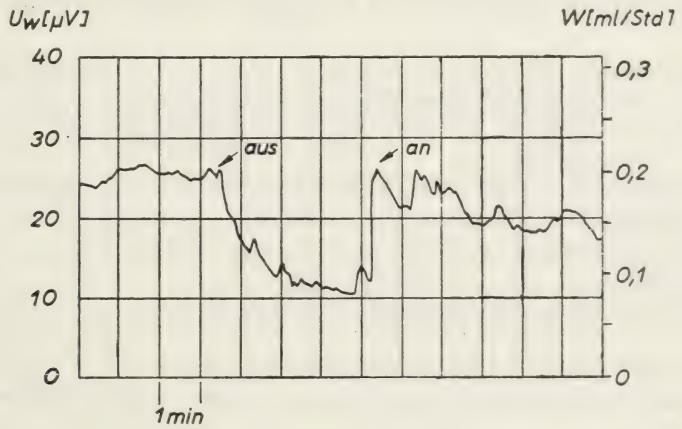

Fig. 7. Verdunstungsmessung mit dem Piche-Evaporimeter bei Belüftung (an, aus)

Bei dem Piche-Evaporimeter wurde ein Wärmestrommesser unter dem Rohrquerschnitt in zwei Picheblättchen eingebettet und in längeren Versuchsreihen die Abhängigkeit der Wärmestromdichte q_W von der Verdunstung W (ml) experimentell bestimmt.

Bei einer Verdunstung von $W = 0{,}2$ ml/h beträgt die latente Verdampfungswärme

$$q_V = \frac{0{,}2 \cdot 590}{12{,}6 \cdot 3600} = 2{,}6\ (\text{mcal/cm}^2\ \text{sec})$$

Der Wärmestrommesser zeigt eine Wärmestromdichte von

$$q_W = 2{,}3 \qquad (\text{mcal/cm}^2\ \text{sec}) \qquad \text{an.}$$

Im Bereich der Rohrquerschnittsfläche ist die Wärmebilanzgleichung ebenfalls größenordnungsmäßig erfüllt. Ein Vergleich von q_V und q_W ist insofern problematisch, als q_V für die gesamte, verdunstende Fläche F berechnet ist und unter dem Rohrquerschnitt ($F \sim 1{,}5$ cm^2) der Wärmeübergang teils gegen Wasser, teils gegen Luft, bei der übrigen Fläche aber nur gegen Luft erfolgt. Die lineare Abhängigkeit der Verdunstung W von der Größe q_W ist jedoch, wie unsere Versuche gezeigt haben, trotz verschiedener physikalischer Umgebungsbedingungen erfüllt. Aufgrund dieser Beziehung läßt sich die potentielle Verdunstung des Piche-Evaporimeters mit Folienwärmestrommessern registrieren. In Fig. 7 wurde das Evaporimeter mit einem Ventilator ($v \sim 1$ m/sec) belüftet. Der Rückgang der Verdunstung infolge der Unterbrechung der Belüftung ist deutlich zu erkennen. Der praktische Wert der Meßmethode besteht darin, daß die Verdunstung allein aufgrund des gemessenen latenten Wärmestromes ermittelt wird. Eine gesonderte Bestimmung der verdunstenden Wassermenge entfällt.

LITERATUR

Aschoff, J. (1944) Grundversuche zur Temperaturregulation. *Pflügers Arch.ges.* Physiol. **247,** 469–496.

Budyko, M. (1958) Untersuchungen über die Temperatur der Erdoberfläche. *Z. angew. Meteor.* **3,** 119–124.

Cammerer, J. S. (1962) *Der Wärme- und Kälteschutz in der Industrie.* Springer-Verlag, Berlin.

Dorno, C. (1942) Zur Entwicklungsgeschichte der Bioklimatologie. *Biokl. Beibl.* **9,** 4–11.

Eitner, H. (1958) Fortlaufende Bestimmung der Hautdurchblutung mit Halbleiterwiderständen. *Z. inn. Med.* **13,** 492–494.

Givoni, B. und Belding H. S. (1962) The cooling efficiency of sweat evaporation. In: *Biometeorology* I, S. W. Tromp. (ed.) Pergamon Press, Oxford, p. 304–314.

Hencky, K. (1919) Ein einfaches praktischen Verfahren zur Bestimmung des Wärmeschutzes verschiedener Bauweisen. *Ges. Ing.* **42,** 437–438.

Hensel, H. (1951) Ein Strömungskalorimeter für beliebige Körperstellen. *Z. ges. exp. Med.* **117,** 587–597.

Hensel, H. und F. Bender (1956) Fortlaufende Bestimmung der Hautdurchblutung am Menschen mit einem elektrischen Wärmeleitmesser. *Pflügers Arch. ges. Physiol.*, **263,** 603–614.

Lustig, W. L. und Cammerer J. S. (1955) Folien-Wärmestrom-Messer für technische und physiologische Untersuchungen. *Ges. Ing.* **76,** 289–294.

Riedel, G. (1958) Messung und Regelung des Klimazustandes durch eine die Erträglichkeit des Menschen anzeigende Klimasonde. *Forsch. Ber. Wirtschafts- und Verkehrsminist. Nordrhein-Westfalen* Nr. 529, Westdeutscher Verl. Köln und Opladen.

Schmidt, W. (1923) Ein neuer Wärmeflußmesser und seine praktische Bedeutung in der Wärmeschutztechnik. *Mitt. Forschungsheim Wärmeschutz – München,* H. 3, 19–26.

Thams, J. C. (1926) Zum Problem der Messung der Abkühlungsgröße in warmen Klimaten. *Arch. Meteor. Geoph. Biokl.* B. **11,** 292–300.

Warmbt, W. (1960) Verwendung von Wärmestrommessern für physiologische Zwecke. Beitr. Rheumat. II *VEB Volk und Gesundheit,* Berlin, 66–74.

Warmbt, W. (1961) Vergleichende Untersuchungen mit Wärmestrommessern zur Bestimmung von Momentanwerten der Abkühlungsgröße. *Z. angew. Meteor.* **4,** 33–49.

Warmbt, W. (1964) Frigorimeter-Wärmeaustauschuntersuchungen unter Verwendung von Folienwärmestrommessern. *Z. angew. Meteor.* **5,** 125–136.

SUMMARY REPORT

J. F. GRIFFITHS

No papers were read during the meeting of this working group, the time being devoted to general discussion concerning the two main facets of the group's interest, namely the instrumentation aspect and the preparation of a biometeorological dictionary.

The Chairman opened the session with a review of the past three years' work. He noted that originally the idea had been to compile a list of biometeorological instruments of a general nature and their limitations plus a list of their manufacturers. However this aim had become changed as the work proceeded and now the work had come to fruition with the publishing, of a book entitled *Environmental Measurement and Interpretation*, written by a committee member, Prof. R. B. Platt, and the Chairman. The book was of a general nature, the specialization would follow later.

The President, Prof. F. Sargent II, congratulated the Chairman on this work and remarked that owing to the growing interest in Biometeorology and the environmental sciences it was a most timely publication.

Dr. B. Primault asked the Chairman to be sure that the limitations of the instruments be stressed, as his own experiences with soil thermometers showed, how careful one must be in order to get correct representative measurements.

The President asked if it were possible to form some sort of "clearing house" for instrument data, but the Chairman answered that he thought the space and time required for such a service were too great for the Society at present.

The Members of the group were agreed that seldom is enough attention paid to the instruments and their limitations. It would be a good thing if more details of the instruments and methods used appeared in scientific papers.

Concerning the Biometeorological Dictionary Dr. Weihe announced that he had compiled some 10,000 words (German) of specific interest in general biometeorology which he would send to Dr. Primault and the Chairman for the comments of the French and English speaking members.

In order to obtain the opinions of specialists in each field the President suggested that the members of the Study Group in Biometeorology in the United States be circulated and this was agreed upon.

Dr. B. Primault then suggested the use of a large card in which the word and its definition would appear in the three languages. Only when all information on the card was agreed would the three columns be separated and alphabetically arranged within each language. This idea was accepted.

The problem of catering for other languages was considered too complex at present but after completion of the *Three Language Dictionary* this possibility could be entertained.

BIOMETEOROLOGY AND EPIDEMIOLOGY OF FUNGAL DISEASES OF PLANTS

Chairmen: R. D. Schein and J. M. Hirst

SUMMARY REPORT

R. D. SCHEIN

THIS working group on phyto-meteoropathology, with a special enabling grant from NATO, met for a total of two weeks. Participants included approximately 50 persons invited from 15 countries. Formal papers were not presented; instead, six months prior to the Congress, participants were invited to indicate on which topics of a prepared agenda they were prepared to present data of personal experience. Short resumés of these were preprinted in a 300-page volume and circulated one month before the meeting. In this manner the way was prepared for a meeting of discussion and any success it had can be attributed to the informal give-and-take among the learned assemblage.

Co-chairmen were Prof. R. D. Schein of the Pennsylvania State University and Dr. J. M. Hirst of the Rothamsted Experimental Station, England. The format or agenda was prepared by a committee consisting of eleven distinguished scientists organized into five subcommittees:

Sources and Origins of Epidemics: Dr. C. T. Ingold (London),
Chairman: Dr. M. V. Carter (Adelaide), Dr. H. Schrödter (Giessen), Dr. Hirst;
Details of Infection Requirements: Prof. A. J. P. Oort (Wageningen),
Chairman: Dr. H. Darpoux (Versailles), Dr. J. C. Zadoks (Wageningen); Dr. Schein;
Biometeorological Measurement and Interpretation: Mr. L. P. Smith (England),
Chairman: Dr. Hirst, Dr. Schein;
Epidemics and Theory: Dr. J. E. van der Plank (Pretoria),
Chairman: Dr. P. Waggoner (New Haven);
Plant Disease Forecasting: Dr. Paul Miller (Beltsville),
Chairman: P. M. Austin Bourke (Dublin), Dr. Hirst.

Besides those already mentioned, it must be acknowledged that we have a debt to the Pennsylvania State University, its Botany Department and its Continuing Education Conference Center for the support provided Prof. Schein in organizing the symposium and administering the funds; as well as to the Rockefeller Foundation and National Science Foundation of the United States for their support of travel of American participants, thus greatly lessening the burden on the NATO funds; and to the universities, research organizations and governments who helped the various members.

Because we cannot burden these proceedings with the over 300 pages of mate-

rial used at the symposium, we have assembled here 5 brief summaries written by the Chairmen of the subcommittees.

One result of the meeting was the decision to hold the group together, add to it, and meet again in 3–6 years. Persons wishing to establish liaison with the group for any reason are requested to contact Prof. Schein.

SOURCES AND ORIGINS OF EPIDEMICS*

There were four sessions in this Section chaired respectively by Ingold, Carter, Schrödter and Schein.

The first session was devoted to the origin and build-up of sources of epidemics. This involved some consideration of over-wintering and over-summering in relation to the provision of foci of infection. Burchill dealt with over-wintering of apple scab *(Venturia inaequalis)* on fallen leaves on orchards and stressed the indirect importance of weather conditions affecting the extent to which sources of infection are buried by earthworms. In apple mildew *(Podosphaera leucotricha)* bud infection in the previous summer determines the strength of the potential source for an epidemic in the current year. Similarly Ponchet on eye-spot of cereals *(Cercosporella herpotrichoides)* emphasized the importance of the severity of the attack in the previous year in determining the potential danger in a particular season. Salazar gave some consideration to the over-summering of *Puccinia graminis* in Spain, and the importance of dryness in relation to over-summering of early blight *(Alternaria porri f. solani)* in Israel was emphasized by Rotem.

The initial source of an epidemic from a distant region was illustrated by van Arsdel for rice blast *(Piricularia oryzae)*. In Florida an epidemic is normally started by invasion by air-borne spores from Cuba 150 miles away.

Early build-up of local sources was considered. Yarwood discussed his concept of "generation time", which is essentially doubling time, suggested by a consideration of generation time in a culture of a bacterium. There was lively discussion on this with a general feeling that "generation time" was more appropriate for the period from spore to spore. Van Arsdel told of work being done in Upper Michigan on local patterns of air circulation which are responsible for the build-up of disease caused by white pine blister rust.

The second session was concerned with the take-off of spores, periodicity in spore liberation and the physical and physiological features affecting their dispersal.

Hirst described recent work at Rothamsted on the dry liberation of fungal spores by raindrop impact as a mechanism distinct from rain-splash. Some experiments using glass beads in place of water drops were reported. The liberation of dry spores by large water drops is probably of considerable importance in such fungi as *Botrytis, Cladosporium* and the uredospores of most rusts. Unfortunately Bock

* Prepared by C. T. Ingold.

from Kenya could not be present to discuss his work on rain showers and spore liberation in *Hemileia*.

Bega discussed the discharge of sporidia in *Cronartium ribicola*. His observation that drop-excretion, at what has usually been called the hilum, as an immediate preliminary to spore discharge does not occur was confirmed by van Arsdel. In *Cronartium* there is a true attachment hilum. Clearly a clarification of nomenclature of basidiospore structure is called for.

A number of observations were reported on diurnal periodicity of spore release or prevalence. According to Carter, in *Mycosphaerella pinodes* there is a late afternoon peak. Yarwood referred to his well-known observations on the diurnal cycle in certain powdery mildews. Ingold pointed out that different master factors may be involved in determining any circadian periodicity. It was frequently emphasized in discussion that periodicity observed in spore-trapping did not necessarily involve periodicity in spore liberation. De Weille brought out the point that the capacity of spores of *Phytophthora infestans* to germinate may be affected by the time of day when they are produced, a point also made for *Erysiphe* by Yarwood. The degree to which spores retain their viability during dispersal was a matter which arose repeatedly during the discussions in this and other sessions. There was a strong feeling that the designing of high-efficiency spore traps, in which the viability of the spores can be tested, deserved more attention.

Schrödter gave an elegant exposition of the importance of rate of fall of spores in still air, determined largely by their size and shape, in relation to range of flight. In discussion it was suggested that Falck's formula for rate of fall of ellipsoidal spores now needs modification. There was some debate concerning the value of a mathematical model in dispersal studies. The defenders of this approach clearly had the better of the argument.

The third session dealt primarily with actual dispersal and with deposition of spores as a preliminary to infection.

Bega showed how the Sierra Nevada Mountains, although 7000–14,000 ft high, do not block the westward movement of aecidiospores of *Cronartium occidentale* liberated from an area of pinyon pines on the eastern slopes, since *Ribes* is infected westwards in a conical patch with a mouth as much as 500 miles wide. Dramatic pictures were shown of air flow patterns, revealed by drifting smoke, which could carry the spores over the mountains. Salazar gave aerobiological evidence of the invasion of Spain by *Puccinia graminis* from North Africa. Zadoks discussed how a study of infection times and gradients in yellow rust *(P. glumarum)* in The Netherlands, combined with race identification throughout Europe, gave clear evidence of effective distances of dispersal amounting to hundreds of kilometres. Van Arsdel emphasized the importance of studying the detailed patterns of air flow in relation to dispersal as illustrated by his own work on blister rust of pines. Study of the drifting of smoke and balloons are especially valuable in this connexion. He emphasized that night-time and day-time patterns of air movement are very different and in this connexion the time of day when the spores are set free

may be highly significant. Schrödter discussed theoretical relationships with special reference to dispersal phenomena associated with wind shelters. Hirst described exciting experiments involving determinations of concentrations of certain spores in the air outside Britain particularly over the North Sea. This work may give evidence of the behaviour and movements of spore clouds originating over southern England.

The question of deposition of spores came in for rather brief discussion. It was generally felt that more information on deposition of spores on leaves and stems in the field is much to be desired. In this connexion Preece gave some interesting information about techniques he has used in studies of apple scab.

The final session of the section was a short one concerned with general meteorological considerations in the overall dispersal story. Dew (which always evoked the cry: "What about guttation?"), rain, wind, temperature and light were all considered in their relation to dispersal. Sunlight was especially emphasized by de Weille as a factor tending to reduce the viability of spores in transit.

It is difficult to pinpoint the most important results of discussions which were free and lively. Certain points did, perhaps, especially emerge. The great interest of carefully planned airplane flights, as carried out by Hirst, in following the movement of spore clouds was recognized. The need in all mycological studies to distinguish between viable and non-viable dispersive units was widely felt. Light as a factor in determining the time of spore shedding and in influencing viability perhaps needs more attention in the future. Where elaborate methods are used in giving a detailed picture of the microclimate, equally refined methods are necessary to deal with spore concentration in the air. Spore deposition is a process deserving of more general field study.

It is highly probably that another member of the group writing a brief account of this section would pick out different items to emphasize, but all would agree that the discussions in the section were well worth while and few can have failed to get some ideas for their future research.

DETAILS OF INFECTION REQUIREMENTS*

In the first and second sessions the infection process was treated by dividing it into eleven consecutive steps, viz. spore germination, germ tube elongation, finding the infection court, penetration, establishment of infection, colonization, symptom development, development respectively of fructifications and spores, spore maturation and spore viability. The papers presented were based on experiments and observations made in conditioned rooms as well as in the field. Much stress was laid on further studies of the separate steps in climate rooms and incubators; and especially as regards experiments on moisture requirements the need

* Prepared by A. J. P. Oort.

for better experimental equipment was discussed. Field experiments and observations proved to be more suitable for the study of a combination of consecutive steps that for the steps separately. These experiments have the advantage that they are carried out under natural conditions. The papers and discussions gave valuable information on the development of disease, contributing greatly to the understanding of epidemiology of several diseases.

In some papers the effect of a preceding step on the following was indicated. It implies that interactions between consecutive steps have to be considered and investigated more than has been done in the past.

In the third and fourth session problems related to the main subject as presented in the first two sessions, were treated. In the first place, attention was paid to the relation between laboratory and field experiments; further to facts and antifacts in experimentation. Renewed emphasis was laid on the use of the microscope as a tool in epidemiological studies, using modern leaf film, leaf strip and staining techniques. These methods make it possible to follow the infection processes closely in the field under natural conditions. As special subjects may be mentioned the relation between numbers of spores and lesions, and the effect of dew. Dew formation as a factor for infection appeared to be extremely important in those regions where rainfall is limited.

Summarizing, it may be concluded that the papers presented in this section (they numbered over 45), together with the animated discussions, gave very valuable information on the environmental conditions necessary for or suitable to disease development as well as on the disease development later. It must, however, be emphasized, that no general overall picture of infection requirements and disease development could we get as the interactions between host, pathogen and environment vary greatly for different hosts, for different pathogens and for different environments.

BIOMETEOROLOGICAL MEASUREMENT AND INTERPRETATION*

Although much of the material for the section on Biometeorological Measurement and Interpretation had been naturally referred to as and when the need arose in other sections, it was found convenient to treat this aspect of the general problem under three main headings: Biological Measurements, Meteorological Measurements, and Techniques for the Handling of the Data. It was also decided that consideration of the methods of communication to the public was better handled in relation to later sessions on forecasting.

Hirst and Bega spoke on spore traps and Hyre on the efficiency of slide orientation in such traps; Preece gave an account of microscopy techniques for use in rapid identification of infected leaves; Zadocks discussed the assessment of yellow rust, and Schein described a quantitative inoculator.

* Prepared by L. P. Smith

On the meteorological side a full discussion of the relative merits of the various types of dew or wetness recorders was hampered by the absence of Van Eimern and Meijneke, but an account of the British instrument was given by Hirst and Wallin presented comparisons of the Taylor ground-glass plate instrument and the Wallin-Polhemus lamb-gut sensor type. Wood described a micrometeorological investigation in a frost environment and Wallin discussed the use of thermohygrographs and the significance of high humidity periods; the handling of hygrographs and their records was the subject of a contribution from deWeille; investigations into local wind structures in the neighborhood of forests and lakes were described by Van Ardsel.

Concerning the handling of data, Schrödter pointed out the advantages and dangers of correlation methods and strongly advocated the avoidance of over-reliance on mean temperature data; deWeille showed the value of reliable climatological models and both he and Bourke discussed the techniques of using meteorological synoptic maps; Gloyne discussed standards of accuracy and precision.

Throughout the session the time allotted to the presentation of papers was kept to a strict minimum to allow the greatest possible opportunity for free discussion during which many interesting details emerged.

In addition to the multiplicity of details, several fundamental principles became evident. In both biological and meteorological measurements it was clearly necessary to be aware of the limitations of the instruments or other methods of measurement and also care had always to be taken in regard to the exposure of any instrument. Above all, possible errors is sampling must always be the subject of serious consideration. While it was considered that, in general, the available meteorological data were superior to the present biological data, it was realized that comparable standards of accuracy and representativeness of both factors must be attempted whenever possible. It was furthermore agreed that in research matters, micrometeorological and micro-biological techniques have to be adopted, and that investigations within the eco-climate of the crop, or similar conditions simulated in the laboratory, were essential unless the results of the experiments were to be confined to the limitations of semi-empiricalism. Firm, unvarying relationships between macro-climate and eco-climate could never be depended upon, but experience had shown that much progress towards practical systems of forecasting could be made by the use of macro-measurements from standard exposures. Progress was therefore to be in two directions, one towards a micro-scale precision, the other towards a macro-scale assessment of an accuracy adequate for the practical demands of a current problem. The greater the knowledge of the true facts, the easier it would be to improve the practical field operational techniques and the more would be known of their degree of reliability.

EPIDEMICS AND THEORY*

Epidemiology is the science of disease in populations. In plant pathology, epidemiology is the science of disease in fields, orchards, forests, and plantations. The central problems in epidemiology are how disease gets into fields or other plant populations and how it increases and declines in the fields. Almost every factor affecting disease—that is, almost every factor studied by plant pathologists, whether it relates to host, pathogen or environment—is a factor affecting epidemics. The problem is to integrate the factors together, so that one can study an epidemic as the consequence of the balance and mutual interaction of all the various factors together.

The final amount of disease in a field depends on:

A. The initial inoculum. This can be local or come as the result of the movement of propagules from outside.

B. The rate at which disease increases: the apparent infection rate.

C. The period of time over which it increases.

In turn one can break down B—the apparent infection rate—into 4 controlling factors.

B (a) The suceptibility or vulnerability to infections, i.e. the proportion of spores or other propagules that establish lesions or start systemic infections. Thus, e.g. a protectant fungicide will affect factor $B(a)$ to the extent it affects the proportion of spores that establish lesions.

B (b) The abundance of spores or other propagules produced.

B (c) The time needed for one generation of the pathogen: the time needed for newly infected tissue to become infectious.

B (d) The rate of removal. Infected tissue is said to be removed when it stops being infectious. An old lesion, or part of a lesion, that stops forming spores is removed. When rusted leaves of bean or coffee fall off the plant, infectious tissue is removed. Alternatively, instead of studying a removal rate one may study the infectious period: the period of time during which tissue is infectious.

When during an epidemic the proportion of disease in a field is plotted against time, one commonly finds a disease progress curve that is roughly S-shaped. If the disease increases fast—if the S is steep—the infection rate is high. This implies that the host is susceptible, the pathogen virulent, and the weather favours disease. If disease increases slowly, as, e.g. on a resistant variety, the infection rate is low. The rate integrates in a single figure all the factors that influence infection.

One can define the rate r as $\mathrm{d}x(t)/\mathrm{d}t = rx(t)\,[1-x(t)]$ where x is the proportion of disease and $x(t)$ is to be read as x at time t. Here r reflects all the factors: $B(a)$, $B(b)$, $B(c)$, and $B(d)$ described above.

* Prepared by J. E. van der Plank

One can also describe a basic infection rate R as $dx(t)/dt = R[x(t-p) - x(t-i-p)][1-x(t)]$ where $x(t-p)$ and $x(t-i-p)$ are x at times $t-p$ and $t-i-p$ respectively. Here i is the period of time during which tissue is infectious i.e. factor $B(d)$; and p is the time for newly infected tissue to become infectious, i.e. factor $B(c)$. Thus $x(t-p) - x(t-i-p)$ is the proportion of tissue actually infectious at time t. R summarizes factors $B(a)$ and $B(b)$ only; the proportion of spores that start lesions and the abundance of sporulation.

Early in an epidemic, during its logarithmic phase, with r constant, solving the equations gives

$$r = \frac{R(e^{ir}-1)}{e(i \text{ plus } p)\, r}$$

The equation shows how any change in the 4 factors, $B(a)$, $B(b)$, $B(c)$ and $B(d)$, affects the infection rate r. Thus if one knows how a change in germination time affects $B(c)$—i.e.p—directly and possibly $B(a)$—i.e. R—indirectly one can determine how this change in germination time affects the infection rate.

In another discussion the effect of temperature was related to the increase of Phytophthora blight of potatoes and fusarium wilt of maize. The rate of increase at any temperature was related to the maximum rate at the optimal temperature.

Epidemics of yellow rust of wheat and barley were discussed. The logistic model for population increase adequately describes the course of a yellow rust epidemic in very susceptible varieties of wheat and barley. Measurement of yellow rust by field assessment methods was found to be superior to a method in which smaller samples of leaves were measured with a planimeter. In the early stages of focus development population increase can adequately be described logarithmically. Over all the stages one can use the regression of the logit of percentage disease on time to represent the integrated effect of environment and biotic variables on the development of yellow rust. A large amount of data for various varieties from different countries was used to illustrate this. The regression of the logit of percentage disease on time was also used to probe the effect of mixing susceptible and resistant varieties on the development of yellow rust.

The progress of an attack of blight in a potato crop can be determined by assessing the percentage of haulm killed. A method that reveals greater detail is to tag the leaves with differently colored wires and study the fate of individual leaflets. In this way one can determine the sequence of attack on the plant (usually the lowest leaves are attacked first) and on the leaflets (usually the terminal leaflets are attacked first). On individual leaflets the tips and edges were attacked more than the blade. Leaflets could be destroyed directly by fungus attack or indirectly by attack on the vascular tissue between them and the stems.

PLANT DISEASE FORECASTING*

Papers and discussions of the Forecasting Section, which concluded the symposium, demostrated the effective application of studies reported in other sections to the development of practical means for predicting the onset and spread of plant diseases. Reports varied in particular emphasis but all showed that progress in plant disease forecasting ultimately depends upon continued investigation into the interrelations between host, pathogen, and environment. The close coordination between the various sections of the symposium developed particularly in discussion, when research reported in other sections was often called upon to explain, support, or question statements made or hypotheses advanced in the Forecasting Section.

Warning services for certain diseases have had a long history of usefulness. Some of the oldest systems concern the downy mildew *(Plasmopara viticola)* of the vine in many European countries, illustrated by an account reporting the problems met with during 30 years' operation in Italy.

Phytophthora blight *(Phytophthora infestans)* is one of the diseases most frequently included in warning services, as well as one of the most troublesome. Difficulties encountered and methods evolved in developing blight warning services are illustrated by reports of experience in various countries in Europe and in different parts of the United States. So far no criteria for prediction have proved generally applicable in all areas. Explanations for the discrepancies have been sought through the study of the effects of different weather-time regimes on pathogen development, host growth, and host–pathogen relations. Bases for prediction of occurrence have been made much firmer by the knowledge gained from these studies.

Papers and discussion brought out that, for most diseases, the main indications upon which predictions could be based, at least at first, were usually furnished by comparisons of weather records with reports on disease severity for as many years as possible. Interpretation of weather–disease relationships was aided by whatever was known about the environmental requirements of the pathogen.

The close connection between disease and weather has led to an increasing emphasis on cooperation between meteorologists and plant pathologists in the forecasting of disease occurrence. The mechanics have not been easy to work out in all cases, but some successful cooperative systems are in operation. The system operated in the United Kingdom has been a conspicuous success. In England and Wales a central advisory office acts as a clearing house for disease and weather information for the forecasting of potato blight and apple scab *(Venturia inaequalis)*. In The Netherlands and Ireland the meteorological service initiates potato blight forecasts. In some of the northeastern states of the United States potato blight forecasting is included in the services of advisory agricultural meteorologists.

* Prepared by P. R. Miller

In discussions of the relation between microclimate and macroclimate, exemplified by studies in potato plantings, lima bean fields, and pine forests, it was agreed that the minimum difference between weather conditions inside and outside field crops occurred in cloudy damp weather favorable to most fungal diseases. In clear dry weather the field crop climate varied more widely from the macroclimate, but differences could be allowed for. It was far more difficult to extrapolate from standard meteorological observations to conditions inside a forest cover.

While special microclimatic observations are essential for specific investigations, practical considerations require that routine plant disease forecasts should, wherever possible, be based on standard meteorological observations, which possess the advantages of continuity, high quality and ready availability. In general, meteorological services are well equipped to provide accurate data on elements such as temperature and rainfall, but radiation, soil temperature, and soil moisture records are less satisfactory. For relative humidity special reporting procedures have been adopted in some cases. In the United States, analysis of Weather Bureau data has indicated the possibility of predicting relative humidity values from the temperature–dew point spread shown by data collected by first-order weather stations. Such predictions might be useful in forecasting potato blight in areas where hygrothermograph records are not available.

One of the most promising developments in recent years has been the relating of plant disease appearance and development to the frequency of occurrence of certain kinds of general weather situations, for example, to air mass types, or synoptic pressure patterns, or both. Experience with work of this sort was reported from Ireland and the United States.

From the meteorologist's point of view, there is no problem with disease forecasting systems where past weather data on, e.g. rainfall or temperature, can be used to assess the probable level of disease some months later; that is, for systems of lesser urgency than those using current forecast weather data for forecasting immediate disease development. Use of such long-term forecasts was described in connection with wheat stem rust *(Puccinia graminis)* epidemics, spread of white pine blister rust *(Cronartium ribicola)*, and incidence of bacterial wilt *(Bacterium stewartii)* of maize and tobacco blue mold *(Peronospora tabacina)*.

Nevertheless, the point was strongly advanced that warnings of plant disease development should be based, ideally, on *forecast* weather conditions rather than on observed "past weather". It was felt, however, that there was a place for both systems, the advantages of the "true forecast" being at least in part neutralized by the increased inaccuracy of warnings based on uncertain weather forecasts.

For most diseases both moisture and temperature have to be considered in forecasting. For tobacco blue mold and maize bacterial wilt, however, temperature is the decisive weather condition. The major relations between temperature and disease development were discussed in one paper.

One important effect of environment that has been neglected in practical fore-

casting systems is host reaction. Development of some diseases is influenced more by the effect of environmental conditions on the host than on the pathogen and forecasting for these diseases should be based on conditions to which the host has been exposed. Certain types of weather injuries increase host susceptibility to infection and it is particularly important to take such injuries into account in forecasts of fruit and vegetable decays.

In the United States methods developed for forecasting the keeping quality of cranberries, grapes, and apples have been proved statisfactory for commercial use.

The use of laboratory studies on environmental requirements of the pathogen for interpreting observations on the spread of infection and the development of the disease in the field is the subject of experimental work reported from the Netherlands and the United States.

The accuracy and advantages of utilizing various instruments for gathering data for experimental purposes or as a basis for forecasts were the subjects of much discussion, not only in the period devoted to instrumentation but in other sessions as well. Other topics that can be mentioned only briefly are the use and improvement of sampling methods and disease counts, and the importance of host phenology.

INDOOR CLIMATE IN ARID AND HUMID ZONES

Chairmen: J. K. Page and †N. Robinson

SUMMARY REPORT*

J. K. PAGE

THE Symposium on Indoor Climate with special reference to Arid and Humid Tropical Zones was attended by about 30 delegates, the majority of whom came from tropical regions. The group was lucky to have had the support of UNESCO and two tropical experts were able to travel to France for the meeting, thanks to this financial assistance.

In the First Session Professor Buchberg described the progress he and his colleagues had made in the use of computing machines for the study of temperature conditions in naturally ventilated buildings. The programme was flexible enough to enable a number of different design solutions to be explored fairly rapidly. In view of the complexities of heat flow under natural conditions, this method clearly opened up new avenues of exploration. The studies showed the importance of the temporal control of natural ventilation, if the internal environment was to be optimized. Professor Buchberg pointed out that the programme was flexible enough to allow biological indices of heat stress to be introduced into the programme, allowing a theoretical prediction of human comfort, and stress. It was generally agreed in the discussion that Professor Buchberg's approach would be very useful for tropical studies, though several speakers pointed out that an important difficulty was the correct estimation of the boundary conditions under different climatic conditions.

In the Second Session Professor Hashimshony described some of his work on building design in the hot dry climate. The importance of natural ventilation design was stressed. Then Mr. Van Deventer of South Africa described some of the extensive research work carried out on climate in towns in South Africa by the National Building Research Institute at Pretoria. Emphasis was placed on the selection of data for building design purposes and some attention was given to the multivariable problem involving several meteorological parameters simultaneously. The need for better information about the microclimate of vertical surfaces was underlined, and some of the South African work concerned with the radiation climate of vertical surfaces was described.

The first part of the Third Session was devoted to a discussion on the problems of daylighting of tropical buildings, led by Professor Rivero. Professor Rivero discussed the contribution of sunlight to daylighting, suggesting that the orthodox methods of calculation based on skylight only were not likely to lead to serious

* The reports are published in full length in the *International Journal of Biometeorology*, Volume 8, No. 2., 1964.

errors. In general when the sun was shining, there was an excess of light, and the problem of sun control became dominant. He particularly stressed the problem of glare. Professor Page followed with a discussion on the effects of orientation. He showed that solar gains could be considerably reduced without loss of daylight on overcast days, simply by careful consideration of orientation.

The last Session dealt with the design of shelter for animals in the tropics, and was lead by Dr. Bianca. The importance of correct design of animal shelters was brought out; also the importance of evolving suitable breeds of stock. The need to find economical solutions was particularly stressed; simple solutions like the use of bales of fodder for roof insulation were often invaluable. In humid areas shelters against solar heat gains did not always pay off because the cattle crowded together under the shelter thus increasing the humidity, decreasing air movement, and hence thermal stress. The problem of insect control was also considered. Clearly the designers of animal shelters in hot climates were faced with difficult problems that varied from region to region and it was necessary to understand both the bioclimatic requirements of the stock, and the local effects of climate before suitable shelters could be devised. Furthermore it was necessary to observe how stock actually used shelter when it had the choice. The erection of shelter buildings could, under certain conditions, actually make things worse, particularly if stock were crowded in under adverse conditions of low air movement and high density of occupation. The effect of transportation conditions on stock were also briefly mentioned.

In spite of the fact that the indoor climate session was arranged late, it proved a very successful meeting, providing a chance for tropical research workers who very rarely see each other to meet for discussion of their mutual problems. The discussions all showed the importance of the link between biological requirements and the artificially created environment in interiors, and emphasized the need for improved understanding of the role of climate in tropical building design. The importance of the radiative climate was particularly underlined; also the role played by air movement.

The group felt that tropical building design was a particularly fruitful field of exploration for biometeorologists, as outdoor climate played such a dominant role compared with buildings in temperate climates where heating appliances could be used to moderate adverse conditions. It was suggested that at the next Conference the group might concentrate on the indoor climate of tropical schools and hospitals as an important topic requiring further exploration, and that efforts should be made to get support from interested groups like UNESCO and WHO to enable suitable experts to attend the Conference. It was stressed that an important difficulty in tropical work was the wide physical separation of the different centres making it very difficult to achieve a satisfactory exchange of scientific ideas. The group was, therefore, particularly grateful for the assistance provided for the present Conference by UNESCO, as such gatherings of tropical research workers on indoor climate are so rare at the present time.

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