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Energy and climate in South-East Asia and the Western Pacific

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ENERGY AND CLIMATE IN SOUTH EAST ASIA AND THE WESTERN PACIFIC

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World wide energy use has increased at an average annual rate of about 3½ per cent over the past 50 years, accelerating to what 5½ per cent during the latter half of this period, but with a perceptible slowing in the late 1960s. By 1971, the per capita consumption of energy among the developed countries had reached 164×10^6 Btu/year, having tripled since the beginning of the Industrial Revolution (Cook, 1971).

Llewellyn and Washington (1977) have reviewed the regional and global aspects of energy use. They comment that the combined result of population increases, changing patterns of population densities, and escalating per capita energy consumption has been to concentrate in some regions of the world very large energy fluxes per unit area (energy flux density) when compared with the world average. According to Landsberg and Perry (1977) annual energy consumption for the world as a whole is about 52.5×10^6 Btu, but for the United States it is 306×10^6 Btu, while for Africa it is only 9.2×10^6 Btu, or 3 per cent of the level of the United States. The present world energy flux density distribution is shown in figure 1. Here it is seen that in 1970 the average energy flux density of the eastern U.S.A., Germany and Japan were equivalent to about 500,000 kg of coal/km^2/year. In contrast much of South-East Asia had an average energy flux density in the range 0-25,000, with Thailand reaching 10,000-25,000 and only Eastern China and the Philippines reaching 100,000-500,000 kg of coal/km^2/year.

According the Llewellyn and Washington (1977) the net population growth rate for the developing countries has risen sharply since 1950, largely as a result of declining infant death rates. This coupled with an increasing concern and ability on the part of these nations for improving the living conditions of their people, has resulted in rising energy consumption to the extent that the ratio of per capita energy consumption for the developed to the developing countries has remained nearly constant at about 8 since 1960. Thus even though the population of the developing world is increasing more rapidly than that of the developed world, the difference in per capita energy consumption has not changed markedly, indicating that the aggregate energy consumption by the developing countries is becoming a larger fraction of the world total as time passes. Llewellyn and Washington (1977) suggest that if this trend continues that it will lead to a more rapid increase of energy flux densities in the developing countries than in the developed nations. Indeed, aggregate consumption of all fuels by the developing nations will equal that among the present developed nations in less than 120 years, if both groups maintain the average annual increase in energy use typical of the past 15 years.

The upward trend of energy use in the developing countries comes partly from a need to feed an increasing population and partly from an increase in industrial activity. Thus providing India's people with the minimum 3,000 kcal/day considered necessary would require that nation to devote more energy to agriculture than it currently uses for all purposes combined. In aggregate global terms, China is now the fourth largest producer of primary energy and its third largest consumer; annual coal output in excess of half a billion tons is surpassed only by the U.S.S.R. and the U.S.A.; crude oil recovery has been expanding at a very fast pace and natural gas potential is undoubtedly quite large (Smil, 1980). Yet according to Smil (1980), in per capita terms the values are decidedly those of a poor developing nation: average annual consumption per capita of primary energy is only around 500 kilograms of coal equivalent; installed capacity of China's thermal and hydro power plants amounts to a mere 50 watts per head; and a large part of the rural population continues to live almost completely outside the reach of modern fuels and electricity. Thus there is ample scope and motive for increased energy consumption within China.

Llewellyn and Washington (1977) have computed the world energy flux densities for 2000, 2025, 2050 and 2075, on the basis of present values and recent trends in per capita energy consumptions and population densities. Calculations are on a country-by-country basis, except where available data made possible smaller geographical computations. Some of the data are displayed in figure 2. In their predicted analysis, South-East Asia shows a rapid energy growth, with Eastern China and India reaching an energy flux density equal to that of Western Europe and the Eastern U.S.A. by 2050. Much of mainland South-East Asia is forecast to have an energy flux density of about 100,000 kg of coal/km^2/year by the year 2000, which is a substantial increase over 1970 values. Nevertheless there are a few countries which are forecast to have low energy flux densities throughout the period.

1. Climate as an energy source

The principal growth in energy use in South-East Asia and the Pacific will come from coal, oil and gas with perhaps some nuclear energy, but climatic energy sources such as solar, wind and water power will also play some part. Brown and Howe (1978) comment that most of the people in the developing countries of Asia, Africa and Latin America live in rural areas. The prohibitive costs of large central generators and massive transmission and distribution systems, as well as the slow pace of the spread of rural electrification programmes, discourage hopes that rural energy needs can be met with a national electric grid. Hence it is useful to inquire into the potential of small-scale technologies that use renewable energy sources coming from the sun. Current solar energy comes from four major systems: (i) photosynthesis, which is the basis of all life, both plant and animal; (ii) rainfall, which comes from the hydrological cycle, which in turn is driven by the sun; (iii) wind, caused by the atmosphere pressure differences due to changing amounts of solar energy falling on different places; and (iv) direct sunshine.

Photosynthesis

In photosynthesis, biogas plants use anaerobic bacteria to turn animal, human, and crop wastes into methane gas and, at the same time, leave a residual slurry that is used for fertilizer. Brown and Howe (1978) state that there were

1.2 million biogas plants installed in China in the first six months of 1976 alone, and that in 1977 there were 4.7 million in operation. China, with four-fifths of its vast population living in the countryside, is the foremost example of a nation where most of the people are still relying on solar energy to produce, via photosynthesis, not only their food and feed for animals, but also the necessary fuel and raw materials.

Water power

According to Perry and Landsberg (1977), South-East Asia has a large water-power potential. Of the major world regions it ranks fourth after Africa, South America and U.S.S.R./China, reflecting the high rainfall of the region. At present less than ½ per cent of the potential water power is developed.

Figure 3 shows the mean annual precipitation of the tropical and sub-tropical world. It is seen that there are some very high totals in both Eastern Asia and the Western Pacific. Since some of these high falls occur in mountainous areas, they are ideal for water power. Riehl (1979) comments that figure 3 is not very satisfactory. There are no stations that record rainfall on a routine basis over any of the oceans. Over land, especially in mountainous areas, the record at any station is notorious for representing only the immediate environment. This situation is accentuated in the tropics compared with higher latitudes since precipitation is cumuliform to a large extent, and any heavy shower may just hit or miss any given station. Riehl (1979) further states that one would think that, with time, the accidental part of the records would even out, but, statistically, this is not so and experience with accumulating rainfall over periods of increasing length in small regions with dense precipitation networks has borne out the fact that isohyt ral patterns do not simplify as time is increased.

Figure 3 shows high rainfalls over Indonesia, Malaysia and the Philippines, an area which is sometimes, referred to as a 'maritime continent'. The Indonesian region as a whole stands out for being the region with the largest rainfall on the globe. Similar high rainfalls are recorded along many of the mountain ranges of Southern Asia facing the Indian Ocean. Clearly all these areas, particularly those which are mountainous, have a good water power potential. Rainfall amounts fall towards central Asia and Central Australia. In many of the high rainfall areas the rainfall is highly seasonal, particularly in the Asian subtropics where it comes mainly in the northern summer. Nearer the equator the seasonal variation in rainfall is less marked, though there can still be pronounced wet and dry seasons. Thus in most areas regular water power would require large water storage reservoirs.

Seasonal rainfall patterns can be complex and show marked variations in relatively small areas. At Singapore, rainfall is heavy and nearly uniform in each month of the year. Penang, on the Indian Ocean side of Malaysia, has the large late autumn maximum typical of the southern coast of India, notably Madras. Stations along the east shore of Malaysia have their highest rainfall in November and December. In West Malaysia there are two particularly wet belts: one running the full length of the South China Sea side of the eastern mountains, and the other confined to the northern part of the peninsula, on the Malacca Straits' side of the western mountain ranges. The axes of the high rainfall belts do not, in general, coincide with the highest land, but rather with the foothills of the mountains. The axis of the western wet belt in West Malaysia appears to approximate with an altitude of between 150 and 350 m, beyond which the rainfall decreases with increasing height. Dry areas are found in interior West Malaysia valleys. A similar phenomena is observed in other equatorial locations, so the highest rainfalls do not necessarily correspond to the highest mountains. Indeed rainfall totals over equatorial mountainous areas may be lower than those over the surrounding lowlands.

It is crucial to know to what extent the mean annual precipitation can be expected to occur in any one year. In figure 4 the average deviation from the annual mean is plotted, expressed as a percentage of this mean. It is seen that variability is highest within any latitude belt where mean annual rainfall is lowest, and vice versa. Annual rainfall variability is low over continental South-East Asia and most of Indonesia, but increases rapidly towards the dry lands of central Asia. Similarly in the India Sub-Continent it is high in the north-west, but decreases towards the south. Annual rainfall variability is also relatively high over New Guinea and the islands to the west.

Dry spells should also be investigated, since they may cause irregular water shortages and thus power shortages. Thus although no part of West Malaysia has a definite regular dry season, all parts are liable to periodic dry spells of variable length. Relatively long dry spells often occur in north-west Peninsula Malaysia, for example, in 1940 Kangar experience a dry spell of two months (January and February), and in the same year Alor Star had only six rain-days in three months (January, February and March). Dry spells tend to become shorter with decreasing latitude, and a completely dry month is a rare occurence anywhere in Peninsula Malaysia south of Penang. Thus extensive dry spells can occur even in areas of low annual rainfall variability such as Malaysia, and should be investigated carefully.

Wind Power

The fact that the power in the wind is proportional to the cube of its speed makes this speed of prime consideration in aeromotor design. Its annual average and distriubtion, or frequency of occurrence is clearly of great importance in assessing the energy potentialities of a site or district. The most essential information required when considering these potentialities is that relating to the annual duration of wind speeds of different magnitudes. Wind speed measurements should thus determine hourly speeds throughout the year. These can then be analysed and displayed in the form of (a) a velocity-duration curve or, (b) a velocity-frequency curve. Clearly most power is available from the higher wind speeds.

A favourable site for wind-driven plant must have a high average wind speed, although the actual value of this speed for economic operation will vary greatly with circumstances - particularly with the generating costs for the alternative means of power production. The annual average wind speed at any site depends upon:

(a) its geographical position;

(b) its more detailed location as, for example, its altitude and distance from the sea;

(c) its exposure; in particular its distance from higher ground likely to give screening, especially in the direction of the prevailing wind;

(d) the shape of the land in the immediate vicinity - since, to gain altitude and so obtain an increased wind speed, sites are often chosen on hill tops, this means in fact the shape of the hill. A summit often has an increased wind speed over it.

Good maps of mean wind speed over Eastern Asia and the Pacific are not readily available. Figure 5 shows the trade-wind systems in the mid-season months, since these are the main tropical wind systems. They are mainly restricted to the oceans and in the Pacific mean wind speeds range through the year from 12 to 16 knots. It is seen in figure 5 that in the Western Pacific, mean winds are strongest in January and weakest in April. In many areas such as the northern Indian Ocean and the South China Sea, winds show seasonal reversals, the so-called monsoons of Southern Asia. Along the coasts of the Indian sub-continent, winds are strongest in January and July and weakest in April and October. At all seasons of the year winds are light over equatorial South East Asia.

Wind power needs to be investigated by individual countries within the region and a search made for suitable wind power sites.

Direct Sunshine

Average annual global radiation (kcal cm^{-2} yr^{-1}) is shown in figure 6. It is seen that there are large variations over the eastern Asia and Pacific area, and these reflect differences in cloud amount. Large areas of the tropical Pacific enjoy anti-cyclonic weather and clear skies, and average annual radiation totals exceed 160 kcal cm^{-2} yr^{-1}. In contrast, skies are cloudly in the equatorial trough region over Indonesia and Malaysia, and global radiation values are low and equivalent to those recorded in southern Europe. Another area of low global radiation is observed over eastern China, and this again is due to cloudiness during the summer season. The reality of this minimum over China is confirmed by the chart showing mean duration of sunshine (figure 7) over central and east Asia. In both figures 6 and 7 it is seen that radiation and sunshine increase towards the northern central provinces where summer monsoon clouds and rains infrequently penetrate. A belt of relatively high radiation values extends from North Africa across India and into Burma and Thailand. Thus radiation totals are higher over India than they are over China. The network of observations used to obtain figure 6 is poor and could be improved, so countries in the region should establish more radiation observing stations.

2. The pollution of the atmosphere by energy use

Among the important pollutants produced by energy use are carbon dioxide, dust and waste heat. Over 97 per cent of the energy demand of the industrial world is met today by the burning of conventional fuels. Most of the by-products of fossil-fuel combustion use at present injected into the atmosphere where they may interfere with the natural radiative processes. The most important gaseous by-product is carbon dioxide, and if the present fossil-fuel consumption growth rate continues, this will lead in the year 2000 to atmospheric carbon dioxide levels about 30 per cent above the pre-industrial base, with levels perhaps doubling around 2025-2050.

Carbon Dioxide

Rottey and Weinberg (1977) comment that most official forecasts of future energy use give to coal a large and increasing role during the next 25 years. Thus nearly all scenarios for future U.S. energy supply systems show heavy dependence on coal. The magnitude depends on assumptions as to the reliance on nuclear fission, degree of electrification, and rate of GNP growth, and ranges from 700 million tons to 2300 million tons per year. The carbon in the carbon dioxide produced from fossil fuels each year is about 1/10 the net primary production by terrestrial plants, but the fossil fuel production has been growing exponentially at 4.3 per cent per year. Observed atmospheric CO_2 concentrations have increased from 315 ppm in 1958 to 330 ppm in 1974 - in 1900, before much fossil fuel was burned, it was about 290-295 ppm. With the current rate of increase in fossil fuel use, the atmosphere concentration should rise to two times its pre-1900 value by about 2030. A shift to coal as a replacement for oil and gas gives more carbon dioxide per unit of energy; thus Rotting and Weinberg (1977) suggest that if energy growth continues with a concurrent shift towards coal, high concentrations can be reached somewhat earlier.

The stores of carbon that are interacting in the short term of a few years consist of fossil fuels, plants and humus, the ocean, and the atmosphere. The fluxes that connect these pools are a continuous exchange with the biota, a constant exchange between the atmosphere and the oceans, and the emission of carbon dioxide through combustion of fossil fuels. Woodwell, et al. comment that the fact that the terrestrial biota and humus together contain a pool of carbon that is probably between two and three times the total in the atmosphere means that any appreciable change in the biota has the potential to cause a short-term change in the carbon dioxide content of the air. This is seen in the seasonal variations in carbon dioxide concentrations observed at Mauna Loa (Hawaiian Islands). Here carbon dioxide is at a maximum in spring and a minimum in early autumn, the difference between maxima and minima being about 5 ppm or 1.5 per cent of the average concentration.

The carbon dioxide content of the atmosphere is increasing at a rate that has ranged over the past 20 years between about 0.5 and 1.5 ppm/yr, with an average of about 1.0 ppm/yr. The increase in atmospheric carbon dioxide has been commonly assumed to be due to the combustion of fossil fuels which release about 5×10^{15} g carbon annually into the atmosphere. When the amount of carbon dioxide released by burning fossil fuels is compared with the total amount accumulating in the atmosphere, it is found that only about half has remained in the atmosphere. It has been thought that some of the 'lost' carbon dioxide went into the oceans, which are a potentially large sink, and that some went into the biosphere, on the assumption that many kinds of photosynthetic systems use it faster as the concentration increases. Kellogg (1979) comments that our current understanding of these sinks is clouded by the realisation that we do not know whether the mass of the biosphere is actually growing or shrinking, and there is some evidence that is difficult to refute indicating that deforestation, especially in the tropics, is causing a decrease of this mass. The biosphere may be another source of carbon dioxide as harvested organic material is burnt or allowed to decay, and according to some estimates it could be an even larger source than that of fossil-fuel burning. The entire ocean contains some 60 times more carbon dioxide than resides in the atmosphere, so it is potentially an enormous sink for new carbon dioxide; however, only the upper well-mixed part of the ocean is in contact with the atmosphere, representing a layer with an average depth of several hundred metres which is only about 10 per cent of the total ocean volume. The rate at which the newly added carbon dioxide can be transported downwards in the oceans by eddy diffusion or large scale over-turning is extremely slow, hence the total exchange time to go half way to a new equilibrium is estimated to be 1000 to 1500 years. Therefore for the next several decades at least it is reasonable to believe that a little over one half of our added carbon dioxide will continue to remain in the atmosphere. On this basis the atmospheric carbon dioxide content will reach twice its pre-1900 level by the middle of the next century.

Carbon dioxide is important because it is one the gases which exerts a so-called 'greenhouse effect' in the atmosphere. The radiative equilibrium or planetary temperature of the earth is determined by the balance between solar radiation received by the earth and outgoing infrared radiation at the top of the atmosphere, and is found to be about 257K (-16^0C). The average surface temperature, however, is about 15^0C or 288K, which is some 31K warmer than the planetary temperature. The difference is due to the fact that there are a number of gases in the atmosphere that absorb infrared radiation, which would otherwise escape to space from the surface. This phenomenon is often called 'the greenhouse effect' though the analogy to a greenhouse is actually not a very good one. An important greenhouse gas in carbon dioxide, and any changes in its concentration will affect surface temperature.

Manabe and Wetherald (1975) investigated the climatic effects of an increase of atmospheric carbon dioxide using a highly simplified model of the atmospheric general circulation. The simplified characteristics of the model included a limited computational domain with idealised geography, no seasonal variation, no heat transport by ocean currents and with fixed cloudiness. The model used in Manabe and Wetherald (1980) is similar to their earlier one, but is used to study the geographical character of the carbon dioxide-induced climatic change.

Manabe and Wetherald (1980) found a number of important changes in global climate accompanying an increase in atmospheric carbon dioxide. For instance the meridional temperature gradient in the lower troposphere markedly reduces in response to an increase in atmospheric carbon dioxide. As discussed by Manabe and Wetherald (1975), one of the important reasons for this reduction is the

of uniform thickness with provision for a sea ice layer. 68 m is chosen as the thickness to ensure that the heat storage associated with the annual cycle of observed sea surface temperature is correctly modelled. The atmospheric carbon dioxide concentration is set at 300 ppm (present concentration around 335 ppm), and 1,200 ppm by volume, respectively (hereafter, these experiments are referred to as $1\times CO_2$ and $4\times CO_2$ experiments). By using this model the seasonal variation of zonal mean surface air temperature is investigated. In low latitudes, the warming due to the quadrupling of the carbon dioxide content in the air is relatively small and depends little on season, whereas in high latitudes, it is generally larger and varies markedly with season particularly in the Northern Hemisphere. Over the arctic Ocean and its neighbourhood, the warming is at a maximum in early winter and is small in summer. It is observed that the sea ice from the $4\times CO_2$ experiment is everywhere less than the sea ice from the $1\times CO_2$ experiment. Therefore the authors suggest that the $1\times CO_2$ atmosphere is insulated by thicker sea ice from the influence of underlying seawater and has a more continental climate with a larger seasonal variation of temperature than the $4\times CO_2$ atmosphere. They consider that although the poleward retreat of highly reflective snowcover and sea ice is mainly responsible for the relatively large warming in high latitudes, the change of the thermal insulation effect of sea ice strongly influences the seasonal variation of the warming over the Arctic region. The seasonal variation of the difference in the surface air temperature between the two experiments over the model continents is significantly different from the variation over the model oceans. At high latitudes the zonal mean surface air temperature over the continents is at a maximum in early winter, being influenced by the large warming over the Arctic Ocean. However, there is a secondary centre of relatively large warming around 65^0N in April. This results from a large reduction in surface albedo in spring when the insolation acquires a near maximum intensity. Manabe and Stouffer consider that their study shows two interacting mechanisms, each acting to produce its own sensitivity maximum. The maximum warming of the early winter over the Arctic Ocean and its neighbourhood is caused by the change in sea ice thickness, and the relatively large warming over the continents in spring is produced by snow albedo feedback. The area mean change of the annual mean surface air temperature of the model atmosphere which occurs in response to the quadrupling of the carbon dioxide content in the atmosphere is about 4^0C. This result suggests that the warming caused by the doubling of the carbon dioxide content would be about 2^0C, which is significantly less than the warming which is estimated by the general circulation model of Manabe and Wetherald (1975).

The temperature response from a global doubling of atmospheric carbon dioxide content is likely to be strongest in the surface layer of the polar regions. Here the temperature response could well be 3-4 times that of the global average of 1.5-3^0C for a doubling of carbon dioxide, and a value of 7-8^0C at 80^0N is suggested by Manabe and Wetherald (1980). The question of what would happen to the Arctic Ocean ice pack in the face of such a warming trend has been investigated by Parkinson and Kellogg (1979). The sea ice model used to perform these experiments is described in detail in Parkinson and Washington (1979). The principal object of the model is to simulate a reasonable yearly cycle of the thickness and extent of the ice over the Arctic Ocean. It was found that with a 5^0C increase in surface temperature the ice pack disappeared completely in August and September but reformed in the central Arctic Ocean in the autumn. Also when atmospheric temperature increases of 6-9^0C were combined with an order-of-magnitude increase in the upward heat flux from the ocean, the ice still reappeared in winter.

Ramanathan et al. (1979) have used radiative transfer model calculations to show that the radiative heating of the surface-troposphere system caused by an increase of carbon dioxide undergoes substantial latitudinal and seasonal variations. The increase in zonal seasonal surface temperature for increased atmospheric carbon dioxide, as predicted by their seasonal model, shows little seasonal variability at low latitudes, but at high latitudes there is a pronounced spring/summer enhancement. At 75^0N, for example, the carbon dioxide induced enhancement in surface temperature is roughly two times greater in summer than in winter, while at 85^0N it is more than three times greater.

Another approach to the problem of climate in a warm, high carbon dioxide world is to use the past as an analogue for the future. Several authors have used this approach and an interesting paper has recently been published by Wigley, et al. (1980). They compared a composite of the five warmest years in the period 1925-74 with a composite of the five coldest years in this period. For the 65°N to 80°N zone the five warmest years were 1937, 1938, 1943, 1944 and 1953, and the coldest years were 1964, 1965, 1966, 1968 and 1972. The average temperature difference between the warm and cold year groups is 1.6°C for the high latitude zone, and 0.6°C for the Northern Hemisphere as a whole, and the years themselves reflect the general warmth of the 1930's and 1940's and the subsequent cooling of the Northern Hemisphere. When the winters are compared (for the high latitude zone), the warm-year groups is, on average, 1.8°C warmer than the cold-year group; for the summers the corresponding difference is 0.7°C. The spatial patterns of temperature and precipitation differences between the cold- and warm-year groups provide a scenario for (but not a prediction of) the changes in climate which might accompany a carbon dioxide-induced global warming.

A study of the differences between cold- and warm-year groups shows that maximum warming occur in high latitudes and in continental interiors, with up to more than five times the hemispheric mean increase in a region extending from Finland across the northernmost parts of Russia and Siberia to about 90°E. This area coincides with the region of greatest natural temperature variability. A large part of North America has positive temperature changes of two or more times the hemispheric mean, and this region extends westwards from Alaska, across northern Asia and into Scandinavia. In contrast, some regions show negative differences, for example: Japan, much of India, an area including and adjacent to Turkey, the Iberian peninsula and adjacent North Africa, the south-west coast of the U.S., a region in central Asia and Southwestern Greenland. In North America there is, in general, warming at all seasons; but in the central region north of 40°N the warming is greatest in autumn, while for the rest of the continent (including Alaska) it is greatest in winter. Most of the large differences which occur at

the Arctic Ocean was believed to be ice free (before 2.5×10^6 yr BP). The most detailed analysis of a past epoch as an analogue for a future warmer world is Kellogg's (1977, 1977-78, 1979) analysis of the Hypsithermal. For this period he produces a map showing those regions of the world which were wetter or drier, but his data are a little uncertain.

Aerosols

Bach (1979) states that the total global aerosol production is at present about 3×10^9 tons/yr of which roughly 1/10 is of man-made origin. Unlike CO_2 with a residence time of 2-5 years resulting in a uniform atmospheric mixing ratio, aerosols with a mean tropospheric residence time of nine days show regionally high concentrations near urban and industrial agglomerations and near areas with agricultural burning. Aerosol observations are so sparse that it is impossible to draw a global pattern of mean man-made aerosol pollution from them alone. Therefore, Kellogg et al. (1975) have attempted to very crude estimate of these patterns based on the considerations listed below.

(1) Aerosol production in a country is proportional to its general industrial activity, and furthermore that this activity can be measured by its gross national product (GNP). That is, gross national pollution is assumed to be proportional to GNP.

(2) Man-made aerosols, with a few trivial exceptions, are released at or within a few hundred metres of the surface, and will therefore be carried more or less with the prevailing surface winds.

(3) Aerosols at mid-latitudes have an average residence time of about a week at cloud level and 3 to 4 days near the surface. An average residence time for man-made aerosols was assumed to be 5 days. Taking the wind speed to be 5 ms^{-1}, the average travel time of a particle will be about 2,000 km; stated another way, the aerosol plume from an industrial region will be depleted to 1/ (37 per cent) of its initial density after drifting 2,000 km.

Kellogg et al. (1975) have constructed maps on these assumptions, and they are reproduced in figure 8. It is seen that man-made aerosols generally lie in a belt at mid-latitudes in the northern hemisphere, the major exception being the North Pacific. There is little cross-equatorial flow, and the countries of the southern hemisphere contribute far less than the industrialised countries of the northern hemisphere. A large plume originates over Japan and extends southeast in January and northeast in July. The bulk of the Pacific is free from the effects of man-made aerosols. This is confirmed by the observations of Ellis and Pueschel (1971), who, using measurements of solar transmittance at Mauna Loa, Hawaii, found no evidence of man-made aerosols.

Recent studies seem to indicate that the heat budget is not so much influenced by the scattering properties of aerosols, but rather by the absorption coefficients of the particles (National Academy of Sciences, 1979; Glazier, et al. 1976). It also appears that the cooling aspect of aerosols has been exaggerated (Rotty and Mitchell, 1976). Although in fact the thermal impact of aerosols cannot yet be assessed reliably, indications now point rather towards a slight net warming (Mitchell, 1975). In a recent paper Grassl (1979) explains why it is not yet possible to assess reliably the effects of aerosol particles on the planetary albedo and hence on the temperature. In cloudfree areas a particle increase may either lead to an albedo increase or decrease depending upon the surface albedo and the imaginary part of the refractive index. In cloudy areas one has to distinguish three albedo-changing effects of aerosols. Acting in combination, these will increase the cloud albedo for thin clouds but decrease the cloud albedo for thick clouds. Bach (1979) comments that since we reliably know neither the imaginary post of the refractive index of aerosols nor the mean optical depth of clouds, it is at present practically impossible to estimate the planetary albedo and temperature changes due to aerosol changes. Clearly this subject provides a number of important research topics for Asian countries.

Waste heat

World energy use has increased from 0.1×10^{12} W in 1860 to about 8×10^{12} W in 1975 (Rotty and Mitchell, 1976). Almost all of this heat input has come from energy removed from long-term storage. Bach (1979) comments that if energy consumption continued at a similar growth rate, then by 2050 a little over 400×10^{12} W could be reached. If, on the other hand, by the year 2050 a population of 10×10^9 is assumed together with an energy use of 20 kw/capita, then only 200×10^{12} W, or half the previous estimate would be reached (Kutzbach, 1974). Compared to the solar input at the top of the atmosphere these two estimates amount to 0.002 S and 0.001 S, respectively. Bach (1979) states that using a planetary albedo of 0.284, one obtains changes in the earth's equilibrium temperature of 0.15 K and 0.07 K for the above scenarios.

Valuable insight can be gained by comparing heat emissions at different scales, because potential climatic alterations depend upon both the size of the area and the density of the energy fluxes from that area. Figure 9 (after Bach, 1979) compares a variety of man-induced energy flux densities at different area and time scales with the global net surface radiation of about 100 W/m^2 and the available potential energy of about 2.4 W/m^2, the latter being the amount of energy used in all weather processes. Energy sources on the meso-scale and below are intense intense enough to produce local climate changes. This is seen in the well-known local heat islands associated with many cities. At the extreme end of the scale, industrial complexes and especially fossil and nuclear power plants are excessive heat islands. These so-called heat islands are small (a few degrees) thermal 'bumps' on the lowest few hundred metres of the planetary boundary layer of the atmosphere.

Regional and global effects of heat emissions can be assessed with the help of atmospheric model experiments. Using the three-dimensional general circulation model of the National Centre for Atmospheric Research in his first experiment, Washington (1971) tested the response of the model atmopshere for an extremely large addition of waste heat (about 250 times the present global heat production) distributed over all non-ocean areas. Surface temperature increases of 8-10 K over Canada and Asia and 1-2 K over Africa were obtained. Clearly this first experiment had a number of major deficiencies. In a more realistic experiment in which the heat input of 200×10^{12} W (about 35 times the present value) was distributed according to population density it was found that the thermal effects upon the atmosphere were within the noise level of the models natural variability (Washington, 1972). Testing for regional effects in January, the present energy flux density of 90 Wm^{-2} for Manhattan was assumed to exist in the year 2000 from the Atlantic Seaboard to the Great Lakes and Florida in the U.S.A. (Llewellyn and Washington, 1977). The main conclusion from this experiment is that temperature may increase by $\sim$12 K in the vicinity of the anomalous heating but that the heating effect is restricted to the boundary layer (a depth of $\approx$3 km). These experiments have been extended by Washington and Chervin (1978). The results from their later experiments indicate that a megalopolis over the eastern U.S.A. with an energy flux density of 90 Wm^{-2} would lead to significant temperature changes not only over the region itself but also upstream and downstream from it both in winter and summer. These experiments give some indication of the likely results of increasing waste heat output in Eastern Asia.

3. Climatic controls on energy use and the effects of climatic variation

Energy use has been found to partly depend on the variations in weather and climate in the region concerned. This is illustrated for electricity generation by figure 10 which shows monthly New Zealand electricity generation and associated weighted temperature departures, April-September, 1961-70. According to Maunder (1974) the analysis indicates that 25 per cent of the variance in the random oscillation of New Zealand monthly electricity generation was associated with the departure of the monthly New Zealand temperature indices (weighted according to the distribution of the human population) from the 1931-60 norms. Maunder comments that information about the weather can play a very important role in the decision-making processes associated with management of 'weather-sensitive enterprises'.

According to Barnett (1972), electricity demand may be forecast using a model containing the following elements:

Electricity Demand = Basic Level + Weather Demand
+ Day of Week Correction
+ Random Component

Barnett quotes the following values to illustrate the sensitivity of electricity demand to weather changes in Britain during the winter period:

(a) Temperature - a fall in temperature of 1 ^{0}C will increase the demand by about 1.8 per cent;

(b) Wind - a change in wind speed from 4 knots to 9 knots will increase the demand by about 1 per cent assuming temperature does not change;

(c) Cloud - a change in lighting conditions from a clear to a half-obscure sky on a dry day would cause an increase in demand of about 1.4 per cent, assuming there are two cloud layers present. On a wet day the response will be doubled.

It should be noted that the above sensitivities are average levels for a typical winter weekday. Sensitivity to weather also has a diurnal as well as a seasonal pattern. The above values may not apply in other countries and particularly not in tropical countries. Nevertheless increases in temperature in tropical urban areas will cause increase use of electricity for cooling, and thus an inverse of the temperature relationship noted above. Individual countries should investigate the sensitivity of their electric power generation to weather factors.

Some indication of the nature variability of temperature can be gained by studying maps (figure11) of the interannual variabilities of monthly mean air temperature (Craddock, 1964). Craddock considers that the interannual variability is greater in the northern winter than in the northern summer, greater in the interior of the continents than it is in the oceanic and maritime areas, and very low in all months in the tropics. The regions of highest variability are generally grouped round the Arctic Circle, and southwards there is a general tendency for variability to decrease with latitude. In January the axis of greatest variability exist over the west coast of Hudson Bay, from Greenland to Novaja Zesula in central Siberia, and over the northern Rocky Mountains, Alaska, and northeast Siberia. Countries in the region should therefore investigate the natural variability of temperature and try to estimate its economic consequences.

Long term climatic changes

Temperature trends may be economically important, and thus have to be considered. They are best approached by considering the historical variations in climate, since future trends may be similar to those in the immediate past.

The climate of northwestern Europe during the past 1,000 years has been described by Lamb (1977). The major features are an interval about AD 1000-1200 with temperatures somewhat higher than those in the twentieth century, followed by a decline to a minimum known as the 'Little Ice Age', between about AD 1500 and 1800. The temperature and precipitation changes between these two intervals in England amounted, for century averages, to approximately 1-3 ^{0}C and 10 per cent respectively (Lamb, 1965). The cooling was probably more pronounced in higher latitudes, where it was associated with marked differences in sea-ice conditions. Following the 'Little Ice Age' there was a marked recovery in the early twentieth century, especially in the higher latitudes of the Northern Hemisphere.

As records have been compiled from other parts of the world, it has become apparent that rather similar fluctuations have occurred elsewhere. Figure 12 from Pittock et al. (1978) illustrates the reconstructed temperature trends from China and Japan compared with England and Iceland. Pittock et al. suggest that an inspection of the graphs indicates that while the changes in China and Japan are broadly in phase with one another, the 'Little Ice Age' appears to have begun in the tenth century in East Asia and temperatures there reached a minimum in the twelfth century. The cooling apparently spread westward reaching European Russia in the mid-fourteenth century and central Europe in the mid-fifteenth century. Pittock et al. comment that such displacements and longitudinal relationships are suggestive of adjustments in the tropospheric wave structure.

In the first half of the twentieth century, the world was enjoying a full recovery from the Little Ice Age of around 1700. Mitchell (1977) suggests that there are indications that the circumpolar westerlies contracted towards the poles, and that, in the northern hemisphere at least, the amplitude of the planetary waves underwent a decrease. A general warming of the earth occurred (see figure 13), which was most pronounced in the Atlantic sector of the sub-Arctic. A rapid worldwide retreat of mountain glaciers and a poleward extension of the ranges of many flora and fauna took place. Mitchell further comments that there is considerable evidence that, between the 1940s and about 1970, the climatic changes of the earlier part of this century had tended to undergo a reversal. Temperatures had mostly fallen, especially in the Arctic and the Atlantic sub-Arctic, where sea ice has been increasing. The circulation of the northern hemisphere appears to have shifted in a manner suggestive of an increasing amplitude of the planetary waves and greater extremes of weather conditions in many parts of the world. Unfortunately, the situation in the southern hemisphere has not been so well documented. These events dramatize the fact that climatic variability is to be expected no less on time scales of months and years than on time scales of centuries and millennia.

For the period 1942-72, zonally averaged temperature changes have been computed by Williams and van Loon (1976). These changes are illustrated in figure 14 for all four seasons, while Table 1 lists the average change in 1942-72 between 15^0 and 80^0 N in each season, the values being weighted by area. The values in table 1 combined given an annual temperature change for the period 1942-72 of -0.26 ^{0}C. Figure 14 shows that the temperature changes were large at high latitudes but relatively small in the tropics.

Isopleths of the slope of the regression line of winter mean temperature for 1942-1972 are shown in Figure 15. This figure corroberates figure 14 in showing that the largest drop of temperature was in the polar region, but also demonstrates that there was a net rise in the latitudes between 42^0 N and 54^0 N and in the tropics as far south as the analysis goes. Temperatures fell over China but rose over the northern parts of South East Asia. Temperature changes over northern India are small. The average trend from 1942-72 between 15^0 N and 75^0 N was -0.21 ^{0}C, and the negative sign is obviously the influence of the change north of 54^0 N. Indeed, van Loon and Williams (1976a) comment that the sign of the overall winter temperature trend in the Northern Hemipsphere to a large extent is determined by the direction of the change in higher latitudes. Summer mean temperature changes are analysed in figure 16, and are positive south of 30 N as far south (15^0 N) as the analysis goes, but negative at middle and high latitudes. The biggest differences between winter and summer were over the polar cap where the negative changes were 4-7 times larger in winter than in summer, and in 45-50^0 N where the zonal mean winter temperature rose but the summer temperature fell. The average change in 1942-72 between 15^0 and 80^0 N in summer was -0.19 ^{0}C, weighted by area. The change was influenced mainly by the large negative values in the middle latitudes, whereas the average change in winter was dominated by the trend in the Arctic. The warming over South East Asia and China was particularly marked, with only small changes over India.

Temperature trends for 1942-72 during spring and autumn are shown in figures 17 and 18. In spring the temperature trend was downward in polar and middle latitudes, with areas of warming over Japan, the Middle East and the Pacific Ocean. In autumn the temperature trend was also downward in polar and middle latitudes, but a belt of warming is clear over the low-latitude Pacific and Atlantic Oceans and much of the low-latitude continental area.

It is clear therefore that temperature trends in the tropics and sub-tropics are complex and do not necessarily follow the hemispheric trend. It is important therefore for individual countries to investigate the temperature trends within their boundaries and for them also to contemplate the possible economic significance of these changes. Rainfall trends are also important for water power, but there is little information on such trends and they too should be investigated.

Scenario of future climatic changes

Man has upset the global carbon cycle by burning fossil fuels and, probably, by deforestation and changing land use. The net result of these activities has been to increase the CO_2 content of both the atmosphere and the oceans. As discussed previously, it is generally believed that if fossil fuel use continues to increase at about the rate of increase experienced over the past century then atmospheric CO_2 levels will reach roughly twice today's level by the middle of the next century. The enhanced greenhouse effect could well cause a significant increase in global mean annual surface temperature, and numerical model experiments suggest this could amount to 2 or 3 ^{0}C. Some of the numerical models suggest that the surface warming due to increased carbon dioxide should be detectable about now at high latitudes. It is not, possibly because the predicted warming is being delayed more than a decade by ocean thermal inertia, or because there is a compensating cooling due to other factors. Thus in the short term the temperature trends over Eastern Asia and the Western Pacific noted in figures 15 to 18 may well continue. In the longer term the increasing energy use noted earlier may well take place against a background of climatic changes induced by increasing atmospheric carbon dioxide. It is therefore necessary to look briefly at the possible nature of these climatic changes.

Wigley et al. (1980) have investigated the mean annual surface temperature changes from cold to warm years in the northern hemisphere. This is a possible analogue for a global warming, the corresponding change in the hemispheric mean temperature being 0.6 ^{0}C. They found cooling trends over much of India, continental South East Asia and Japan. China showed a slight warming trend. It cannot therefore be assumed that hemispheric warming will necessarily lead to a warming trend in tropical Asia. Wigley et al. (1980) also investigated mean annual precipitation changes from cold to warm years. Increases in precipitation were observed over India, varying from a few per cent in Bangladesh and along the eastern coast, to almost 100 per cent in the North-west. Decreases in precipitation occurred in southern India and in the north around New Delhi. The patterns are generally those of a more intense monsoon circulation in the warm years. Decreases in precipitation were also observed over Southern China, much of continental South East Asia and over Japan. Increases in precipitation were observed over Northern China.

The scenario of Wigley et al. (1980) therefore suggests that a warming northern hemisphere due to increasing atmospheric carbon dioxide will lead to a complex series of climatic changes in Eastern Asia. Large parts of India may be cooler and wetter than at present. Large parts of continental South East Asia could be cooler and drier than now, and the same applies to Southern China. Central Northern China could be both warmer and wetter than at present. The temperature changes near the equator are likely to be small, but the precipitation changes could be considerable.

The climatic background to the increasing energy use in Eastern Asia is therefore uncertain. Climatic changes in the near future are likely to be a continuation of present trends. In the longer term climatic changes are likely to be dominanted by increasing atmospheric carbon dioxide, but this could lead to large areas of slightly reduced temperature and decreased rainfall. It would be wise of the countries in the region to consider the economic consequences of such climatic changes.

Table 1.

Average temperature change 15-80^0 N during the period 1942-72

Winter	-0.21 ^{0}C
Summer	-0.19 ^{0}C
Spring	-0.36 ^{0}C
Autumn	-0.29 ^{0}C
Year	-0.26 ^{0}C

(After Williams and van Loon (1976))

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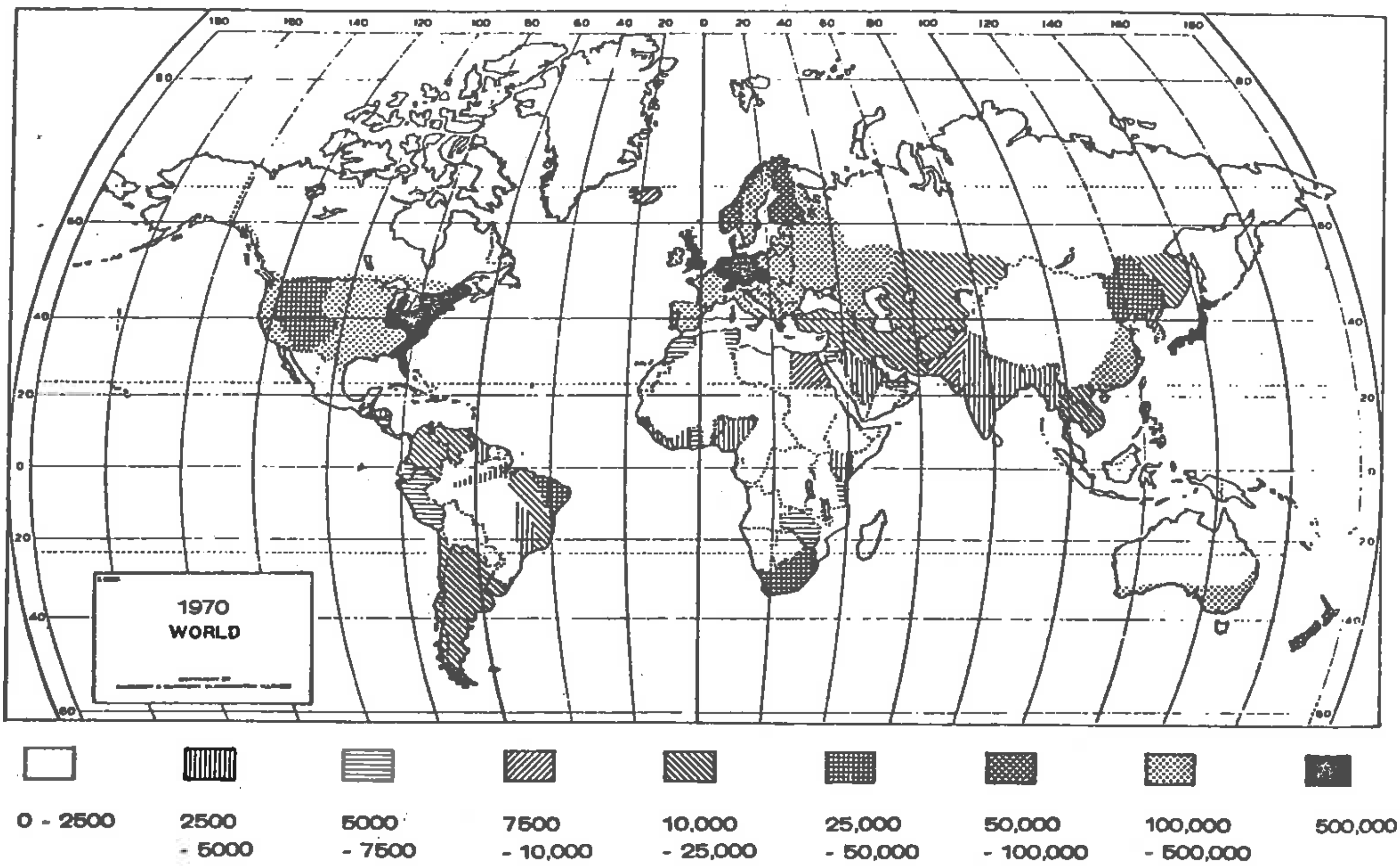


Figure 1. World energy flux density (kg of coal/km^2/year) A.D. 1970.

(After Llewellyn and Washington, 1977)

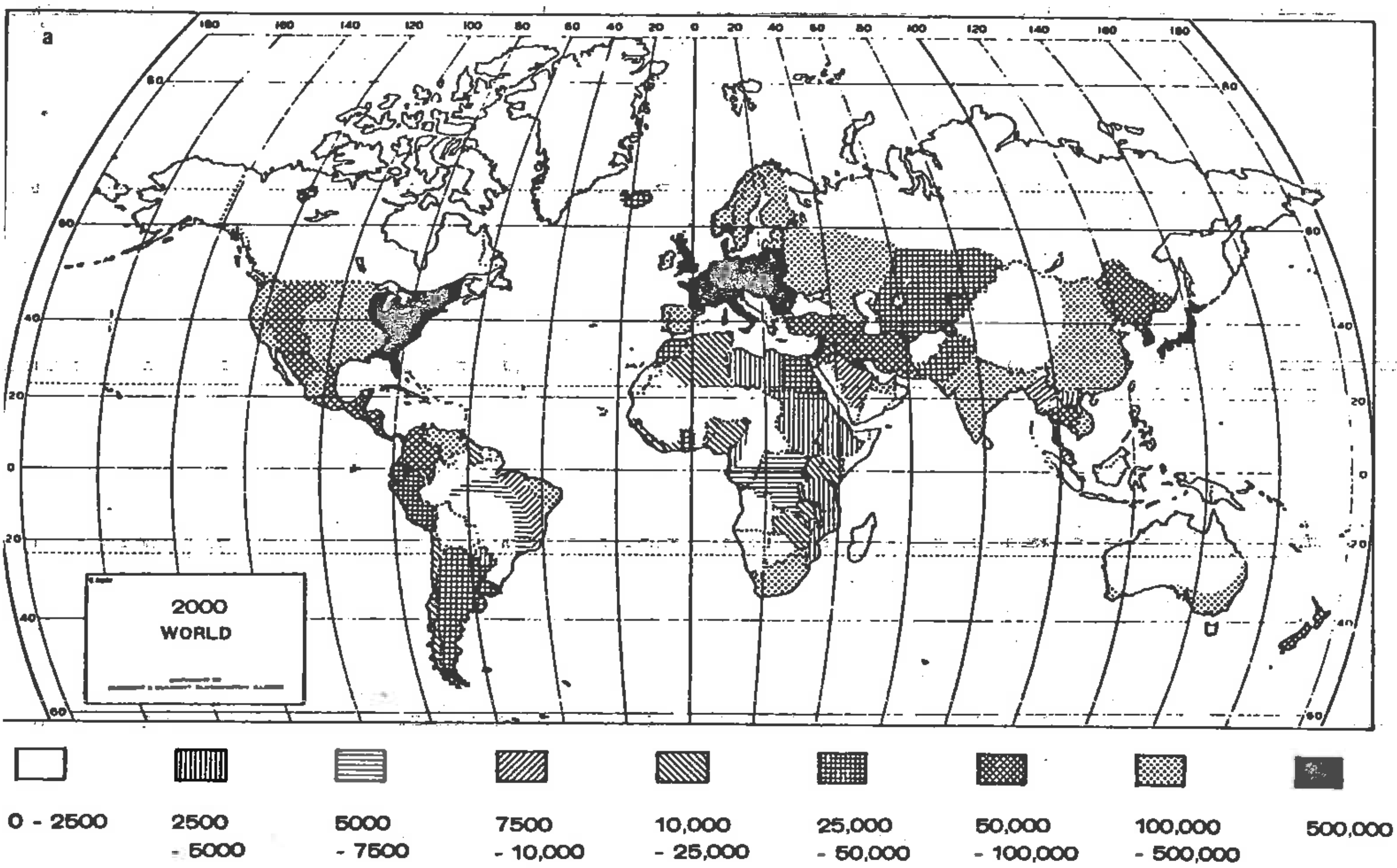


Figure 2(a). World energy flux density (kg of coal/km^2/year) in 2000 A.D.

(After Llewellyn and Washington, 1977)

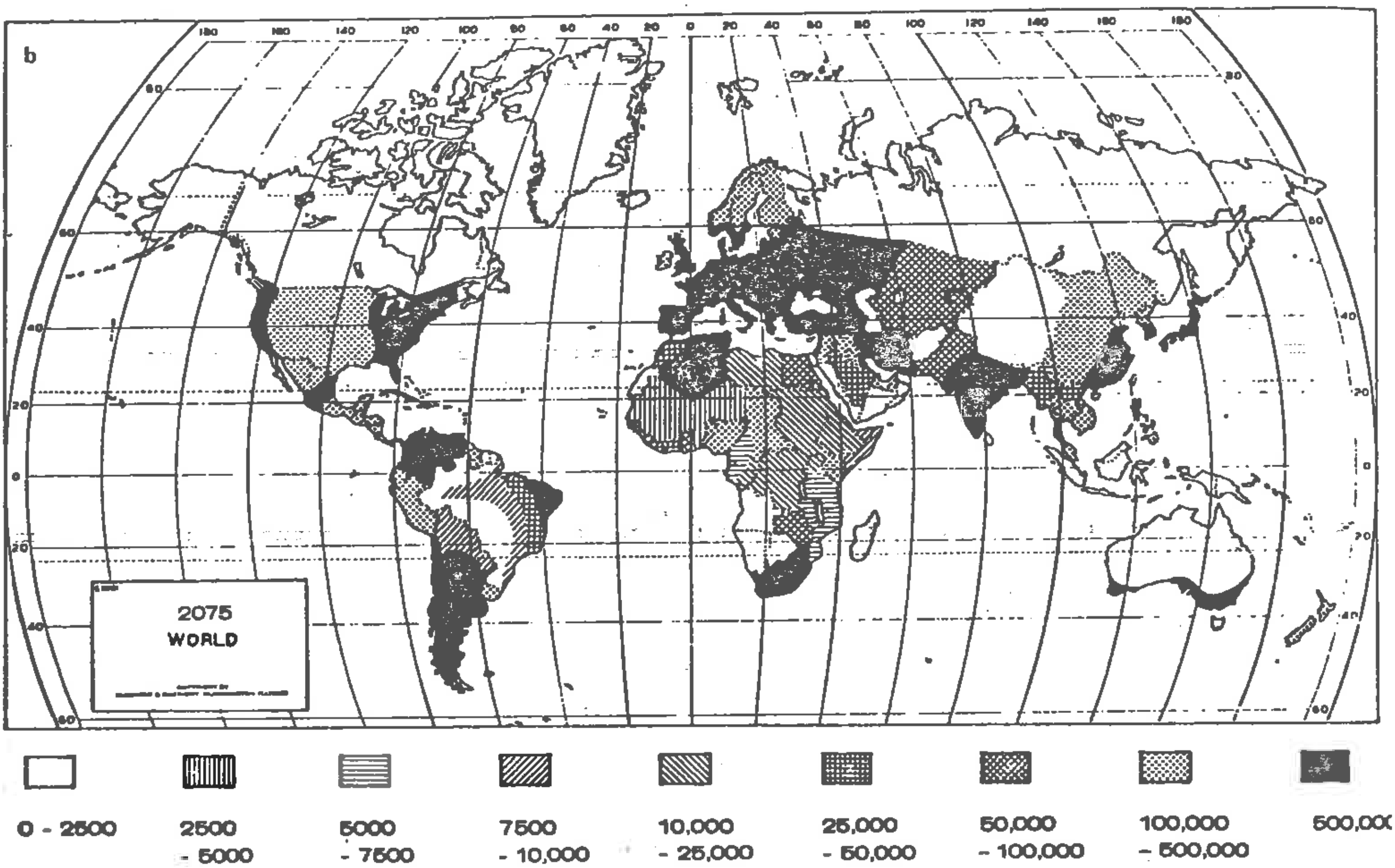


Figure 2(b). World energy flux density (kg of coal/km^2/year) in 2075 A.D.

(After Llewellyn and Washington, 1977)

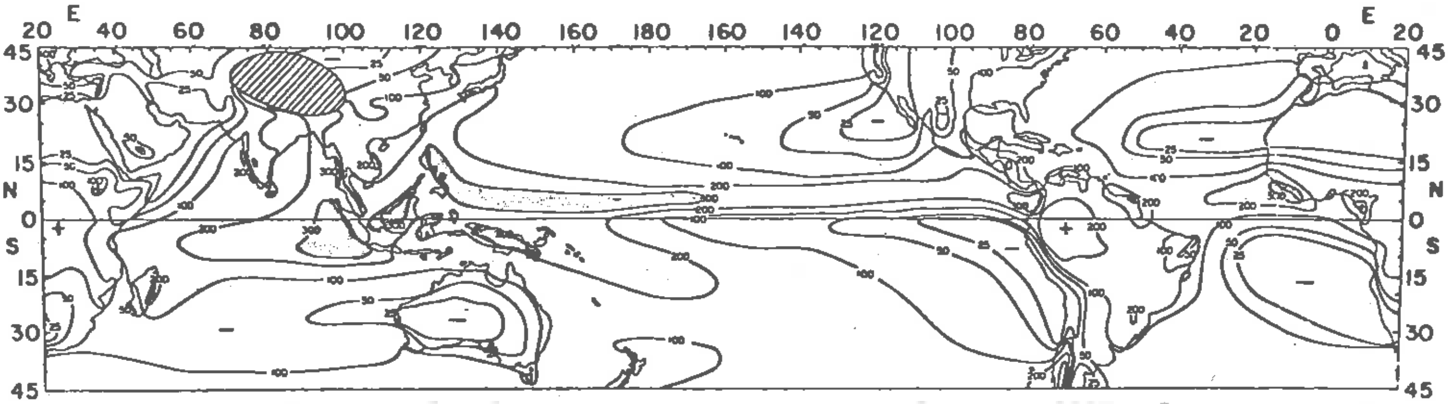


Figure 3. Mean annual precipitation (cm). Shaded: regions with more than 300 cm/year.

(After Riehl, 1979)

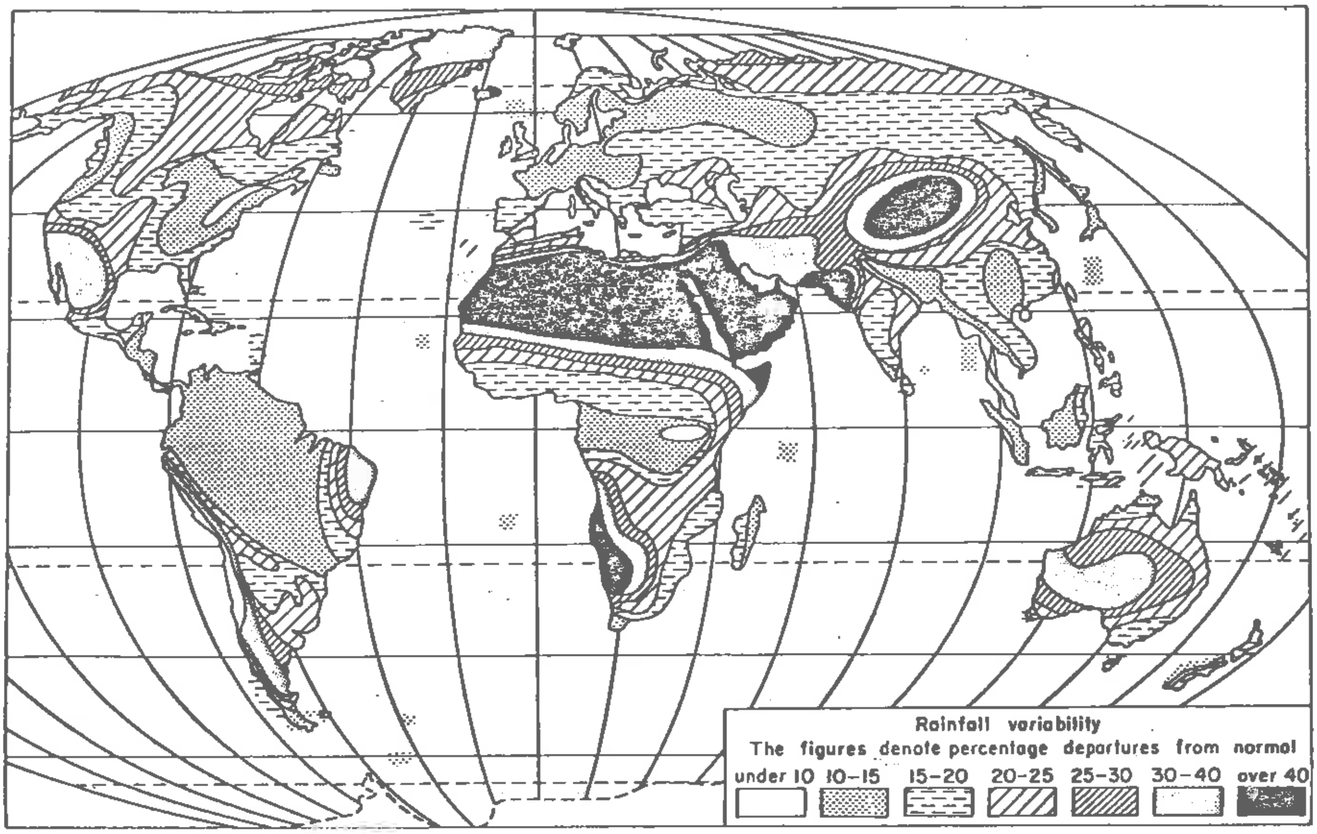
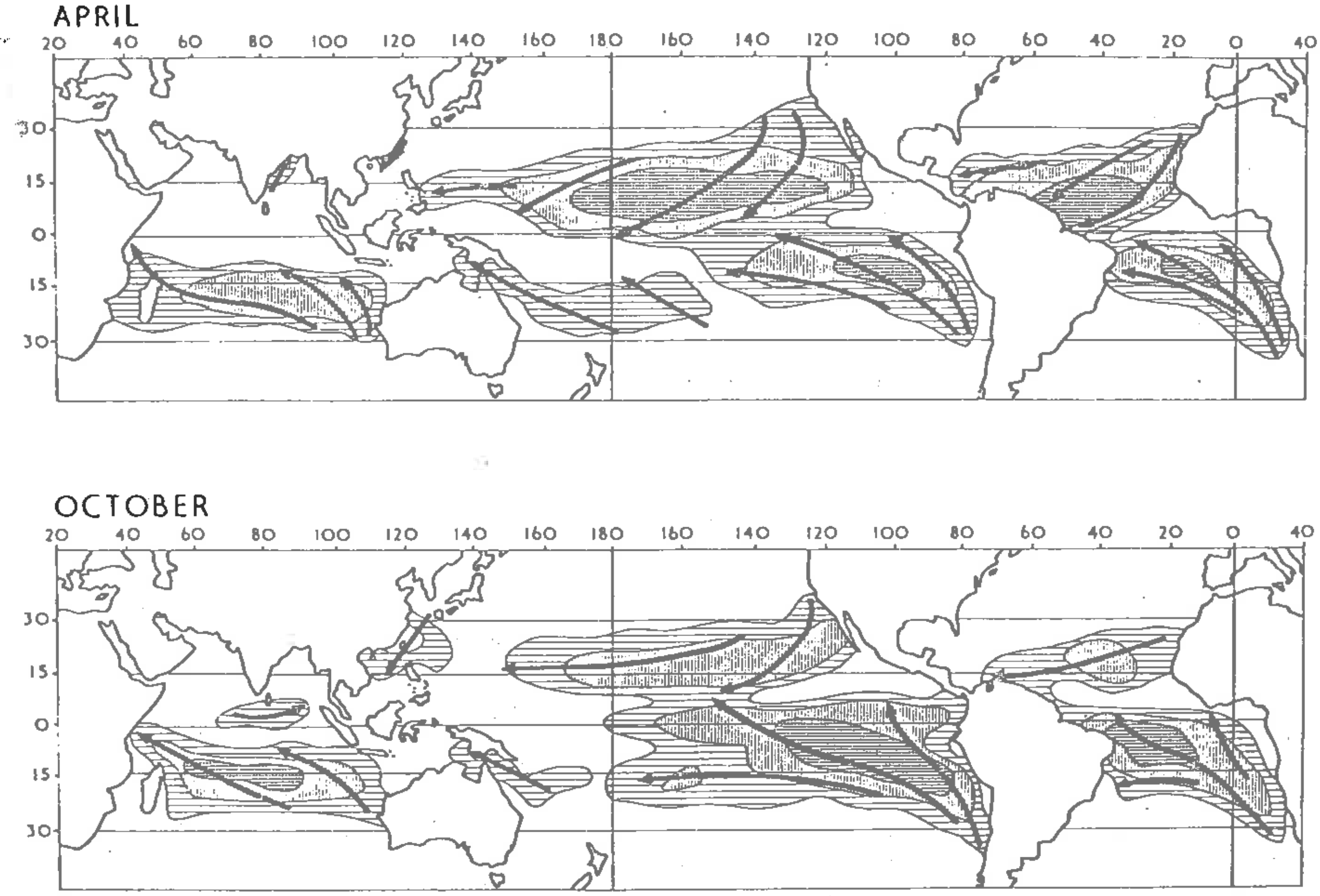


Figure 4. Annual rainfall variability of the globe.

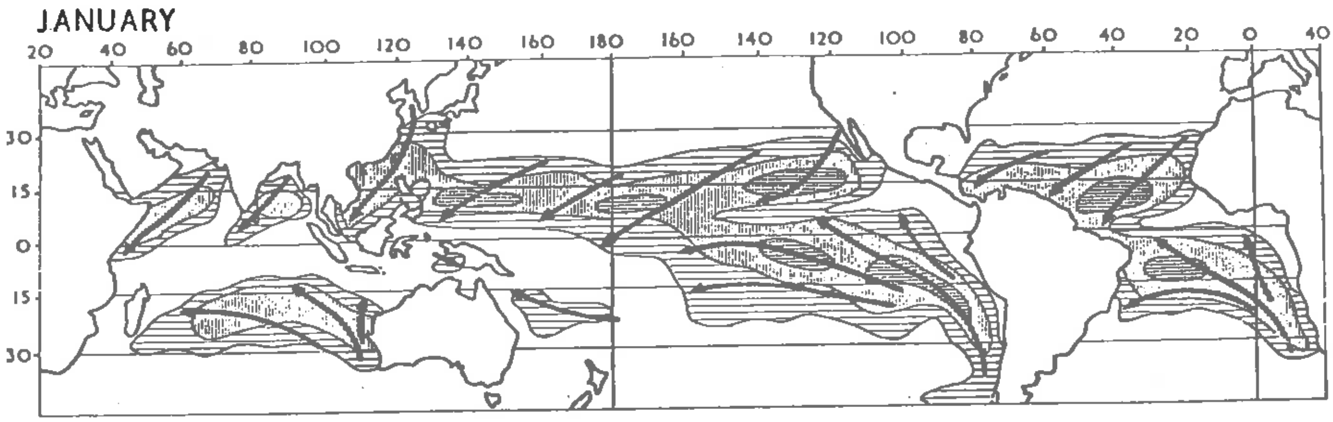
(After Riehl, 1979)



<u>Figure 5</u>. The trade-wind system of the world.

The isopleths are in terms of relatively constancy of wind direction and enclosed shaded areas where 50, 70 and 90 per cent of all winds blew from the predominant quadrant with Beaufort force 3 or more (over $6\frac{1}{2}$ knots).

(After Crowe, 1971)



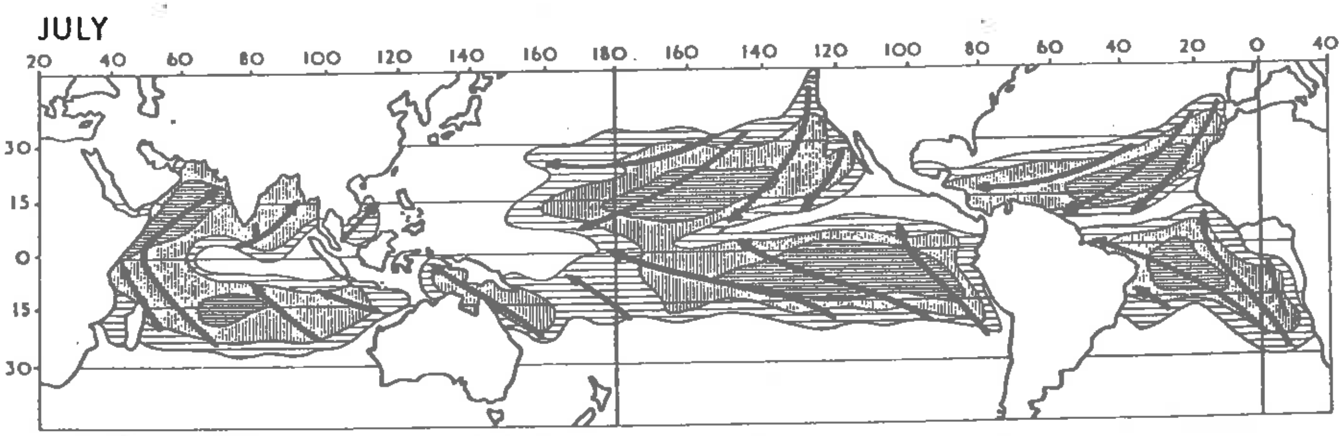


Figure 5 (continued)

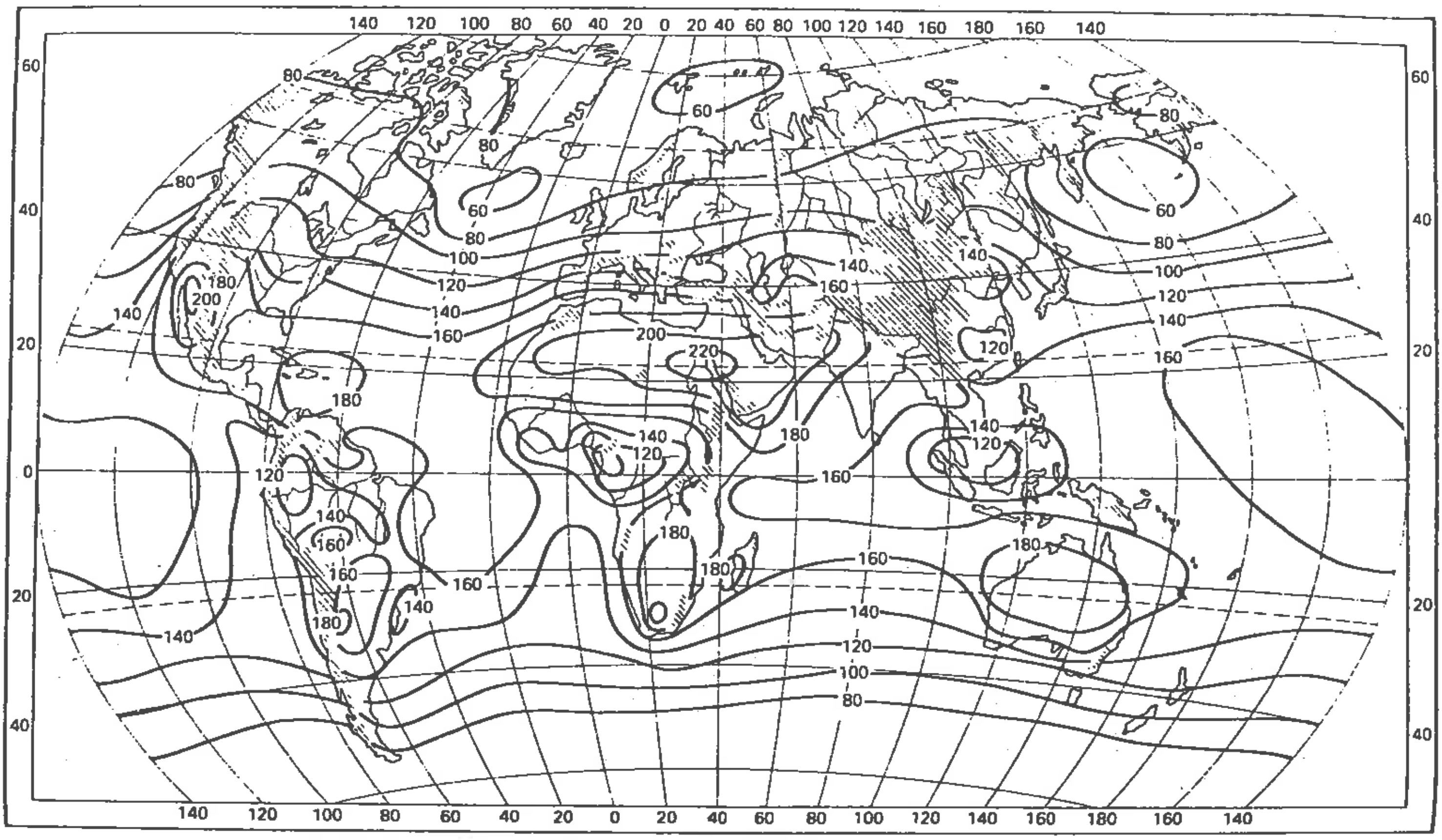


Figure 6. Average annual global radiation (Kcal/cm/yr).

(After Budyko, 1974)

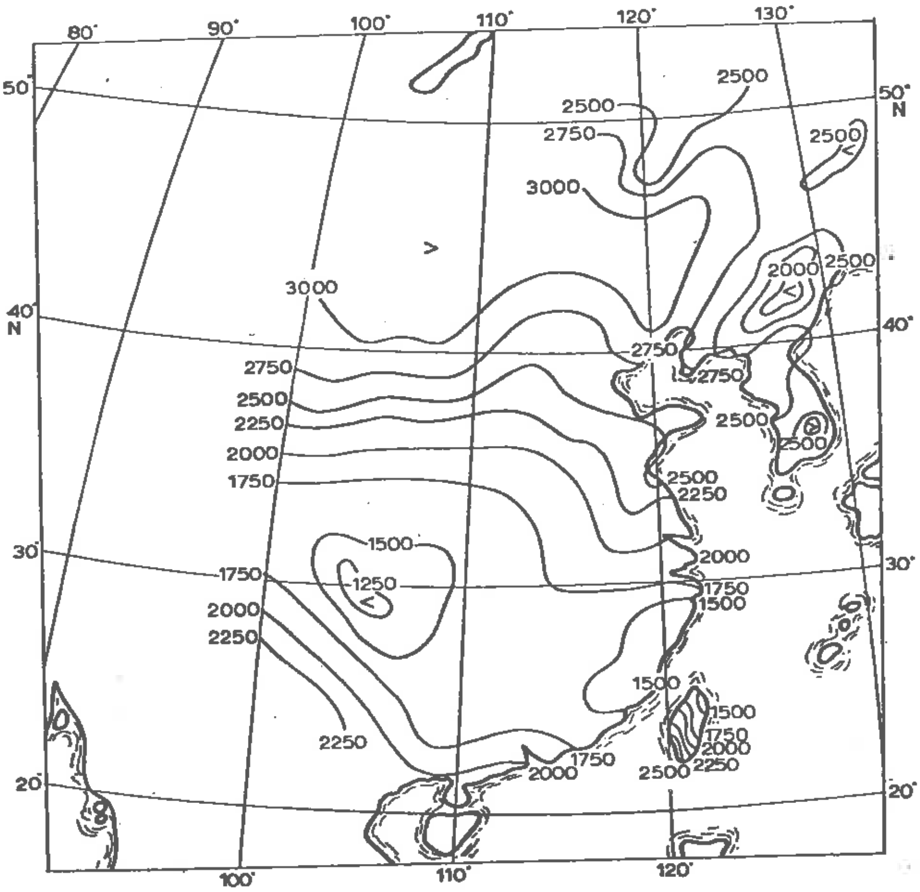


Figure 7. Mean duration (hours) of sunshine each year over Central and Eastern Asia.

(After Watts, 1969)

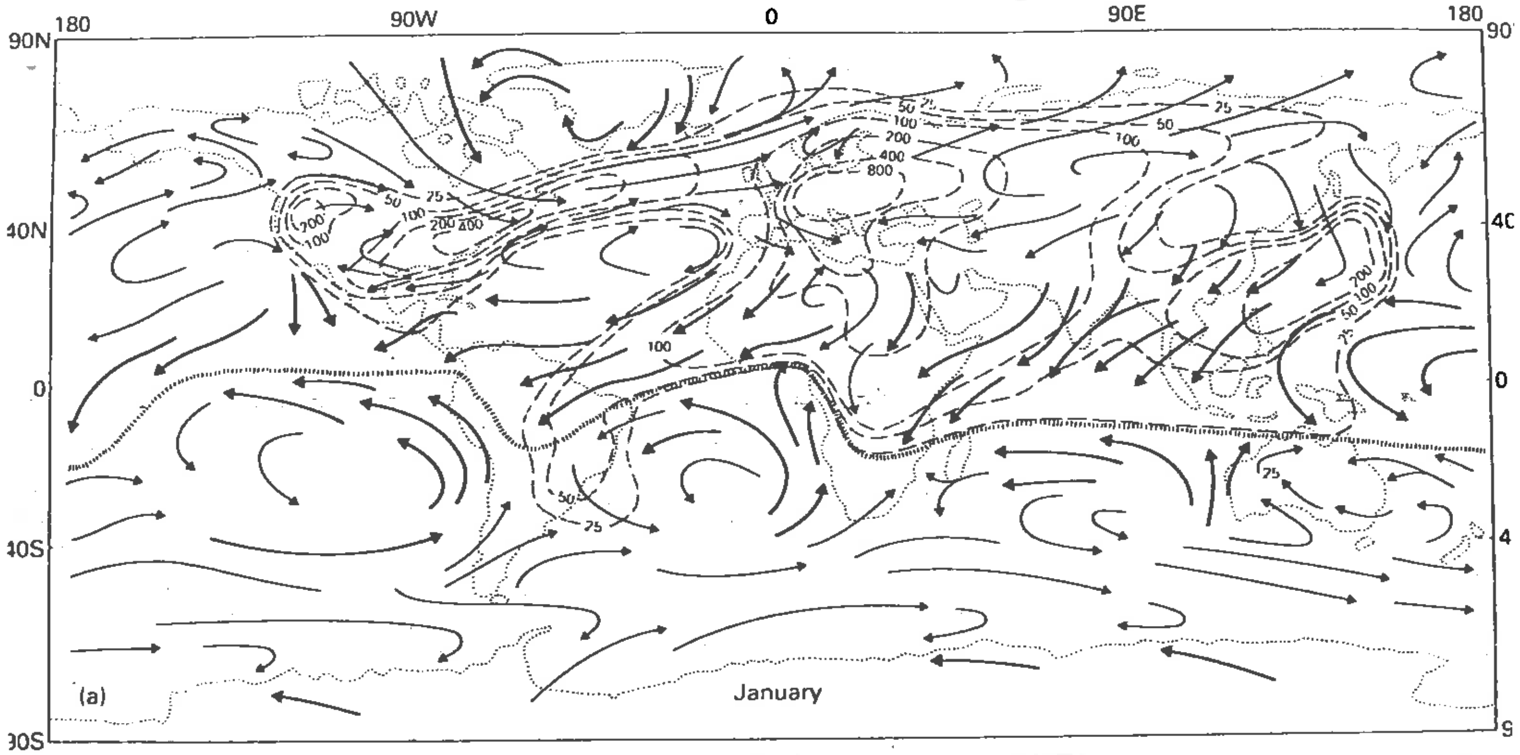
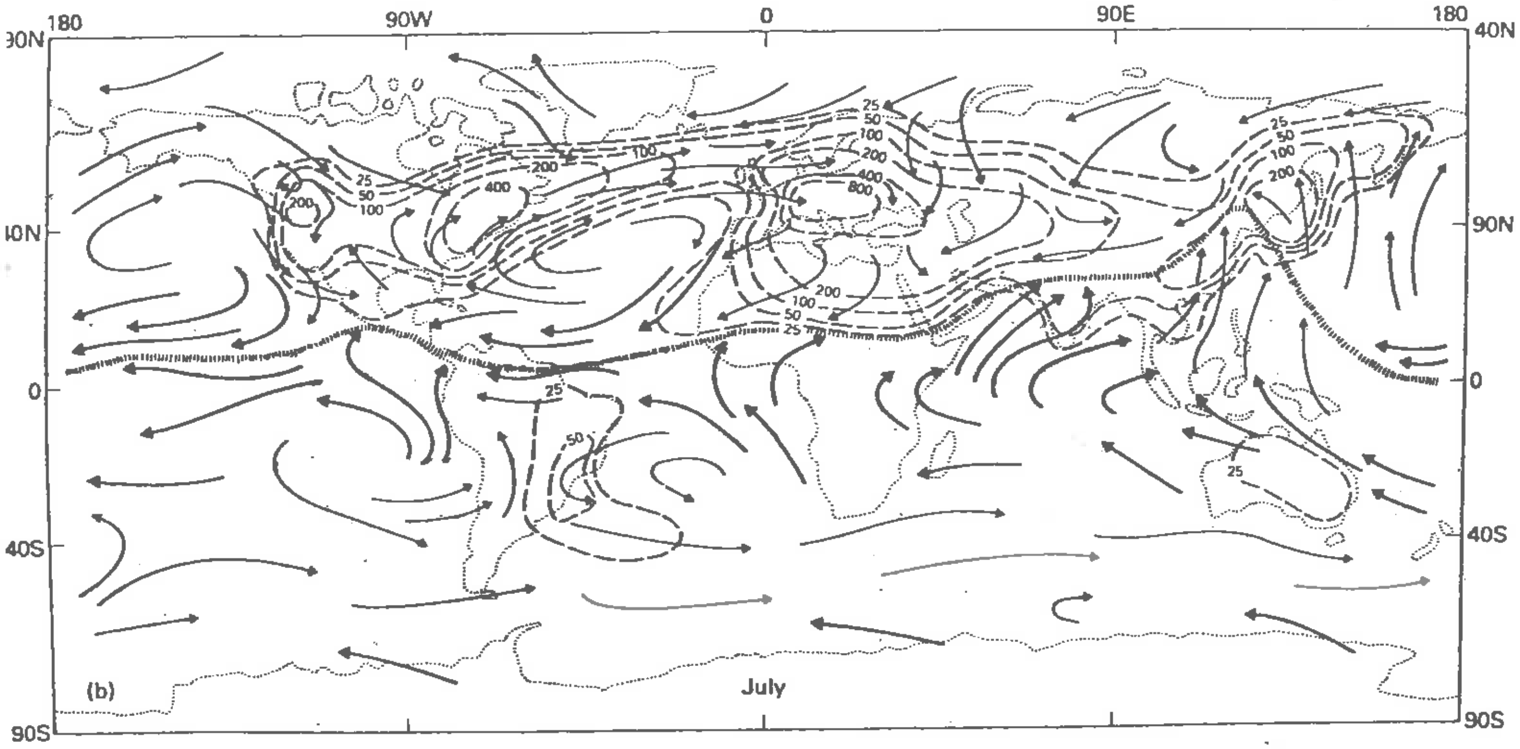


Figure 8(a). Estimated global patterns of man-made aerosol distribution for January.

See text for explanation.

(After Kellogg, et al., 1975)



<u>Figure 8(b)</u>. Estimated global patterns of man-made aerosol distribution for July.

See text for explanation.

(After Kellogg <u>et al</u>., 1975)

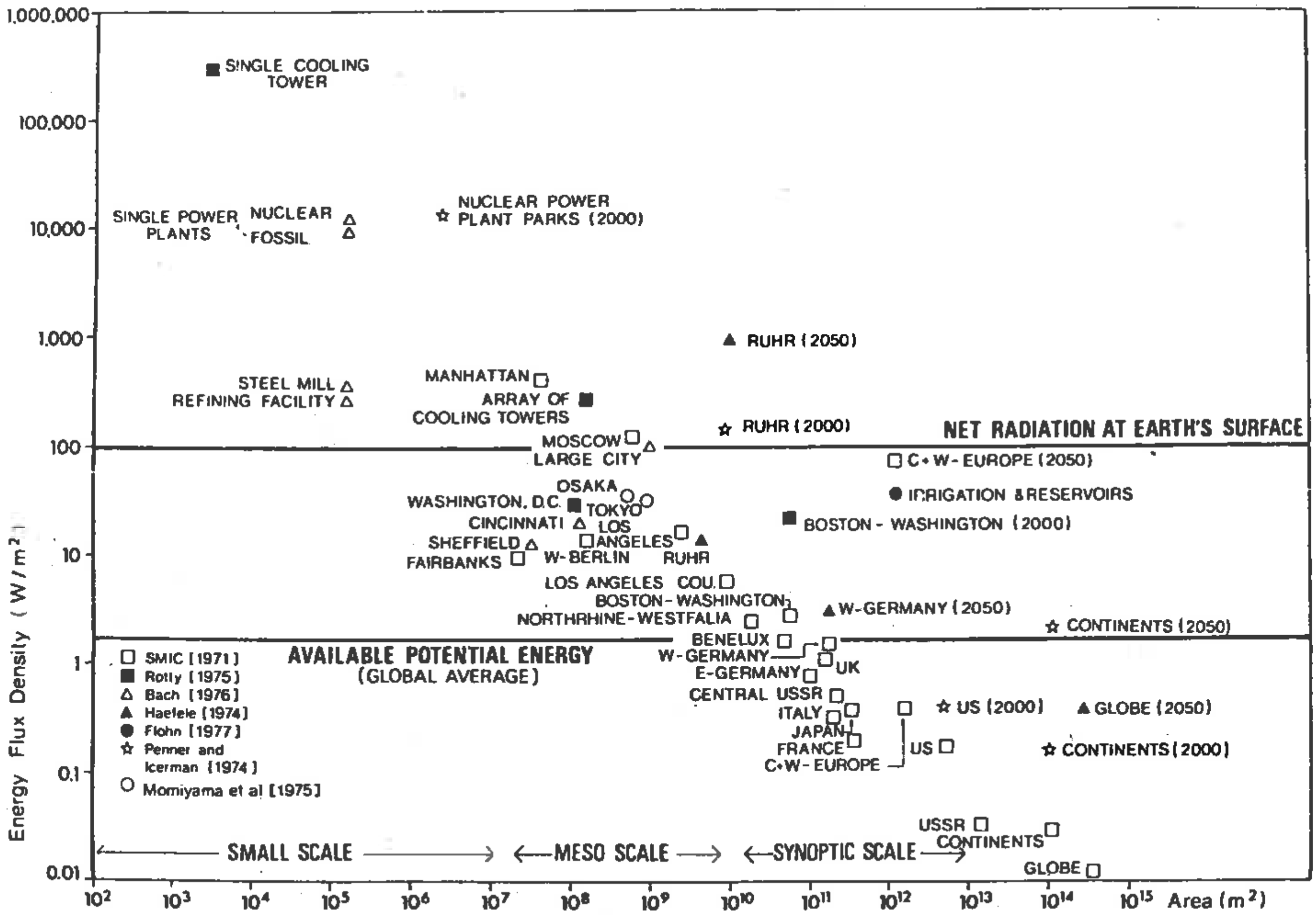


Figure 9. Energy flux densities related to man's activities c. 1970.

(After Bach, 1979)

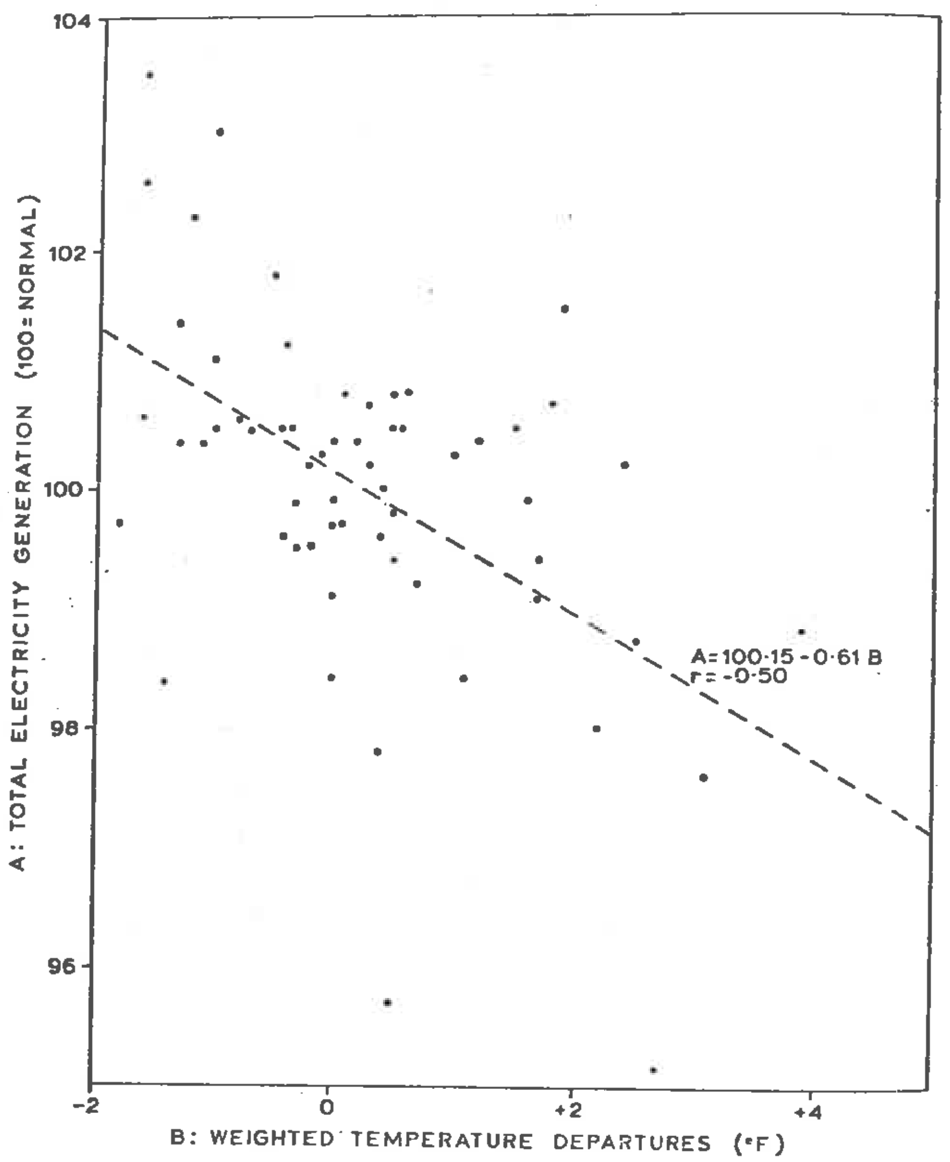


Figure 10. Monthly New Zealand electricity generation and associated weighted temperature departures, April-September, 1961-70.

(After Maunder, 1974)

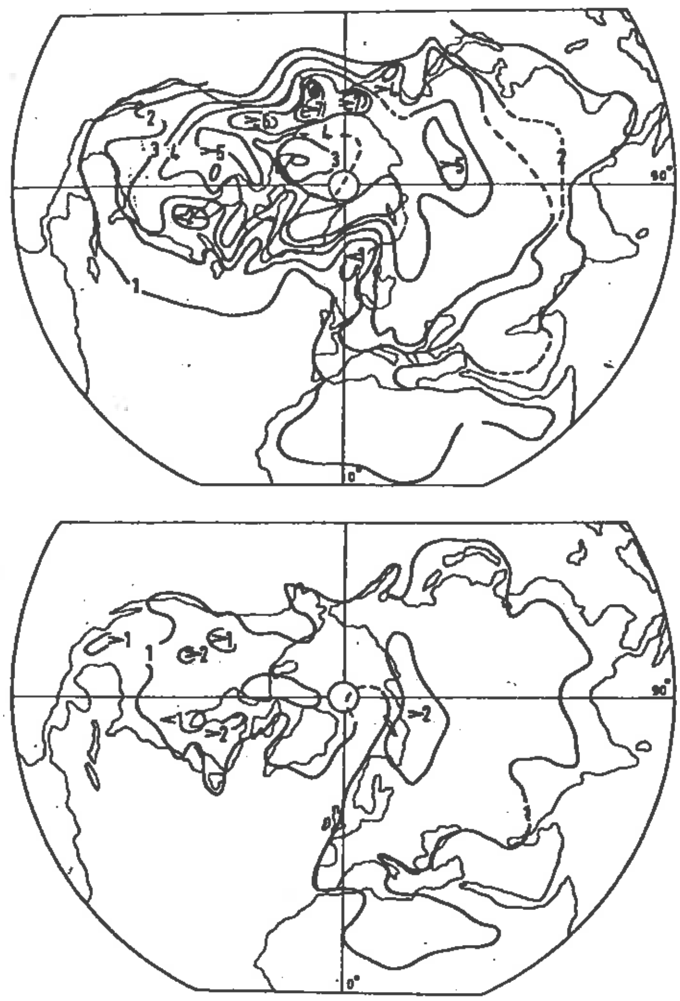


Figure 11. The interannual variability of monthly mean air temperature over the northern hemisphere.
Upper: January
Lower: July.

(After Craddock, 1964)

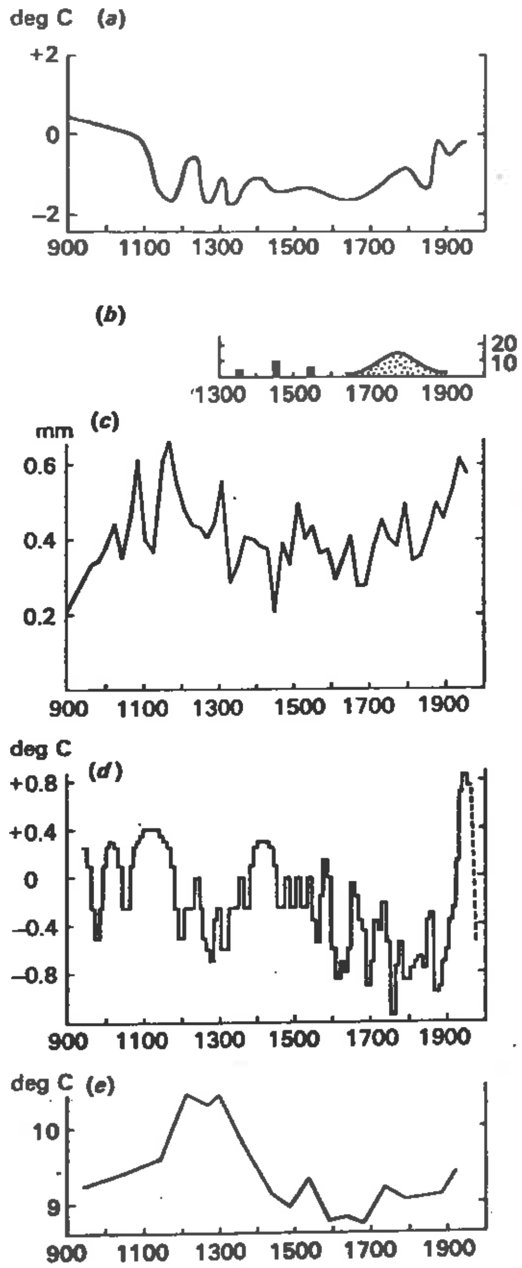


Figure 12. Climatic changes in the Northern Hemisphere over the last millenium.

(a) Temperatures in China (departures from present day, ^0C). (After Wen-Hsiung, 1974)

(b) Prolonged rains (frequency/50 years) in Iwate, Japan. (After Yamamoto, 1972)

(c) Ringwidth of bristlecone pine, White Mountains, California. (After La Marche, 1974)

(d) Mean annual temperatures (departures from average, ^0C) in Iceland. (After Bryson, 1974)

(e) Mean annual temperatures in central England. (After Lamb, 1965)

(After Pittock, et al., 1978).

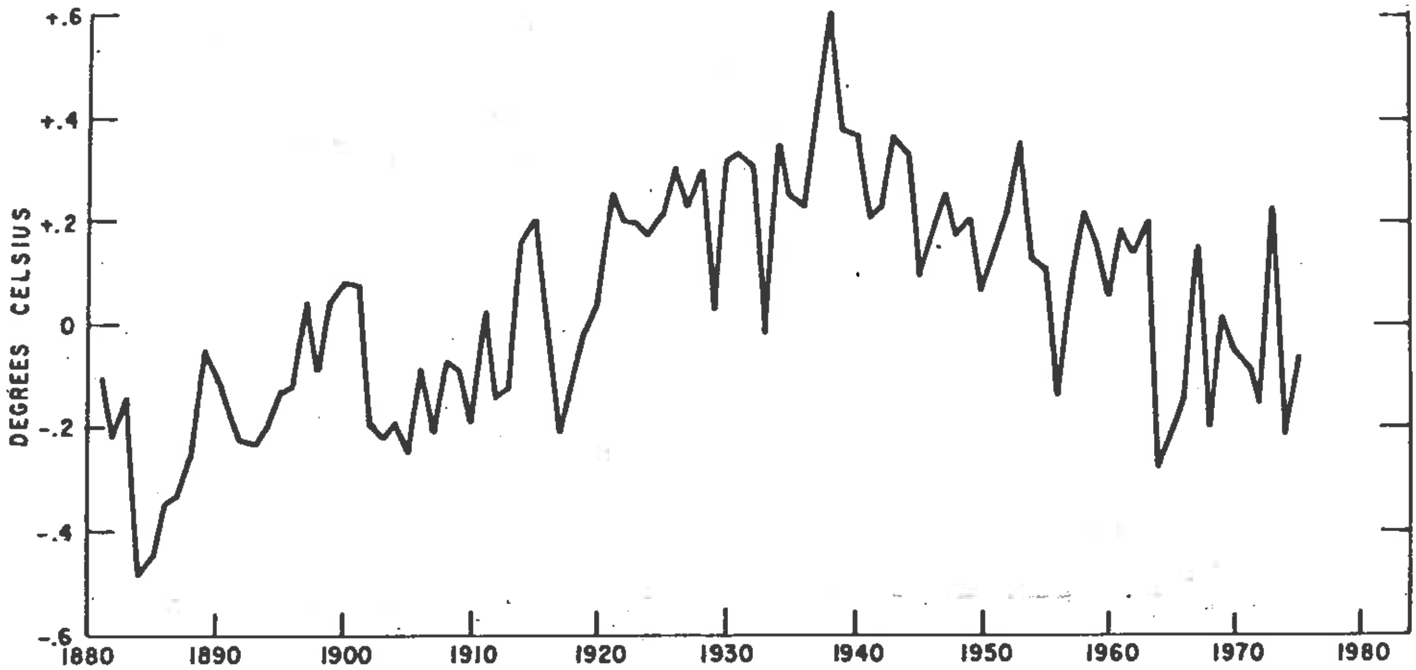


Figure 13. Recorded changes of annual mean temperature of northern hemisphere.

(After Mitchell, 1977)

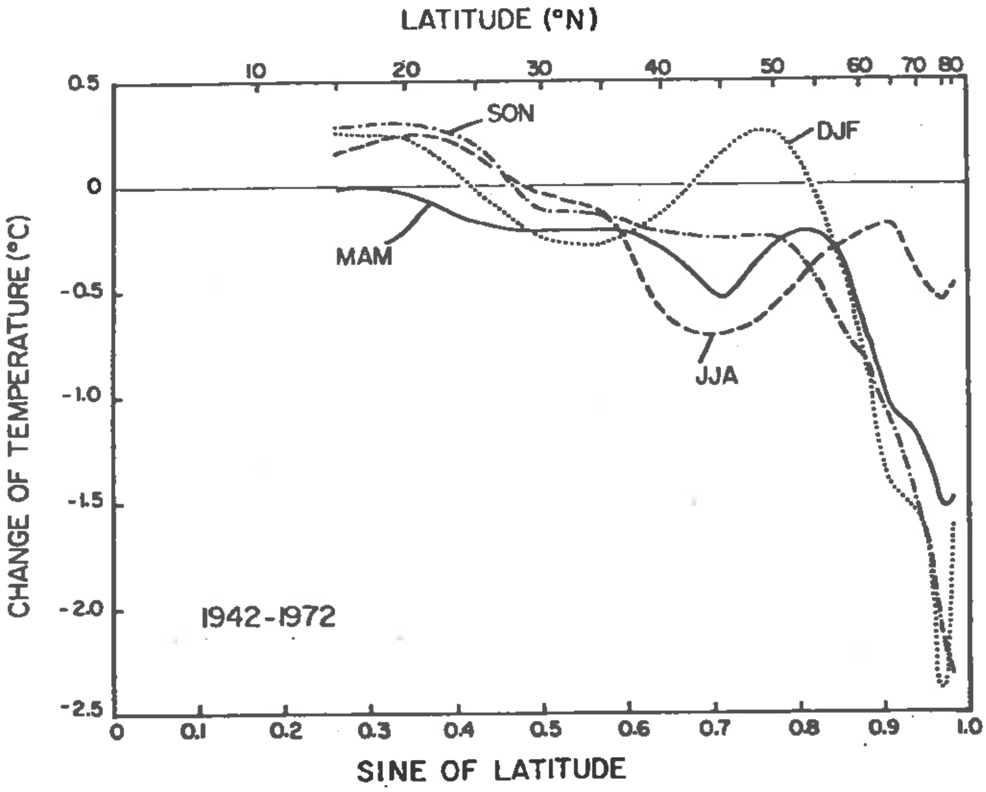


Figure 14. Meridional profile of the change in each season from 1942 to 1972 of zonal mean temperature (^{0}C) in 31 years.

(After Williams and van Loon, 1976)

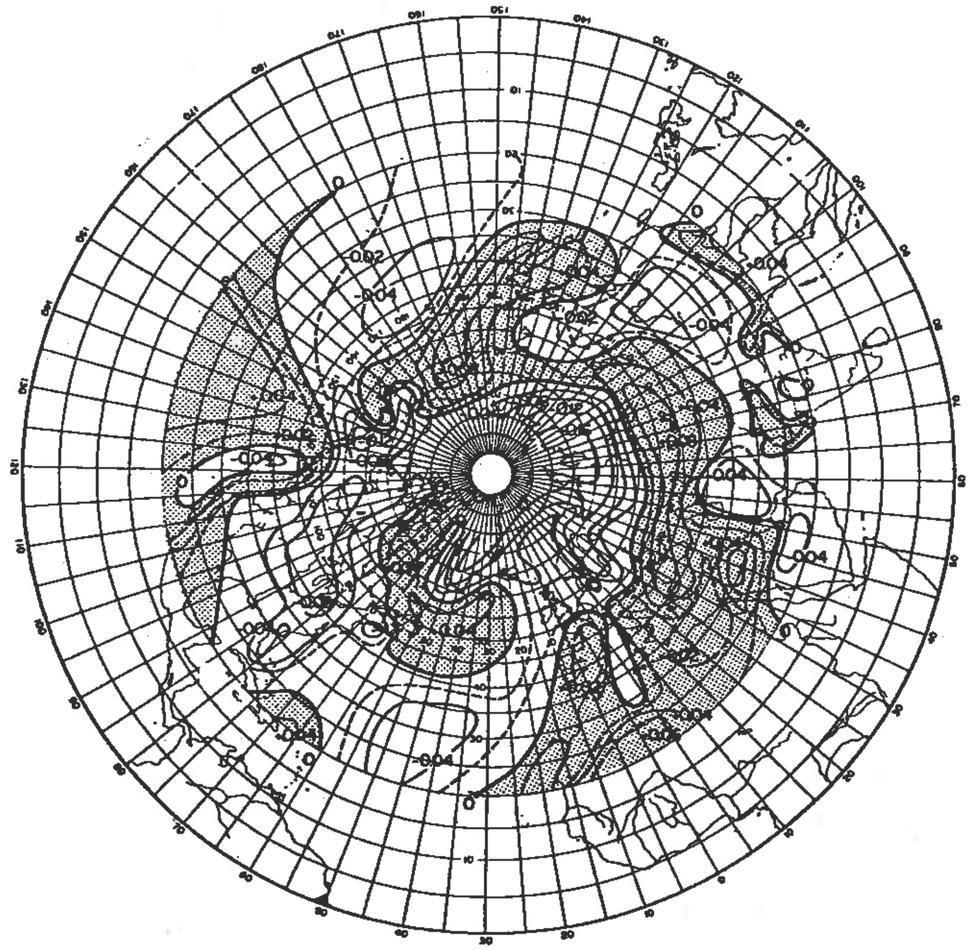


Figure 15. Isopleths of the slope of the regression line of winter mean temperature for 1942-1972 ($^0C\ yr^{-1}$).

(After van Loon and Williams, 1976a)

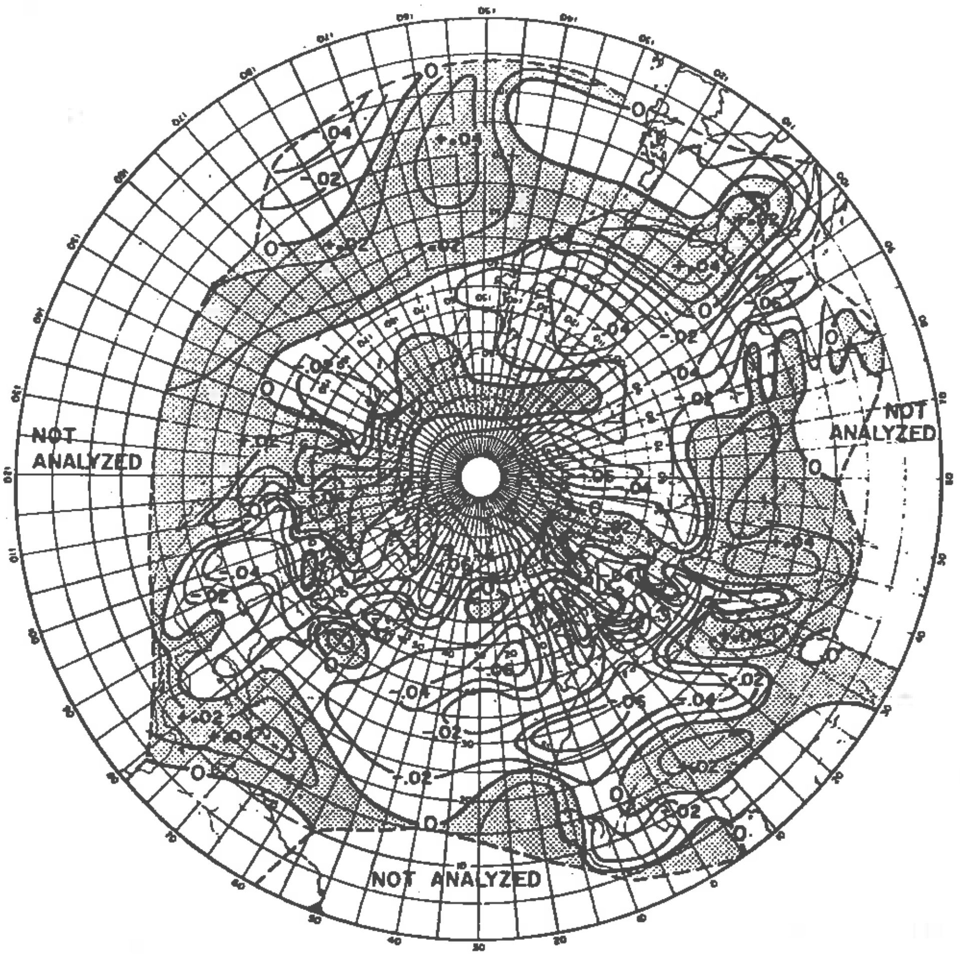


Figure 16. Isopleths of the slope of the regression line of summer mean temperature for 1942-1972 ($^{0}C\ yr^{-1}$).

(After van Loon and Williams, 1976b)

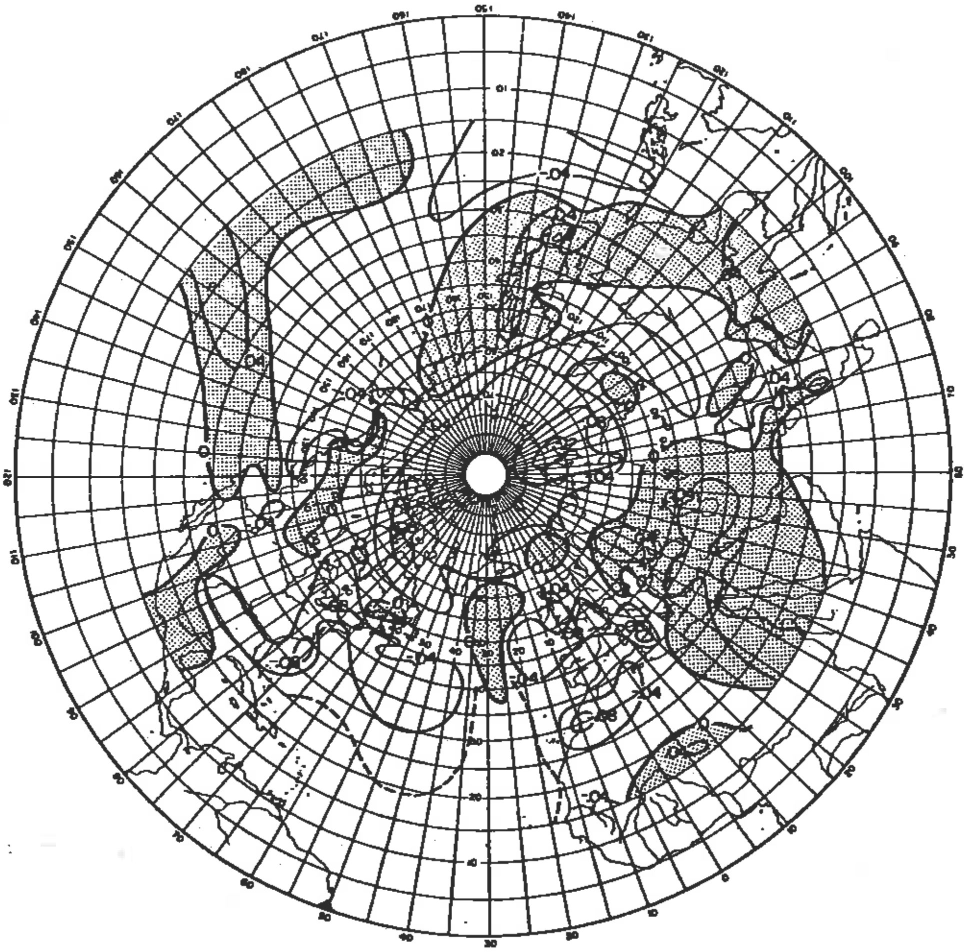


Figure 17. Isopleths of the slope of the regression line of spring mean temperature for 1942-1972 ($^{0}C\ yr^{-1}$).

(After Williams and van Loon, 1976)

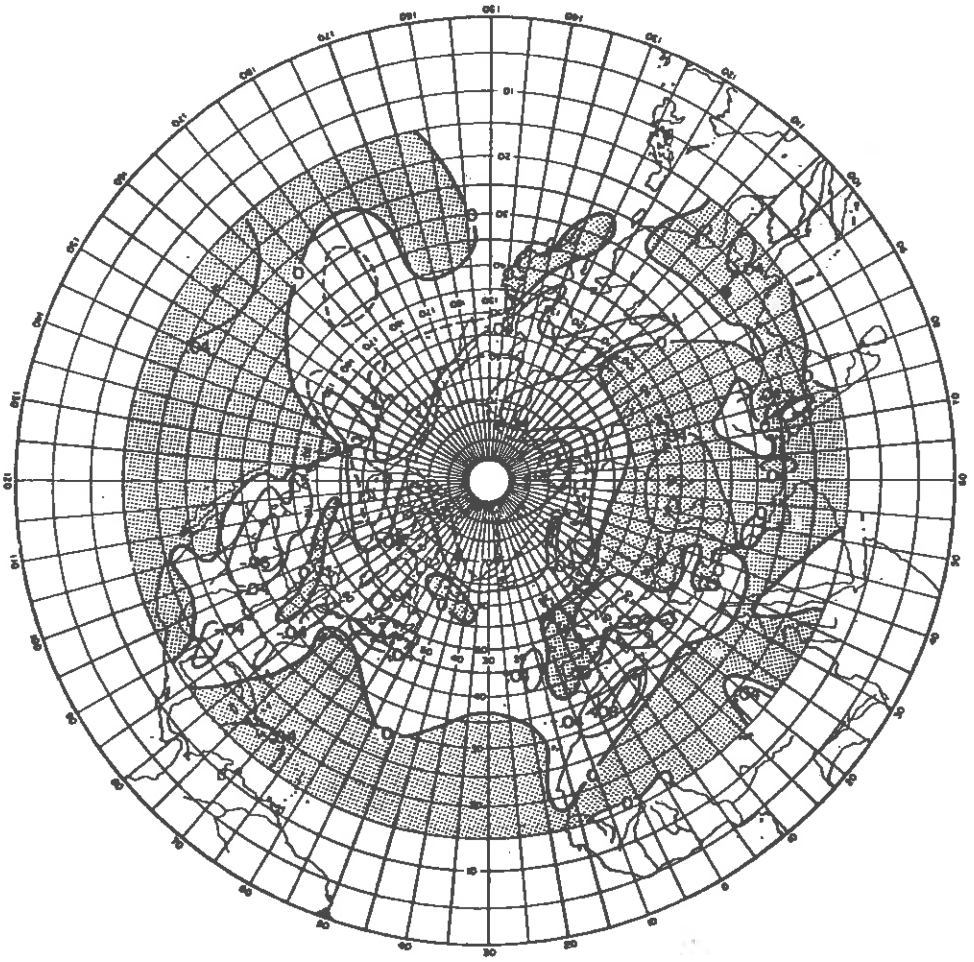


Figure 18. Isopleths of the slope of the regression line of autumn mean temperature for 1942-1972 ($^{0}C\ yr^{-1}$).

(After Williams and van Loon, 1976)