Fluctuations of climate and of general circulation of the atmosphere in extra-tropical latitudes of the Northern Hemisphere and some problems of dynamic climatology

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ABSTRACT

A problem of the methods involved in studying long-period climatic variations in the northern hemisphere is discussed. The data obtained at individual points are compared with circulation characteristics (ratio of the zonal and meridional components) for the whole hemisphere. In analysing the variability of the circulation use is made of the system developed by the author and his co-workers for typifying atmospheric processes over the hemisphere for the past 56 years. In view of the good agreement previously obtained between the long-period variations of these circulation types and solar activity it is considered that a continuous chain (sun–general circulation–climate of individual points) is set up by means of such a dynamic-climatological analysis. The existence during the first half of the 20th century of periods—"epochs"—differing in both circulation characteristics and average level of climatic values is established. The conclusion is drawn that it is for such epochs that climatic calculations and climatic classification should be made.

1. Introduction

1.1. There are more than 50 definitions of climate. The common feature underlying these definitions is an understanding of climate as a regime which preserves its stability for a long period of time. To define climatic characteristics, series of meteorological observations, which are as long as possible, are usually used.

The following three factors are to be noted: (1) Such data are predominantly used as mean values for calendar periods; (2) it is assumed that the longer the series which supplied the mean values, the more reliable and stable are the climatic characteristics; (3) the long-period mean values are regarded as "normal".

1.2. All climatologists are well aware of the fact that such a mean value is not "normal"; that in the majority of regions it occurs, in fact, extremely rarely, or does not occur at all, and that actual deviations from it may prove to be very considerable. Nevertheless, long-period means are often used in practice not only as a convenient datum for subsequent mathematic calculations but actually as "normal" ("standard") values. Numerous investigations of all kinds of "anomalies" may be called in evidence.

1.3. Climate is one of the main geographic components and climatological data play a very important role in geographical characteristics. It is known what considerable pains are taken to work out principles of climatic classification and to put them into practice.

Trying to render the boundaries of climatic and also of geographic regions as constant as possible, some authors seek the most stable indices. From climatological data the long-period "normals" are regarded as such stable values.

1.4. However, climate is less stable than other geographic components, such as botanic and especially geomorphologic or soil components. This means that the relation and interaction between these and the climatic components are variable and each time require additional analysis. In some extreme cases (very severe frosts, or hard, prolonged droughts) geobotanic boundaries are notably displaced and are restored only in the course of time.

1.5. The problem of climatic variations and fluctuations has attracted and continues to attract the attention of many scientists. A great deal has been written about it in many different languages.

Numerous attempts have been made to find different causes of climatic change. The majority of authors are inclined to connect it with a variation in solar activity. This connection has been investigated in two ways: (*a*) long-period variations of *one* of the meteorological elements at *one* point were directly correlated with the variations of *one* of the indices of the solar activity; (*b*) the circulation processes of the earth's atmosphere were used as a connecting link.

1.6. In our opinion the most important and urgent tasks facing the study of climatic variations are the following: (1) to estimate the scope and character of the observed fluctuations of climatic elements and to determine whether they are regular fluctuations or anomalies; (2) to clarify their origin and to determine the role of the general circulation of the atmosphere, i.e. to develop general principles of dynamic climatology.

2. Discussion

In the first place we shall discuss the problem of the connection between climatic fluctuations and solar activity, as well as methods of studying this connection.

2.1. Numerous well-known papers have been devoted to this problem. It is neither possible nor necessary to give an account of these works here. I shall only make the following observations.

Attempts to establish a direct dependence of climatic fluctuations at some given point on solar activity have not yielded and cannot yield positive results, since in this case the powerful factor of the general circulation of the atmosphere, which redistributes the incoming solar energy, is neglected.

Unfortunately the majority of papers have often used the circulation processes which are restricted either in space (the region immediately surrounding the point) or in time (study of separate years or seasons: very dry, cold and so on).

2.2. To render the evidence on the general circulation of the atmosphere useful the following main principles are to be observed: (*a*) it is not separate circulation processes but really the general (global) circulation of the atmosphere that should be made the subject of investigation;[1] (*b*) the circulation characteristics should be expressed in simple terms (indices), convenient for quantitative calculation and comparison, but at the same time representing the main processes in the atmosphere over the entire earth or the whole hemisphere.

2.3. In our opinion these requirements are to a considerable extent fulfilled by the atmospheric circulation types developed by the author and his co-workers (DZERDZEEVSKII *et al.*, 1946). (*a*) They give a general characteristic for the whole hemisphere and, at the same time, a more detailed one for its sectors: the Atlantic, Western Europe, Eastern Europe, etc. (DZERDZEEVSKII, 1956*a*, 1959); (*b*) this typification is rather simple (only 13 types of processes)[2] and, at the same time it fairly well reflects all the processes; (*c*) it is in good agreement with the calculated indices of the circulation (DZERDZEEVSKII & MONIN, 1954) and reflects blocking actions; (*d*) it allows us to analyse the evidence for the past years, i.e., it provides the material for statistical analyses (DZERDZEEVSKII, 1957).

Up to the present time we have analysed the data for the first 56 years of the 20th century (more than 20,000 daily synoptic maps of the northern hemisphere) and carried out calculations and analyses of various characteristics of the circulation for this period.

2.4. Our typification was based on the following: Attention was centred on the ratio of the meridional and zonal components of the circulation. By these we meant the correspond-

[1] In a number of cases, owing to a lack of data on the southern hemisphere, one has to limit oneself to the northern hemisphere, but to take a smaller region is inadmissible.

[2] To obtain more detailed characteristics for some parts of the hemisphere the majority of types were broken into subtypes. 1*a* and 1*b* differ due to small variations in the position of the polar anticyclone and in cyclone tracks from the south; 4*a* and 4*b* differ slightly due to variations in the intrusions of arctic air; the difference between 7*a* and 7*b* is due to variations in the circulation pattern in Siberia, etc.

[3] Owing to the lack of the contour maps of isobaric surfaces of the northern hemisphere for the whole mentioned period we were compelled to give up their complete statistical analysis. A combined analysis of the surface and upper-air maps was carried out for the periods when the latter were available. A good agreement of the results allows us to take advantage of the existing long series of surface maps of the hemisphere.

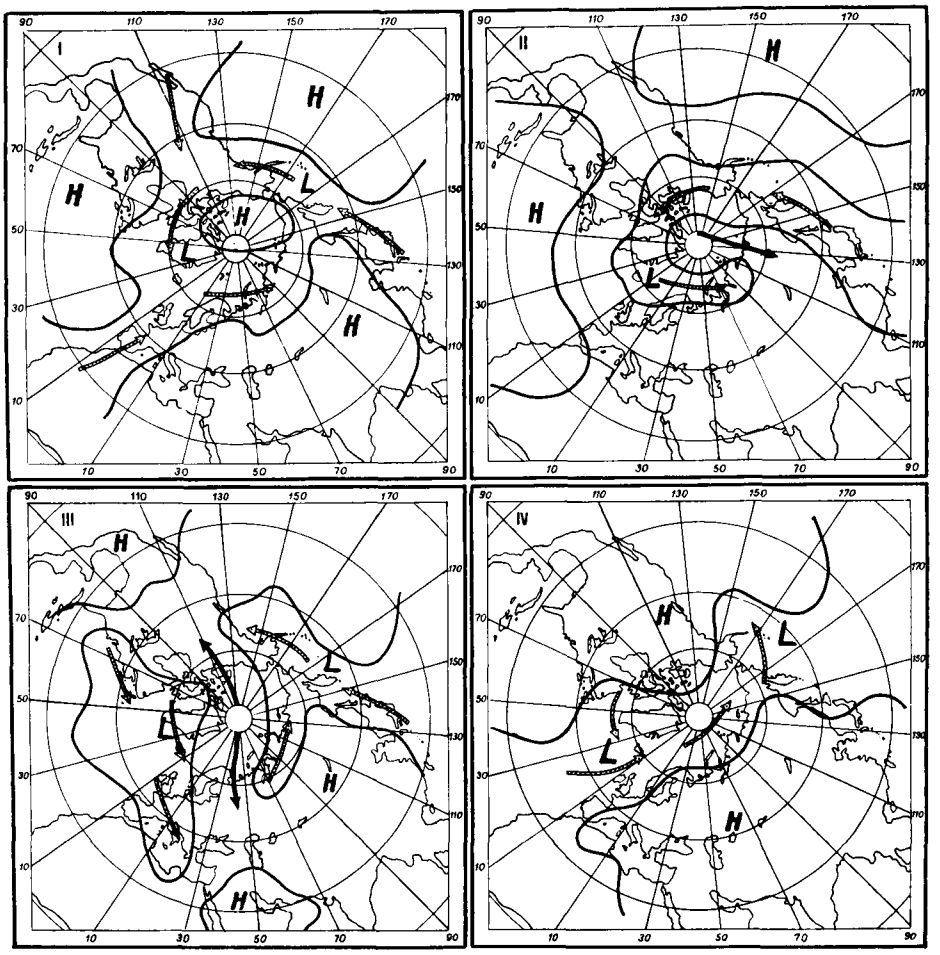

FIG. 1. Four principal groups of circulation types over the Northern Hemisphere. ⇨ Cyclonic tracks; ⟶ anticyclonic tracks; L—Areas of cyclonic activity; H—Areas of anticyclonic activity.

ing directions of cyclone and anticyclone tracks which well reflect the basic transfers—steering currents at the 700 mb isobaric surface (and not infrequently at the 500 mb surface).[3]

The circulation processes over the hemisphere were divided into four main groups (Fig. 1).

(*a*) A ring of cyclonic tracks around an isolated polar anticyclone. Over the greater part of the hemisphere the zonal transfers are preserved. The first and the second circulation types fall into this group.

(*b*) Arctic intrusion in one direction. Here the meridional advections are well expressed, while in the remaining parts of the hemisphere the zonal transfers prevail. This group of processes has been called "violation of zonality".

The direction of the intrusions is distributed over certain sectors of the hemisphere: the Atlantic, Europe and Western Siberia, Eastern Siberia, the Pacific Ocean, America (types 3–7).

(*c*) Arctic intrusions in 2, 3 or 4 directions; meridional currents are observed over the greater part of the hemisphere. Types 8–12 falling into this group are called meridional circulation types.

(*d*) Northward-directed cyclones in the arctic regions; in the remaining part of the hemisphere zonal transfers prevail (type 13).

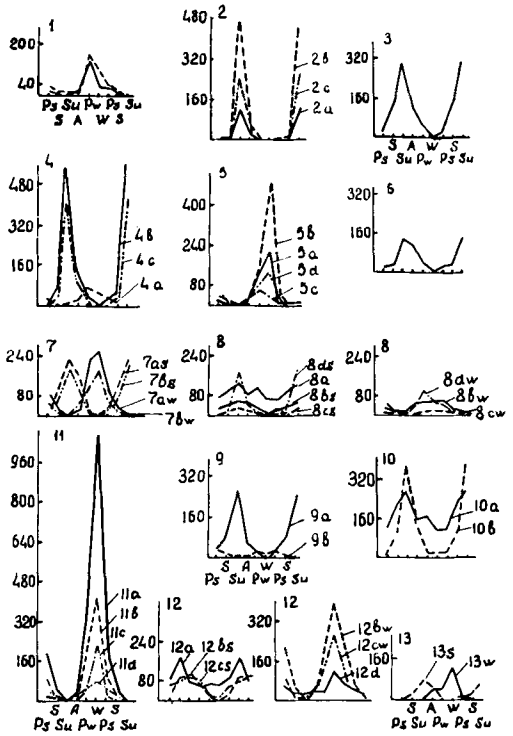

FIG. 2. Seasonal variations of duration of different circulation types over the Northern Hemisphere. PS—Pre-spring; S—Spring; Su—Summer; A—autumn; Pw—Pre-winter; W—Winter.

With the exception of an extremely limited number of cases the entire bulk of synoptic maps was aptly distributed among these 13 types.

2.5. The use of the maps covering the entire hemisphere allows one to follow the development of each process from its inception to its dying out and excludes common errors occurring when maps of artificially restricted regions are used.

One circulation type is replaced by another very rapidly, so that two successive days can be referred to different types of processes. Each homogeneous process is called an "elementary circulation machanism" (ECM). The duration of an ECM is usually equal to 4 days, more rarely to 3 days. The probability of longer or shorter duration (ranging from 1 to 9 days) drops drastically.

2.6. The degree of detail of the system and, consequently, the number of types, was established on the basis of the following considerations. If we average all the processes observed during a year and construct a single generalized scheme of the circulation it will reflect neither the diversity of individual processes nor their variable character induced by the annual cycle of the components of the heat balance of the underlying surface and the atmosphere and expressed in the alternation of the seasons. Therefore the separation of atmospheric processes into types and subtypes must be carried on to a lowest limit where there still exists a close connection between the circulation type and the season.

A detailed analysis prompted us to divide the year into six seasons, summer, autumn, *pre*-winter, winter, *pre*-spring and spring (DZERDZEEVSKII, 1957). Fig. 2 shows the seasonal distribution of all the types of the ECM, including subtypes (see note 2, page 329).

2.7. The borders of synoptical seasons, their duration and circulation structure are not fixed, but notably differ from one year to another as a reflection of the different character of the weather of individual years.

Fig. 3 shows the circulation structure during different years. It is illustrated by departures of circulation components (zonal and meridional) from 56-year average values. These examples well illustrate essential differences in the circulation, though we have not chosen here the extreme years.

A similar analysis of the long-period data allows one to obtain circulation characteristics of the climate in its dynamics and is to be regarded as a development of the principles of dynamic climatology formulated by T. BERGERON (1930).

2.8. An analysis of the circulation characteristics for all the years of the first half of the 20th century points to the existence of a regular distribution, i.e., a long-period march. The existence of two periods—"epochs"—is established, with a meridional circulation prevailing during the first period, and a zonal one during the second (Fig. 4). The existence of such circulation "epochs" is in good agreement with different data and especially with climatological material (DZERDZEEVSKII, 1956*c*).

Climatological materials (temperature of the air, precipitation, atmospheric pressure) were calculated according to a special scheme from a world-wide network of stations (about 500 stations) for all the years of observation.

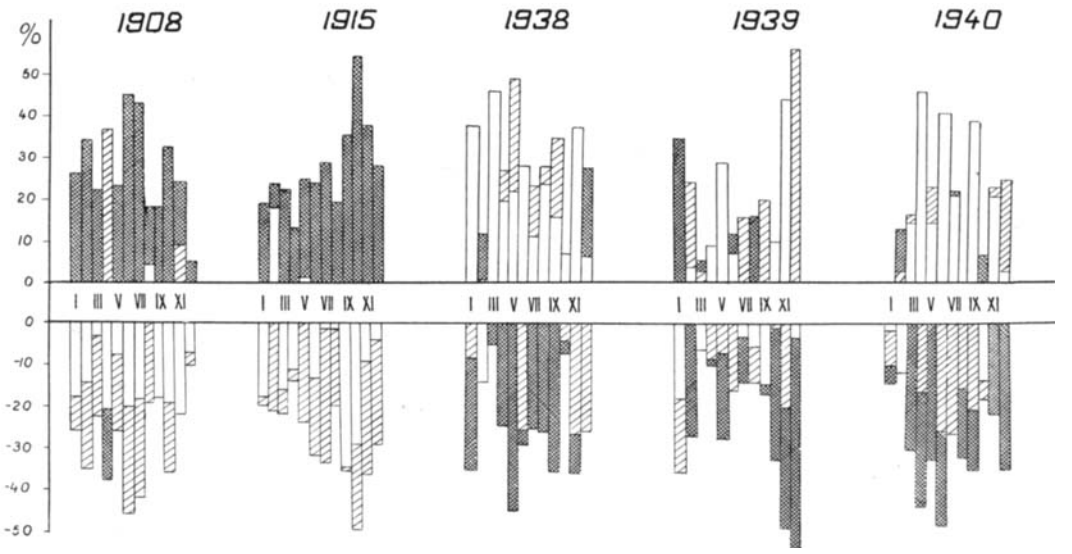

FIG. 3. Departure of circulation components from long-period average values in different years (examples).

zonal circulation; violation of zonality; meridional circulation.

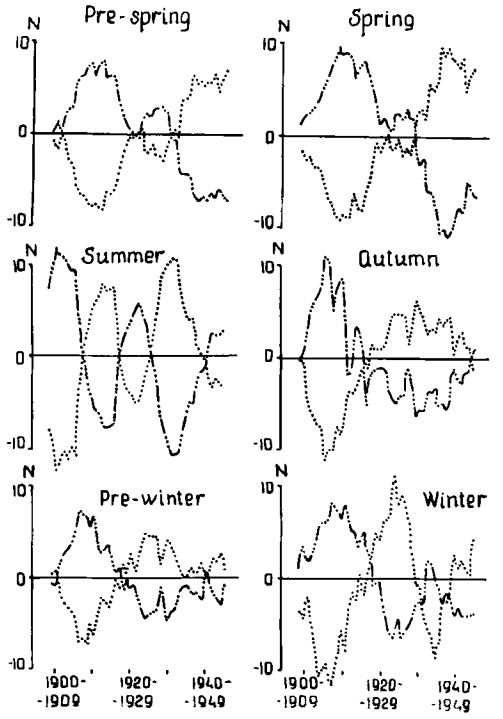

Fig. 4 a.

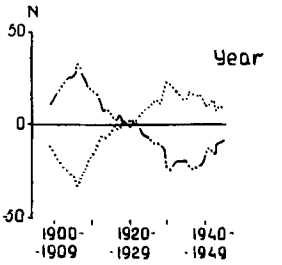

Fig. 4 b.

FIG. 4. Departure of duration of zonal and meridional components of general circulation of the atmosphere over the Northern Hemisphere in the 20th century from long-period average values. (*a*) seasons; (*b*) year.

2.9. Fig. 5 presents curves of the trend of half-age average temperature and precipitation in different points of the northern hemisphere and also curves of the general circulation characteristics for the same period. Use was made of the duration of the 3 main components of the general circulation: zonal, meridional and intermediate, i.e. violation of zolanity within each decade. The figure shows the calculated results for 10-year overlapping means. Similar

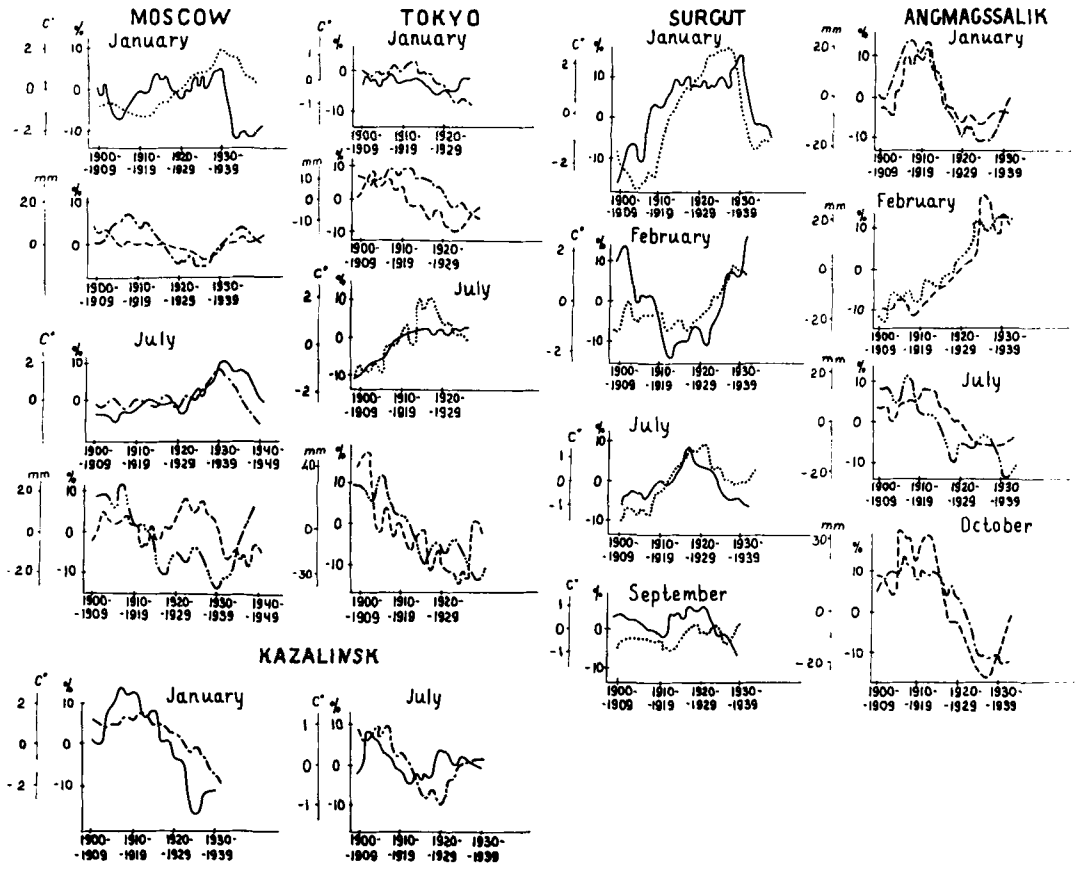

FIG. 5. Long-period march of components of the general circulation of the atmosphere over the Northern Hemisphere and variations of temperature and precipitation at different points. ——, Temperature of the air (C); – – –, Precipitations (mm); · · · ·, zonal component of circulation; —·—, violation of zonal circulation; —· · ·—, meridional component.

calculations were made for 5- and 20-year overlapping means.

To simplify the figures, instead of the 3 circulation curves we have left only one which reflects the prevalent influence of this specific type of circulation on the climate at a given point. It is evident that intensification or weakening of the zonal circulation has opposite temperature and precipitation effects on the western and eastern coasts of the continent, that the change in the frequency of the meridional circulation is different in the Atlantic and Siberia and so on. Therefore, such differentiation of the prevalent circulation components is justified; it confirms the geographic dependence between the processes under investigation and reflects the dynamic-climatological characteristics of different regions.

Only a few graphs are given here from the collection of graphs which were plotted on the basis of all the above-mentioned data. In all the cases from New York, Stykkisholm, and Ponta Delgada, London and Haparanda, Bucharest and Lugansk—to Surgut and Omsk, Barnaul and Kazalinsk, Anadir and Tokyo—an agreement between the curves remained quite satisfactory.

It is worthwhile to emphasize once again that the long-period variations of meteorologic elements at some *single point* were in all cases compared with the variations of the general circulation of the *whole hemisphere*. It once

again confirms the necessity and *possibility* of making wide use of general circulation data in studying climate fluctuations at individual points.

2.10. The adduced materials allow one to establish direct, immediate causes of climatic fluctuations. In order to clarify the main, more remote causes responsible for the fluctuations of the general circulation itself, we shall, in the first place, have to turn to the effects of solar activity. A great number of papers dealing with this problem can be referred to. But here I want to mention only the investigations carried out by the Soviet heliophysicists A. BEZRUKOVA (1950, 1954) and B. RUBASHEV (1958*a*, 1958*b*, 1959) since in their analyses they used our circulation types of the northern hemisphere.

A. Bezrukova has carried out a combined study of the long-period variations of the solar activity indices and the march of the circulation types. As an index of solar activity she has chosen the relative number of sun-spots and their total area. Investigating the dependence of all the 13 circulation types upon the mentioned indices of solar activity A. Bezrukova established a good agreement between them. Direct agreement is observed for all the types of zonal transfers and violation of zonality; a contrast agreement is inherent to the types of meridional circulation. According to this main pattern all the circulation types can be united into two groups: zonal and meridional. Fig. 6 shows the corresponding curves. A. Bezrukova has also investigated the connection between solar activity and the atmospheric circulation—severe droughts, variations in the level of the Caspian Sea, of the lakes Chad, Victoria-Nyanza, and others. B. Rubashev examined the short-period reactions of our primary circulation types to fluctuations of geomagnetic activity. In all cases fairly good results were obtained. This is partly attributable to the fact that the same circulation processes were used in establishing ties between solar activity, circulation and climatic variations in individual points. Thereby a continuous chain (sun–general circulation–climate–weather) was set up, which is necessary for the serious investigation of both the problem of climatic variation and the problem of forecasts for the next circulation and climatic epochs.

2.11. Bearing in mind the foregoing, we shall now return to the problem of the validity of

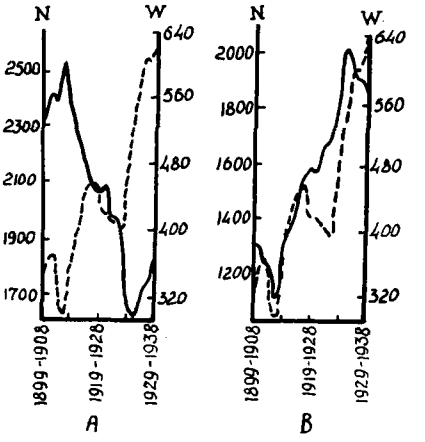

FIG. 6. Long-period variations of solar activity and variations of atmospheric circulation. (A) Variations in frequency of meridional types of circulation; (B) variations in frequency of zonal types of circulation. ——, Circulation of the atmosphere; · · ·, solar activity; N—duration (in days) of Dzerdzeevskii's circulation types; W—relative number of sunspots.

the long-period values ("normals") for meteorological and climatological investigations and in particular to their utilization in climatic classifications.

As we have seen above, combined analysis of the circulation and climatological data has helped to establish the existence of two "epochs" in the first half of the 20th century. These two epochs have marked differences both with respect to the circulation and to the values of climatic data (suffice it to recall that the second epoch was characterized by a warming of the Arctic).

Within the boundaries of each "epoch" a similarity of circulation processes is observed which manifests itself in a notable prevalence of definite circulation types (ECM). The fields of distribution of the values of climatic elements within each "epoch" also have their own "level" (see Figs. 4 and 5).

2.12. The meteorological literature devotes considerable attention to all kinds of "anomalies" of both meteorological values and circulation processes. But the term "anomaly" itself is understood rather broadly. As a matter of fact it is applied to any deviation (either in magnitude or time) from the long-period "standard" of any index whatsoever.

A careful analysis of such investigations

reveals that it is very rarely that they were dealing with really considerable deviations of the indices exceeding their usual fluctuations. A statistical analysis of the available circulational and climatic data shows that atmospheric processes of "the lower order" are of a fluctuating nature with respect to the processes of "the higher order" (diurnal processes—with respect to seasonal and annual ones; the latter—with respect to the secular data). The relationship between these categories of processes is expressed by stochastic ties.

Using this conclusion and taking into account 2.11 we are to conclude that it is for each individual circulational and climatic epoch that the average "level" of the circulation character and of climatic values should be determined. In the old terms it would mean that values of any kind of "anomaly" should be taken from such an "epochal" average and not from a long-period "normal". The deviation magnitudes will then inevitably decrease and will not exceed the limits of regular fluctuations. Here are several examples.

The long-period average temperature of Copenhagen (the "normal") is equal to 0.6°C. For an average value calculated for the two "epochs" we obtained 0.1°C and 1.2°C. The average temperature "anomalies" were respectively brought down from 3.1°C (taken from the "normal") to 2.5°C and 2.6°C (taken from the "epochal" means), i.e. they were reduced by 0.6°C. Similar calculations for San Francisco reduced the annual "anomaly" by 0.5°C.

The difference was found to be particularly striking at other points. For instance, at the station of Angmassalik deviations of the average annual temperature values ("anomalies") were reduced from 2.8°C to 1.3°C and from 2.3°C to 0.5°C (i.e. by 1.8°C); at the station of Barnaul the difference in the annual amounts of precipitation was brought down from 177 mm to 140 and 120 mm.

For annual means these are rather large values, although we have cited here only the instances when the difference between annual values remains rather high with respect to the "epochal" average as well. In the majority of other cases the deviation of annual means from the "epochal" average becomes so insignificant that we cannot speak about any sort of "anomaly" at all.

Thus, in our opinion it is becoming increasingly clear that homogeneous periods—climatic epochs—should be distinguished in the long-period climatic regime. It is within these periods that one should perform calculations of average values, deviations, frequencies of these or those processes, gradations, in other words, of all the climatic characteristics (DZERDZEEVSKII, 1956*b*). The borders of such epochs are to be determined from the development of circulation processes, i.e., they should not be fixed. Since the nature of such "climatic epochs" essentially differs, the borders of climatic (and geographical) regions established on the basis of the data provided by one epoch will prove to be inadequate for another epoch. The more inadequate will be the borders of the regions established on the basis of a single long-period average (the "normal") (KENDALL, 1935; STANLEY, 1954).

Consequently, climatic classification can be successfully carried out only within one climatic "epoch" with the indication of possible deviations from the established borders.

These conditions being observed, climatic characteristics will become dynamic making it possible to work out calculation techniques.

3. Conclusions

3.1. Progress in the important and equally complicated problem of the causes of climatic changes can be achieved only if the methods of dynamic climatology, which allow the setting up of a continuous chain of connections between the sun, the general circulation and the climate, are employed.

3.2. An important link in this chain, the evidence of the general circulation, should embrace at least one hemisphere. It must be expressed in simple terms convenient for quantitative and statistic calculations.

3.3. It is the opinion of the author that these conditions are to a considerable extent complied within the typification of circulation elaborated by the author and his co-workers for the northern hemisphere because this typification allows us to explain some problems of dynamic climatology.

3.4. It is to be concluded that the circulation and the climatic data should be analysed for "climatic epochs"—periods characterized by

homogeneous macroprocesses and climatic regimes—but not for long-period average values ("normals").

3.5. Climatic maps and maps of climatic classification should be plotted for the same "climatic epochs".

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