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The Current Trend of World Climate - a Report on the Early 1970's and a Perspective

H. H. Lamb

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Climatic Research Unit
School of Environmental Sciences
University of East Anglia

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THE CURRENT TREND OF WORLD CLIMATE - A REPORT ON THE EARLY 1970's AND A PERSPECTIVE

by H.H. LAMB.

Much has been written in recent years about climatic change, the global cooling since 1945 which reversed the earlier upward trend of temperatures, and so on. But after the run of four mild winters in Britain and much of Europe since 1970, there must be an impression in some quarters that the subject, though interesting and possibly shedding new light on history, has been overstressed as regards its practical implications for the world of today. The political uncertainties surrounding the supply of basic fuels at this moment doubtless appear to most authorities to represent a wider margin of uncertainty, and a greater threat, to the economy. There are solid grounds, however, for regarding this as a dangerous misconception (or, at least, a dangerous oversimplication). Indeed, stresses manifestly set up by the current tendencies of world climate are deeply involved in the economic and political upsets of the last few years.

In the present state of the world, with the growth of the human population straining resources, particularly as regards food production and water supply for people and for agriculture and industry, rainfall variations are at least as important as those of temperature. In three or four years since 1960, most notably in 1972, droughts in Soviet Asia and China and failures of the monsoon in India, have driven those countries to make massive purchases of grain in the West. Despite the achievements of science in increasing harvest yields, the world surplus grain stocks available for emergency shipment have been reduced to a quarter of what they were in 1945. And the price of wheat doubled in many countries within a few months in 1972-73.

Compared with the rainfall deficiences in individual years (and short runs of years) in this or that area in middle latitudes, however, the long-continued drought that has been developing in latitudes 10-20°N, particularly over Africa, is a much worse disaster. In the area known as the Sahel, in Africa, in these latitudes, in the territories of Mauretania, Senegal, Mali, Upper Volta, Niger and Chad, as well as in the Cape Verde Islands in the Atlantic, 1973 was designated as the fifth consecutive year of drought (though in fact rainfall has been decreasing since the 1950s). On May 11th 1973 the United Nations Food and Agriculture Organisation issued a communique about it, appealing for airlifts of aid. In the Sahel zone of west Africa it is estimated that many thousands of people and 3½ million head of cattle died in 1973; many more people left their homes and migrated southward. In eastern Africa, Ethiopia was similarly stricken, with an estimated 100 000 people dead and the livelihood of two million gravely threatened, events which have led to political turmoil in 1974. The coffee harvest in Ethiopia, Kenya and the Ivory Coast and the harvests of ground nuts, sorghum and rice in Nigeria were sharply reduced.

Similar troubles elsewhere in the last few years in about the same latitude zone, affecting India and Bangladesh in the east and parts of Mexico in the west, as well as the cane-sugar harvest in Trinidad, indicate a still greater zonal extent of the drought phenomenon and hint that a latitude anomaly in the general circulation of the atmosphere may underlie and link all these experiences.

WINSTANLEY (1973a, b) has shown that the records of a limited selection of representative stations in the summer-monsoon rainfall zone display a remarkable parallelism with the frequency of westerly weather type over the British Isles (LAMB 1972a), which appears to behave as an index of the strength of the general wind circulation over the globe. This means that there has been a downward tendency of the rainfall in the zone since the main peak value attained in the 1920s-30s and more rapidly since the later peak around 1950-55. WINSTANLEY also suggests that this trend in latitudes 10-20°N may be in some way connected with the recent cooling of the Arctic. If such linkages can be demonstrated, the way may be opened to seasonal weather forecasting for tropical Africa as soon as such forecasting for Europe reaches a reliable standard and to reasoned assessment of the prospects for the longer-term future. The latter may be assessed in the light of what is known of the history over the last thousand years of the variations of general temperature level, and of the extent of the Arctic ice in particular. The position could be further strengthened by research aimed at identifying the nature of certain repetitive fluctuations of climate and the global atmospheric circulation on time-scales ranging from two years to many hundreds of years.

The remaining paragraphs of this article are devoted to demonstrating the global character of the present climatic trend and the relationships which justify the above statements.

THE GLOBAL TEMPERATURE TREND

Figure 1 shows the changes of prevailing surface temperature averaged over the Earth during the 100 years from 1870 to 1969 by successive five-year periods. The computations were done in the United States, largely in the Environmental Data Service and updated at the National Center for Atmospheric Research, using observations from all over the world though necessarily relying on the available islands to represent the great ocean areas.

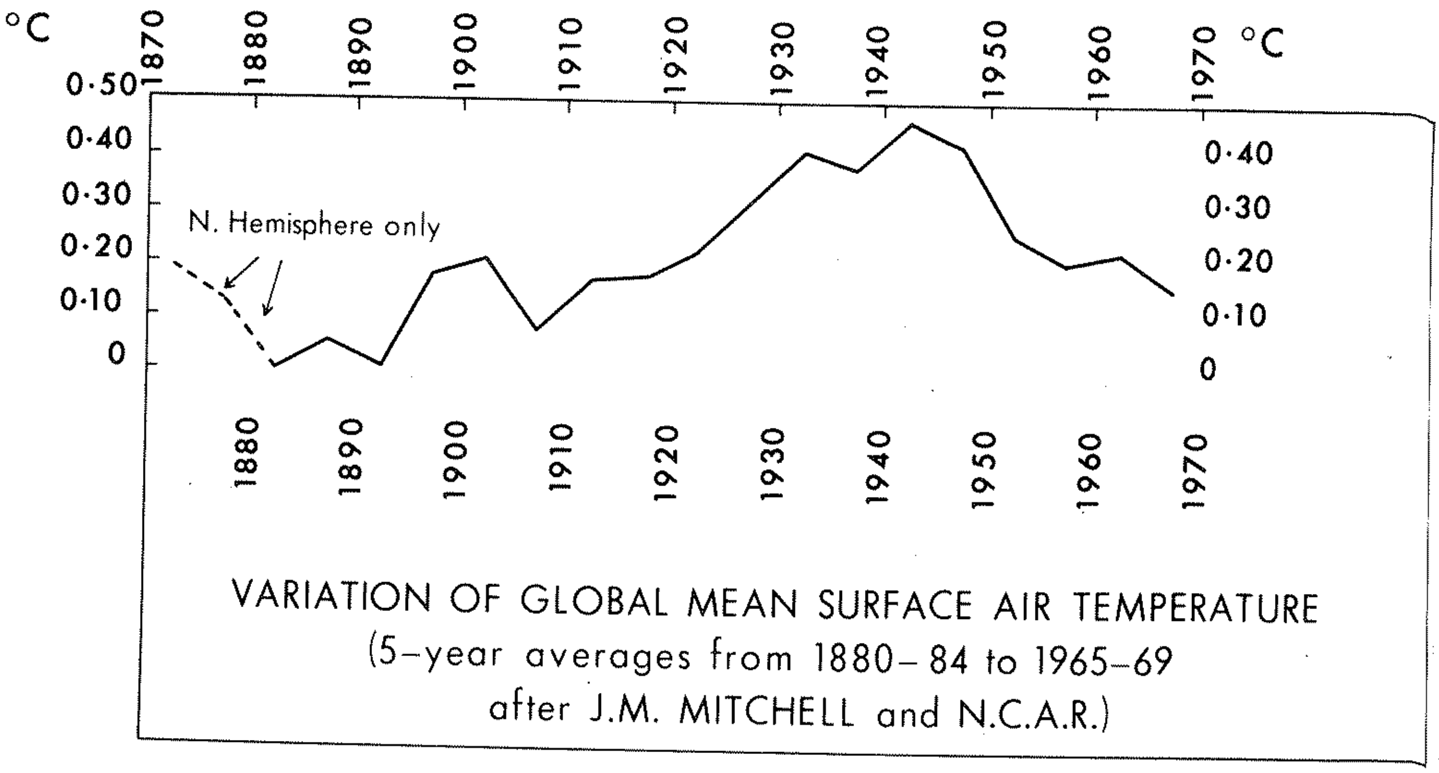

Fig. 1. Changes of mean surface air temperature averaged over the globe.

Successive 5-year means from 1880-84 to 1965-69.
(After J.M. MITCHELL and National Center for Atmospheric Research, Boulder, Colo.)

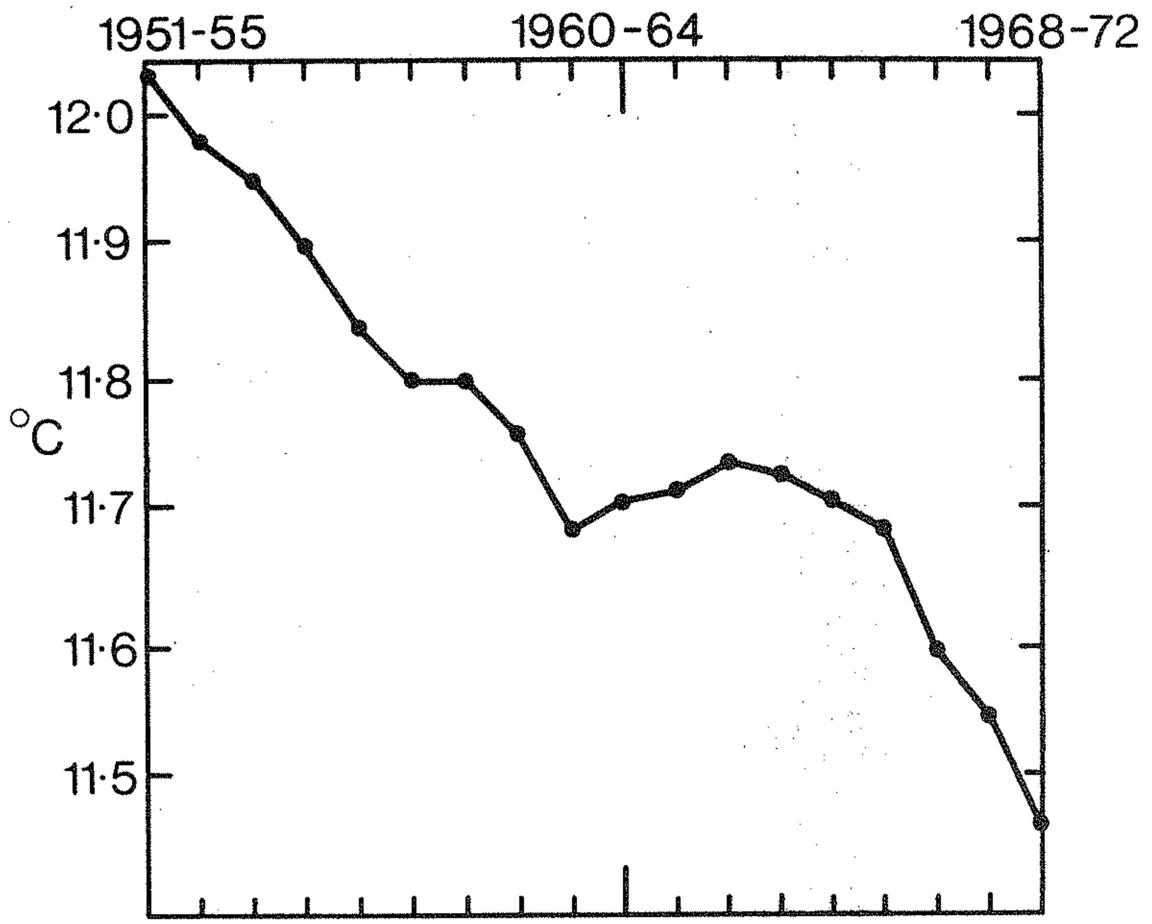

Fig. 2. Changes of mean sea surface temperature in the North Atlantic, averaged for the 9 Ocean Weather Ships, from 1951-55 to 1968-72.

Overlapping 5-year means.

(After M. RODEWALD.)

Figure 2 demonstrates that the recent cooling has affected the general temperature of the surface waters of the North Atlantic as well as the land areas and that it continued at least until 1968-72, by which time the average for the nine Ocean Weather Ships between 35 and 66^{o}N in the Atlantic was rather more than half a degree Centigrade below the peak value reached around 1950. Indeed, it has been shown* that the

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* Report by M. RODEWALD in <u>Beilage zur Berliner Wetterkarte</u> (119/73 SO 29/73), Berlin (Inst. f. Met., Fr. Univ.) 23 October 1973.

cooling registered by the weather ships continued in 1973.

There seems no room for doubt, therefore, that the run of mild winters since 1970 in England has taken place within the context of continued general cooling or, at least, maintenance of the lower level of world temperatures that was set up during the 1960s. Part of the paradox is due to the sudden, and as yet not understood, transference of the cold centre of the northern hemisphere atmospheric circulation from the Siberian sector back to the Canadian sector, where it had mostly been in the 1950s and earlier; though in the new situation it has been so much colder than in the earlier occurrences that the renewed growth of snowbeds and glaciers in Baffin Island and elsewhere in the Canadian north has been viewed with concern.

The cooling during the last twenty years has been greatest in the Arctic (just as the warming in earlier decades of the twentieth century had been). A simple index of the change is given in the following tables.

TABLE 1. Number of months each year with mean temperature below the 1931–60 averages over most of the Arctic north of 70°N.

Year / Decade	0	1	2	3	4	5	6	7	8	9
1950s							2	3	6–7	3
1960s	5	8	6	9	11	7–8	8–11	7–9	10–12	6
1970s	8–9	7–9	7–8	7						

TABLE 2. Number of months each year with mean temperature warmer than the 1931-60 averages over most of the Arctic north of 70^{o}N

Year Decade	0	1	2	3	4	5	6	7	8	9
1950s							4	4	1	7
1960s	4	1	0	0	0	1-2	1	1-2	0	2
1970s	0-1	1-2	1-2	0-1						

These tables are compiled from the maps given in the monthly Beilagen zur Berliner Wetterkarte (Fr. Univ. Berlin) and Die Grosswetterlagen Europas (Deutsher Wetterdienst, Offenbach am Main).

In the 1960s there was a remarkable frequency of months in the Franz Josefs Land area (near 80^{o} N 53^{o} E) with mean temperatures more than 10^{o} C below the previous 30-year average, there having been no such occurences for about 80 years previously. Despite the "preference" of the main cold centre for the Canadian sector since 1970, it returned to the Franz Josefs Land sector for some months in late 1973 and the monthly temperatures there in October, November and December were respectively 10^{o} C, 9^{o} C and 11^{o} C below the 1931-60 averages. The overall mean temperature for 1960-69 at Franz Josefs Land was about 4^{o} C below that of the previous four decades.

In England the overall mean temperature of the 1960-69 decade was just 0.3^{o} C below the average of the previous thirty years. The mild winters since 1970 have put the average for 1971-73 back to the previous level, though the springs and summers have continued colder and the cooling trend may have begun to affect the autumns also. Expressed as a change of overall average temperature, the figure in any case looked very small. Nevertheless, the changes have been significant e.g. as regards length of the growing season and the snowiness of the years between about 1954 and 1970 in Britain. The effect is also seen in the number of days with heat-wave temperatures in the summers. A carefully kept temperature record at Belstead near Ipswich in East Anglia from 1902 to 1972 shows that the average yearly number of days with air temperature over 80 ^{o}F (26.7 ^{o}C) ranged from 6.7 in 1920-29 to 11.4 in 1940-49 but since 1960 has averaged between 2 and 4 with at least three individual years having no such days. (Examination of nearly 300 years of monthly mean temperatures in England published by MANLEY (1957, 1959) suggests that despite a range of only 1 to 1.5 ^{o}C between the warmest and coldest decades the implied difference in the heating (fuel) requirement over the ten years would amount to 20%: the requirement in the coldest individual year would probably be just double that in the warmest of the last 300 years.)

A 40-year farm record from 160-170 m. above sea level in Swaledale, Yorkshire (kindly supplied by Mr. E. Potts, now of Northallerton) illustrates what the fluctuations have meant for farming in England: despite introduction of the combine harvester about 1950 the harvests in 1960-73 were completed on average 9 days later than those of the previous 20 years. The date of the spring sowing in 1970-73 was almost as late as in the 1940s, which were affected by several severe winters; but in the 1960s, despite colder winters and springs, the sowing was particularly early, the earliest group of years in the 40-year record, presumably because the ground dried early. (It seems quite clear that the early spring sowings in the 1950s and '60s, which were generally a week to ten days earlier than in the other decades, were associated with reduced winter rainfall.)

GLOBAL RAINFALL SHIFTS

In order to examine the nature of the shifts in the world rainfall distribution which have brought about the increasing drought that is now so serious in part of Africa and occasional serious droughts in a number of places in middle latitudes, figs 3 and 4 have been prepared.

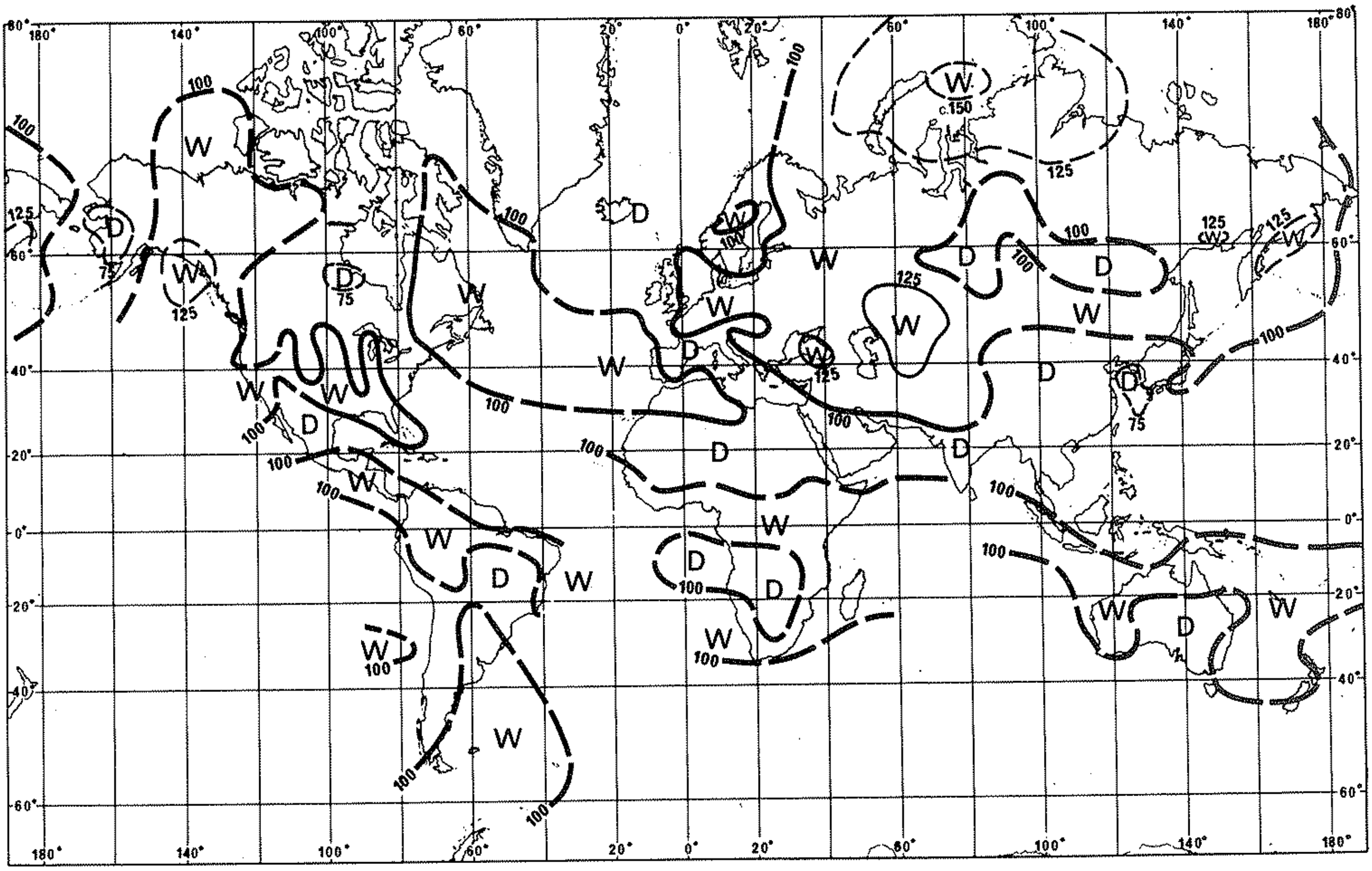


Fig. 3. Global distribution of mean yearly rainfall for the decade 1960-69. Percentages of the 1931-60 average.

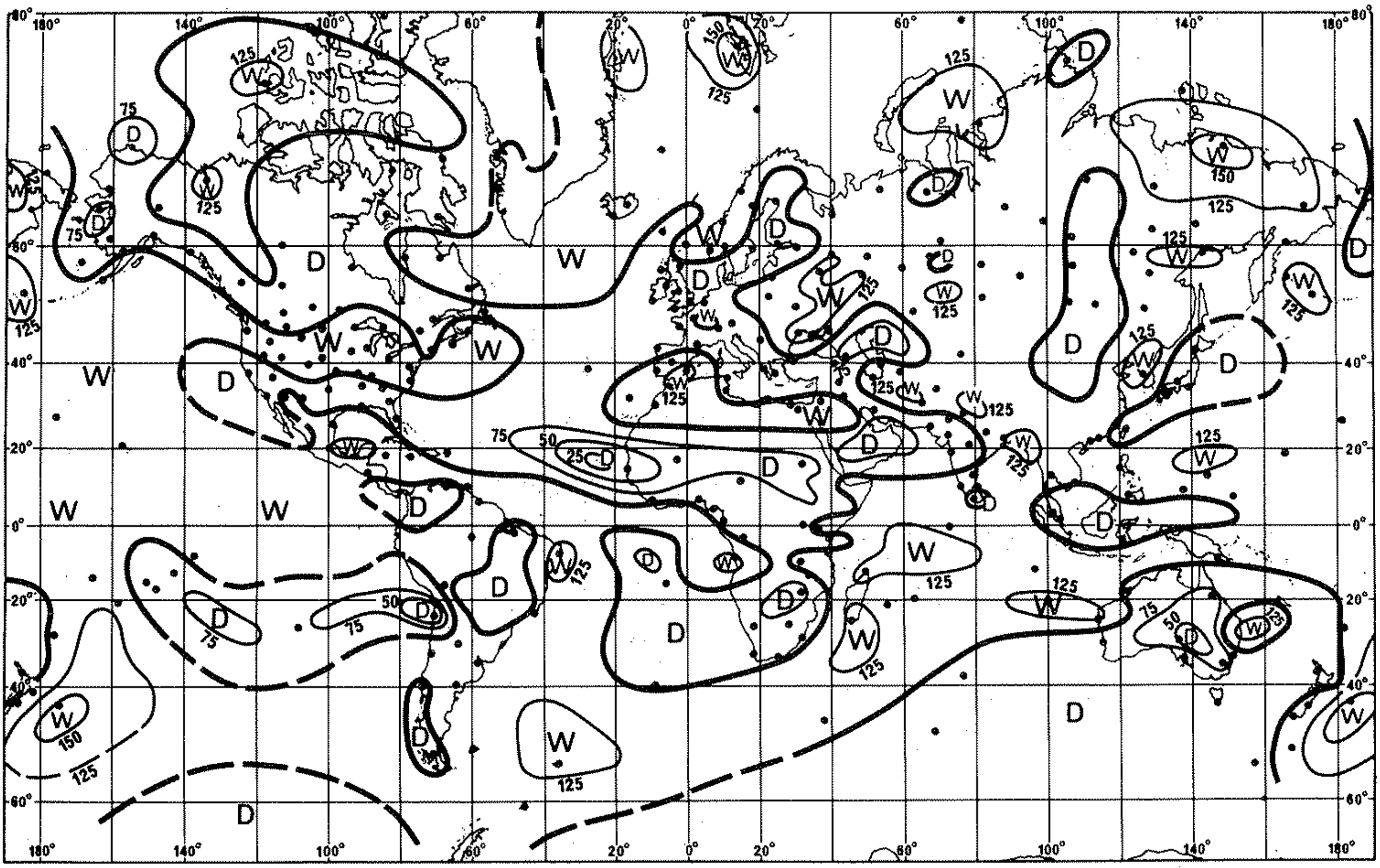


Fig. 4. Global distribution of mean yearly rainfall for 1970–72.

Percentages of the 1931–̂0 average.

Dots show positions of the observation records used.

This type of survey seems to be quite new, though it is likely to be the simplest way of revealing the links between changes in the prevailing weather and the atmospheric circulation mechanism responsible, which we shall proceed to explore in the next section, as well as with the temperature changes already described. (NAMIAS (1974) has recently made a somewhat similar survey of the differences of global rainfall distribution as between individual months characterised by the extremes of zonal and meridional or "blocked" circulation.) The present resources of the Climatic Research Unit do not permit as elaborate a coverage as might be desired, but it is possible to outline with assurance all the main areas affected by substantial changes of total rainfall. The map for the 1960s is based on the minimum necessary data and must be considered almost schematic. The map for 1970-72 is, however, based on the rainfall measurements at over 300 stations well distributed over the globe.

There is a remarkable degree of agreement between the two maps, which presumably tends to verify the features shown on the map of the 1960s. In fact, this persistence in the development shown by the maps of rainfall anomalies in the two decades could hardly have been expected; it indicates the long time-scale of the development of this global anomaly pattern. We may readily describe the salient features of the two maps together as follows:

(i) There is an extensive zone of deficient rainfall in latitudes between about 10 and 20 to 30°N, where the deficiency has become greater since 1970 than the average of the previous decade, and a somewhat similar feature in about the same latitudes in the southern hemisphere. Near the equator, between these two zones, rainfall amounts have mostly increased, as was already noted in connection with the rise of the East African lakes in the 1960s (LAMB 1966).

(ii) A nearly continuous zone of increased rainfall is seen in the lower middle latitudes, across the United States as well as in the southern part of the Mediterranean and over Spain and Portugal.

(iii) In most temperate latitudes, areas of increased rainfall and areas of decreased rainfall alternate around both hemispheres. Between 40 and 70°N the arrangement tends to be in meridional (north-south) stripes, but in the southern hemisphere a pattern of belts orientated rather from southwest to northeast is suggested. In both hemispheres, it seems probable that there has been an increase in the occurrence of "blocking" anticyclones in middle latitudes and a shortening of the prevailing wave length in the upper westerlies, which has placed some of the prevailing troughs and ridges in different longitudes from those mostly affected in the earlier part of the century. This is likely to have changed the geographical distribution of rainfall within the temperate zone as well as its total amount.

(iv) In several regions in high latitudes in the northern hemisphere there have been substantial increases in the downput of rain and snow. In parts of the Canadian Arctic and in Arctic Siberia totals in the regions of 130% of the 1931-60 average are observed. In Spitsbergen and part of northeast Siberia since 1970 there are figures of 150 to 170% of the previous averages.

The 1970-72 averages over a wide region in those parts of the temperate zone which became drier than before were 85 to 95% of the 1931-60 normal - a serious deficiency in some industrialised and densely inhabited regions - and locally as low as 70%. In the drought-afflicted zone of northern Africa, however, figures ranged from 40 to 70% and were under 25% in the Cape Verde Islands at 17°N in the Atlantic.

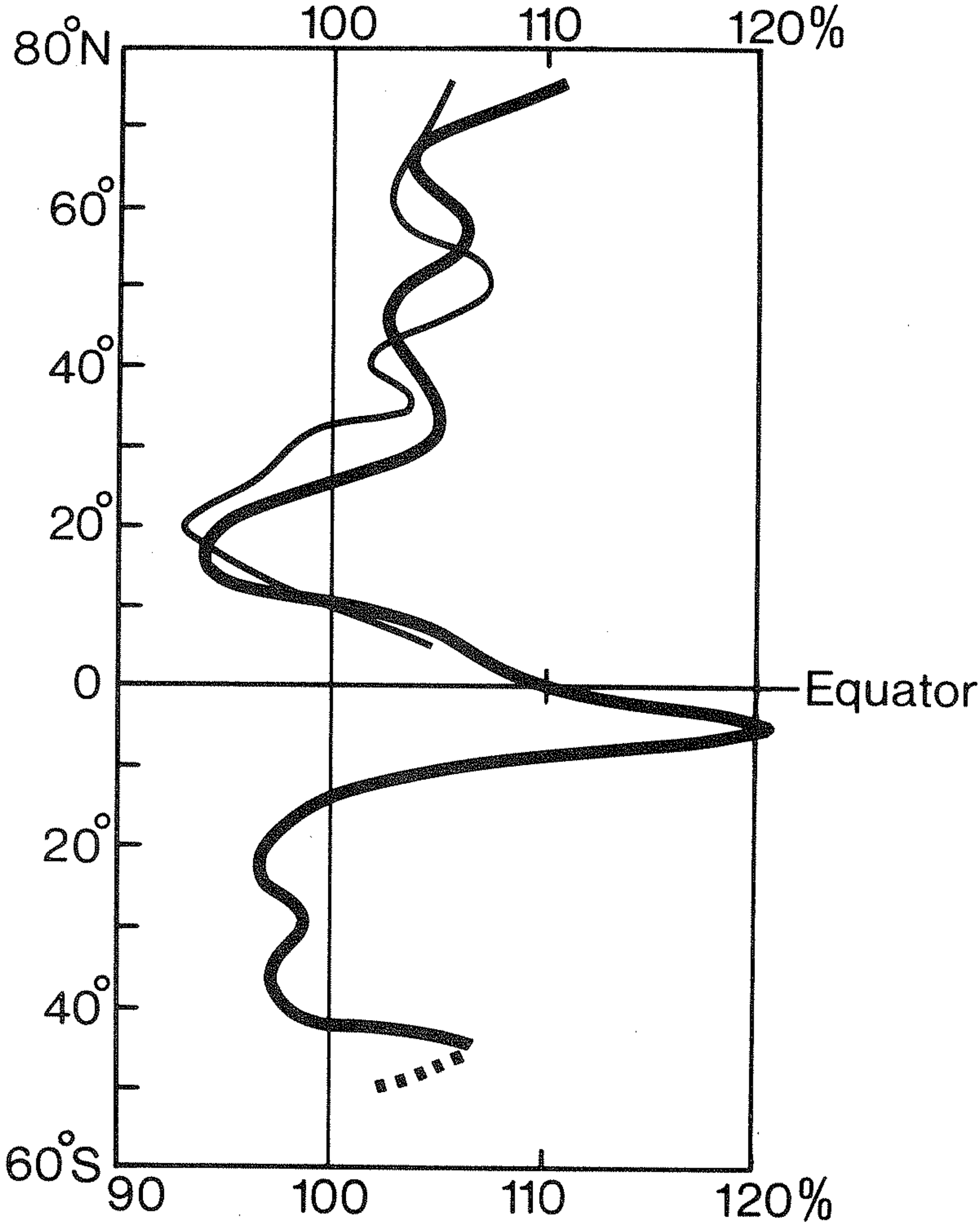


Fig. 5. Departures of mean yearly rainfall 1970-72 from the 1931-60 average, by latitude zones.

The thin line shows how the rainfall of the decade 1960-69 departed from the 1931-60 average in different latitudes.

Figure 5 shows the result of computing the average rainfall anomalies in successive five-degree zones of latitude from the Arctic to the Antarctic. This presentation makes it very clear that we are dealing with a phenomenon of global extent, characterised by a narrow zone of increased rainfall near the equator - the exact latitude of the maximum cannot be placed with certainty - and some approach to symmetrical adjustments in both hemispheres on either side: the greatest reduction of rainfall is near the tropics and probably the most general increases are found in high latitudes. It may be reasonable to suppose that a key to this pattern is greater concentration of the equatorial rainbelt close to the equator, probably indicating weakened and less extensive meridional circulation cells (Hadley cells) accommodating the organised vertical and north-south exchanges of air which entail the development of the Trade Winds and the Counter-Trade current aloft within a smaller range of latitudes than formerly. If this diagnosis is right, it may be right to suppose that the global pattern and accompanying cooling of the Arctic registers some overall reduction in the energy available.

Displacements of the main features of the former wind circulation pattern are also hinted at by the strongly zonal (west-east) banding of the global distribution of rainfall anomalies in latitudes between about 40°N and 40°S and the breakdown of the anomaly pattern by longitudes in middle latitudes.

THE ANOMALY IN THE GLOBAL CIRCULATION OF THE ATMOSPHERE

To explore the alterations in the general wind circulation over the Earth, which underlie the rainfall distribution changes, it is convenient to use the average atmospheric pressure at sea level. There is an intimate relation between the distribution of barometric pressure and surface winds, which is basic to the practice of weather services and is made use of in displaying the prevailing patterns of atmospheric pressure and winds in atlases. (The winds blow anticlockwise around the regions of low pressure in the northern hemisphere, clockwise in the southern hemisphere, and their general strength and frequency from the principal direction are expressed by the steepness of the pressure gradients represented by closeness of the isobars on period-averaged maps.)

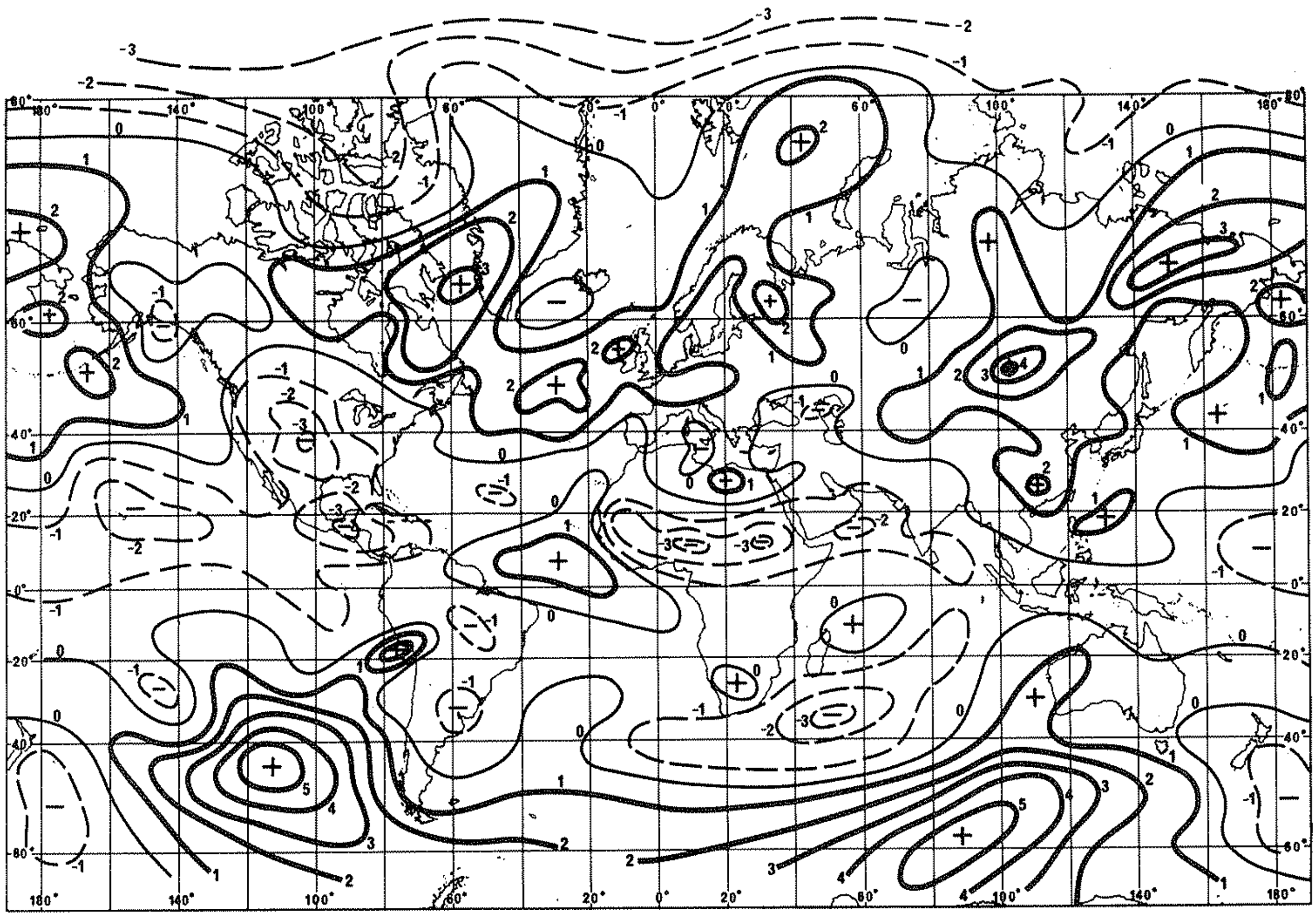


Fig. 6. Global distribution of average atmospheric pressure at mean sea level 1970-72, as departures in millibars from the average of the first half of the century. (See text for details.)

The world map in fig. 6 shows the amounts in millibars by which the overall mean pressure for the years 1970-72 departed from the average values of the first half of this century. The averages for 1900-1939 have generally been used as datum in the northern hemisphere, because careful investigations (including special care over the values to be adopted in the northern polar region) have produced more reliable maps for that period than for any other: the period, moreover, has the virtue of an unusually homogeneous character, marked by persistently strong zonal circulation, which makes the interpretation of the departures of other years from it relatively simple. In the southern hemisphere the datum from which the departures are measured had to be less clearly defined (and is less securely established), but can be taken as an approximation to the average conditions obtaining between 1900 and 1950 or 1960 in most areas.

It is unfortunate that the data resources of climatology are not yet so organised as to make it easy to show both the global rainfall and pressure anomolies from the same datum, namely the period of zonal circulation in the first half of the century; but in view of the magnitude of the departures observed in recent years, this is not likely to make much difference.

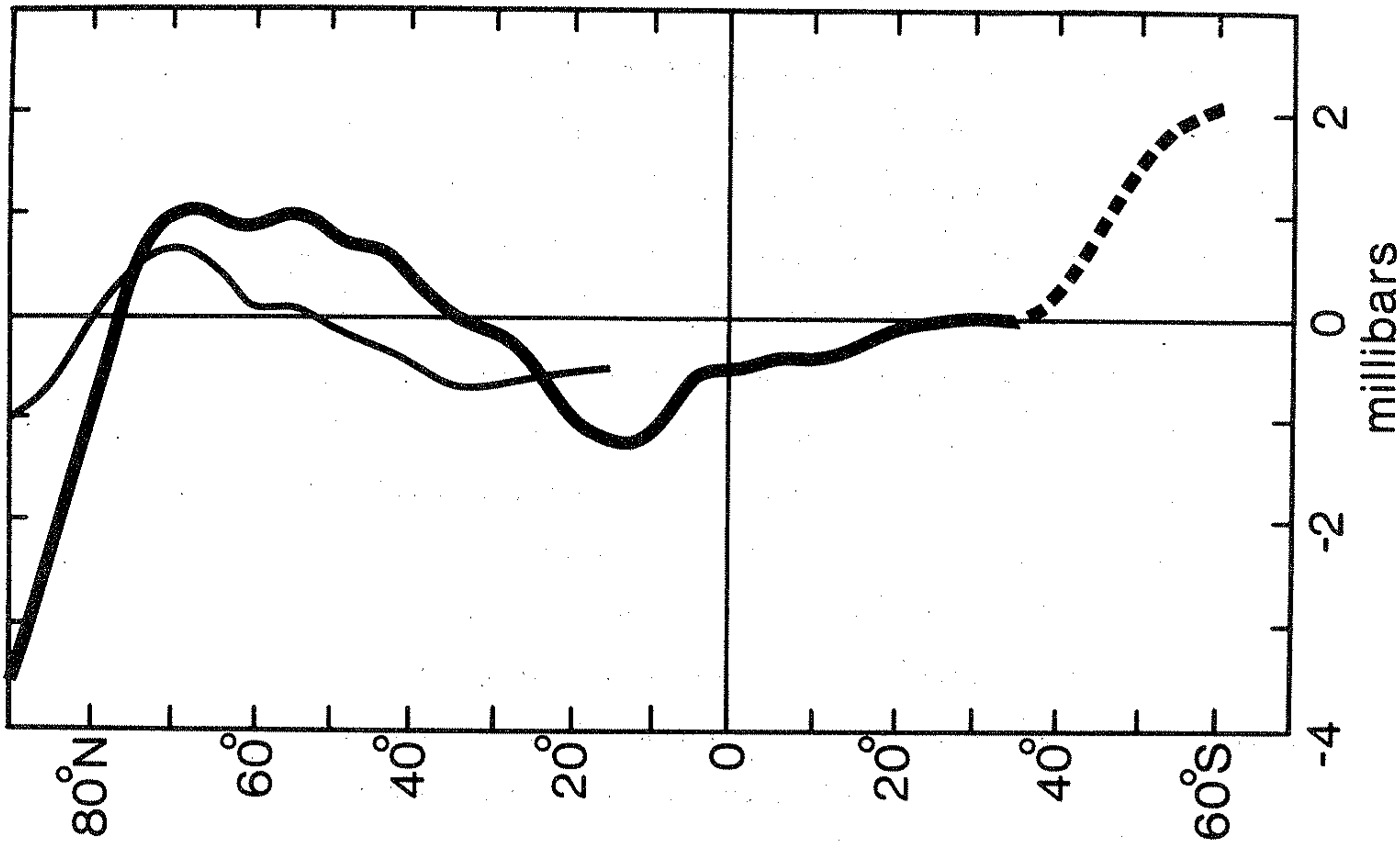
Annual mean pressures have rarely been used in investigational work, because the magnitude of seasonal changes of pressure associated with the monsoons over south, central and eastern Asia make their interpretation obscure in those regions. Nevertheless they have some virtue: the world distribution of annual mean pressure is in fact an approximation to the average for all the colder seasons of the year, and the recognition of significant changes from one epoch to another is facilitated by the small range of the normal year-to-year variability.

The main message of fig. 6 is immediately apparent: that we are dealing with a large scale phenomenon whose structure is of global extent and largely symmetrical in the two hemispheres. Its character may be described quite simply. There are two broad zones of higher pressure than before, dominating the middle latitudes between about 40° and 70° (or beyond) in both hemispheres, while pressure is generally lower than before in low latitudes and near the north pole. There has been a substantial increase of cyclonic activity in the Arctic basin. (We cannot say whether there has been a corresponding change in the Antarctic because of lack of data before the International Geophysical Year of 1957-58, when the continuing observation network was established there.)

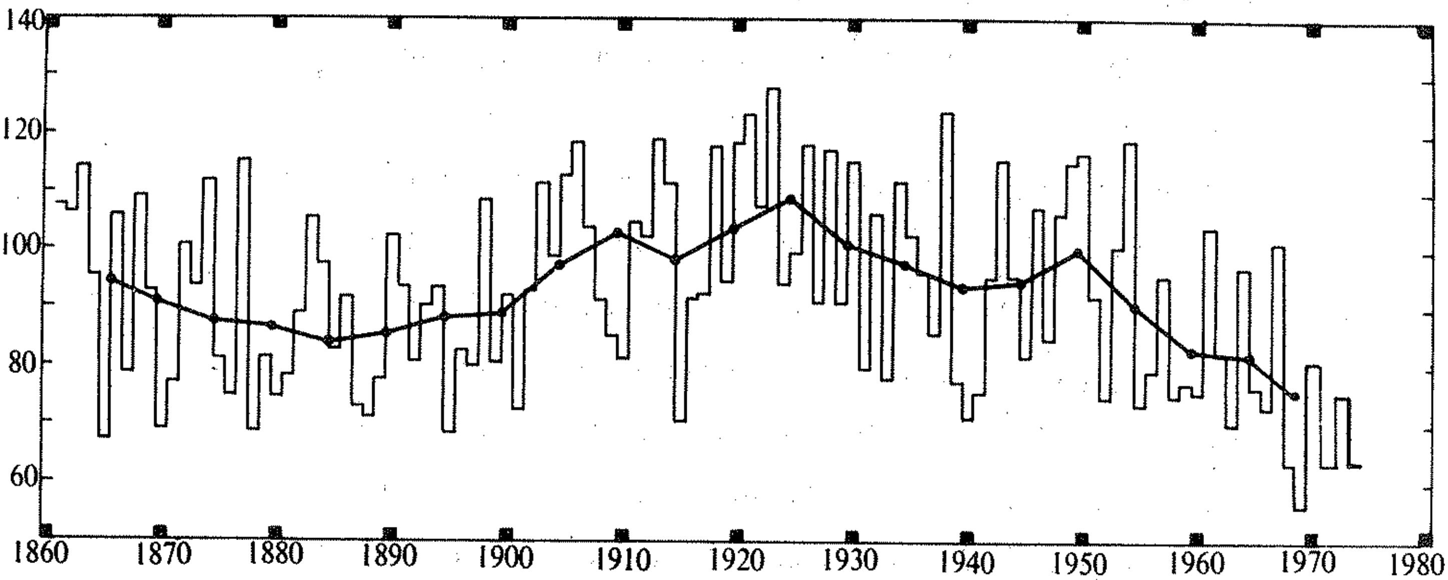
A high level of statistical significance can be attached to the anomalies, since the standard deviations for a three-year mean in the middle and higher latitudes of the northern hemisphere, computed from records extending over the last 90 to 100 years, are small; their range was from 0.72 to 1.12 millibars. The standard deviations in low latitudes are almost certainly less than these figures. In the southern hemisphere the range of year-to-year variability is so far less well established than in the north, but for the year as a whole is probably quite close to the values for corresponding latitudes in the northern hemisphere. We conclude that there are many areas of the world in both hemispheres where the anomaly of atmospheric pressure for the three years 1970-72 would be expected to occur less than once in a hundred such samples of years.

The essence of the pattern is even more simply portrayed in fig. 7, in which the thin line indicates that what was apparently an incipient stage of the same development already prevailed over the years 1951-66 in the northern hemisphere. The similarity of the northern hemisphere anomaly map for 1951-66, published in LAMB (1972 b,p. 260), to the 1970-72 situation further strengthens the case for believing that this is so. The phenomenon therefore appears to be both large-scale and a long-term development.

Continuance of the broad features of the pattern through 1973 is shown by the northern hemisphere map of departures of the mean pressure at sea level (from the 1900-39 averages) for that year published in Die Grosswetterlagen Europas (Deutscher Wetterdienst, Offenbach am Main). A broad belt of positive anomalies rings the Earth between about 30 and 60-70°N, the greatest anomaly in 1973 being more than plus 5 mb. over and near Ireland; negative anomalies dominate the low latitudes and the Arctic basin, the greatest departure being -4.8 mb. at the pole.



7. Departures of average atmospheric pressure at sea level in 1970-72 from the average values of the first half of the century, by latitude zones. The thin line shows the departures that had already developed in 1951-66.



8. Number of days each year with general westerly winds blowing over the British Isles from 1861 to 1973.

The bold line links 10-year averages plotted at 5-year intervals.

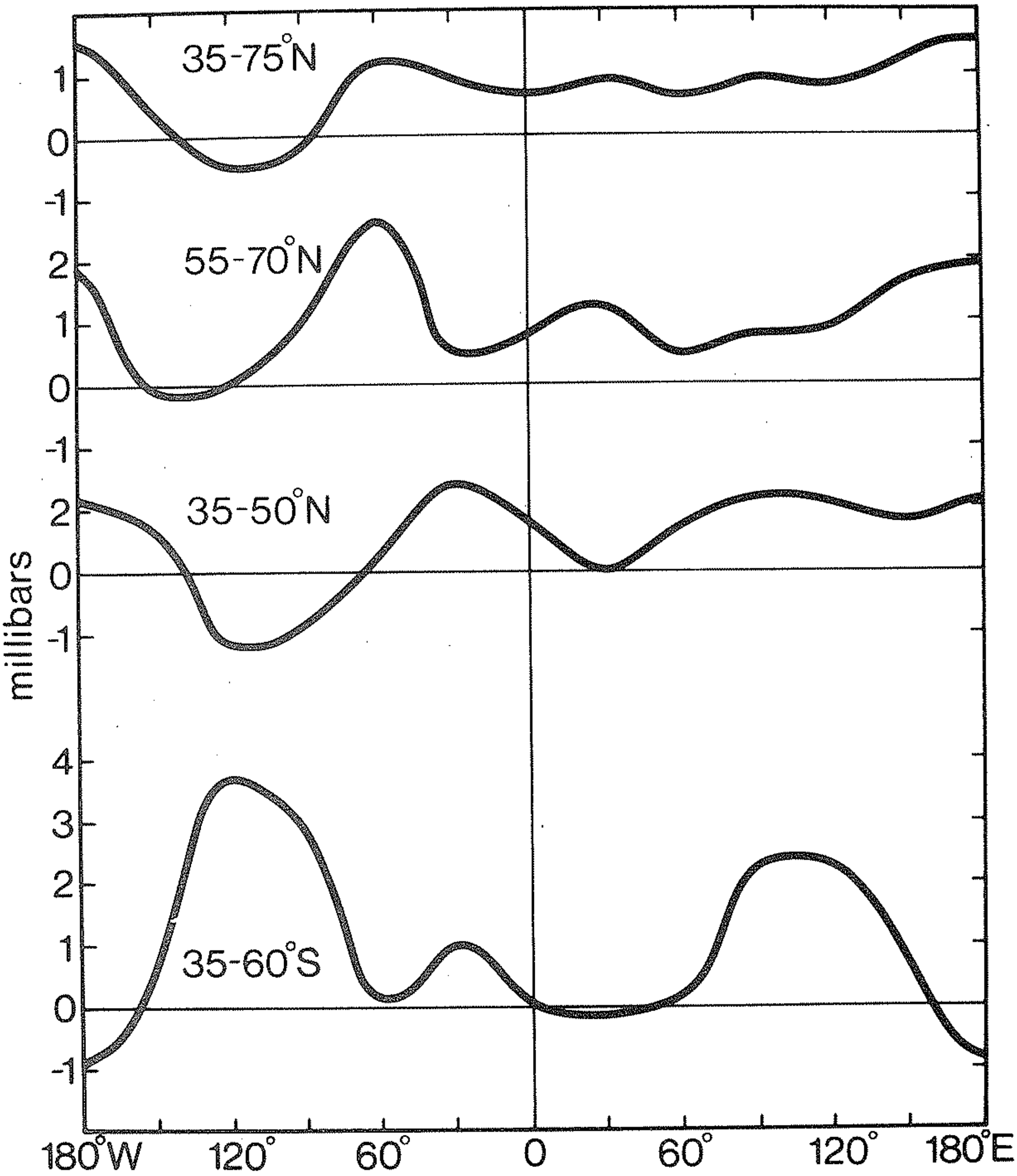
(Reproduced by kind permission from Nature, 244, p. 296; London August 17th 1973).

It has been characteristic of this long-term development that, though interrupted from time to time by a month or more with patterns of a quite different character (but usually affecting no more than half of one hemisphere), the familiar pattern always returns. It is possible to suspect a continued, slow equatorward drift of the belts of the anomaly pattern, but so far the more obvious features are enlargement of the area of enhanced cyclonic (low-pressure) character over the Arctic since the 1950s; accompanied by a broadening and intensification of the zone of high-pressure anomaly, particularly between latitudes 70 and 50°N, in the 1970s.

One aspect of the mechanism seems to be that increased thermal gradient between the colder Arctic ice region and the neighbouring latitude zone generates increased cyclonic activity over the central Arctic and high pressure systems over the surrounding sub-Arctic zone and middle latitudes. This is thought to have affected all seasons of the year roughly equally. In summer there has been more persistence of the snow-cover (and hence higher albedo) over the Arctic ice than before 1960 and in the other seasons lower temperatures than in the earlier part of the century have developed, presumably by radiation cooling from the cloud tops as well as from the ice surface in clear sky areas. The anticyclones repeatedly generated in latitudes between 50 and 70°N may be classified as blocking anticyclones and are the reason for the sharp decline of the westerlies in middle latitudes (fig. 8), which is another feature of recent years that demonstrably goes beyond the experience of more than a century past. These anticyclones also account for the rather general decline of rainfall in the same latitudes and the occasional serious droughts (mentioned in the introduction) which have affected the international economy.

Figure 9 studies the distribution by longitude of the changes of atmospheric pressure prevailing within the zones of general positive anomaly in recent years. This diagram makes it clear that the tendency for "blocking of the westerlies" in middle latitudes has been accompanied by important differences in different longitudes. These look as if they represent shifts of prevailing position of the troughs and ridges in the flow pattern of the upper westerly winds (circumpolar vortex). And there has been an intensification of the meridional (north-south) currents of the mean wind flow (except over Asia). These aspects account for the fact that some areas in middle latitudes, notably California, the U.S. Middle West and parts of Europe, have also experienced in these same years great floods, high levels of the lakes and rivers, and avalanches. Long-continued rains associated with slow-moving cyclones at times of weak or very distorted flow of the upper westerlies have been the characteristic feature of these episodes (and, for instance in England from 1968 onwards, have repeatedly produced 24 to 36-hour rainfalls beyond the statistical expectations based on previous data).

An unexpected feature of fig. 6 is the interpretation it suggests of the increased dearth of rainfall in the Sahel zone of Africa. Atmospheric pressures prevailing over that zone have been lower, not higher, than formerly. In other words, the situation is not readily to be explained by an increase of anticyclonic influence. Fig. 6 clearly registers the increased frequency of blocking anticyclones in middle and higher latitudes and (more faintly indicated) a tendency for rather weak subtropical anticyclones farther south than the formerly predominant position of the Azores anticyclone and its eastward extension over the Mediterranean and North Africa. But, if we read fig. 6 as a straightforward pressure map, the main implication is a strong tendency for the winds reaching the Sahel zone to come from the northeast, the air, moreover, being drawn over long land tracks in Europe and Asia before crossing the Sahara. Since fig. 6 is really a pressure anomaly map, registering how the situation in 1970-72 differed from previous years, it implies that these winds from the northeast have been much more prominent than formerly. It is in this feature that the immediate cause of the drought is evidently to be found.



9. Departures of average atmospheric pressure at sea level in 1970-72 from the average values of the first half of the century, by longitude, in the zones of generally increased pressure.

INTERIM CONCLUSIONS AND PERSPECTIVE

At many points in this presentation the need for more knowledge and better organization of a long observation record for climatic research has had to be stressed. The relevance to anxious problems of human welfare and the stability of the international economy is obvious.

Despite inadequacies in our survey, some aspects of the climatic change that is going on emerge quite clearly. It is global in extent and is developing on a grand time-scale such that superposed fluctuations affecting periods less than a decade in length have nothing to do with it and could lead to misleading conclusions. In this connexion, it may well be that the drought of the last 5 to 6 years in the Sahel zone and the very low frequency of the westerlies over the British Isles represent a short-term extreme superposed on the underlying trend, which nevertheless is in the direction of this extreme. If this is so, then some years of rather more rainfall and recovery of the middle latitudes westerlies will surely come, only to be followed by a still greater extreme next time the short-term fluctuations operate the same way. (Components of variability on time scales of about 14 months and around 2, 5 - 6, 11, 19 and 22 years, among others less pronounced, may be involved here.)

Some commentators have presented the events of the latest years in the context of the approach to the next ice age or of a return to the cold climate of the period about AD 1550 to 1850, which is sometimes called the "Little Ice Age". There is no doubt that some features of the pattern revealed in this article can with some justification be described as "glacial": e.g. the cooling of the Arctic accompanied by great increases in the downput of snow in some areas in high latitudes, perhaps also the flooding events in California and southern Europe and in Australia and South Africa, and a number of notable penetrations of snowfall towards low latitudes in both hemispheres. Indeed, it has recently been reported (KUKLA AND KUKLA 1974) that the extent of snow and ice averaged over the year has increased by 12% since 1967. Until we have a better organized and fuller knowledge of the record of climate in the past, however, it will not be possible to assess the significance of these events adequately.

Assessment at present is rendered more difficult by a certain lack of integration of the growing knowledge of meteorology and of the sciences concerned with the much longer-range behaviour of climate. There is some hope that this situation will improve as a result of the symposia being arranged by the World Meteorological Organization and the International Association for Meterology and Atmospheric Physics in Norwich and Grenoble in August and September 1975.

At this stage it seems possible to venture the following conclusions:

(i) Forward computation of the solar radiation available in different latitudes and seasons over the Earth with the slow cyclic changes of the orbital arrangements (VERNEKAR 1972) seems to imply development towards an ice age situation (possibly less extreme than the last glaciation) about 10 000 years hence.

(ii) The operation of superposed fluctuations on time scales from about 200 to 2000 years, possibly attributable to solar output fluctuations and changes of the combined tidal force of sun and moon*, must be expected to produce periods of climatic recovery (increasing warmth) or of apparent long-continued stability of climate, followed by sharp (step-like) cooling, superposed on any slow general decline of temperature level in the millennia ahead. These shorter-term changes must of course be much more apparent to

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* It has recently been indicated (KING 1974) that investigation of the apparent association between the long-term westward drift of the Earth's magnetic field and the eccentricity (wave number 1) component of the general atmospheric circulation in the middle and upper troposphere may throw further light on the causes of climatic change on these time scales.

the people living at the time than the 10 000-year trend, but at some point within the next few millennia one of these combinations may be sufficient to change the climate near 50° N in Europe rapidly to one favouring pine rather than oak forest and the possibilities of cultivating grain and fruit crops accordingly. The corresponding changes to be expected in Africa and elsewhere in low latitudes might be partly elucidated by studying evidence of the tendency during analogous climatic fluctuations in the past.

(iii) There seem to be similarities between the course of the climatic fluctuations that have taken place during the present century and those that occurred just 200 and 400 years earlier. The parallel with the sixteenth century may be the closer of the two, but both are in some respects impressive.

The pattern observed in middle latitudes in recent years probably implies a very awkward kind of year-to-year variability developing there. Just as opposite extremes of warmth and cold, wet and dryness have occurred in different sectors in that zone, the same season at one and the same place may tend to opposite extremes in different years as the locus of blocking anticyclones shifts from sector to sector. It is worth noting that in the long record of the Baltic ice since AD 1535, in terms of the date of the spring opening of the port of Riga, the two earliest and the latest date of opening all occurred in the same decade, the 1650s. The whole of that century seems to have been marked by excessive blocking, and on the whole tended most to the cold extreme.

In regard to the global cooling trend since the 1940s and concomitant phenomena, it may be important to observe that there appear to be common characteristics between this and most earlier global climatic cooling episodes, the pattern of which can be traced. Among these characteristics, an increase in the frequency of northerly and northwesterly winds and of storms from these directions affecting Britain, the North Sea and much of northern Europe seems prominent. It may be that all climatic cooling episodes are alike in being marked by decline of the middle latitudes westerlies (perhaps particularly in the British Isles sector), reduced zonal circulation index and increased meridional circulation character: hence all major episodes of this kind would have some appearance of a glacial-onset regime.

The question of whether a lasting increase of glaciation and permanent shift of the climatic belts results from any given one of these episodes must depend critically on the radiation available during the recovery phase of the 200-year and other, shorter-term fluctuations. An influence which may be expected to tip the balance rather more towards warming - and possibly inconveniently rapid warming - in the next few centuries is the increasing output of carbon dioxide and artificially generated heat by Man (MITCHELL 1972).

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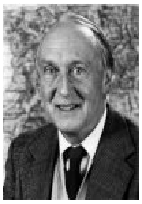

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