Table A3 Typical properties of aerosols in different regions*

Region	Total number (cm^{-3})	Mass <1 μm ($\mu g\,m^{-3}$)	Mass 1–10 μm ($\mu g\,m^{-3}$)
Urban (pollution)	1×10^5–4×10^6	30–150	70–150
Rural	2×10^3–1×10^4	3–8	5–30
Remote continental	1×10^2–1×10^4	0.5–3	1.5–7
Remote marine	1×10^2–4×10^2	1–4	10–35

* Derived from Seinfeld and Pandis (1998).

conditions in remote continental regions the mass concentrations can be as low as one microgram per cubic meter or less. In areas near major dust storms concentrations of 1 gram per cubic meter or more have been observed.

Aerosols have both a direct and an indirect role in the radiative forcing of climate. The direct forcing results because they can absorb and scatter both infrared and solar radiation in the atmosphere. Indirect forcing occurs because aerosols can affect and change the processes that control cloud and precipitation formation, which in turn can affect the radiative properties of the atmosphere. There has been strong interest in aerosol forcing. This is because the forcing is negative for most aerosol types, rather than the positive forcing associated with the major radiatively active trace gases, such as carbon dioxide, methane, nitrous oxide, halocarbons and tropospheric ozone. Once again, size distribution and chemical composition are critical factors in the efficiency of aerosols in affecting these forcings. While significant progress has been made in recent years in determining the importance of aerosols of various types in radiative forcing, the uncertainties are still quite large. The most recent Intergovernmental Panel on Climate Change (IPCC, Houghton et al., 2001) report has developed new estimates of aerosol forcing, and some of their results are shown in Table A2. Note that the numbers given represent the mean direct radiative forcing for the aerosols described (except for mineral dust, where only a range was given), but the uncertainties in these estimates range from a factor of 2 to 3. Aerosol types where the evidence shows negative forcing include sulfate aerosols, organic carbon aerosols, and aerosols from biomass burning. The sign of the net forcing for mineral aerosols is still uncertain. Black carbon aerosols appear to cause a positive forcing. Note also that the indirect forcing is estimated to be from 0 to $-2.0\,W\,m^{-2}$. The values for aerosol forcing in Table A2 can be compared with the best estimate for carbon dioxide forcing of $+1.46\,W\,m^{-2}$.

Robert A. Duce

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Cross-references

Air Pollution Climatology
Albedo and Reflectivity
Cloud Climatology

AFRICA: CLIMATE OF

Africa covers an area of more than 30 million km^2 and is second in size only to Asia. Of all continents it is the most symmetrically located with regard to the equator, and this is reflected in its climatic zonation. The coastline is remarkably smooth and the continent has been called a giant plateau, since there is a relative absence of very pronounced topography, although some high mountains exist, especially in the East African region (Kilimanjaro, 5894 m; Mount Kenya, 5199 m; and the Ruwenzoris, 5120 m). Lake Victoria, astride the equator, covers an area of 70 000 km^2 and is exceeded in size only by Lake Superior among the world's fresh water lakes.

We will note below how certain evidence can be used to reconstruct the early climate of Africa, but climatic observations really only began with the European explorers of the late eighteenth and nineteenth centuries. Then, in the last few decades of the nineteenth century, meteorological services were formed that began systematic observations at a network of stations. In most cases the meteorological service followed the meteorological practices of the colonial or governing power and this characteristic has tended to persist, even after independence was obtained. A number of the countries have suffered from internal disturbance since independence, a fact often leading to a hiatus in the records. Nevertheless, the standard of observation generally has remained high at the first-order or synoptic stations, but care must be taken when using data from many of the cooperative or second-order stations.

Weather controls

As in other regions of the globe, the pattern of solar radiation is the major control of climate. However, the nature of the air–surface interface and topography also play important roles. Although ocean currents help to determine the climate of some narrow bands of land, it is by appreciating the nature of the air masses reaching a region that one can begin to understand the observed climatic pattern.

Most of the time the continent is affected by tropical air masses, often maritime (moist) in nature, but in certain areas and during certain months they can be of continental (dry) origin. At the extreme latitudinal boundaries of the continent, in the littoral region of the Mediterranean Sea, and in the area around and east of Cape Town, the effects of polar air masses cannot be ignored at the time of low sun. The terms high sun (summer) and low sun (winter) are often used when discussing reasonal variation in the topics.

Temperature, at a particular station, is a rather conservative element with a relatively small annual range, and wind speeds are normally low compared to areas in higher latitudes. Precipitation, mostly rainfall, is the significant feature of the African climate. For rainfall to occur two criteria must be met – an adequate amount of water vapor within the atmosphere and the initiation of a cooling mechanism.

The cooling mechanism is usually obtained through the ascent of a large parcel of air. Such uplifting is generally due either to topography or to horizontal convergence of the air, which is simply the coming together of air parcels or masses. The ways in which such horizontal convergence can occur over Africa are detailed in Johnson and Morth (1960).

There are four important phenomena that determine rainfall amounts and patterns over the tropical continents: (1) the intertropical convergence zone (ITCZ), (2) the equatorial trough (ET), (3) easterly waves, and (4) tropical cyclones. The latter two play relatively minor roles over Africa.

The ITCZ, defined as a surface discontinuity separating the trade winds of the two hemispheres, can be identified readily on climatic charts, but it is not easily found on daily weather maps. The confluence of convergence of the usually relatively moist air masses leads to rainfall patterns that reflect the seasonal migration of the sun, with a time lag.

The equatorial trough (ET), the zonal pressure minimum, is detected up to an average height of 500 mbar (5500 m) with a mean position near the equator at that height. At lower levels there is evidence of a pronounced shift in location with season.

Weather situations

To set the stage for an appreciation of the various climatic patterns experienced, it is helpful to understand the weather situations dominant during certain months.

January

A broad low-pressure region is noted north of the equator with only light winds in evidence. In the upper air the divergent northeasterlies act to suppress rainfall. The surface position of the ET is north of the rain belt in Central Africa whereas, in the southern sector, upper-level troughs cause heavy rains over the Angolan plateau. Frontal activity brings rain to the North African coast.

April

There has been a movement of the ET northward from the January situation. In West Africa the ET becomes identified more easily on the daily surface charts. Thompson (1965) considers the rainfall now to be the result of many complex interplays among synoptic processes and dismisses the concept of a continuous zonal belt of rainfall moving northward.

July

The position of the surface ET is now at about its furthest north, near 20°N. There is a meridional (longitudinal) pressure gradient extending from the high-pressure belt of the southern hemisphere to the intense heat lows of Arabia and North Africa. In East Africa the topography leads to periods of convergence above the 700 mbar (3000 m) level, giving rise to the wettest month, while there is subsidence at 850 mbar (1500 m), where little rainfall is reported.

October

The rain belt is now moving southward, while a new trough begins to develop over Somalia and the Arabian Sea. Like April, this is a transitional month between the extremes of January and July.

Continental patterns of important climatic elements

The best method of identifying analogous climatic zones is to consider aspects of each of the important elements separately and then to combine them to obtain the overall picture. The elements selected here are temperature, precipitation, humidity and radiation.

Temperature

The mean annual temperature range (MATR), the difference between the mean temperatures of the hottest and coldest months, is of small magnitude over most of the continent, being less than 6°C over about half the continent. Its minimum value is 1.4°C at Barumbu in northernmost Zaire whereas the greatest is 23–24°C in parts of the Algerian Sahara. The dependence of the MATR on the continentality of the station, as well as its latitude, is shown in Table A4.

The mean annual diurnal temperature range is extremely dependent on continentality, as shown in Figure A3. Nearly all the coastal regions exhibit values of below 10°C, whereas in the central Sahara the range reaches 20°C, one of the highest values for any region of the world.

Actually, the best measure of the temperature variation is the highest mean monthly maximum temperature (H) and the lowest mean monthly minimum temperature (L). The patterns of these two variables are given in Figures A4 and A5. Figure A4 shows that it is only north of the equator where values exceeded 35°C and only in parts of the foggy coastal strip of southwestern Africa where values less than 20°C were reported. In Figure A5 the effects of elevation and latitude are more evident than those of continentality. Values below 5°C are unusual and only at high altitudes (over 1000–1500 m) in Algeria, Morocco

Table A4 Mean annual temperature range (MATR)

	Latitude E	Longitude N	MATR (°C)
Port Harcourt	7°01′	4°46′	2.5
Lokoja	6°44′	7°48′	3.6
Kano	8°32′	12°32′	5.8
Zinder	9°00′	13°48′	9.4
Agadez	7°59′	16°59′	13.3
Tamanrasset	5°31′	22°42′	16.7
Ourgla	5°20′	31°54′	23.3
Biskra	5°44′	34°51′	22.7
Constantine	6°37′	36°22′	18.3
Philippeville	6°54′	36°52′	14.2

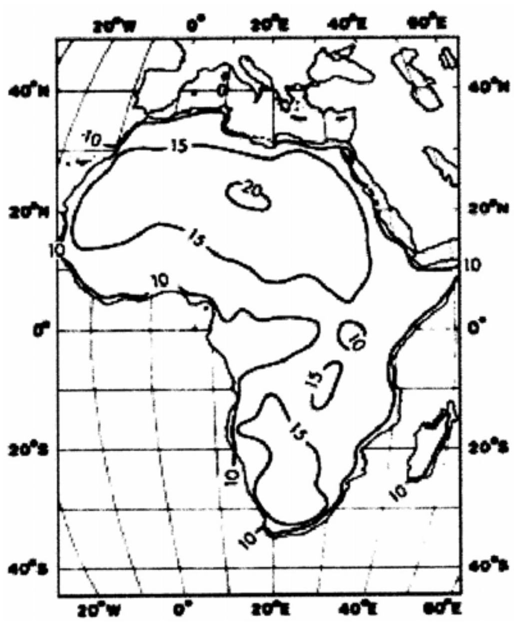

Figure A3 The mean diurnal temperature range (°C).

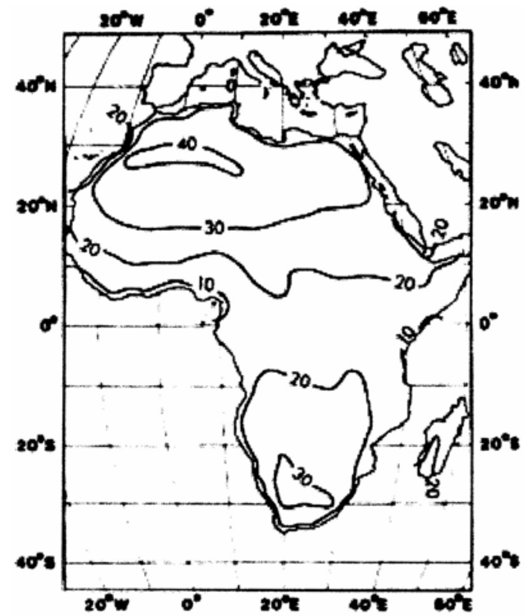

Figure A5 The lowest mean monthly temperature (°C).

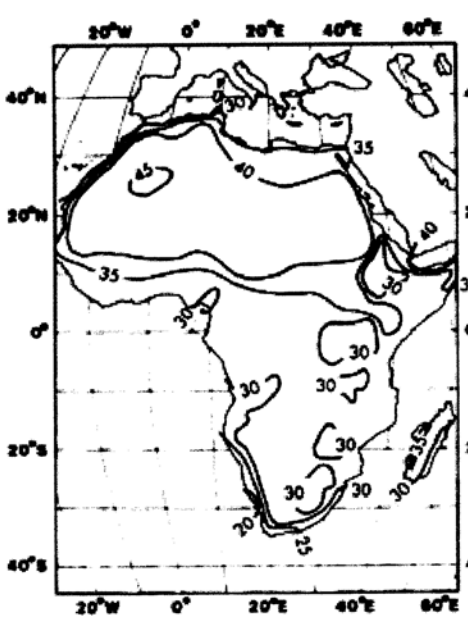

Figure A4 The highest mean monthly temperature (°C).

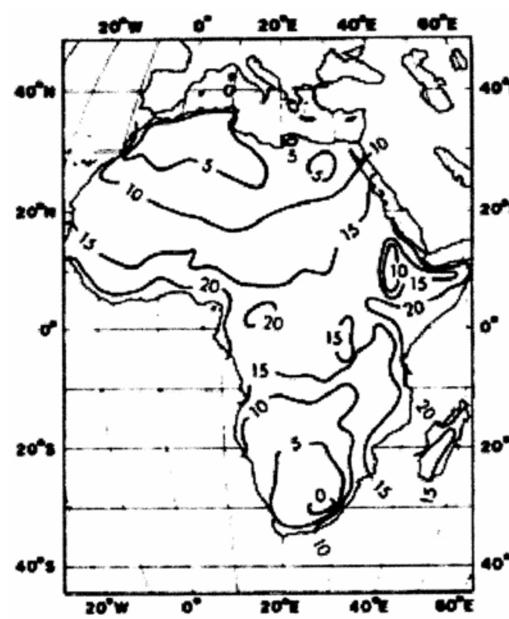

Figure A6 The difference between the highest mean monthly maximum temperature and the lowest mean monthly temperature.

and South Africa does L go below 0°C. The largest value is 26°C noted at Dallol, Ethiopia. The mean annual temperature variation (MATV), defined as H − L, which is depicted in Figure A6, is a combined measure of both annual and diurnal range and shows a relationship with both latitude and continentality. Again, the maximum values (above 30°C) occur in drier areas, the greatest being at Adrar in western Algeria, with 42°C. As would be expected, the equatorial littoral yields the lowest values, reaching only 8°C in Liberia and Sierra Leone.

Precipitation

Because both the ITCZ and the polar front lows exhibit large spatial movements, a basic seasonal pattern of precipitation can be identified on the continent. However, the complexities introduced by topography, upper-air conditions, ocean currents and inland lakes, among others, make the detailed pattern extremely complicated. An example of this is given by Griffiths (1972) for East Africa, whereby overlaying the spatial patterns of mean monthly precipitation, 52 separate regions with 30 different rainfall seasons evolve.

Over most of the continent the seasonal distribution of precipitation exhibits the single significant maximum pattern, such as shown in Table A5. The season of maximum amount is generally around the time of high sun. In Figure A6 those regions in which three consecutive months receive at least 50% of the annual rainfall are shown. Only in the eastern sector of the Mediterranean coast is there a maximum at the time of low sun, but amounts involved are very small.

In the central belt of the continent most stations exhibit some degree of double maxima. However, the areas in which there is a really significant double swing during the year are quite small (Figure A7). For this illustration, significance is defined as occurring when the difference between the secondary maximum and secondary minimum exceeds 5% of the annual mean (see example of Lagos in Table A5), and this criterion limits the regions to just two. The sector in the Horn of Africa is mostly semiarid, except around Nairobi, Kenya. For stations with annual mean rainfall of over 1000 mm, Kitui, Kenya, is unique; its mean monthly totals (mm) being 41, 24, 118, 244, 56, 5, 3, 5, 0, 82, 304 and 143, giving a 22% swing.

The average annual rainfall totals show a wide range (roughly 0–10 000 mm), exhibiting a decrease away from the equatorial regions to reach a minimum around 20–30° latitude, then showing a slight increase (Figure A8). Since snow and hail amounts are generally small, all precipitation can be considered as rain. Nevertheless, snowfalls have been recorded in the Sahara, as far south as 15°N. Some falls have been quite heavy and reference to Dubief (1959, 1963) will give fuller details and some interesting photographs.

A distinctive feature of tropical rainfall is its large variability, interpreted as the difference within monthly, seasonal and annual totals. The station of Makindu, Kenya, is outstanding in this respect. Although its mean annual value is 610 mm, it has recorded as low as 67 mm and as high as 1964 mm of precipitation. On the other hand, April, its wettest month (111 mm average), has had amounts ranging from 822 mm, which exceeds the annual mean, to 0 mm. In Figure A9 a measure of annual rainfall fluctuations is depicted. Use is made of the relative variability statistic, V_r, defined as mean deviation/mean:

$$V_r = \Sigma(X_i - \bar{X})/\Sigma X_i$$

where X_i is individual yearly amounts and $\bar{X}$ is the yearly mean. Values of V_r show dependence on the mean, $\bar{X}$, so data for 500 stations were used to compute the expected value of V_r as a function of $\bar{X}$, called $V_r(\bar{X})$, and comparing V_r for the station with its corresponding $V_r(\bar{X})$. Differences are given as a percentage of $V_r(\bar{X})$.

The great variability in certain areas of the continent can be illustrated further by two examples. Quseir, Egypt, has received 33 mm in a day – 11 times its average annual total; Lobito, Angola, had 536 mm of rain in one day – over 1.5 times its annual average fall of 330 mm.

Hail is not a common phenomenon on the continent, especially on the coast of the tropical regions. However, Maputo, Mozambique, experienced a very heavy fall in October 1977 that did considerable damage. Few places have more than five incidences annually, but a region around Kericho, Kenya, reports as many as 80 hailstorms per year. (Fresby and Sansom, 1967)

Thunderstorm days are frequent with over 20% of the continent reporting in excess of 100 annually. This band of 100 occurrences stretches from about Sierra Leone across the central area as far as Lakes Victoria and Malawi. There are a few locations where convective instability leads to annual values of more than 200, with Kampala, Uganda, 242; Bukavu, Zaire Republic, 221; and Calabar, Nigeria, 216 holding the top places.

Humidity

Relative humidity, as an expression of the atmospheric moisture condition, can be rather misleading because its impact on human comfort is dependent on the air temperature occurring at the same time. For this reason it is preferable to use the dew point temperature as an indicator since this shows little diurnal variation and can be related more readily to human comfort. Values in excess of around 21°C can be considered very sultry, and this isopleth is indicated by a thick line in Figures A10 and A11. Some scientists consider dew points above 18°C uncomfortable. With this threshold about 30% of the continent falls into this category in January and 25% in July.

Along the humid and hot coastal regions of Africa the trade winds and/or sea breezes provide reasonably comfortable conditions, contrary to most people's concepts of the humid tropics. When there is little wind, as is often the case inland, in cities or in wooded areas, the situation is quite enervating. For a good discussion of and information on human comfort conditions consult Terjung (1967).

Table A5 Seasonal distribution of precipitation

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Single maximum													
Algiers, Algeria	116	76	57	65	36	14	2	4	27	84	93	117	641
Kano, Nigeria	0	1	2	8	71	119	209	311	137	14	1	0	873
Mbeya, Tanzania	199	165	161	116	17	1	1	1	3	15	52	152	883
Pretoria, South Africa	117	101	78	46	25	9	8	6	25	63	110	120	708
Wau, Sudan	0	4	20	69	132	170	199	234	179	130	8	0	1145
Double maxima													
Lagos, Nigeria	40	57	100	115	215	336	150	59	214	222	77	41	1625

Note: Double maxima significance (222 − 59)/1625 = 10%. See text.

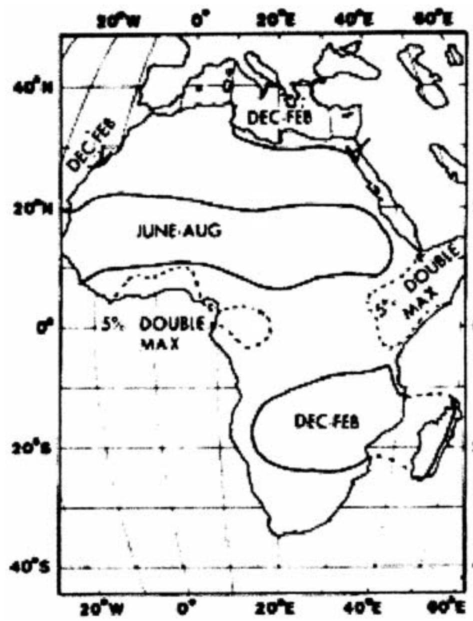

Figure A7 The 3-month period of maximum precipitation and those areas with a significant double maximum distribution.

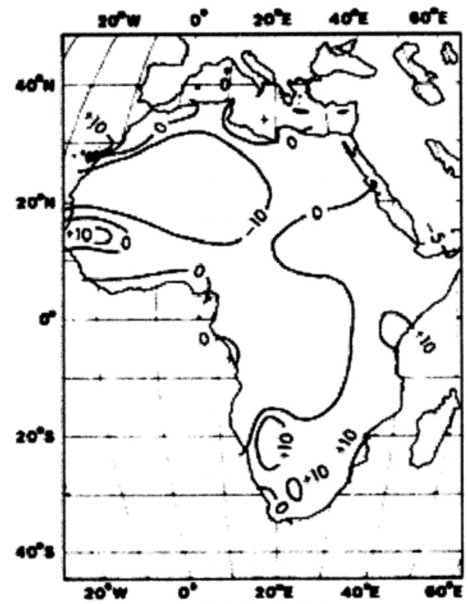

Figure A9 Variation of annual precipitation values in per cent (see text for details).

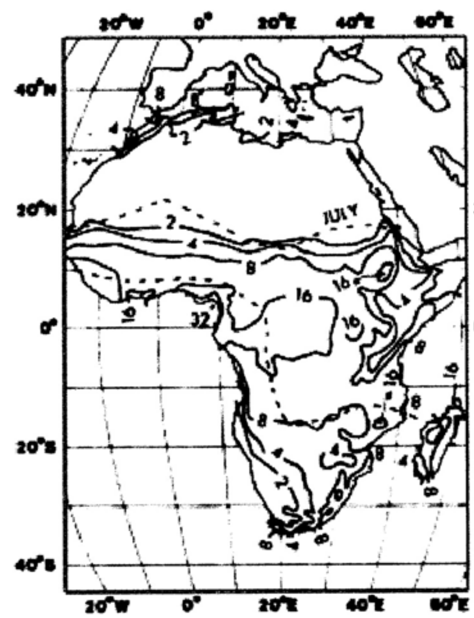

Figure A8 Mean annual precipitation (mm).

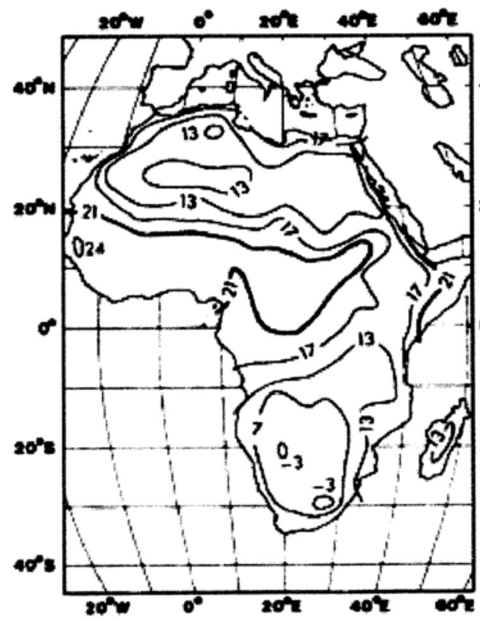

Figure A10 Mean January dewpoint temperature (°C).

Radiation

Africa extends from 38°N to 35°S, so that the annual fluctuation of solar radiation at the top of the atmosphere is small compared with that in higher latitudes. Mean annual global radiation (solar radiation measured on a horizontal plane at the surface) varies from nearly 600 ly day^{-1} in the Sahara–Nubia area to something less than 400 ly day^{-1} around Gabon, the Algerian coast and East London, South Africa.

Climatic zones

Using the findings of the earlier sections, it is possible to identify eight important climatic zones in Africa: (1) tropical wet; (2) tropical, short dry spell; (3) tropical, long dry spell; (4) tropical desert; (5) tropical highland; (6) subtropical desert; (7) subtropical, summer rain; and (8) subtropical, winter rain.

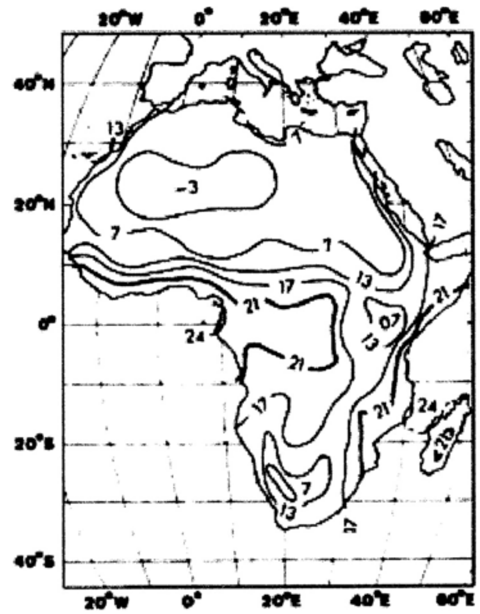

Figure A11 Mean July dewpoint temperature (°C).

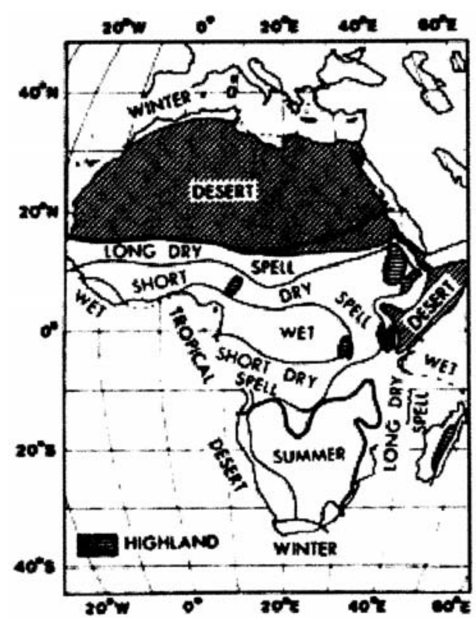

Figure A12 A simple climatic classification. Thick lines (N and S) indicate tropical boundaries (see text for details).

In addition, smaller zones of subtropical, uniform rain and subtropical highland can be found. The eight major zones are shown in Figure A12. For these purposes "tropical" designates that the mean temperature of each month is 18°C or greater; "desert" occurs when the mean annual rainfall (cm) is less than $16 + 0.9\overline{T}$, where $\overline{T}$ is the mean annual temperature (°C), and "highland" is where the altitude causes the region to be classified in a different thermal zone from what it would be if at sea level.

The tropical wet climate (Kisangani, Table A6) exhibits some rain in all months. Temperatures are uniformly high all year round and the conditions are very enervating, although sea breezes and/or trade winds can reduce the stress along the coast. The tropical rainforest is found in abundance in this zone.

Surrounding the first zone is the tropical, short dry spell climate (Kinshasa, Table A6). Here a period of 3–5 dry months is experienced. Precipitation and temperature are still high, but the annual temperature range tends to be larger than in the wet climate. Vegetation changes from forest near the boundary with the previous zone to deciduous woodland on the drier side although, because this is an important climate for agriculture, much clearing has taken place.

The tropical, long dry spell climate (Niamey, Table A6) is on the equatorial side of the desert regions and has low rainfall for at least 6 months. Rainfall amounts are less than in the two zones discussed above and temperatures show a much larger seasonal swing. The area is susceptible to drought and at such times the often marginal agriculture suffers tremendously. Vegetation is normally savanna and scrubland. The northern belt is referred to as the Sahel, a region in which famine has afflicted millions of inhabitants. The extreme variability of rainfall amount and frequency is a characteristic of the zone (Todorov, 1984).

Tropical desert climates (Obbia, Table A6) are not common, the biggest region being in the Horn of Africa where the prevailing winds, NE at low sun and SW at high sun, ensure that very few moist air masses reach the area.

The tropical highlands climate (Nairobi, Table A6) offers relief from the tropical heat, as well as a decrease in absolute humidity. Precipitation amounts can change quite rapidly in short distances as exposure to prevailing winds plays a dominant role. Generally, there is an increase in annual amount with height up to a belt of maximum rainfall, often around 2000 m or more, but changing according to the direction of slope. If the elevation is high enough (over about 5500 m) the region is permanently snowcapped. This transition from sea level to snowfield means that many vegetation belts are identifiable on the slopes.

The subtropical desert climate (Wadi Halfa, Table A6) is the most extensive of all zones on the continent. Summer temperatures in the Sahara are among the highest in the world, although they are not quite as great as in Namibia. Due to the low relative humidity and clear skies, diurnal temperature ranges can be extreme, with values in excess of 20°C often being reported. As may be expected, radiation and sunshine amounts are extremely large. Vegetation, while sparse, springs to life after any brief shower.

The subtropical, summer rain climate (Harare, Table A6) is found mainly in the southern plateau. Precipitation usually is so concentrated that about half the annual total falls in 3 months. Winters are generally very pleasant and comfortable.

The subtropical winter rain (or Mediterranean) climate (Cape Town, Table A6) is found at the extremities of the continent. These areas can experience extremely hot and dusty winds in summer from their adjacent deserts, but from fall to spring conditions are ideal. Vegetation is xerophytic, able to withstand the long dry spell.

Table A7 lists some climatic extremes for the continent. It is interesting to note how many of these are also world record extremes. Even in the precipitation class only two stations, Waialeale, Hawaii, with 1455 mm and Cherrapunji, India, with 10 820 mm, exceed Ureka's total. At another site near Cherrapunji a 5-year mean of 12 650 mm has been reported.

Table A6 Monthly temperature and precipitation data for representative stations

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average temperature or total precipitation for year
Kisangani, Congo, D.R.: 0°26′N, 25°14′E, 410 m													
Mean maximum temperature (°C)	31.1	31.1	31.1	31.1	30.6	30.0	28.9	28.3	29.4	30.0	29.4	30.0	30.0
Mean minimum temperature (°C)	20.6	20.6	20.6	21.1	20.6	20.6	19.4	20.0	20.0	20.0	20.0	20.0	20.6
Precipitation (mm)	53	84	178	157	137	114	132	165	183	218	198	84	1703
Kinshasa, Congo, D.R.: 4°20′S, 15°18′E, 324 m													
Mean maximum temperature (°C)	30.6	31.1	31.7	31.7	31.1	28.9	27.2	28.9	30.6	31.1	30.6	30.0	30.0
Mean minimum temperature (°C)	21.1	21.7	21.7	21.7	21.7	19.4	17.8	18.4	20.0	21.1	21.7	21.1	20.6
Precipitation (mm)	135	145	196	196	157	8	3	3	30	119	221	142	1355
Niamey, Niger: 13°31′N, 2°06′E, 215 m													
Mean maximum temperature (°C)	33.9	36.7	40.6	42.2	41.1	38.3	34.4	31.7	33.9	38.3	38.3	34.4	36.7
Mean minimum temperature (°C)	14.4	17.2	21.7	25.0	26.7	25.0	23.3	22.8	22.8	23.3	18.3	15.0	21.1
Precipitation (mm)	0	2	5	8	33	81	132	183	91	13	1	0	549
Obbia, Somalia: 5°20′N, 48°31′E, 15 m													
Mean maximum temperature (°C)	29.4	30.6	32.2	33.9	31.7	29.4	28.3	28.9	39.4	30.0	31.7	30.6	30.6
Mean minimum temperature (°C)	22.2	23.3	24.4	25.5	25.0	23.9	22.2	22.2	22.8	23.3	23.3	22.8	23.3
Precipitation (mm)	12	0	8	21	33	0	1	1	2	38	25	25	166
Nairobi, Kenya: 1°16′S, 36°48′E, 1820 m													
Mean maximum temperature (°C)	25.0	26.1	25.0	23.9	22.2	21.1	20.6	21.1	23.9	24.4	23.3	23.3	23.3
Mean minimum temperature (°C)	12.2	12.8	13.9	14.4	13.3	11.7	10.6	11.1	11.1	12.8	13.3	12.8	12.8
Precipitation (mm)	38	64	124	410	157	46	15	23	30	53	109	86	1155
Wadi Halfa, Sudan: 21°55′N, 31°20′E, 125 m													
Mean maximum temperature (°C)	23.9	26.1	31.1	36.7	40.0	41.1	41.1	40.6	38.3	36.7	30.6	25.6	34.4
Mean minimum temperature (°C)	7.8	8.9	12.2	16.7	21.1	23.3	23.3	23.9	22.2	19.4	14.4	9.4	16.7
Precipitation (mm)	T[a]	T	T	T	T	0	T	T	T	T	T	0	1
Harare, Zimbabwe: 17°50′S, 31°08′E, 1403 m													
Mean maximum temperature (°C)	25.6	25.6	25.6	25.6	23.3	21.1	21.1	23.3	26.1	28.3	27.2	26.1	25.0
Mean minimum temperature (°C)	15.6	15.6	14.4	12.8	9.4	6.7	6.7	8.3	11.7	14.4	15.6	15.6	12.2
Precipitation (mm)	196	178	117	28	13	2	1	2	5	28	97	163	828
Cape Town, South Africa: 33°54′S, 18°32′E, 17 m													
Mean maximum temperature (°C)	25.6	26.1	25.0	22.2	19.4	18.3	17.2	17.8	18.3	21.1	22.8	24.4	21.7
Mean minimum temperature (°C)	15.6	15.6	14.4	11.7	9.4	7.8	7.2	7.8	9.4	11.1	12.8	14.4	11.7
Precipitation (mm)	15	8	18	48	79	84	89	66	43	30	18	10	508

[a] Trace.

Table A7 Some climatic extremes for Africa

Temperature		
Absolute maximum	58°C[a]	Azizia, Libya (13 Sept. 1922)
Highest mean monthly maximum	47°C[a]	Bou-Bernous, Algeria (July)
Highest mean monthly	39°C[a]	Bou-Bernous, Algeria (July)
Highest mean annual	35°C[a]	Dallol, Ethiopia
Highest mean monthly minimum	32°C[a]	Dallol, Ethiopia
Highest mean of coldest month	31°C[a]	Dallol, Ethiopia
Highest absolute minimum	21°C[a]	Dallol, Ethiopia
Absolute minimum	−24°C (11°F)	Ifrane, Morocco (11 February 1935)
Precipitation		
Highest mean annual	10 450 mm	Ureka, Equat, Guinea
	10 300 mm	Debundscha, Cameroons
Lowest mean annual	0.5 mm	Wadi Halfa, Sudan
Miscellaneous		
Highest average dewpoint	29°C	Assab, Ethiopia (June afternoons)
Highest mean annual sunshine	4300 + h	Wadi Halfa, Sudan
Highest hourly radiation	113 langleys[a]	Malange, Angola
	112 langleys[a]	Windhoek, Namibia

[a] World record.

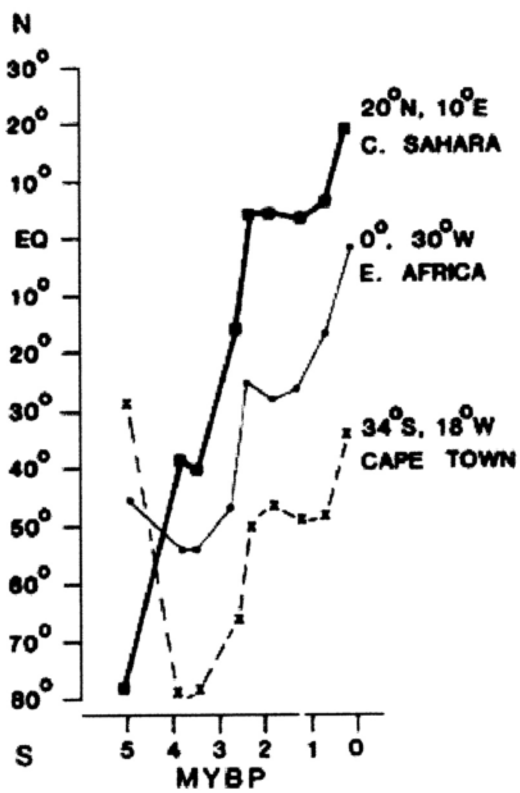

Figure A13 Latitudinal changes at three locations during the past 500 million years. (After Newell, 1974.)

Past climates

There has been relatively little study of past climates in Africa compared with studies of Europe and North America. However, it is known that the continent has occupied very different latitudes from that in which it is presently situated due to tectonic plate movements. In Figure A13 the latitudinal changes in the positions of three points on the continent are shown. From this alone it can be appreciated that in the period 450–200 million years before present (Ma BP) the Cape Town site, occupying a position within the Antarctic Circle, must have had a very cold climate, whereas now it is in relatively the same latitude as it was 500 Ma BP. The Central Saharan site has shown an almost steady progression from 80°S and it is likely that around 300 Ma BP it was also semiarid to arid, but from 200 to 50 Ma BP it was quite wet and humid. The East African location has not shown such extreme latitudinal variation but, nevertheless, must have experienced midlatitude and subtropical climates before reaching its present equatorial situation.

Some remark must be made concerning climate changes in the Saharan area. There have been many papers on this subject and the consensus of opinion is that from 20 000 to 12 000 years ago there was great aridity and the desert advanced southward. Following this period there were some very moist periods, while over the past 2000 years the rainfall has declined sufficiently to make the agriculture practiced in the time of Roman occupation no longer feasible (Carpenter, 1969). Murphey (1951) claimed that the cause is basically artificial and, even today, the growth of the desert must be attributed in great measure to anthropogenic influences. It is interesting to note that there are reports of ice on the Nile in the ninth and eleventh centuries (Oliver and Fairbridge, 1987).

For eastern Africa a more recent study (Hastenrath, 1984) suggests that there was a distinct retreat or disappearance of glaciers around 11 000–15 000 years ago, the deglaciation beginning at lower altitudes (*ca.* 3000 m). The most detailed studies of the historical climatology of Africa have been published by Nicholson (1976, 1978) and Nicholson and Flohn (1980). Nicholson finds, in the times of anomalous climate and climatic discontinuities, reasonable correlation between the sub-Saharan area and that of southern Africa. She identifies anomalous weather patterns in the 1680s and 1830s and a major rainfall change around 1800. Apparently the nineteenth century had greater snowfall than the twentieth century.

In the period 1870–1895, both the Sahara and eastern Africa had above-average rainfall, after which drier conditions set in and by the mid-1910s severe droughts were common in much of the tropics and subtropics. In the 1920s and 1930s there were indications of wetter conditions – Nile discharge up 35%, Lake Chad depth up 50%, and Sierra Leone reporting a third more rainfall than in the late nineteenth century.

Studies of African climate during the last 100 years or so are made problematic because of the vast areas for which the periods of record are very short. It is true that some temperature and precipitation measurements exist from the first half of the nineteenth century, such as in Tripoli and western Africa, but in general few reliable records exist before about 1890. Exceptions to this would include the island of Mauritius which has an almost unbroken record since around 1851.

A special project of the Global Climate Laboratory, part of the National Climatic Data Center, located in Asheville, North Carolina, is concerned with locating, extracting and digitizing data of monthly mean maximum and minimum temperatures and precipitation amount. In a few countries, including Egypt, Nigeria and South Africa, there are enough stations to allow a regional investigation.

John F. Griffiths

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Cross-references

Airmass Climatology
Atmospheric Circulation, Global
Intertropical Convergence Zone
Mediterranean Climates
Rainforest Climates
Savanna Climate

AGROCLIMATOLOGY

Agroclimatology, often also referred to as agricultural climatology, is a field in the interdisciplinary science of agrometeorology, in which principles of climatology are applied to agricultural systems. Its origins relate to the foremost role that climate plays in plant and animal production. Formal references to the terms "agrometeorology" and "agroclimatology" date to the beginning of the twentieth century, but use of empirical knowledge can be traced back at least 2000 years (Monteith, 2000). Agroclimatology is sometimes used interchangeably with agrometeorology, but the former refers specifically to the interaction between long-term meteorological variables (i.e. climate) and agriculture. As such, they share common fundamental principles, methods and tools, but specific concepts are applied as described here.

Fundamental principles

Understanding the interactions between atmospheric variables and biological systems in agriculture, and applying this knowledge to increase food production and improve food quality, are the main goals of agrometeorology. Biological systems in agriculture are comprised of crops and forests, including the soil in which these grow; animals; and associated weeds, pests and diseases. Atmospheric variables that may affect these systems range from physical variables, such as solar radiation, precipitation, wind speed and direction, temperature, and humidity, to chemical variables, such as trace gas concentrations (e.g. CO_2, O_3). Agrometeorology is concerned with the characterization of these variables not only in the natural environment, but also in modified environments (e.g. irrigated areas, greenhouses, and animal shelters).

The fundamental principles used in the study of interaction between the atmosphere and agricultural systems are: (1) conservation of mass and energy, (2) radiation exchange, and (3) molecular and turbulent diffusion. The response of biological systems to these interactions draws on principles of soil physics, hydrology, plant and animal physiology, plant and animal pathology, entomology and ecology. Topics of research include water and radiation use efficiency by crops, animal comfort levels as affected by the physical environment, air pollution damage to crops, disease and pest development as a function of environmental conditions, and greenhouse gas emission by agricultural activities.

Methods and tools

Spatial scales in agroclimatology cover a wide range, from <0.1 m (e.g. response of fungi to leaf wetness) to regional and global scales (e.g. drought monitoring). Temporal scales may span past, present or future climate. Choice of instrumentation and measurement methods for weather and biological variables occurs according to the spatial and temporal scales of interest. Most often, agroclimatologists rely on long-term climate data provided by national meteorological services. In some countries weather stations originally were established in association with agricultural research institutes, attesting to the importance of weather and climate to agricultural production. Expertise in instrumentation, typically sensors for air temperature and humidity, solar radiation, precipitation, and wind measurement, is required from agroclimatologists in some applications, particularly those involving smaller spatial scales than provided by weather stations (i.e. microclimatological scales).

In all cases data describing the condition of the biological system are also needed. These include observations of developmental stages in crops, weeds, or insects; crop, milk or meat yield; grain or forage quality; and other physical and