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Temperature fluctuations and trends over the earth

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SUMMARY

The annual temperature deviations at over 400 meteorological stations are combined on a regional basis to give the integrated fluctuations over large areas and zones. These are shown in graphical form, and it is concluded that a solar or atmospheric dust hypothesis is necessary to explain the world-wide fluctuations of a few years duration. An important change in the relationships of the zonal fluctuations has occurred since 1920. The overall temperature trends found from the data are considered in relation to the homogeneity of recording, and also to the evidence of glacial recession in different zones. It is concluded that the rising trend, shown by the instruments during recent decades, is significant from the Arctic to about 45°S lat., but quite small in most regions below 35°N. and not yet apparent in some. It is thought that the regional and zonal distribution of recent climatic trends is incompatible with the hypothesis of increased solar heating as the cause. On the other hand, the major features of this distribution are not incompatible with the hypothesis of increased carbon dioxide radiation, if the rate of atmospheric mixing between the hemispheres is a matter of decades rather than years.

1. INTRODUCTION

The many books and articles published during the past century or more on the subject of climatic change testify to its unflagging interest, and, no doubt, also to the number and variety of the theories which have been advanced to account for such changes. Some of these theories, and much evidence of change, are discussed in *Climatic change* (Shapley 1953), and also by Lysgaard (1949) who has assembled a bibliography of no less than 500 items on this subject. Another source of much useful data and discussion of recent events in this field will be found in Ahlmann (1953). Recently Kraus (1960) has suggested that both ancient and modern climatic fluctuations are most readily explained on the basis of changes in the atmospheric cooling rate by long-wave radiation.

The present paper is intended to illustrate the fluctuations and trends of temperature which have occurred in various parts of the world during recent decades, and to suggest possible conclusions which may be drawn from them. This subject, however, is a vast one, and only too easily submerged in an ocean of repelling statistics, unless firm measures are taken to reduce the mass of data into a form which eliminates distracting or irrelevant detail, whilst emphasizing the large-scale features. With this object in view an attempt is made to illustrate the data in a manner which is not too uninviting for the ordinary reader's attention.

As regards the longer-period fluctuations, or trends of climate, which are, no doubt, of the most general interest outside the specialist field, it may be said that the extension of the data for another 10 to 20 years lends support to the conclusions reached in earlier studies of this nature by Lysgaard (1949) and Willett (1950); namely, that a gradual rise in the temperature climate has been in progress for several decades, with a maximum rate in higher latitudes of the Northern Hemisphere, and relatively small rates in most other regions. Temperatures, however, still appear to be quite stable in a few limited areas, amongst which the Black sea – Caspian region, most of Australia, and the far south Atlantic Ocean, are the most notable.

Some suggestions concerning the origin of these climatic trends will be found in the final section of this paper, but this is a difficult subject : by long tradition the happy hunting ground for robust speculation, it suffers much because so few can separate fact from fancy.

2. The data

Continuous temperature records of long duration are available nowadays for most parts of the world, although wide gaps still exist in some regions – notably the southern oceans and the Antarctic. Much experience is necessary, however, in handling these data because of the extreme variability in accuracy of the recordings over long periods, and it is always advisable to take into account any historical information concerning them before accepting the published figures. Some general remarks on the methods used for assembling the data presented here will be found in the following sub-sections.

(a) *Assembly of data*

In order to limit the size of this investigation to reasonable proportions, and to obtain results of the most general significance, only mean annual temperatures are used. About 600 of these records have been examined, and the combined differences from average used to compute the fluctuations in all countries or regions where there are several series of long duration. When weighted according to area, the averages in these regions give the zonal or world-wide fluctuations, apart from the blank areas in the south previously mentioned. Because of the amount of computation involved by this procedure, and in view of the possible use to other investigators, it has been thought worth while to include the annual deviations for the zones as appendix tables to this paper. The majority of these annual temperatures have been obtained from *World Weather Records* (1927, etc.), and the historical notes included therein have proved most valuable in assessing the homogeneity of many series. Some few score others have come from a variety of sources, too numerous for mention here.

The method recommended by Willett (1950) of taking back successive differences from a late period, has been used to bring in stations which do not cover the whole of the standard average period required to place regional fluctuations on a uniform basis. Any period of 30 or more years is suitable for this purpose, but it is preferable to use a middle period, such as 1901-1930, which is covered by a very large number of stations. The difference from, say, 1921-1950, in particular districts or regions, may then be used to bring in shorter series, after checking back their decadal fluctuations with neighbouring stations.

(b) *Assessment of accuracy*

As might be expected from the number of series used, and the random nature of most of the errors, the latter will hardly affect deviations for large areas or zones which are only taken to the nearest one-hundredth of a degree, (i.e., one or two figures in almost all cases). There are, however, certain well-known sources of error which cannot be classed as random because they may similarly affect a number of stations, and thus seriously influence the temperature trend recorded for wide areas. Of these the most common is known as ' Urban effect ' – the rising trend usually found when an observing site becomes sheltered by new buildings, or a large increase of population in the near neighbourhood. In certain countries where large numbers of temperature series have been published in compact form (e.g., ' Climate records of Japan and the Far East area,' 1954) it has been possible to compare the trend shown at both city and rural stations. Thus it was found that the 30-yr change, 1921-1950 minus 1891-1920, averaged for the nine largest cities in Western Europe, was 0·42°C, whereas the average of this change at 14 rural-type stations, covering approximately the same area, was 0·36°. Similar comparisons in other regions, over a variety of periods, usually showed a small excess of rising trend at the urban stations, amounting to from 0·03 to 0·1 on a 30-yr change. Thus when using a mixture of urban and rural sites, as is typical of those given in *World Weather Records*, one must bear in mind that average temperature trends may be too large by a factor of around $U/400\,n$ °C/yr, where U/n is the proportion of urban sites used for the average. This correction, however, has not been used here owing to compensating factors in many regions.

Almost as common as urban increase is the opposite effect on temperatures caused by ' improved exposure ' of the instruments. This is especially noticeable in some of the very old series, and also in some nineteenth-century readings from tropical climates, when the importance of radiation effects was becoming recognized and modern screens were substituted for inefficient, or badly placed old types. Also under the heading of improved exposure comes the removal from city to airport sites, so frequent of late decades, which may give a sharp drop in recorded temperature. Corrections for these exposure changes are, however, often given, or used, in the published data, and, in any case, are less difficult to detect than the urban effects. Other sources of error have been fully documented by Mitchell (1953). Most are small and of a random nature, provided reasonable inspection of the stations is maintained.

Apart from rejecting some few dozen obviously erratic or over-urbanized series, the policy here has been to avoid introducing any subjective factor into the data, and to rely on numbers to minimize the minor exposure changes. The results of various tests for the homogeneity of all the stations used are as follows :

(1) Known from history, site, and intercomparison to be very reliable – 16 per cent.

(2) Appear from history and cross-checking to be quite reliable – 58 per cent.

(3) Towns stations showing marked urban increase – 8 per cent.

(4) Doubtful, and probably unreliable records – 18 per cent.

From this analysis it appeared that about three-quarters of the temperature records as published are reasonably homogeneous, in the twentieth century at least, and a few of those in Europe for 100 years, possibly more. In addition many of the doubtful series are reliable enough after a break in an early period.

(*c*) *Presentation of data*

In order to present this mass of data in an acceptable form some smoothing is necessary, because annual deviations are unattractive for illustrating a long series : the significant oscillations are lost to the eye in a jumble of confusing detail. Here a 5-yr smoothing* has been used to date the short-period fluctuations – a procedure which gives graphs similar to the 5-yr moving average, but with better appearance and dating of the short fluctuation. For illustrating longer variations, or temperature trends in the zonal averages, a 20-yr moving average seems to be quite acceptable, although this average usually gives an ugly and distracting graph for a single station in higher latitudes, owing to the erratic incidence of cold or warm years.

3. Discussion of figures

For brevity, the sections are sub-divided, but only a few of the more outstanding points can be discussed here. For the rest, the Figures must speak for themselves.

(*a*) *The reality of temperature fluctuations integrated over large areas*

To begin we may consider the fluctuations in various tropical regions, as shown in Fig. 1, because doing so will bring out a point of fundamental importance in an investigation of this kind; namely, that the averages of temperature from a few well-distributed

* $Ts = \frac{1}{9}(T(n-2) + 2T(n-1) + 3Tn + 2T(n+1) + T(n+2))$ where n is the date-year on the graph.

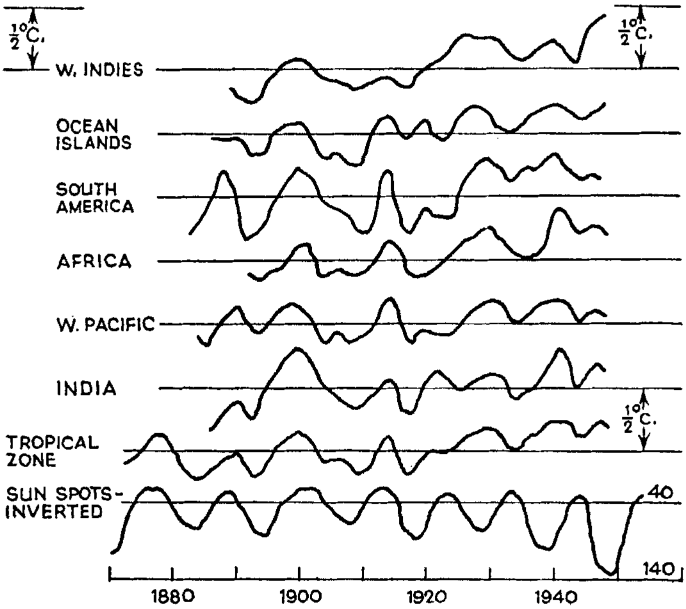

Figure 1. Temperature fluctuations in tropical regions, 5-year annual mean departures from mean 1901-1930.

stations, (in this case 10 to 20 stations for areas of 4 to $7 \cdot 10^6$ km^2), do in fact record real fluctuations over great regions : otherwise it would not be possible to account for the remarkable concurrence in time of those fluctuations shown by the graphs in Fig. 1. The latter supply definite observational evidence on a point which is by no means above controversy amongst those who are unfamiliar with this type of data.

(b) *Regional fluctuations in the tropical zone*

Regarding the fluctuations themselves, the impression is certainly given that they are caused by some overriding factor such as solar variation, or atmospheric transparency. Undoubtedly there is a striking correspondence between them and the inverted sun-spot curve, (bottom graph in Fig. 1), from 1875 to 1920. Since then, however, the phase has apparently reversed. On the other hand, if the fluctuations are caused by pulses of the trade winds or general circulation – in the sense that a warm period represents a tendency to stagnation, soon corrected by the induced pulse of advection from colder latitudes – it seems remarkable that they should occur at approximately the same time all round the tropical zone. Solar fluctuations would seem necessary to set the time scale.

In the case of the largest tropical fluctuations, about 1900, 1915 and 1940, annual temperatures rose and fell almost simultaneously at the great majority of the stations. Even with a greatly increased number of stations in the last decade, almost all showed a significant fall from 1941 to 1943. Another point of interest, and possible significance to a solar origin for these fluctuations, is that the high-level station of Quito, on the Equator, regularly records all the warm and cool years given by the zonal average for the Tropics. Thus the latter gives 1893 and 1917 as coolest years, and 1941 as warmest in the 70 years 1881 to 1950. These were also the ' record ' cold and warm years at Quito.

(c) *Regional fluctuations in the temperate zones (Fig. 2)*

Only a few widely separated temperate regions have been shown in Fig. 2, because it was found that if many were plotted on one small-scale figure the result was a confusing jumble of lines, too unattractive for anything but a hasty glance. Even so the contrast

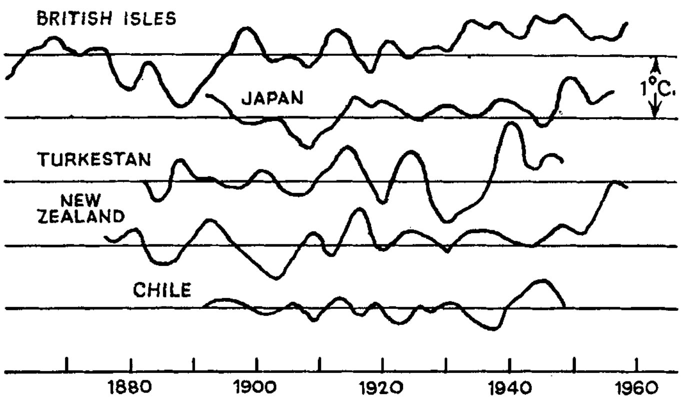

Figure 2. Temperature fluctuations in parts of temperate zones; 5-year annual mean departures from mean 1901-1930.

between Fig. 1 and 2 is very striking. In place of the orderly progression of oscillations in different parts of the tropics, we find a chaos of vigorous fluctuations in the temperate regions, sometimes directly opposed for long periods, at others running parallel over many years. These variable fluctuations in the temperate zone certainly do not lend themselves to a solar explanation. As a rule they can be related to semi-permanent displacements, in the average ridge and trough structure of the zonal westerlies, although there are difficulties where the longer-lasting fluctuations are concerned. (For example, Petterssen (1949) finds that the higher average temperature in the West Greenland region during the 1930's cannot be explained by increased advection from the south).

(*d*) *Temperature fluctuations integrated for the zones* (*Fig. 3*)

The annual deviation for the zones (appendix tables), has been obtained by combining each region, after weighting them according to the area represented. In the case of isolated stations such as oceanic islands, an equivalent area of 100-degree squares has been allotted to bring them into the zonal average. These deviations for the whole zone, however, are only computed to the nearest 0·01°, or two figures at most, and experience shows that it makes hardly any difference whether the stations are grouped into large regions of roughly equal area, or into many small districts of about the same size.

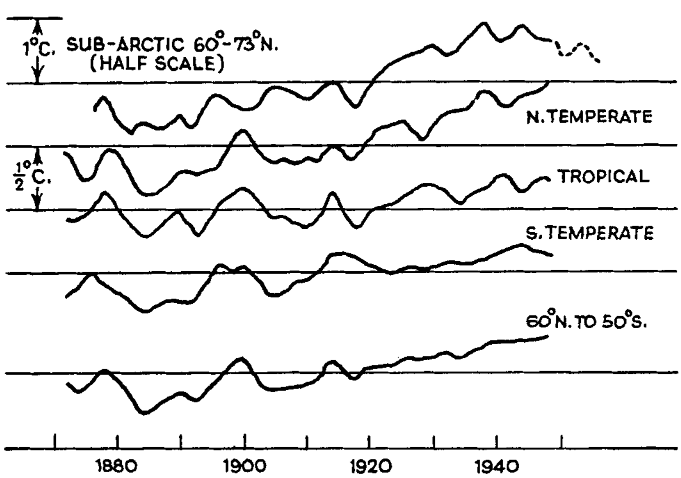

Figure 3. Temperature fluctuation integrated for the zones; 5-year annual mean departures from mean 1901-1930.

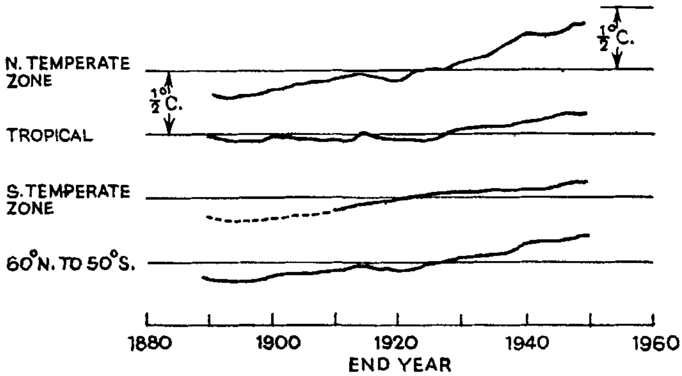

Figure 4. Temperature trends integrated for the zones; 20-year moving average departure from mean 1901-1930.

The zonal graphs of Fig. 3 demonstrate that all the chief fluctuations from 1875 to 1915 occurred simultaneously in both temperate and tropical regions. Since then the picture is more confused, with the minor fluctuations taking a different course in each zone; and, from about the same time, a marked rising tendency has occurred in the northern zones, with a small but significant rise in the Tropics. From about 1900, if not before, these fluctuations are undoubtedly a fair approximation to the actual variations of temperature over a major part of the earth's surface, and, as such, they must be taken into account when considering how recent changes in northern latitudes came about. In doing so it is probably necessary to assume quite separate causes for the short fluctuations than for the overall rising tendency during recent decades.

The fluctuations in the sub-Arctic zone, from approximately 60° to 73° latitude, have not been included in the continued zonal average (bottom graph, Fig. 3), because they are very large, and there are no equivalent areas represented in the Antarctic to counterbalance them. In any case they cover such a small area, compared with the other zones, that their inclusion would make little difference to the overall zonal average. Scattered data for the 1950's show that the big rise in this zone during the 1930's and 1940's has receded, for the time being at least, with averages in Alaska and north Scandinavia nearly back to those for 1901-1930. There is, however, little indication of a similar recession in temperate latitudes, for the 1950's have given higher averages than previous decades at several places, of which the most notable are eastern North America, Japan, Egypt and New Zealand.

4. Trends in zonal temperatures (Fig. 4)

Before considering these zonal trends a reminder is necessary that the nineteenth-century averages are less reliable than those for later decades. This is especially so for the Southern Hemisphere owing to the small number of stations available at that time, and it also applies to the early tropical data, although there are many more stations, and a smaller proportion of urban sites in the latter. Some general remarks on accuracy, with special reference to 'urban effect,' have already been made in sections 2 and 3, and in the following sub-section an indication is given of where the zonal averages are likely to be most reliable.

(a) *Reliability of the zonal temperature trends*

In all the land areas of the north temperate zone, with the exception of east Central Asia, there are reasonable numbers of published temperature series for cross-checking back 60 to 70 years. In Western Europe to about 20°E. long., U.S.A. and Japan, ample records have been available for very close checking, using wherever possible, the ' rural type ' stations. For U.S.S.R., it is reported that thermometer screens are established ' in an open place outside the town,' (*Notes, W.W.R.*, 1921-1930), and examination of the 10-yr deviations at 50 stations in that large country certainly suggests that very few of them have suffered from urban effects, or sudden exposure changes. Quite a large proportion of the many coastal and island stations used to represent the northern oceans have unexceptionable sites, but the central North Pacific for nearly 100° longitude is a blank area, which might be expected to have a somewhat smaller trend than the continents. (At the Azores the trend for 1891-1957 appears to be only about half the zonal average, but further north it is considerably greater). It may be noted that the 20-yr deviations for the north temperate zone 1900 to 1940, as given in Fig. 4, are closely similar to those computed from Willett's (1950) curves for the zone between 30° and 60°N. lat., although about 4 times as many stations have been used here.

In the tropical regions a marked feature is the smallness of the 10 or 20-yr deviations as compared with the other zones. There is a close cover of stations available since 1881 for India (Pramanik and Jagannathan 1954), but many of the individual series are erratic by northern standards. The vast tropical oceans are only represented by a dozen or so long series, which, however, include a few of the highest class, such as the Royal Alfred Observatory at Mauritius and, most probably, Apia, should be included with Honolulu in this class. These show the same tendency as the zonal average for the temperature to creep up a few tenths of a degree in the later decades, but on the Mexican plateau, and at the high Andes stations of Quito and La Quiaca this tendency is much more marked. It could, no doubt, be related to recent recession of glaciers on the high tropical mountains (Ramirez 1958, Spink 1949, Charnley 1959, etc.).

Little can be said about the south temperate zone. The uncertainty of the earlier data has already been mentioned, and later it can only give the trend for the very limited land areas. No doubt very stable temperatures prevail over the great southern oceans from one decade to another, and it would be quite legitimate to doubt the small upward trend for this zone shown by the average in Fig. 4, were it not for the evidence of considerable glacial recession in the Southern Alps and Andes (Harrington 1952, Broggi 1945, and several others). This latter suggests that the trend found for the land areas in this zone is reflected in a similar, though perhaps smaller, trend of ocean surface temperature, as in the north Atlantic Ocean (Brown 1953).

Farther south there are only two long temperature series on the fringe of the Antarctic zone, at Grytviken 55°S and at Laurie Island 61°S, and neither of these shows any overall trend during the period 1904-1950. Both stations lie in a very stormy zone of pack-ice and icebergs, where the thermostatic properties of melting ice must have a powerful influence on surface temperatures, so perhaps we should not expect to find any trend here so long as the sea-ice is plentiful.

(*b*) *Overall temperature trends in the zones*

The difference between succeeding 30-yr averages is a convenient way of recording long-period temperature changes, when only the general trends are required, without the fluctuations of moving average or accumulated temperature graphs. It is not, however, really satisfactory for mapping the trend over the earth from individual stations, because an unsuspected lack of homogeneity at an isolated station may be magnified to cover a great area with the wrong sign. The half-period change 1891 to 1950, together with the approximate areas covered by the stations used here, is shown in Table 1.

The overall change marked N – T – S in Table 1, is simply the average for the 3 major zones, because it was found that a more elaborate system of weighting according to the area covered by stations in each zone, and assuming this change was zero over the Antarctic, led to virtually the same result for the whole earth.

TABLE 1. 30-YR CHANGE 1921-1950 MINUS 1891-1920 INTEGRATED FOR THE ZONES

Zone	Latitude range of zone	Zone area per cent Earth	Approx. station cover per cent zone	Average for zone °C 1921-1950 minus 1891-1920
Sub-arctic	73-60 N	4½	80	0·83°
North temperate	60-25 N	23	72	0·39°
Tropical	25 N-25 S	42	75	0·17°
South temperate	25-50 S	17	25	0·14°
N – T – S	60 N-50 S	82	63	0·23°

(c) *Seasonal trends*

Although only annual temperature trends are illustrated here, a word should be said about those for the seasons, because there appears to be a widespread impression that it is only the winter which has advanced. Although true for certain ice-infested districts of the sub-Arctic, this is far from being the case in several major regions of the north temperate zone, where the summer (June to August) temperature has risen more than the annual. In Table 2 the summer and annual 30-yr changes are shown for a few reliable stations, which have an annual trend quite typical of the region in which they are situated. Out of 40 stations in the north temperate zone, for which the summer temperatures were examined, only Valentia, Father Point, Tomsk and Irkutsk, showed rather less rise in summer than for the year.

TABLE 2. 30-YR CHANGE 1921-1950 MINUS 1891-1920 FOR SUMMER AND YEAR (°C)

Station	Region	Summer	Year	Station	Region	Summer	Year
Oxford	England	0·52	0·34	Suttsu	N. Japan	0·60*	0·21
Neuchatel	Switzerland	0·55	0·41	Hikone	S. Japan	0·71	0·12
Sonnblick	High Alps	0·75	0·49	Blue Hill	NE. U.S.A.	0·72	0·63
Irkutsk	Central Siberia	0·33	0·40	Alpina	Great Lakes	0·68	0·46
Tomsk	West Siberia	0·29	0·35	Concordia	Mid-west	0·69	0·56
Tashkent	Central Asia	0·29	0·08	Winnemucca	Plateau	0·91	0·59

* July to September

5. CAUSE OF THE RISING TEMPERATURE TREND

The cause of climate fluctuations and trends is speculative in the present state of knowledge, but a few brief remarks on this subject seem called for here. These are confined to certain radiative effects in the atmosphere, because limitation of space does not allow the discussion of several other theories which have been proposed from time to time.

(a) *Atmospheric dust as a cause*

It has been suggested by Wexler (1953) that the rising temperature trend could be due to increased atmospheric transparency for solar heat, owing to a reduced number of dust-producing volcanic eruptions in recent decades. There is no doubt that the short-period fluctuations in the zones (Fig. 3) lend some support to this view, for they strongly suggest disturbances to the radiation balance affecting all three zones in the same way rather than the transport of heat from one zone to another. For example, the high-altitude dust from Krakatoa 1883, and Pelée 1902, could have caused the sharp falls in all three zones about those dates, and the absence of concurrent fluctuations since 1920 might be attributed to a lack of explosive eruptions of sufficient size to affect the whole earth. But the problem is very complex, and it would be difficult to explain the big oscillations about 1912-20 on the basis of the Katmai eruption in 1912, or the fact that the many eruptions since 1920 do not appear to have had a significant effect on the zonal fluctuations. Evidently there are other factors at work besides volcanic dust.

If the upward temperature trend shown by the zonal averages (Fig. 4) were due to an increase of solar heat reaching the earth's surface, either because of greater atmospheric transparency, as proposed by Wexler, or a rise in the energy output of the sun itself, one would expect to find a greater rising trend in sunny sub-tropic countries than in the cloudy north Atlantic region. But the reverse is observed, in fact some of the sub-tropic and desert regions are notable for their absence of any temperature trend in the last 60 or more years – particularly sunny Australia and the Lake Balkhash-Caspian region of Central Asia. Also there would be reason to expect increased precipitation in the tropical rain belt if the solar heating grew stronger. In fact a decrease has been reported in some parts of this region (Kraus 1955).

The alternative theory that a warmer and drier trend has been caused by decreased solar heating is very hypothetical. It would require a decrease in the vigour of the general circulation, with reduced polar temperatures, both of which are contrary to observation as far as the North Atlantic sector is concerned (Lamb and Johnson 1959).

To summarize this brief discussion it could be said that, although a solar or dust hypothesis is applicable, or even necessary, to explain the short-period fluctuations found in the zones, it fails as an explanation of the pattern of recent climatic trends observed in various parts of the world.

(b) *Increased carbon-dioxide radiation as a cause*

Some years ago the writer suggested that rising temperature trends, already observed in certain regions, could be due to back radiation from the extra CO_2 produced by fossil-fuel combustion. (Callendar 1938, 1949). Since then calculations on atmospheric radiation by Plass* (1953) have supported this view, and he considers that variations of atmospheric carbon dioxide are an important factor in climatic change (Plass 1956). Here it will be assumed that the essential features of this hypothesis are well known, and also that a rise in the amount of atmospheric carbon dioxide has actually occurred since the turn of the century* (Callendar 1958). But if these factors are taken for granted an attempt

* For very small changes of CO_2 in the atmosphere Plass finds a surface temperature derivative, $dt/d\ CO_2$, of 12, in °C and gm cm^{-2}. From this a rise of 0·4° (North temperate zone, Table 1) would require 33 mg cm^{-2} more CO_2 in the atmosphere, equal to an average increase of 7 per cent between 1891-1920 and 1921-1950. This compares with an observed increase of CO_2 over these periods of approximately 6 per cent in the European region, (Callendar 1958). It should be remembered, however, that this matter of atmospheric CO_2 increase is highly controversial at the present time, and several authors (Revell and Suess 1957; Flohn 1958, and others) have expressed doubt as to the possibility of a CO_2 increase approaching the amount, (40 mg cm^{-2} by 1950) added by fossil-fuel combustion.

must be made to show that the observed distribution of recent climatic trends over the earth is not incompatible with the CO_2 hypothesis, and that in certain cases the latter can supply a reasonable explanation. It must be emphasized, however, that this hypothesis can only explain general trends, for the short-dated fluctuations are clearly due to quite other factors.

There are many features of the recent climatic fluctuations and trends which cannot be explained in the present state of knowledge, but it is possible that the CO_2 hypothesis can supply the answer to more than one of them. Examples of this explanation follow :

(1). It is observed that the rising temperature trend is very small in the south temperate zone as compared with that in the north (Table 1). Apart from the natural time lag due to the thermal inertia of the great southern oceans, with their constant supply of melting icebergs, there is also a large, but unknown, time lag in the transport of excess CO_2 from where it is nearly all produced, in middle northern latitudes, across the equator into the southern westerlies. Thus a considerable fraction of the extra CO_2, and the warming effect which goes with it, may still remain in the northern westerly circulation to give the greater temperature rise there than in other latitudes. This argument appears to be supported by radio-carbon measurements showing a much smaller proportion of fossil carbon (i.e., from coal and oil) in living vegetation taken from the Southern Hemisphere than in samples from the north temperate zone (Arnold and Anderson 1957).

(2). The tendency for precipitation to decrease in many warm regions, and remain sub-normal during the first three or four decades of this century (Kraus 1955). In this case the following explanation, although plausible in a general sense, does not presume to cover the details of this fluctuation in either time or space. As the quantity of precipitation is a measure of the latent heat released at the cloud level, anything which retards the loss of this heat will tend to slow down the convection currents and precipitation. Increased CO_2 in the atmosphere would be effective in reducing the loss of heat by radiation from the upper surface of clouds, the more so because there is seldom enough water vapour above the cloud level to interfere with radiation in the CO_2 wave bands. Thus more CO_2 should tend to depress the convective precipitation in the tropics, at least for a time while temperatures rise to restore the overall balance between heat supply and loss. In this connexion it has been pointed out by Kraus (1956) that the rainfall has apparently not decreased in the area of the SE Asia monsoon, where land heating drives the system. Therefore it may be that the thermal inertia of the oceans has delayed the re-establishment of radiative equilibrium in other tropical regions, with consequences as suggested.

(c) *Trends in the Arctic region*

There is no doubt that the most spectacular climatic event, of which we have reliable instrumental record, has been the big rise of temperature in most parts of the sub-arctic zone during the 1920's and 1930's (Fig. 3). This rise, however, has been quite local in relation to the major zones, and it cannot have a direct connexion with variations of atmospheric radiation, whether caused by CO_2 or any other factor. On the other hand, an indirect connexion is quite feasible because warming in lower latitudes could cause the polar vortex to contract and bring the westerly circulation, with its storms and clouds, more often into this marginal zone.

The significance of the latest developments in the sub-arctic zone, which include a marked temperature recession in some sectors, 1948-1956, cannot be judged as yet, but there is little sign of this recession spreading to temperate latitudes, where 1957-1959 have been warm years in many parts.

Acknowledgments

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Appendix

Annual deviations integrated for the zones from mean 1901-30, °C × 100

SUB-ARCTIC ZONE. 60-73°N

Decade	No. of stations	1	2	3	4	5	6	7	8	9	10	Decade mean
1870	8				-50	-27	-49	-63	26	-16	-60	-34
1880	14	-100	-135	-8	-57	-85	-43	-73	-110	-4	-35	-65
1890	18	-70	-102	-62	6	-37	-18	-2	-47	-58	-31	-42
1900	20	4	-127	13	-5	32	-14	-30	0	-18	-38	-18
1910	23	-25	-9	7	0	-4	9	-62	-59	-37	26	-16
1920	29	17	-2	42	47	2	77	-10	95	52	47	36
1930	46	57	50	-12	107	37	55	110	132	87	47	67
1940	59	30	55	129	119	49	41	94	86	31	29	66
1950	34*	0	40	100	90	-30	0					

(N) NORTH TEMPERATE ZONE 25-60°N

Decade	No. of stations	1	2	3	4	5	6	7	8	9	10	Decade mean
1870	60	-25	4	11	-22	-66	-25	-11	32	-22	-9	-15
1880	136	-11	10	-40	-48	-35	-24	-19	-42	-3	-3	-21
1890	159	-22	-28	-34	-3	-26	-21	-11	8	11	23	-10
1900	169	13	-13	-19	-14	-8	12	-35	-18	-14	5	-9
1910	171	-6	-35	0	16	15	-10	-36	+10	-8	-1	-7
1920	187	39	10	20	1	41	25	12	9	-24	28	16
1930	159	31	42	-8	54	16	34	22	65	55	24	34
1940	200	22	18	51	53	13	56	36	60	53	27	39
1950	100*	34	35	74	36	44	10	40				

(T) TROPICAL ZONE 25°N-25°S

Decade	No. of stations	1	2	3	4	5	6	7	8	9	10	Decade mean
1870	10	-2	2	9	-11	-6	-8	26	56	-19	2	+5
1880	30	13	-20	-20	-32	-9	-13	-43	11	20	-18	-9
1890	44	-1	-5	-44	-19	-4	15	30	-8	9	30	+1
1900	63	10	23	-6	-35	1	6	-12	-10	-13	-28	-7
1910	75	-10	3	-8	21	41	-10	-43	-22	14	1	1
1920	91	-2	4	0	4	-7	23	13	27	8	12	8
1930	94	28	15	0	-3	4	16	17	10	8	26	12
1940	151	48	31	-2	13	13	25	30	26	18	4	21

(S) SOUTH TEMPERATE ZONE 25-60°S

Decade	No. of stations	1	2	3	4	5	6	7	8	9	10	Decade mean
1870	11	-34	-1	2	-32	-13	15	15	-24	-31	-4	-10
1880	13	-10	-15	-24	-46	-25	-12	-23	-7	-19	-16	-20
1890	17	-20	-30	-23	-14	-5	37	7	-37	1	26	-6
1900	37	13	-15	-20	-10	-28	-20	-21	-4	-5	-4	-11
1910	38	-10	0	22	20	7	12	22	-2	30	6	11
1920	36	-10	12	-6	-6	-5	17	1	5	7	-8	1
1930	39	1	19	7	13	-3	8	10	9	2	27	9
1940	46	11	10	25	32	12	13	31	6	3	5	15
1950												

N − T − S (NORTH-TROPICAL-SOUTH) 60°N-60°S

Decade	No. of stations	1	2	3	4	5	6	7	8	9	10	Decade mean
1870	80	-20	5	0	-22	-28	-6	10	21	-24	-4	-7
1880	159	-2	-8	-28	-41	-23	-16	-28	-12	0	-12	-17
1890	220	-14	-21	-33	-12	-11	11	9	-12	7	27	-5
1900	269	12	-2	-15	-20	-12	-1	-23	-11	-11	-9	-9
1910	284	-9	-11	5	19	21	-3	-19	-5	12	2	1
1920	314	9	9	5	0	10	22	9	14	-3	11	9
1930	292	20	25	0	21	6	19	16	28	22	26	18
1940	400	27	20	25	33	13	31	33	31	25	12	25
1950												

(* 1951-1957 without U.S.S.R. or about one-third of the zonal area)