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CONTEMPORARY CHANGE IN CLIMATE

by

Ye. S. Rubinshteyn and L. G. Polozova

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ABSTRACT: In the book a survey is given of the basic works on the change in climate. Extensive factual data of variations in air temperature is given as one of the most important elements of climatic indices. Variations in temperature are investigated for each month of the year and on the average for the year on Earth from instrumental observations of the last 100-200 years. The connection is studied of the change in temperature with atmospheric circulation, solar activity, and ice cover of the Arctic and Antarctic seas. The book is intended for meteorologists, climatologists and all those who are interested in changes in climate. There are numerous graphs and tables, and in the appendix a list of meteorological stations and a map showing their location are given. English translation: 278 pages.

TABLE OF CONTENTS

In the book a survey is given of the basic works on the change in climate. Extensive factual data of variations in air temperature is given as one of the most important elements of climatic indices. Variations in temperature are investigated for each month of the year and on the average for the year on Earth from instrumental observations of the last 100-200 years.

The connection is studied of the change in temperature with atmospheric circulation, solar activity, and ice cover of the Arctic and Antarctic seas.

The book is intended for meteorologists, climatologists and all those who are interested in changes in climate.

PREFACE

In this work results are given of investigations of the change in air temperature on Earth, which were conducted at the Climatology Branch of the Main Geophysical Observatory (GGO) named after A. I. Voyeykov.

It is known that different authors have revealed fluctuations in temperature from several days to hundreds and even thousand of years. The purpose of the present work was the investigation of the fluctuations in a range of 5-7 years to several decades. The majority of the authors studying the change in climate was limited to examination of temperature of two months (January, July) or the winter season and the mean annual. Since it was clarified that the rate of change in temperature even in months of the same season can be considerably different in directivity and intensity, the establishment of physical regularities without analysis of extensive material for all months of the year is barely feasible.

As a result of analysis of data for each month of the year regions of synchronous fluctuations in temperature in different months of year are seperated, the community of the trend of the change in temperature in both hemispheres in certain months and their peculiarities are clarified, and regions of the Earth and months of year are determined when the connections of changes in temperature with indices of circulation of the atmosphere and solar activity are expressed most clearly.

The collected and thoroughly analyzed data on air temperature in the form of graphs of moving mean 10 year values permits objectively judging the conclusions made in the work. This data is of independent interest for numerous researchers of the change in climate for which the authors considered it expedient to put a considerable part of it into the work.

The Introduction and Chapters II, IV, VI were written by Ye. S. Rubinshteyn and Chapters I, III, and V by L. G. Polozova. Paragraph 6 of Chapter II ("Criterion of reality of the distinction of a series of observations from the accidental") was written by O. A. Drozdov.

The analysis of data assigned to B. L. Dzerdzeyevskiy on the classification of circulatory processes was carried out by Engineer O. V. Reshetova. She performed all the calculations on an electronic computer.

All the calculations and graphic works at different time were fulfilled by Zh. D. Alibegova, L. L. Gracheva, L. S. Demidova and I. P. Zernova.

Much laborious work on the shaping of extensive graphic material placed in the book was carried out in the Cartography Branch of GGO under the leadership of the branch chief M. B. Galinoy and colleagues Z. P. Pereshivkina and V. V. Lasenker, to whom the authors are grateful.

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INTRODUCTION

Since 40 years ago when there was revealed a warming of the winter extending over a vast distance, the problem of the change in climate has become one of the most important problems of climatology. Thousand of works of scientists of various countries are devoted to this problem, since the solution of it is of great scientific and practical interest. However, factors leading to a change in climate are complicated and are manifold, they act jointly, being imposed on one another, and it is difficult to conisder quantitavely the role of each of them in the change in climate. But besides these fundamental difficulties, the investigation of the change in climate is complicated by the irrational distribution of the network of of weather stations, the heterogeneity of a series of observations with time, and sometimes the incomparability of them in space (in different countries), the quite insufficient quantity of meteorological observations above the water surface of oceans with very nonuniform distribution and distinction in duration of meteorological series. These deficiencies are possessed also by series of aerological observations and radiation observations. All the above-indicated difficulties are, apparently, the cause of the fact that an overwhelming number of works devoted to the change in climate pertains to territories limited in dimension and only a few works, to the entire planet as a whole. Basically in these works there is investigated the variation of air temperature with time, and considerably less attention is paid to the variation in atmospheric precipitation.

Of works on the contemporary level of knowledge and pertaining to the whole Earth we can name those works of Scherchang (1936), Rubinshteyn (1946) Lysgaard (1949), Willett (1950), Mitchell(1963), Callendar (1961), Polozova and Rubinshteyn (1963). Despite the fact that these works contain many new interesting conclusions, they cannot be considered sufficiently complete. Thus Callendar and Willet analyzed only average annual temperatures, Scherchang and Mitchell — data for the winter (total) and the year; Lysgaard examined January, July and the year, Rubinshteyn — separately every month from November to March, and also May and September, Polozova and Rubinshteyn — January and the year and only partially April and November.

Furthermore, Scherchang, Willett, Callendar and Mitchell allotted the main attention to the change in air temperature of every latitudinal zone as a whole, although Mithcell realized that in various regions of the same latitudinal zone the variation in temperature can be unequal. A tendency to total characteristics of the change in climate is caused, apparently, by the difficulty of analysis of the quality of series of observations with respect to their homogeneity and comparability in scales of the whole planet. The total characteristics to a certain degree smooth out these defects. At the same time the use of only total characteristics leads to a great loss in information. Thus, for example, in the eastern and western regions of the same latitudinal zones variation in temperature is distinguished. This is shown in the work of Polozova and Rubinshteyn (1963). It is known also that at various months of the year the variation in temperature is unequal. Examples of similar variation in temperature are given in Chapters III and VI.

Nonconsideration of these factors with the use of only total characteristics of the change in climate for latitudinal zones as a whole and for winter as a whole can lead to false conclusions in the investigation of causes of the change in climate.

In this work the authors set as their problem the investigation of the change in air temperature on Earth for the period when there are instrumental observations (approximately 80 to 200 years), taking into account fluctuations with wavelength of more than 10 years. The analysis should be conducted for each point individually, for all months of the year and for the year as an average.

The initial data were from reports of observations published in four volumes of the collection World Weather Records (1929, 1934, 1947, 1959), and also in annuals and monthlies of different countries of the world. All these data were analyzed from the point of view of their homogeneity and comparability. An extensive work in this direction was made by Sokhrina and Sharova in the calculation of the perennial mean temperatures of the northern hemisphere. In connection with the fact that for investigation of the change in climate requirements for homogeneity of series were somewhat different than for the construction of maps of anomalies, the authors of this work conducted additional investigation of the homogeneity of series of observations by stations of the northern and southern hemispheres, after which a sampling of more or less uniform series was made which could be used during the study of the change in the temperature regime.

CHAPTER I

BRIEF SURVEY OF RESULTS OF THE INVESTIGATION OF VARIATIONS IN CLIMATE

Among numerous investigations of variations in climate, as was already mentioned, works of a regional character predominate; investigations of variations in climate on a planetary scale are unique, and more specific information about them will be mentioned below.

Taking in account the fact that results obtained by different authors in regional investigations are often contradictory and difficult to associate, it is inexpedient to give a traditional survey of the literature. References and critical remarks will be made during the analysis of variations in climate in corresponding regions of the Earth. Given here are basic results of preceeding investigations of variations in climate. They are briefly discussed by Verjard (1963) in a survey report at a symposium on variations in climate taking place in 1961 in Rome and also in the recently published (Rüge, 1965) survey of literature (true, by far not complete) on the contemporary state of knowledge of variations in climate.

In order to give a general concept of possibilities of study of the problem of variations in climate, let us give results of the investigation of variations in basic elements of climate: temperature, precipitation, atmospheric pressure and wind, cloudiness and solar radiance. Let us dwell in greater detail on results of the investigation of variations in mountain and marine ice formation; these are unique indicators of variations in climate which usually in surveys of literature concerning this question insufficient attention is allotted.

In investigations of variations of climate the majority of authors are forced to be limited to the study of fluctuations in temperature and at best precipitation. This is connected with the absence of prolonged and reliable (in the sense of homogeneity and accuracy) observations of the majority of the elements of climate. Considering this, it is necessary to examine below the mentioned results of the investigation of fluctuations of separate elements (besides air temperature, to which a separate chapter is devoted) as very tentative.

1. Fluctuations in the Magnitude of Different Meteorological Elements

Atmospheric precipitation. Precipation, especially that falling in the form of snow, is not determined completely reliably, the homogeneity of the series is often disturbed, the influence of the local conditions is great. As investigations showed, fluctuations in precipitation in space are more irregular than fluctuations in temperature. Therefore, the application to these series of observations of static criteria for determining regularity of fluctuations, as this is done during analysis of a temperature series, is ineffective. This is necessary to consider in examining results of investigations of secular variation of precipitation, especially in the scale of hemispheres or planetary.

On the map given by Wagner (1940) of the change in precipitation from decades of 1886-1895 to 1911-1920 there is shown a decrease in precipitation between 40° N. Lat. and 30° S. Lat. in considerable expanses inside the tropic zone where here and there regions are interspersed with an increase in precipitation; a planetary increase in the meriodional contrast of precipitation was observed: the dry horse latitudes became drier, the humid latitudes with a predominance of westerlies became more humid. This position was turned to the reverse starting from the decade of 1921-1930.

In the tropic belt there was observed an increase in precipitation, in the middle latitudes of Eastern Asia and Northern Atlantic, a decrease in precipitation, in general spreading westward. In the middle of the period 1921-1940 monsoon and convection precipitation in the tropics were intensified.

This general picture is considerably complicated if one were to examine the geographic distribution of fluctuations in precipitation.

In the works of Lysgarrd (1949, 1950) there are given tentative data on fluctuations in precipitation between on 30-year periods of 1881-1910 and 1911-1940: in January the increase is noticeable in precipitation over Europe, Northern America, Indonesia and a decrease over Western Africa, Central and Eastern Asia. An even greater diversity in the distribution of fluctuations of precipitation is observed in July. Above the Arctic and northern part of the moderate zone an increase in the annual amount of precipitation predominated. A decrease in precipitation on the whole for the year was observed over the United States of America, Africa and Australia.

Mather (1954) obtained interesting dependences: in the winter over the land there predominates the combination temperature drop — decrease in precipitation or warming — increase in precipitation, whereas over the oceans in the northern hemisphere is observed more frequently during warming a decrease in precipitation and, with a temperature drop an increase. For July Krames (1952) found a reverse relationship in the low latitudes, where the secular variation of temperature and precipitation has a negative correlation.

In the interesting work of Drozdov (1958) secular variation of precipitation is examined in the warm and cold periods of the year in the USSR territory and certain regions of the northern hemisphere in connection with a change in meridional temperature gradients as characteristics of secular variation of atmospheric circulation. According to the form of secular variation of temperature gradients of the cold period in the northern hemisphere it was possible to expose three basic types:

Type I — an increase in meridional temperature gradients during a temperature drop and a decrease in them during warming in the Arctic; it covers a zone of moderate latitudes of Eurasia north of 47°N. Lat. and westward from the Yenisey River; variation in amount of precipitation is changed in parallel to the variation in temperature gradients.

Type II — the course of the gradients is mirrored with respect to the preceding, i.e., an increase in gradients is observed during warming of the Arctic and a decrease with a temperature drop; this type predominates in the western part of Asia, Southern Europe and presumably in North America; variation in precipitation and movement of gradients of the temperature are parallel.

Type III — maximum values of gradients are observed for 10-15 years earlier than those in regions of type I; this covers the monsoon regions of Eastern and Southern Asia (Transbaykal, Far East, Japan, China, India); coordination in the secular variation of precipitation and temperature gradients is not established.

Such in broad terms is the picture of the fluctuation in precipitation in their secular variation.

Atmospheric pressure. In investigations of fluctuations in pressure due to the great dependence of its magnitude on the level of measurements, the installation of instruments, their corrections, etc, rarely are there used directly series of observations. Usually for characteristic of the change in pressure there are such relative values as its gradients or deviation from mean values.

Brier (1947), using materials of weather world maps for 1900-1939, determined a noticeable decrease in air mass in the northern hemisphere from 1909 to 1934, where the lowered pressure in high latitudes corresponded to a weak opposite tendency in the equatorial regions.

Many researchers determined the lowering of pressure in the high and partially tropic latitudes and the increase in it in the subtropics; for the most part this was observed in regions of great baric centers. This was determined by Wagner (1940) for changes in pressure from the decade of 1886-1895 to 1911-1920, Scherhag (1936) — for 1921-1930 and Lysgaard (1949, 1950) — for the 30-year periods of 1881-1910 and 1911-1940. Later Scherhag (1950) found that from the decades 1921-1930 to 1931-1940 the pressure began to be increased north of 40°N. Lat.and farther south of 20°S. Lat. in the zone located between these latitudes there occurred a reverse change, but in the equatorial regions it was weakly marked.

In recent years Lamb (1961) published world maps of the distribution of pressure in January and July for each 10-year period from 1760 to 1950, and then together with A. Johnson (1961) – mean pressure maps for 1950-1959 and changes in pressure during 1940-1949. On these last maps in January the increase in pressure in the 10-year period of 1950-1959 is well-defined in the high latitudes of the northern hemisphere (with the exception of Scandinavia where there was a lowering of the pressure) and in the equatorial latitudes of both hemispheres; in the moderate latitudes of the southern hemisphere pressure in the last decade as compared to the preceding dropped (excluding the region of New Zealand where the pressure was increased). In July at almost all latitudes an increase in pressure was observed. The maximum of pressure before the temperature drop came not everywhere at an identical time, but was displaced according to Schove (1950, 1961) similarly to warming to the south in the similarly to warming to the south in the middle latitudes of the northern hemisphere; at the Arctic circle the greatest 30-year mean pressure values were observed during 1866-1895, in Central Europe and British Isles – during 1881-1910, in the Mediterranean region – during 1901-1930 and around the Azore Islands during 1906-1935. Whether the minimum of pressure was displaced in the 20th centruy to the south Schove does not indicate.

Wind. In investigations data of direct observations on wind are rarely used due to the frequently encountered nonrepresentation of data, which is caused by the influence of a great number of factors (incorrect installation of instruments by which observations, inaccuracy of readings, local peculiarities, reflected on degree of protection of the instrument etc. are conducted).

Therefore, instead of direct characteristics of the wind, for the investigation of their variations over large territories we frequently use the difference in pressure with latitude or longitude. However, such an appraisal cannot serve as the full value replacement of direct measurements. It is known that even insignificant changes in the direction and speed of wind, effective directly in a certain time interval, affect the temperature of the underlying surface, evaporation, amount of precipitation.

Results of a great number of investigations show that prolonged periods of anomalous weather in defined seasons are connected with the shift in paths of basic wind flows at the earth's surface and at elevations. Hence it is clear how it is important for the investigation of variations in climate the accumulation of high-quality (uniform in time and comparable in scale of the whole Earth) observations on wind.

Cloudiness and solar radiance. Secular variation of cloudiness and duration of solar radiance is an important characteristic of variations in climate. However, observations of these elements for large territories are frequently not coordinated because of the great influence of subjective errors of observers and distinctions in the method during observations of cloudiness and in instruments for observations of solar radiance. Therefore, investigations of peculiarities of the variation in cloudiness and duration of solar radiance of large regions are as yet impossible; there are only separate regional investigations in which there is used a very limited number of stations, chiefly in Europe. As follows from works of Wagner (1940) and Steinhauser (1957), the duration solar radiance on the European continent increased in period from 1915 to 1940. After 1940, according to H. Götschmann (1960), in Germany there began a decrease in the annual number hours with solar radiance chiefly in the summer months, whereas the spring and autumn months became more solar; there are indications of the increase in duration of solar radiance in Jakarta from a minimum in 1908 to a maximum during 1930-1932. (Rodewald, 1954).

The increase in cloudiness over the western part of the Baltic Sea in summer months from the 30-year period of 1901-1930 to 1931 to 1960 Hupfer (1962) attributes to the growth in unstable stratification of the atmosphere due to warming above the continents.

According to data of the station at Tbilisi, a scantily clouded period in January was observed from the end of the last century to the 10-year period of 1909-1918; an increase in cloudiness was noted from the decade of 1917-1926 to 1939-1948, and in the last 10-year period cloudiness decreased.

It is understandable that on the basis of similar information it is impossible to give a concept of variations in cloudiness and solar radiance at least in the hemisphere scale.

Temperature of water. It is known that the World ocean is one of main climate forming factors. The heat of oceans represents an important component in the mechanism of climatic variations, since the ocean and atmosphere interact by means of heat exchange. Variations in temperature of water in the North Atlantic for the period from 1876 to 1952 is the subject of the published work of Smeed (1952), where he indicates the secular increase (0.5°) in water temperature for the northwest shores of Europe.

Lamb and Johnson (1959), using all available data in the British Admiralty on water temperature in the Atlantic since 1780, came to conclusion concerning that in the beginning of the 19th century the North Atlantic warm current was farther south than it is now, and was deflected westward from the shores of Europe so that the ocean region more north and east of Bermuda was then considerably warmer. The Labrador current was wider at American shores and colder. North of 50°N. Lat.the water temperature was lower than it is now. The region of reduced temperatures was also between the equator and 20° N. Lat. due to deflection of North-equatorial current to the south, for which into the Gulf of Mexico less warm waters proceeded.

In Chapter III results are given of investigations of Brown (1953, 1963) on variations in air temperature over the Atlantic.

He determined the parallelism in variations in temperature of the air and water. Let us give briefly his conclusions with respect to variations in temperature of water surface of the ocean. In the zone of 70°-60° N. Lat. there is well-defined the tendency of the increase in annual temperature from the beginning of the century to the decade of 1930-1939 in the eastern part of zone and to 1940 to 1949 in the western part; less clearly marked are tendencies in the zone of 60°-30° N. Lat. In the zone 30°-0° N. Lat. there was observed cooling from the last century up to 1910-1919, and then warming to end of the period examined by Brown (1949). In the zone 0°-30° S. Lat there predominated a tendency of a solid increase in the water temperature to 1930-1939, and in certain places to the end of the period.

Lamb and Johnson (1959) assume that north of 60° N. Lat from the beginning of the 19th Century continuous warming of the surface of the ocean occurred. In the region between Iceland and Norway there was observed the greatest increase (3-4° C) in temperature during the period 1890-1940. Rodewald (1958) considers that the water temperature in the Northern Atlantic during the 20th Century has increased 0.5°. In the middle latitudes of the Atlantic, as Brown noted, the picture is more complicated. After a minimum during 1900 to 1929 positive anomalies began to be observed from 1932-1929 farther south of Island in zone 55°-60° N. Lat. and less considerable – in the zone 50°-55° N. Lat. In the zone farther south of Newfoundland Brown (1963) revealed a warming from 1912 to 1921 to 1950-1954, and then a temperature drop of 2.5°C up to 1959. Near the Azore Islands a slight warming was observed. In the north European waters the warming was 0.5° between the 40-year periods of 1881-1920 and 1921-1960. In his last work Rodwald (1963), summing up former investigations, noted the record warming of waters during the first half of the 20th Century for the eastern seacoast of Canada and eastward (up to 1000 miles) from this region. However, in the last decade (1951-1960) considerable temperature drop is observed here, whereas in the northeast warming is noted.

The interaction of the atmosphere and ocean depends on a great number of factors whose degree of influence is difficult to estimate from their variability both in space and with time. But in the process of variations in climate thermal inertia of oceans should play an important role, and investigations of interaction of these two media and reflections of this interaction in perennial fluctuations of characteristics of the composition of atmosphere and ocean are still in the initial stage.

As Bjerknes (1963) notes, the solution of the problem of the influence of fluctuations of atmospheric circulation with time and in space on resultant changes in the temperature of the surface of waters is complicated by a reverse influence of the ocean on the atmosphere. The atmosphere in turn in its disturbances includes influence of at least the whole hemisphere. In this whole complicated interaction there is included, in the opinion of Bjerknes, the basic cause of variations in climate.

The role of ocean in this case is difficult to overestimate, however, many investigations as showed, and all of this interlacing of terrestrial interferences to a considerable degree is complicated by the influence of external influences.

2. Fluctuations of Mountain Ice Formation

It is known that in the contemporary epoch glaciers cover about 11% of land. Their mass, according to Shumskiy and Krenke (1964), exceeds almost 32 times the mass of surface waters of land. The power and area of mountain ice formation depend on many factors of climate: on advection of heat and cold, amount of arriving and departing radiation, atmospheric humidity, annual distribution of precipitation, duration of seasons melting and accumulation of snow. Therefore, glaciers are good indicators of variations of climate. But, Ahlmann (1953) as indicates, it is possible to use information about the state of glaciers only for confirmation of variations in climate in broad terms, since the interconnection between on glaciers and climate are very complicated and still by far are not clarified.

In the last decade much attention was payed to the investigation of glaciers in connection with the problem of variations of climate. A great number of works about dynamics of glaciers in separate regions have been published, but there are very few generalizing investigations giving a presentation about fluctuations of boundaries of glaciers on Earth.

Flint (1951), summarizing results of the measurement of glaciers during the last 100 years according to different authors, drew two main conclusions:

1) between the area and power of glaciers and variations in climate, in particular air temperature, there exists a definite dependence: prolonged increase in average annual temperature is accompanied by the retreating of glaciers;

2) fluctuations of glaciers all over the Earth have common directivity.

The contemporary reduction of ice formation is ascertained by Al'man (1953), who based this on data of a number of authors indicating the retreating of the majority of glaciers in the northern and southern hemispheres in the first half of the 20th Century.

Published in recent years is the through investigation of Shnitnikov (1961) on the intrasecular variability of mountain ice formation of the northern hemisphere. The author gives a detailed analysis of the majority of published information about the dynamics of glaciers during the 19th and 20th Centuries. Proceeding from results of this analysis and his previous investigations

(1957, 1951), he determined the presence of rhythmic fluctuations in movements of mountain glaciers — centuries-old (about 1850 years) and intrasecular (chiefly 30-35 years).

In fluctuations of glaciers in the 20th Century he established the well-defined phase of advancing in the 1920's of all glaciers of the northern hemisphere and, suppositionally, the southern. The next phase of omnipresent recession of glaciers began to be developed from the second half of the 1930's and the greatest was expressed in the second half of the 1940's and first half of the 1950's. In certain regions after the 1930's there was noted a stopping of the recession of glaciers or even insignificant advancing. The phase of omnipresent advancing of glaciers started at the end of the 1940's — beginning of 1950's but it is weakly marked. Shnitnikov explains this by the fact that the intrasecular phase of advancing (8-12 years) occurs against the background of the centuries-old phase of general recession of glaciers of the Earth, which started about 1750-1800 and will continue, in the opinion of Shnitnikov for 14-15 centuries. For the same reason he considers, taking into account the intrasecular cyclic recurrence of ice formation that the forthcoming phase of recession of glaciers in the 60's and 70's will be even better expressed than the phase of the 30's and 40's of the current century.

A. V. Shnitnikov connects fluctuations of glaciers with the variability of total moisture of large territories, determined by fluctuations in the level of lakes, and fluctuations in moisture with Fluctuationsin solar activity. At the same time he absolutely does not touch upon the dependence of fluctuations of glaciers from large-scale fluctuations in air temperature, to which the majority of researchers point.

If one were to consider the fact that with an increase in air temperature glaciers recede, then the assumption of Shnitnikov about the future centuries-old recession of glaciers should be connected with the prolonged increase in planetary temperature, but the intense retreating of glaciers expected by them in the next two decades (which should be connected with the total increase in air temperature) will not agree with the opinion of the majority of researchers about the forthcoming temperature drop in connection with expected lowering of solar activity in the secular variation and changes in the character of atmospheric circulation.

In their articale about contemporary ice formation of the Earth and its changes Shumskiy and Krenke (1964), confirming the dominating influence of general warming on the retreating of glaciers note the complexity of this association. Thus, with the synchronism of secular variations in individual years and decades there is observed an asynchronism and counterphasability of short-period changes in the mass of glaciers, which is connected with a different character of intrasecular variations in climate in different regions. This explains the frequent contradictory information about phases of recessing and advancing individual glaciers. Connecting the reduction of glaciers with planetary warming in the first half of the 20th Century, the authors note that an increase in temperature in excess compensates the influence of simultaneous increase in the amount of precipitation, since not only the rate increases but also the duration of the melting of the ice, and the feeding of glaciers is delayed due to the increase in the amount of liquid precipitation and intensification of runoff. In the opinion of Shumskiy and Krenker, the increase in the last decade of a number of advancing glaciers indicates, possibly, the approach of the end of the stage of reduction of glaciers and the beginning of their new advancing.

In geographic literature there is very lively discussion of the question about tendencies of the change in the glaciers of Antarctica. Interest in this is understandable if one considers that area of the glaciers of Antarctica covers about 86% of the total area of the glaciers of the Earth. A majority of researchers, in spite of the scantiness of factual material, are inclined were to consider that the glaciers of Antarctica retreated synchronously with glaciers in the northern hemisphere. Such a conclusion to a considerable degree was based on information appearing in foreign literature about general-planetary warming.

However, very recently Zhantuarov and Markov (1964) doubted the correctness of affirmation about the general retreating of glaciers of Antarctica in the period of warming of the 20th Century. The reason for this was, on the one hand, contradictory data about dynamics of the edge of the glacial cover in different sectors of Antarctica, on the other hand — data of climatologists about the various-directed change in temperature in different regions of the Earth, and also the fact that on the islands nearest to Antarctica (Orkney and South Georgia) during the 20th Century there was not observed a tendency of warming, and in Australia and islands lying to the south of it there was noted even a temperature drop. All these facts permitted authors to arrive at the very reasonable conclusion that the warming of the climate of Antarctica, if there was one, occurred very nonuniformly in different sectors, but this conditioned the diversity in the development of the glaciers of Antarctica. In agreement with this basically are also Shumskiy and Krenke (1964), although they give much weight to data on the general-planetary warming, considering the temperature drop in certain regions of Antarctica the expression of local peculiarities of circulation against the background of general secular warming.

It is impossible to solve this problem at present because of the absence of sufficient number of data in the polar latitudes of the southern hemisphere. However, as will be shown in Chapter III, the position on general-planetary warming is not indisputable, and much data indicates the fact that it did not spread over all the regions of the Antarctic.

The question of marine ice formation (ice cover of seas) in connection with variations of climate is discussed in the huge quantity of investigations for which it was considered expedient to discuss the basic results of investigations of fluctuations in ice cover of polar seas in a special section.

3. Fluctuations of Ice Cover of Polar Seas

3.1. State of the Question

For a long time the opinion was declared (Hildebrand-Hildebrandsson, 1914, Wiese, 1922, 1925) about the fact that a good indicator of the intensity of the general circulation of the atmosphere is the state of the ice in polar seas. Atmospheric conditions above ice fields due to great radiation from their surface covered by snow are a sensitive reagent for changes of intensity in atmospheric circulation. The increase in atmospheric pressure above polar regions conditions and the increase in the quantity of ice cover in turn promotes an increase in pressure. Thus baric conditions above polar regions and the ice state in polar seas acquire a stable character.

Observations of the state of ice, for example, in the region of Iceland began several centuries ago. In literature Thoroddseen (1884), and Koch (1945) there are combined data on the ice state of the region of the ocean adjacent to Iceland since 860 AD. It is obvious that accuracy and reliability of these data are small, but extreme values of ice state, apparently, were determined reliably enough, since these data were needed for the economy of Iceland, which was closely connected with the state of surrounding regions of the ocean.

By even earlier observations of the state of ice for Iceland it was established that fluctuations exist in the quantity of ice and duration of their stay at the shores of Iceland both during one year and from year to year.

Scientific systematization of observations on the state of ices was started in the last quarter of the last centruy. The first generalizing investigation of the ice cover of polar seas belongs to Chavanne (1875). He conducted a chronologic survey of the state of ice of Arctic seas and established that the cause of fluctuations of ice cover of seas are fluctuations of "atmospheric heat and the relationship of marine and air currents in their periodic and nonperiodic changes". Further investigation confirmed the validity of these positions and in many respects are based on them, although thus far there remain still a great deal of open questions.

In the beginning of the 20th Century there appeared a series of works in which the interconnection was investigated between cover of seas of the North Atlantic and distribution of atmospheric pressure [Meinardus (1906), Schott (1904), Brennecke (1904), Mecking (1906)].

As basic conclusions from these works it is possible to cite the empirically established connections of the state of ice with preceding distribution of atmospheric pressure.

In the Greenland Sea fluctuations in ice cover are determined by changes in magnitude of the pressure gradient directed from Greenland eastward. Considerable pressure gradients in the spring condition the great ice content, weak gradients — the small ice cover in the summer of the current year. During the years with great ice cover in the eastern part of Greenland sea there is observed a small ice cover in the region of Newfoundland, and conversely. This is connected with peculiarities of the distribution of pressure in these regions and corresponding changes in the oceanic circulation: the deepeningof the Icelandic minimum corresponds to the intensification of the Gulf Stream (near shores of Europe) and Labrador Current; due to this at the eastern and northern shores of Iceland the quantity of ice decreases, and near Newfoundland it increases. Fluctuations in pressure in all parts of the North Atlantic have an identical character, where pressure anomalies determined from fall hold during the whole year. Hence there is a prognostic conclusion: according to the character of deviation in atmospheric pressure set in autumn it is possible to predict the intensification or weakening of ice cover at shores of Iceland and Newfoundland.

Many of these conclusions, although they are based on scanty material of observations, were found to be correct and were developed in further investigations.

The above-mentioned works, essentially, were the first contribution in the study of the interconnection between atmospheric circulation and ice content of polar seas and the North Atlantic.

Fluctuations of ice cover of the Barents and Kara Seas were investigated by Lesgaft (1913). In this work Lesgaft examined in detail the conditions of formation and extension of ice in the Barents and Kara Seas in connection with circulation of the atmosphere and waters of the North Atlantic.

In the Barents Sea, according to Lesgaft, the influence of the Gulf Stream on ice cover in two ways: direct — by means of intensification of melting of ice, and by means of circulation of the atmosphere appearing in the region of low pressure above the sea and connected with heat of the Gulf Stream. The higher the temperature of the Gulf Stream in winter, the sharper is expressed the minimum above the Barents Sea, and the greater the force of southwest winds in the southern part of the sea and of the eastern winds — in the northern part, promoting extension of ice into the Atlantic. The state of ice in the Kara Sea depends on the middle and southern parts of it on the relative force of northeast winds connected with the system of circulation of the atmosphere above the mainland. In northern part of the sea the position of the border of ice is closely connected with the position of them in the Barents Sea, in connection with the fact that in the north both seas are connected between them a constant exchange of water occurs. Thus, concludes Lesgaft, the state of ice in the Kara Sea is a function of the oceanic and continental influences.

The question of the influence of the warm Atlantic water on ice conditions of the Barents Sea, discussed by Lesgaft half a century ago on the basis of very scanty and fragmentary information, is thus far still not solved simply. Even in the presence of already comparatively great quantity of data on the ice cover of the

Barents Sea and circulation of the atmosphere there are two opinions on this question. One group of researchers (Drogaytsev, Gevorkyants, 1945 and others) considers that interannual variations in the heat content of the Atlantic waters in the Barents Sea are determined mainly by local conditions of heating and cooling of the water masses. Another group (Somov, Zubov, Karakash, 1957, and others) is of the opinion that variations in heat content of Atlantic waters in the Barents Sea depend on the variability of thermal power of the North Cape current and fluctuations in intensity of autumn-winter cooling of the water masses.

In recent years Uralov (1961) undertook a new attempt to clarify in what measure the variability (with time) of the power of the current of Atlantic waters affects the variability of the thermal state of waters and ice cover of the Barents Sea. He determined that fluctuations in power of the Atlantic current in the Barents Sea depend mainly on the variability of atmospheric circulation in the region of the Norwegian Sea and that fluctuations in ice cover in the Barents Sea to a considerable degree are explained by the influence of the warm Atlantic waters. Thus in his conclusions Uralov confirmed the validity of the point of view of the second group of researchers.

The fact that fluctuations in ice cover of the Barents Sea are a phenomenon of not a local character is confirmed in the work of Polozova (1963), where there is shown good coordination between fluctuations of ice cover in the Barents Sea and air temperature on the southern extremity of Greenland (Ivigtut). Subsequently there was found also sufficient coordination of tendencies in fluctuations of atmospheric circulation and ice cover of the Barents Sea. One can see this from Fig. 1, on which there are given moving 10 year average values of the annual recurrence of the zonal western circulation (after Dzerdzeyevskiy) in the Atlantic sector of northern hemisphere and total (for the season) ice content of the Barents and Baltic Seas, and also the duration of the stay of ice for Iceland. From the end of the last centruy the increase in the number of days with the meridional northern and disturbance of zonality) conditioned the exceptional warming of the Arctic. Comparing the variation of components of circulation (Fig. 1) with those given in Chapter III by graphs of the annual variation in temperature in the Atlantic sector (for example, Upernavik, Stikkisholmur, Fig. 7a), it is possible to see their sufficient coordination. A break in the course of warming and subsequent temperature drop coincides in time with the rapid decrease in 40-year period of the recurrence of zonal western and increase in meridonal northern circulation.

In the variation of ice cover seas in the Atlantic sector the tendency to lowering from the 1920's of the current century is also well-defined. However, the sharp break occurring in the 1940's in the course of circulation and temperature, in the common movement of ice cover of the Barents and Baltic Seas is weakly expressed, and in subsequent years the ice cover continued to decrease (to the middle 1950's). The least ice cover in these seas was observed in 1954 and 1955 (average for the season of April to August), after which there began a gradual increase. The quantity of ice appearing at the shores of Iceland and duration of its stay there also decreased from the beginning of the century; it attained a minimum in the 1940's, but then the ice content began to increase, attaining in individual years (1949 and 1955) values which were observed only in the beginning of the century, i.e., prior to the period of warming.

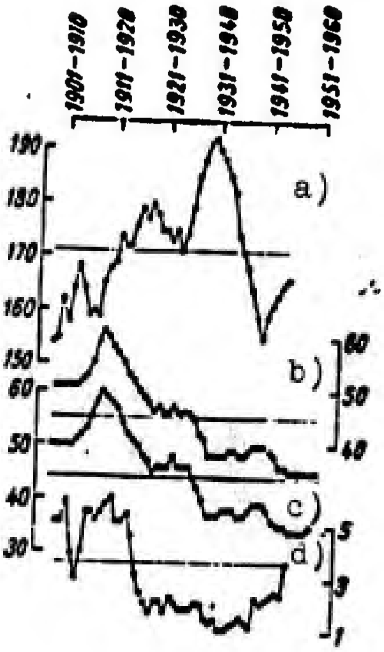

Fig. 1. Moving 10-year average values. a) number of days with zonal western circulation (after B. L. Dzerdzeyevskiy) b and c) ice cover of the Barents and Baltic Seas (in percent of total area of the sea), d) duration of stay of ices at shores of Iceland (number of weeks).

For the Greenland Sea there is, unfortunately, incomplete series of observations prior to 1955, which were interrupted during the years of the war, but a tendency common with the above-described, apparently, was observed here also.

Thus as a result of the performed comparisons it is possible to say that the state of ice content in the polar seas in broad terms reflects great changes in the atmospheric circulation, but cannot serve its sensitive indicator. The inertness of the ice cover is so great that it reacts to sharp changes in the character of the circulatory processes after one or two decades. This soon indicates that fluctuations in ice cover are the result of fluctuations in atmospheric circulation but not the cause.

The same conclusion was obtained by Lamb and Johnson (1959) in studying the interconnection between ice cover for Iceland and intensity of the western transfer.

Fluctuations in ice cover in the Barents Sea are determined to a considerable degree, as the Urals showed by fluctuations in the flow of warm Atlantic waters. At the same time the fact of the secular increase in temperature of the surface of the sea in the North Atlantic is established in a number of investigations (Smeed, Rodewald, Brown and others). The increase in temperature, according to Rodewald (as was shown above), in the area of the ocean between Greenland and Western Europe continues (data prior to 1960). This, apparently, is the basic factor determining the lowering of ice cover in the Barents and Baltic Seas, observed up to the recent (approximately prior to 1958) years. It can be said that the ice cover is the product of the complicated interaction of atmospheric and oceanic circulation. With this interaction there occurs interference in the mobile fluctuations, with rapid replacements of air temperature of the medium and more inertial masses of the ocean. This greatly complicates the phenomenon of fluctuations of ice cover, the knowledge of which will require efforts of many investigations.

3.2. Cyclic Recurrence in Fluctuations in Ice Cover

Establishment of the fact of the existence of fluctuations in ice cover, naturally, led to the search of their causes and attempts to determine the period of these fluctuations.

According to investigations of Meynardus, in the region of Iceland the ice season lasts from January to July. Maximum ice cover is observed during April-May, the minimum – in October. Fluctuations in the quantity of ice during one year and duration of the ice season are explained by two causes: 1) general temperature background set in a polar sea in autumn and winter, and 2) distribution of atmospheric pressure and, connected with it, the intensification or weakening of the polar (East Greenland) current. The recent appearance of ice for Iceland is explained by the considerable remoteness of the island from regions of ice formation, with which the shift of the largest ice cover in the spring months is connected. No less important role here is the speed of the current, attaining a maximum in April.

Analysis of data on ice cover for Iceland, collected for more than 100 years permitted Meynardus to establish that on the average of every 4-5 years the quantity of ice and duration of the ice season attain a maximum.

A comparison of this period with an 11-year cycle of fluctuations in solar activity, performed by Meynardus, showed that great ice cover is observed approximately one year prior to the approach of the sunspot maximum and simultaneously with the sunspot minimum. It is clarified also that the great ice content for Iceland coincides with periods of low temperatures in Greenland and intensive circulation of the atmosphere in the North Atlantic, and little ice cover – with periods of increased temperature in Greenland and weakened circulation in the Northern Atlantic.

Further investigation definitized the period of fluctuations of ice cover in the Greenland Sea; according to Brooks and Glasspoole (1922), this period is 4.8 years.

A period similar to this is revealed for the ice content of the Chukchi Sea where local inhabitants long ago noticed that every 4-5 years the seacoast is deposited with ice. From data of observations from 1906 to 1924 Wiese (1926) obtained the average period of fluctuations in ice cover in the Chukchi Sea equal to 4.6 years. Reality of the period of fluctuations of about 4.5 years was set by Weise by indirect means and in an earlier work (1922) where he used the original procedure.

On the basis of data of Meynardus on 4.5-year periodicity of fluctuations in ice cover the assumption was made that the interval of time necessary for the drift of ice from hearths of its formation (at the Siberian Seacoast) to the Greenland Sea is 4.5 years. As a result there was determined the rather close connection (correlation coefficient r = -0.83) between the autumn air temperature in the region of ice formation and the magnitude of intensity (speed) of extension of ice by the East-Greenland current after 4.5 years.

The assumption of Weise on the duration of ice drift in the Polar basin was confirmed by direct observations when in the Soviet Union there were developed works on the conquering of the Arctic, about which will be mentioned in greater detail below.

Analyzing fluctuations of ice cover in the Kara, Laptev, East-Siberian and Chukchi seas for the period of 1924-1940, Weise exposed a wave-like sequence of the extent of peaks of ice content in seas mentioned with a shift in them in each subsequent (mentioned) sea of 2-3 years. For an explanation of this phenomenon Wiese advanced the following hypothesis. Repetitions of peaks of flucutations in ice cover are the result of the rotary shift of the Arctic circumpolar baric wave. In the region of increased pressure in the Polar basin pass baric waves with an 18-year period analogous to the period of astronomical tidal-ebb waves in the ocean. The direction of the shift of baric wave is counterclockwise, from west to east. As a result shifts in this wave are intensified and there are displaced four main spurs of the polar maximum – Greenland, Taymyr, Eastern-Siberian and Canadian. Thus the full period of the circumpolar wave (18 years) leads to a fourfold repetition of the intensive spur of the polar anticyclone in every region, which leads to the periodicity of recurrence of baric conditions on the average of every 4-5 years. In the opinion of Wiese, the period of 4-5 years does not have prognostic importance (it varies from 3 to 6 years), but confirms well the existence of the baric circumpolar wave with a period of about 18 years extending from west to east.

Later Nazarov (1949) advanced the diametrically opposite hypothesis on the propagation of ice anomalies from east to west in the direction of the general drift of ice in the Arctic basin. However, a single opinion concerning this question was not established. Only very recently was there made an attempt to check the hypothesis of the direction of propagation of ice anomalies from data of observations of the last 10 years (Kovalev, 1960), as a result of which the author arrived at the conclusion that the hypothesis of Nazarov is more probable. This, however, does not prove the unfoundedness of the hypothesis, which assumes one of the causes of fluctuations in ice cover with a cycle of 4-5 years to be presence of the circumpolar baric wave of tidal character in the atmosphere with an average period of about 18 years.

This question was discussed in the investigations Maksimov (1960), who considers one of the factors causing ice cover fluctuations the circumpolar atmospheric tide with a cycle of fluctuations of about 19 years.

We must assume that the hypothesis of Wiese, undoubtedly, contains a rational beginning, and to reject it is quite impossible. The circumpolar atmospheric tide, if it has any importance, should be connected with one of the self-oscillation systems in the atmosphere and the investigation of this phenomenon is of great interest for the study of variations in climate.

Results of the investigation of atmospheric circulation over the Arctic, conducted during the last few years (Kenneth, 1959), permitted revealing the peculiarity of evolution of circumpolar whirling formed in the powerful alyer from the middle troposphere to the middle stratosphere. Fluctuations in intensity of surface formations (Icelandic and Aleutian minimum, Siberian maximum, etc) are determined by properties of high-altitude circumpolar whirling the more detailed study of which can shed light on causes of ice cover variations. In this connection, in our opinion, Wiese's idea on the circumpolar baric wave can obtain futhere development and foundation.

The question of ice cover variations of polar seas attracted the attention of many researchers. In an article on the development of the Northern Sea Route, Itin (1930), on the basis of data collected by him about conditions of the sailing of vessels gives data of the state of ice in the Kara and Chukchi Seas. In spite of the incompleteness of the data and not quite reliable estimate of ice cover of separate years, Itin managed to show that ice cover variations in these seas have on the average of 4-5-year cyclic recurrence, and they occur synchronously but in opposite phases.

The last conclusion confirms law of ice opposition of Wiese that little ice cover of the Kara Sea corresponds to great ice cover of the Chukchi Sea, and conversely. As will be shown below, these relationships are not always realized.

Simultaneously with that of Itin an article was published on the periodicity in ice conditions by Brooks (1936). Given in this article are considerations on the approach of favorable ice conditions in the Northern Sea Route every third year. These short-term fluctuations whose cause, in the opion of Brooks, are oscillatory movements of the solid ice pack, occur against the background of more prolonged cold and warm periods (of the order of 30 years each).

That circumstance that Itin and Brooks revealed periods of ice cover fluctuations of different duration for Arctic seas fully agrees with conclusions Shokal'skiy (1939) made from results of works of different expeditions in the Arctic Ocean. In particular, he noted that the totality of obtained data indicates the existence in the Atlantic current of periodic fluctuations of both temperature and the mass of water. Besides great fluctuations (warming from the 1920's) there exist fluctuations with periods of 3-5 years of various amplitude and with a different beginning of phases, which darkens and complicates the essence of the phenomenon.

A large article of the survey type, devoted to the relation between polar ice and weather, was published by Schell (1939). Using results of works of a number of authors engaged in study of the question (Wiese, Brooks, Helland-Hanson,[1] Meynardus and others), Schell gives a detailed survey of works on the relation between ice cover of seas and weather of adjacent regions, world weather,

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[1] This name is unverified [Trans. Ed. note].

and also values of individual meteorological elements. It should be noted that the greater part of the article of Schell is devoted to an account of the content of Wiese's works concerning the given question.

Schell maintains the opinion of the advantage of the use of ice cover as an index of total circulation of the atmosphere in connection with the relative inertness of changes of ice cover and the action stabilizing it on the circulation of the atmosphere.

In the middle 1940's Wiese published the great work conveying the result of his numerous investigationsin which a separate chapter is devoted to ice cover fluctuations of Arctic Seas. Using more complete data of observations on the ice cover of Arctic Seas, Wiese managed to give new explanations of the connection of atmospheric circulation with ice cover and subjected to reconsideration some of his former hypothesis.

Proceeding from the fact that warming of the Arctic is connected with amplification of the atmospheric circulation above the Polar basin, Wiese treated this connection in the following way. With animation of the total circulation of the atmosphere the speed and recurrence of the winds with an eastern component in the polar regions should be increased with an intensification of the polar maximum or deepening of the Icelandic minimum. Accordingly there should be intensified the drift of ice from the Polar basin in the direction of the Greenland Sea, but in the Central Arctic the quantity of perennial pack ice, which will be replaced by young thin ice, should decrease. The result of this will be an increase in heat exchange between the ocean and the atmosphere (the increase in flow of warm Atlantic waters also plays a definite role here), an increase in air temperature in the Polar basin, and consequently, a decrease in power of the Polar anticyclone.

Thus the influence of fluctuations of intensity of total circulation of the atmosphere on temperature and ice conditions of the Arctic bears a dual character: on the one hand, an accentuation of the polar anticyclone is observed, and on the other hand, with prolonged influence its weakening occurs.

With these considerations as a base, Wiese examined his hypothesis on the connection of solar activity with ice cover (during sunspot maximum there is little ice cover, and conversely) expressed by him in one of his early works (1925).

Considering the dual character of the influence of fluctuations of the total circulation of the atmosphere on ice content, Wiese formulated the so-called law of accentuation of the baric field, according to which the increase in solar activity intensifys the existing type of circulation but does not determine it.[1]

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[1] Subsequently the second part of the law was definitized: in works of Witels, Girs, Eygenson, Kats, Tyabin and other researchers, it was shown that with a change of activity of the Sun the form of circulation changes.

Wiese also examined the explanation of ice opposition of the Kara and Chukchi Seas, which is not the result of the shift in the Arctic wind belt, as was assumed earlier, but is connected with fluctuations in intensity of the total circulation of the atmosphere.

Let us add several words concerning the question on the opposition of distribution of ice in seas of the Northern Atlantic and in the north of the Pacific Ocean. Judging by mean maps of ice distribution, published by the Danish Meteorological Institute for the period of 1900 to 1932, such a tendency exists in general, but is carried out not in all years.

Table 1

Years	Western sector of the Arctic	Eastern sector of the Arctic
1902	+	−
1916	−	−
1917	+	−
1925	−	−
1929	+	+
1931	−	+
1937	−	+
1949	+	+
1955	+	+
1960	+	−
1963	+	−

Given in Table 1 data (taken from different sources) for the most extreme years in ice cover in the current century for the western and eastern sectors of the Arctic. The "+" sign denotes great ice cover and the "-" sign little content.

As can be seen from these data, of 11 examined years in four of them ice opposition was absent, and therefore it is doubtful whether raising to a "law" of cases of ice opposition between the North Atlantic and the Pacific Oceans can be justified.

In works of Nazarov (1947, 1948, 1949) much material is collected on the ice content of certain regions of the North Atlantic (Newfoundland, Iceland, Davis Strait), Baltic Sea, and seas of the Northern Sea Route. Analysis of these data permitted Nazarov to arrive at the following conclusions: in the region of Newfoundland are distinguished periods of ice cover fluctuations with a duration of 24-25 years, for Iceland, 90-100 years, in region Kronshtadt, 23-24 year, in Davis strait the defined periodicity was not revealed. Points of observations, which are subjected to direct influence of Atlantic waters, reveal more a regular course of fluctuations corresponding to fluctuations of the power of the Gulf Stream with a period of 24-25 years.

The connection is insignificant between ice cover fluctuations of seas of the Northern Sea Route and Northern Atlantic.

Seas of the Northern Sea Route, with respect to stability of ice cover are divided into four zones: Navaya Zemlya zone and zone of Novosibirsk Islands — unstable ice cover; Severnaya Zemlya and zone of Wrangle Island — stable ice cover. Fluctuations in ice cover in the Kara Sea with a period of 9-10 years are observed also in the Chukchi Sea but in opposite phase.

The ice cover of the Polar basin can be divided by age into these zones: northern Alaska and Chukchi Sea, 1-2 years, further to the north, 2-4 years, at the pole, 4-5 years, at the Papanin Strait, about 5 years. Renovation of the ice occurs on the average during 5 years. The drift rate of the ice depends on the intensity of the passing baric systems.

The ice cover anomaly appearing in Chukchi Sea appears in the Laptev Sea every 1-2 years, in the Kara Sea every 2-3 years, and in the Greenland Sea every 5 years. This causes ice cover variations in the region of Iceland with a period of about 5 years. In the conception of ice cover anomaly in the east the water coming from the Pacific Ocean through the Bering Straight should play a considerable role.

Fluctuations with a period of 4-5 years are observed only for Iceland and in the Chukchi Sea; in the Laptev Sea the period of fluctuations is 3-4 years, in Kara Sea – 3 years.

Fluctuations in ice cover are caused by the cyclic recurrence of water exchange in the oceans and processes in the atmosphere. The accumulation and expenditure of nonuniformly incoming solar heat and the peculiarities of transformation create a complicated system of fluctuations with different periods, for which sometimes it is difficult to notice, in general, some periodicity. In spite of this, the latter is more frequently found in ice cover fluctuations than in fluctuations of atmospheric circulation, which is less inertial and more complicated. In ice cover fluctuations there appears a complicated interaction of ocean and atmosphere, and in connection with this investigations of ice cover fluctuations can give impetus to the knowledge of synoptic processes.

Antonov (1957) attributes the following to basic causes of fluctuations of total ice cover of the Arctic seas:

1) mainland waters as the initial impulse of the draining movement of water surface layers;

2) stability of the system of constant curretns of the Arctic Ocean;

3) total wind conditions above ocean, determined by the character of atmospheric circulation of the northern hemisphere.

Numerous expeditionary investigations have established the existence in the Arctic Ocean of a general draining movement directed from Canadian and Asian shores to Greenland. This flow, essentially, serves as the border between two opposite baric systems, the anticyclonic eastern and cyclonic western. The greatest activity of the first appears in the summer causing an intensive inflow of Pacific Ocean waters, and the second, causing an intense inflow of Atlantic waters in the high latitudes, in winter.

The amplitude of fluctuations in flow of Atlantic waters in the winter period from year to year can be changed 4-5 times. Such fluctuations, although they put a definite imprint on the scheme of constant flows in the ocean, nonetheless this scheme in broad terms is preserved, and only the rates of water masses are changed noticeably and the axis of the general extension flow is deflected. This in turn affects the character of distribution of ice in the marginal Arctic Seas. Deviation of the trajectory of the general extension flow to the direction of the Asiatic mainland should sharply increase the ice content of the Arctic Seas.

The change in speed of the extension flow is most considerably affected by the variability of recurrence in the western circulation, expressing basically the powerful influence of the Atlantic. It follows from this that the general background of ice cover of Arctic Seas, which is the result of interaction of the atmosphere and ocean, is established in the winter period during the maximum entering of Atlantic waters and in basic features in maintained during the entire year due to the ice inertia or stability of anomalies in conditions of the Arctic Seas.

Thus atmospheric circulation, conditioning and at the same time reflecting the state of the system of constant flows of the ocean, can to some degree to serve as an indicator of the whole complicated complex of dynamic causes determining the ice cover of the Arctic Seas. Antonov (1957) revealed very close asynchronous connecteions (having prognostic importance) of fluctuations in ice cover with the recurrence of a certain type of circulation (after classification of Vangenheim); for example, the ice cover in August is connected with the recurrence of the western type in October of the preceding year.

The relation of ice cover fluctuations with the recurrence of types of Vangenheim circulation is revealed by many other authors (Vangengeim, Girs, Witels, Stantsevich and others). However, the quantitative expression of this relation could not be obtained. Apparently, a thinner and more detailed classification of the synoptic processes is necessary.

Investigations of recent years, based on data of observations of drifting stations (Gordienko, 1958; Felzenbaum, 1959, and others), established that the ice drift in the Arctic basin is accomplished from the shores of the Chukchi Sea and Alaska in the direction of the Greenland Sea, on approaches to which due to narrowing of the basin the flow and drift of the ice are accelerated. Regions adjoining the northwest Greenland and Canadian Arctic archipelago do not have the shortest path of the extension of ice.

The distance from Franz-Joseph Land to the Greenland Sea is passed by ice on an average of 1 year, from the western part of the Laptev Sea, 2 years, from Novosibirsk Islands, 3 years, from Wrangel Island, 6 years.

Ice cover fluctuations of the Baltic Sea and Danish Straits were investigated Betin and Preobrazhenskiy (1959, 1962). They collected much material of ice observations in the Baltic Sea and Danish Straits: data of Stakle (1936), who collected records on periods of dissection of the ice cover in the Riga port from the winter of 1929/30; data of Jurva (1952) and Palosuo (1952) on ice cover from 1919/20, obtained by them at the base of ship, beacon and shore observations of the state of ice in the Baltic Sea and straits.

On the basis of these data Betin and Preobrazhenskiy plotted curves of the movement of ice in Baltic Sea and Danish Straits. In the course of these curves they revealed secular variation with half-periods of increase and decrease in ice cover, on which secondary variations are superimposed. The tendency of the course of secular variations essentially affects the form of secondary cycles of ice cover fluctuations. In the period of the secular cycle with a tendency of increase in ice cover secondary fluctuations have a more correct form with a gradual increase in amplitude of fluctuations in the chronologic course of the series. In the period of the secular cycle with a tendency of decrease in ice cover the form of secondary fluctuations is less. Cycles of secondary fluctuations have a duration of 20-22 years, 10-12 years, 5-6 years and 3 years. There is a high degree of the connection between meteorological factors (sum of negative air temperatures for the winter period, course of winter temperatures, magnitude of summer heating of water masses) and ice cover. On this basis authors predict the movement of ice cover of the Baltic Sea two decades ahead, using data Simojoki (1955) on the expected course of winter temperatures in Helsinki.

In the opinion of Betin and Preobrazhenskiy, recently there is the formation of the pahse of increase of a secondary cycle of ice cover fluctuations sea with a positive anomaly; the maximum of this phase will approach in the next few years, and then the process will start the decrease in cover, which will be completed approximately in the beginning of the 1970's. Upon the expiration of this a new period with a tendency of ice cover increase should begin.

The study of hidden quasi-periodic regularities in the total series of observations and the exposure of causes generating cyclical oscillations of ice cover of periods differnet in duration are the subject of investigation of Maksimov (1952, 1954, 1960). He analyzed variations of different factors (ice cover of the northern part of the Atlantic, continentality of the climate of Western Europe, height level of the Caspian Sea overflows of the Nile River, thicknesses of wood rings) and revealed the coordinated character of these fluctuations in 80 and 250-year cycles, connected with the 80-year cycle of fluctuations of solar activity and the 250-year cycle, apparently, caused by the change in speed of rotation of Earth.

Maksimov considers that the change in climate have a general planetary character, are directly caused by the increase in intensity of the total circulation of the atmosphere in both hemispheres, are connected with the increase in zonal component of circulation of the atmosphere, and have as one of the causes periodic changes in solar activity.

The most detailed analysis were given to data on ice cover in the northern part of the Atlantic in the Davis Strait, in regions of Iceland and Newfoundland and in the Greenland Sea. For the exposure of considerable fluctuations in ice cover the data were processed according to the method of the moving average, where averaging was produced in the beginning for 7 years, for exclusion of cyclical fluctuations of ice cover created by Chandler's motion of the pole of Earth; then for 11 years -- for the exclusion of heliocaused fluctuations, and but then for 19 years — for the exclusion of fluctuations due to the perennial circumpolar atmospheric tide. As a result of the analysis of data there were distinguished fluctuations of ice cover with a period of about 80 years and there appeared two cycles of 250 years each (according to data of ice cover for Iceland from 1860 to 1940). With this Maksimov established that the last 80-year fluctuations occur against the background of a minimum of 250-year ice cover fluctuations of the Arctic Seas.

Based on this Maksimov considers that the greatest development of change in climate was reached in period of 1938-1940, after which the sign of the variation in ice cover should be changed to the opposite. Hence it is possible to expect after 1940 an increase in ice cover of the Arctic Seas, an increase in continentality of climate in Western Europe, and a cessation of the fall in the level of the Caspian Sea.

It is now already possible to say that these assumptions were justified only partially: although in the polar regions there approached after the 1940's a phase in temperature drop and ice cover, for example, in the Barents Sea (Fig. 1) this continued to decrease until recent years; a general increase in ice cover in the Arctic Seas, according to Lamb (1963), started only from 1958. This once again confirms, first, the unreliability of extrapolationon the basis of insufficiently founded and variable cyclic recurrence, and, secondly, the absence of a simple synchronous connection between fluctuations in climate and ice cover of the seas.

3.3. Conclusions

The above-stated material on fluctuations of ice cover of polar seas gives an idea of the extreme complexity of this phenomenon caused by atmospheric and oceanic circulation. Although fluctuations of the area of ice formation on the Earth are a definite index of climatic changes of large scale, the study of the connection between these phenomena is still by far not completed. This is prevented by the absolutely insufficient quantity of observations and absence of a single method in the estimation of ice cover. Prolonged, continuous, more or less reliable series of observations are only for individual seas of the Atlantic sector. The situation is poor with observations in the Pacific Ocean sector of the Arctic, where, in the opinion of many researchers, ice anomalies are engendered.

Data is quite insufficient on fluctuations of glaciers and ice cover in the Antarctic where there is concentrated about 4/5 of all ice reserves on Earth. The absence of prolonged observations in the Antarctic prevents solution to many problems on the connection of variations of general circulation and climate in both hemispheres.

Many researchers (Mossman, Yoker, Wiese, Willet) assumed that fluctuations of the edge of ice in both hemispheres should occur synchronously in accordance with the expansion or narrowing of circumpolar vortexes (to the equator or from the equator).

Nazarov (1963) considers it possible to tract the perennial course of changes in quantity of ice in the World ocean with the Kara Sea as an example. On the basis of the connection found by him between fluctuations of ice cover in the Kara Sea and solar activity, he predicts in the forthcoming decade, in connection with the reduction in solar activity, the increase in ice cover not only in the Kara Sea, but also in all seas of the northern and southern hemispheres.

But Lamb and Johnson (1959) consider that displacement of borders of perennial ice depend more on latitudinal displacements of the main thermal gradients in the atmosphere than on the change in intensity of the circulation. Therefore, depressions of the southern hemisphere are displaced to the south in those years when the northern polar ice extend far to the south, displacing to the south the paths of the North Atlantic cyclones. In orther words, these authors consider that the displacement of borders of ice in the southern and northern hemispheres occur in parallel in the direction of the North or South Pole.

Opposition to judgements on the conjugateness of fluctuations of ice cover in both hemispheres, naturally, is caused by absence of data, for which authors must use indirect proofs, which in view of the complexity of interdependence can be interpreted ambiguous.

Hence it is clear that for the use of data on ice cover, as an index of variations in climate data are necessary on planetary changes of ice borders for a number of years. Now there is already the possibility of obtaining such data with the help of satellites, and if this possibility is realized in several years researchers of variations in climate will be able to predict far ahead the solution of this most complicated problem.

CHAPTER II

METHODS OF INVESTIGATION OF THE CHANGE IN CLIMATE AND AN ESTIMATE OF THE REALITY OF THESE CHANGES

1. Terminology

Authors of works devoted to the study of the change in climate use for this purpose different methods depending upon the set concrete problem. It is necessary to analyze basic methods of those used at present in order to select the most suitable for resolution of the problem formulated in this work. However, before doing this, one should definitize the terminology. The concept "change in climate" has different meaning to various authors. Discordance in this question reached the point where at the Fourth Session of the Climatological Commission of the Universal Meteorological Organization (UMO) (1965) the working group on variations in climate presented a proposal for the standardization of terms connected with the concept "change in climate".

Basically this proposal is reduced to the following.

"Change in climate" is a general term including all forms of inconstancy of climate irrespective of their nature, statistical (connected with the internal structure of series) or conditioned by physical causes.

The particular cases in the concept "change in climate" are the following:

a) stepwise change in parameters of statistical distribution from one part of the series to another;[1]

b) variation in climate – such a change of climate at which values of the variable are gradually and smoothly changed between consecutive maximum and minimum values;

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[1] In the proposals of the working group only mean values are mentioned, but it is more correctly to discuss all the basic statistical parameters.

c) climatic rhythms — fluctuations at which consecutive maxima and minima are encountered on approximately equal time intervals;

d) climatic periods — such rhythms in which time intervals between maxima and minima are constant or almost constant for the whole series;

e) climatic tendencies (trend) — change in climate characterized by a smoothed, monotonous increase or decrease in values of the variable in the period of observations. This tendency should not necessarily have a linear character, and the presence of only one maximum and one minimum at the beginning and at the end of the period of observations is important;

f) climatic fluctuations — climatic inconstancy representing one of the forms of the systematic change of climate, with the exception of the climatic tendency and the stepwise form of the change in climate. Climatic fluctuations are characterized by at least two maxima and one minimum or two minima and one maximum.

Not all the particular cases which working group on variations in climate proposed to include in the concept "change in climate" are enumerated here, since they are partly debatable and do not have a direct relation to this work.

Important and quite acceptable is the fact that the concept "change in climate" is as a generalization of any form of inconstancy of climate, and "variation in climate" and "climatic trend" are its particular cases. These definitions, essentially, coincide with those which were used by us in the preceding works. A definition of climatic fluctuations is debatable and is mentioned only for the reason that authors of certain works introduced it as a synonym of climatic variations of any form. Used in this work are only the terms "change in climate", "variation in climate", and also "climatic rhythms" (cycles) and "climatic trends" in accordance with their definitions given above.

2. Analysis of the Homogeneity of Series of Observations

The change in climate can be studied full only if the initial series of observations are uniform with time and comparable in space. Causes of heterogeneity of series of observations, objective methods of the exposure of these heterogeneities and the quantitative appraisal of them, and the removal of the heterogeneity by means of introduction into part of the series of corresponding corrections are described in detail in the textbook of Alisov, Drozdov and Rubinshteyn (1952) and in the work of Drozdov (1956), and therefore there is no need in this work to discuss the theory of these questions. In those cases when the history of station is known, the heterogentity of the series can sometimes be removed. Thus, for example, Mitchell (1953), on the basis of parallel observations, determined the difference of temperatures caused by the transfer of the station New Haven (the longest series of observations in the United States) from the city to the airport. In

World Weather Records 1941-1950 (1959) these differences are given in the form of corrections to temperature of the station at the airport so that it would be possible to unite its data with temperatures of the station in the city. The same corrections were given by us to data of the station at the airport for the period of 1951-1960. Analogously there was determined the magnitude of heterogeneity appearing in connection with the transfer of the station at Vienna. Differences in temperatures at the new and old locations at New Haven during eight months in the year (from April to November) are from 1.0° to 1.5°, and in Vienna from May to August they are 0.8 to 1.0°.

Inasmuch as these differences are averages from observations of a series of years, the addition of them to data for individual years cannot completely remove the heterogeneity of the series. At New Haven we considered possible, however, to unite both series, since the corrections were given only to data for 20 years. For Vienna it was considered more expedient to use data of the station only after its transfer, since 1851, than to give corrections to the old 75-year old series in order to unite it with the new.

When work is conducted on the scale of the entire Earth, the history of the station — the change of its location or the surrounding environment in separate parts of the period of observations the change in periods of observations or formula which are use for the derivation of average diurnal temperature values — by far is not always known. But also in those cases when there is this information, it is far from always possible to determine quantitatively heterogeneity caused by the above-indicated causes while one can see by examples of New Haven and Vienna that differences in temperature connected with the move of the station 1-1.5°C, differences of the mean diurnal temperatures, calculated by the formula 1/2 (maximum + minimum), and averages for 24 hours in many regions of the Earth are also about 1°C. In the case when in some years the mean temperatures are calculated by the formula 1/2 (max + min) and in other years at the very same station as an average of some combination of periods of observations, the series of observations becomes nonuniform.

In the present work if it was not possible to determine the magnitude of heterogeneity quantitatively, stations were used only as auxiliary (for establishing the community of variation with other stations), or the nonuniform part of the series was rejected.

3. Method of Integral and Integral-Difference Curves[1]

The essence of this method consists in the following.

Let us designate terms of the initial series by

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[1] Sometimes such curves are called cumulative curves.

$a_1, a_2, a_3, \ldots,$ an. Then its mean value will be

$$\bar{A}_n = \frac{1}{n}\sum_{1}^{n} a_i,$$

and the deviation of every term of the series from the perennial average

$$d_i = a_i - \bar{A}_n.$$

The integral is called a series whose terms are equal to

$$a_1, a_1 + a_2, a_1 + a_2 + a_3, \ldots, a_1 + a_2 + \ldots + a_n,$$

and the integral-difference, a series whose terms are equal to

$$d_1, d_1 + d_2, d_1 + d_2 + d_3, \ldots, d_1 + d_2 + \ldots + d_n.$$

Usually during the study of the change in climate this second variant of the method is used.

A comparison of properties of integral-difference series with the initial leads to the following conclusions. Since

$$\sum_{1}^{n} d_i = \sum_{1}^{n} (a_i - \bar{A}_n) = \sum_{1}^{n} a_i - n\bar{A}_n = 0,$$

then the last term of the integral-difference series should be equal to zero. Practically, if quantity $\bar{A}_n$ is not calculated accurately enough (with rounding off), it somewhat differs from zero.

If the structure of the initial series is such that its terms are somehow connected with each other, but their magnitude is influenced by random (in statistical sense) factors, then in the converted series the role of systematics increases as compared to the influence of random factors. If the initial series includes the cylical process, then in the integral-difference series it will shift a quarter of a phase, since the integral of cos x is equal to sin x. Amplitudes of long waves will be increased greater than amplitudes of shortwaves, since the integral of cos x is 1/2 sin x.

The fact that in the integral-difference series its regular structure appears more clearly than in the initial series, and amplitudes of long waves are increased greater than those of short (and, consequently, the alternate filtration of waves of various length is possible), attracted a number of authors to use this method for the study of the change in climate. However, this method has a number of deficiencies. Thus, for example, Drozdov (1964) showed that with the initial incoherent series the dispersion of terms of the integral-difference series will be greatest in the middle of series studied and that the accumulation of random errors can considerably increase the amplitude of accidental variations in this part of the series. He also calculated coefficient of correlation between neighboring terms of the integral-difference series and showed that it is considerable, especially in the middle of the series. In connection with this the character of curve becomes smooth and produces an impression of regularity.

Considering the above-indicated deficiencies of the method of integral-difference curves one should not recommend it for extensive use. An exception can be the investigation of such character when cumulative properties of a series are important, for example an analysis of precipitation and river drainage for an estimate of the accumulation of water in a reservoir. In this case the use of the integral-difference series has real physical meaning.

4. Method of Moving (Overlapping) Averages

This method is one of the most often applied in the investigation of the change in climate; just as the method of integral curves, it was proposed at the end of the last century for the smoothing of series of observations.

The essence of this method consists in the in the transformation of the initial series $a_1, a_2, \ldots, a_n$ into the series

$$\frac{1}{m}\sum_{1}^{m} a_i, \frac{1}{m}\sum_{2}^{m+1} a_i, \ldots, \frac{1}{m}\sum_{n+1-m}^{n} a_i,$$

Obtained after averaging with respect to m of consecutive terms of the first series when $m < n$.

If in the initial series the periodic term is contained, then it is easy to show that in the converted series this term will have an amplitude decreased as compared to the first in the ratio

$$A = \frac{\sin m\frac{\pi}{p}}{m \sin\frac{\pi}{p}},$$

where p is the wavelength of the period.

With p equal to m, 1/2m, 1/3m etc., $A = 0$, i.e., such periods are completely liquidated. If $p > m$, then the greater the p, the less the amplitude decreases in the smoothed series, since at very small angles $\sin m\frac{\pi}{p}$ is close to $m \sin\frac{\pi}{p}$ and A is close to one.

Thus the method of moving averages presents a certain "mathematical filter", allowing the isolation of variations with a large wavelength, consideraly extinguishing the short-period oscillations.

This method is simple, and in the converted series the phase of periodic terms does not change (for waves of sinusoidal character with a wavelength exceeding the period of averaging, with attributing the results of smoothing to the middle of interval). Furthermore, when necessary from the smoothed series always it is possible to turn to a series of averages for consecutive (nonoverlapping) time intervals, in which the influence of random factors and small cycles is just as suppressed as in the series of moving averages, but whose terms with incoherence of the initial series remain independent.

Application of this method requires, however, the calculation of certain properties of this series without which it is possible to arrive at false conclusions.

Establishment of fact of the change in climate is reduced basically to an analysis of time series. It is complicated by the fact that not all noticeable variations in these series are real. Slutskiy (1927) showed that "the addition of random causes generates wave-like series having a tendency during the period of a greater or smaller number of waves to simulate harmonic series formed from a relatively small number of sinusoids. Upon the expiration of the greater or smaller number of periods of the defined conditions are upset, and the transition to other conditions can occur either gradually or more sharply near the special critical points."

The appearance of these waves can be caused by the following circumstances. With moving averaging in the influence of every term of the series spreads on m terms of the moving series. Terms whose value considerably differs from the average will manifest their influence during the whole period of averaging. At the same time in the random series the number of maxima and minima is about 1/3 of the terms of the series. If these maxima and minima were not covered, in the moving series there had to appear apparent cycles with an average wavelength equal to the triple period of averaging. Partial covering of the influence of extreme terms of the series will somewhat reduce the duration of such apparent cycles, and they will exceed the period of averaging 2-3 times. In connection with this it is expedient to apply the moving averaging either for detection of cycles with a wavelength greater than the tripled interval of averaging, or to control the reality of the cycles by applying in parallel several periods of smoothing.

Here an account was of the simplest variant of the method of the moving average when all terms of the series have identical weight. There are used sometimes more complicated variants of this method, a short summary of which is given in the report mentioned earlier at the Fourth Session of the Climatological Commission of the Universal Meteorological Organization. These methods are not analyzed, inasmuch as in the present work they were not used.

An illustration of that said about properties of time series, smoothed according to method of moving average, can be Figs. 2 and 3, where there is given a comparison in the variation in temperature in the initial series of observations with temperatures smoothed by means of the formation of 5, 10, 35 and 80-year moving averages. The data are given for Leningrad as for the longest and most uniform series of observations in the Soviet Union.

With attentive examination of the graphs it is possible to notice already in the initial series a certain tendency toward an increase in temperatures in the 20th century as compared to the 18th and 19th centuries. This can be seen from the course of deviations for every year from the perennial mean temperature. In first

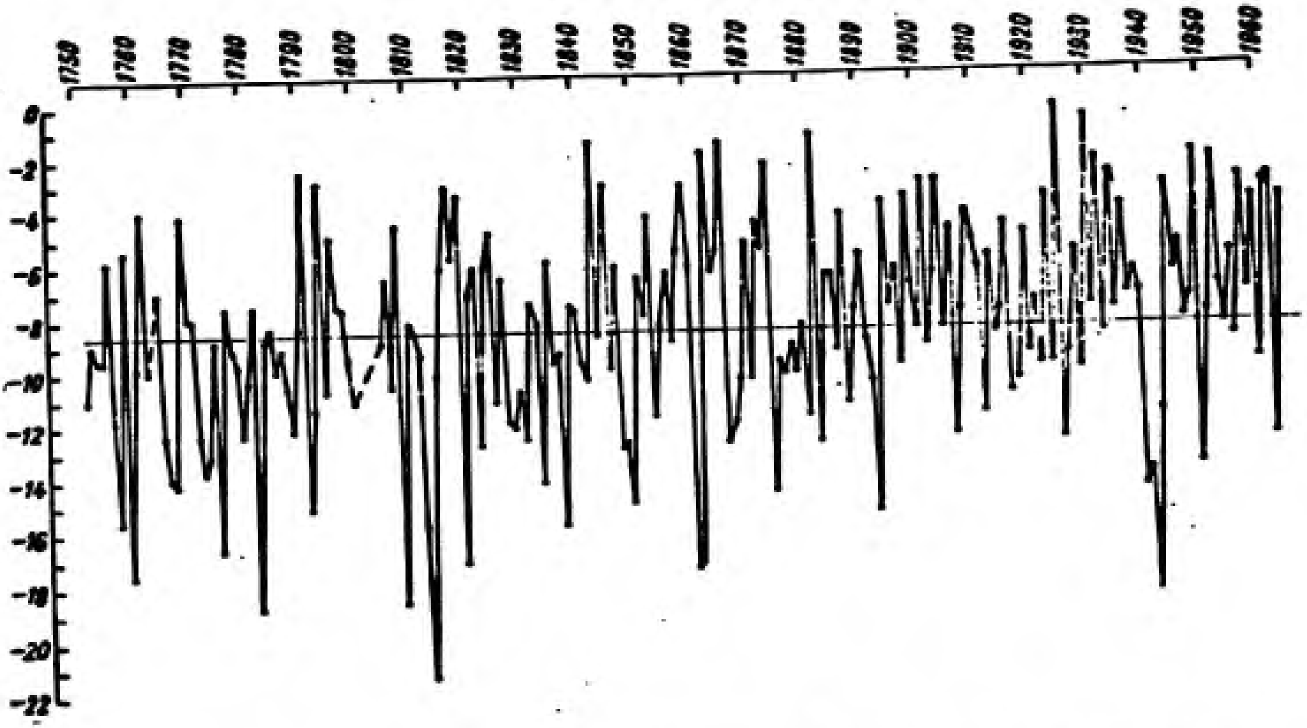

Fig. 2. Mean monthly air temperatures. Leningrad. January.

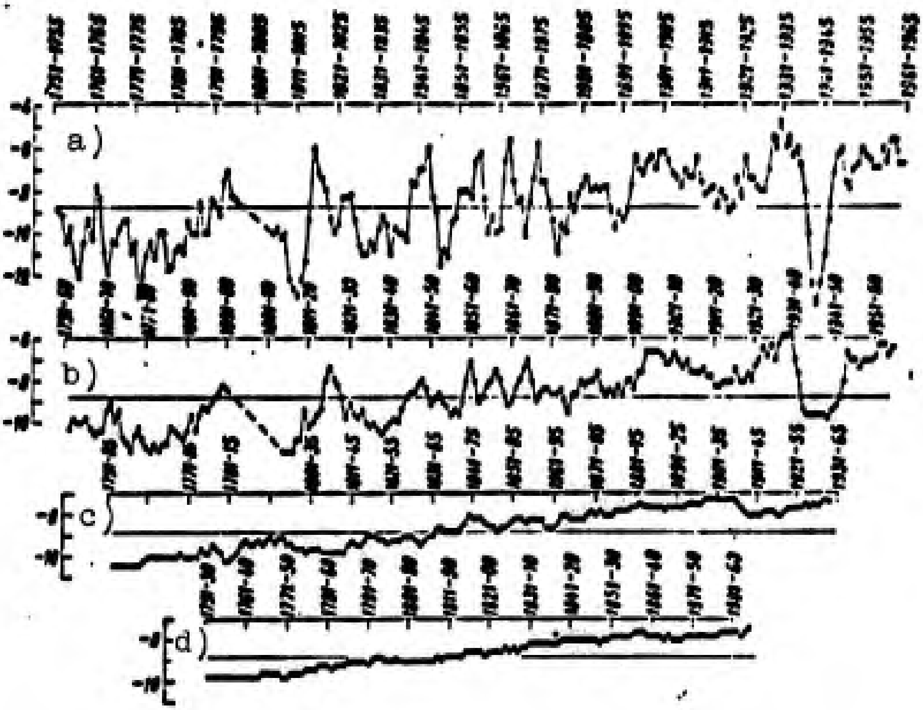

Fig. 3. Moving average of air temperature. Leningrad. a) 5-year, b) 10-year, c) 35-year d) 80-year.

part of the series there are considerably greater negative deviations in temperature than in the second, where only the deviation in temperature in 1942 can be compared with deviations of 1783, 1809 and 1814.

In the course of moving averages the tendency toward the increase in averages of monthly temperatures is more sharply expressed, but great deviations in temperature from the perennial averages are well evident even on 5 and 10-year moving averages (for example, low temperatures in the beginning of the 19th Century and in 1940's and high temperatures of the 1930's). The horizontal lines correspond to the perennial mean temperature for the whole period of observations.

There is interest in the comparison of the analysis of the time series by methods of integral-difference curves and the moving average. Figure 4 gives the variation in temperature Kazalinsk in Spril calculated by both methods. Variation of the curves on this Figure shows that the moving average temperatures give a more graphic representation of the actual changes in temperature than do the integral-difference curves. Thus the highest 10-year mean temperature of April was in the period from 1932 to 1941, and the integral-difference curve occupies during this time almost the lowest position, which is caused by the influence of the low temperatures of the preceding period (as is well evident from the curve of moving temperatures up to 1905-1914). One should not assume that the course of curves on Fig. 4 is accidental, and an example is specially selected. Such movement of the curves is typical, in any case for series characterized by great variations in temperature, and they represent for us the greatest interest. The fact is that integral-difference curves in principle are the integral of the initial series and, therefore, should have with respect to this series an opposite movement. We compare these curves with the smoothed series, but, since in it during the 10-year averaging there still are preserved the basic features of the initial series, tendency to an opposite movement of curves remains noticeable.

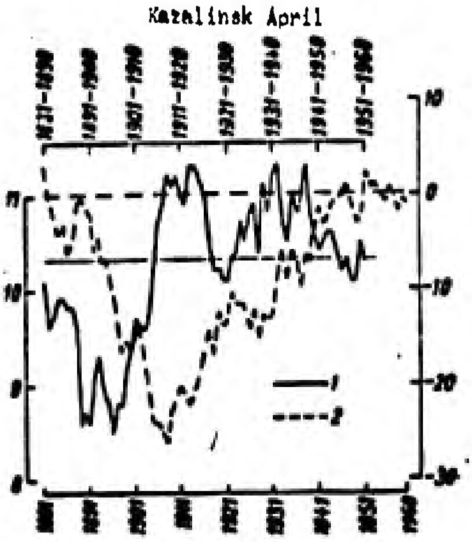

Fig. 4. Moving 10-year avearage temperatures (1) and integral-difference curve (2). Scales above and to the left pertain to the moving average, and scale at the bottom and to the right – to the integral curve. The horizontal solid line is the mean temperature of April at Kazalinsk for the period from 1881 to 1960, and the horizontal dotted line corresponds to the beginning of the reading of the integral-difference curve.

To deficiencies of the method of integral-difference curves having a technical character should belong the fact that with the desire to extend the series during the accumulation new data is necessary to calculate deviations from the perennial average anew, since the mean value of the series under conditions of variable climate can be different.

5. Methods of Spectral Expansion of Series of Observations

These methods, as also the method of integral-difference curves and method of moving average already described, are for the purpose of detecting hidden variations in series of eteorological observations.

5.1. Schuster Periodogram. In 1898 Schuster proposed themethod periodogram analysis, which was widespread in his time. The idea of this method was founded by Bayes-Ballo in 1847. There is no need here to give many research works and textbooks. In connection with the laborious for preliminary analysis of cyclic recurrence, in the present work there was used the periodscope method of Carruthers (1944).

5.2. Carruthers Periodoscope. The basis of this method, as other methods of such kind, is the expansion of the series of observations to several components selected with such calculation in order to distinguish periods with an interesting wavelenght, which smooths other waves. By means of very simple calculations we obtain tentative magnitudes of the length, amplitude and phase of periodicities. Subsequently, with necessity, a more precise definition is possible of these magnitudes by the method of harmonic analysis of those variations with which it is possible to give a definite physical interpretation.

The method of calculation of the periodoscope, in particular for a series of mean monthly temperatures, consists in the following. The initial series is divided into segments u in such a manner that the length of the period of variations which we want to isolate covers from 3u to 6u observations; then we will form average of u data (u_1, u_2, ..., u_n) and calculate the difference:

$$u_1 - u_3 = v_2,$$
$$u_2 - u_4 = v_3,$$
$$\cdots\cdots$$
$$u_{n-1} - u_{n+1} = v_n.$$

From the series of differences (v_2, v_3, ..., v_n) again we calculate the differences:

$$v_4 - v_2 = z_3,$$
$$v_5 - v_3 = z_4,$$
$$\cdots\cdots$$
$$v_{n+1} - v_{n-1} = z_n.$$

Then

$$z_n = -u_{n-2} + 2u_n - u_{n+2}.$$

This expression serves for the control of calculations.

The obtained differences z_3, z_4, ..., z_n are plotted on a graph, having selected convenient scale. On the obtained curve there is excluded secular variation, and large variations are essentially smoothed.

Giving different values to quantity u, we obtain a series of curves which make it possible to study the wide range of periods of variations.

Reality of the exposed periodicity is confirmed by the presence of it on two or more curves obtained at close values of u.

If the series of observations contains periodicity with the length L, then this periodicity will be contained in curves of the periodoscope with the same length, but with an amplitude increased in the ratio R:1, where

$$R = \frac{16L}{\pi u} \sin^3 \frac{\pi u}{L} \cos^2 \frac{\pi u}{L}.$$

Quantities of R for values of the ratio L:u from 2.5 to 6.9 are reproduced from the article of N. Carruthers (1944) in Table 2.

Thus in order to obtain the real magnitude of the amplitude of the periodoscope of period L found on curve u, it is necessary to divide the mean value of amplitude, determined by u, by the quantity R.

Table 2. Degree of Increase in Amplitude for Different Ratios of the Length of Periodicity and the Period of Averaging

l:n	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
2						1,05	1,36	1,51	1,97	2,23
3	2,48	2,76	2,89	3,06	3,20	3,31	3,41	3,48	3,53	3,57
4	3,60	3,62	3,62	3,62	3,59	3,57	3,54	3,51	3,47	3,43
5	3,30	3,34	3,29	3,24	3,18	3,13	3,07	3,02	2,97	2,92
6	2,86	2,81	2,75	2,70	2,65	2,61	2,56	2,51	2,46	2,41

An example of the calculation of the amplitude on periodoscope curves and results of the periodoscope analysis, carried out for the series of temperature, will be given in Chapter V.

5.3. Method of autocorrelation. One of the variants of the method of spectral expansion of series of observations more perfected than that of the periodogram, is themethod of autocorrelation. The idea of it consists in the following.

If there is given a series of equidistant values a_1, a_2, ..., a_N and their deviations from their average value $\overline{A}_N$ will be $d_i = a_i - \overline{A}_N$, then the coefficients of correlation between terms of this series a_i and a_{i+k} will be

$$r(k) = \frac{\Sigma d_i d_{i+k}}{(N-k)\sigma^2},$$

where k = 1, 2, 3 ...

Thus the coefficient of correlation is the function k. This function is called a correlogram. If in the initial series there is the periodic term, then it will be preserved and in the series r(k); on the correlogram, at places corresponding to the length of the period, "peaks" will be seen. In the case when the series is not strictly periodic the amplitude of the periodic variations r(k) will fade with an increase in k due to the growth in the difference of phases of rhythmic fluctuations.

5.4. Method of analysis of continuous spectrum of variations. In recent years in investigations of variations of different meteorological elements the method of analysis of the continuous spectrum of variations is frequently used. Proceeding from the fact that the time series can be represented consisting of an infinite number of variations giving continuous distribution of wavelengths, measurement is produced of the distribution of variations in time series in a continuous region of all possible wavelength from the infinitely long to the shortest. With the help of spectral expansion we isolate predominant periods of variations and estimate scales of disturbances which introduce the greatest contribution to these variations. The continuous spectrum or spectral density is calculated on the basis of empirical correlation functions and, just as the latter, is the most effective in the case of stationary processes.

This variant of the method of spectral expansion of series of observations is more perfected than that of the preceding, since it allows determining the continuous distribution of wavelengths contained in the time series. All variants of methods of spectral expansion characterize the structure of random processes contained in the time series. All variants of methods of spectral expansion characterize the structure of random processes contained in the time series. But the method of composition of the continuous spectrum of variations of series, just as the method of autocorrelation, has the deficiency that it does not permit determining the phase of cyclical components of the series.

A large part of the spectral peculiarities of the series, which is revealed in the method of analysis of variations with the help of the continuous spectrum, is contained in the correlogram, although in a somewhat less graphic form.

Considering the least laboriousness the methods of periodoscope and Correlogram of all the mentioned methods of spectral expansion of series of observations, we used these methods in the application to the problem set in the present work along with the basic method of moving averaging.

At the same time in Paragraph 2 of this chapter it was noted that in the smoothed series there can appear "waves" which in the initial series were not noticeable. It is necessary to find the criterion on the basis of which it would have been possible to arrive at conclusion whether these waves, becoming noticeable due to the suppression of shorter waves, are real or are they only an imitation of variations, caused by the addition of random causes.

6. Criterion of Reality of the Distribution of a Series of Observations from the Incidental

As is known, variations in meteorological quantities differ with great diversity. Part of the spectrum of variations in its structure resembles incidental incoherent variations or random disturbances covering considerable periods within which there appears connectivity of meteorological series simulating the cyclic recurrence of the variations. Other variations in their structure considerably differ from the incidental and reflect the influence of prolonged effective factors, creating a certain form of systematics in the structure of the series. The establishment of such systematics has much importance for the estimate of the influence of the internal structure of a series and external factors on terms of the series and also for checking the hypotheses of the existence of connections, especially those more complicated than the linear correlation (Drozdov, Pokrovskaya, 1962).

For the purpose of facilitating the analysis of prolonged variations most interesting for climatologists measures are taken for the suppression of short-term cycles and also those similar in structure to the incidental. For this there is used most frequently either the consecutive summation of terms of the series (integral curves) or different methods of smoothing (filtration). The first procedure does not change, essentially, the quantity of information embodied in the series and only facilitates the detection of long-term cycles against the background of shorter ones. The second procedure can in certain cases completely turn off defined periods from the converted series.

As was already mentioned, among methods of smoothing comparatively frequently there is applied the method of moving average. A great deal was written about its merits and deficiencies. They are discussed in Paragraph 4 of this chapter. In addition to this one should dwell on the merits of this method noted earlier insufficiently. In particular it can be proved that with the same averaging the method of moving averages liquidates the random effect the greatest as compared to other methods of smoothing.

Let us assume that suppression of the influence of random factors is carried out by means of averaging n consecutive terms of the series

$$x_1, x_2, \dots, x_n, x_{n+1}, \dots, x_N, \tag{1}$$

with weights

$$a_1, a_2, \dots, a_N; \ \sum_1^N a_i = 1. \tag{2}$$

Let us determine dispersion of the accidental incoherent series smoothed by the above-indicated method. It is obvious that as a result of smoothing there will be obtained the quantity of the form

$$y_k = \sum_1^n a_i x_{i+k}. \tag{3}$$

With this the mathematical expectation of quantities of the initial series and averaged series will be equal to Ey = Ex, where E is the sign of mathematical expectation, then the dispersion y_k will be equal to

$$\sigma^2_{y_k} = \sum_1^n a_i^2 \sigma_x^2. \tag{4}$$

To clarify the influence on dispersion of the series of irregularity of weights, quantities of weights a can be replaced by quantities b by the relation

$$a_i = \frac{1}{n} + b_i, \tag{5}$$

where

$$\Sigma b_i = 0, \tag{6}$$

but then instead of (4) it is possible to write

$$\sigma_{y_k}^2 = \sum_1^n \left(\frac{1}{n} + b_i\right)^2 \sigma_x^2 = \left(\frac{1}{n} + \frac{2\sum b_i}{n} + \sum b_i^2\right)\sigma_x^2. \quad (7)$$

The second term of the expression, (in parentheses) is identically equal to zero on the basis (6), and the third term in parentheses (7) is essentially positive. There, the minimum σ_{y_k} will be under the condition

$$b_i = 0 \ (i = 1, 2, 3, \ldots, n). \quad (8)$$

This proves that any smoothing with unequal weights in the interval of n consecutive terms less effectively suppresses incidental variations than that of the moving average.[1]

Preliminary smoothing is frequently found necessary for composition of the spectrum of basic cycles, without which the level of significance remains inadequate for definitiveness of judgement on the reality of the obtained results. At the same time smoothing does not save from the necessity of estimating the degree of reality of exposed peculiarities of the series structure. Among such criteria rather sensitive in many cases (Drozdov and Pokrovshaya, 1961; Drozdov and Pokrovskaya, 1962) are the relationships collected by B. P. Veynberg (1929) and strictly founded by M. A. Omshanskiy (1936).

For the present work there was interest in the criteria allowing establishment of the distinction in variations in the investigated series from variations, taking place in incidental incoherent series for which there is maintained approximately the equality of the number of increases and decreases, and the number of extrema is approximately 2/3 of the number of the terms of the series.

The first of thementioned criteria permits revealing the systematic change in the level of the series (on the whole or on some section), and the second permits estimating the duration of the characteristic cycles. These criteria were developed earlier only for nonsmooth series. Considering that the methods of moving averages are used by great propagation in practice, they are generalized in the case of smoothing (Drozdov and Pokrovskaya, 1962). The application of them to factual material immediately led to unexpected and interesting results. Let us show this in the example of an analysis of the series of January temperatures in Leningrad. This series started in 1743 but had in the beginning several omissions. Since 1805 the observations have been conducted continuously. For an analysis of the quantity of extrema it is expedient to use this last section of series, which up to 1964 numbered 160 years.

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[1] In the report already mentioned earlier of Commission on the Change in climate at the 4th Session of the Climatological Commission of UMO there is examined the generalized method of moving averaging of series whose terms have unequal weight. This method is frequently used by various authors. As was shown above, the most effective is the method of simple smoothing of terms of series with equal weights.

For the initial series the number of extrema $\nu = 2/3N = 107$ with a probable error

$$f(\nu)=0{,}477\sqrt{\frac{16N-29}{45}}=3{,}5,$$

where N is the number of terms of the initial series.

For smoothing of the series, with a period of smoothing $n > 3$, the number of extrema will approach $1/2(N - n)$ with a probable error

$$f(\nu)=0{,}1124\sqrt{11(N-n-1)}-2n.$$

A test of the difference of the number of extrema from the accidental is conducted for the nonsmoothed series and for the moving smoothing with respect to 10 and 35 terms. More prolonged periods of smoothing were not tested, since with such averaging the series of adjacent terms appeared within the accuracy identical, and determination of the number of extrema was difficult. Results of the test are given in Table 3.

Table 3. Test of a Number of Extrema in a Smoothed Series of January Temperatures in Leningrad for the Difference (Δ) from the Expected in Random Series

Period of smoothing n	$N-n+1$	ν	ν for randon series	Δ	$f(\nu)$	$\frac{\Delta}{f(\nu)}$	$\frac{\Delta}{\sigma_\nu}$
1	160	122	107	+15	3,5	+4,3	2,9
10	151	82	75	+7	4,5	+1,5	+1,0
35	124	71	62	+9	4,0	+2,2	+1,5

Note. In first line there are data of the nonsmoothed series.

In the nonsmoothed series the number of extrema was found to be considerably more incidental than the presence in the series of a biennial cycle ($4.3f = 2.9\sigma$, level of significance is 0.37%) is found reliable.

After smoothing the deviation of a number of extrema from that expected became unimportant, and the certain exaggeration of the number of extrema as compared to the expected is apparently connected with the inaccuracy of their counting in the flat sections of the curve (in every flat section there was taken one extremum, which is somewhat conditional).

No less interesting were results given by the analysis of the number of increases and decreases in the series. Here up to $n = 50$ inclusively the length of the series was used the same as in the preceding case, but with smoothing over 80 years omissions were disregarded and counting was conducted over the entire series with averages for the actual number of years of observations in the given 80-year period. The number of increases (or decreases) in the nonsmoothed random series should on the average be $m = N/2$ with a probable error (Veynberg, 1929)

$$f_m = 0,195\sqrt{N+1}.$$

For smoothed series the number of terms will be less by n, and consequently, the number of increases and decreases is each on the average $\frac{N - n}{2}$ with a probable error $F = 0.195\sqrt{N + n}$.

In order to decrease as much as possible the influence of flat segments of smoothed curves, on which to distinguish the increase from the decrease in series it is practically impossible, it is expedient to take the difference of a number of increases and decreases, considering that on the flat segments the increases and decreases are equally probable. But it is natural that the variability of the difference in the number of increases and decreases in the series is twice greater than the variability of the number of increases, and consequently if the mathematical expectation of the difference $m(+) - m(-) = 0$, then $f_{m(+)-m(-)} = 0.390\sqrt{N + 1}$ for the nonsmoothed series and $f_{m(+)-m(-)} = 0.390\sqrt{N + n}$ for the smoothed parts of the series.

As a result of the analysis of the January temperature for Leningrad Table 4 is obtained.

Table 4. Test of Differences of Numbers of Increases and Decreases in a Smoothed Series of January Temperatures of Leningrad for Difference from the Expected in the Random Series

Period of smoothing n	$N - n + 1$	$m(+) - m(-)$	$f_{m(+)-m(-)}$	$\frac{m(+)-m(-)}{f_{m(+)-m(-)}}$	$\frac{m(+)-m(-)}{\sigma_{m(+)-m(-)}}$
1[1]	100	+4	5,0	+0,80	+0,53
10	151	+8	5,1	+1,57	+1,06
35	126	+5	5,3	+0,94	+0,65
50	111	+13	5,6	+2,30	+1,55
80	134[2]	+16	6,7	+2,39	+1,61

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[1] In first line there are data of the nonsmoothed series.

[2] All years of observations are used.

Data of this table show that in the nonsmoothed series the number of increases and decreases in practically equal, and up to the period of averaging $n < 50$ there appears only an insignificant excess of the number of increases over the number of decreases, after which the predominance of increases over decreases is more clearly revealed. Translating the calculations given in Table 4 from probable deviations into units of standard deviation more accepted now, we find that for the 50-year smoothing the difference in the number of increases and decreases composes is about $1.55\sigma_{m(+)-m(-)}$, and for the 80-year period, $1.61\sigma_{m(+)-m(-)}$. The level of significance of similar deviations as random is equal to 12 and 11% respectively. Thus the criterion of Veynberg was found insufficiently sensitive for the given purpose and only with averaging over periods, greater than 50 years are there revealed noticeable differences in the number of increases and decreases from that which one should have expected in random incoherent series. But the level of significance for categorical conclusion remains insufficient. This shows that the analysis of changes in climate requires more sensitive criteria than, for example, the analysis of levels of reservoirs, in connection with the great variability in temperature from year in year.

Let us analyze the ways of possible more precise definition of criteria of systematics. The profitable side of the criteria of Veynberg is that, by applying them, it is possible to trace the accumulation of distinctions from accidental with an increase material at constant structure of the series. A shortcoming of them is the fact that peculiarities of the series utilized in the criteria are considered only in qualitative form. Hence the replacement by their analogous criteria is natural, but founded on the quantitative calculation of peculiarities of the series, in particular on the calculation of the increase and decrease of its level. For obtaining a similar criterion we will use certain ideas of sequential analysis developed by Wald (1947, 1960). Let us compose a series of consecutive differences of neighboring (equidistant with time) members of series $x_1, x_2, \ldots, x_N$.

$$d_1 = x_2 - x_1,\quad d_2 = x_3 - x_2,\quad d_3 = x_4 - x_3, \ldots,\quad d_{N-1} = x_N - x_{N-1}. \qquad (9)$$

As is known,

$$D_k = \sum_1^k d_i = x_{k+1} - x_1, \qquad (10)$$

i.e., with summation of consecutive differences anew difference series is obtained but with an interval in k of the terms.

For incoherent series

$$\sigma^2_{D_k} = 2\sigma^2_x. \qquad (11)$$

As can be seen, dispersion D_k does not depend on k and it can be designated by σ_D. At the same time D_k is expressed the direct change in the level of the series from the first term to the (k + 1)-term. Obviously, it makes sense to compare D_k with σ_D or to estimate the series of ratios $\frac{D_k}{\sigma_D}$ for establishing the significance of systematic tendencies in the series as compared to their natural variability.

With this if systematic tendencies of the evolution of the level will be important, the series $\frac{D_k}{\sigma_D}$ (k = 1, 2, ..., N) finally will emerge beyond the limits of several units, which will characterize the reliability of setting the tendency (with conservation of the law of formation of terms of the series).

For cyclical processes the series $\frac{D_k}{\sigma_D}$, emerging some time beyond the limits permissible for random series, again will return to relatively small values, which usually is not anticipated in sequential analysis. However, this criterion will also not always be sufficiently sensitive, since variability in the x series can appear is so great that accidentally x_1 can negligibly differ from x_k. In this case sensitivity of the criterion can still be increased if one were to take the differences of not consecutive terms of the series, but the averages of consecutive n-year of the same series:

$$d_k^{(n)} = \frac{1}{n}\left(\sum_{k+1}^{k+n} x_i - \sum_{k-n+1}^{k} x_i\right). \qquad (12)$$

Summing $d_k^{(n)}$ gives quantities

$$D_k^{(n)} = \frac{1}{n}\left(\sum_{k+1}^{k+n} x_i - \sum_{1}^{n} x_i\right). \qquad (13)$$

For random incoherent series $\sigma^2_{D(n)} = 2^{\frac{\sigma_x^2}{n}}$ it also does not depend on k.

Comparing the series of quantities $D_k^{(n)}$ with $\sigma_{D(n)}$, we can more accurately estimate the importance of distinction in changes in the series x_i from variations in the random incoherent series. The influence of various kinds of connectedness in the x_i series (Markovian processes, stationary processes etc) does not change meaning of the criterion, since the very fact of stability of the tendency in the level of series independently of its origin is important (it is immaterial whether stability is determined by connections of subsequent terms of the series with the preceding or by the influence of external factors on them).

The period of averaging n can be taken as arbitrary, but its rational selection is determined by the following conditions: n should be great enough in order to substantially lower the variability of the initial value of the level of the series induced by random factors, and at the same time the quantity n should not be so great that it smoothes the real peculiarities of the structure of the series subject to exposure. The biggest values of n, naturally, can be taken during linear evolution of the level of the series. For this case the rational value of n is easy to calculate theoretically. Benefit of the increase in n with incoherence of series x_i is in the decrease in $\sigma_D^{(n)}$, which will decrease proportional to $\sqrt{n}$. Loss from the increase in n is obtained as a result of reduction in the time interval during replacement of initial members of the x_i series by mean values. The relative importance of reduction in the length of the series is with averaging of $\frac{N-n}{n-1}$. Consequently, the most profitable interval is determined by the maximum relation

$$y=\frac{\sqrt{n}}{\frac{N-1}{N-n}}=\frac{(N-n)\sqrt{n}}{N-1}, \qquad (14)$$

then

$$\frac{dy}{dn}=\frac{(N-n)\sqrt{n}}{N-1}\left(\frac{1}{2n}-\frac{1}{N-n}\right). \qquad (15)$$

Equating the derivative with respect to n to zero and rejecting the values n = 0 and n = N the giving minimum, we find

$$N-n=2n,$$

or

$$n=\frac{N}{3}. \qquad (16)$$

Consequently, the interval of averaging even for linear evolution should not exceed 1/3 the length of the series.

If, however, evolution has a more complicated character, then, by dividing series into sections within which the evolution can be considered rectilinear, it follows for every such section to have not less than three averaged values.

In this work to ensure the maximum comparability with the main part of the material, n most frequently was taken equal to 10. The ten-year period leaves in the series many interesting parts of the secular variation and therefore is acceptable in first approximation. However, with great variability of temperatures in certain seasons in defined regions, averaging over 10-year periods was found to be insufficient to ensure the necessary sensitivity of criterion $\frac{D_k(10)}{\sigma_D(10)}$, then there were used larger periods of averaging (examples are given in subsequent chapters of the work).

The course of quantities $D_k(n)$ accurately reproduces the course of the actual quantity x in appropriate averaging, and only changes are counted off not from the average for the whole series but from the initial level of the series. In those cases when the initial level of reading will be far apart from the average level of the series, this has decisive importance in the increase in sensitivity of the introduced criterion.

If one were to take reading of deviations not from the initial level of the series but from the average for the whole series, then the criterion should be converted accordingly. Similar replacement reduces twice the modulus of the greatest deviations in the case of linear evolution of the level of the series, which on the level of significance is felt extremely great, and sometimes it is increased hundreds of times. For example, if changes in $D_k(n)$ reach $4\sigma_D(n)$, then deviations from the average will lie within $\pm 2\sigma_D(n)$, but the level of significance of the yield for 4σ for the for the normal law of probability distribution is 0.0064%, and for 2σ – only 4.55%; therefore, if one were to use the criterion without some changes, the sensitivity of it will decrease 700 times.

It is true that by modifying criterion it is possible and in this to improve the position considerably. Thus in last case the series will twice approach the extreme values, in beginning and at the end. The probability of coincidence of similar moduli of deviations will already be $(0.0455)^2 \cdot 100\% = 0.207\%$.

Such a procedure anew increases the sensitivity of the criterion 22 times, but there still remains a loss of 32 times, which actually will be still greater, since the probability of appearance of certain deviations should be multiplied by the total number of terms of the investigated series. Meanwhile such a case can appear when in the series instead of a systematic tendency of level there take place only great cyclical variations. In this case the initial section of the series can coincide with any phase of the cycle, including and with that close to the perennial mean value. Averaging in this case will help little since the averaged level will also approach the perennial average. Then for the initial level it is expedient to take the quantity of the cycle nearest to the beginning of the series. An analogous procedure can be applied when cyclical changes in the series are combined with systematic changes of the level. It is necessary to remember only that each such shift increases the probability of the random appearance of a great variation in differences the number of times corresponding to the number of years of the shift in the initial level of the series.

Somewhat better is the situation, if reading is conducted strictly from the average level of the series, since dispersion of deviations from the average are less than the dispersion of differences, and, consequently, for conditions introduced above,

$\sigma_{\bar{x}(n)} = \frac{\sqrt{2}}{2}\sigma_{D(n)}$ and $2\sigma_{D(n)} = 2{,}84\sigma_{\bar{x}(n)}$. The probability of yield for 2.84σ is 0.462%, which corresponds to the lowering of sensitivity of the criterion for the given case 70 times. If, however, for this case we again use the probability of double appearance of the given, then it will be equal to 0.0021%, i.e., three times less than with the application of the criterion $\frac{D^{(n)}}{\sigma_{D^{(n)}}}$.

If, however, we consider that this probability must be multiplied by the number of terms which are necessary to use on each border of the series in order to enter the section of the noticeable evolution level, then great benefit in the accuracy of the criterion cannot be obtained by this means, and the criterion itself is considerablycomplicated. It is easy to show that, without recourse to averaging in series, the linear evolution of its level on the basis of calculation of extreme values of deviation from the average, in general, cannot reliably be revealed.

Let us assume that the amplitude of variations of the series values, variable strictly linearly (random scattering is absent), will be 2a. Then

$$\sigma_x^2 = \frac{1}{2a}\int_{-a}^{+a} x^2 dx = 0{,}3332a^2 \text{ and } \sigma_x = 0{,}58a. \tag{17}$$

Consequently, under these conditions extreme values in the series, in general, cannot exceed the value $1.76\sigma_x$, and therefore calculation of deviations even on both ends of the series does not give an essential difference from chance. The low sensitivity of dispersion of the series to influences of systematic tendencies makes hardly acceptable the criterion of systematics proposed by Budyko and Yudinyy (1960). It is based on the average of σ_d^2 (on which systematic changes of level do not affect) and σ_x^2. By it the disturbance of the relation $\sigma_d^2 = 2\sigma_x^2$ with a change in the level is checked. It is true that for the case of a purely linear evolution of level, examined above $\sigma_d^2 = 0$, when $\sigma_x^2 \neq 0$ it immediately solves the problem, but, in general, the sensitivity of this method quickly drops with an increase in the influence on the level of the series of random factors, since σ_d^2 becomes within errors of that indistinguishable from $2\sigma_x^2$.

For example, for the same January temperatures in Leningrad $\sigma_x = 3.9°$, and the change in level from the end of the 18th Century was about 3.0°, hence $a = 1.5°$ or $0.58a = 0.72°$. Thus the total variability of terms of the series exceeds 5.4 times the influence on it of variations of the level. Contribution of the latter in the total dispersion will be, consequently, about 4%, which will cause divergence of the theoretical and actual values of σ_d only within 2%.

But the duration of observations at Leningrad is about 208 years, which gives $\frac{\sigma_{\sigma_d}}{\sigma_d} = 4.8\%$. Thus the divergence of theoretical and actual values of σ_d will lie wholly within the errors.

All of this once again confirms the rationality of the use of criteria founded on the calculation of evolution from the initial level of the series, which is one of the principles of sequential analysis. This principle in qualitative from was used even in the criteria of Veynberg, which have, nevertheless, greater sensitivity than criteria founded on replacement of the series by the totality, i.e., founded on comparisons of dispersion with extreme terms of the series and of analogous procedures. Let us consider the application of the above-stated method of analysis of systematics of variation of January temperatures in Leningrad as the same example. For the given case $\sigma_x = 5.6^\circ$, $\sigma_{D^{(10)}} = 1.75$. The course of quantity D_k is given in Table 5.

Table 5

Period	$D_k^{(10)}$	$\frac{D_k^{(10)}}{\sigma_D^{(10)}}$	Level of significant,[1] %
1815—24	3,4	1,94	5,24
1825—34	1,2	0,69	49,02
1835—44	2,5	1,43	1,52
1845—54	2,1	1,20	23,01
1855—64	3,0	1,71	8,73
1865—74	4,2	2,40	1,64
1875—84	1,8	1,03	30,30
1885—94	2,9	1,66	9,69
1895—04	4,6	2,63	0,85
1905—14	3,7	2,11	3,49
1915—24	3,3	1,88	6,01
1925—34	5,1	2,92	0,35
1935—44	1,7	0,97	33,20
1945—54	4,2	2,40	1,64
1955—64	4,9	2,80	0,51

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[1] In accordance with the established terminology, the sharper the distinction from chance are expressed, the lower the level of significance. Obviously, this is connected with the fact that in the term "level of significance" there is omitted its further continuation of "random phenomenon".

The course of values $\frac{D^{(10)}}{\sigma_{D^{(10)}}}$ corresponds to the combination of evolution of the level with random cycles. In accordance with this, although the indicated relations increase with time, in their course great variations take place; for example, in the decade of 1895-1904 the level of significance dropped to 0.85%; in the decade of 1915-1924 the level of significance was raised to 6.01% and again fell to 0.35% in the decade 1925-1934. Further, in connection with cold winters of end of the 1930's and beginning of the 1940's, the level of significance again reached 33.20%. The most "outstanding" (except chance) warming was in the decade of 1925-1934, indeed, and in the decade of 1955-1964 the level of significance was found close to its extreme value in the series (0.51%). Comparing data of Tables 4 and 3, it is possible to see that the sensitivity of the proposed criterion was found to be approximately 30 times more than the sensitivity of the criterion of Veynberg.

As will be shown in Chapter VI, by an increase in the period of averaging the sensitivity of the proposed criterion can be made even more considerable.

In present work the connection of cyclic recurrence of variations in the series of temperatures with solar activity is also analyzed. The distinctive peculiarity of heliogeophysical connections is the fact that they do not always appear and by not fully set causes can from time to time even change the sign of the connection. It is difficult to distinguish such a complicated form of the connection from random coincidence cycles close in average duration, and the danger of acceptance in similar cases of fictitious connections for real ones was indicated by Slutskiy (1935).

In the practice of investigation of the influence of solar activity on geophysical processes, there has long been used the probability distribution of certain phenomena by phases of the solar cycle, which permits considering statistical formsof the connection which are not even correlated. In this case it is expedient in phases of the solar cycle to disperse the extrema (or separately maxima and minima respectively) of the course of temperature curves. If the connection is real, then there should take place natural grouping of the probability of singular points of the temperature curve with respect to phases of the solar cycle, and it remains only to check the level of significance of deviations from the average level in the given grouping.

Let us assume that in m years of the solar cycle n cases of analyzed criterion are necessary. Then the probability of entrance of every case with the given criterion for a certain year of the solar cycle for chance of distribution of the given criterion will be equal to 1/m, and the average number of cases of combination of the given criterion with the corresponding year of the solar cycle will be n/m.

Tests are important on: a) the irregularity of distribution of the criterion (extrema) with respect to the solar cycle; b) the correlation of signs of the deviation in frequencies from probabilities within one phase of solar activity. A check on the criterion "a" can be made in the following way. The probability of incidences of k times or more of the criterion on a concrete year of the solar cycle is in accordance with the binomial distribution

$$P_k = C_n^{n-k}\frac{(m-1)^{n-k}}{m^n} + C^{n-k-1}\frac{(m-1)^{n-k-1}}{m^n} + \ldots + \frac{1}{m^n}. \qquad (18)$$

Since m = 11, the subsequent terms of the series, as a rule, quickly decrease as compared to the preceding ones, and most frequently it is possible to be limited in (18) by the first number of the expansion. If the probability of the appearance of the large value of k, observed in reality, is small, then this testifies to great probability of the nonrandom appearance of the given irregularity of the distribution of deviations of frequencies from probabilities. It is less profitable to make calculation determining $\sigma_{\frac{1}{m}}$, due to the asymmetry of distribution of deviations of frequencies from probabilities, but at small $\frac{n}{m}$ it is possible to estimate the probability of a certain grouping of the criterion according to the Poisson law:

$$p = \frac{\left(\frac{n}{m}\right)^k e^{-\frac{n}{m}}}{k!} + \sum_{k+1}^{\infty}\left(\frac{n}{m}\right)^i \frac{e^{-\frac{n}{m}}}{i!}, \qquad (19)$$

where terms of higher orders, as a rule, can be rejected.

With respect to criterion "b" one should estimate the probabilities of the appearance of large or, conversely, very small (for example, zero) numbers of the incidence of the criterion in a defined phase of the solar cycle. Then the probability of preserving the anomaly of one sign arriving on several adjacent years of the solar cycle (on assumption of a chance of its appearance) will be equal to the product of probabilities of these anomalies are practically equally probable, corresponding to the degree of probability of such an anomaly.

A check in the stability of coincidence of extrema of smoothed (over five years) variation in temperature for 80 years at the station Funshal showed that the cophasal and antiphase relationships of the variation in temperature and solar activity are encountered considerably more frequently than those of the intermediate values of shift phases. These distinctions are so important that they permit setting the great probability of the influence of solar activity on the level of temperatures in defined regions. Examples of similar relationships are given in Chapter V of this work.

It should be noted that in searching for similar connections huge amount of material is considered, and until the sought connection is found, then, naturally, there can be revealed very unlikely peculiarities of secular variation caused by action of random factors. However, if the tendency toward grouping of extrema is preserved in all cases, this will be an additional argument in favor of the reality of heliogeophysical connections, since with their accidental appearance the relationships of phases of variations in temperature and solar cycle should be arbitrary.

CHAPTER III

PERENNIAL VARIATION IN TEMPERATURE AT DIFFERENT PARTS OF THE EARTH FOR PERIOD OF INSTRUMENTAL OBSERVATIONS

1. Basic Results of Investigations of the Change in Air Temperature

Results expounded in Chapter I of the investigation of variations of different elements of climate indicate, on the one hand, the necessity of such information and, on the other hand, shown the limited possibility at present of using data on variations of the majority of basic meteorological indices without risk of obtaining disorienting results. Data on air temperature, one of the main climatic elements, suffer to a lesser degree from the deficiencies in observations mentioned in Chapter I, are comparable (with the appropriate climatological analysis) in scale of the entire Earth, and are at a great number of points. All of this is the reason air temperature is used as the basic index for investigations of variations in climate of large territories.

In the last two decades a number of works has been published devoted to the investigation of variations in temperature in a scale the entire Earth (see introduction). Let us give a brief survey of the results of these investigations.

Soon after termination of the Second World War there was published the investigation of Ye. S. Rubinshteyn (1946) on the presence and character of changes in climate, mainly one of its most important elements, air temperature. Investigations were conducted basically for the territory of the USSR, but in individual cases for revealing interrelationships data were used of certain stations of the northern and southern hemispheres. Analysis of the moving 10-year averages of annual temperatures (up to 1940) showed the presence of considerable variations, their coordination in large territories and a noticeable tendency toward lowering on the greater part of the northern hemisphere (north of 40° N. Lat.) in the last 10-year period, with the exception of North America where according to the data available then warming was not revealed.

Analysis of variations in thermal conditions in separate months for 54 stations of the northern hemisphere and 10 stations of southern hemisphere showed that warming is basically caused by the increase in temperature in January, November and December, and furthermore, the amplitude of variations in the winter months are considerably greater than those in summer. The absence of synchronism is clarified of variations between regions of Iceland, Western Greenland and northwest USSR, despite the fact that in these regions warming was the most noticeable.

Lysgaard (1949), in his investigation, conducted a detailed survey of works on variations in climate (more than 500 names) and gave a picture of the change in temperature in January, July and on the average for the year on Earth, using data of all stations having a long series of observations prior to 1940. He, just as Ye. S. Rubinshteyn, showed that warming in January was the greatest in Greenland and on Spitsbergen, and to the south warming decreased or did not appear at all. In part of the southern hemisphere, especially in Southeast Asia and Australia, in January a lowering of temperature was observed. In July the greatest temperature rise took place in Finland, Northern Scandinavia, the central regions of Canada and the United States, and also in Australia and South America; a decrease in the July temperature was observed in Central and Southern Asia.

A year later there emerged the work of Willett (1950), in which he tried to estimate the total planetary temperature tread, using data of observations of about 100 stations located for the most part in the northern hemisphere during the period of 1880-1939. For investigation Willett applied the method of zonal averaged temperature trends.

Zonal integrated trends were determined by means of calculation of differences between consecutive 5-year mean temperatures for stations distributed as far as possible evenly over the earth's surface. Then the obtained differences were grouped by 10-degree latitudinal belts and were averaged for every belt; integral sums of these averaged differences were accepted as a measure of the change in temperature between consecutive 5-year periods in the given latitudinal belt. Such a method, in the opinion of Willett reduces to a minimum the influence of heterogeneity of the series of observations at certain stations. Mean trends – planetary and by hemispheres – were established by the corresponding weighted averaging of data of 10-degree latitudinal belts.

Willett found that from 1885 there was observed a considerable tendency in the increase in winter and annual temperature, which is unequal over different parts of the planet. A tendency of temperature rise was about 1°C in winter and about 0.5°C as an average for the year, where it is more clearly expressed in the high latitudes of the northern hemisphere; in the polar latitudes of the southern hemisphere the presence of a negative trend is assumed.

Mitchell (1961, 1963) continued the investigations of Willett in more extensive (over 200 stations) material, augmented by observations of the subsequent 20 years. This gave to the possibility to ascertain the presence of the planetary trend of warming, which in the 1940's changed sign, i.e., there began a temperature drop, although in certain regions the temperature rise still continues. With this regions of especially intense warming prior to the 1940's turned out to be regions of a rapid temperature drop in subsequent years.

On Fig. 5 a graph is reproduced from this work of Mitchell, depicting the trend of mean annual and winter temperatures in the northern and southern hemispheres. On graph there is seen good coordination in the course and magnitude of change of the mean annual temperature (about 0.4°C for 60 years) in both hemispheres. In the winter period the magnitude of the trend in the northern hemisphere (0.5°C) exceeds more than twice that of the trend in the southern hemisphere (0.2°C). Especially interesting is the increase in annual temperature in the tropics (30 N. Lat. to 30 S. Lat.), which had the same order (0.5°C for 60 years), as that for the hemispheres. On the whole the method of determination of zonal-integrated trends applied and Mitchell is fully correct, and the obtained results, as Mitchell showed, have sufficient statistical significance.

However, as Mitchell himself notes, zonal integrated trends cannot be representative for all longitudes inside the latitudinal zone. Maps constructed by Mitchell of differences in annual and winter temperatures for consecutive 20-year (1920-1939 and 1940-1959) and 10-year periods (1940-1949 and 1950-1959) showed, how poorly the planetary trend is correlated with trends in separate geographic regions. It was possible to judge this from results of preceding investigations of Rubinshteyn, Lysgaard, Prohaska and others, who indicated the different character in variations in climate in various areas of the Earth.

Simultaneously with that of Mitchell, Callendar (1961) published an investigation on fluctuations in temperature and their trends on the Earth. He used data on mean annual temperatures of 400 stations on the Earth prior to 1950 averaged by moving 5-year periods. Deviations from the mean for the period 1901-1930 were used by him for calculation of trends of fluctuations in temperature of individual countries or regions; the weighted means (according to the area) for these regions give zonal or planetary trends of fluctuations in temperature.

As a result Callendar, similar to Mitchell, arrived at conclusion about the general trend toward the increase in temperature from the Arctic to 45° S. Lat. Results of investigations of the planetary trend of Willett, Mitchell and Callendar in general coincide, in spite of the different approach to the estimate of zonal and planetary trends; this is clearly shown in Table 6, taken from the work of Mitchell (1963).

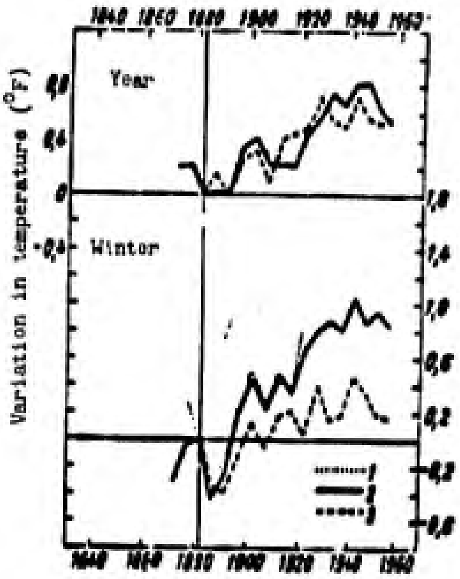

Fig. 5. Trend of the change in 5-year mean temperatures in different latitudinal zones (after Mitchell). 1) 0-80° N. Lat.; 2) 0-60° N. Lat.; 3) 0-60° S. Lat.

Despite the fact that in the examined works differences are given of mean annual temperatures for not fully coinciding 30-year periods and latitudinal zones, the magnitudes of these differences well enough agree and indicate a general trend (from 60° N. Lat. to 50° S. Lat.) toward warming in the last (up to 1950) 30-year period.

Similar results can be of great importants in the solution of many problems of the theory of climate and causes of its variations, if the trends of fluctuations in heat balance of the atmosphere are determined and vertically, i.e., in three measurements.

However, just as the mean annual temperature conceals peculiarities of the distribution of it in seasons of the year, the planetary trend of fluctuations of temperature camouflages their great diversity in various areas of the Earth.

Investigations of fluctuations in temperature for every month of the year show how they can differ in individual months. Therefore, for example, it is impossible to judge the character of fluctuations in temperature in the winter period in January and in summer in July, although these months most frequently appear in investigations as representatives of main seasons of the year.

In connection with this it is expendient to investigate variations in temperature by months of the year for the whole Earth. This makes possible to present the actual picture of variations in temperature in a space-time aspect, without knowledge of which it is impossible sufficiently to base any hypotheses on causes of variations in temperature and their trends.

Table 6. Differences Δ of Mean Annual Temperature (°F) Between the 30-year Periods of 1891-1920 and 1921-30

Zone	After Callendar		After Willett and Mitchell	
	latitude	Δ	latitude	Δ
Planetary	60° N. Lat.-50° S. Lat.	+0.41	60° N. Lat.-50° S. Lat.	+0.37
Moderate north	60° N. Lat.-25° N. Lat.	+0.70	60° N. Lat.-30° N. Lat.	+0.64
			60° N. Lat.-20° N. Lat.	+0.57
Tropical	25° N. Lat.-25° S. Lat.	+0.31	30° N. Lat.-30° S. Lat.	+0.35
			20° N. Lat.-20° S. Lat.	+0.39
Moderate south	25° S. Lat.-50° S. Lat.	+0.25	20° S. Lat.-50° S. Lat.	+0.10
			30° S. Lat.-50° S. Lat.	+0.08

NOTE: Callendar's data are for 1891-1920 and 1921-1950, and the data of Willett and Mitchell for 1890-1919 and 1920-1949.

In the following section of this chapter results are given to the investigation of variations in temperature for all months and for the year according to data of continental and insular stations of the Earth.

2. Method of Analysis of Data and the Form of Its Presentation

As a result of investigations conducted at the Main Geophysical Observatory (Rubinshteyn, 1946, 1956; Polozova and Rubinshteyn, 1963) of variations in air temperature, there has been accumulated extensive data containing a series observations on temperature analyzed from the point of view of homogeneity, and graphs of 10-year mean monthly temperatures for all months and the year at 240 stations of the Earth.[1] This enormous graphic material (over 3000 graphs) was possible to systematize, considering that considerable variations in temperature, caused by atmospheric processes of large scale, spread over considerable territories, as was shown even in the first work of Rubinshteyn (1946).

With a comparison of graphs of the variation in temperature in high and moderate latitudes of the northern hemisphere there is distinguished a series of rather extensive regions, inside of which variations in temperature in broad terms are synchronous during the investigated period of the observations (basically during 70-80 years). In lower (farther south than 40-35° N. Lat.) latitudes variations in temperature are less considerable, and as a rule, are non-synchronous, so therefore it is possible to examine here only a general trend of the change in temperature at selected stations, about which will be discussed further.

Since for the investigation of variations in temperature there are used, as a rule, only stations with long series of observations; naturally, in Europe one region covers up to ten stations, while in other parts of the northern hemisphere one region of the same area is united by a smaller number of stations.

It is understandable that between regions of synchronous variations in temperature there cannot be clear-cut lines; these regions are divided by sections of the transition type of variations. This is revealed where there is a dense network of stations. For example, in January between regions of Northern and Southern Europe (without the western seacoast) there is a zone which is intermediate between these two types of variations (approximately along 54-56° N. Lat.).

Separating regions of synchronous variations in temperature is not only important essentially, but it also considerably facilitates the problem of presentation in this work of results of the investigation of variations in temperature on the Earth.

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[1] Data were used from the beginning of continuous observations up to 1960 and where there were data up to 1963 and 1964.

The fact is that graphs of perennial variations in temperature are a form of presentation of data on the character of these variations but are not illustrative material. However, the placing in the present work of all 3000 graphs would burden it too much and considerably hamper the analysis of these graphs.

The grouping of stations by regions of synchronous variations makes it possible to give curves of the variation in temperature of one or two datum stations, as which stations with sufficiently uniform prolonged series of observations for each region are selected.

3. Regions of Synchronous Variations in Temperature (Northern Hemisphere)

A list of stations, united into regions of synchronous variations of temperature,[1] is given in Table 7.

In the first column of this table the number of regions is given. Numeration was produced from west to east starting from northwestern Europe. Borders of the regions are changed depending upon seasons and even months of year, and therefore in the line of every station of Table 7 for every month there is entered the number of region in which station is found at different months of the year.[2] If two figures are in series, for example, in February Berlin 2, 3, this means that the curve shape of variations in temperature was intermediate between characteristic curves of regions 2 and 3, i.e., Berlin is in a given month in the transition zone between these regions. In certain months one region, according to the character of the variation in temperature, is divided into two subregions or more; in these cases in series with the number of region are placed the letters a, b, c; for example, region 1 in May has two more subregions, 1a and 1b; region 3 in April, 3a and 3b, etc. Sometimes in Table 7 near their number there is the asterisk sign (*), which designates insufficiently good coordination of the variation in temperature at the given station with the variation at the datum station of the region.

If the variation in temperature at some station, in general, did not coincide with the variation in temperature weather in given region nor in a neighboring one, then in Table 7 a line was given. Datum stations in the table are given in italics. As can be seen from Table 7, almost in all the regions are separated stable "range of operation" of synchronous variations in temperature around bench mark stations in all months of the year and peripheral for the given region of the station, which according to the type of variations at different months pertain first to their own region, then to the neighboring one or have a transition type of variations.

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[1] Subsequently, for brevity we will call these simply regions.

[2] It is necessary to emphasize that the number of the region is preserved for all months of the year, but this does not indicate synchronism of variation in all months of the year; in all the the analyzed data there was not one case of synchronism perennial variations even in adjacent months of the year.

Table 7. Regions of Synchronous Variations of Mean Monthly Air Temperature

[illegible]	Stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
(a)1	Вардё	1*	1*	—	1	1б	1	2б	1	1	1a	1	1
	Кола	1	1	1	1	1a	1	1	1	1	1	1	1
	Канин Нос	1	1	1	1	1a	1	1	1	1	1	1	1
	Скомвер	1*	1*	—	1a	1б	2	—	1	1	1a	1	1
	Тронхейм	1*	1*	1a	1a	1б	1	1	1	1	1a	1	1
	Хапаранда	1	1	1	1a	1	1	1	1	1	1a	1	1
	Кемь	1	1	1	1	1	1	1	1	1	1	1	1*
	Архангельск	1	1	1	1	1	1	1	1	1	1	1	1*
	Ленинград	1	1	1	1a	1	1a	1	1, 3	3	1a	1	1a
	Мандаль	1*	1*	1a	1a	2a	1a	1	1, 3	1*	1a	1	1*
	Упсала	1	1	1a	1, 2	2*	1a	1	1, 3	3	2	1	1a
	Рига	1	1, 3	1, 3	1a, 3	1	1a	1, 3	1, 3	3	1a	1, 3	1a
	Троицко-Печорское	1*	7	7	1	3a	1	3	3	1	1a	1, 1a	3a, 4
(b)2	Дублин	2	2	2	2	2	2	2	2*	2	2	2	2
	Валенсия	2*	2	2	2	2б, 4	2	2	2	2	2	2a	2
	Гринвич	2	2	2	2	2	2	2	2	2	2	2	2
	Нант	2	2	2	2	2	2	2	2	2	2	2, 3	2
	Париж	2	2	2	2	2	2	2	2	2	2	2, 3	2
	Марсель	2	2	—	2	2*	2	2	2, 3	—	—	—	—
	Мадрид	—	—	2	2	2	2*	—	—	2	—	—	—
	Утрехт	2	2	2	2	2, 1	2*	2	2	2	2	2	2
(c)3	Копенгаген	1	2	1a, 2	1, 2	—	—	—	1, 3	3	1, 3	1, 3	1a
	Вильнюс	1, 3	1, 3	1, 3	3	1	1a	3	3	3	1a	3	3
	Берлин	3	2, 3	2*	1, 2, 3	3	1a	2, 3	3	2, 3	2, 3	3a	3
	Вена	3	2, 3	2, 3	3a	3	3	3	2, 3	2, 3	2, 3	3a	3
	Загреб	3	2, 3	2, 3	3a	1	3	3	2, 3	2, 3	2, 3	3a	3
	София	3	2, 3	2, 3	3	1	3	3	2, 3	3a	1a	3a	3*
	Киев	3	3	3	3	1	1б	3	3	3	1a	3	3
	Богородицкое-Фенино	3	3a	3, 4	3	3	1б, 4	3	3	3	1a, 3	4*	4
	Одесса	3	3a	3	3	1	1б	3	3	3a	1a	3	3
	Луганск	3	3a	3	3б	3	1б	3	3	3	1a	4	3a
	Октябрьский городок	3	3a	3a	3б	3	1б	3	3	3	1a	4	3a
(d)4	Оренбург	4*	4*	3a	3б	3a	—	3*	3	3	1a	4	3a
	Тотьма	1, 3	1, 4	1	4	1, 4	1, 1a	4	4	4	1, 4	1, 4	4
	Москва	1, 3	4	4	3	3	1б, 4	3	3	3	1a	4	3a
	Киров	1, 3	1, 4	4	1, 3	1, 3	1, 4	1, 4	1, 4	4	1a	4	4
	Казань	1, 3	4	4	3	3	4	3	3	3	1a	4	3a
	Свердловск	3*	4*	3a	3б	3г	—	3*	3	3	1a	4	3a
(e)5	Форт-Шевченко	5	5	5, 6	5	5	5	5	5	5	5	5	5*
	Поти	5	5	5	5	5	5*	5a	5	5	5	5	5
	Тбилиси	5	5	5	5	5	5	5	5	5	5	5	5
	Баку	5	5	5	5	5	5	5a	5*	5	5	5	5
	Махачкала	5	5	5	5	5*	5	5	5*	5	5	5	5
(f)6	Целиноград	6, 6	—	6, 7	6, 7	7	6*	7*	—	6	6	7*	6, 6
	Казалинск	6	6	6	6	6	6	6	6*	6	6	6	6
	Кзыл-Орда	6	6	6	6	6	6*	6	6	6	6	6	6
	Ташкент	6	6	6, 5	6	6a	6a	6a	6	6	6a	6a	6
	Байрам-Али	6	6, 5	6, 5	—	6a	6a	6a	—	—	6a	6a	6
(g)7	Бухта Тикси	7a	—	—	—	1a	1	7a	1	7a	—	7	7
	Мыс Желания	7a	—	—	—	1a	1	7a	1	7a	7a	7	7
	Мыс Челюскин	7a	7	7	7a	7	7	7a	7a	7a	7a	7	7
	Малые Кармакулы	7a	7	7	7a	1a	—	1, 7	7a	7a	7a	1	7
	Диксон	7a	7	7	7a	7	7	7a	7a	7a	7a	7	7
	Хатанга	7a	7	7	7a	7	7	7a	—	7	7a	7	7
	Салехард	1*	7*	7	7a	7a	7	1, 7*	1, 3	7	7	1a	3a*

Table 7. Regions of Synchronous Variations of Mean Monthly Air Temperature (Con't)

Number of the region	Stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Туруханск	7	7	7a	7	7	7	7	7	7	7	7a	7
	Тарко-Сале	7	7	7	7	7	7	7	7	7	7	1a	7
	Сургут	1, 4	7	7	7*	7*	7, 8	7*	7	7	7	1a, 4	3a*
	Тобольск	4	7	7	3б	—	8	1, 7	7, 3	7	7	4, 1a	3a
	Тура	7	7	7	7	7	7	7	—	7	7a	—	7
(h)8	Енисейск	8	8	7	7	7	8*	7	7	8	8	7	7
	Томск	8	8	7	7	7	8	7	7	8	8	7	8
	Барнаул	8	6	7	7	7	8	7	7	8	8	8	6, 8
	Киренск	8	9	7	7	7	8*	—	7	8	8	7	7, 8
	Иркутск	9	9*	7	7	12	—	—	7	8	8	7	8
(i)9	Олекминск	—	—	—	8	—	9*	9	—	9	9	—	9a
	Жиганск	9	7	9*	9	7	—	—	—	—	9	9	9
	Кюсюр	9	9*	9*	9	9	9	9	9	9	9	9	9a
	Верхоянск	9	9	9	9	9	9	9	9	9	9	9	9a
	Якутск	9	9*	9	9	9	9	9	9*	9	9	9a	9
	Вилюйск	9	9	9	9	9	9	9	*	9	9	5a	9
	Среднеколымск	9	9, 10	9	9	9	10	10	9	9	—	9	9a
	о. Котельный	10	10	—	9	10	9	9	9	9	9	9	9
(J)10	о. Четырехстолбовой	10	10	10, 9	10	10	9	10	10	10	10	9	10
	о. Врангеля	10	10	10	10	10	10	10	10, 9	10	10	9	10
	Уэлен	10	10	10	10	—	10	10	10	10	10	9	10
	Анадырь	10	10	10	10	10	10	10	9	—	—	—	—
(k)11	Никольское	11	11*	11	11	11	—	11*	—	10	11	11	11
	Петропавловск-Камчатский	11	11	11	11	11	11	11	11	11	11	11	11
	Ключи	11, 11a	11	11*	11a*	11	11	—	11a	12a	—	11*	11*
	Охотск	11, 11a	11	9	11a	11	11, 10	—	11a	—	9	11	11
	Аян	11a	11	11	11a	11	11	11	11a	12a	9	11a	12a
	Александровск-на-Сахалине	11a	12	12	11*	12a	12a	11a	11a	12	11a	11a*	12*
(l)12	Бомнак	11a	12	9	7, 9	12a	12*	12	—	12a	9	11a	12a
	Благовещенск	—	12	9	7	12a	12	12	12*	12a	9	12a	12a
	Николаевск-на-Амуре	—	12	12	11*	11a*	12a	11a	12a	12*	11a	11a	12*
	Владивосток	12	12	12	12	12	12	12	12	12	12	12	12
	Нерчинский Завод	12*	12*	12	7	12a	12*	12a	12*	9	9	12a	12a*
(m)13	Барроу	13	13	13	13	13	13*	13a	10	13a	13a	13	13a
	Доусон	17	13	13	13	13a	13	13	10	—	13	13	13
	Гуд-Хоуп	17	13	13	—	13a	10	13a	10	13	13	13	—
	Бетел	—	13	9	13	13	10	13*	13*	13	13*	13a	13
	Танана	13	13	9	13	13	10	13	13	13	13	13a	13
	Фербенкс	13	13	9	13	13	10	13	13	13	13	13a	13
	Ном	13	13	9	13	10*	10	13, 10	13	—	13a	13*	13a*
(n)14	Кадьяк	14	14	14	14	13*	14	14	14	14	14	14	14
	Ситка	15	—	15	14	13*	13*	14*	—	14*	15*	14*	13*
	Датч-Харбор	14	14*	14	14	—	14*	—	14	—	14*	—	—
(o)15	Мессет	15	13	15	15	15	—	—	15	15	15	—	15
	Виктория	15	—	15	15	15	—	—	15	15	15	15	15
	Бойсе	15	—	15	15	15	—	—	17	—	—	15a	15
(p)16	*Лос-Анжелес*	15	15	16	15	16	16	16	16	16	16	—	16
	Сан-Диего	15	15	16	15	16	16	16	16a	16	16a	—	16
	Эль-Пасо	16	15	16*	15	16	16	16	16	—	16a	—	16*
	Юма	16	—	16	—	16	16	16	16	16	16a	—	16
(q)17	Мусони	17	17	19a	18б	—	17	—	18	—	—	17	—
	Виннипег	17	17	17	17	17	17	17	17	17	17	17	17
	Омаха	17	17	17	17	17	17a	17	17*	—	17	17	17
	Кью-Эппел	17	17	17a	17	17	—	17	17	17	17	17	17
	Шеридан	—	17	—	15	15a	17a	17	15a	17a	17a	—	15
	Эдмонтон	17	17	17a	—	17	—	—	15	—	—	—	—
	Амарилло	—	17	17, 16	15*	17	17a	17	17	17a	17a	—	15*

Table 7. Regions of Synchronous Variations of Mean Monthly Air Temperature (Con't)

Number of the region	Stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
(r)18	Ашвилл	18	17	18a	18a	18a	18	18a	18a	18a	18a	18a	18a
	Хаттерас	18	17	18a	18a	18a	18	18a	18a	18a	18a	18	18a
	Чарлстон	18	—	18*	18a	18б	—	18a	18a	18a	18a	18a	18a
	Новый Орлеан	18	—	18	—	18б	—	18a	18a	18a	18a	18a	18a
	Шарлоттаун	18	18	18*	18a	—	18	—	—	—	—	18	—
	Ньюпорт	18	—	18	18a	18	18a	18	18	—	18	18	18
	Сейбл	18	18	18	18	18	18a	18	18	—	—	18	—
	Блу-Хилл	18	18	18	18	18	18	18	18*	18	18	18	18
	Нью-Хейвен	18	18	18	18	18	18	18	18	18	18	18	18
	Торонто	18	18	18	18б	17	18б	18	18	18	18	18	18
	Маркет	—	—	17	18б	17	18б	18	18	—	18	17*	—
	Монреаль	18	18	18	18б	17	18б	—	18	18	18	18	18
(s)19	Арктик-Бей	19a	19	—	19	—	—	—	19	19	—	19	19a
	Уперневик	19	19	19	19	19	19	19	19a	19	19	19	19
	Якобсхавн	19	19	19	19	19	19	19	19	19	19	19	19
	Готхоб	19	19	19a	19	19	19	19	19	19	19	19a	19a
	Ивигтут	19	19	19a	19	19	19	19	19	19	19	19a	19a
	о. Резольюшен	19a	19	19, 19б	19	—	19	19	19	19	19	19a	19a
	Черчилл	19a	19	19б	18б	—	17	19	17	19a	19a	17	19б
	Честерфилд	19a	19	19б	18б	17*	17	19	19	19a	19a	17	19б
(t)20	Ангмагссалик	19a, 20	20a	19, 19a	19	20	20	20a	2	19	—	—	19
	Мюггбукта	20	20a	20a	19	20	20	20a	1	19	20	20a	20
	Ян-Майен	20	20a	20a	19	20	20	20a	1	20	20	20a	—
	Гримсей	20	20	20	20	20	20	20	2	20	20	20	20
	Стиккисхоульмур	20	20	20	20	20	20	20	2	20	20	20	20
	Торсхавн	20	—	20a	2	20a	—	—	2	20	20	20a	20

KEY: Table 7. (a) Varde; Kola; Kanin Nos; Skomvaer; Trondheim; Haparanda; Kem'; Arkhangel'sk; Leningrad; Mandal; Upsala; Riga; Troitsko-Pechorsk; (b) Dublin; Valencia; Greenwich; Nant; Paris; Marseille; Madrid; Utrecht; (c) Copenhagen; Vilnius; Berlin; Vienna; Zagreb; Sofia; Kiev; Bogoroditskoye-Fenino; Odessa; Lugansk; Oktyabr'shiy Gorodok; (d) Orenburg; Tot'ma; Moscow; Kirov; Kazan; Sverdlovsk; (e) Fort Shevchenko; Poti; Tbilisi; Baku; Makhachkala; (f) Tselinograd; Kazalinsk; Kzyl-Orda; Tashkent; Bayram-Ali; (g) Bukhta Tukhaya; Mys Zhelaniya; Mys Chelyuskin; Malyye Karmakuly; Dikson; Khatanga; Salekhard; Turukhansk; Tarko-Sale; Surgut; Tobol'sk; Tura; (h) Yeniseysk; Tomsk; Barnaul; Kirensk; Irkutsk; (i) olekminsk; Zhigansk; Kyusyur; Verkhoyansk; Yakutsk; Vilyuysk; Srednekolymsk; Kotel'nyy Island; (j) Chetyrekhstolbovoy Island; Wrangel Island; Uelen; Anadyr'; (k) Nikol'skoye; Petropavlovsk-Kamchatskiy; Klyuchi; Okhotsk; Ayan; Aleksandrovsk on Sakhalin Island; (l) Bomnak; Blago-veshchensk; Nikolayevsk on Amur; Vladivostok; Nerchinskiy Zavod; (m) Barrow; Dawson; Good Hope; Bethel; Tanana; Fairbanks; Nome; (n) Kodiak; Sitka; Dutch Harbor; (o) Masset; Victoria; Boise; (p) Los Angeles; San Diego; El Paso; Yuma; (q) Mussonee; Winnipeg; Omaha; Qu'Appelle; Sheridan; Edmonton; Amarillo; (r) Ashville, Hatteras; Charleston; New Orleans; Charlottetown; Eastport; Sable Island; Blue Hill; New Haven; Toronto; Marquette; Montreal; (s) Arctic Bay; Upernavik; Jakbshavn; Gothob; Ivigtut; Resolution Island; Churchill; Chesterfield; (t) Angmagssalik; Myggbukta; Jan Mayen Island; Grimaey; Stikkisholmur; Torshavn.

The stablest range of operation of synchronous variations is distinguished in all months of year in these regions: 1 – northwestern Europe, 2 – Great Britain and northern France, 5 – Transcaucasus and Caspian Sea regions, 6 – south of Central Asia.

The presence of a stable range of operation in the area of which variations in temperature are synchronous in each month of the year during 70-80 years is caused perhaps by the stability of the space localization of influences causing perennial variations in temperature in these regions. On the periphery of such regions the intensity and directivity of influences are changed, which leads to a migration of stations, i.e., to the adjoining of them by form of variations first to one, then the other region.

Influences directly causing perennial variations in temperature can be in the first place peculiarities of circulation of the atmosphere; and stable regions of synchronous variations are nodal regions of trajectories of such influences. With any directivity and intensity of them they pass through these nodal regions during the period of the entire period of observations.

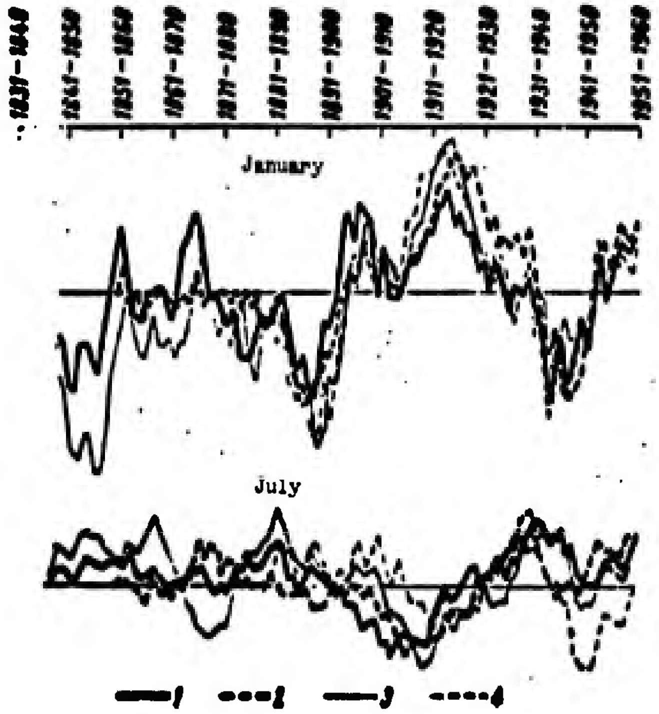

Fig. 6. Moving 10-year mean temperatures. January. 1 – Kiev, 2 – Vienna, 3 – Lugansk, 4 – Octyabr'skiy Gorodok.

It is necessary once again to emphasize that the variation in perennial variations in temperature at various months has the most diverse form, and in one not region are there two neighboring months in which variation would be identical. Even greater importance is the space stability of variations in considerable territories: this to some degree facilitates the still unsolved problem of the investigation of causes of variations in temperature

Table 8. Coefficients of Correlation Between Moving 10-year Mean Temperatures for the Period 1881-1960 Station Kiev and Other Stations

Month	Vilnius	Vienna	Sofia	Odessa	Lugansk	Octybr'skiy Gorodok	Orenburg
I	0,76	0,65	0,64	0,77	0,90	0,91	0,80
VII	0,68	0,88	0,73	0,62	0,86	0,87	0,86

and the setting of their trends.

From Table 7 it is possible also to see that on seacoasts of the Pacific Ocean regions of synchronous variations in temperature are actually not separated. Here weak coordination is observed in the course of temperature even between not too remote stations as, for example, Okhotsk and Ayan, Petroplavlovsk-Kamchaskiy and Klyuchi, Kodiak and Sitka and Victoria and Masset. This, apparently, is connected with peculiarities of circulation in the frontier areas of monsoon regions of moderate latitudes (this pertains to the first two pairs of stations) in combination with great distinctions in the form of relief and possibly with the quality of observations. This question requires further investigation.

In finishing the analysis of the table of regions, let us illustrate the synchronism of variations in temperature in region 3, combining graphs of moving 10-year mean temperatures at main stations of the region for January and July (Fig. 6). On this figure general features are quite distinctly expressed in the perennial variation in temperature at stations distant from each other by thousands of kilometers.

The relationship between 10-year mean temperatures of datum and other stations of the examined region is expressed by the quite high coefficients of correlation, which are given in Table 8 for several stations of region 3.

As calculations showed, coefficients of correlation in January and July are, as a rule, one order, although the amplitude of variations in temperature in winter is more considerable.

Subsequently, it is assumed one most obtain quantitative criteria for more precise definition of borders of regions in all months of the year.

4. Analysis of the Variation in Temperature in Regions of Synchronous Variations

Figures 7-19 give graphs of moving 10-year mean air temperatures for bench mark stations of regions distinguished in the northern hemisphere. Knowing what interest for numerous researchers of variations in climate there is in such data, we set the graphs for all months of the year. As a rule, stations were used with series of observations of 70-80 years, but where the series were longer data were used from the beginning of continuous observations. In regions, of few observations, as an exception data of stations with 30-40 year series of observations were used.

With the setting of borders of regions sometimes there were used series with a disturbance of homogeneity, if the form of curves of variation in temperature of such stations differed little from the curve of variation of the bench mark station.

From the stations enumerated stations used in every region, on the graphs (Fig. 7-19) moving mean temperatures of 32 datum stations are represented. One should note that on the figures the order of the location of the stations somewhat changes from month to month depending upon community of trends in variation in temperature in different regions.

Year. An analysis of perennial variations in temperature is expediently started from the consideration of annual quantities as resultant and giving presentation about the general trend of variations in temperature. One should not forget, moreover, that the peculiarities discussed below of variation in temperature of bench mark stations pertain to all stations of the region.

In examining of Fig. 7a-7d it easy to note the well-defined trend toward the increase in temperature at stations of high latitudes (60-70 N. Lat.) from the beginning of the observations (for the most part since 1881), and according to data of Leningrad, for example, where there is a continuous series of observations since 1805, the increase in temperature started from the middle 70's of the last century. The most intense warming was observed in the northwest part of Greenland (Upernavik). Here even the smoothed over a 10-year mean annual temperature for 45 years was raised 4°. Culmination of warming was observed in the beginning of the third (1927-1936) decade of the 20th Century. This is the earliest date of the change in the sign of the annual trend in high latitudes of the northern hemisphere. In subsequent years level of variations in temperature dropped prior to 1960. As was already noted in the work of Polozova (1963), in the eastern half of the North Atlantic (Skomvar, Tondheim, Jan-Mayen) the greatest warming approached somewhat later (1929-1938), after which the variation in temperature shows a well-defined trend toward a temperature drop, but not so intense as with the preceding warming.

Turning to an examination of variation in annual temperature on northern stations of the Soviet Union (from 60 N. Lat.), it is possible to note that at leningrad the peak[1] of warming belongs to the same years as in the eastern part of the Atlantic. But further eastward this peak is displaced to later years. Thus at Turukhansk, the most eastern of stations with a long series (at Yakutsk and Verkhoyanske there are many omissions in data on mean

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[1] For brevity the peak of warming will be the 10-year period of greatest warming.

annual temperatures), the peak of the increase in annual temperature is noted in the decade of 1936-1945 (Fig. 7a).

In the eastern part of Soviet Union in high latitudes there are not stations with a sufficiently long period of observations. But, judging by data of stations with comparatively short series (Srednekolymsk and Uelen), confirmed by data of sufficiently prolonged observations of the station at Nome (Alaska), eastward from Turukhansk the displacement of the peak in warming ceased, and at the stations mentioned it is noted even a little earlier (1934-1943).

At Dawson (Canada) a peak of the increase in annual temperature in the decade of 1936-1945 is again observed.

The character of the lowering of temperature after the indicated periods of its culmination is similar at all stations of high latitudes with the exception of Leningrad prior to 1960. In Leningrad the trend toward lowering is maintained from the decade of 1931-1940 to 1940-1949, after which the temperature anew started to increase. A secondary maximum is only 0.5° lower than the main one, and further temperature variation does not have a clearly marked trend.

To the south of 60° N. Lat. in moderate latitudes at stations of Eurasia, from Greenwich to Barnaul, there is observed a tendency toward an increase in annual temperature up to recent years (Fig 7c). Judging by stations with a long series of observations, the beginning of this stable trend in the western regions can be referred to the end of last century (Greenwich), and eastward this date is displaced by earlier years (Kiev — 1870's, Sverdlovsk and Barnaul — from the beginning of observations, i.e., the 1840's), but at Vladivostok the beginning of a stable increase in temperature again shifts to the beginning of the current century.

One should specially examine the region with the bench mark station of Moscow. The configuration of the curve of variation in temperature here is very similar to the curve of Leningrad (Fig. 7a) up to the decade 1939-1948, after which the temperature in Moscow began to increase and in recent years (1956-1965) reached a level of the peak of warming of 1929-1938. Thus the variation in annual temperature in the region represented by Moscow unites the lines of two regions (first and fourth). As will be shown below, the variation in temperature in this region in different months has an intermediate, transitional character.

Regarding the variation in annual temperature in moderate latitudes of North America, here there is not observed a general trend in variations in temperature of different regions as takes place in Eurasia.

If the region of the eastern seacoast represented by the station New Haven, in form of the variation in temperature has common features with regions of high latitudes but with a shift of the peak

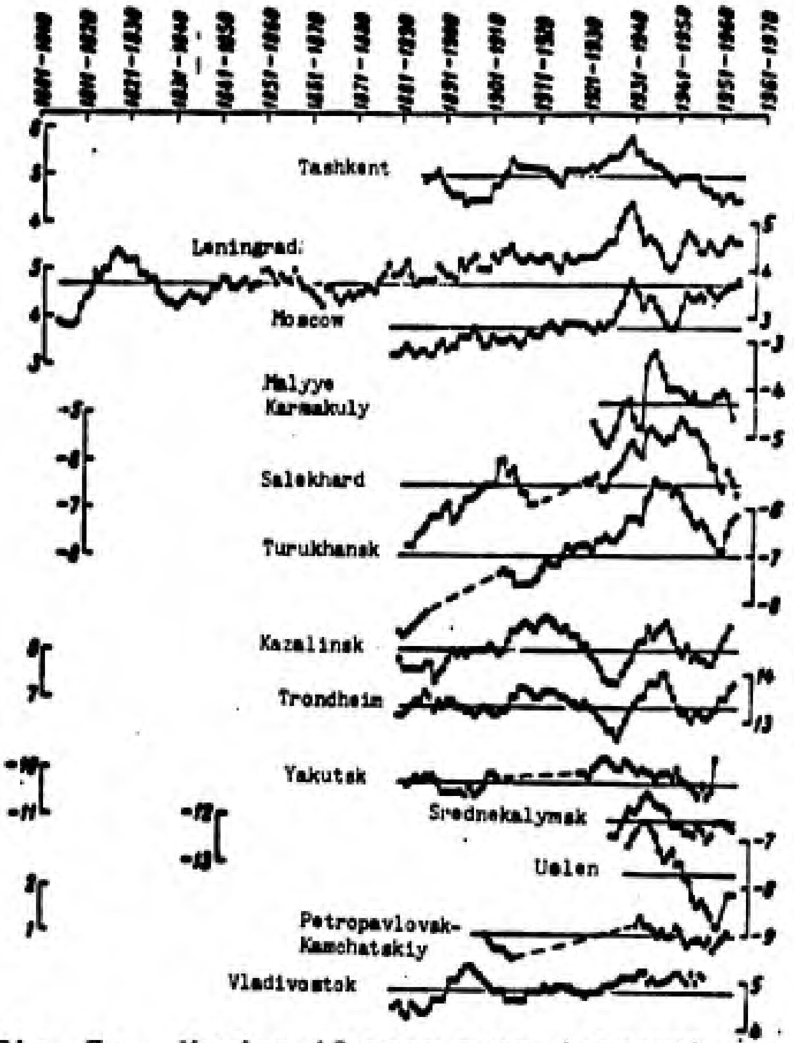


Fig. 7a. Moving 10-year mean temperatures. Year.

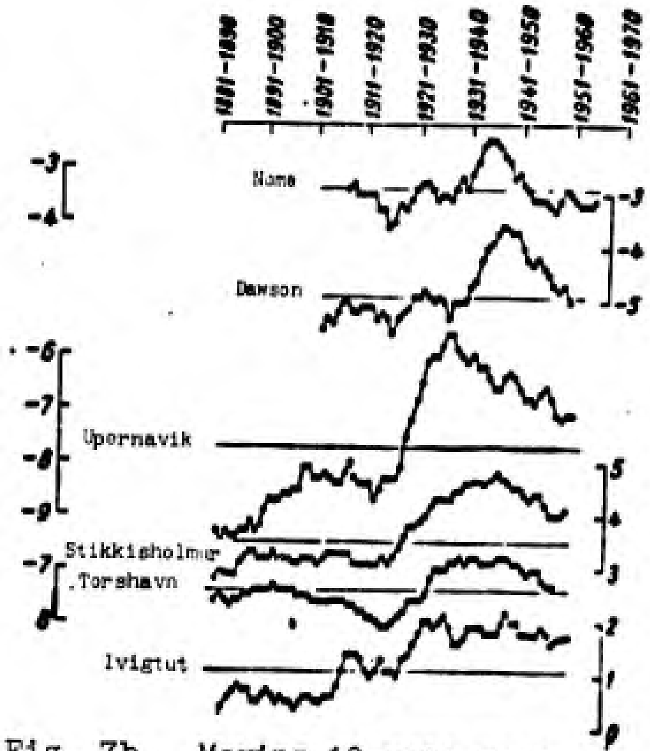


Fig. 7b. Moving 10-year mean temperatures. Year.

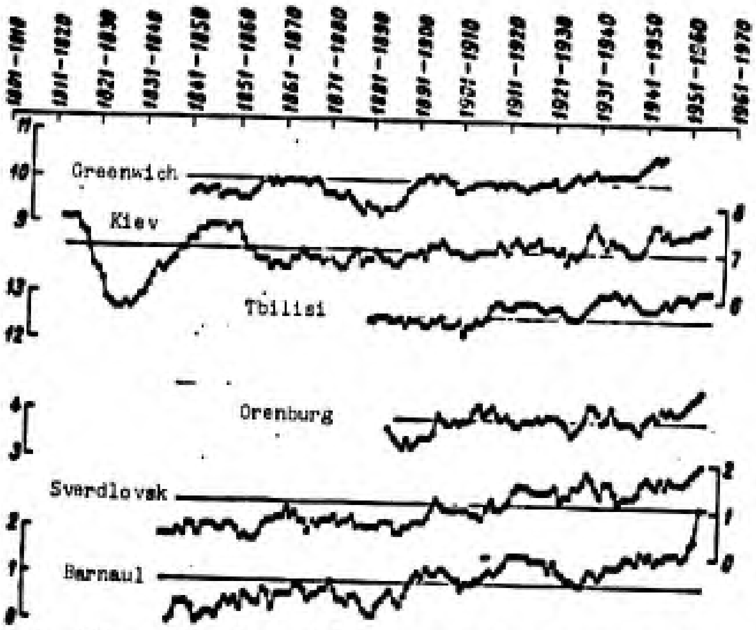


Fig. 7c. Moving 10-year mean temperature. Year.

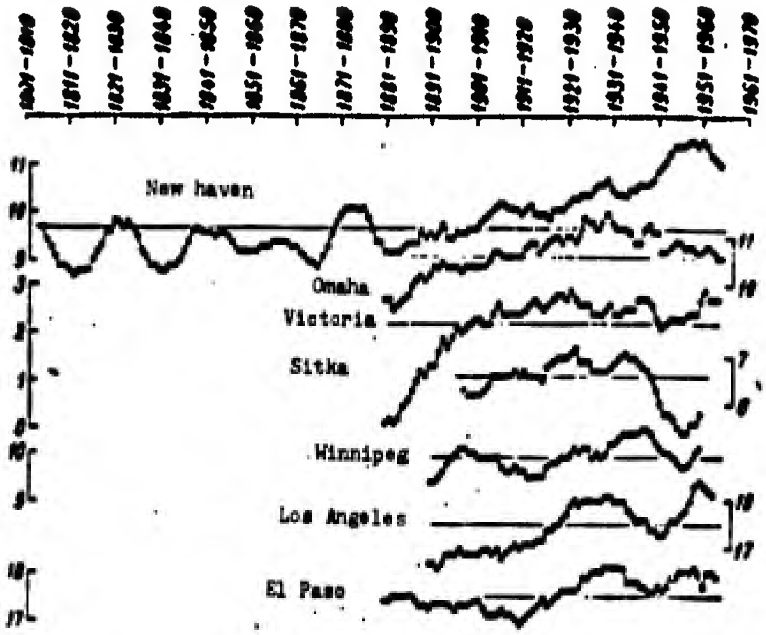


Fig. 7d. Moving 10-year mean temperatures.
Years.

of warming to 1945-1954 (Fig. 7d), then at continental stations (Omaha, Winnipeg) the peak in warming is illegibly marked or is quite absent. The same pertains to stations of the western seacoast of North America.

As was already noted earlier, the variation in temperature in separate months of a certain season of the year can greatly differ from the temperature variation in other months. Therefore the characteristic of the perennial temperature variation by seasons does not represent the distribution of temperature within the season, but is only a resultant, indeed, of more a detailed one than that of the annual. Optimum for investigation of variations in climate are the mean monthly values, which give a sufficiently detailed characteristic of the year by natural gradation and at the same time are not too small, which has great advantages during the investigation of them.

Let us turn to the examination of peculiarities of the variation of mean monthly temperature in different months of year.

January (Fig. 8a-8e). The most considerable variations in temperature are observed in the northwest regions of Greenland (Upernavik) on Novaya Zemlya (Malyye Karmakuly) and, apparently, on Spitsbergen (Barentsburg), a graph for which is not given due to the heterogeneity of the series of observations. The warming of the Arctic in these regions was the most intense. After a break in the course of warming the temperature drops at the same rate (Fig. 8a), but recently still by far did not attain that level from which started its extremely rapid rise.

In Upernavik the mean temperatures for the decade 1939-1948 10° higher than that for the decade 1907-1911; in Malyye Karmakuly the temperature for the decade 1937-1946 is higher than that for the decade 1909-1918 by almost 9°.

Differences between 10-year mean temperatures of the order of 6-8° are also encountered in Canada (Dawson, Winnipeg), the United States (Omaha), Soviet Union (Kazalinsk, Salekhard, Leningrad).

With a whole variety of variations in temperature in different regions during certain periods, for example, from the decade 1918-1927 to 1943-1952 (the wave of maximum warming and subsequent sharp temperature drop), a community of large-scale variations from Trodheim to Salekhard (Fig. 8b) is observed; to this group adjoins the region of the eastern seacoast of the United States (New Haven). At the same time variations at New Haven mirror the oscillations in the adjacent continental regions of North America (Dawson, Winnipeg, Omaha) which one can see well from a comparison of Fig. 8b and 8d. In Eurasia, to the south of 60 N. Lat., the general course of variations from Greenwich to Kiev is traced approximately from the middle of the 19th Century. With this the amplitude of variations, naturally, decreases westward (Fig. 8c).

The community of great variations from Tbilisi to Tashkent is well defined. These regions are joined with Orenburg and partly Barnaul. Here intense warming occurred between the decades 1886-1895 and 1911-1920; the difference in their mean temperatures was about 8°. After that at the same rate there occurred a temperature drop in the 10-year period of maximum warming in the high latitudes (1928-1937); the temperature reached the initial minimum. Frequently there is given the example of the mirror-like nature of variation in temperature in January between Kazalinsk and Salekhard (Fig. 8b and 8c). However, this mirror-like nature is somewhat inaccurate:

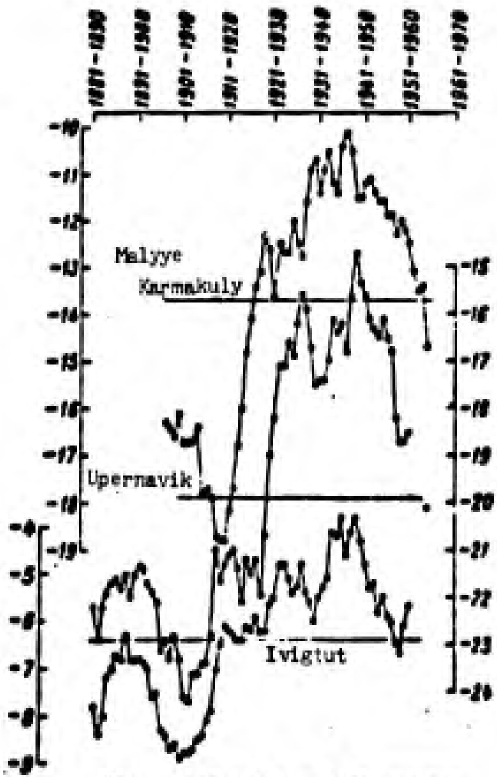


Fig. 8a. Moving 10-year mean temperatures. January.

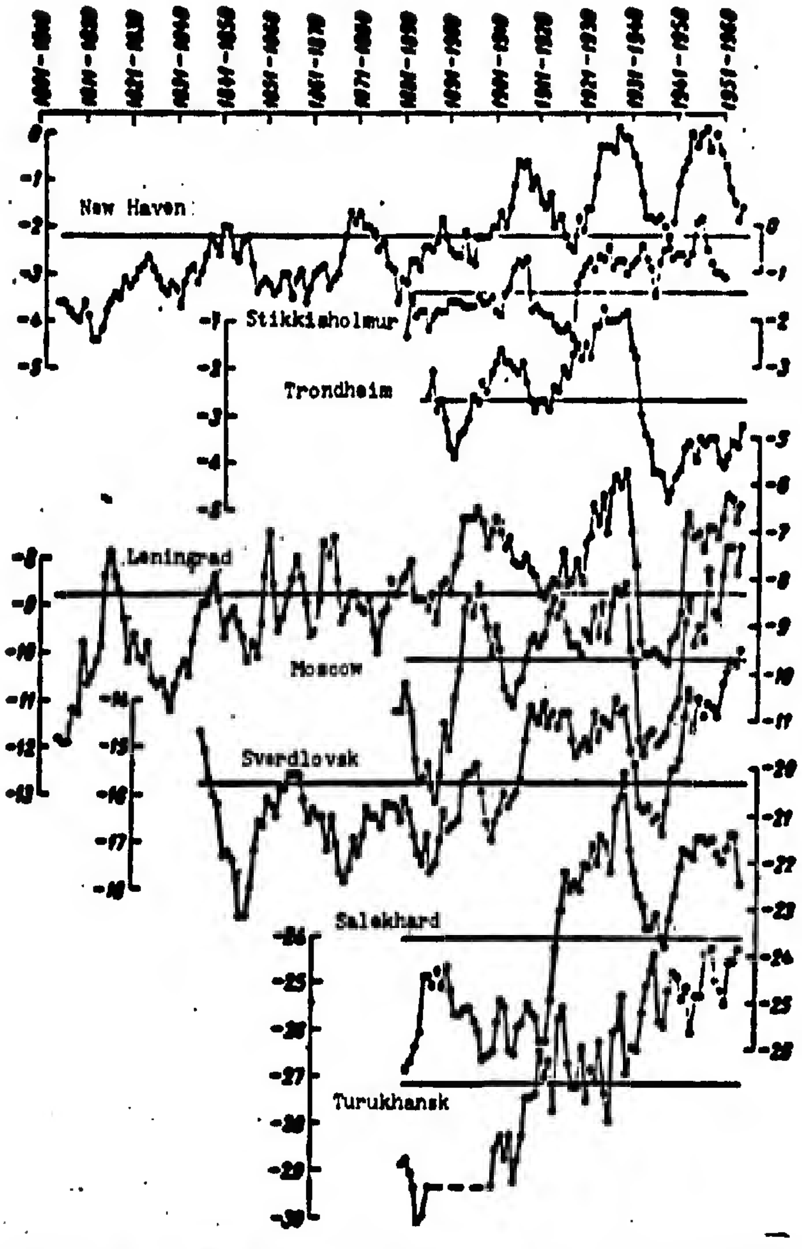
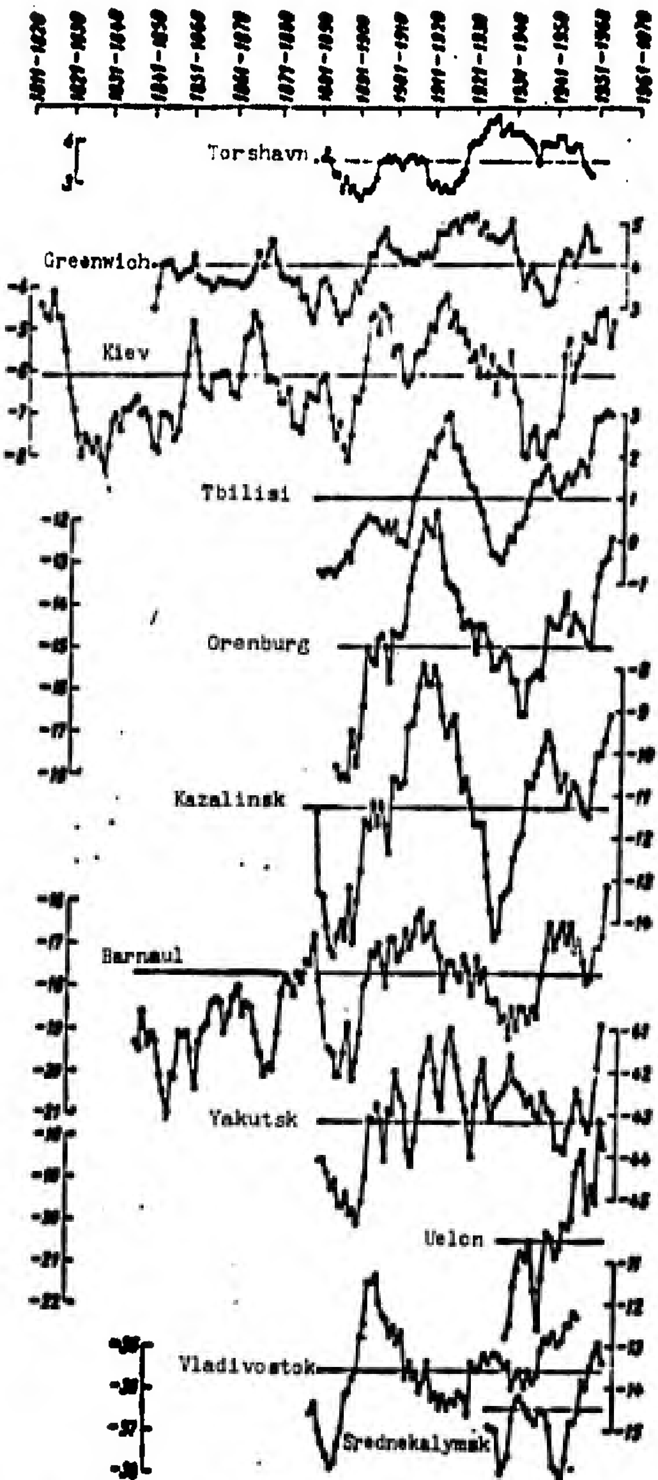


Fig. 8b. Moving 10-year mean temperatures. January.



'Fig. 8c. Moving 10-summer mean temperatures. January.

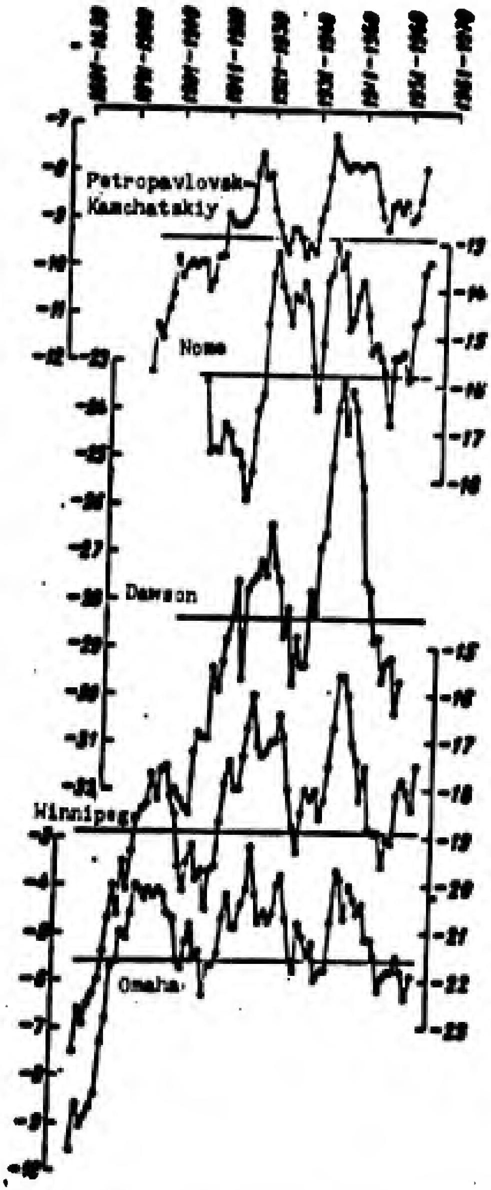


Fig. 8d. Moving 10-year mean temperatures. January.

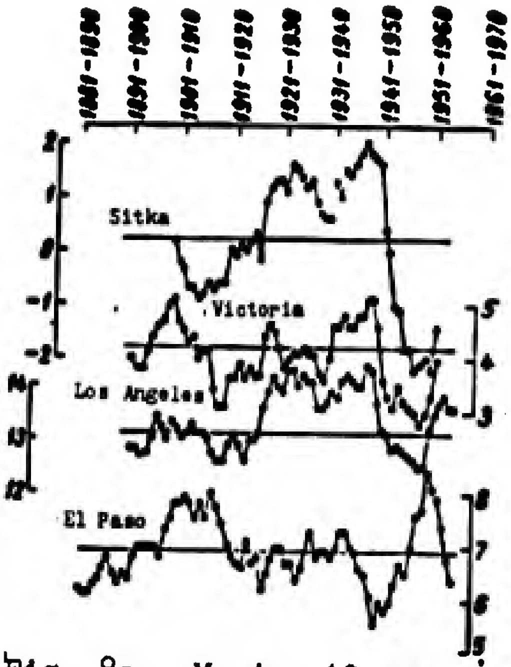


Fig. 8e. Moving 10-year mean temperatures. January

if in Salekhard even with considerable variations there is a trend toward an increase in temperature, then in Kazalinsk sharp variations occur near the mean level.

In Eastern Siberia and the Far East variations in separate regions are heterogeneous in the absence of a definite trend. An exception is the region Turukhansk, where from the beginning of observations there occurs a steady oscillatory rise in temperature.

In Northern America, as was already noted above, the general course of variations in continental regions is observed not in a latitudinal, as in Erasia, but a meridional direction (Dawson, Winnipeg, Omaha) with a decrease in the amplitude of variations southward (Fig. 8d).

On the western seacoast of North America variations are observed near the mean level, with the exception of the region of Sitka, where variations are synchronous with those at Dawson, but a tendency toward warming at Sitka is more sharply marked. Of interest is the fact that at Uelen and Nome, divided only by the narrow Bering Strait, in certain months, and, in particular, in January, the variations in temperature are nonsynchronous.

February (Fig. 9a-9e). Warming in this month occurred only in Greenland, and it was not as considerable as that in January. With the great amplitude in variations (Upernavik, Ivigtut) the 10-year mean temperature during 40 years was raised approximately 5°, attaining a maximum in the decade 1927-1936 in Upernavik and 1939-1948 in Ivigtut. After these years variations in temperature occurred at a level considerably exceeding the mean perennial (Fig. 9a). On the eastern seacoast of the Atlantic, as one can see from Fig. 9a, there is no definite trend in the variations. An exception is the seacoast of Scandinavia (Trondheim), where after a maximum in the decade of 1905-1914 to the end of the period, the temperature descended more than 3°.

In the territory of the Soviet Union from the beginning of the current century, the synchronism of variations in broad terms is traced almost to Irkutsk. These variation are of great amplitude, but do not have a definite trend.

With a more detailed examination of Fig. 9b and 9c it is possible to establish easily that form of curve shape of temperature in regions of Western Siberia is slightly modified (for example, a deeper minimum in the decade (1923-1932) in comparison with the European territory of the USSR; but common traits of large-scale variations emerge very clearly. It is interesting to note the synchronism of great variations at Kiev and Sverdlovsk, which is sustained during the total period of observations (about 120 years).

Regions of high latitudes (Malyye Karmakuly, Salekhard, Turukhansk) differ by another type of variation with more considerable amplitude (up to 6-7°) and clearly marked cyclic recurrence of the variations (Salekhard and Turukhansk, Fig. 9c).

In the northeast of Siberia (Srednekolymsk, Uelen) and northwest of North America (Nome, Dawson) the variations in contrast to January are synchronous, but in continental regions (Winnipeg, Omaha) the variations are the same with respect to Dawson (Fig. 9d and 9e). Variations at New Haven are similar in form to variations at Omaha, but have a considerably smaller amplitude. In all three regions there is noticed a trend toward an increase in temperature: sharp variations in the current century occur on a level considerably higher than those in the last century. In this respect regions of the central and eastern parts of North America are similar to the region of Greenland. Nowhere in the northern hemisphere was there observed a trend toward an increase in temperature in February.

On the western seacoast of North America variations in temperature are insignificant and are not of interest (Fig. 9d). Subsequently, we will not dwell on an analysis of these regions, presenting them only in the figures.

March (Fig. 10a-10e). A trend toward an increase in temperature, just as in February, is most clearly marked in Upernavik (Fig. 10a). Here approximately during four decades the mean 10-year temperature was raised 9° and attained the highest value in the decade 1928-1937, and in subsequent years (1951-1960) it dropped to the perennial

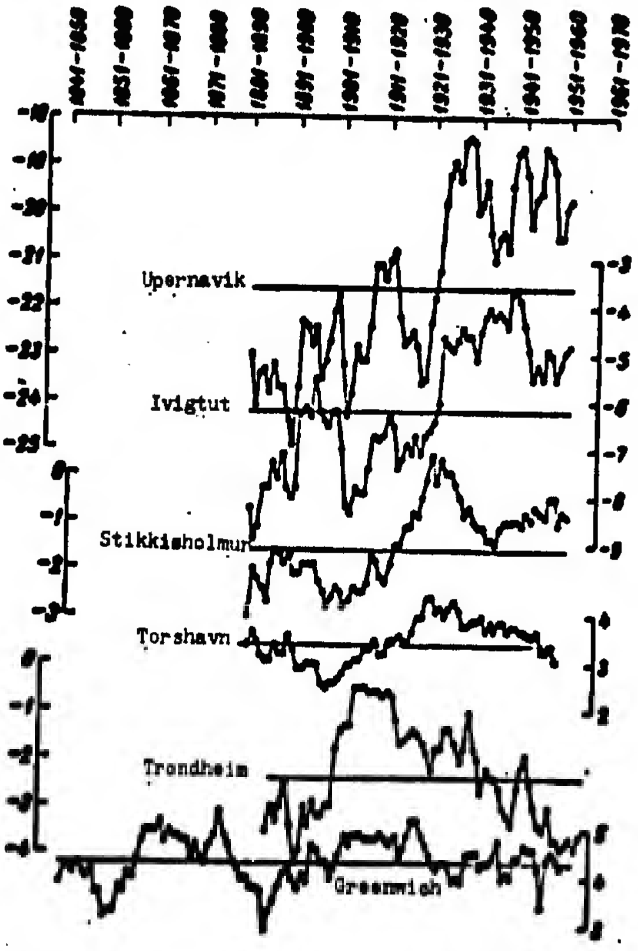


Fig. 9a. Moving 10-year mean temperatures. February.

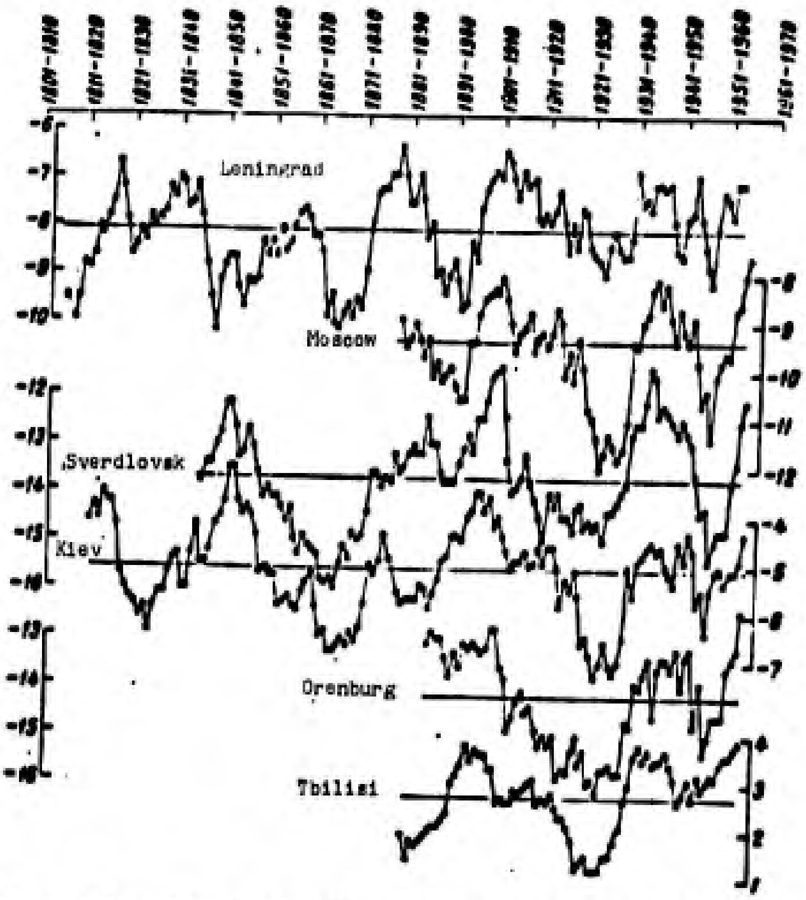


Fig. 9b. Moving 10-year mean temperatures. February.

mean. A weaker tendency toward a temperature rise was observed on all the coastal and insular stations of the North Atlantic with the exception of the seacoast of Norway (Fig. 10a). In the Atlantic regions of Western Europe (Greenwich) and Northern America (New Haven) from the end of the last century a small warming trend started (Fig. 10a and 10e).

In the territory of the Soviet Union there were observed considerable variations in temperature near the perennial mean. Common traits in the course of temperature are noted in a smaller number of regions than in January and especially in February. One group of regions of synchronous variations is that of Leningrad, Moscow and partly Kiev, a second group is Malyye Karmakuly and Salekhard, and a third - Orenburg, Sverdlovsk and Kazalinsk (Fig. 10b and 10c).

In the central regions of North America the synchronism terms is noticeable between curves of Winnepeg and Omaha (Fig. 10e).

April (Fig. 11a-11e). In Upernavik, against the background of a general trend toward an increase in temperature variations

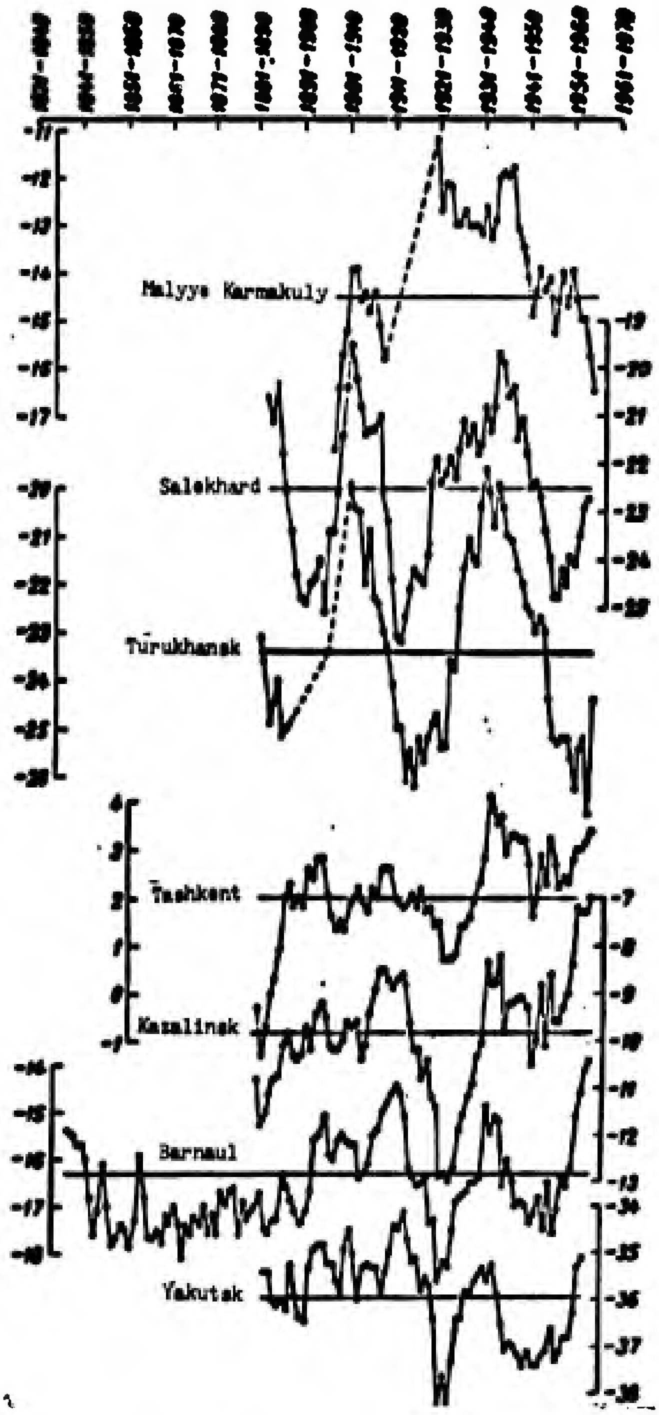


Fig. 9c. Moving 10-year mean temperatures. February.

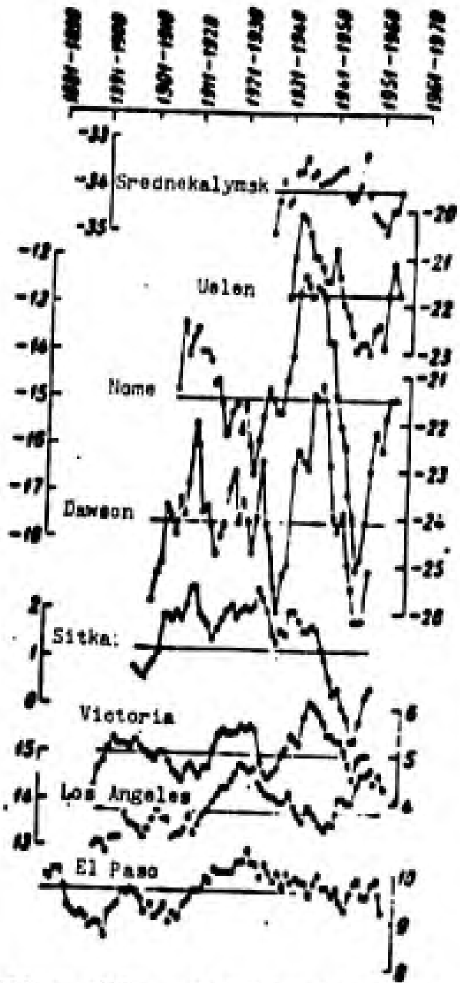


Fig. 9d. Moving 10-year mean temperature. February.

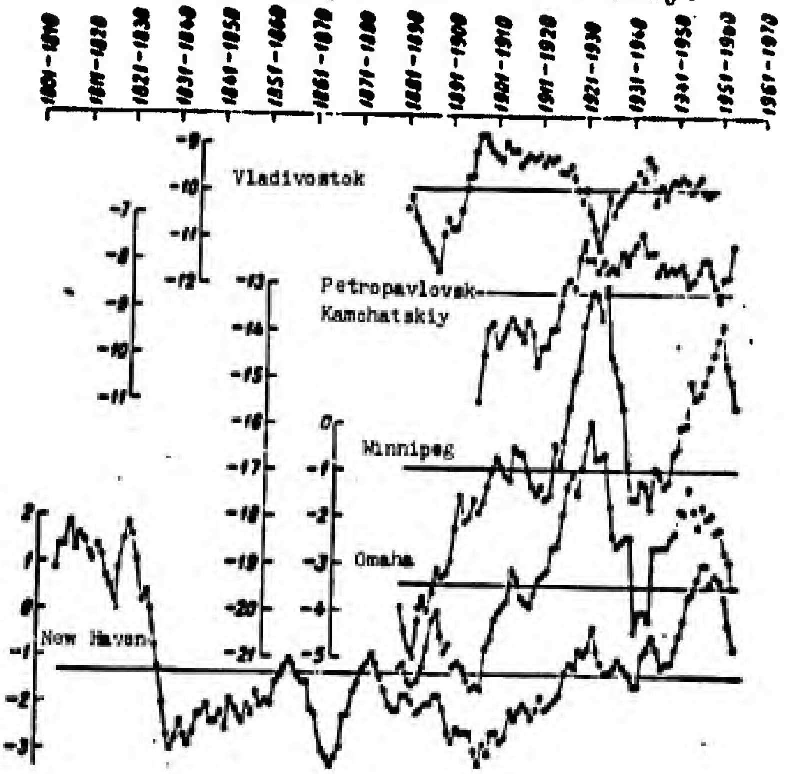


Fig. 9e. Moving 10-year mean temperatures. February.

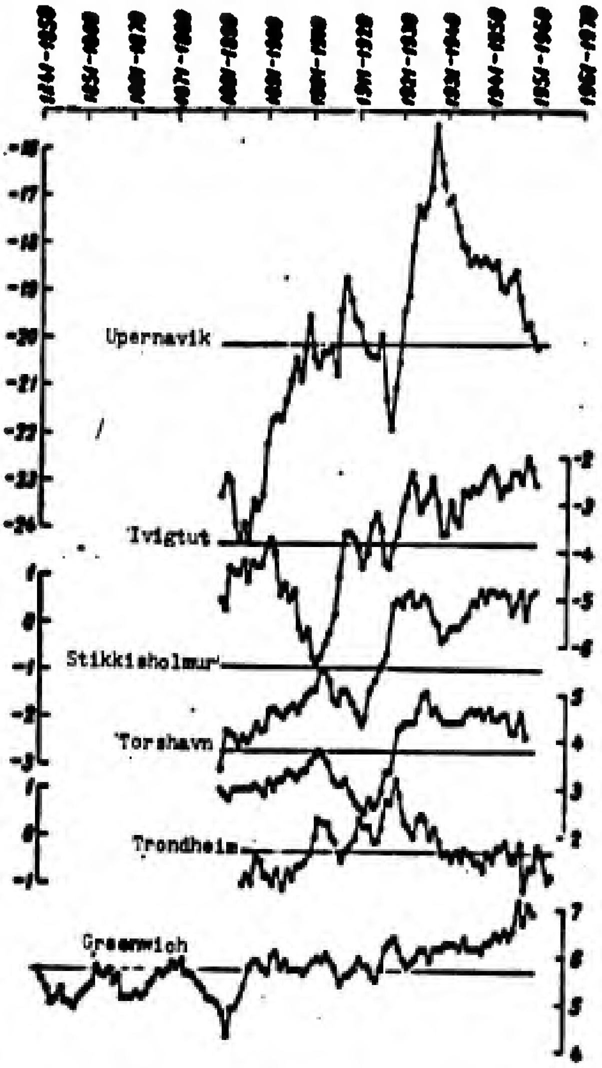


Fig. 10a. Moving 10-year mean temperatures. March.

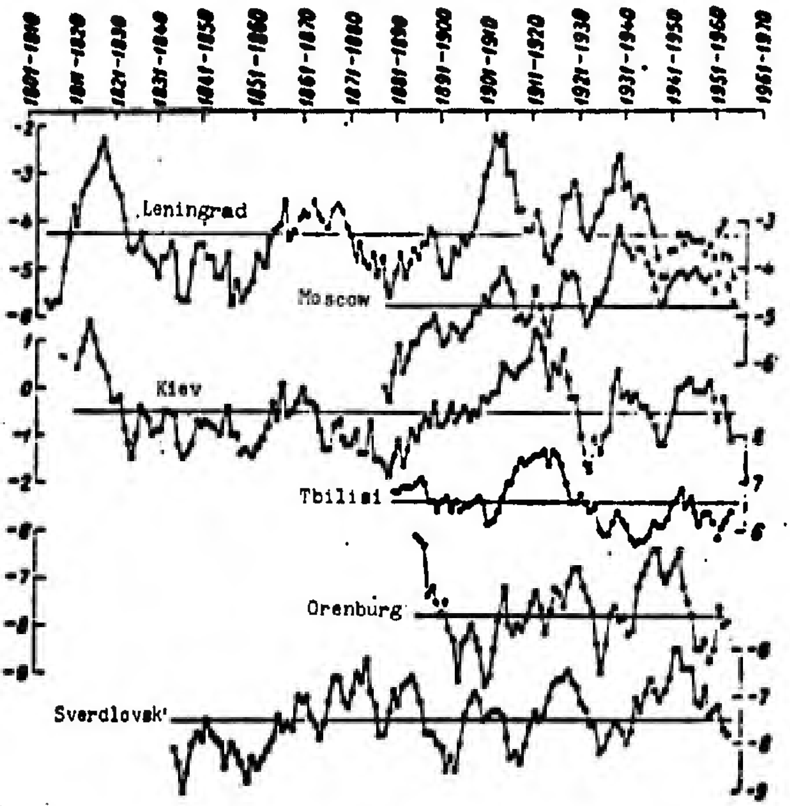


Fig. 10b. Moving 10-year mean temperatures. March.

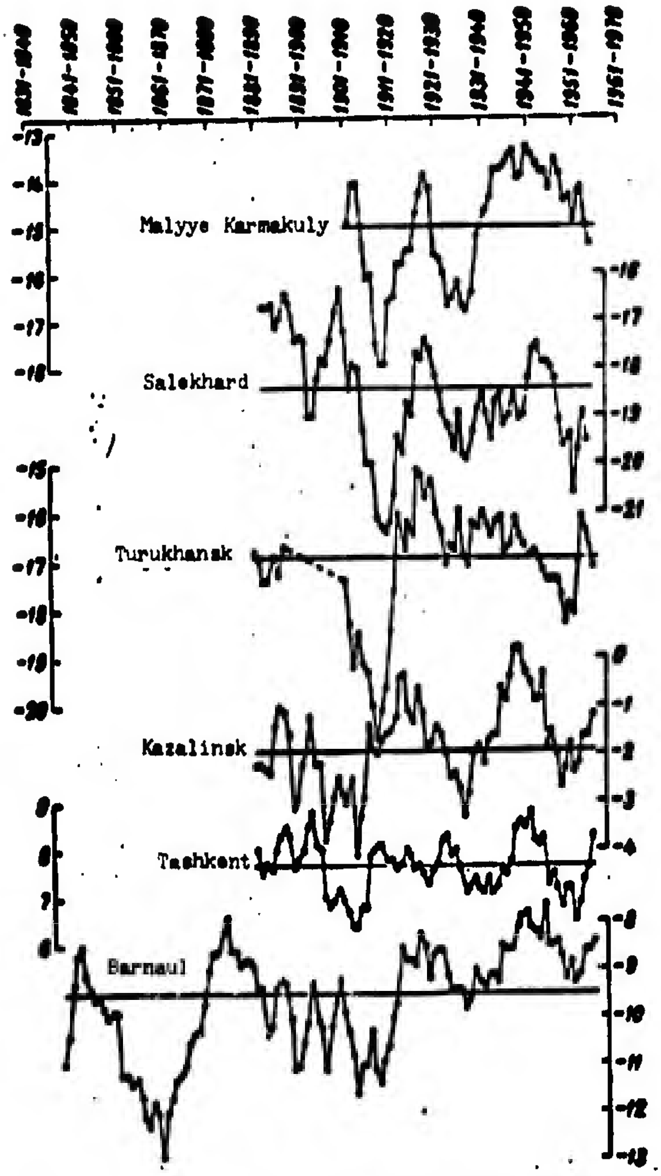


Fig. 10c. Moving 10-year mean temperatures. March.

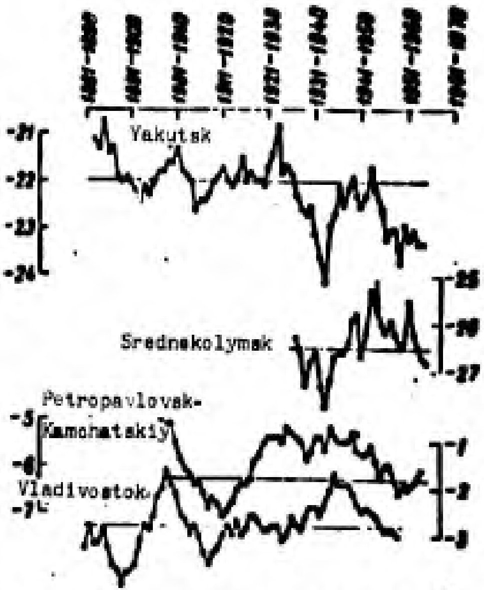


Fig. 10d. Moving 10-year mean Temperatures. March.

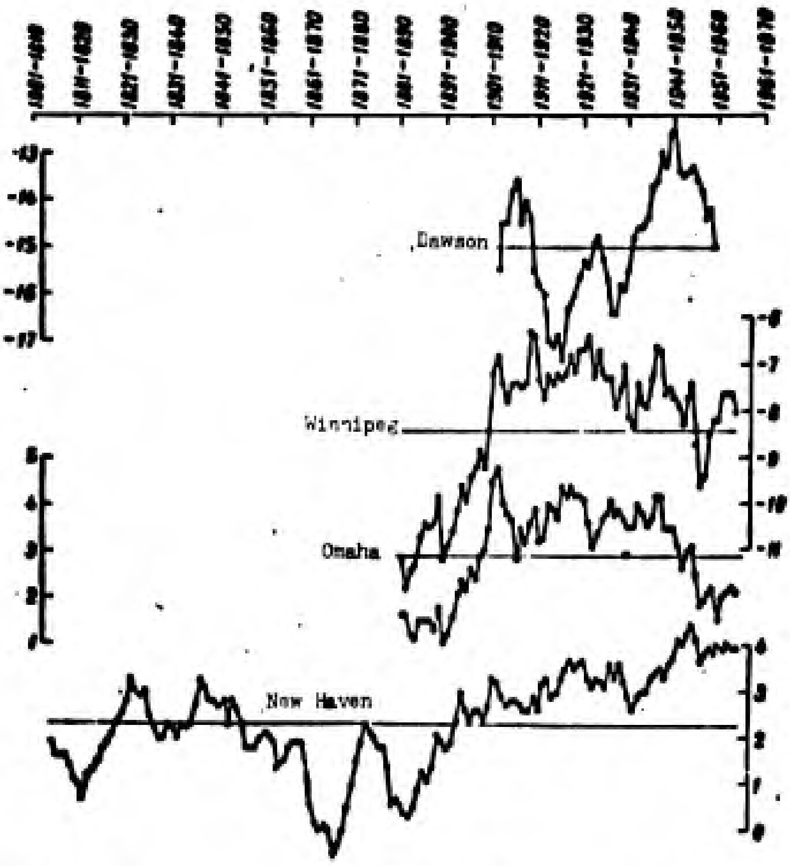


Fig. 10e. Moving 10-year mean temperatures. March.

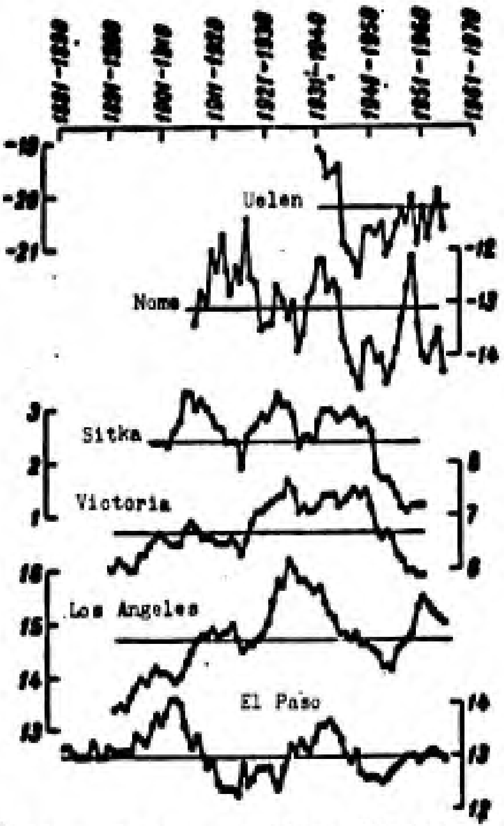


Fig. 10f. Moving 10-year mean temperatures. March.

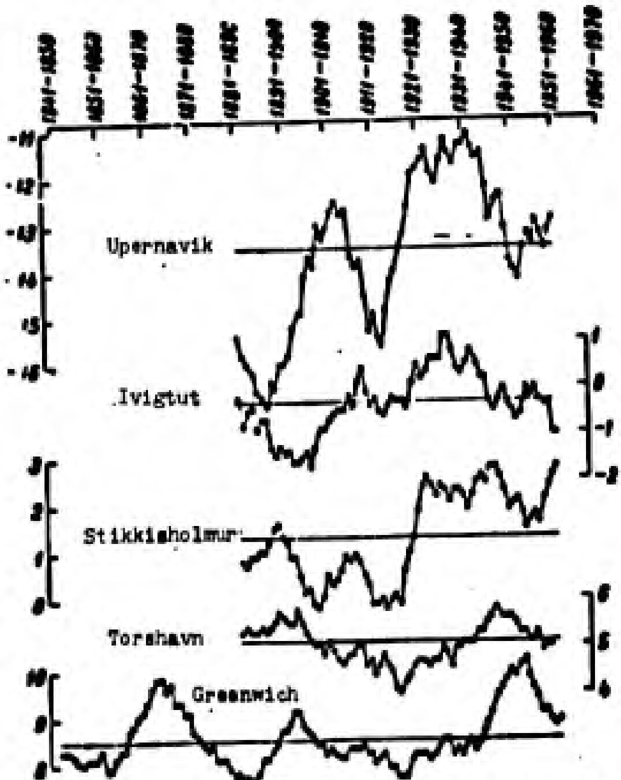


Fig. 11a. Moving 10-year mean temperatures. April.

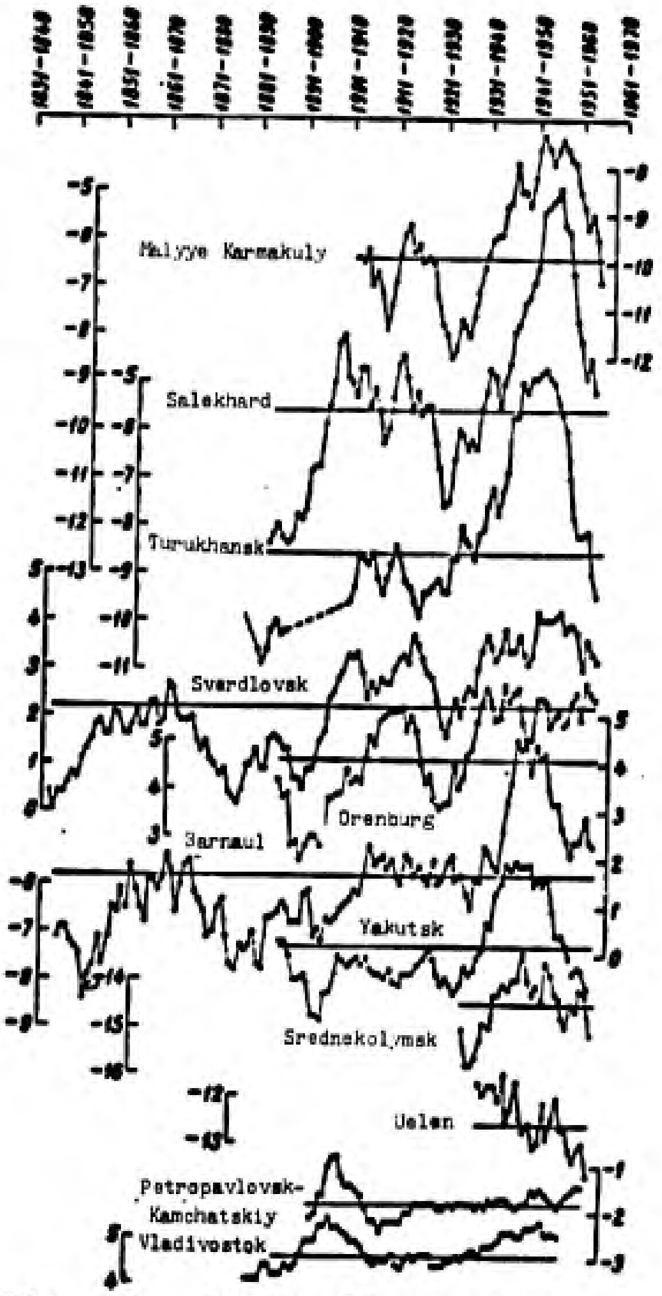


Fig. 11b. Moving 10-year mean temperatures. April.

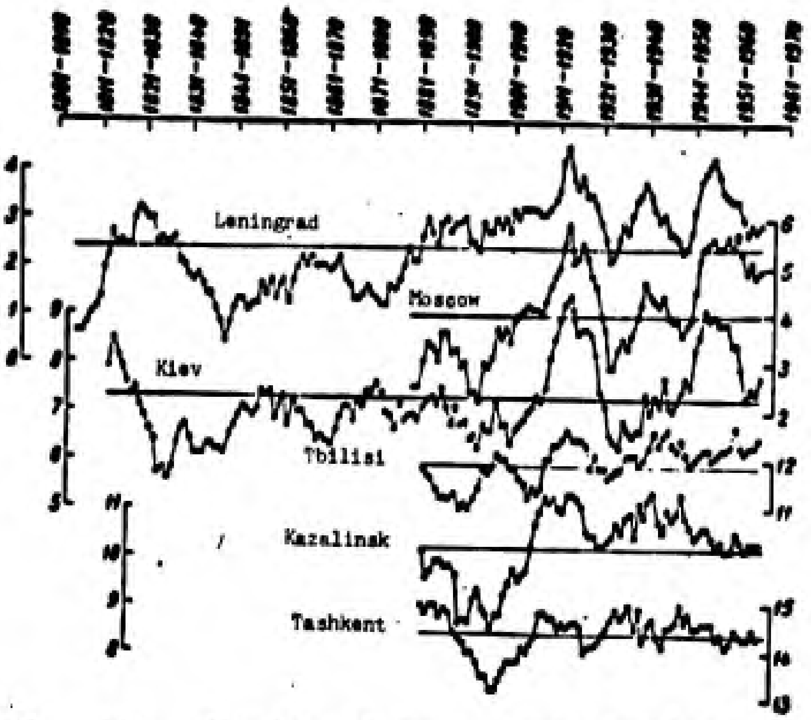


Fig. 11c. Moving 10-year mean temperatures.
April.

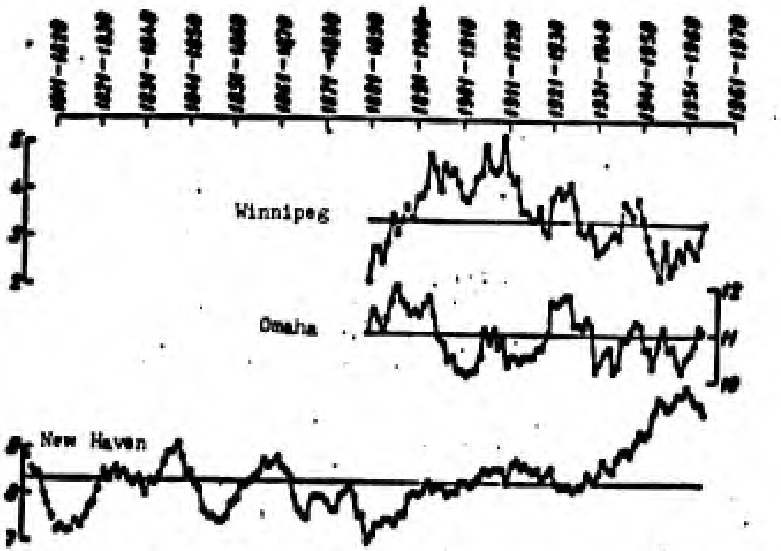


Fig. 11d. Moving 10-year mean temperatures.
April.

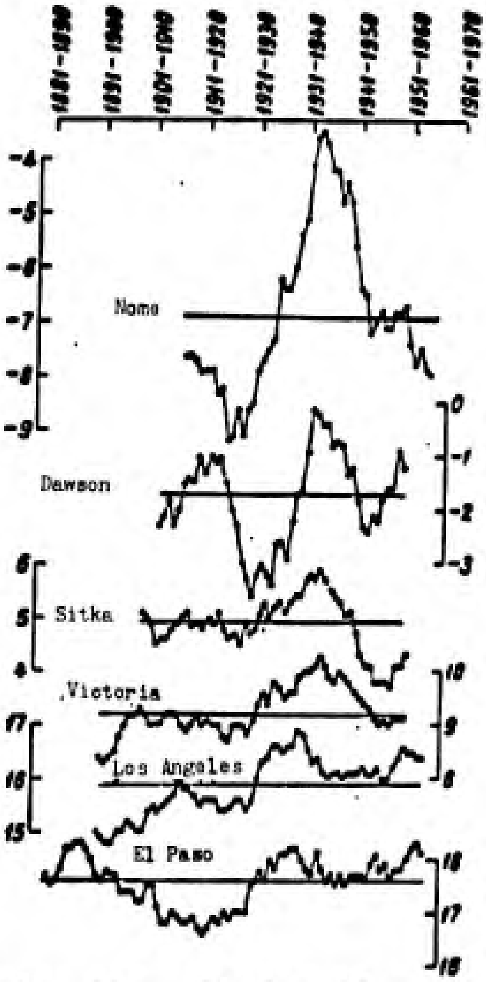


Fig. 11e. Moving 10-year mean temperatures. April.

of considerable amplitude are observed. At Stikkisholmur this trend is also noticed, but the variations have a smaller amplitude. A slight rise in temperature is observed in the region of New Haven.

In the northern regions of the Soviet Union (Malyye Karmakuly, Salekhard, Turukhansk) the variations are synchronous and similar to variations in Upernavik, but are opposite it in phase. Such variations are of great duration and amplitude in the region of Nome (they are synchronous with those of Upernavik) and Dawson. Thus, in the high latitudes of the western and eastern hemispheres there were observed variations of the same order but opposite in phase (Fig. 11a, 11b, and 11e), with a common tendency of temperature increase.

The synchronism of variations in the following groups of regions is noted: Leningrad, Moscow, Kiev – from the beginning of the current century; Sverdlovsk and Chkalov – from the end of the last century; Barnaul, Yakutsk, Srednekolymsk and Kazalinsk, Tashkent – during the whole period of observations (Fig. 11b, 11c). In all these groups of regions except the last, a certain tendency toward the rise of temperature.

In the temperature variation of remaining regions of the northern hemisphere there is nothing remarkable, and therefore to dwell on them is senseless.

May (Fig. 12a-12d) Variations are considerable and are synchronous starting from the middle of the last century (Fig. 12a), judging by the graphs of Leningrad and Kiev. In broad terms this is joined by Sverdlovsk. In the course of the curves a slight tendency toward an increase in temperature is noticed. It is expressed in the northern regions to a greater degree (Malyye Karmakuly, Salekhard, Upernavik, Ivigtut, Nome) and also farther south in the region of Los Angeles.

As can be seen from Fig. 12b, 12c and 12d there are regions with a well-marked cyclic recurrence (Barnaul, Winnipeg, Greenwich).

June (Fig. 13a-13e). Perennial variations in temperature and in summer months are rather considerable, but groups of regions with common tracts of variations include not more than two regions (Moscow and Leningrad, Fig. 13a; Torshavn and Trondheim, Fig. 13a; Los Angeles and El Paso, Fig. 13e).

On Fig. 13a it is possible to note a certain community in the form of curves in regions of the North Atlantic (Torshavn), Scandinavia (Trondheim), Leningrad and Moscow. The deep minimum in the Atlantic in the decade 1921-1930 shifts to the southeast in the decade 1925-1934. (Moscow); a subsequent short-term rise up to 1931-1940 occurred in these regions synchronously. But subsequently with synchronism of even small variations the trends in them are different, at Torshavn and Trondheim the temperature steadily decreases at Leningrad it varies near one level, but in Moscow it was increased noticeably.

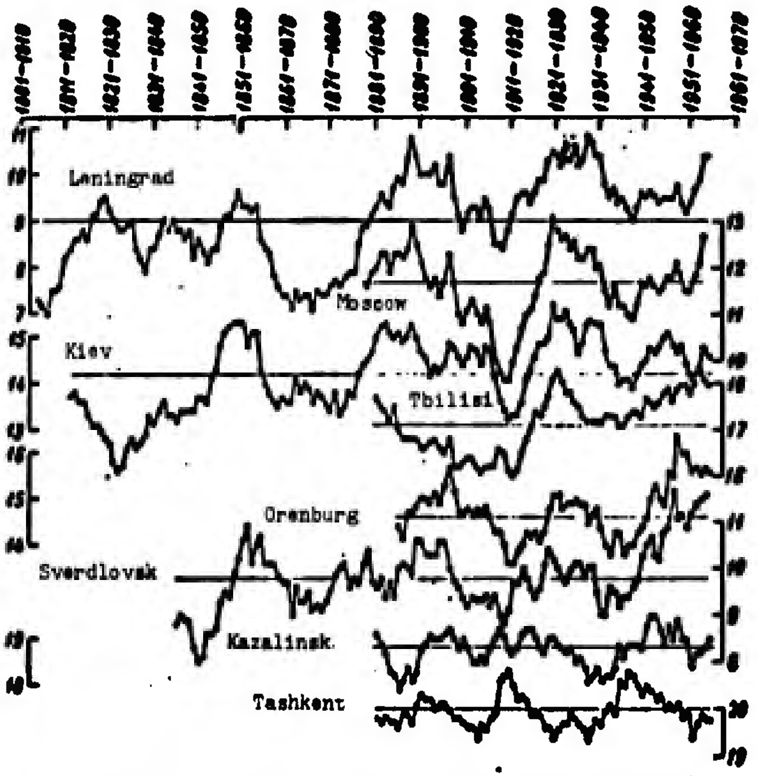


Fig. 12a. Moving 10-year mean temperatures. May.

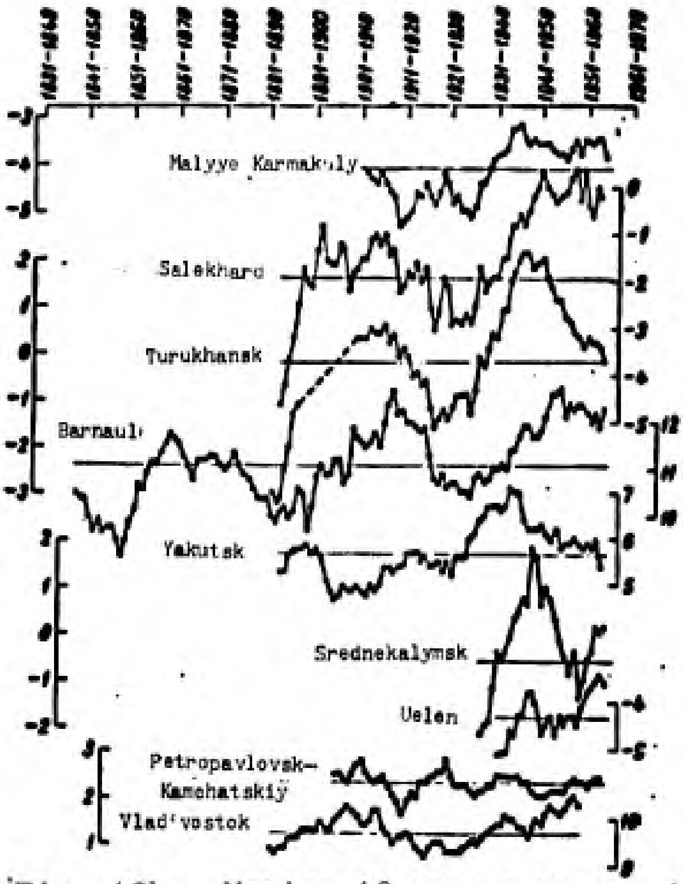


Fig. 12b. Moving 10-year mean temperatures. May.

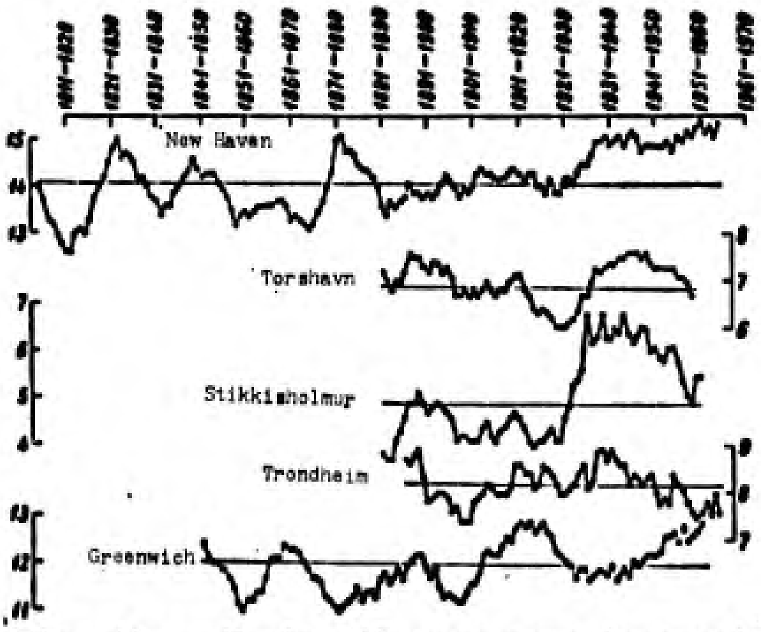


Fig. 12c. Moving 10-year mean temperatures. May.

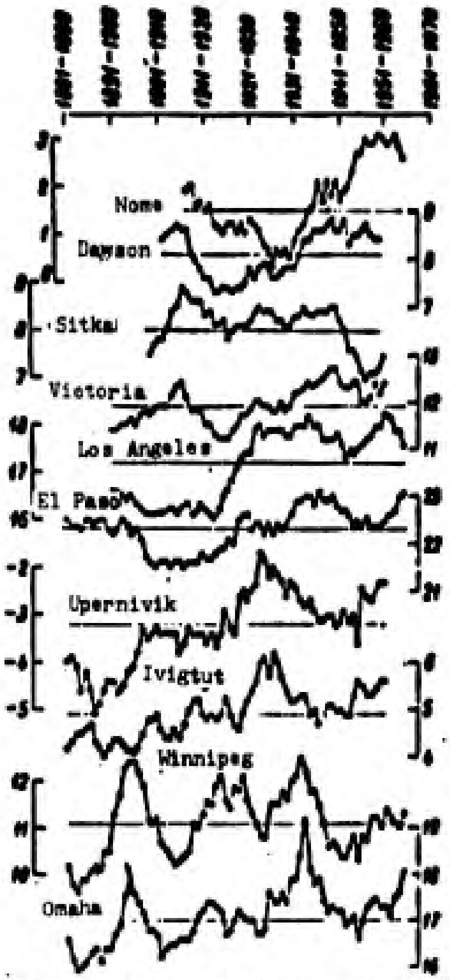


Fig. 12d. Moving 10-year mean temperatures. May.

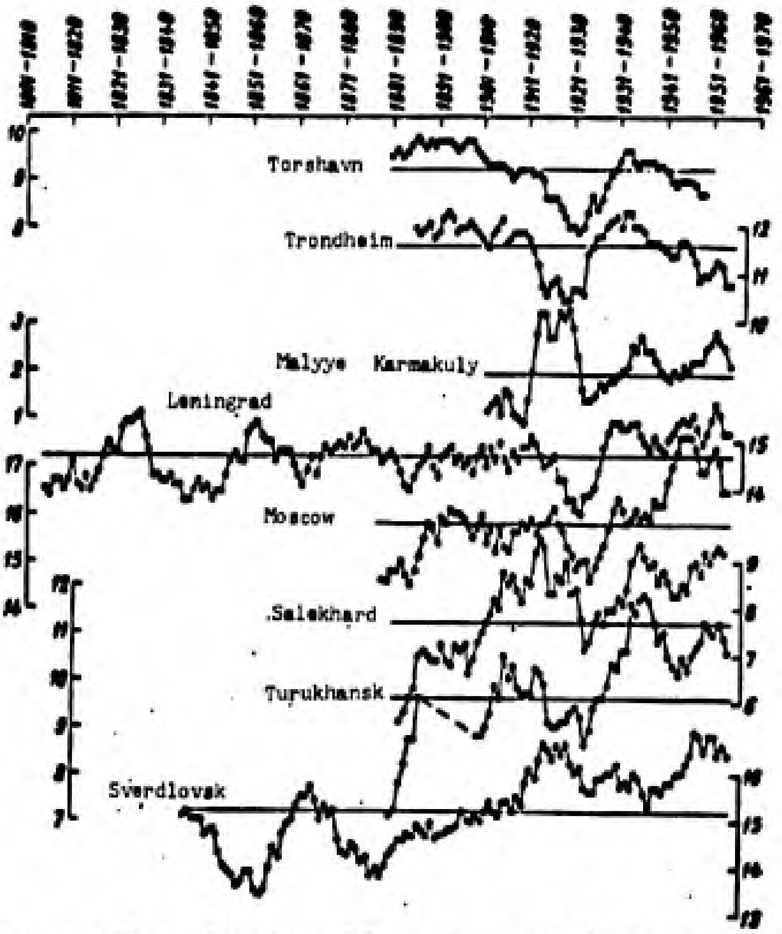


Fig. 13a. Moving 10-year mean temperatures. June.

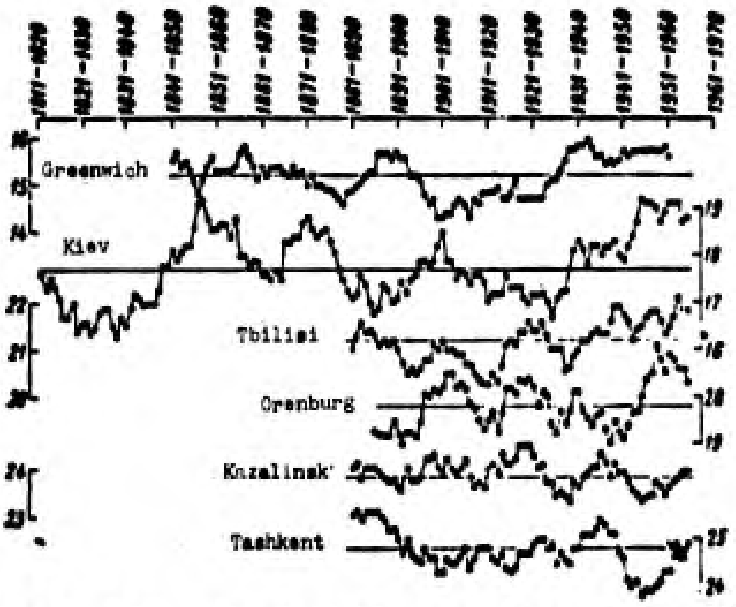


Fig. 13b. Moving 10-year mean temperatures. June.

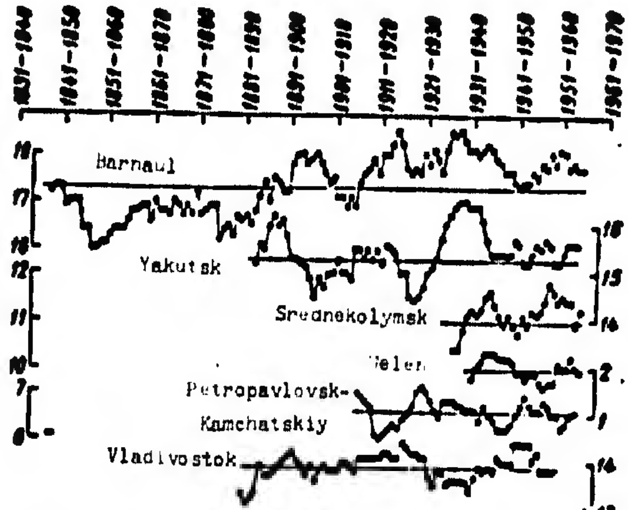


Fig. 13c. Moving 10-year mean temperatures. June.

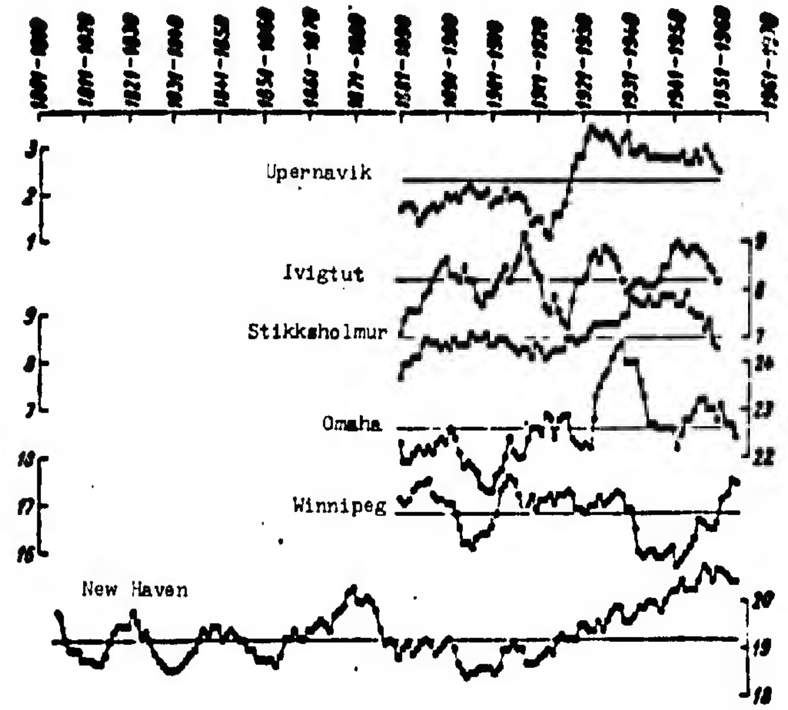


Fig. 13d. Moving 10-year mean temperaures. June.

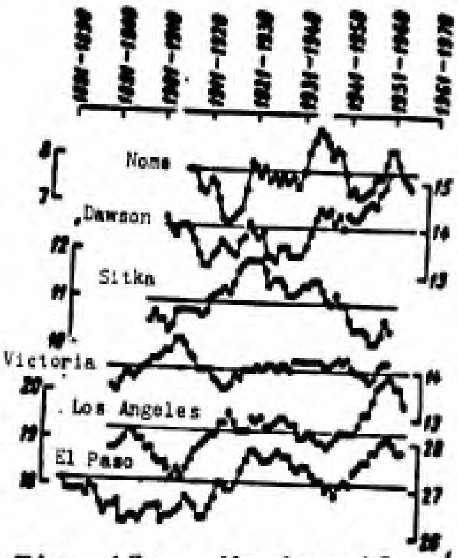


Fig. 13e. Moving 10-year mean temperatures. June.

Even more noticeable is the tendency toward an increase in temperature in Western Siberia (Sverdlovsk, Salekhard, Turukhansk, Barnaul).

It is interesting to note that on the western seacoast of North America there is observed good coordination of the variation in temperature at Los Angeles and El Paso from the beginning of the 20th Century and an evident of variation for these stations is observed. In Upernavik an intense rise in temperature occurred: from the decade 1914-1923 to 1923-1932 the mean 10-year temperature was raised 2.5°, and then it began slowly to drop but still did not reach the perennial mean. Thus here during the years of greatest warming of the winter the temperature of June was also considerably higher than that of the perennial.

July (Fig. 14a-14d). Almost from the same 10-year period as that in June, there began an intense rise in temperature at Upernavik. The peak of warming was observed in the decade 1931-1940,

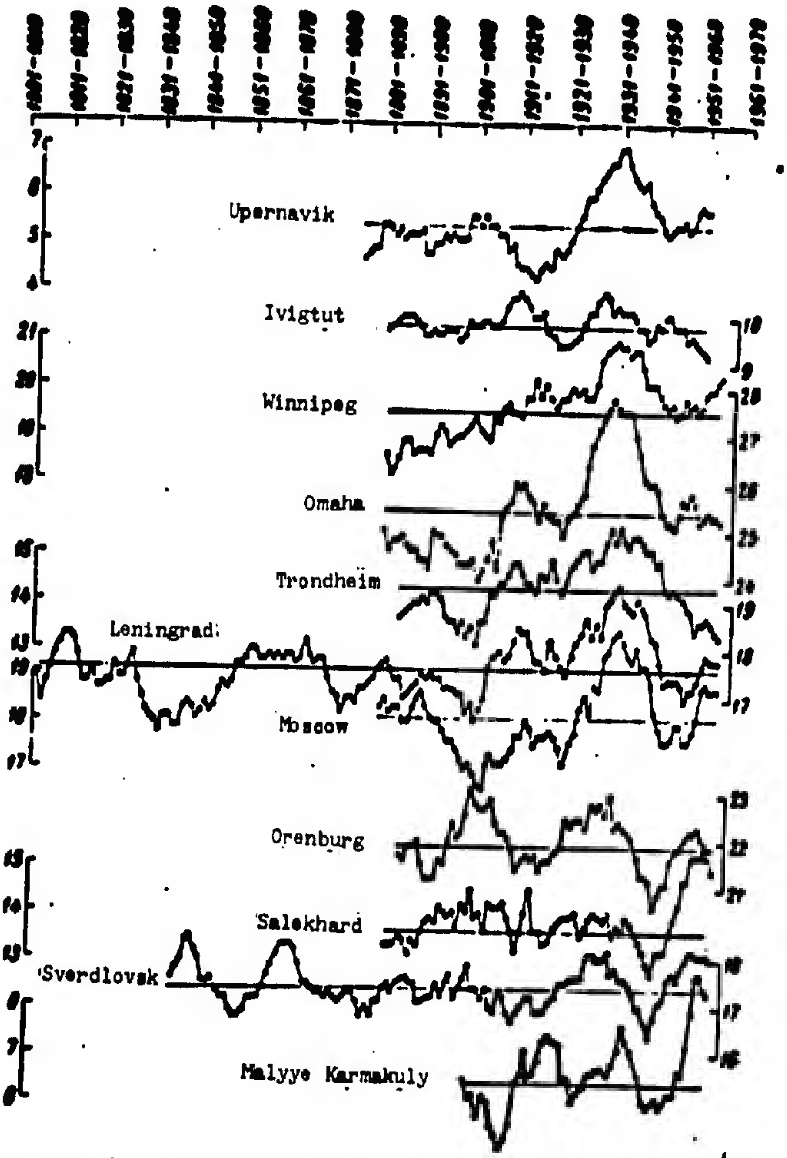


Fig. 14a. Moving 10-year mean temperatures. July.

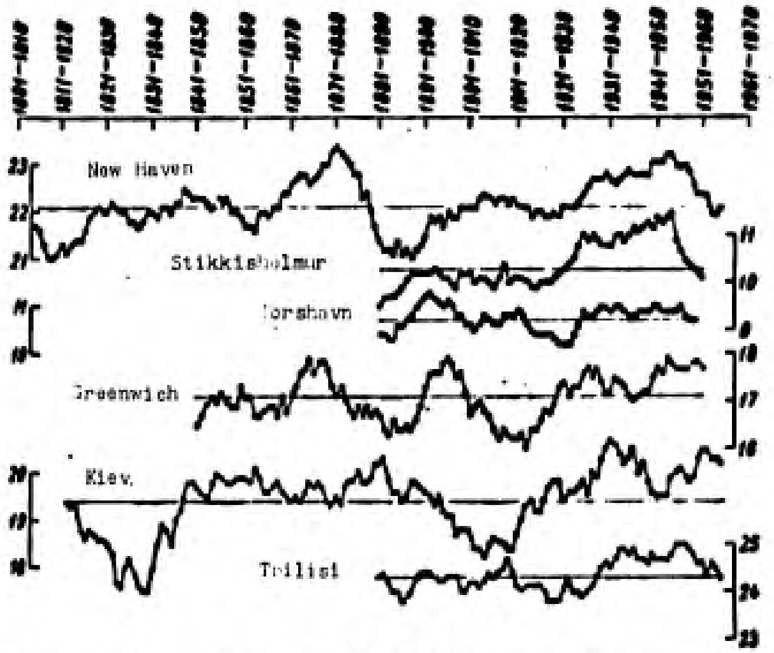


Fig. 14b. Moving 10-year mean temperatures. July.

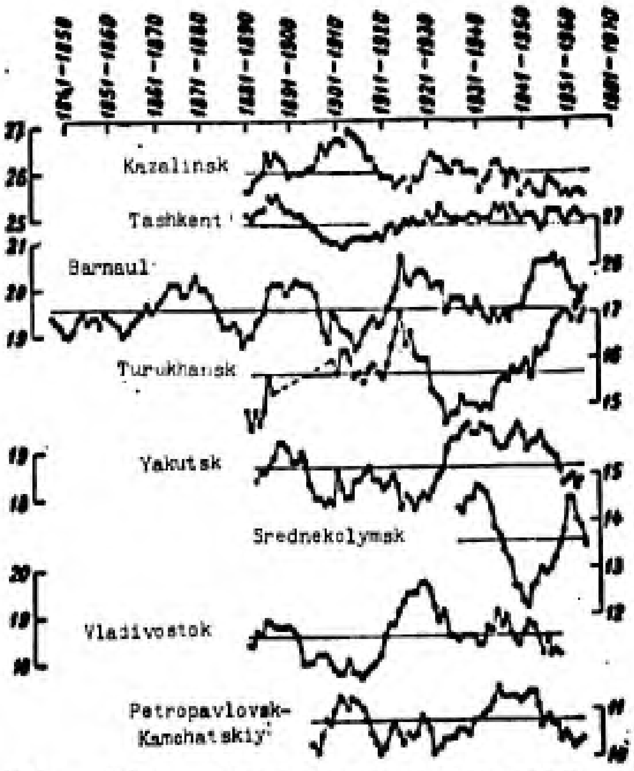


Fig. 14c. Moving 10-year mean temperatures. July.

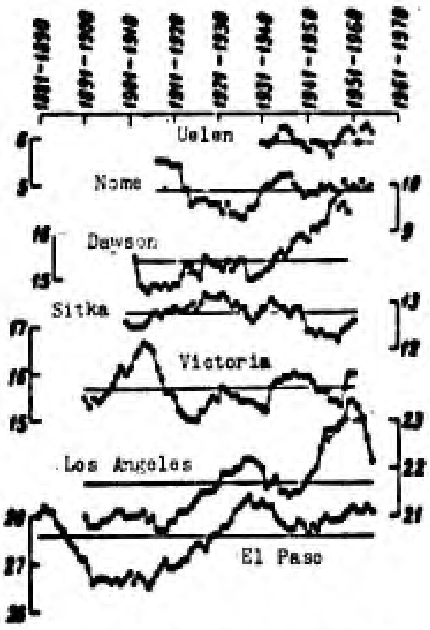


Fig. 14d. Moving 10-year mean temperatures. July.

when the mean 10-year temperature was 1.5° higher than that of the perennial, and in subsequent years the mean 10-year temperature dropped to the level of the mean perennial.

As can be seen from Fig. 14a, the same (in basic features) variation in temperature was observed in the northwest of Europe (Trondheim, Leningrad, Moscow) and in continental regions of North American (Winnipeg, Omaha). In all these regions the maximum increase in temperature coincides with the period of the greatest warming in the winter months.

Warming of July is noticeable in regions of Los Angeles and El Paso, where almost prior to the last decade there was observed, as in June, a synchronous rise of temperature with noticeable variations. In the remaining regions a definite trend in variations of temperature was not observed.

August (Fig. 15a-15c). Warming covers a greater number of regions than it did in July: from the beginning of the 19th Century the temperature increased in all regions of high and moderate latitudes of Europe, the North Atlantic and the eastern seacoast of North America. The peak of warming in Europe came earlier (1930-1939), and in Iceland and on the eastern seacoast of North America it was later, about 1944-1953. This warming was, for example, in Leningrad, the greatest for 150 years (1.5° higher than that of the perennial average).

A noticeable increase in temperature occurs almost from the beginning of instrumental observations in the whole territory of the United States (Winnipeg, Omaha, Los Angeles, El Paso). In the two last regions during three summer months coordination of variations and a noticeable temperature rise are observed. While in months of the year the variation in temperature in these regions was quite different. In Greenland there is an insignificant tendency toward warming.

September (Fig. 16a-16d). All over Europe there is noticeable a slight trend toward an increase in temperature from the beginning of the 20th Century approximately up to the the decade 1945-1954, after which in the western part of Europe the temperature continued insignificantly to vary near this level (approximately 1° higher than that of the mean), and in the territory of the Soviet Union it began rapidly to descend and in recent years reached the perennial mean.

Common features in the course of the temperature are already noticeable in considerable territories: in Europe and Trans-Urals in five regions (Leningrad, Kiev, Moscow, Sverdlovsk, Orenburg); in the Northern Atlantic in four regions (Upernavik, Ivigtut, Stikkisholmur, Torshavn); in the continental part of North America from the first decade of the 20th Century the level of variations insignificantly decreased (Omaha, Winnipeg), but on the eastern (New Haven) and especially in the western seacoasts (Los Angeles) it noticeably increased. In Los Angeles, for example, the increase in mean 10-year temperatures is about 3° for 60 years. But in contrast to summer months, in September the synchronism of variations

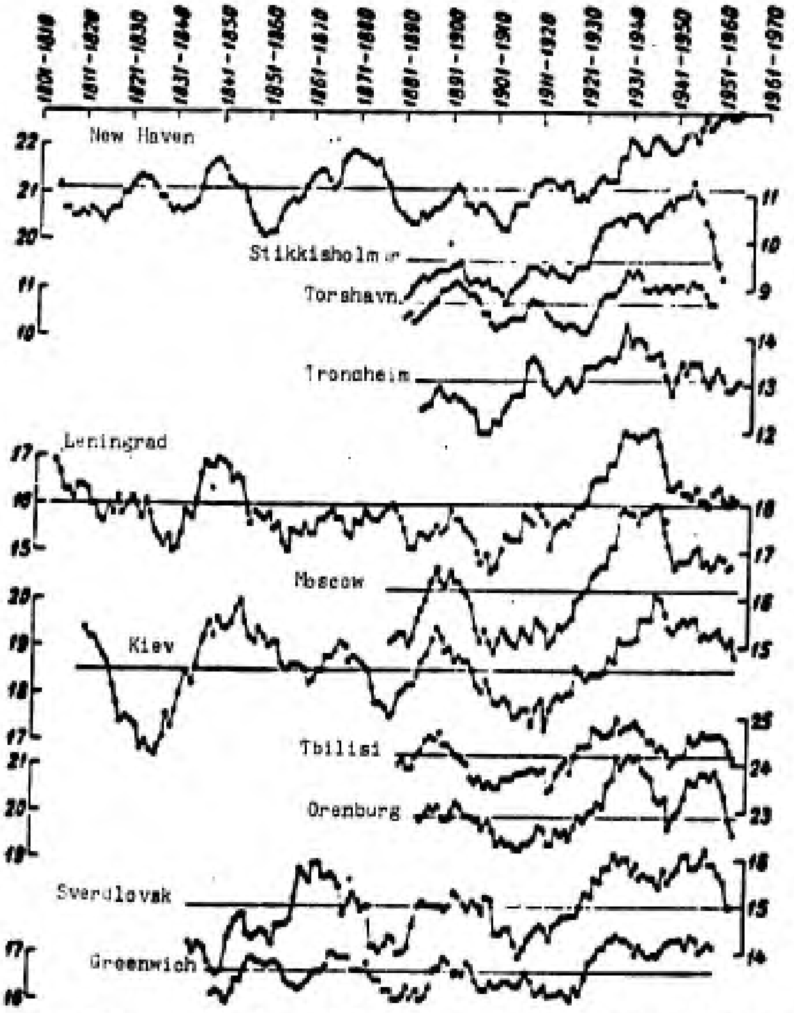


Fig. 15a. Moving 10-year mean temperatures. August.

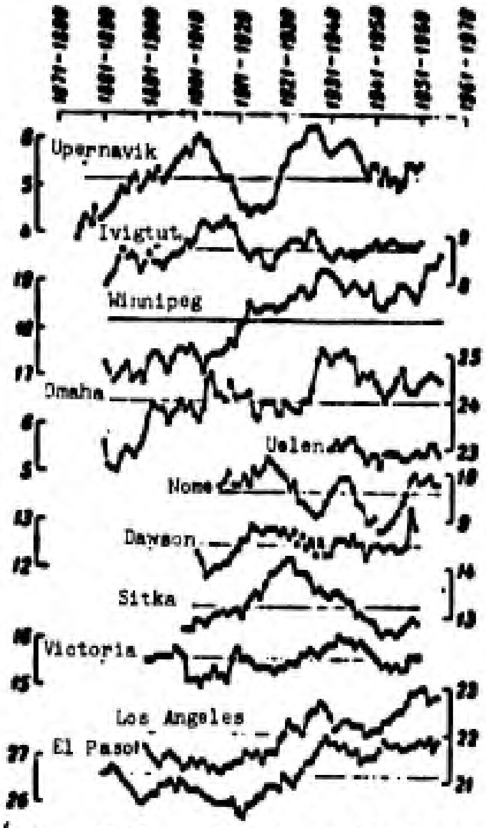


Fig. 15b. Moving 10-year mean temperatures. August.

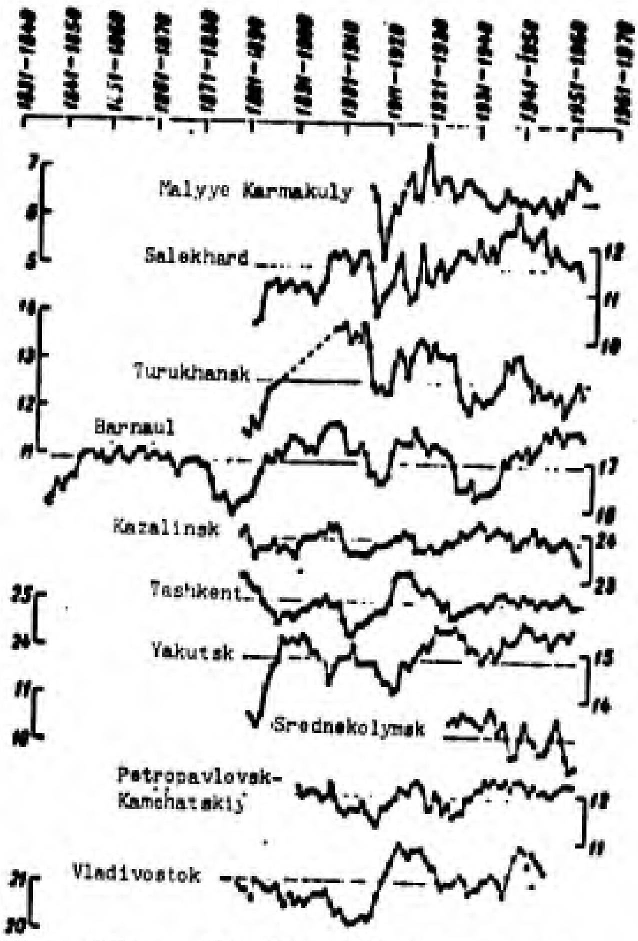


Fig. 15c. Moving 10-year mean temperatures. August.

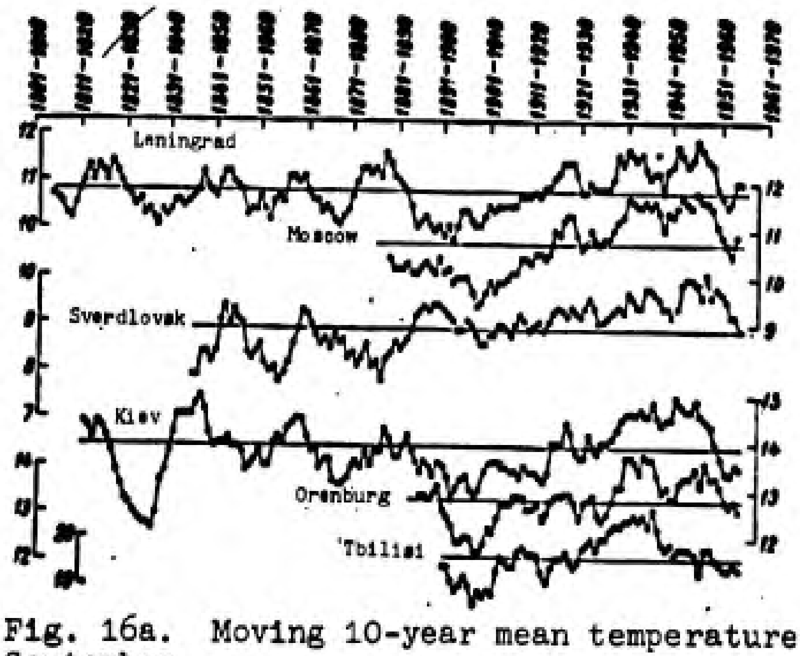


Fig. 16a. Moving 10-year mean temperatures. September.

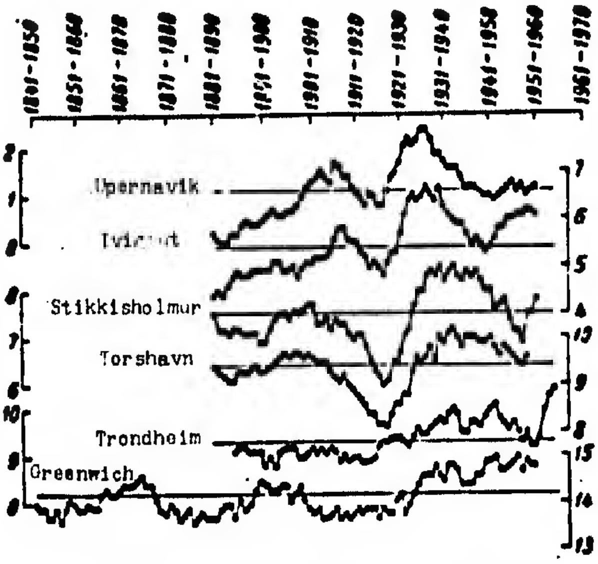


Fig. 16b. Moving 10-year mean temperatures. September.

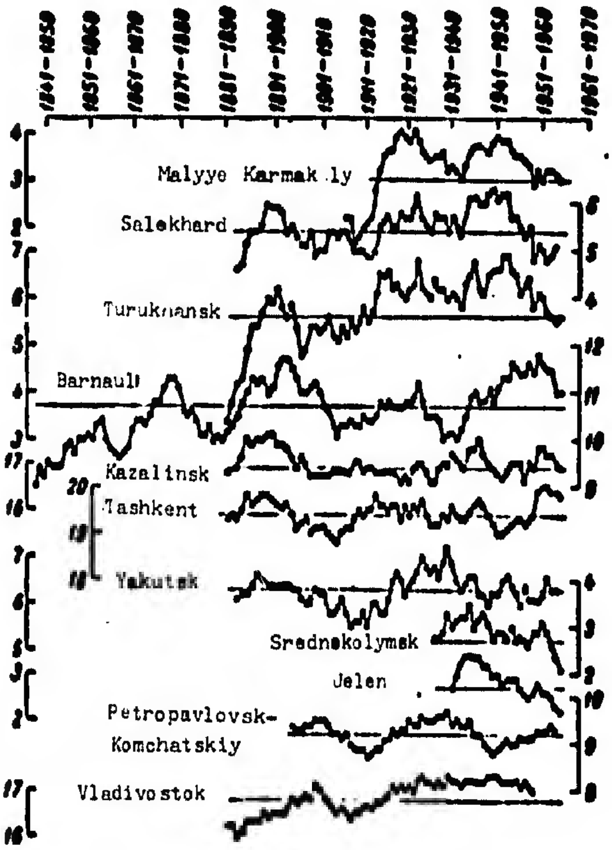


Fig. 16c. Moving 10-year mean temperatures. September

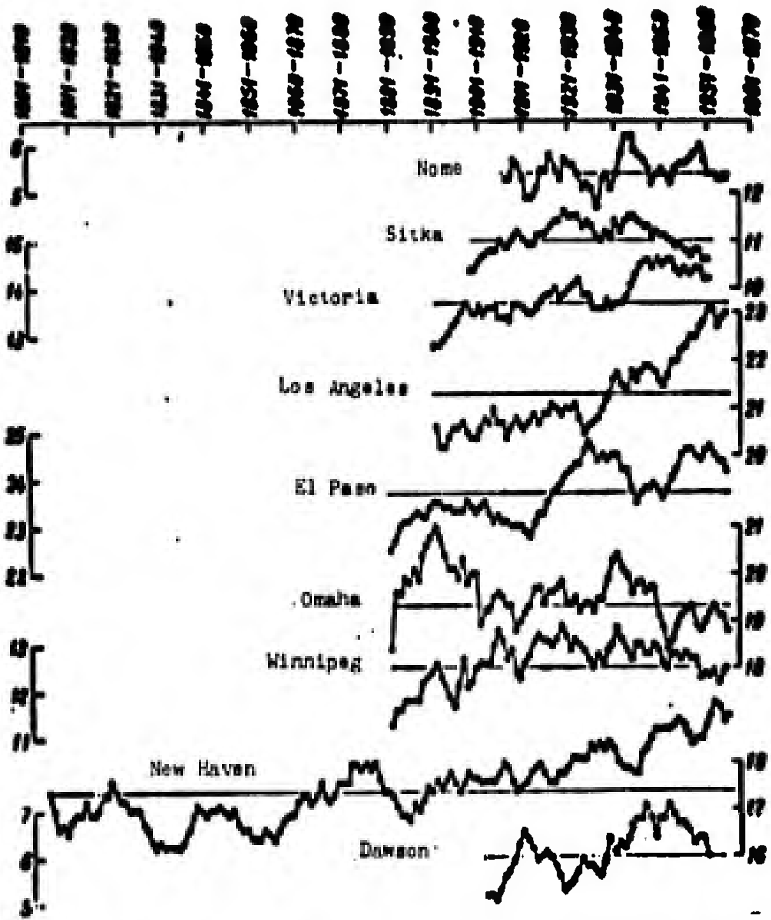


Fig. 16d. Moving 10-year mean temperatures. September.

in Los Angeles and El Paso is observed no longer.

October (Fig. 17a-17d). In this month there are already observed considerable variations similar in common features to the whole territory of Eastern Europe and Trans-Urals. The greatest amplitude of variations is observed in the middle belt (Kiev, Orenburg, Moscow, Sverdlovsk). If in the first two more southern regions variations occur near the level of the perennial mean temperature, then in more northern regions there is a well-marked trend toward an increase in the level of variations. At Kiev, having a series of observations of over 150 years, there is clearly expressed the cyclic recurrence of variations. In Western Europe there is a trend toward an increase in temperature. Variations of great amplitude are observed in Western Siberia (Salekhard, Turukhansk, Barnaul), where in the current century the mean level of variations is higher than that of the perennial mean.

In the extreme northeast of the Soviet Union and northwest of North America the considerable warming of October, observed approximately up to the decade 1936-1945, was changed by an intense omnipresent temperature drop from Srednekolymsk to Dawson. This is expressed somewhat weaker in the southern regions of Canada (Sitka and Victoria).

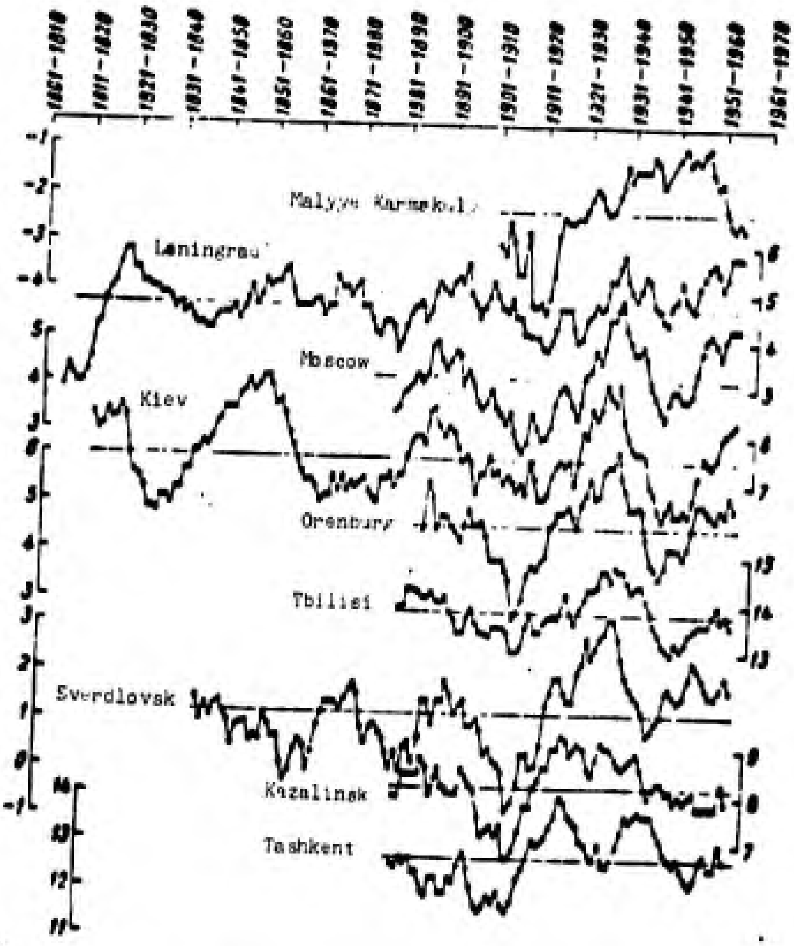


Fig. 17a. Moving 10-year mean temperatures. October.

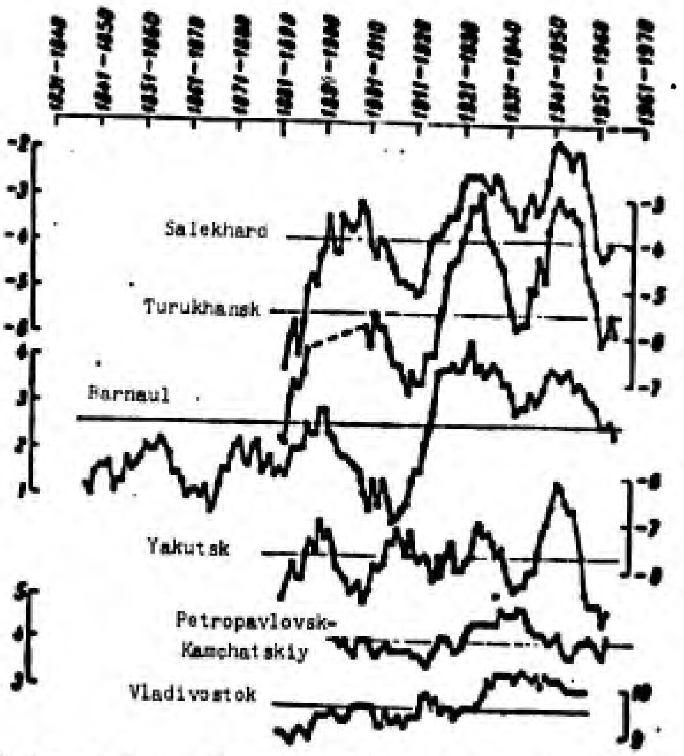


Fig. 17b. Moving 10-year mean temperatures. October.

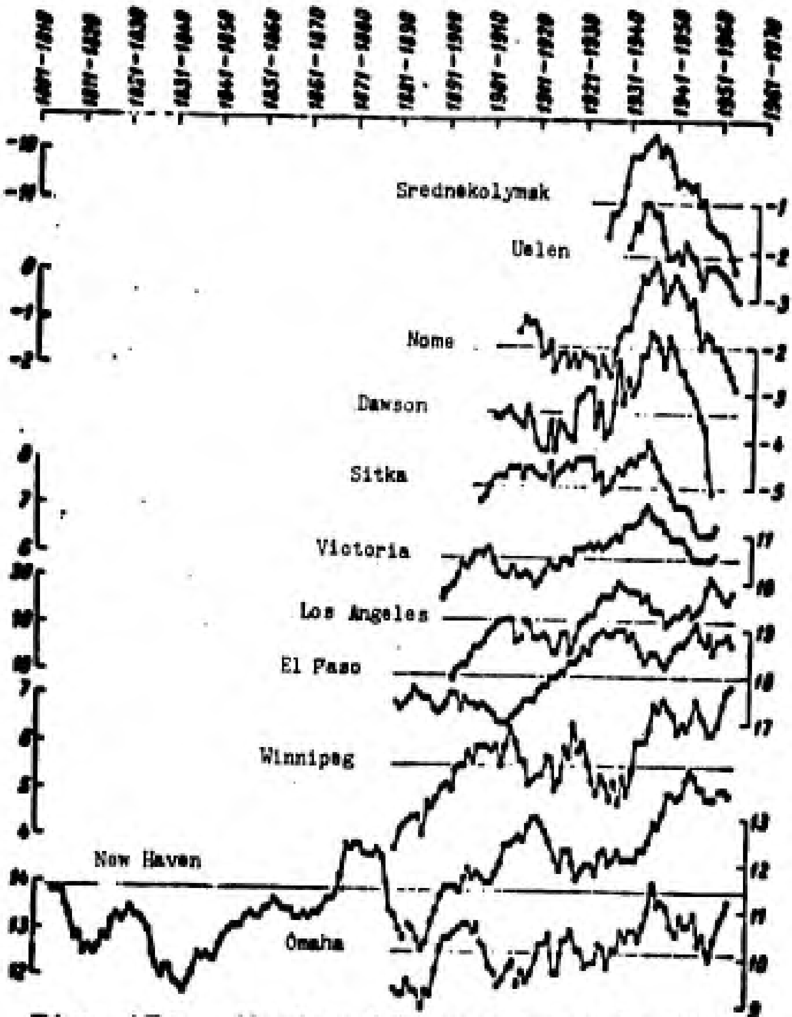


Fig. 17c. Moving 10-year mean temperatures. October.

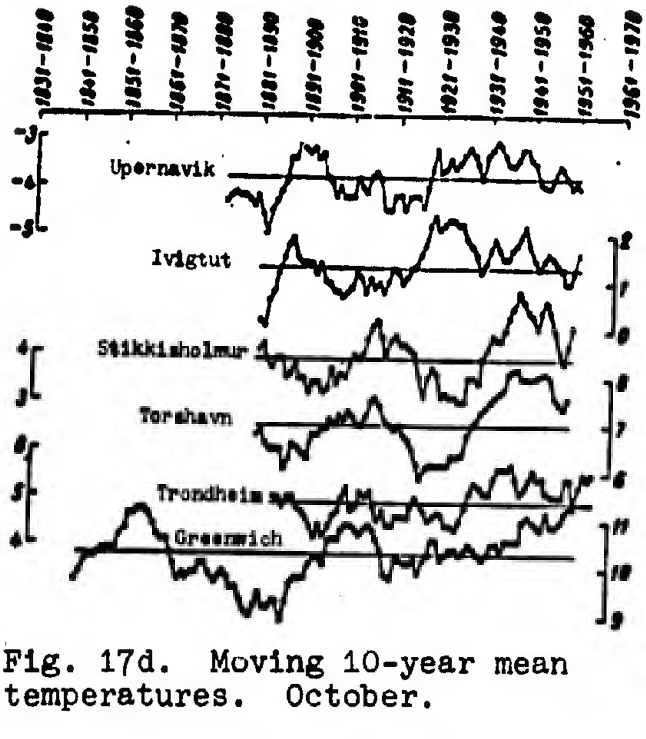


Fig. 17d. Moving 10-year mean temperatures. October.

In the remaining regions of North America, from the end of the last century there is observed a considerable increase in the level of variations in temperature at New Haven, having a series of observations of over 150 years, and this increase in temperature is traced even from the middle of the 19th Century.

Considerable synchronous variations are observed in regions of Iceland (Stikkisholmur) and Faeroes Islands (Torshavn), which do not occur in all months of the year.

November (Fig. 18a-18d). For this month there is characteristic, together with oscillations of great duration and amplitude, an extreme variegation of curve shapes. This conditions the presence of synchronism of variations between regions only in comparatively short periods (3-4 decades).

In the European territory of the USSR and Trans-Urals from the end of the last century up to the decade 1922-1931 (in Leningrad – up to 1929-1938) there is a trend toward the increase in temperature, after which the trend changed sign and prior to the 1960's there was observed a considerable drop in temperature, but in recent years an increase again. In Tashkent from the beginning of the century the level of variations in temperature continuously drops.

An especially intense warming in November was observed in regions of Malyye Karmakuly and Salekhard (Fig. 18b). In Salekhard the mean 10-year temperature during approximately five decades was raised almost 9° and attained a maximum in the decade 1935-1944, after which was observed such an intense drop in temperature; however the temperature still did not reach the initial (the lowest) level of the 1880's.

A type of variation similar to that described above is observed in the regions of Turukhanska, Barnaul and Yakutsk (Fig. 18b). But here the maximum of warming is approximately a decade earlier, and from the decade 1944-1953 a rise in temperature started anew.

From the 1870's November in the region of New Haven warmed greatly (Fig. 18c). After a low temperature level in the last century with two deep minima (2.5-3.0° below the mean) from the decade 1866-1875 the temperature increased with insignificant variations and in recent years has held even 1° higher than that of the mean perennial. Such is the trend of variation in temperature in the region of the North Atlantic (Ivigtut, Stikkisholmur). In Upernavik from the 1890's the temperature increased with great variations. The maximum in the course of the temperature was in the 1930's. In regions Winnipeg and Omaha considerable variations were observed at the end of the last and in the beginning of the current century, and in the last four decades the variations are little (Fig. 18d).

December (Fig. 19a-19e). Just as in January, there was extremely intense warming in the regions of Upernavik, Malyye Karmakuly, Turkhansk, where the peak of warming in Upernavik was

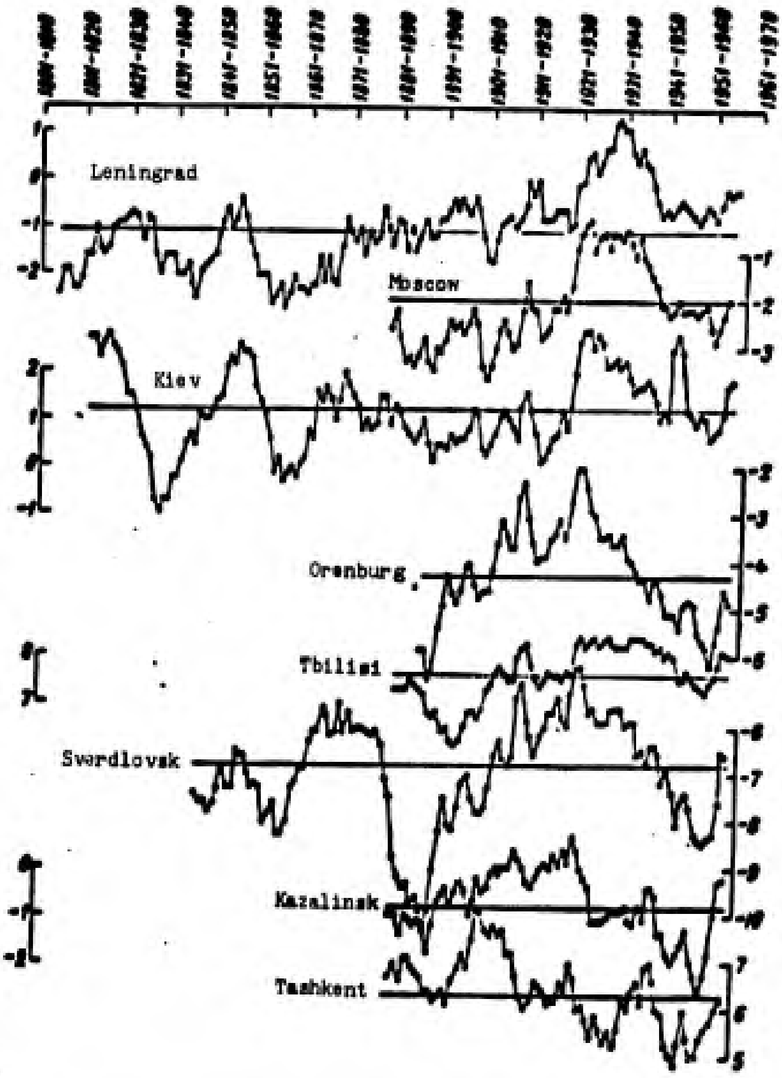


Fig. 18a. Moving 10-year mean temperatures. November.

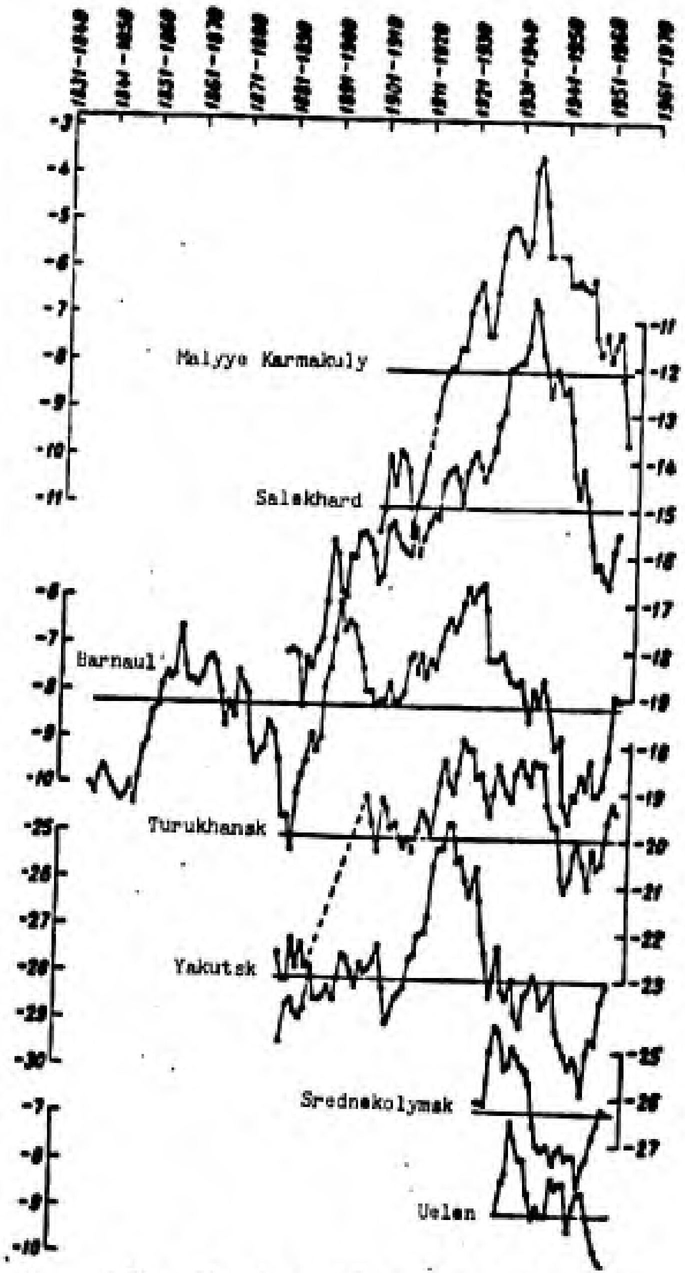


Fig. 18b. Moving 10-year mean temperatures. November.

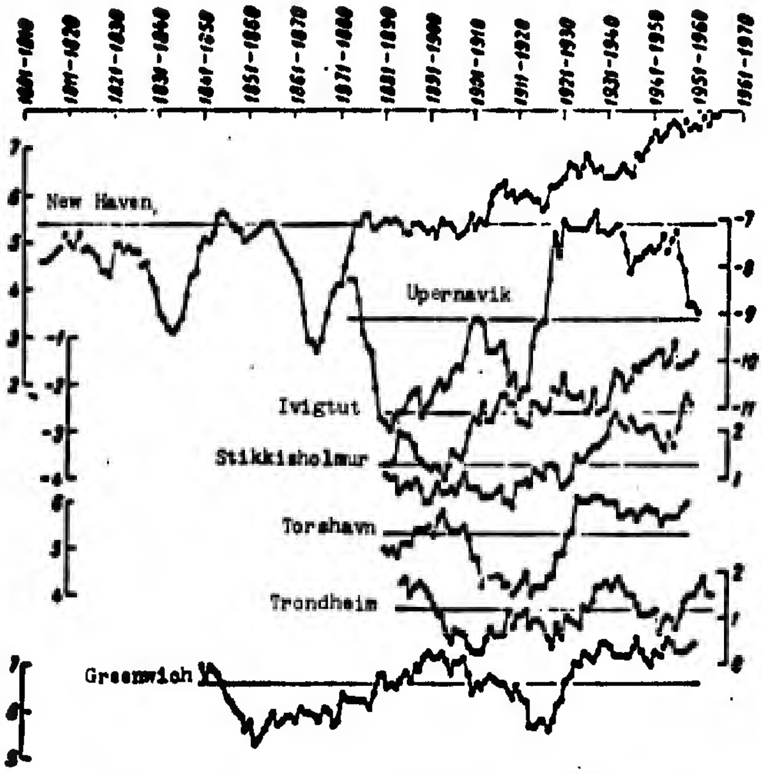


Fig. 18c. Moving 10-year mean temperatures. November.

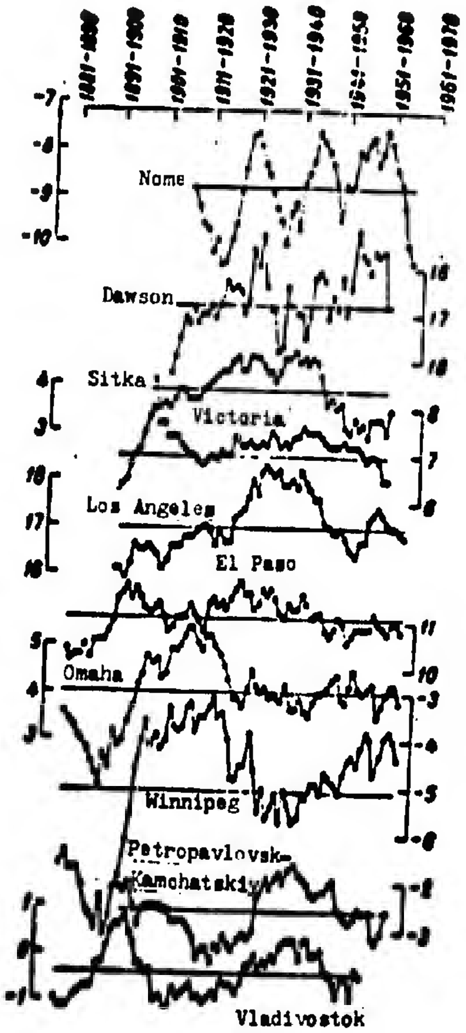


Fig. 18d. Moving 10-year mean temperatures. November.

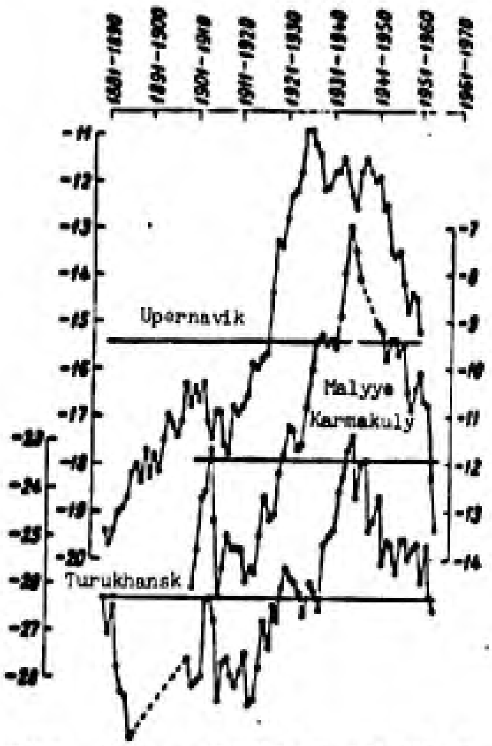


Fig. 19a. Moving 10-year mean temperatures. December.

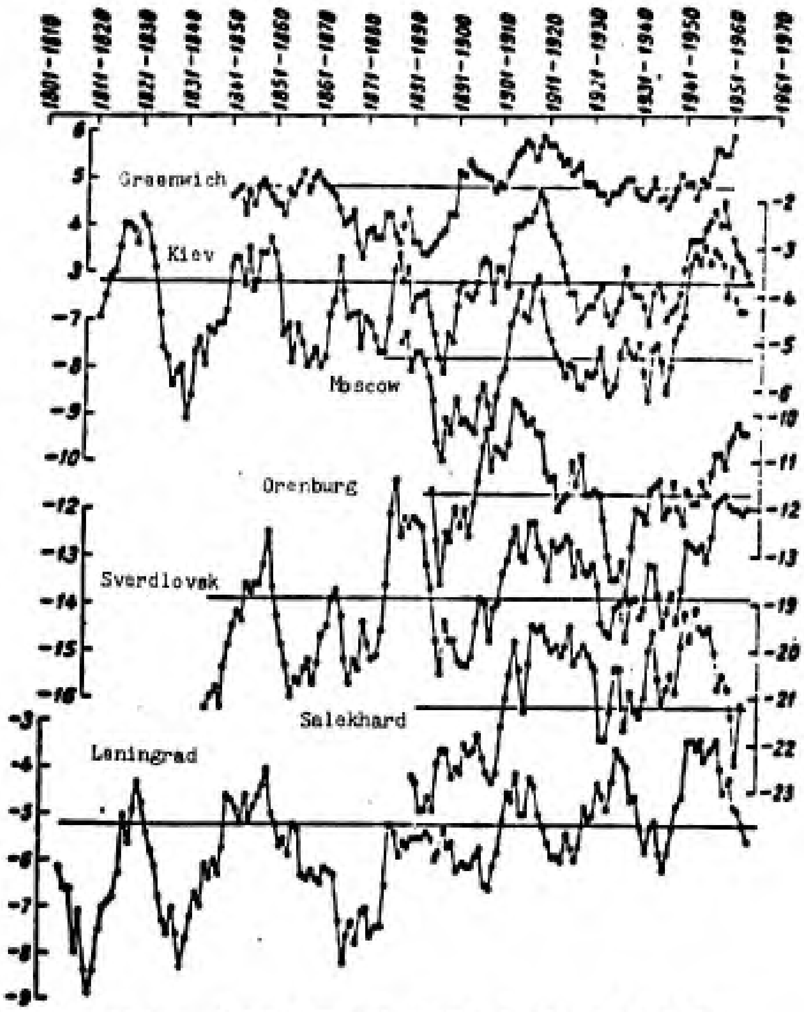


Fig. 19b. Moving 10-year mean temperatures. December.

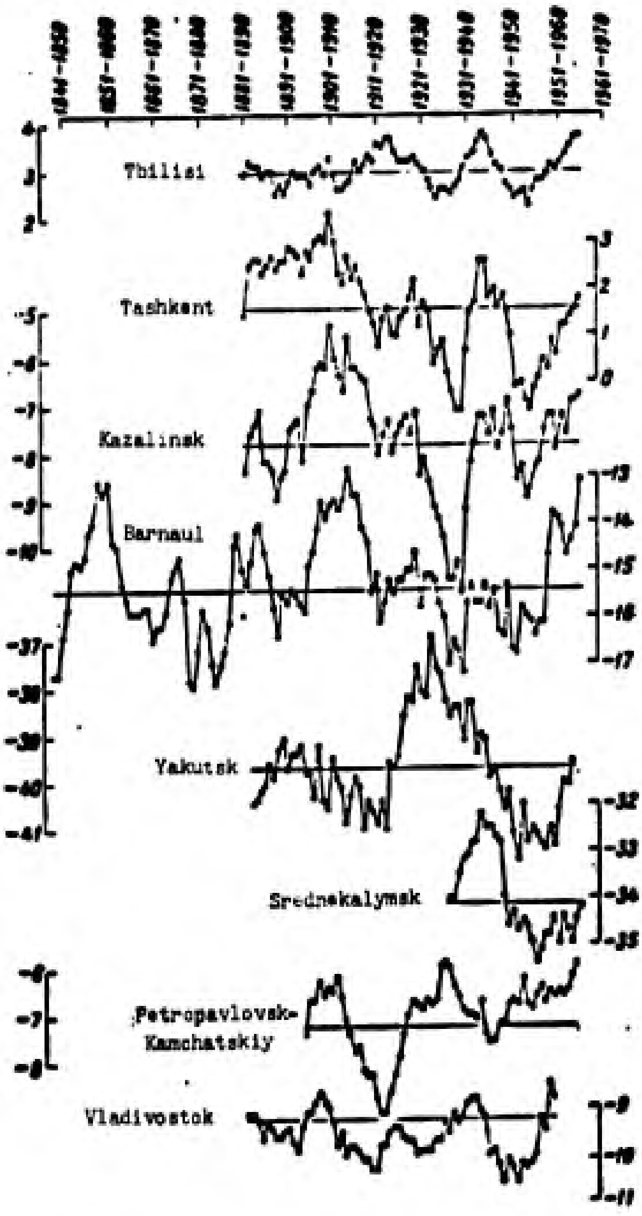


Fig. 19c. Moving 10-year mean temperatures. December.

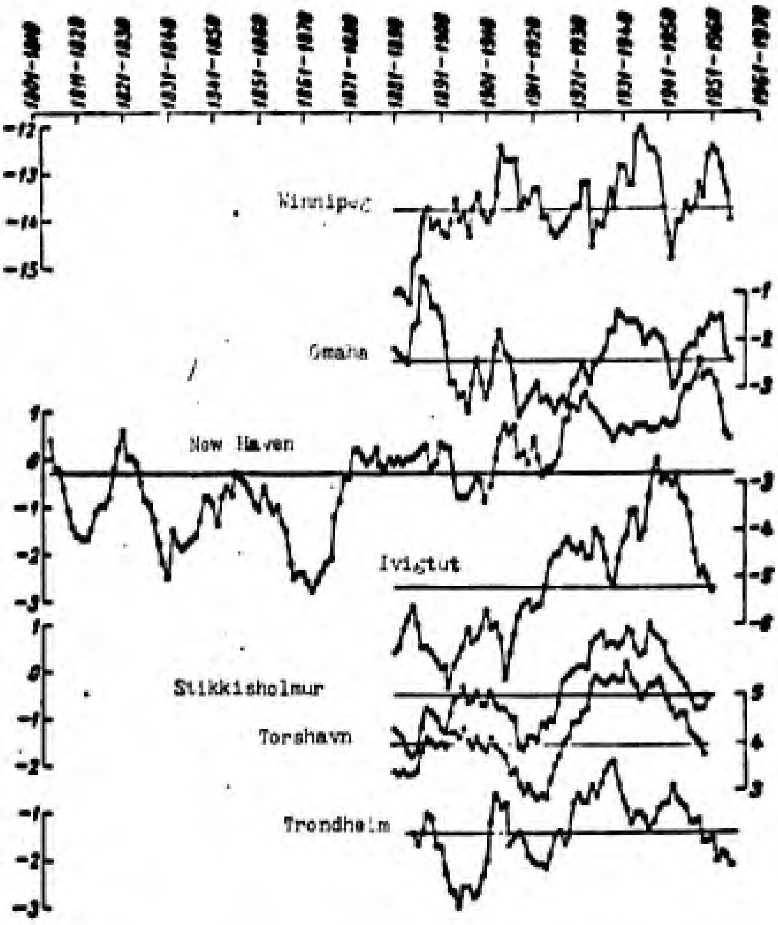


Fig. 19d. Moving 10-year mean temperatures. December.

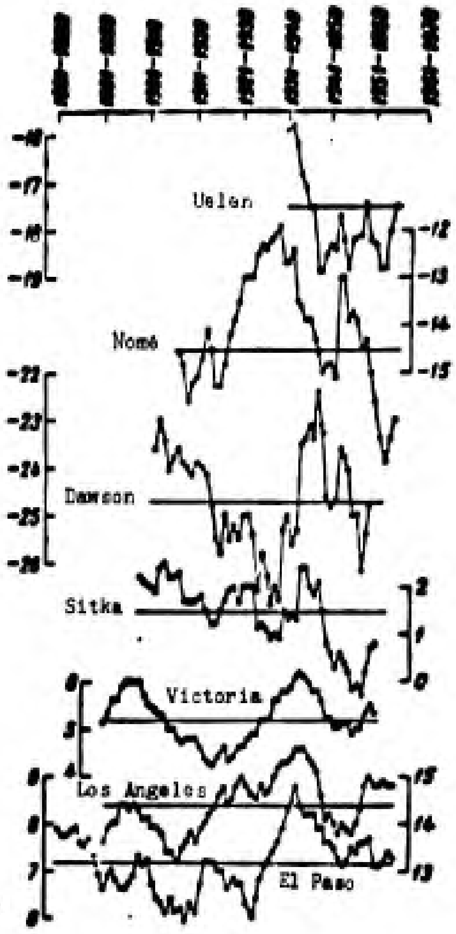


Fig. 19e. Moving 10-year mean temperatures. December.

observed earlier (1926-1935), and the most intense position of the temperature occurred at both stations synchronously and, as it is possible to judge according to Malyye Karmakuly, continues up to recent years.

In the southern part of Greenland (Ivigtut) the rise in temperature was more moderate, and a maximum was observed even later (1938-1947) than that at preceding stations (Fig. 19d).

The synchronous course of temperature in regions of Iceland and the Faeroes Islands in broad terms is more similar with the course of it in Upernavik, but the amplitude of variations here is a few times less.

There is a completely different character of variations in the territory of Europe (from Greenwich to Moscow). Here there were two peaks of warming in 1909-1918 and about 1946-1955 (Fig. 19b). To this group of regions can belong the region of Salekhard, but here the temperature drop after 1944-1953 is more intensive and in the last 10-year period the temperature attained the lowest level, from which in the 1880's warming began.

In America in December, as in the majority of the months, warming is observed in the eastern seacoast (New Haven). If one compares curves in Fig. 18c and 19d, then it is possible to note their great similarity in November and December, which is noted extremely rarely. Just as in November, after a deep minimum in the decade 1863-1872 there occurred a rapid in temperature and after the decade 1872-1883 variations occurred on a level exceeding the perennial average.

It is necessary to pay attention to the relativity of the concept "perennial mean temperature" and the judgements hence emanating. If for New Haven we are limited to an examination of variations for period of observations common for all stations, i.e., from 1881, then on the graph the line of the mean perennial would pass 0.6° higher, and it would have been possible to ascertain that in December were observed immaterial variations near this mean. Actually the mean level of temperature from the 1880's exceeds by 1.5° the level of the proceding 70 years. This example especially visually demonstrates the necessity of calculation of the maximum length of the series with calculation of the perennial average, if it is desired that this value include possible variations with the maximum accessible probability.

As can be seen from the examined figures, regions of synchronous variations in temperature occur a large territory where macroscale atmospheric processes dominate. It is known that in Europe such a process is heat transfer from the ocean - the influence of the Atlantic. Here there are distinguished two large regions of synchronous variations in temperature covering several thousand kilometers (for example, regions 2 and 3.) In the high and moderate latitudes of Asia the predominant process in the cold half of the year is the anti-cyclonic activity, and the great role in the formation of temperature background is played by the underlying surface, intensifying with this the influence of local conditions. All of this, apparently, in some degree determines the comparatively variegated picture of variations in temperature in regions of Central and Eastern Siberia and also the Far East.

In North America, on account of orographic and circulatory peculiarities, the influence of the Pacific and Atlantic oceans is limited to a narrow zone stretched along the seacoasts, and the continental regions are subject to the frequent Arctic intrusions. In connection with this in January and February there is distinguished an extensive region of monotypic variations in the continental part of the mainland, and in other months of the year the synchronism of variations is limited to comparatively small regions.

5. Analysis of Changes in Temperature in an Unregionalized Territory of the Northern Hemisphere

For a territory not enveloped by regionalization in the northern hemisphere (located chiefly to the south of 40° N. Lat.) let us give graphs of the variation in temperature for all months and the year according to certain stations with the most uniform series of observations.

Figures 20a-20f give curves of the variation in temperature for certain stations of the southern part of Asia. The densest network of stations is in Japan. Synchronism of the variation in temperature is observed in all months of the year on a great part of the territory (except the northern); a representative of this region is the station Sakai, and for the northern part (Hokhaido) – the station Nemuro. With a general distinction in the character of variations in temperature at stations Sakai and Nemuro in certain months of the warm half of the year (April, June, August, September) variation in these regions are synchronous. In individual months of the year there is not observed here any secular trend. But in the last two decades (up to 1960) the warming of almost all (except June and July) months, especially the winter (1° and more), is marked.

A general increase in mean annual temperature in the decade 1948-1957 is indicated by Yamamoto (1960), and Aracava (1961) considers the contemporary warming in Japan, which agrees with the increase in temperature for the entire Earth, indubitable.

In the territory of China for investigation there were taken data of the station Shanghai, which has the longest series of observations. Here in almost all months of the year(except January and June) there is a well-defined trend toward warming from the end of the last century, but in the last decades a temperature drop began (in Japan – warming).

From the published investigations it was not possible to obtain more detailed information about variations in temperature in China. It is possible to cite only the data of Duan' Yue-Vey[1] (1964) about a rather high positive correlation (r = 0.84) between the winter temperature of Asia and Europe but a negative one with North America. In the summer the correlation of temperature of Asia with the temperature of Europe is positive, and with the temperature of the Atlantic it is negative; with temperature in regions of the Pacific Ocean and North America the correlation is close to zero.

In India variations in temperature are small, but a secular trend toward warming is noticeable, especially in the winter months, and even in mean annual values (Fig. 20f). An analysis of data of the soil temperature in Bombay (at a depth of 60 inches), performed by Ramdas and Radjagopalan (1963), also showed a clearly expressed trend for all months toward a temperature rise during period of observations (from 1879 to 1925).

Of all the countries of the Near and Middle East (except the United Arab Republic) it was possible to cite data only of the station Nikosia (Cyprus Island), where the series of observations is more or less uniform. As can be seen from Fig. 20, there are observed here insignificant variations near the mean level.

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[1] This Chinese name is transliterated from the Russian. [Trans. Ed. Note]

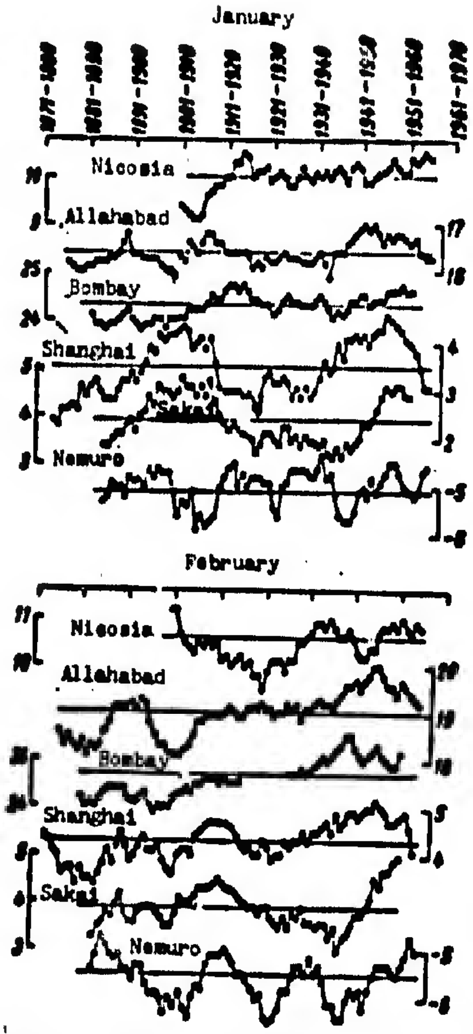

Fig. 20a. Moving 10-year mean temperatures. January, February.

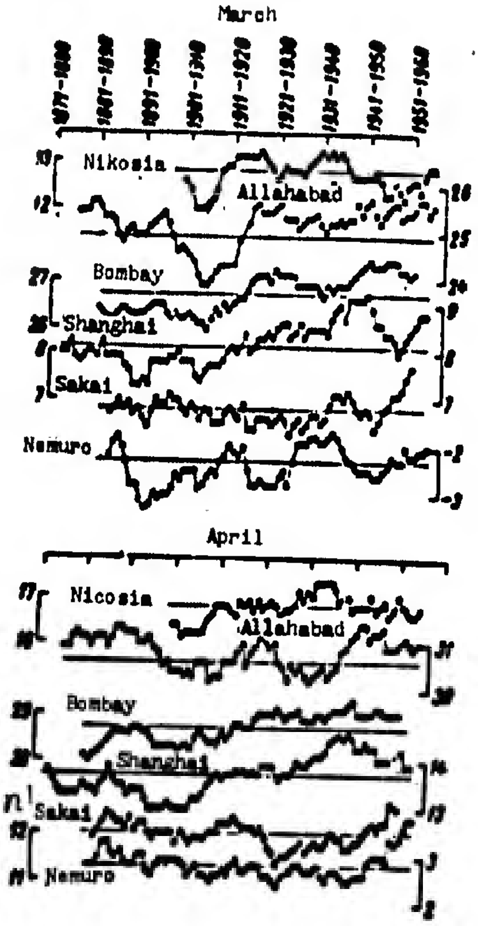

Fig. 20b. Moving 10-year mean temperatures. March, April.

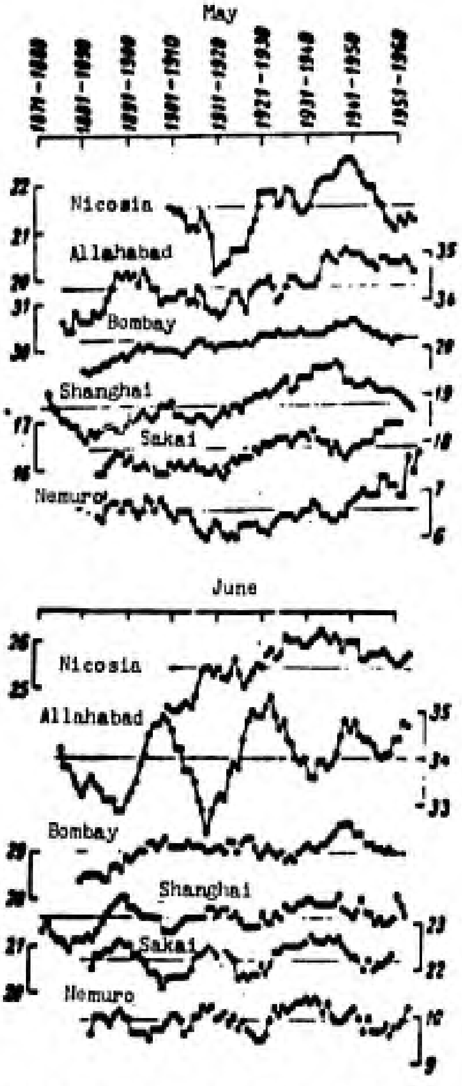

Fig. 20c. Moving 10-year mean temperatures. May, June.

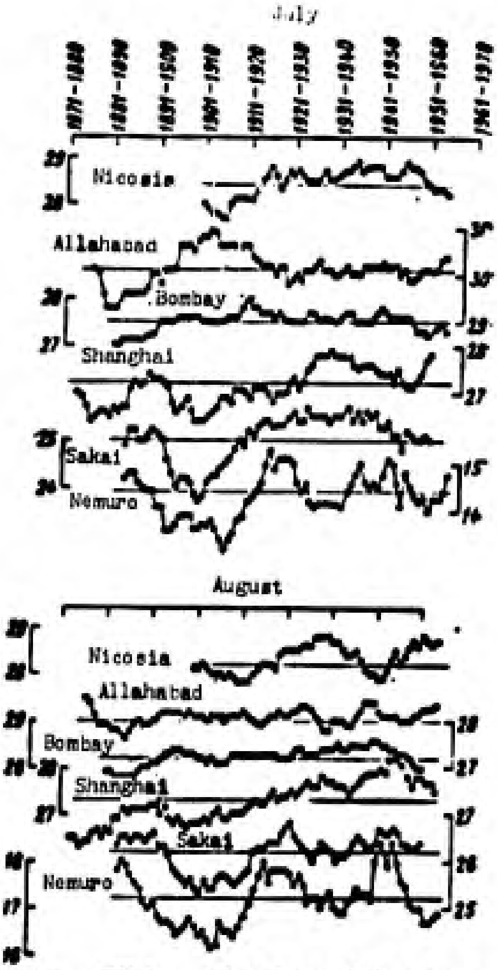

Fig. 20d. Moving 10-year mean temperatures. July, August.

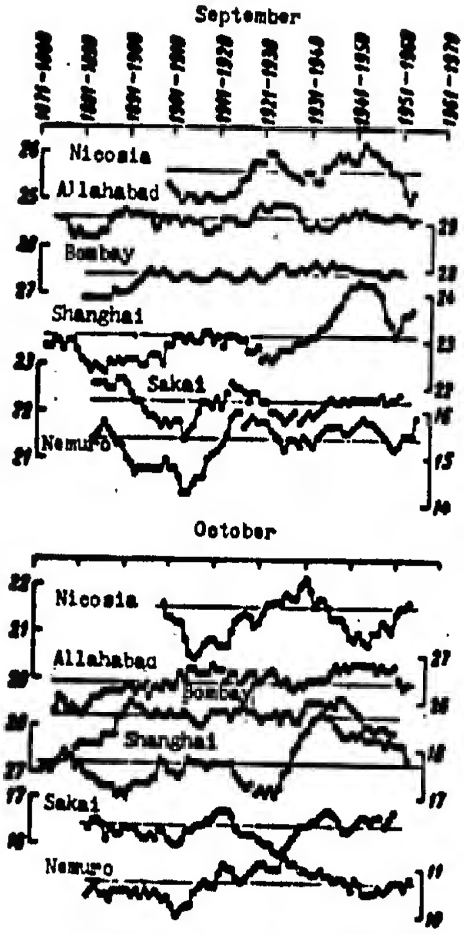

Fig. 20e. Moving 10-year mean temperatures. September, October.

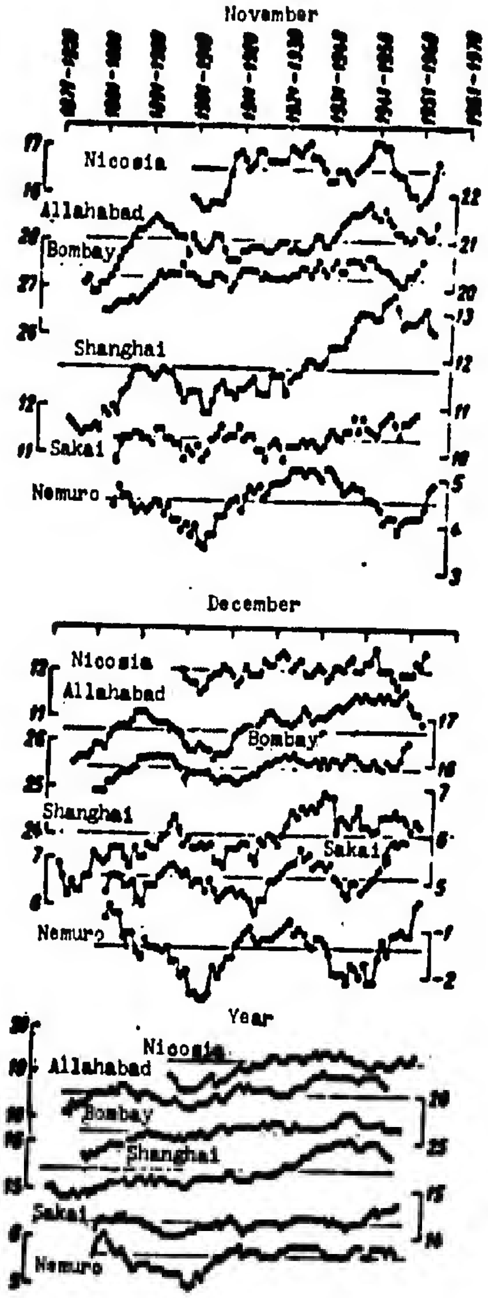

Fig. 20f. Moving 10-year mean temperatures. November, December. Year.

It should be noted that data cited at the Rome symposium (Rosenan, 1963) on variations in temperature in the Near East are based on very nonuniform series of observations (Beirut, Alexandria, Cairo, Jerusalem). Although the author makes reservation about the "low degree" of homogeneity of the initial data, he still considers it possible to use them, referring to the coordination of trends and the identity of the sign of their change from station to station according to their geographic position.

One should refer to such kind of data with great caution, since with the insignificance of variations in temperature the role of heterogeneity increases, and it is possible to reveal false trends.

On Fig. 21 curves are given of the variation in temperature of stations located in the examined latitudinal zone on islands of the Atlantic and the Pacific Oceans. These curves indicate the evident increase in temperature at Funchal (Madeira Island and Honolulu, Hawaiian Islands) in January and July. Such a trend in the variation in temperature is noted on islands of the Caribbean Sea (San Juan, graphs are not given here). But on the most northern islands of this zone – the Azore (Ponta-Delgada) – variations near the mean level are very insignificant, and a trend toward an increase in the level of variation is not observed. At the same time on the Bermuda Islands, located somewhat farther south of the Azores in the western (open) part of the ocean, curves of the course in temperature indicate considerable variations, especially in July. Such variation in temperature at this station seems somewhat doubtful, but the available information on certain disturbances in the homogeneity of the series does not give bases for confirmation of these doubts.

Variations in temperature over vast expanses of oceans cannot be judged according to several insular stations. Brown (1953, 1963), in trying to obtain data on perennial variations in temperature over the Atlantic, used a great quantity of ship observations of the period 1880-1959 (with considerable omissions) and calculated the 10-year mean temperatures for 5-degree latitudinal-longitudinal squares.

Let us the give basic results of his investigations, which, in spite of thorough critical analysis of rather variegated initial material, can be assessed only as tentative.

Brown showed that in the zone 70-60° N. Lat. in the Atlantic there is a well-marked trend toward the increase in annual temperature of the air and water from the beginning of the current century to 1930-1939 in the eastern part of the ocean and to 1940-1949 in the western part (farther south of Iceland). This agrees with data of mainland and insular stations, about which it was mentioned above. In the zone of 60-30° N. Lat. the trends are less distinctly expressed, just as in the region to the west of Ireland.

More complete data for the period of 1880-1949 are given by Brown in his last work (1963) for the tropic zone of the Atlantic (30° N. Lat.-30° S. Lat.). According to the course of trends of

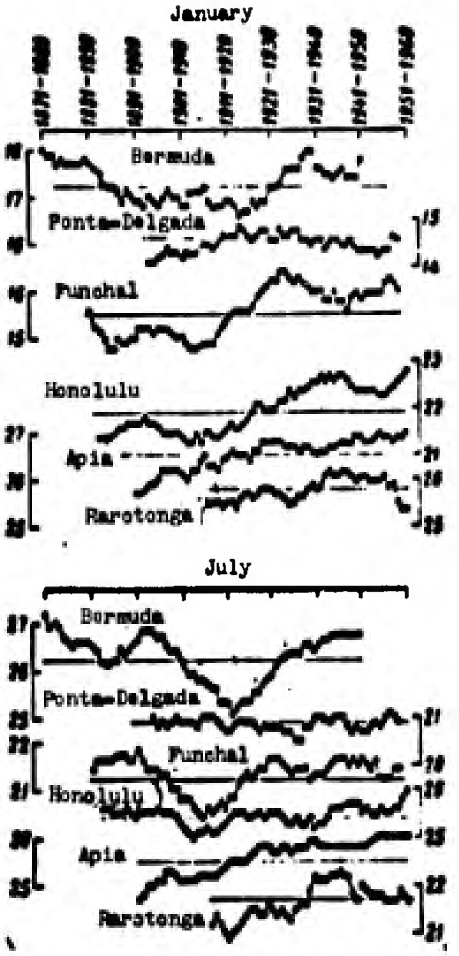

Fig. 21. Moving 10-year mean temperatures. January, July.

variations of the 10-year mean annual temperature, this zone is divided into three regions:

I) north of the equator where a temperature drop from the end of the last century to 1910-1919 was observed, and then a warming to the end of the examined period of observations;

II) farther south of 5° S. Lat. the southwest part where slight variations were observed, especially near the southern border of the zone, but in the majority of the squares after the 1920's there predominated a trend toward an increase in temperature;

III) farther south of 5° S. Lat. the southeast part where there predominates the trend toward a general slow increase in temperature up to 1930-1939 or 1940 to 1949.

Generalizing Brown's results, it is possible to note the good coordination in variations in annual temperature of the air and water and the general trend toward an increase in temperature in the tropic regions of the Atlantic approximately from the decade 1910-1919. With this the character of variations in the period 1880-1949 is distinguished in various regions of the examined zone, which is confirmed also by data of insular and coastal stations.

Unfortunately, analogous investigations on the Pacific Ocean are unknown, but data of insular stations of Honolulu, Apia (Samoa Islands) and Rarotonga (Cook Island), shown in Fig. 21, also indicate a considerable secular trend of the increase in the mean annual temperature. In Honolulu and Apia this trend is observed almost in all months of the year, but in Rarotonga it is more pronounced in winter months.

Variations in temperature in the tropic latitudes of the Indian Ocean can be judged only hypothetically, since the available frequently incomplete series of observations on the Seychelle Islands and Madagascar have considerable heterogeneity, and in the eastern part of the ocean, in general, there are no stations useful for investigation of variations climate.

In Indonesia the long series of observations of Jakarta indicates a gradual increase in temperature in all months (after 1940 the homogeneity of series is disturbed). A secular increase in temperature, as was already noted above, was observed at many other stations of this part of the Earth (Bombay, Calcutta, Honolulu, Apia and others). Indicating the continuous increase in annual temperature in Jakarta (1° from 1866 to 1940), De Boer and Euwe (1949) note that it is frequently tried to attribute this to "urbanization," but this is refuted by the fact that such a trend is revealed for rural and mountain stations of Indonesia.

6. Analysis of Changes in Temperature in Africa, South America and Australia

On continents of Africa, South America and Australia regions of synchronous variations in temperature, naturally, cover considerably less territory than those in the northern hemisphere. This is connected with the geographic position and dimensions of continents and the great influence on temperature of radiation factors as compared to circulatory ones, which strengthens the role of local conditions in variations in temperature. Therefore, for the mentioned continents there are not isolated regions of synchronous variations, but graphs are represented of the variation in temperature by stations having prolonged and as uniform a series of observations as possible.

It is necessary to consider that homogeneity of the series of observations at many stations of the southern hemisphere even more frequently than in the northern hemisphere is disrupted due to transfers, the change in quantity of periods of observation, incorrect setting of the quality of instruments.

Africa. In Africa the longest and most uniform series of observations in the moderate latitudes of the southern hemisphere is at Capetown. Given on Fig. 22a-22g are data up to 1955, since in this year the station was transferred, which introduced into the series of observations great heterogeneity. Variation in temperature in Capetown shows that with the general small range of secular variations of temperature, the most considerable variations are observed in the summer of the southern hemisphere, i.e., in months of the cold half of the year in the northern hemisphere. In all months of the year (except September) in Capetown there was observed a trend toward an increase in temperature at the beginning of the current or the end of the last. This trend in the majority of the months of the year was changed to the opposite approximately in those same year as in the northern hemisphere. The most considerable increase in temperature was observed in November, when the mean 10-year (1930-1939) temperature exceeded the perennial mean by 1.2°, and during three decades (from 1900-1909) it was increased 2.2°. In the same month as mentioned above and approximately in the same longitudinal zone (Malyye Karmakuly, Leningrad, Moscow, Kiev), exceptional warming of November was observed.

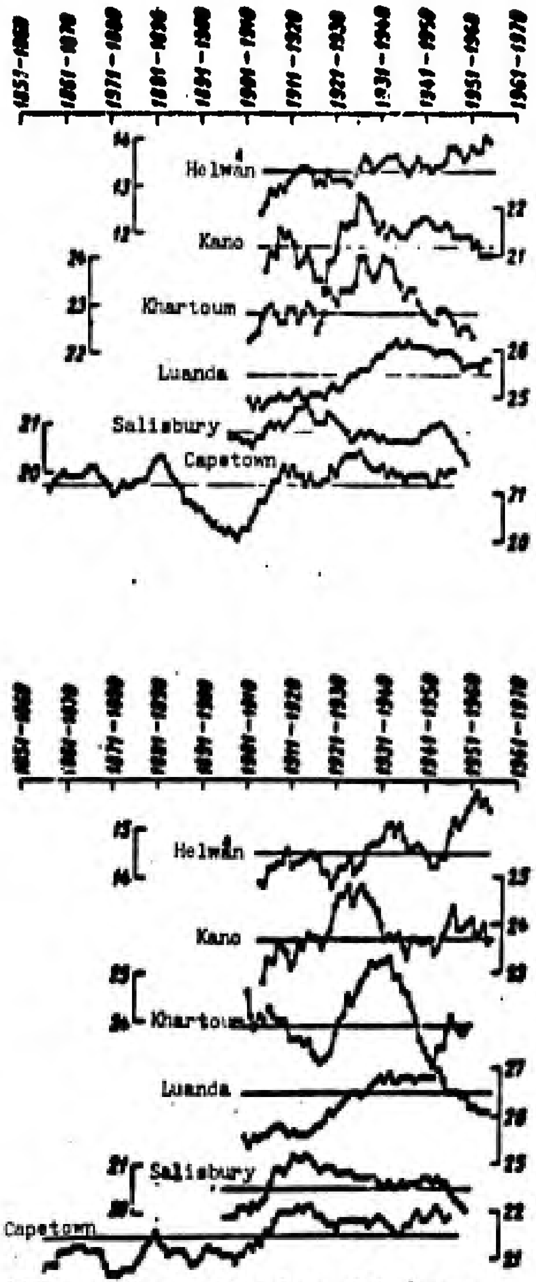

Fig. 22a. Moving 10-year mean temperatures. January, February.

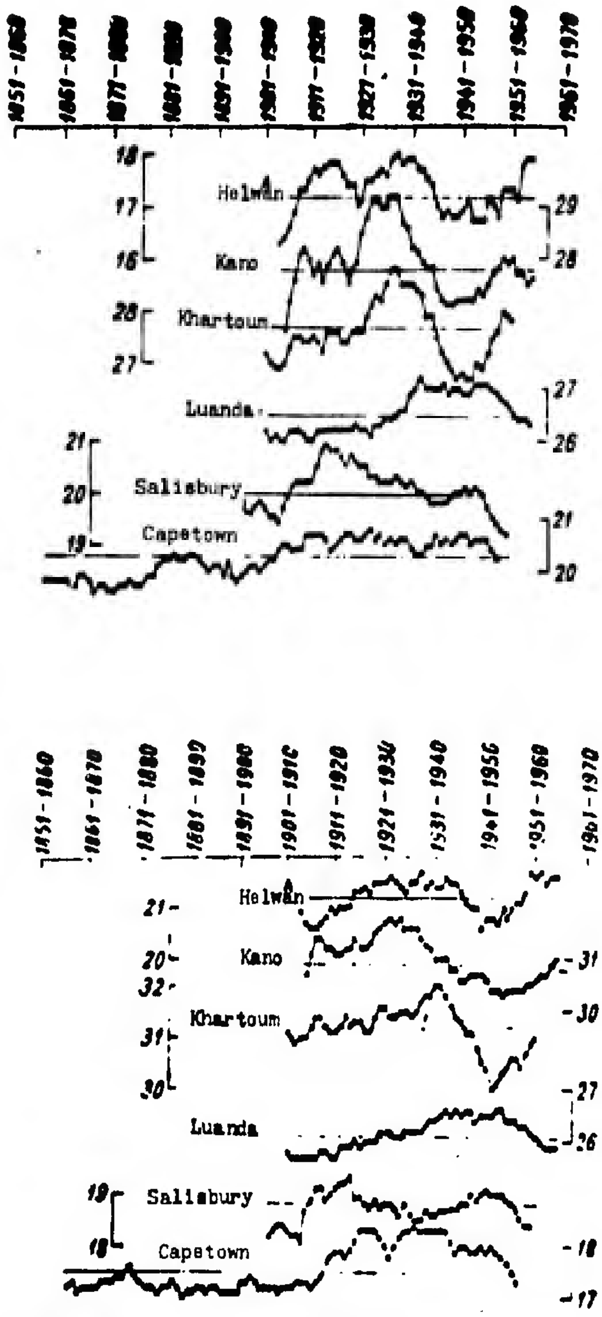

Fig. 22b. Moving 10-year mean temperatures. March, April.

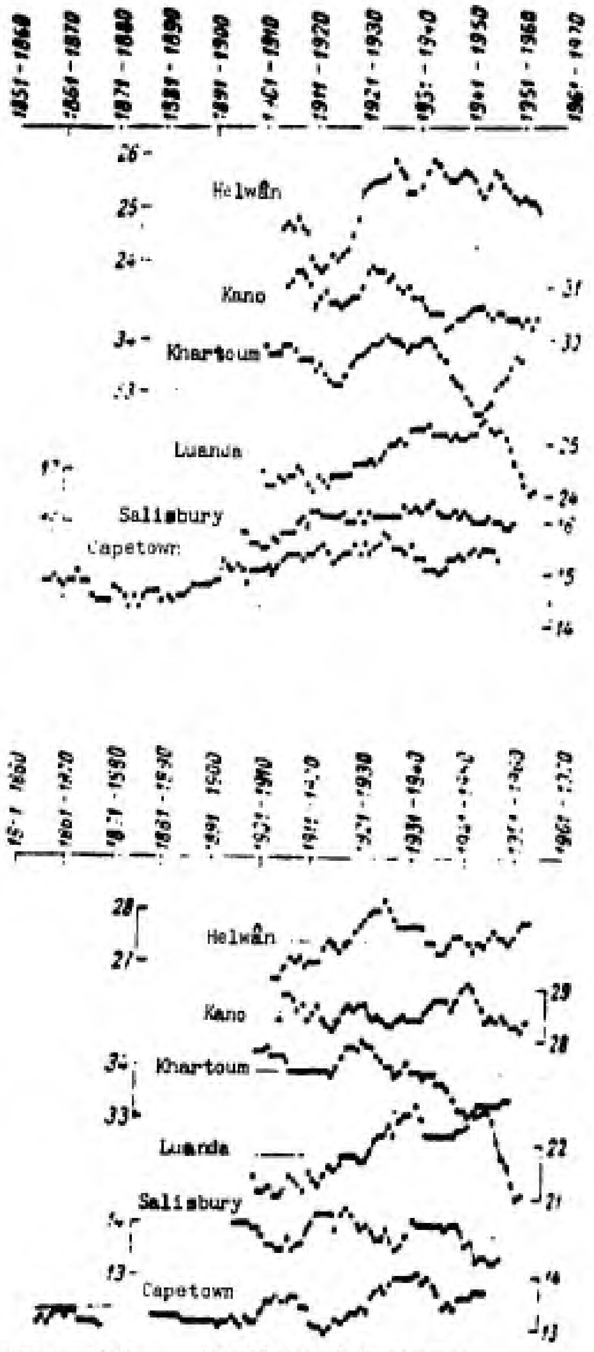

Fig. 22c. Moving 10-year mean temperatures. May, June.

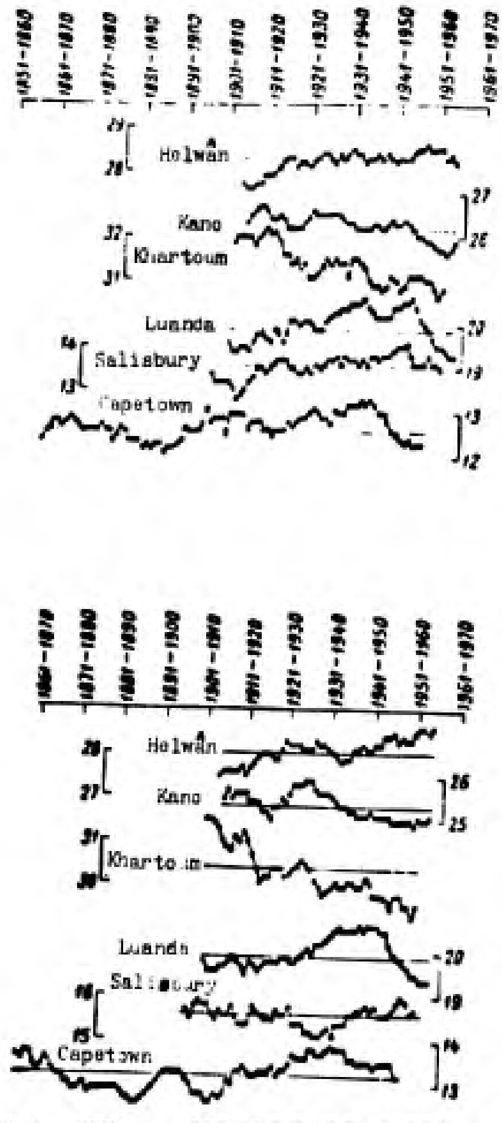

Fig. 22d. Moving 10-year mean temperatures. July, August.

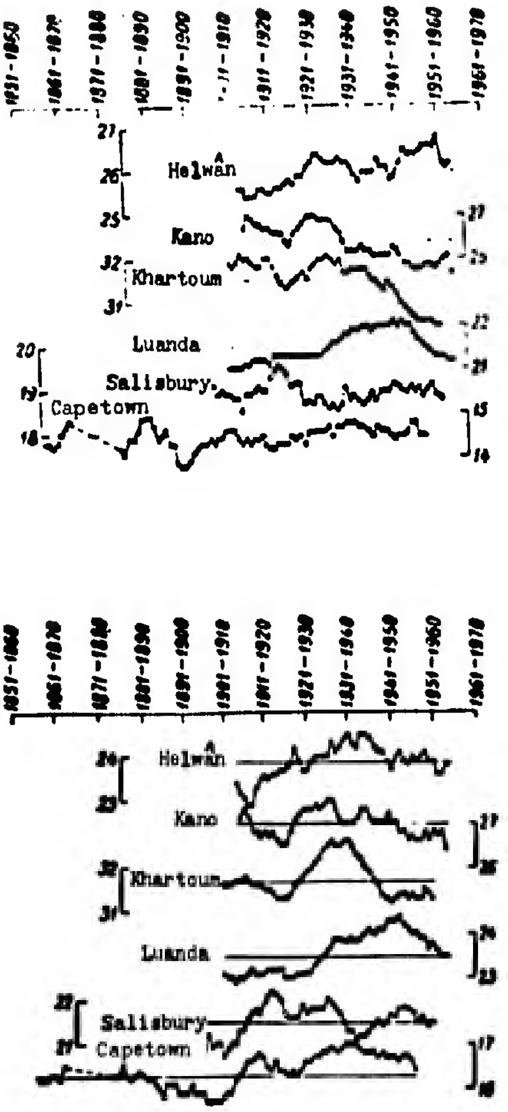

Fig. 22e. Moving 10-year mean temperatures. September, October.

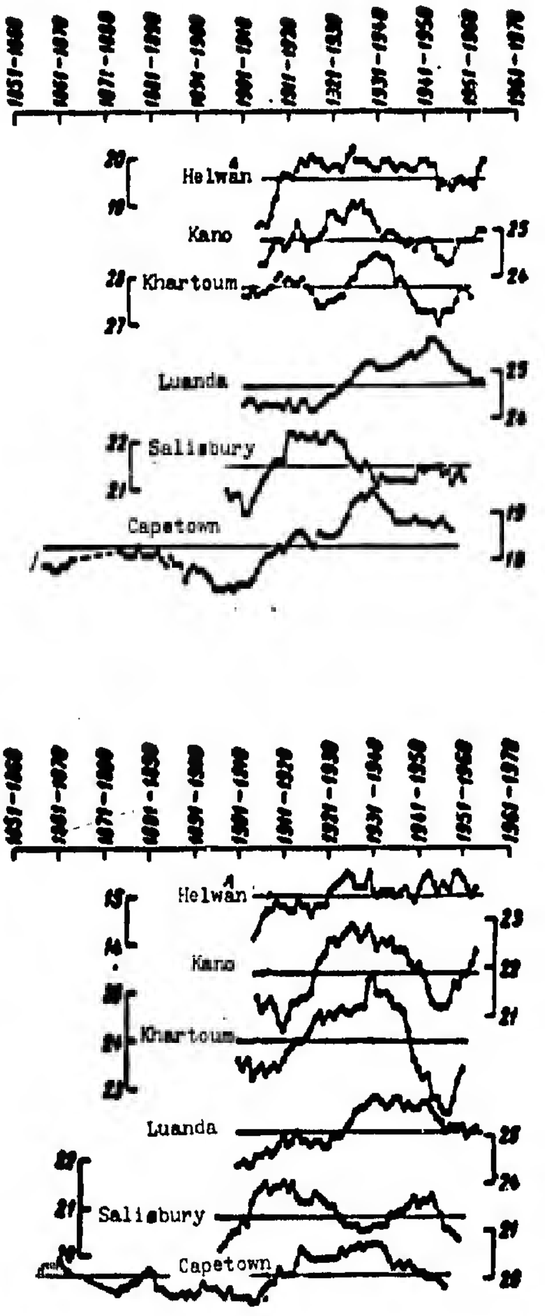

Fig. 22f. Moving 10-year mean temperatures. November, December.

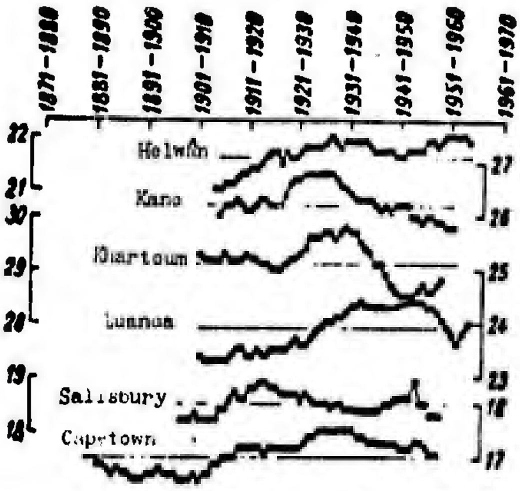

Fig. 22g. Moving 10-year mean temperatures. Year.

At the station of Helwân, located approximately at the same latitude that of Capetown but in the northern hemisphere, there is observed a weakly marked trend toward the increase in temperature only in the winter and summer months; in November the variations are insignificant. In continental regions of Africa (Kano, Khartoum) even in the low latitude (about 15° N. Lat.) there are observed considerable variations, which in the majority of the months are synchronous at the indicated two points. In winter and in the transition months the variations here do not have a clearly marked trend, but in the summer, from June up to September, it definitely is negative; the temperature drop of the summer, especially noticeable at Khartoum, reaches for example, 2° in August (from the beginning of the century).

On the western seacoast of Africa farther south the station Luanda is located. It is remarkable in the fact that the variation in temperature here is monotypic in all months of year and repeats, naturally, in a considerably smaller scale (in conformity with latitude) the scheme of warming and subsequent temperature drop at the same longitude in the northern hemisphere. The temptation of establishing such relationships is very great, but here the general character for all months of the course of temperature seem doubtful whether this is the result of the station transfer or other causes affecting homogeneity of observations.

As an average for the year the trend to warming is observed in two extreme points of Africa: southern (Capetown) and northern (Helwân). Regarding, however, continental regions, then here (Khartoum and Kano) there is a more pronounced temperature drop from the 30's of the current century.

In investigations of African climatologists a slight trend toward warming in North Africa during the last 50 years is noted (Dubief, 1963) and a considerable trend in South Africa in the period 1901-1930 (Hofmeyer, Schulze, 1963).

South America. The greater (northern) part of the continent has a very widely spaced network of stations with a long series of observations, from which not one was found useful for investigation of variations in climate.

South of the tropics the number of stations is greater, and it was possible to select several stations for investigation. Figures 23a-23f give graphs of the variation in temperature at stations of seacoasts of the Atlantic (Rio de Janeiro, Buenos Aires) and the Pacific Ocean (Santiago), within the mainland (Goya, Cordova), southern extremity of the mainland (Punta-Arenas) and the antarctic islands: South Georgia (Gritviken[1]) and South Orkneys (Orcadas).

In the course of the temperature on the seacoasts and mainland there is observed a noticeable trend toward an increase in temperature which is better expressed in the months from August to February.

In certain months (March-July) at the indicated stations (Buenos Aires, Goya and Cordova) there are observed considerable synchronous variations near the mean perennial level. On the Pacific Ocean seacoast (Santiago) the most intense warming is observed in the warm period from November to March, i.e., in the winter of the northern hemisphere. The mean 10-year temperature of these months was increased during 80 years on the average of 2°.

In Rio de Janeiro an increase in temperature was observed in all months except November and December.

At most southern stations (Punta-Arenas and islands) in the warm part of the year, from December to April, the trend toward an increase in temperature is absent, while at more northern stations such a trend is best expressed in precisely this period.

In January at these stations nearest to Antarctica there is even observed a trend toward a decrease in temperature. In the cold period of year (May-August) on the islands there were observed sharp variations in temperature, and the lowest temperatures in June and July at the most southern station (Orcadas) were observed in the 1920's and the highest, in the 1940's to the 1950's. The range of variations reached 5.5°, but the trends toward a continuous increase in temperature was not observed. Whether the variation in temperature in Antarctica have the same character is difficult to decide now since there are no sufficiently long series of observations. Nonetheless, certain authors (Wexler, 1959, 1961; Buynitiskiy, 1953, and others) confirm that in Antarctica, just as in the Arctic, warming occurred. It is true that these conclusions are insufficiently founded. Aver'yanov (1960), for example, to solve the question of warming of Antarctica, compares the temperatures at Mirnyy and at the earlier operational station in Queen Maud Land and on this basis draws conclusions about warming by 9-10°, which is unlikely. Apparently, the question here is not in the change in temperature with the flow of time, but in different local conditions of these stations.

What such great differences of temperatures, depending upon local conditions, are possible can be seen from a comparison of parallel series of observations at stations McMurdo and Scott.

According to data of the station Little America it is also impossible to judge the warming of Antarctica, as is done by Buynitskiy and Wexler. If one were to examine a series of

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[1] This name is not verified. [Trans. Ed. Note]

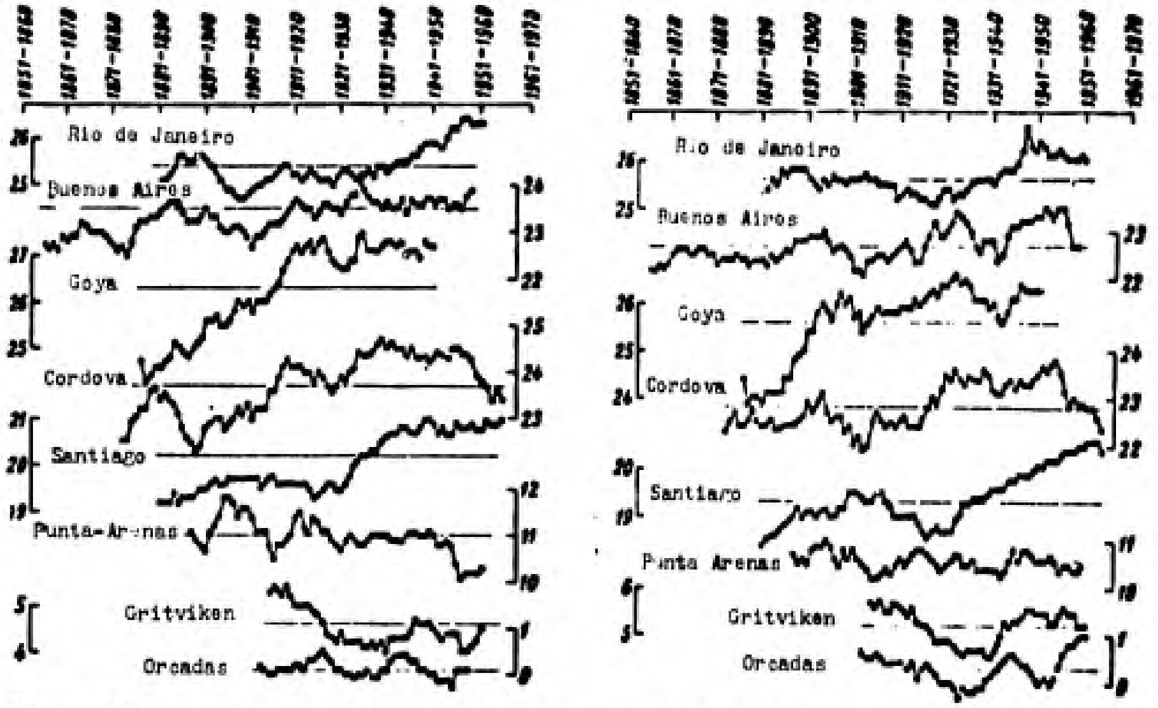

Fig. 23a. Moving 10-year mean temperatures. January, February.

Fig. 23b. Moving 10-year mean temperatures. March, April.

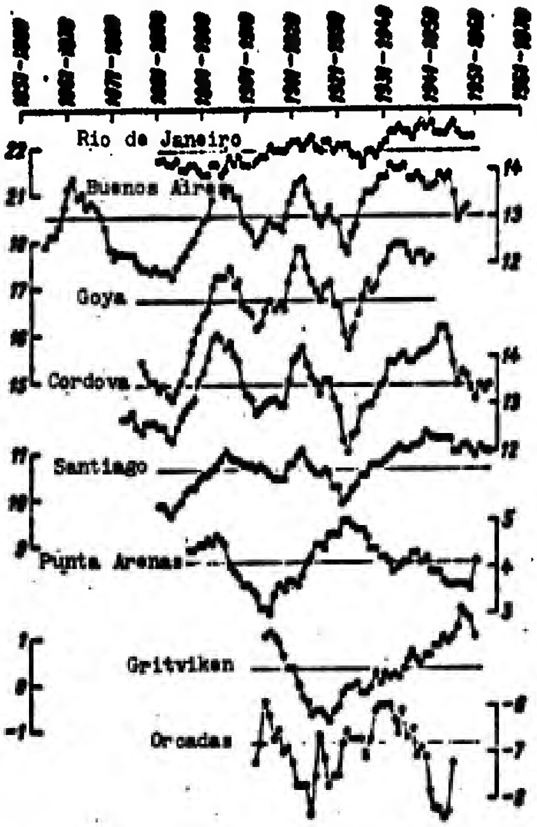

Fig. 23c. Moving 10-year mean temperatures. May.

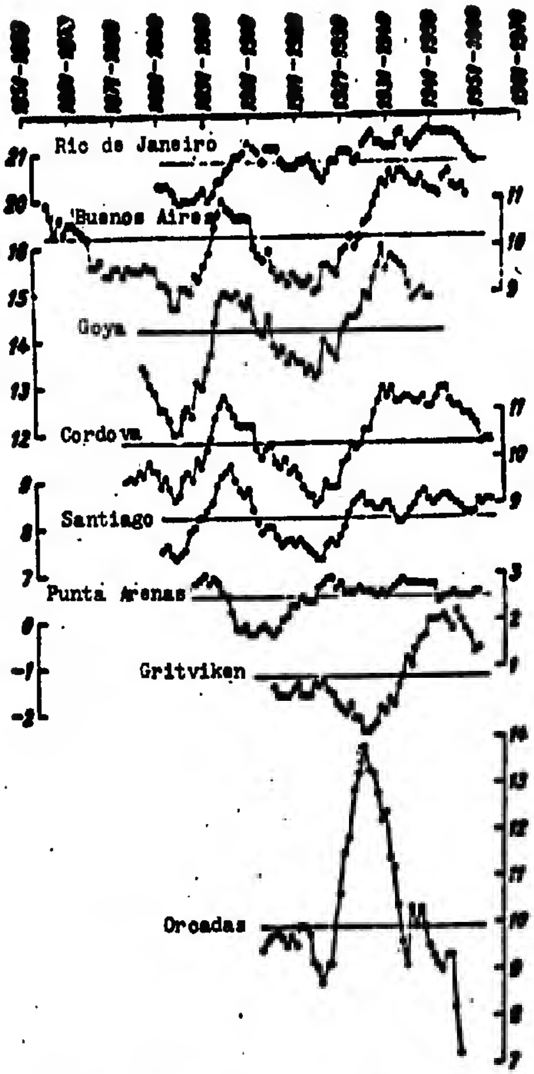

Fig. 23c. Moving 10-year mean temperatures. June.

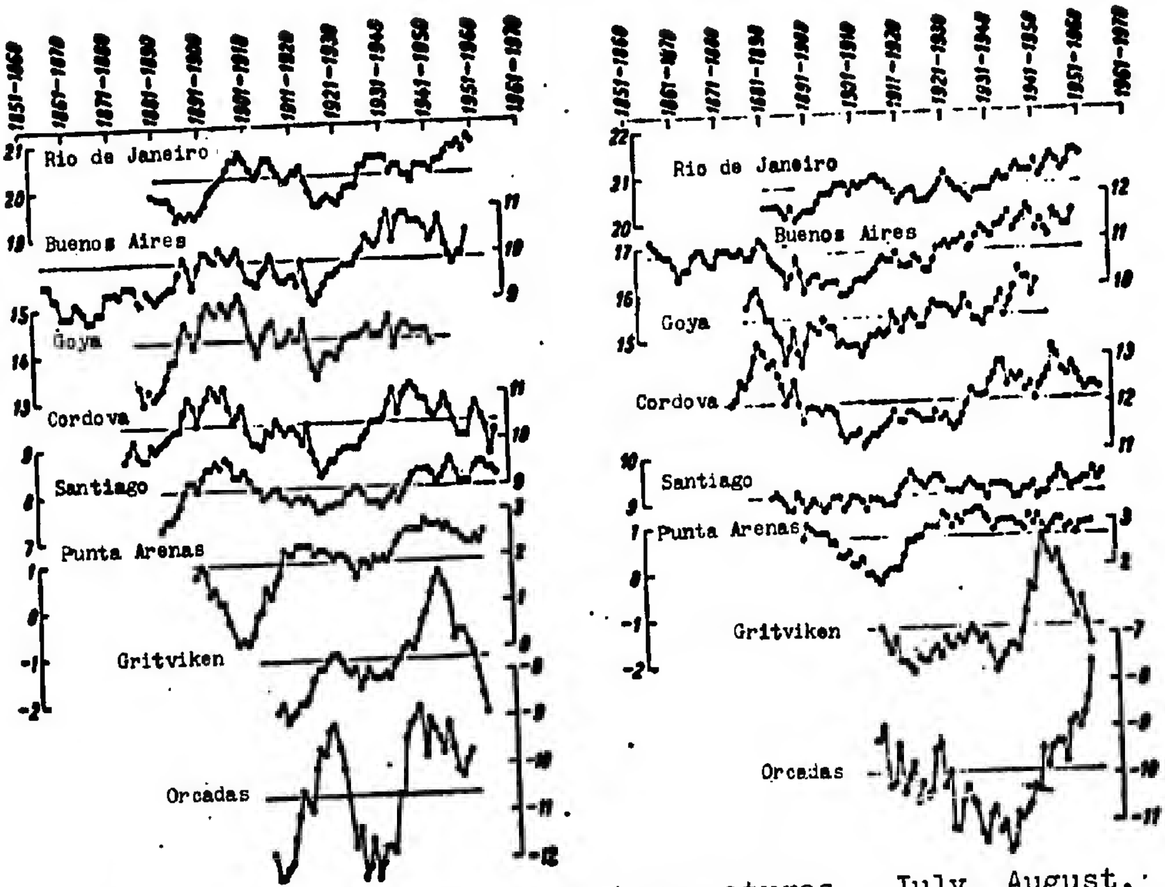

Fig. 23d. Moving 10-year mean temperatures. July, August.

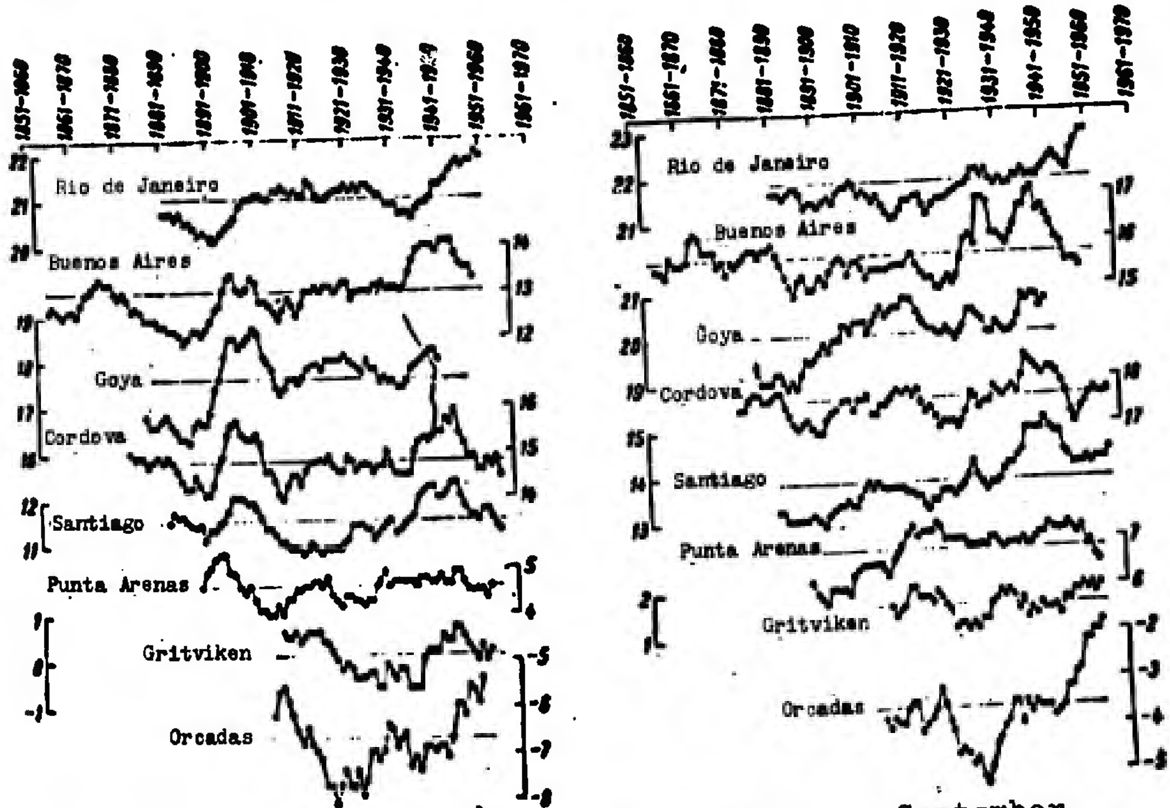

Fig. 23e. Moving 10-year mean temperatures. September, October.

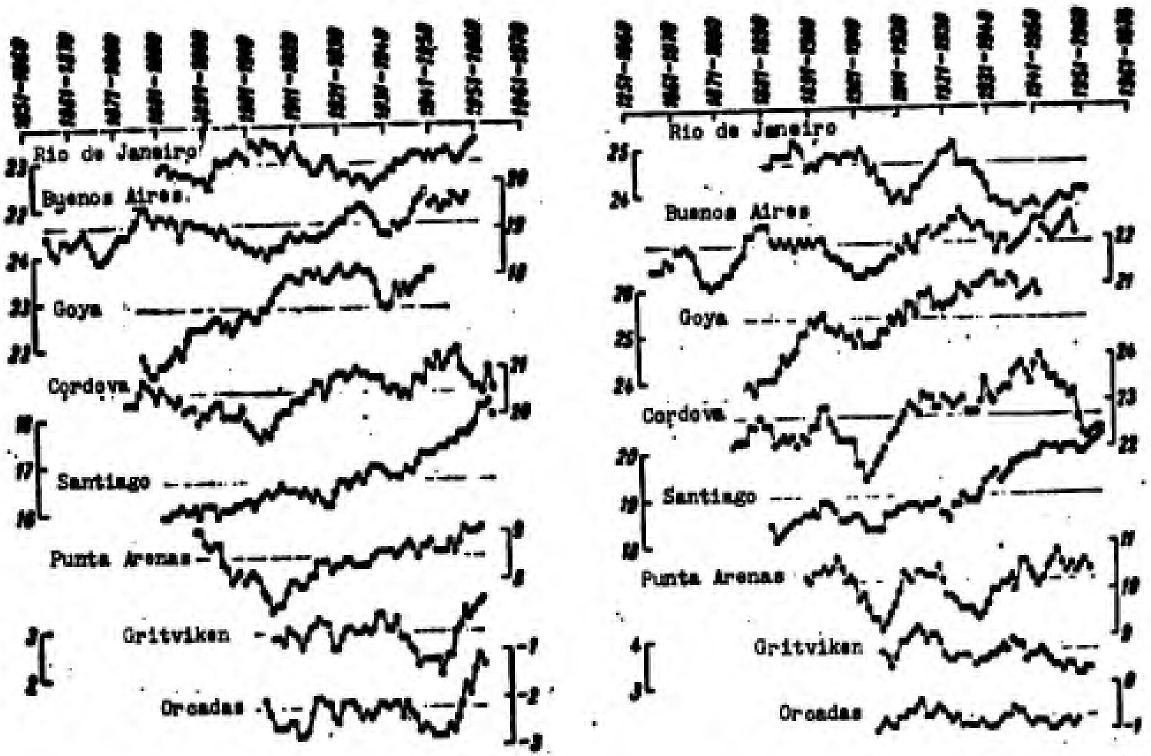

Fig. 23f. Moving 10-year mean temperatues. November, December.

observations at this station for each month separately, it is easy to see that the difference in temperatures in individual years do not have a systematic character and do not exceed the bounds of usual interannual variations.

The absence of a simple change in climate in the polar zone of the south Atlantic is indicated by Prohazka (1951): in the southern hemisphere nowhere were there observed such changes in temperature as in the moderate and polar zones of the northern hemisphere. He justly considers that affirmation of certain researchers on the increase in temperature in the northern hemisphere as on general-planetary phenomenon need checking and, apparently, will not be confirmed.

Australia. In spite of relatively small dimensions, Australia differs by a great diversity in the perennial variation in temperature even at stations close to each other.

Figures 24a-24g give graphs of the change in temperature at three stations of the continent (Alice Springs, Adelaide, Sidney), Tasmania Island (Hobart) and New Zealand (Dunedin).

As an average for the year (Fig. 24), in the central regions of Australia (Alice Springs), there is a clearly expressed trend toward a temperature drop, which is especially considerable in warm period (September-March). In the 1850's almost in all months there began an intense warming. Such a trend is noticeable in the

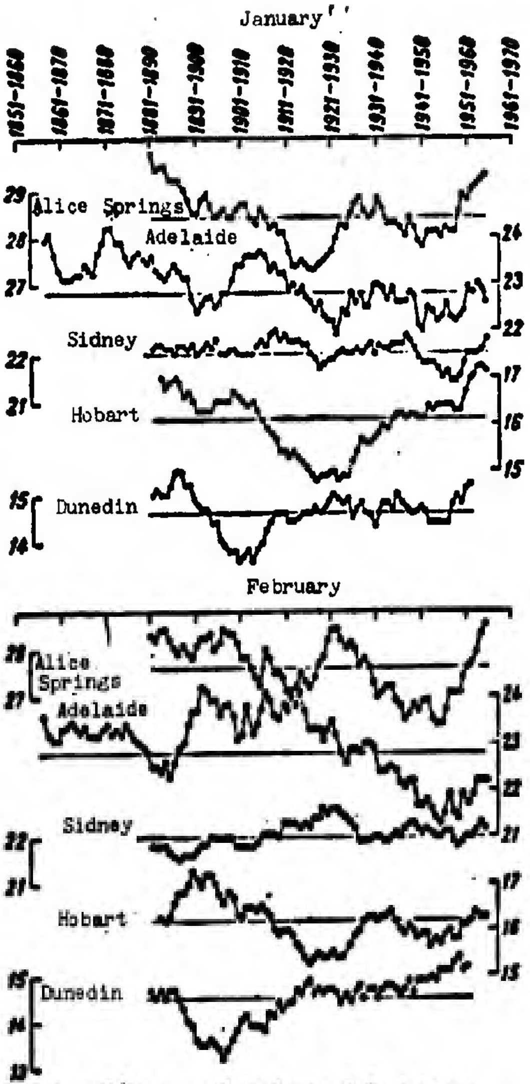

Fig. 24a. Moving 10-year mean temperatures. January, February.

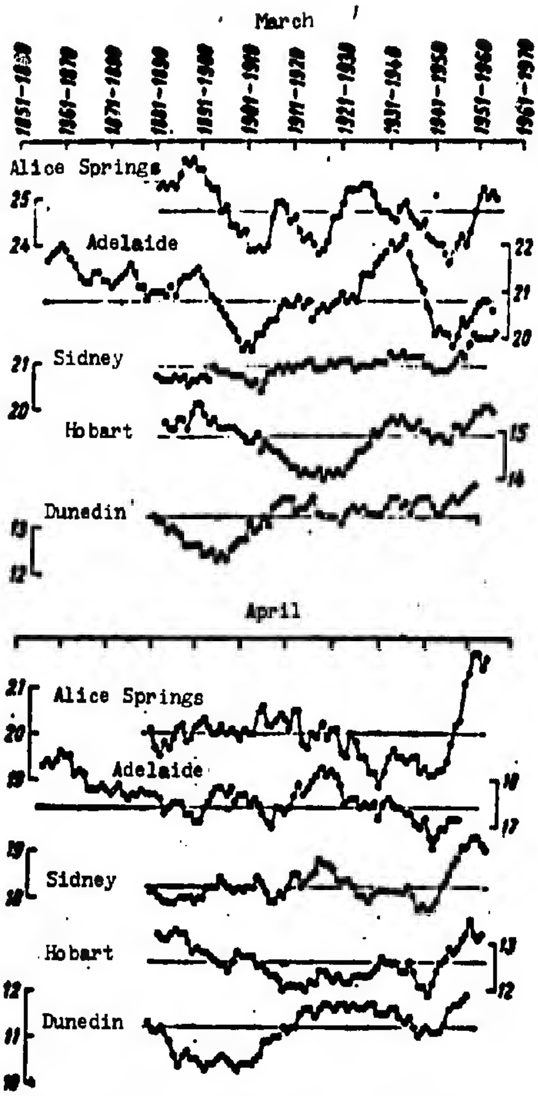

Fig. 24b. Moving 10-year mean temperatures. March, April.

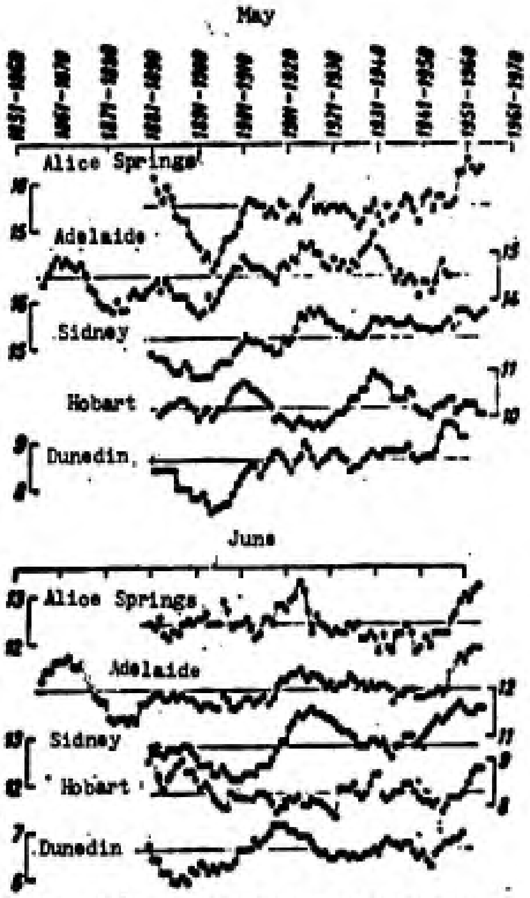

Fig. 24c. Moving 10-year mean temperatures. May, June.

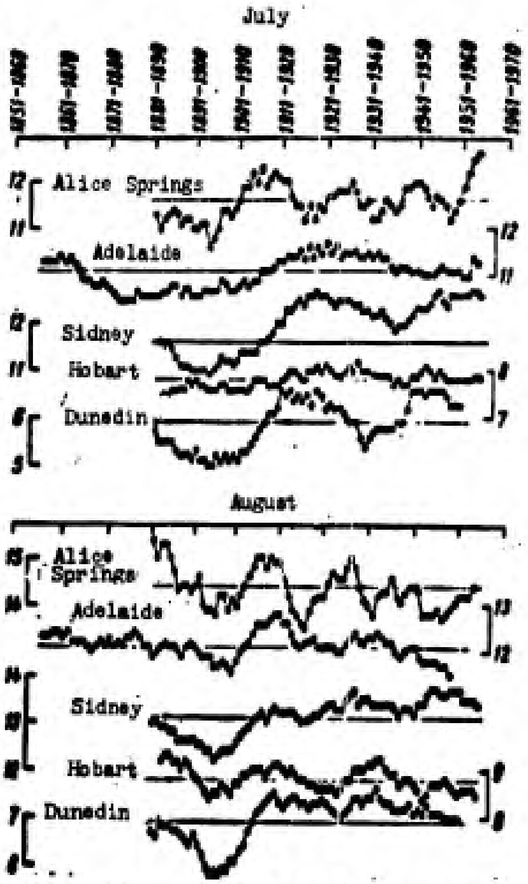

Fig. 24d. Moving 10-year mean temperatures. July, August.

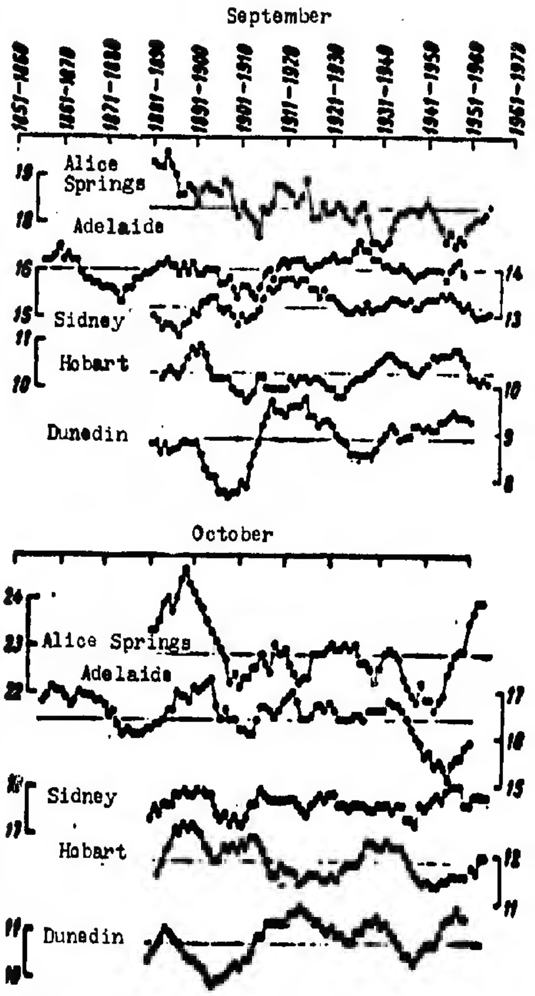

Fig. 24e. Moving 10-year mean temperatures. September, October.

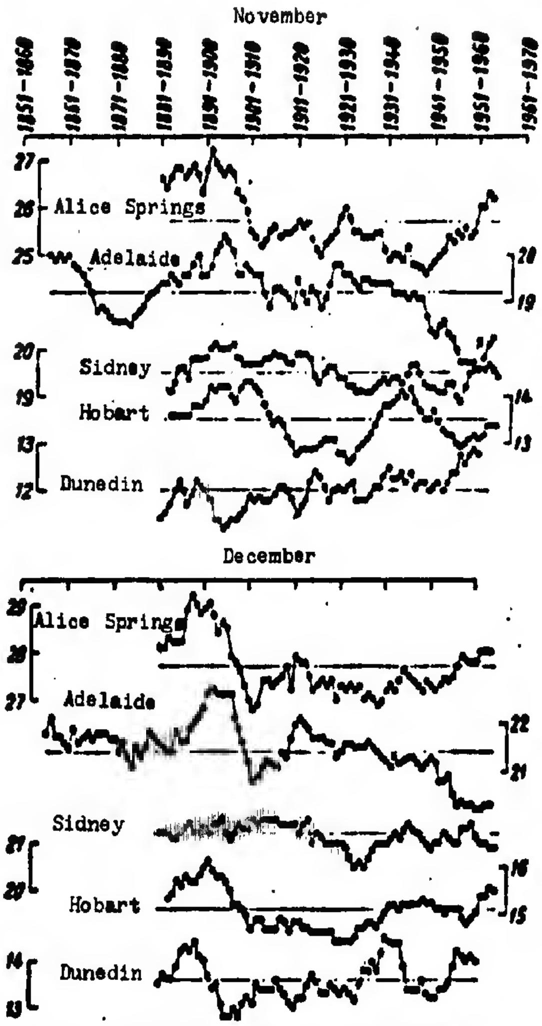

Fig. 24f. Moving 10-year mean temperatures. November, December.

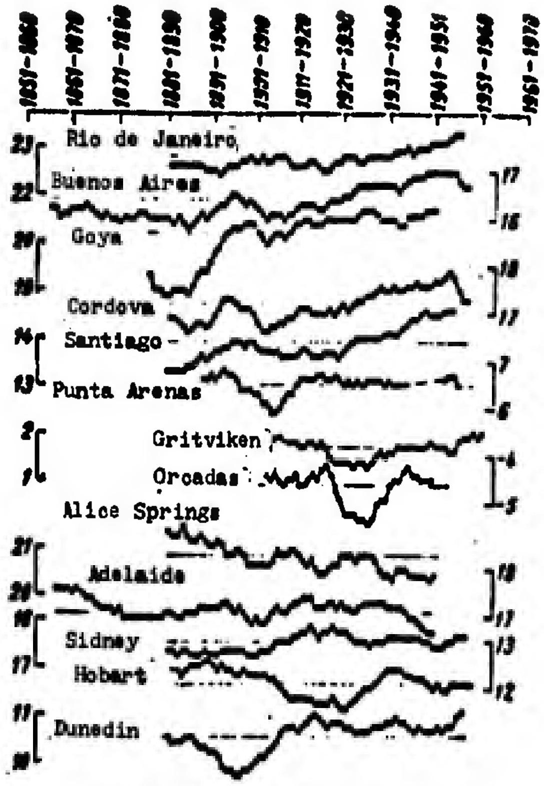

Fig. 24g. Moving 10-year mean temperatures. Year. South America and Australia.

north of the continent, at Darwin. A temperature drop of the summer months is especially great in the south (Adelaide). This station has the longest (since 1857) series of observations. From October to March during all period of observations there is noted here a lowering of the level of variations in temperature, which is especially considerable in the 1890's the mean 10-year temperature dropped 3° during five to six decades.

In the cold half of the year the temperature varies near the mean perennial level.

It is necessary to emphasize that, just as in South Africa, the most considerable variations in temperature are observed in the warm period, whereas in the winter months the amplitude of perennial variations is noticeably decreased at all stations of Australia.

This fact is very important for investigation of causes of variations in temperature on the Earth. It indicates that maximum perennial variation in temperature in Southern Africa and Australia do not depend on the season, but are observed in months of the cold half year of the northern hemisphere. In southern America, conversely, the greatest amplitude of variation in temperature is obtained in winter of the southern hemisphere (June, July).

Quite opposite trends as compared to Adelaide are observed on the eastern seacoast of Australia (Sidney): with insignificant variations in winter (from May to August) from the beginning of the century warming is well marked; in the warm period there are observed insignificant variations near the mean level. Farther south of Adelaide on island (Hobart and Dunedin) in the majority of months of the year considerable variations occur in a reversed phase. At Hobart there is a quite distinct difference in the amplitude of perennial variations in winter and in summer. Thus, in the middle month of summer (January) the maximum range of variations of mean 10-year temperatures reached 2.5° and in winter (in July), only 0.7°

The station Dunedin is one of three stations with a long series of observations in New Zealand. Data of the oldest of these stations (series of observations since 1864) of Wellington are not given here, since homogeneity of the series of this station was disturbed. Although Wellington lies between Dunedin and Auckland, the variation in temperature in Wellington has nothing in common with the variation of these stations. Variations at extreme points (Dunedin and Auckland) are synchronous in the warm half year.

For both points an increase in temperature since the 1850's, especially in the warm half year is characteristic: although variations in temperature in the majority of the months at Dunedin occur near the mean level, it is, nevertheless, impossible not to pay attention to the fact that in those same months (February and November) when at Adelaide there is observed a maximum temperature drop, at Dunedin since the end of the last century there is a clearly expressed trend toward warming.

Regarding Western Australia, the according to the incomplete series of observations available there at Perth and Onslow it is possible only tentatively to assume that the greatest variations in temperature is exposed in the warm half year and insignificant in the cold half, just as in the remaining part of Australia (except the eastern seacoast).

7. Conclusions

The air temperature undergoes perennial variations of different duration and amplitudes, which in broad terms are synchronous during the whole period of observations on considerable territories of high and moderate latitudes in the northern hemisphere. The period of instrumental observations, the time interval, is too insignificant in order to judge the maximum wavelengths of these variations.

Within the period illuminated by observations, the most considerable in intensity and duration was the phenomenon acquiring in literature the name "warming of the Arctic". However, till now there has been no clear presentation on the territorial propagation of this warming and peculiarities of its manifestation in different months of the year.

As a result of the performed detailed analysis of perennial variations of temperature in different months and for the year as a whole it is established (just as in preceding investigations) that the center of this exceptional warming was in the northwest region of Greenland. As an average for the year maximum warming was noted at Upernavike, on Spitsbergen, in the Malyye Karmakuly and spread to the east, south and west with diminishing intensity. A map of differences between 10-year mean annual temperatures of 1930-1939 and 1881-1890, which for the most part correspond to periods of the end and beginning of the warming (Fig. 25), shows that warming covered a considerable part of the Earth. It spread into the low latitudes, seizing also part of the southern hemisphere in the Atlantic and Pacific Ocean sectors approximately to the southern tropics. Warming (as an average for year) did not spread to regions of Middle and Central Asia, continental regions of Africa, Australia and the Antarctic Islands (shaded on the map). Warming in Antarctica, even if it occurred is, apparently, only in its individual areas.

Regarding the annual course of warming, the most intense warming in Greenland (Upernavik) was in winter (from November to March), less considerable in the summer (from April up to August), and in the

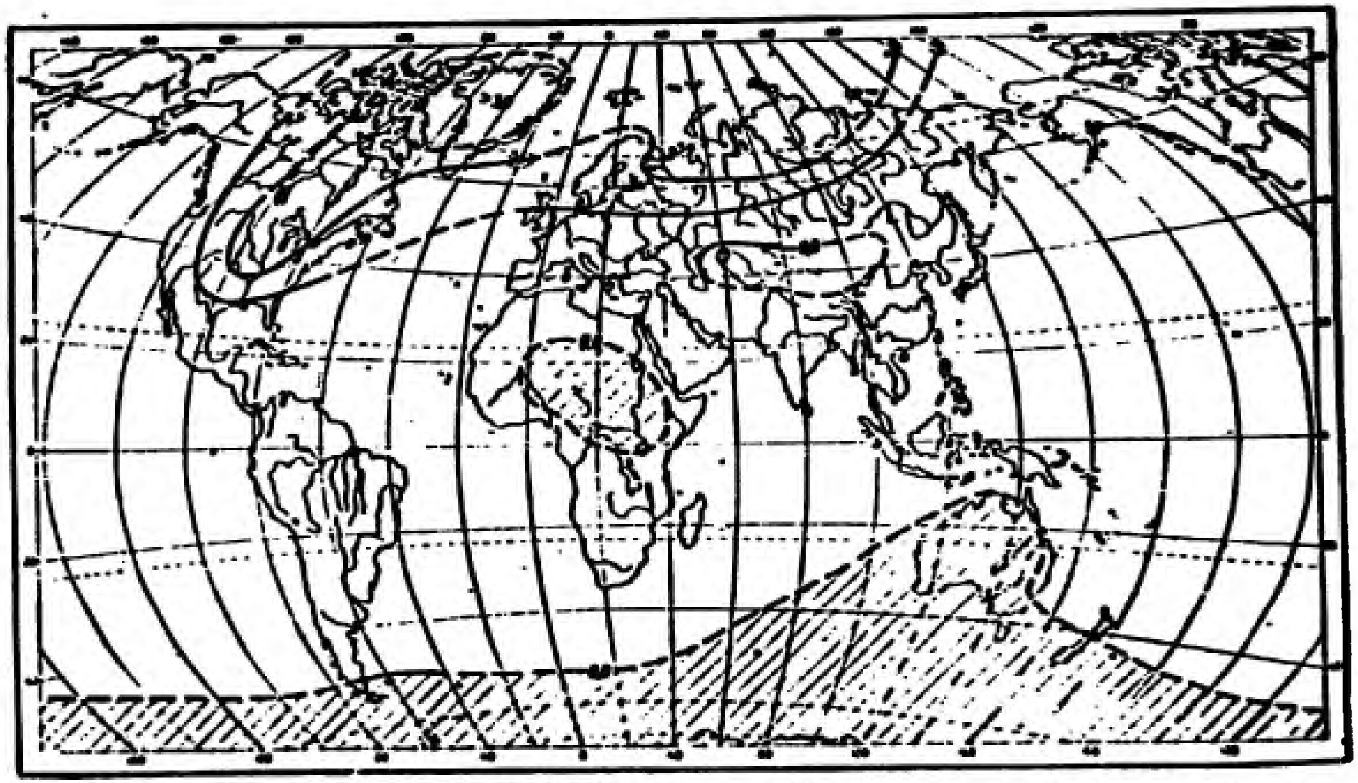

Fig. 25. Schematic map of differences of 10-year mean temperatures during 1930-1939 and 1881-1890.

autumn months (September-October) a trend toward warming was not observed. In Malyye Karmakuly along with a shift in the maximum of warming in later years, a shift was observed also in the annual course in warming (with respect to Upernavik): here the most intense warming was observed from November to January, less intense from March to May, and from June up to September there was no warming. Westward from Greenland the nearest station in the high latitudes with a long series of observations is Dawson. Here great warming was observed only in January, and in other months there was no definite trend in the change in the level of variations in temperature.

Thus, warming, apparently, spread basically from west to east with considerable inertia (5-10 years). This inertia is increased in the process of propagation of warming to the south: the peak in warming (as an average for the year) is displaced to later years with a decrease in latitude, so that farther south of 40-38° N. Lat. warming still continues.

In the tropic zone of Southern America the trend toward warming is more distinct in the summer months (December, January, February), i.e., in the months of the greatest warming in the northern hemisphere.

Warming in Africa (on its northern and southern extremity) also is better expressed in winter months of the northern hemisphere.

On the Pacific Ocean seacoast of Australia there is well-marked trend toward warming in winter (May-August). But in the remaining regions from the beginning of the century there was observed a temperature drop, especially considerable in the spring-summer months (September-March) of the southern hemisphere.

A peculiarity of perennial variations in temperature in South Africa and also at the majority of the stations of Australia and islands adjacent to it is the fact that the most considerable variations occur here not in the cold period of the year, as usually, but in the warm period when variations in temperature in the northern hemisphere are especially great.

Exclusiveness of the phenomenon of warming of the Arctic is somewhat dimmed when after the 40's in the high latitudes a steady lowering in the temperature began. Now already oscillatory (and not forward) character of this phenomenon becomes even more evident, but the wavelength of variation in about this case is great and is commensurable with the length of series of observations.

The temperature drop started first of all (1927-1936) on the northwestern part of Greenland, i.e., where there was the most intense warming. Eastward, westward and southward from this region the beginning of the temperature drop came in later years. In moderate and low latitudes of the northern hemisphere warming still continues in many regions, especially in the southern half of Europe and on the eastern seacoast of Northern America. One can see well this on the map of differences of 10-year mean temperatures between decades of greatest warming 1930-1939 and 1951-1960 (Fig. 26).

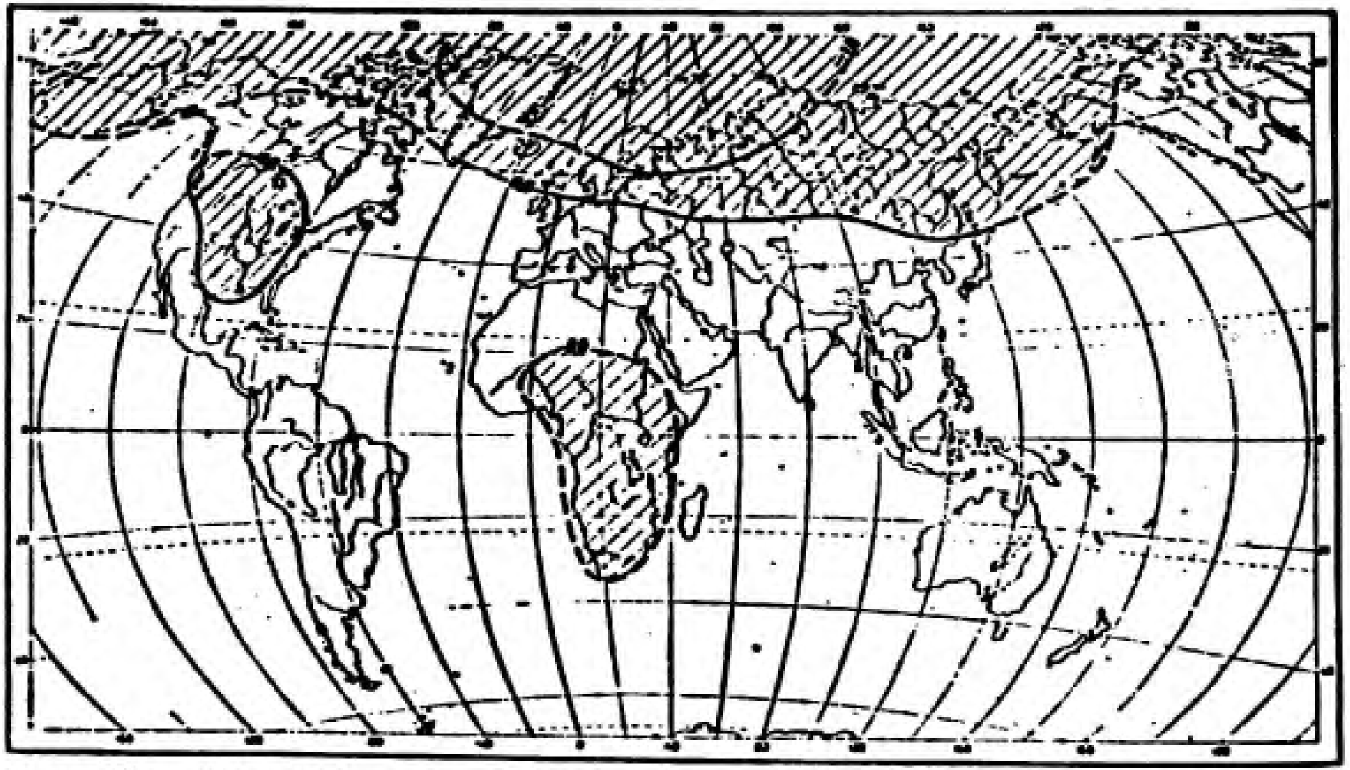

Fig. 26. Schematic map of differences 10-year mean temperatures during 1951-1960 and 1930-1939.

It should be noted with this that for comparability there is taken the mean decade for high latitudes of greatest warming (1930-1939) (the earliest pertains to 1927-1936, and the latest to 1936-1945).

A temperature drop, as can be seen from Fig. 26, envelopes regions (shaded on the map) in which there was observed considerable warming (above 1°) and intensity of the temperature drop on an average for one decade is approximately equal to the intensity of the preceding warming. Farther south of $40-38^{\circ}$ N. Lat. and the southern hemisphere a temperature drop was not observed (with the exception of Africa).

Thus the propagation of considerable as an average for the year warming and temperature drop for the greater part of the Earth itself already confirms its reality. However, as was shown above, the changes in temperature in different months of the year are unequal, the variability of mean monthly temperatures from year to year in different regions of the Earth is also different. In connection with this, although curves of the variation in temperature leave no doubt as to the existence of its directed changes, quantitative confirmation is necessary of non-randomness of the changes revealed.

For this purpose is used the sufficiently simple and reliable method proposed by O. A. Drozdov allowing by means of simple calculations the estimation of how changes in the given series of observations differ from variations in random incoherent series. The essence of the method is expounded by Drozdov in Chapter II (§6) of the present work, and here we will give results of the use of this method for an appraisal of the reality of changes in the series of observations of stations located in different parts of the Earth.

The application of the criterion of Drozdov for a 10-year interval of averaging of the temperature requires fulfillment of following operations:

1) calculations from the initial series ($x_1, x_2, \ldots, x_N$) of the mean quadratic error (σ) differences between neighboring terms of the series ($x_2 - x_1, x_3 - x_2, \ldots, x_N - x_{N-1}$);

2) calculations of differences $\left(d_k^{(n)}\right)$ between mean temperatures of consecutive decades of the same series. In this case in formula (4) of Chapter II the quantity $n = 10$ and k-th difference are equal to:

$$d_k^{(10)} = \frac{1}{10}\left(\sum_{k+1}^{k+20} x_i - \sum_{k}^{k+10} x_i\right);$$

3) consecutive algebraic addition of quantities $d_k^{(10)}$ for obtaining of total differences $D_k^{(10)}$ of consecutive 10-year series;

4) determination of the criterion $\frac{D_k}{\sigma_D}$ (where $\sigma_D = \frac{\sigma}{\sqrt{n}} = \frac{\sigma}{\sqrt{10}}$), which is most convenient of all to produce graphically placing the time scale on the axis of the abscissas and on the axis of the ordinates, the magnitude of deviations. On the graph constructed in these coordinates of the change in quantities D_k from decade to decade are quantities σ, 2σ, 3σ and etc. plotted on the ordinate axis, plotted by lines in parallel to the axis of the abscissas of the ordinates. Thus there are immediately obtained quantities of the criterion $\frac{D_k}{\sigma_D}$ for any 10-year examined series. With this $D_k = 2\sigma$ and $D_k = 3\sigma$ correspond to 5 and 0.3% level of significance or 95 and 99.7% of the probability of distinction of changes from the random.

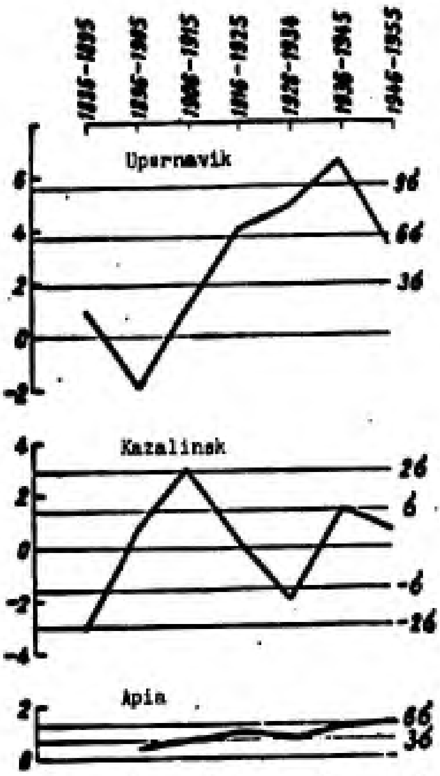

Fig. 27. Criterion of nonrandomness of the change in temperature. January.

Let us clarify what has been said by several examples. Figure 27 gives graphs $\frac{D_k}{\sigma_D}$ for three stations (Upernavik, Kazalinsk and Apia) in January (σ_D is respectively equal to 0.7, 1.8 and 0.2). As this graph shows, in Upernavik from the decade of 1916-1925 total differences in temperatures exceed the bound of 3σ and for the decade 1931-1940 reach 9σ, which practically corresponds to the zero level of significance or 100% probability of the distinction of these changes from the random.

In Kazalinsk, as one can see from the graphs of the course of the moving 10-year mean temperatures (Fig. 8c), changes in temperature have a cyclical character with the length of the cycle at several decades. However, due to the great variability in temperature from year to year ($\sigma_D = 1.8^\circ$) the criterion $\frac{D_k}{\sigma_D}$ for extreme limits of D_k is only 2.0, which corresponds to 95% of the probability of distinction from random changes.

There is much interest in the graph $\frac{D_k}{\sigma_D}$ for Apia (Island of Samoa in the tropic zone of the southern part of the Pacific Ocean). With secular systematic rise in temperature and the extraordinarily small quantity σ_D the criterion $\frac{D_k}{\sigma_D}$ in January increases from 2 to 6 during the period of observations. This indicates (if observations are uniform) that insignificant (in absolute value) directed changes in temperature in the tropic zone are just as important for the given latitude as are considerable changes in high latitudes.

Table 9. Values of the Criterion $\frac{D_t}{\sigma_D}$ by Months of the Year in Different 10-year Series of Observations

Decade (years)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
Leningrad													
1811—1820	1,9	1,2	2,2	2,1	1,7	0,0	−0,1	−1,7	1,0	2,6	−0,3	−0,4	2,8
1821—1830	0,7	1,1	0,8	2,1	1,8	1,9	0,3	−1,1	−0,4	2,6	0,9	0,1	2,2
1831—1840	1,4	1,2	0,8	0,9	1,9	0,1	−1,4	−1,7	0,0	1,8	−0,6	−0,5	1,2
1841—1850	1,2	0,4	0,4	0,7	1,2	0,4	−0,4	−0,4	0,6	2,4	1,4	1,0	2,0
1851—1860	1,7	1,1	1,2	1,8	1,4	1,2	0,6	−2,4	0,1	2,6	−0,7	0,2	2,2
1861—1870	2,3	−0,2	1,4	1,1	0,1	0,4	0,7	−1,6	−0,1	3,0	0,3	−0,1	1,8
1871—1880	1,0	1,6	0,6	1,0	0,7	1,5	−0,7	−1,7	0,8	1,5	0,6	−0,8	1,5
1881—1890	1,6	1,2	0,9	2,6	2,7	0,0	0,0	−2,1	−0,7	1,9	0,6	0,5	2,2
1891—1900	2,6	0,7	0,8	2,3	2,8	0,8	−0,3	−2,0	−0,3	2,6	1,2	0,1	2,5
1901—1910	2,0	1,9	2,8	2,9	2,4	1,2	0,4	−2,3	−0,1	2,0	1,1	1,3	4,0
1911—1920	1,8	0,8	0,7	3,3	2,3	0,6	0,6	−2,0	0,7	2,2	1,2	0,2	2,8
1921—1930	2,8	1,1	1,5	2,1	3,6	−0,1	2,0	−0,4	0,4	2,4	2,6	0,9	3,0
1931—1940	0,9	1,7	1,8	2,3	2,3	1,8	2,0	0,8	1,0	3,0	2,1	0,7	4,2
1941—1950	2,3	0,9	1,2	4,1	2,4	1,9	0,0	−1,0	1,3	2,2	1,2	1,8	4,2
1951—1960	2,7	2,0	0,4	2,6	3,4	1,5	0,6	−1,1	0,6	3,6	1,6	0,4	4,2
Salekhard													
1886—1895	1,1	−2,1	−1,2	1,1	2,6	1,4	0,7	1,0	1,0	1,5	0,8	0,1	1,0
1896—1905	0,6	−0,1	−0,6	2,6	2,9	2,6	0,7	1,4	1,0	1,8	1,8	1,0	2,6
1906—1915	0,4	−2,6	−1,4	2,5	2,5	4,0	0,3	1,6	0,3	1,2	2,1	1,6	—
1916—1925	2,7	−0,7	−1,2	1,3	1,4	2,4	0,7	1,8	2,1	2,9	2,8	1,3	—
1926—1935	2,6	−0,1	−1,5	2,0	2,6	3,1	0,4	1,8	0,8	2,0	4,6	1,0	0,4
1936—1945	2,7	−1,2	−0,4	5,1	3,7	3,0	−0,1	2,1	2,1	3,4	3,5	1,7	1,9
1946—1955	2,4	−1,3	−1,2	2,8	3,8	4,1	2,4	1,8	0,3	1,5	1,6	0,9	0,0
Upernavik													
1865—1894	1,4	−0,3	0,7	−0,5	−0,5	0,6	−0,6	1,5	0,6	1,8	0,4	0,7	0,8
1895—1904	−3,0	−0,1	1,8	1,8	0,8	0,2	0,2	2,7	2,2	0,6	2,2	2,0	2,0
1905—1914	1,8	1,0	2,2	0,4	0,5	−0,4	−1,6	0,3	1,8	0,6	0,5	1,7	1,5
1915—1924	6,5	0,6	2,4	2,8	1,9	2,2	0,2	1,8	3,0	1,4	4,3	4,4	5,0
1925—1934	7,7	1,5	3,9	3,2	2,0	3,2	3,4	2,2	3,0	2,0	4,0	5,1	6,4
1935—1944	10,5	1,7	3,0	1,2	1,1	2,2	7,0	1,8	1,6	1,6	3,6	5,0	5,4
1945—1954	5,3	3,4	4,4	3,9	2,8	0,6	6,0	0,0	1,4	2,0	4,1	4,8	4,4
New Haven													
1891—1900	−0,3	0,4	2,1	0,2	1,0	−0,8	0,8	0,8	1,6	1,6	0,3	−0,9	1,0
1901—1910	1,3	0,6	2,4	0,7	1,0	0,0	2,2	0,8	1,8	3,6	1,5	0,8	4,0
1911—1920	1,2	1,3	2,6	1,0	0,5	−0,2	1,5	1,8	2,0	3,8	1,2	−0,2	3,5
1921—1930	2,1	2,7	2,9	0,2	1,3	1,0	2,5	2,0	3,2	2,4	2,3	1,1	5,5
1931—1940	0,6	2,6	2,6	0,7	2,3	1,5	3,8	4,2	2,2	3,4	2,2	0,8	6,0
1941—1950	2,2	3,9	4,4	3,5	1,8	2,0	4,8	4,0	4,0	6,4	4,0	1,7	10,5
1951—1960	0,8	2,7	3,8	3,0	2,8	2,3	4,8	5,5	4,4	5,8	4,2	0,4	8,5

Note: The quantity of criterion 2.0 corresponds to 95% of the probability of distinction of changes from the random, and the quantity of criterion 3.0 to 99.7%; a quantity of criterion higher than 4.0 practically corresponds to 100% of probability of nonrandom changes.

Table 9 gives values of the criterion $\frac{D_t}{\sigma_D}$ and the level of significance (probability of chance of variations for different stations of the Earth and various months of the year). Here there is quantitatively confirmed the irregularity of changes in temperature during the year in different regions of the Earth. For annual changes in temperature the criterion $\frac{D_t}{\sigma_D}$ is obtained higher than it is in separate months due to the smoothness of variation and, consequently, smaller quantity σ.

A more definite general trend of the change in temperature is expressed with an increase in interval of averaging, as will be shown during the analysis 35-year mean temperatures in Chapter VI.

CHAPTER IV

RELATIONSHIP BETWEEN THE CHANGE IN AIR TEMPERATURE WITH ATMOSPHERIC CIRCULATION

1. Principles of the Classification of Atmospheric Processes of Vangengeym-Girs and Dzerdzeyevskiy

It is known that a number of factors determining the change in climate acts jointly, being in a complicated interaction with each other. It is necessary at least approximately to estimate the role of each of the basic factors participating in the process of the change in climate. Since atmospheric circulation is an important link in the chain of these factors, in this chapter an attempt is made to investigate the relationship between the change in the character of atmospheric circulation and change in temperature rate.

First of all one should establish what circulatory characteristics are most expedient to select for a comparison of them with indices of air temperature.

There are many schemes of the classification of atmospheric processes, each of which has its merits and deficiencies. Not dwelling on this question in detail, we will note only that for the problem formulated in this chapter, it is necessary to select the typification in which data would be developed for the prolonged period of time comparable with the period of contemporary change in climate and which would extend over the whole northern hemisphere. These conditions are satisfied by typifications of Vangengeym and Dzerdzeyevskiy.

Vangengeym (1933, 1935) classified the macrosynoptic processes proceeding from the concept about the elementary synoptic process, during which there is preserved geographic distribution of the sign of the baric field and the direction of basic air transfer within the Atlantic-Eurasian sector of the northern hemisphere. As a result elementary synoptic processes, observed for 42 years, were grouped into 26 types. Subsequently these 26 types were generalized into three basic types of atmospheric circulation: western W, eastern E and meridional C, which were determined by the predominant transfers in the troposphere of moderate latitudes.

Subsequently Vangengeym (1946, 1952) showed the relationship between processes in the Atlantic-Eurasian sector and processes over the whole northern hemisphere, assuming that each of the three types in this sector corresponds to the simple symmetric field in the whole hemisphere. It turned out, however, that this is correct only in periods of strong and stable development of processes of the given form, and in periods of transformation of forms of circulation in the Atlantic-Eurasian and Pacific Ocean-American sector there are observed simultaneously various forms of circulation. In connection with this, Girs (1956) produced typification of macrocirculatory processes for the Pacific Ocean-American sector, separating also the three forms of these processes.

The typification Dzerdzeyevskiy (1946, 1962a, 1962b) was at once developed for the whole northern hemisphere, but at first on data of 8 years and in the last variant for 60 years. In this work there is used the typification of Dzerdzeyevskiy, since for it there is a calendar of types belonging to the whole hemisphere, and for separate groups of these types also six sectors of the northern hemisphere.

Dzerdzeyevskiy, jointly with Kurgan and Vitvitska (1946), conducted typification of atmospheric processes, assuming as its basis the following indices: a) directivity of arctic intrusions during uniform circulatory mechanisms in the hemisphere; b) interconnection and interaction of them with processes in southern latitudes and c) zonality or meridionality of circulation.

Dzerdzeyevskiy established 13 types of processes. They were united by him into, 4 groups, according to the following criteria:

Group I. Types 1 and 2. Zonal circulation predominates. Arctic intrusions are absent.[1]

Group II. Types 3-7. Disturbance of zonality. In this group processes are united with one meridional intrusion in whatever geographic region (Greenland, Chukotski peninsula, America, etc.,) it occurs. On a great part of the hemisphere there is preserved zonal circulation, and in the region of an intrusion — meridional.

Group III. Types 8-12. Two or more Arctic are carried out intrusions, simultaneously.

Group IV. Two varieties of Type 13 (summer and winter). Cyclonic activity cover the polar region and adjacent regions.

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[1] It should be noted the Dzerdzeyevskiy uses the "zonal circulation" when cyclones and anticyclones move in a direction close to meridional and the term "meridional" when trajectories of them are meridional.

Trajectories of cyclones pass through the North Pole. In this scheme certain detailization is conducted: meridional type of circulation is divided into the northern and southern, the zonal type – into western and eastern. Furthermore, there is distinguished the "stationary position." By this term such a position is designated when in a definite region baric formations have low mobility, and clearly marked trajectories are absent. Practically this type is connected with the Asiatic and subtropical anticyclones.

Initial synoptic data for the exposure of the connection between atmospheric circulation and thermal conditions was the calendar of the course of atmospheric processes in accordance with typification of Dzerdzeyevskiy, compiled at the Institute of Geography of the Academy of Sciences of the USSR for the period of 1899-1958.

2. Analysis of Recurrence of Types of Circulation for Every Month of the Year

First of all there was calculated by months of the year the recurrence of each of the 13 types in percent of the total number of days and also percent of days "outside the type." In this group are included days when the synoptic situation corresponded to the transition position from one type of circulation to the other. In Table 10 recurrence is given of different types of circulation not only for the whole 60-year period of 1899-1958 but also for the individual decades of this period. There is no need here to give a full analysis of this table. Let us limit ourselves only to an indication of certain important regularities in the course of recurrences of types of circulation in various parts of the 60-year series.

Table 10. Recurrence of Types of Circulation in Various Time Periods (%)

Type	1899—1958	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1958
				January			
1	3,9	2,5	0,0	5,1	9,0	4,8	2,0
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
4	1,5	0,0	0,0	1,2	0,0	4,5	4,0
5	14,5	14,3	12,6	21,0	18,1	5,1	12,0
6	0,2	0,0	0,0	0,0	0,0	0,0	1,6
7	10,1	10,3	3,2	11,9	10,6	16,6	10,8
8	3,9	2,9	1,0	2,6	0,0	9,0	10,4
9	0,3	0,0	0,0	0,0	0,0	0,0	2,8
10	3,0	2,2	2,2	1,2	3,5	6,7	2,8
11	37,0	39,2	42,6	40,5	36,8	31,1	27,8
12	20,0	26,1	35,5	11,4	11,3	16,4	17,2
13	3,5	0,0	1,0	3,5	7,5	2,6	8,0
Outside the type	2,1	2,5	1,9	1,6	3,2	2,6	0,8

Table 10. Recurrence of Types of Circulation in Various Time Periods (%) (Con't)

Type	1899—1964	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1964
				February			
1	1,1	1,1	0,7	2,1	2,8	0,0	0,0
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,5	1,4	0,0	0,0	0,0	1,4	0,0
4	0,9	1,1	0,0	1,8	0,0	0,0	3,5
5	14,2	10,3	14,2	21,3	18,0	6,0	15,1
6	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	8,6	7,1	7,3	6,7	11,3	14,6	3,5
8	8,4	7,1	3,9	2,5	8,1	9,9	21,7
9	0,4	1,1	0,0	0,0	1,4	0,0	0,0
10	1,2	1,4	1,6	0,0	2,1	0,7	1,8
11	37,6	35,1	49,9	46,5	32,8	34,0	27,9
12	22,4	30,3	20,1	13,8	15,2	27,0	23,9
13	2,8	1,1	0,7	3,2	6,5	5,0	2,2
Outside the type	1,9	2,9	1,6	2,1	1,8	1,4	0,4
				March			
1	2,9	0,3	1,3	4,7	3,6	4,5	4,0
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,9	3,9	0,0	0,0	1,0	0,0	0,8
4	2,6	0,6	3,5	1,3	4,4	4,5	1,6
5	8,8	8,4	8,7	12,9	7,4	8,4	7,7
6	0,5	0,6	1,0	2,3	0,0	0,0	0,0
7	10,6	10,9	2,3	11,0	13,5	16,1	10,5
8	9,0	8,4	7,5	6,8	4,5	11,4	15,3
9	2,1	4,5	0,0	2,6	2,4	1,3	1,6
10	3,2	9,4	1,3	3,6	1,0	6,1	13,3
11	26,0	22,6	37,5	27,2	33,9	16,4	15,3
12	27,0	27,4	35,0	25,5	23,6	21,3	25,4
13	2,1	0,6	0,6	0,0	2,3	6,1	4,1
Outside the type	2,3	2,4	2,3	2,1	2,4	3,9	0,4
				April			
1	2,5	1,3	1,0	5,4	1,0	1,7	6,2
2	0,8	1,0	0,0	0,0	0,0	1,3	1,7
3	3,1	2,3	0,0	0,0	9,7	2,7	2,1
4	3,1	3,7	2,0	4,7	4,0	3,2	1,2
5	3,4	0,0	7,3	0,0	6,3	3,7	2,5
6	1,7	2,0	1,0	3,7	0,0	3,0	0,8
7	14,6	11,0	10,3	14,3	11,3	25,4	15,8
8	9,4	9,0	5,4	6,6	11,3	7,7	15,4
9	5,3	9,7	7,0	5,4	0,7	5,3	4,5
10	13,0	17,7	12,0	11,0	9,7	19,3	8,7
11	12,3	13,3	23,3	8,6	13,6	8,0	4,5
12	27,5	25,3	26,5	38,4	30,0	15,0	30,4
13	1,0	0,0	0,0	0,0	0,7	1,7	5,0
Outside the type	2,3	3,7	4,2	2,0	1,7	2,0	1,2
				May			
1	0,3	0,0	0,0	0,0	0,0	1,0	0,8
2	5,6	3,2	4,2	7,4	6,8	4,9	8,7
3	7,3	10,0	5,1	1,6	12,6	10,0	2,8
4	11,2	11,9	14,5	12,6	11,7	11,9	2,4
5	0,4	0,0	0,0	0,0	1,0	1,3	0,0
6	1,9	0,3	1,2	1,2	1,2	1,3	6,3
7	12,7	7,4	10,6	11,7	16,4	11,3	19,7
8	11,4	10,0	8,5	13,2	7,4	16,4	16,2
9	4,2	1,9	4,3	3,5	6,2	5,2	4,8
10	16,2	18,7	21,6	17,4	16,1	12,8	10,1
11	1,2	2,9	3,2	0,0	1,0	0,0	0,0
12	23,1	29,4	23,9	28,5	13,2	17,1	24,6
13	1,1	0,0	0,0	0,0	1,9	2,3	2,8
Outside the type	3,4	4,3	2,9	2,9	4,5	4,5	0,8

Table 10. Recurrence of Types of Circulation in Various Time Periods (%) (Con't)

Type	1899—1958	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1958
June							
1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	11,4	3,7	7,7	11,3	26,7	6,3	15,7
3	9,0	3,3	10,6	0,0	13,4	18,0	7,9
4	14,9	13,3	14,4	13,4	13,0	17,4	11,2
5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	4,3	3,3	10,0	4,0	4,7	0,0	4,9
7	11,3	2,3	15,3	17,3	11,3	9,3	14,9
8	9,7	16,3	7,4	17,7	0,0	7,0	12,0
9	7,7	7,7	8,3	8,0	6,0	6,7	8,6
10	16,7	28,4	13,7	13,0	16,5	19,3	7,4
11	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	9,4	16,0	8,2	14,3	1,7	9,7	6,2
13	3,7	2,7	1,7	0,0	4,7	4,0	11,2
Outside the type	1,9	3,0	2,7	1,0	2,0	2,3	0,0
July							
1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	22,8	17,1	26,2	25,8	23,8	21,6	24,1
3	7,9	3,5	10,3	5,8	10,3	8,2	8,9
4	23,2	17,1	24,8	25,2	32,2	17,2	19,7
5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	4,1	2,4	1,0	7,8	3,9	2,2	8,0
7	6,1	8,9	4,8	4,2	7,8	4,5	8,5
8	7,8	13,5	5,2	5,1	7,2	6,8	7,6
9	7,4	8,4	14,8	6,1	6,2	3,5	6,8
10	13,2	21,3	9,4	9,4	3,9	27,4	6,8
11	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	3,0	4,3	2,9	3,2	1,2	3,2	2,4
13	3,0	1,2	0,0	5,5	1,9	3,2	7,4
Outside the type	1,5	2,3	0,6	1,9	1,6	2,2	0,0
August							
1	0,4	0,0	0,0	0,0	0,0	0,0	2,8
2	17,3	8,9	19,6	21,8	33,5	10,7	7,7
3	7,2	5,8	8,4	7,7	5,5	7,1	8,1
4	18,0	16,1	21,8	14,8	20,0	21,2	12,9
5	0,2	0,0	0,0	0,0	0,0	0,0	1,6
6	3,3	1,9	2,9	1,6	4,5	2,3	5,2
7	11,6	15,5	12,2	8,4	8,1	13,9	11,7
8	9,6	13,9	8,7	10,0	5,2	10,3	8,1
9	3,6	5,1	4,3	2,6	2,9	2,3	3,2
10	13,3	14,8	8,7	23,3	13,2	10,7	12,5
11	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	8,8	16,4	11,7	7,5	1,9	4,8	10,1
13	5,2	0,0	0,0	1,3	2,9	14,1	16,1
Outside the type	1,5	1,6	1,6	1,0	2,3	2,3	0,0
September							
1	3,3	4,7	0,0	3,3	8,0	1,7	2,8
2	2,9	2,7	3,7	3,7	2,4	3,0	0,8
3	3,3	1,3	3,0	4,3	4,7	5,7	0,8
4	9,8	16,7	5,7	6,0	12,6	11,1	3,6
5	5,9	4,0	3,3	6,0	5,3	7,4	6,8
6	5,8	3,7	6,7	4,7	5,7	6,1	6,8
7	15,2	9,3	17,1	18,0	12,3	14,2	17,9
8	11,5	6,7	7,7	13,6	11,7	12,4	16,7
9	3,0	1,3	3,7	3,3	2,7	4,0	3,6
10	11,8	22,0	10,7	5,7	7,3	8,1	20,8
11	6,3	10,7	7,8	8,0	2,4	7,1	2,8
12	14,5	12,6	26,6	18,7	12,9	11,1	5,2
13	4,2	1,0	1,0	2,0	10,0	5,4	7,2
Outside the type	2,5	3,3	3,3	2,7	2,0	2,7	0,4

Table 10. Recurrence of Types of Circulation in Various Time Periods (%) (Con't)

Type	1899—1958	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1958
				October			
1	11,1	8,1	2,2	17,4	13,5	16,1	10,5
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	3,1	3,5	2,3	3,5	3,9	2,6	2,0
4	5,4	9,4	1,0	2,2	3,9	10,7	5,3
5	12,8	10,6	16,3	13,2	21,6	5,5	7,7
6	1,4	1,3	3,5	1,6	1,3	0,3	0,0
7	10,9	10,9	10,3	5,5	12,6	7,8	14,2
8	11,8	5,2	7,0	15,2	13,2	19,7	10,8
9	2,1	1,0	6,4	1,0	0,7	1,0	1,6
10	8,5	12,6	7,4	2,2	7,4	16,4	6,5
11	13,3	16,5	21,1	15,2	13,9	3,5	11,7
12	13,9	19,0	19,7	16,5	2,6	13,2	13,2
13	2,5	0,0	0,3	3,9	0,3	0,6	9,7
Outside the type	2,9	1,9	1,9	2,6	5,1	2,6	2,4
				November			
1	8,5	4,3	5,0	8,0	13,0	12,0	11,7
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	1,2	2,0	0,6	0,6	2,7	1,3	0,0
4	2,8	0,0	1,0	0,3	8,0	4,0	2,5
5	13,6	14,0	21,4	18,7	9,7	7,4	10,8
6	1,1	2,7	0,7	1,2	0,0	1,0	0,0
7	10,4	9,3	8,0	11,7	9,4	12,7	9,6
8	10,8	16,7	5,0	12,3	6,3	12,0	15,0
9	1,2	2,0	0,0	0,0	1,2	0,0	3,7
10	5,4	5,0	4,0	2,7	4,3	13,4	4,2
11	21,4	22,6	24,1	22,5	31,0	20,3	18,8
12	16,5	17,0	21,4	20,0	7,7	13,0	19,2
13	1,3	0,0	0,6	0,0	4,0	0,6	3,7
Outside the type	2,8	4,4	1,2	2,0	2,7	2,3	0,8
				December			
1	4,6	4,8	0,0	7,0	8,1	3,8	8,9
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
4	0,7	0,6	1,3	0,0	1,3	1,0	0,0
5	19,6	21,3	22,1	20,0	21,3	14,6	14,1
6	0,06	0,3	0,0	0,0	0,0	0,0	0,0
7	10,3	6,5	13,5	8,3	6,2	15,3	14,1
8	4,6	1,6	3,5	7,5	3,2	5,5	7,7
9	0,8	2,9	0,0	0,0	0,0	0,0	2,4
10	5,0	8,4	3,5	0,0	9,9	6,6	2,0
11	33,8	32,0	37,3	37,0	36,9	30,6	24,8
12	15,5	17,8	17,0	13,6	7,3	17,0	16,5
13	2,7	0,6	0,0	3,0	3,9	4,2	5,1
Outside the type	2,2	3,2	1,6	2,7	4,9	1,4	0,0

In the period from November to February the most frequently repeated are Type 11, characterized by Arctic intrusions in Yakutia and North America, Type 12 — with an intrusions (besides those shown) also in England and Alaska, and Type 5 — with an intrusion only in Yakutia (Figs. 28, 29, 30).

In Table 11 the total recurrence of these three types is given.

From this table it is clear that in the period prior to 1930 the recurrence of characteristic winter types of circulation (with the exception of only November for the period of 1901-1930) is higher than that of the perennial mean, where in February for periods 1911-1920 and 1921-1930 this recurrence exceeds 80%, and in January

Table 11. Total Recurrence of Types of Circulation 5, 11 and 12 (%)

	1899—1958	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1958
XI	54,5	53,6	73,9	61,2	44,4	40,7	48,0
XII	69,1	71,1	76,6	71,5	65,5	62,2	59,2
I	71,5	79,6	90,7	72,9	66,2	52,6	57,0
II	74,2	75,7	84,2	81,6	66,0	67,0	66,9

for the period 1911-1920 it is even more than 90%. Starting from the decade 1931-1940 the recurrences of these types, without exception, are all lower than those of the mean for the period 1899-1958. The numbers of Table 10 make it possible to judge what types decreases the total recurrence, and by what types of circulation are they replaced.

Fig. 28. Type 11.

Such course of recurrences, of basic winter types of circulation is one of indices indicating the warming of winter in a scale of the whole hemisphere.

Table 11 permits noting one more characteristic peculiarity connected with the change in climate. In the decades 1901-1910 and 1911-1920 the greatest total recurrence of types 5, 11 and 12 is observed in January; starting from the decade 1921-1930 the recurrence of these types in February is greater than that in January, or these

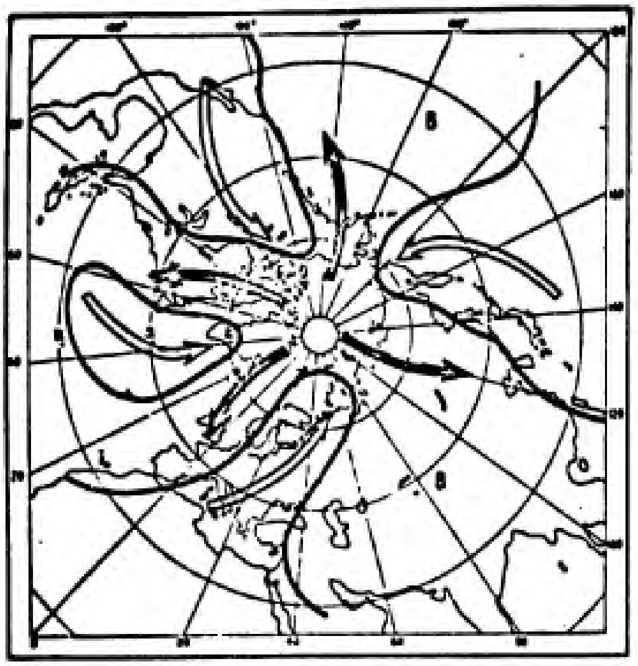

Fig. 29. Type 12.

Fig. 30. Type 5.

recurrence are equal. Transition of the minimum of temperature in its annual variation from January to February presents a typical peculiarity of the marine climate, and therefore an increase in total recurrence of basic winter types of circulation in February starting from the decade 1921-1930 indicates that climate from this time became more marine, which is noted by many authors investigating the change in climate by the most diverse methods.

As an average for the period 1899-1958 there is observed a gradual accretion of the recurrence of Types 5, 11 and 12 from November to February.

Fig. 31. Type 7, winter.

From March there begins reconstruction of the circulation on spring types. From December to February in the perennial average a considerable excess of the recurrence of Type 11 over Type 12 is observed, in March the mean perennial recurrence of Type 11 decreases, and Types 12 and 7 (Fig. 31) is increased (owing to Type 5). These traits of circulation are even stronger in April and May. In June Type 11 is not at all observed, recurrence of Type 12 as an average for the period 1899-1958 is small, and the main role is played by Types 10 and 4 (Figs. 32 and 33). In July and August to them Type 2 is added (Fig. 34). In Table 12 data are given on the recurrence of basic summer types of circulation in July and August.

From this table it is clear that the total recurrence of basic summer types of circulation in the main summer months does not reach so great values as recurrence of the winter types in the cold period of the year. In August for periods 1951-1958 and 1901-1910 recurrence of the two summer types does not attain even 40%, and on the average

Fig. 32. Type 10.

Fig. 33. Type 4.

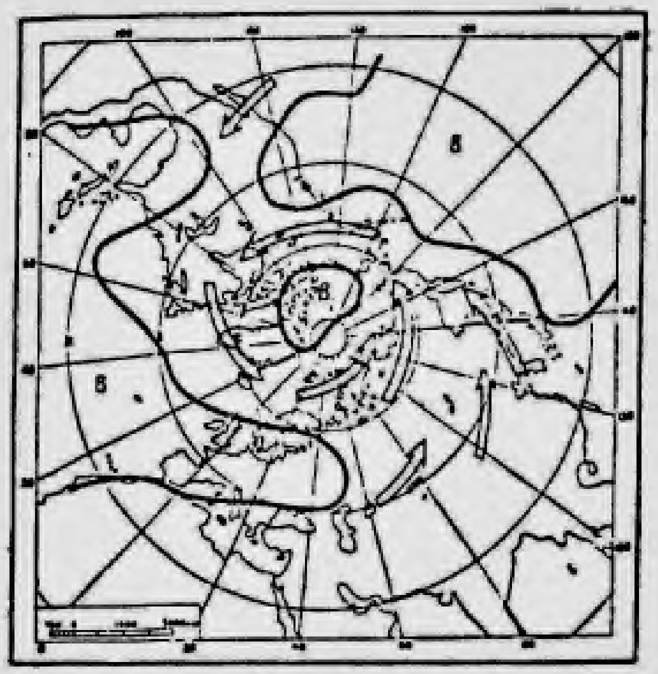

Fig. 34. Type 2.

for the period 1899-1958 it is less than 50%. Systematics is absent in the course of total recurrence of Types 2, 4 and 10 from one decade to the other, so clearly expressed in winter. It is possible to note only the recurrence of less than the perennial average in July in the beginning and end of the period studied, and in August, furthermore, in the decade 1941-1950.

Table 12. Total Recurrence of Types of Circulation 2, 4 and 10 (%)

Month	1899—1958	1901—1910	1911—1920	1921—1930	1931—1940	1941—1950	1951—1958
VII	59,2	55,5	60,4	60,4	59,9	66,2	50,6
VIII	48,6	39,8	50,1	59,9	66,7	42,6	33,1

Table 10 representation the instability of values of recurrence of types of circulation calculated from short series of observations. Thus, for example, recurrence of Type 5 in January and February in the period 1921-1930 is 4 times more than that in the period 1941-1950, and in July recurrence of Type 10 in 1931-1940 is 7 times less than that in the period 1941-1950.

With analysis of data for the short period rarely realizable types of circulation can be absent. As an example it is possible to indicate that with analysis by Dzerdzeyevskiy (1946) of data for the period 1933-1940 absence of the type of circulation 1 from May to

August was ascertained, whereas in the period of 1941-1958 it was observed both in May and August. Type 3 was not observed in the winter, and in the periods 1901-1910 and 1941-1950 it was observed in February. It is necessary to pay special attention to this circumstance, since the authors of many synoptic and synoptic climatologic works use for their conclusions short series of observations. Such works can have only a certain methodical value.

Recurrences of types of circulation given in Tables 10-12, pertain to all the northern hemisphere as a whole. But realization of the same type of circulation in various parts of the hemisphere can lead to different temperature regimes, and therefore for a comparison of the character of general circulation with variation in temperature in individual parts of the hemisphere it is necessary to produce calculations of recurrence of types of circulation according to individual sectors of the hemisphere. The number of sectors and geographic position of the borders between them should be set, as the author of typification will recognize, every time in accordance with the problem requiring solution. At present for several reasons this is impracticable, and in this work, as in works of Dzerdzeyevskiy published till now, it is necessary to be limited to exposure of the connection between the change in temperature and circulatory characteristics for six constant sectors proposed by Dzerdzeyevskiy. Boundaries between these sectors with physicogeographic and climatic points of view have certain foundation.

Shown on Fig. 35 are boundaries between six sectors of the northern hemisphere and stations at which there is performed a comparison of air temperature with circulatory indices. The stations were selected as far as possible in different parts of the sectors. As it is known (Rubinshteyn, 1956, 1962), mean monthly air temperatures of different stations have a considerable correlation connection even at great distances, and therefore there is no need to select for comparison with circulatory characteristics a great number stations. For the characteristic of the connection between air temperature and circulation data were analyzed only for those points and for those months of the year when variations in temperature from year to year and also in 10-year means were considerable. Otherwise conclusions would not be objective enough.

The comparison of air temperature with the character of circulation for individual years is greatly complicated by the difference in the state of the underlying surface in the time period examined and preceding it (dry or humid soil, snowless surface or a surface covered by snow, etc.), and also by what the character of circulation was in the preceding period. In order to trace the presence of the relationship and to find its general regularities, it is expedient to examine the value of the temperature and types of circulation not for individual years, but averaged over a 10-year period. In this case the factors complicating the comparison to a certain degree are levelled.

Exposure of the relationship between temperature and circulation is expediently conducted not with 13 types, but with types united into 4 groups, about which was discussed in the beginning of the

Fig. 35. Location of sectors of the northern hemisphere by typification of Dzerdzeyevskiy processes and stations for which a comparison of air temperature with circulatory indices is made.
KEY: (a) Winnipeg; (b) New Haven; (c) Upernavik; (d) Kyusyur; (e) Yakutsk; (f) Vilyuysk; (g) Malyye Karmakuly; (h) Salekhard; (i) Greenwich; (j) Leningrad; (k) Kiev; (l) Kazalinsk.

chapter. In each of these groups there are carried out several forms of circulation, where the basic, most frequently repeated forms are usually two. Since the remaining forms are rarely encountered (several days per month), then one of basic forms replaces the other, the course of their recurrence is almost mirrored, and there is no need to make a comparison with the temperature observed with both these forms. There are, however, cases, when there predominates almost the whole month one form of circulation or, conversely, 4 forms have practically identical recurrence. All these cases and results emanating from these differences in distribution in forms of circulation will be discussed concretely later.

3. Relationship of Indices of Circulation with Variation in Temperature According to Moving Decades (by Sectors)

After these preliminary remarks let us turn to an analysis of the comparison of the temperature regime with circulatory characteristics in individual sectors according to moving decades.

3.1. First Sector

January. Those which are most frequently observed in this sector are zonal circulation[1] and disturbance of zonality, the variation of which with time is almost mirrored. As can be seen from Fig. 36, the moving 10-year mean temperatures at New Haven prior to the decade 1921-1930 are opposite the moving 10-year values of zonal circulation and in subsequent years, parallel to it.

It is difficult to give a full explanation of this phenomenon from a quantitative side without special developments, since data which we dispose are not fully comparable with each other. Thus with the use of a series of different duration borders of regions where there predominates cyclonic and anticyclonic circulation can be changed. The number of days with a definite character of circulation (zonal, meridional, etc.) is calculated for the 60-year period, but these calculations, as it is natural to expect, pertain basically to the central parts of the sectors, and they cannot be completely referred to points lying near borders of the sectors, which in separate parts of the 60-year period can be displaced.

Nevertheless it is possible to express certain considerations because of change in character of the connection between air temperature at New Haven in January and the number of days with zonal circulation in the first sector.

As can be seen from Table 10, prior to the decade 1921-1930, recurrence of Type 12 is much higher than that of the perennial average, and therefore, as it is possible to judge by Fig. 29, the main influence on air temperature at New Haven should be the disturbance of zonality. Tables, in which there are given moving 10-year averages of days with various forms of circulation,[2] show that in a greater part of the period 1899-1958 the number of days with disturbance of zonality considerably exceeds the number of days with zonal circulation. Thus in January in the decade 1905-1914 the average of days with zonal circulation is 9.0, with disturbance of zonality, 15.1. Feedback between recurrence of zonal circulation and temperature of New Haven before the decade 1921-1930 is explained not by the fact that this circulation possessed then some special properties, but by the fact that the course of it was mirrored with respect to the course of the disturbance of zonality, which was determined by temperature. Starting approximately from the period 1921-1930 the numbers of days with both forms of circulation are levelled, and subsequently recurrences of zonal circulation and disturbance of zonality change in certain places. In the period 1931-1940 the number of days with zonal circulation is 15.2, with disturbance of zonality, 9.0, and in subsequent years again

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[1] Here and subsequently the term "zonal circulation" pertains to zonal western circulation. Zonal eastern circulation, in view of its low recurrence in the given division, is not examined.

[2] These tables are not cited in the work because of their large volume.

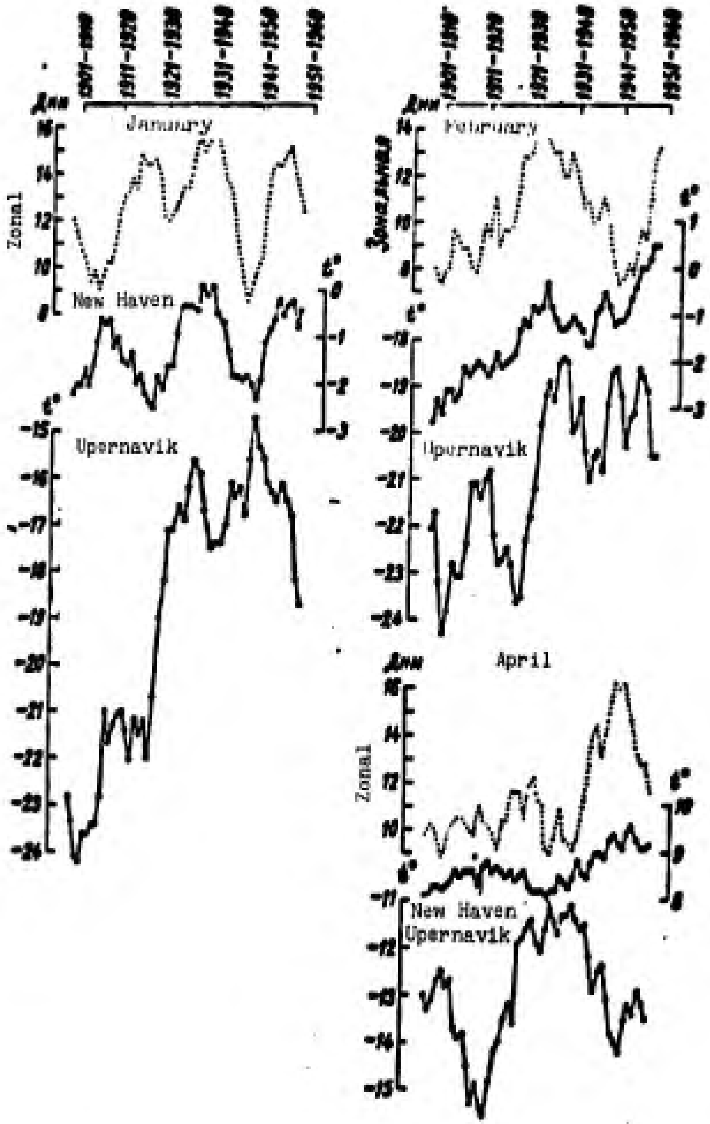

Fig. 36. Number of days with zonal circulation and air temperature according to moving decades. First sector. January, February, April.

recurrences of both forms of circulation are almost identical, but the role of meridional northern and southern circulation increases. After 1920 variation in temperature at New Haven is basically parallel to the variation of the zonal circulation. Apparently, this is connected with a decrease in recurrence of Type 12 and replacement of it in the period 1921-1940 by Type 5, and later Type 7 (Table 10, Figs. 30 and 31).

Variation in temperature in Upernavik located on northwest Greenland is more or less similar to the variation in temperature in New Haven only up to the period of 1921-1930, and then in the period of warming of the northern latitudes it is opposite to it. It is natural to expect that those changes in recurrence of forms of circulation about which was earlier said will lead to other results in the variation in air temperature in the north.

February. Circulatory characteristics in February differ little from those of January. The predominant forms are, as in January, zonal circulation and disturbance of zonality, and the course of their recurrence is opposite to each other. In specific gravity somewhat greater than that in January, there is importance in other forms of circulation, namely, meridional northern and meridional southern, which complicates the comparison of some form of circulation with mean monthly temperatures. Thus, for example, in the period 1900-1909 the number of days with zonal circulation, disturbance of zonality, meridional northern and meridional southern was 7.2, 9.4, 5.8 and 4.9 respectively. With such relationship of recurrences it is difficult to expect similarity of variation in temperature with any of these forms separately. As can be seen from Fig. 36, with a comparison of temperature curves of New Haven and zonal circulation, it is possible to replace only the tendency to similarity of variation and coincidence of basic maxima in the 1920's and minima from the beginning of the century and in the 1940's. In Upernavik there are noticeable certain shifts in the course of temperature with respect to the variation in temperature at New Haven and the course of zonal circulation. There is basis to assume that the reason for this is the greater role of other forms of circulation (meridional) in the northern regions as compared to southern. Inconnection with this it is necessary to pay attention to the fact that, just as in January, after 1930 the total recurrence of types of circulation 5, 11 and 12 drops, which in the period from 1931 to 1950 is compensated by an increase in recurrence of Type 7 and in the 1950's, a Type 8 (which, however, for sector 1 there are special distinctions as compared to Type 7).

In March the circulatory characteristics acquire certain features peculiar to the transition season of the year. Although, as in preceding months, the basic forms of circulation remain zonal and disturbance of zonality, the variation of which is opposite but the amplitude of fluctuation of them with time is less considerable, the number of days in the month when they are observed is also decreased (not more than 13 on the average for a 10-year period). In the remaining days of the month the basic form of circulation is meridional northern (up to 7.6 day).

The proportion of Types 11 and 12 in the perennial average is identical, and after 1940 the recurrence of Type 12 is considerably greater than that of Type 11. All these conditions lead to the fact that good coordination of variation in temperature with some form of circulation is not observed.

In April reconstruction of the circulation continues in accordance with the transition season in the same direction as that in March, — opposition of the course of zonal circulation and disturbance of zonality, increase in proportion of the meridional northern. The predominate in the perennial mean becomes Type 12, and the next types are 7, 10 and 11.

These conditions were reflected in the variation in temperature in such a form: curve of temperature in New Haven with insignificant amplitude of variations in general follows behind the variation in zonal component, and the temperature in Upernavik is changed opposite to this movement. Let us try to express certain considerations of the reasons for this.

The lowest 10-year mean temperatures of April were observed in Upernavik in periods of approximately 1913-1922 and 1943-1952. In the first of these periods the recurrence of zonal circulation was small and almost identical with the recurrence of disturbance of zonality (10.3 and 10.5 days respectively). During this time, on a level with Type 12, characteristic for spring Type 11 had great recurrence, which for this season is unnatural. Zonal flows went more farther south (Fig. 28), and on the northwest of Greenland conditions for cooling were created. In the 1940's recurrence of zonal circulation attained their greatest values, but the temperature of Upernavik was nevertheless low, since with great recurrence of Type 7 zonal flows went, as in the first decade, farther south (Fig. 31). The highest temperatures were observed in Upernavik in the 1920's and 1930's. The relationship between recurrence of forms of zonal circulation, disturbance of zonality and meridional circulation is the same as that in the decade 1911-1920, but recurrence of Type 11 sharply decreased and the temperature in this period was considerably higher than that in preceding years.

In May the recurrence of the form "disturbance of zonality" considerably drops and its course is no longer opposite to the course of zonal circulation, and the meridional northern acquires an even greater circulation. Under such conditions it is impossible to expect good coordination of variation in temperature with any one form of circulation, all the more so that variations in temperature are small, at New Haven the difference in the 10-year mean temperatures does not exceed 1.3° and at Upernavik, 2.1°.

In June the basic forms of circulation are zonal and meridional northern circulation. Variations in recurrence of each of these 10-year forms from one decade to the other has great amplitude, but the air temperature reacts weakly on them its (variations are insignificant).

In July on an average over 60 years types of circulation 2 and 4 predominate and in a separate 10-year period, also Type 10 (Figs. 34, 33 and 32).

The zonal component acquires much weight (its recurrence is from 14 to 21 days per month), and the variation in temperature in Upernavik well agrees with the course of zonal circulation. In New Haven with small variations in temperature it is difficult to set the degree of similarity objectively (Fig. 37).

In August, September and October during great variations in recurrence of circulatory characteristics variations in temperatures

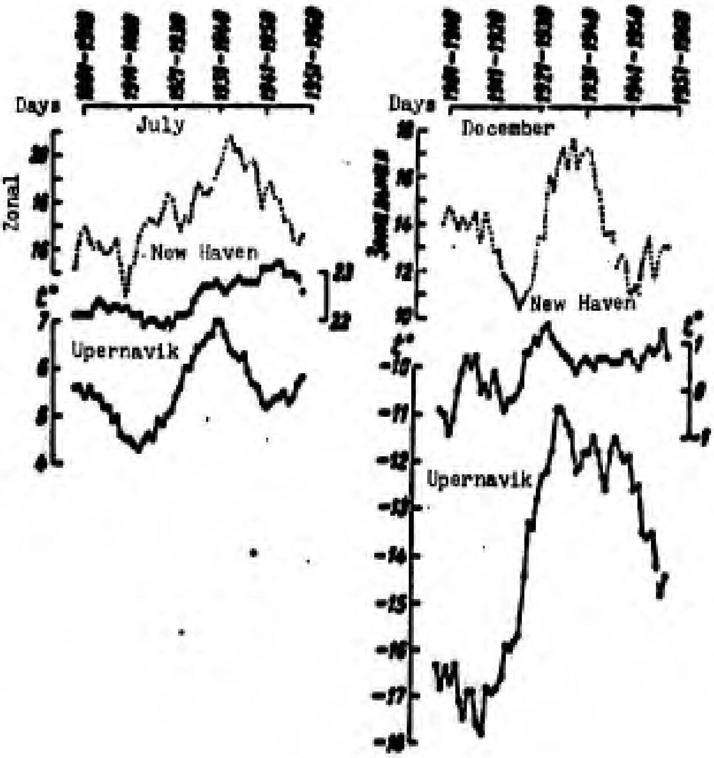

Fig. 37. Number of days with zonal circulation and air temperature according to moving 10-year periods. First sector. July, December.

are small; in November, conversely, the recurrence of zonal component and disturbance of zonality is held very stably, the recurrences of them being almost equal. The variation in temperature does not correspond to them, apparently, because of the complexity of interaction of circulatory components between themselves.

In December the basic forms of circulation as before are the zonal circulation and disturbance of zonality, the course of which in general is opposite. In New Haven variations in temperature are small and correspond little to the variation in zonal circulation, and in Upernavik the coordination of the variation in temperature and circulation is obvious (Fig. 37). It is evident especially clearly in the period of warming. In the period when recurrence of zonal circulation is least (1917-1926), the dominating influence is the disturbance of zonality and meridional northern circulation the course of which is parallel, and the mean total recurrence for this decade is 18.3 day per month. This is explained by the noncorrespondence of temperature of Upernavik in this period with variation in zonal circulation. An analogous position is observed in the period 1941-1950.

3.2. Second Sector

January. The basic circulatory form, just as in the first sector, is zonal circulation (from 12 to 20 days per month), the disturbance of zonality in this sector is observed rarely, and a greater role here is played by the meridional southern circulation. The relationship of it with zonal circulation is rather complicated; up to the decade 1921-1930 its course is opposite to the zonal course, and in the period of about 1937-1946 their course is parallel to each other. In Greenwich, Kola, Leningrad and Kiev one can see the conformity between recurrence of the meridional southern circulation and the warming in the 1920's and 1930's and also with the temperature drop of the 1940's (Fig. 38). In the earlier period (about 1911-1920), in spite of a rather great recurrence of meridional southern circulation, the temperatures remain low. Apparently, this is connected with the sharp increase of recurrence of Type 12 as compared to later years.

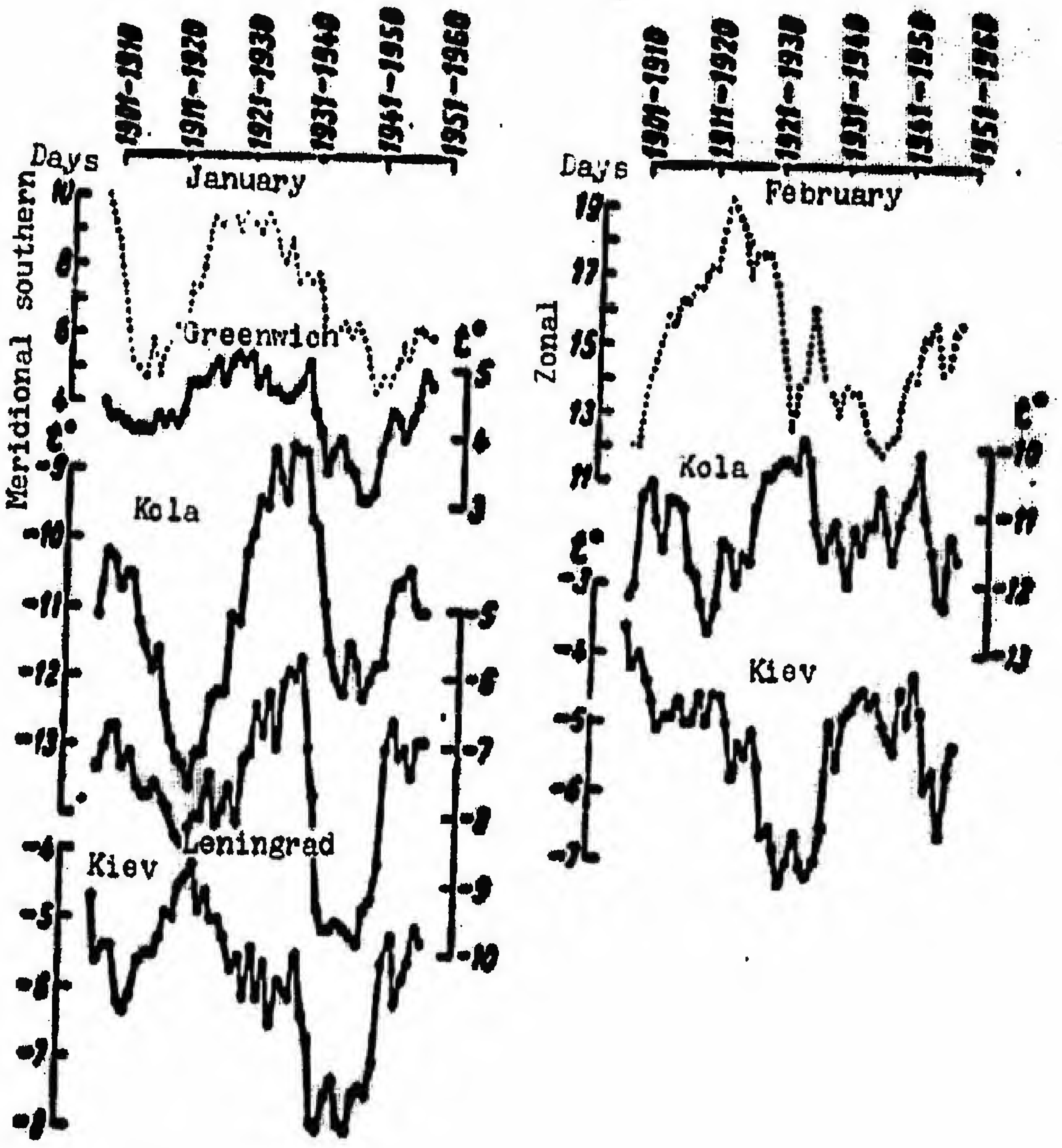

Fig. 38. Number of days with meridional southern and zonal circulation and the air temperature according to moving 10-year periods. Second sector. January, February.

It is characteristic that the variation in temperature in the period prior to 1921 in Kiev agrees better with the course of the meridional southern circulation than that in a more northern stations, Leningrad and Kola.

For February there is given a comparison of recurrence of zonal circulation only with temperatures of stations of Kola and Kiev, since in Greenwich variations in temperature are small, and in Leningrad they are not clear and systematic enough to judge their connection with circulation objectively. The basic circulatory characteristics are zonal circulation and meriodional southern opposite to it in the course with time. Great recurrence of zonal circulation is connected with low temperatures of Kola. In those periods when zonal circulation is rare it is basically replaced by the meridional southern circulation bringing heat.

Prior to 1940 variations in temperature at Kola and Kiev have a mirror character, which is in accordance with the predominate types of circulation; starting from the period 1941-1950 the variation in temperature at Kola and Kiev is basically parallel. Such a distinction becomes intelligible if one were to remember the synoptic situations depicted on Figs. 30, 28, 29, and consider that after 1940 the recurrence of Type 12 was increased.

In March traits of a transition season are noticeable. The proportion of types of circulation 11 and 12 decreases, on a level with Type 5 importance is acquired by Type 7 and in separate 10-year periods, Type 8. Although zonal circulation predominates, at the same time the role is increased of not only the meridional southern but also meridional northern circulation. In these conditions it is impossible to expect good coordination of the variation in temperature with any one form of circulation.

In April the recurrence of zonal circulation considerably decreases and is compared practically with the recurrence of the meridional northern, meridional southern and disturbance of zonality, but the maximum values of recurrences are apportioned to various periods: the course of zonal circulation is opposite to the course of disturbance of zonality, and the course of the meridional northern is opposite to the course of the meridional southern.

With such a synoptic situation, as one should have been led to expect, the relationship of temperature with whatever one form of circulation cannot be quite clear.

In May the basic form (in recurrence by circulatory form) is the meridional northern, and the same course with respect to it is that of the disturbance of zonality. Variations in temperature in Greenwich are opposite to the variations in Kola, Leningrad and Kiev, which is fully intelligible if one were to consider that in May Types 12 and 10 predominate (Figs. 29 and 32). The variation in temperature in Greenwich is basically parallel to the course of the meridional northern and at the remaining stations is opposite to it.

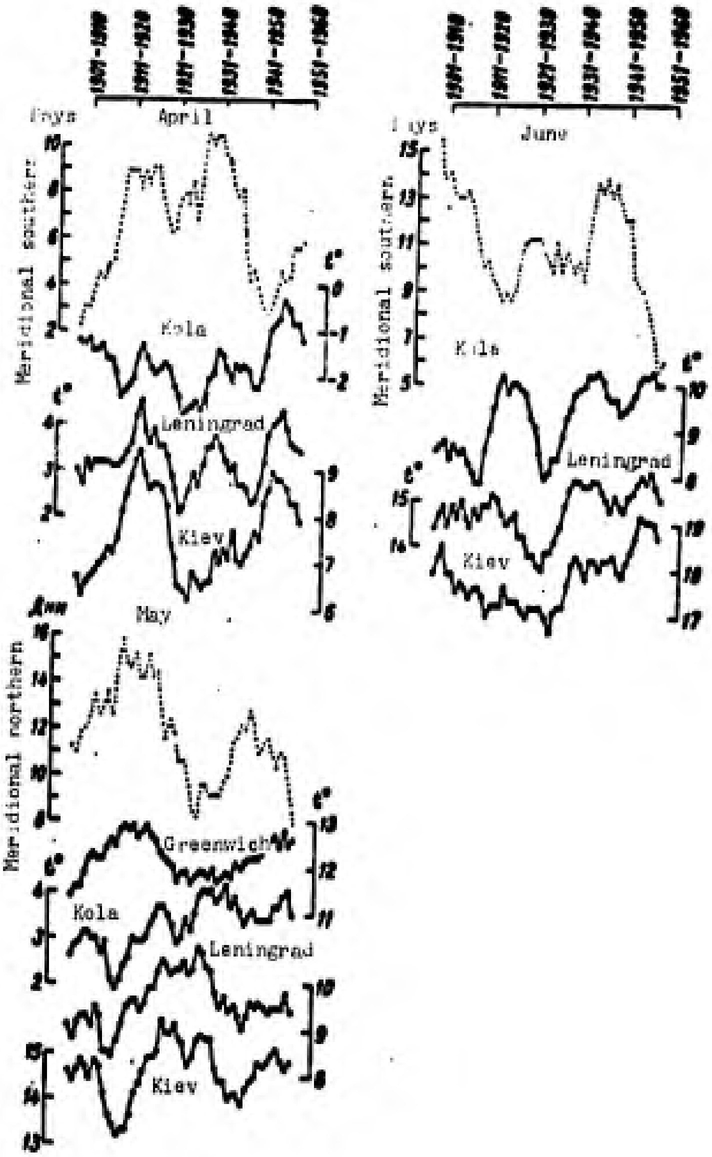

Fig. 39. Number of days with meridional southern and meridional northern circulation and air temperature according to moving 10-year periods. Second sector. April, May, June.

In June in the perennial mean Types 10 and 4 predominate; both are characterized by Arctic intrusions in the examined sector. The predominant forms of circulation are the meridional northern and disturbance of zonality, and in certain years there also is quite often observed zonal circulation. The course of temperatures is opposite to the meridional northern course (Fig. 39).

July, according to the character of circulation, is already the typical summer month. In the perennial mean Types 2 and 4 are most frequently observed and in a certain 10-year period, also Type 10. As in June, the basic form of circulation is meridional northern, but of considerable importance also are the disturbance of zonality and zonal circulation. In connection with this the conformity of temperature with any one form of circulation is expressed less clearly than it is in June.

In August the same types of circulation as in July predominate (Table 10). The basic forms are the disturbance of zonality and zonal circulation opposite it in departure. Of the same order is the recurrence for the meridional northern, but variations of it with time are small (the amplitude is less than 4 days), and therefore its role in the change of temperature from year to year is insignificant. As can be seen from Fig. 40, the variation in temperature of all stations in August is well linked with the variation in recurrence of zonal circulation (and, consequently, with the disturbance of zonality).

In September, according to circulatory characteristics, transition is seen from summer to autumn. Types 12 and 7 are already predominant. Most frequently there is observed a meriodional northern circulation (up to 16 days per month); during years with its lowered recurrence it is replaced on the whole by disturbance of zonality and zonal circulation, which during this time are practically repeated often equally. Thus, for example, in the decade 1919-1928 the numbers of days with zonal circulation, meriodional northern and disturbance of zonality are equal to 9.0, 7.1, and 8.2 respectively. This relationship between recurrence of different forms of circulation results in the fact that variation in temperature does not have a close connection with any one form of circulation.

In October the transition character of circulation is even more effective, on a level with even considerable (in a perennial average) recurrence of summer types the proportion of circulatory Types 11 and 5 is increased. Almost identical recurrence (up to 12-13 days) is possessed by western and meridional northern circulations whose course is basically opposite, but the meridional southern is also repeated quite frequently (up to 10 days). Such relationships do not lead to good connection of the temperature with any of the forms of circulation.

Circulatory characteristics of November have a typically winter character. Predominate types of circulation are 11, 12 and 5. The most frequently repeated is the zonal circulation and meridional southern. The course of temperature in Greenwich, Kola, Leningrad and Kiev is basically opposite to the course of meridional southern circulation, but there are definite distinctions in the north and south of the sector. In a period with a small number of days with a meridional southern circulation (about 5-6 days) zonal circulation predominated (16.4 days), which caused relatively high temperatures. In the period when the recurrence of meridional southern circulation is high, zonal circulation has an almost identical recurrence with it. In this case the interaction of both forms of circulation should affect differently the variation in temperatures of the northern and

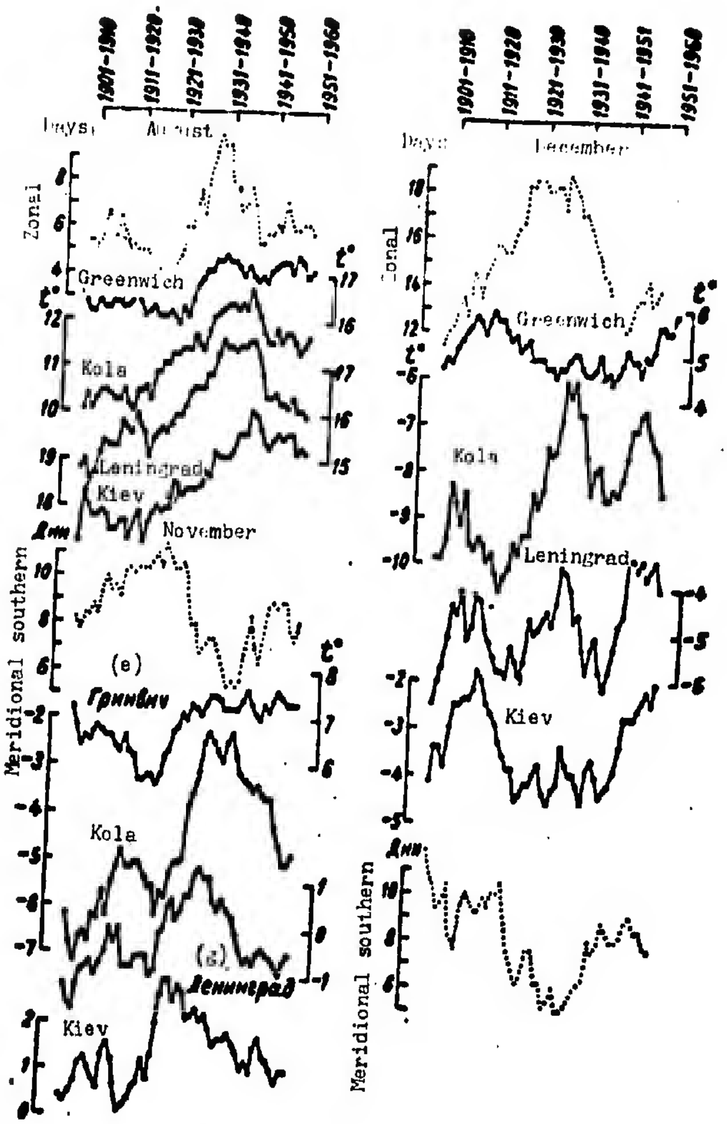

Fig. 40. Number of days with zonal and meridional southern circulation and air temperature according to moving 10-year periods. Second sector. August, November, December.

southern parts of the sector, as can be seen from Figs. 30, 28, 29. Actually, near period 1921-1930 Greenwich, Kola and Leningrad have low temperatures, and Kiev has high temperatures.

In December, as also in November, zonal circulation predominates. A comparison of the air temperature with recurrence of this circulation shows that the dependence between them is rather complicated.

The variation in temperature in Kola and Leningrad starting from the period 1916-1925 agrees well with the recurrence of zonal circulation, and in earlier years when the number of days with zonal circulation is almost equal to the number of days with meridional southern circulation this plays an important role and assists in the appearance of a secondary temperature maximum. The course of temperature in Greenwich and Kiev is opposite in their phase to the course of temperature in Kola and Leningrad, as can be expected with Types 5 and 11 (Figs. 30, 28). It clearly agrees better with the course of the meridional southern circulation.

3.3. Third Sector

In circulatory characteristics in the winter this sector considerably differs from the second sector.

In January the basic form of circulation is the stationary position which is observed from 14 to 24 days per month. In remaining days of the month in most cases is replaced by a meridional northern circulation, so that the course of these forms of circulation is opposite to each other. Comparing the course of temperature of a series of stations with the recurrence of the stationary position (Fig. 41), we see that results of this comparison in various parts of the sector are different. In the Malyye Karmakuly in a period of about 1911-1920 a small number of days with stationary position corresponded to very low air temperatures, and in the period near 1936-1945 just as low a number of days with a stationary position corresponded to high temperatures in the Malyye Karmakuly. In Salekhard located to southeast both minima of recurrence of stationary position corresponded to comparatively low temperatures. Table 10 shows that in the period 1911-1920 the recurrence of Type 12 is considerably greater than that in the 1930's when recurrence of Type 5 is greater than that of Type 12. Examining Figs. 30, 28, 29, we see that in all basic winter types (11, 12 and 5) both the Malyye Karmakuly and Salekhard lie close to the border dividing the cyclonic and anticyclonic regions. This can condition the distinction in variation in temperatures at these stations in various time periods.

Variation in temperature in Kazalinsk, as was already noted by Rubinshteyn in previous works (1946, 1956), is opposite to the variation in it in Salekhard. Kazalinsk is in the zone of the Asian anticyclone, and the stationary position causes here a lowering of the temperature and the meridional northern circulation, its growth. The same trend is observed in Barnaul whose temperature is considerably stabler from year to year than it is in Kazalinsk.

In February the basic circulatory characteristics are the same as those in January; basically a stationary position predominates. Meridional northern circulation has a smaller recurrence than it does in January. In periods when the number of days with stationary position is small, there is observed not only a meridional northern but partially a disturbance of zonality and zonal circulation. Thus, for example, in the decade 1949-1958 the number of days with a stationary position is 10.0, with a meridional northern, 7.9, with a disturbance of zonality, 5.4, and with zonal circulation, 4.7. It is natural that in such periods great conformity in the course of

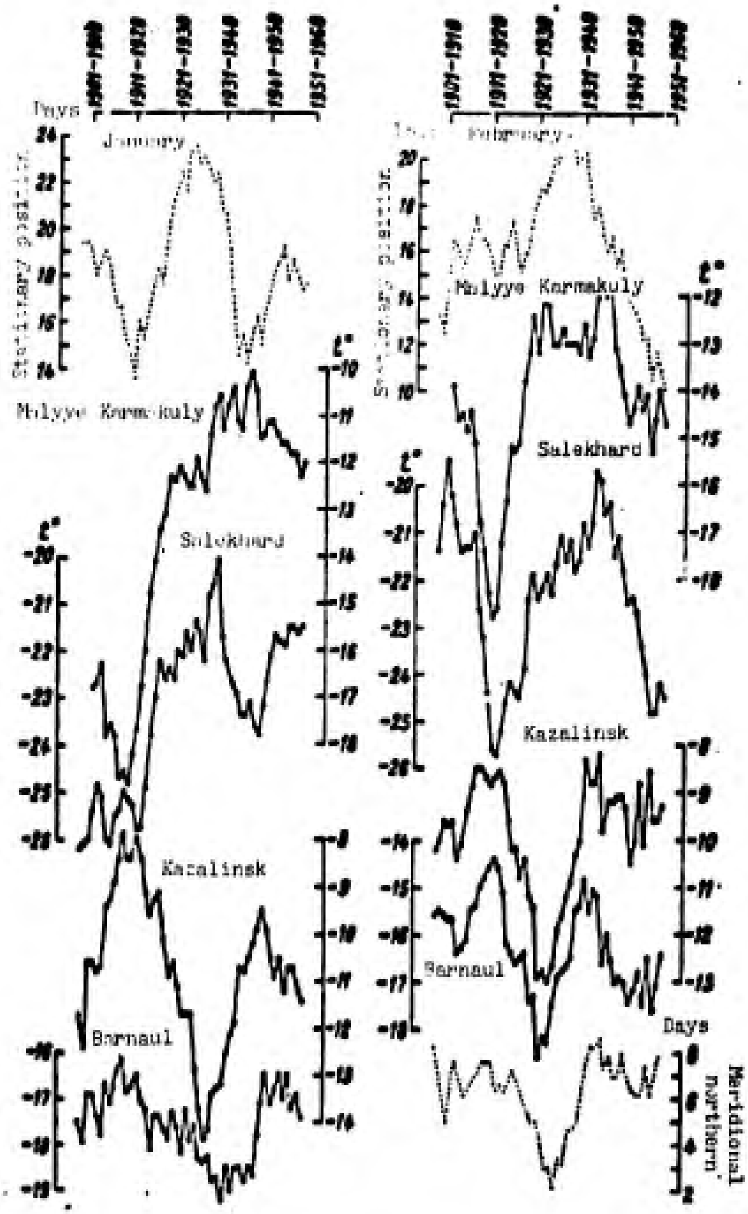

Fig. 41. Number of days with a stationary position and meridional northern circulation and the air temperature according to moving 10-year periods. Third sector. January, February.

air temperature with recurrence of the stationary position is absent. On Fig. 41 conformity with temperature of stations Malyye Karmakuly and Salekhard can be seen especially clearly only in the period of the maximum of days with a stationary position.

The course of temperature in Kazalinsk and Barnaul corresponds to the recurrence of the meridional northern.

In March, as before, the greatest recurrence has a stationary position and meridional northern circulation, but they already in only certain periods have an opposite course, since the importance of other forms of circulation increases. A comparison of temperature at the stations Malyye Karmakuly, Salekhard, Kazalinsk and Barnaul with recurrence of the meridional northern circulation shows an opposite course of them: the meridional northern circulation is connected with the lowering of the temperature at all stations.

In April a comparison of temperatures in Malyye Karmakuly and Salekhard with recurrence of the stationary position, which in this month is observed most frequently, does not show full conformity between them. This is explained by the considerable proportion of remaining circulatory characteristics. Let us explain this in following example. At both stations the highest temperatures are observed in the period near 1941-1950 coinciding with years when the number of days with stationary position and with meridional northern circulation is close to the minimum. In the period near 1921-1930 the recurrence of the stationary position is also small, but the number of days with meridional component is almost 3 times more than it is in the first case, and the temperature in Malyye Karmakuly and Salekhard is 5-7° lower than that in the decade 1941-1950.

The distinction of these two decades is well seen in Table 10. In the decade 1941-1950 the recurrence of Type 12 sharply decreases and the recurrence of Type 7 increases as compared to that of the decade 1921-1930.

In Kazalinsk the period of low temperatures coincides in time with the northern stations, but the rise in temperatures in the 1940's and beginning of the 1950's is no longer observed, and in Barnaul it is still preserved. Since these trends are expressed less noticeably than those at northern stations, these data are not given in Fig. 42.

The period from May to August has much in common to the circulatory indices. First of all the similarity consists in that the number of days with different forms of circulation is distributed more evenly than it is in winter. In May the basic forms of circulation are meridional northern and zonal circulation, the course of which is basically opposite. In June and July the basic form of circulation is the disturbance of zonality, and the stationary position has an opposite movement but its recurrence is small. Analogously, an opposite course is found in the meridional northern and zonal circulation, the numbers of days with which in June are basically of the same order; in July recurrence of zonal circulation somewhat exceeds the recurrence of the meridional northern. In August the basic form of circulation is also the disturbance of zonality, and the meridional northern and zonal circulation have an almost identical recurrence and opposite course. The number of days with a stationary position is insignificant. Under such conditions in the summer period a clear parallelism between one of the circulatory characteristics and temperature is impossible to expect, and all the more so that in the southern regions the variations in temperatures themselves are small.

In September, just as in the preceding months, the number of

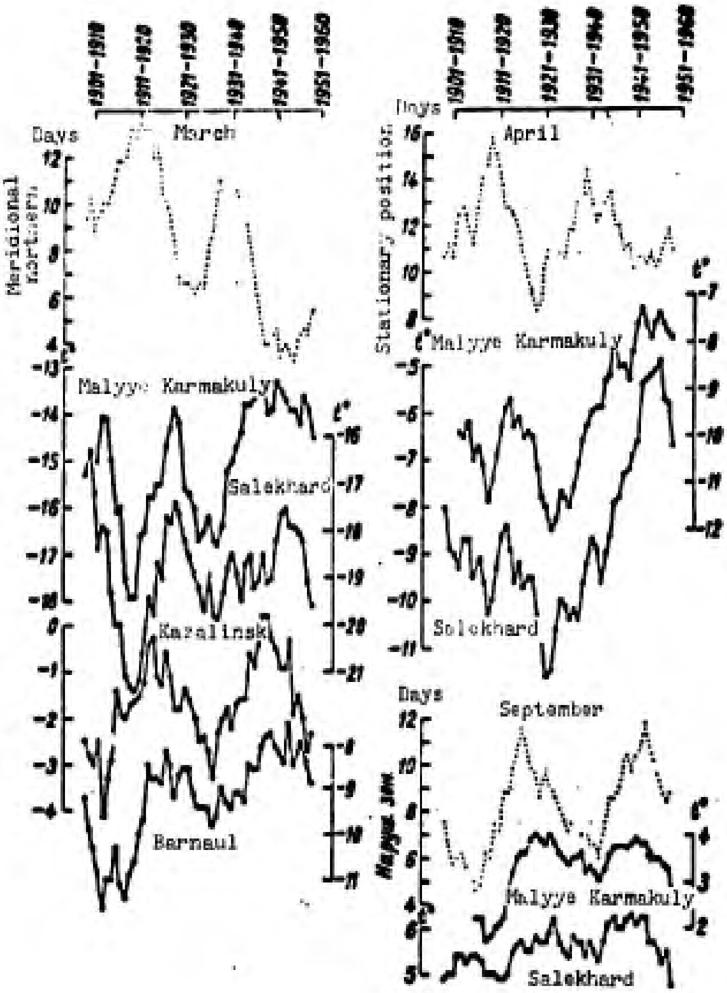

Fig. 42. Number of days with a meridional northern circulation, stationary position and disturbance of zonality and the air temperature according to moving 10-year periods. Third sector. March, April, September.

days with various forms of circulation is almost equal, where the zonal circulation has a course opposite to the meridional northern, and the disturbance of zonality is opposite to the stationary position. Figure 42 gives a comparison of recurrence of the disturbance of zonality and variation in temperatures in Malyye Karmakuly and Salekhard. At the more southern stations variations in temperature are small.

October in a circulatory relation is the transition month to the winter type. The stationary position dominates, but, as one can see from Table 10, in the perennial mean Types 1, 5, 7, 8, 11, and 12 have almost identical recurrence. Such position results in that good conformity of any one circulatory index with temperature conditions is not observed, and only definite trends of similarity between them are revealed.

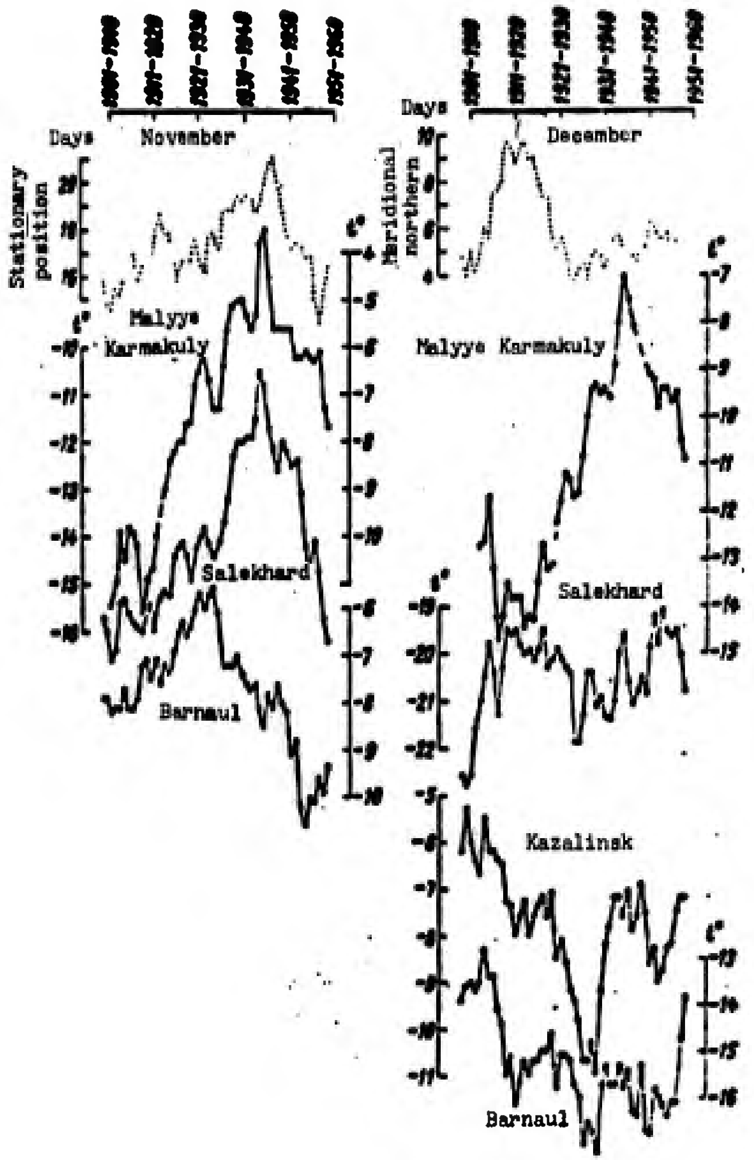

Fig. 43. Number of days with stationary position and meridional northern circulation and the air temperature according to moving 10-year periods. Third sector. November, December.

In November the stationary position on an average for a 10-year period is observed from 14 to 21 days per month. Variation in temperature in the Malyye Karmakuly and Salekhard basically corresponds to a circulatory characteristic, but qualitatively the difference in temperatures at these stations in different time segments, which characterizes the intense warming of the 1930's, is much more sharply pronounced than the difference of days with a stationary position in corresponding periods. It is necessary to note that this was also observed in January and February. The variation in temperature in Barnaul is basically linked with the recurrence of the stationary position only in the first half of the period.

In December circulatory characteristics differ little from those of November. A comparison of the course of temperature with the recurrence of the stationary position is difficult to produce, since although it predominates it is held very stably during the whole period (17-21 days per month as an average for the 10-year period). For this reason Fig. 43 gives a comparison of temperature with the recurrence of the meridional northern circulation. In the Malyye Karmakuly there is distinctly seen feedback between them into the period prior to 1930; in Salekhard this connection becomes direct, and in Kazalinsk and Barnaul it is more clearly expressed after 1930.

3.4. Fourth Sector

First of all one should note that in this sector the relationships between circulatory characteristics and air temperature are expressed often less clearly than those in the preceding sectors and spread basically over the territory to the north of 60° N. Lat. In winter months here mainly a meridional northern circulation is observed. The number of days with such circulation in January is from 15 to 25 on an average for a 10-year period.

Variation in temperature in Kyusyur, Vilyuysk and Yakutsk basically coincides with the recurrence of the meridional northern circulation, but variations in temperature are not proportional variations in circulation. Thus, for example, the least number of days with meridional northern circulation was observed in the 1930's and 1940's, and a secondary minimum in the beginning of the century is expressed considerably weaker. At the same time the temperature in Vilyuysk in the beginning of the century is lower than it is in the 1930's and 1940's.

In February circulatory characteristics almost completely coincide with those of January, but the connection of them with the temperature regime is the reverse. To explain the cause of this as yet remains unsuccessful. Almost the same picture is observed in March, but it is expressed not as sharply as it is in February, in view of the fact that variations in temperature are less than those in February.

In April the meridional northern circulation is still observed more frequently than other forms of circulation, but recurrence of it is considerably less than that in preceding months (from 6 to 14 days on the average for a 10-year period). The distribution of days with different forms of circulation becomes more uniform, and with a comparison of the temperature with any one form of circulation it is possible to note the similarity in them only in the most general outline.

In May, just as in April, the distribution of days with various forms of circulation is more evenly than it is in winter, where the recurrence of meridional southern circulation is greater than that of the meridional northern, and the disturbance of zonality has a course opposite to the meridional northern. A comparison with the temperature permits noting only general trends in the course of the temperature and circulatory indices.

In June the most frequently observed is the disturbance of zonality, and in number of days it only somewhat exceeds the meridional southern circulation whose course is basically opposite. The recurrence of other forms of circulation is insignificant. Under such condition as Fig. 44 shows, the variation in temperature well agrees with the course of the disturbance of zonality.

In July the basic forms of circulation are the same as those in June, where the recurrence of them is increased. Disturbance of zonality is observed from 11 to 18 days per month on an average for a 10-year period and the meridional southern, from 9 to 15 days. The course of these forms of circulation is basically opposite.

A comparison of the course of curves of disturbance of zonality and temperature shows that conformity is observed only with Kyusyur and Vilyuysk. With Yakutsk, located farther south and east of the indicated stations, there is observed a reverse trend – a lowering of the temperature with an increase in the number of days with disturbance of zonality. Distinction in the course of the curves as compared to June, apparently, is connected with a considerable increase in July of the recurrence of types of circulation 2 and 4 (Table 10, Figs. 34, 33).

In August the same circulatory forms as those in the preceding summer months preserve their importance, and in September there is considerable importance in the meridional northern circulation owing to a certain decrease in the number of days with remaining forms of circulation. However, in both August and September the variations in temperature are small and it is difficult to judge the conformity to their components of circulation.

In October the meridional northern circulation becomes already the basic form of circulation (from 6 to 19 days per month on an average for a 10-year period), but during years when it is rarely observed it is replaced by a stationary position and disturbance of zonality, and therefore good conformity between the course of circulatory characteristics and temperature is not observed.

In November and in December the circulation takes on a typical winter character with great predominance of meridional northern circulation and in accordance with the decrease in the proportion of other forms of circulation (Fig. 45). In these conditions there is observed good conformity with the variation in temperature, where in November the variation in temperature is reverse to the course of the meridional northern circulation, but in December it is parallel to it. The same phenomenon was shown with respect to other winter months. Thus in December and January the course of temperature and course of the meridional northern circulation are parallel, and in November, February and March they are opposite. As was already said, this phenomenon not accidental, but for its explanation special investigation is required.

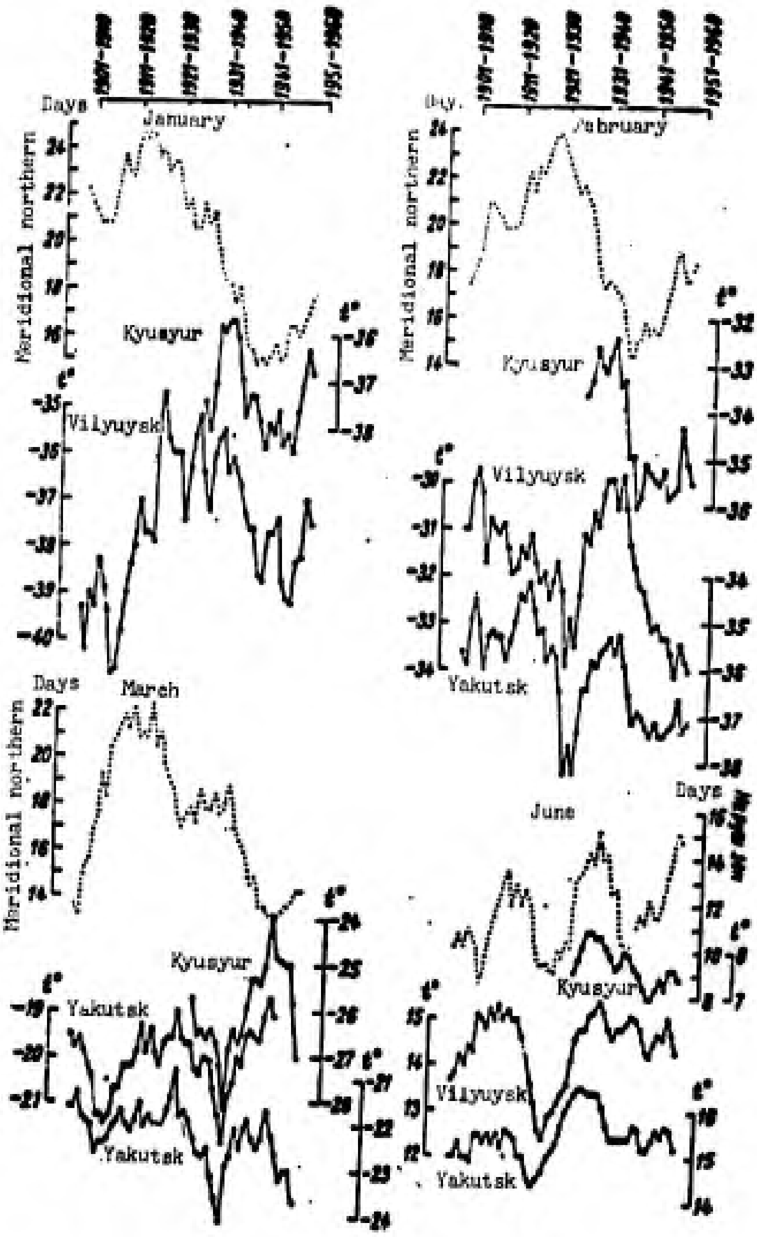

Fig. 44. Number of days with meridional northern circulation and disturbance of zonality and the air temperature according to moving 10-year periods. Fourth sector. January, February, March, June.

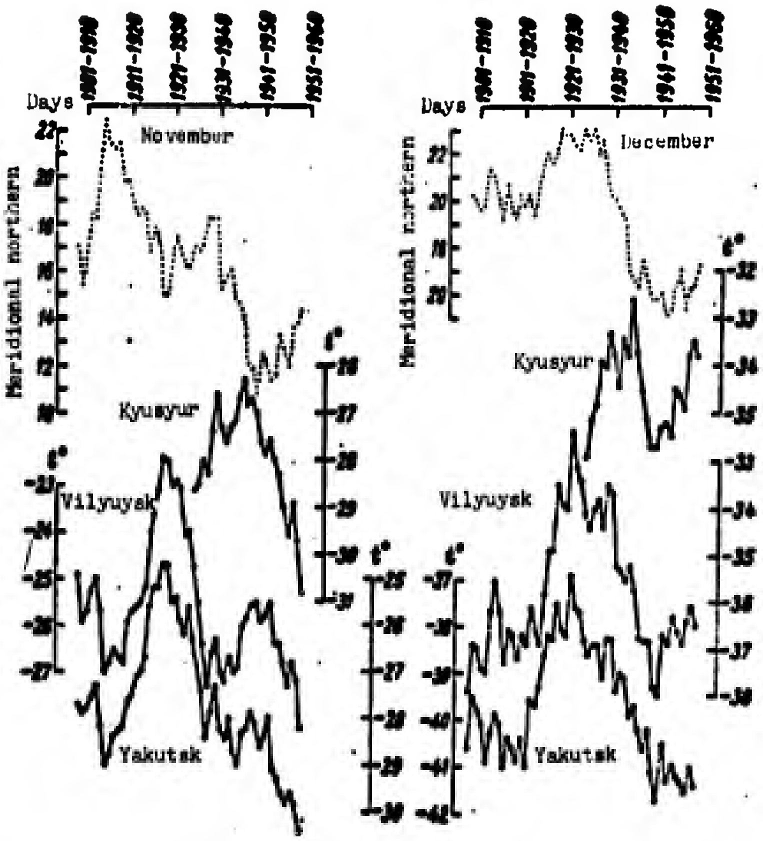

Fig. 45. Number of days with meridional northern circulation and the air temperature according to moving 10-year periods. Fourth sector. November, December.

3.5. Fifth Sector

For the Pacific Ocean sector during a number of months there is typically predominance of zonal circulation. In the period from November to March the number of days with zonal circulation in not one decade was lower than 19, and in separate decades it reached 26-28. With such stability of circulation one should have expected good conformity of recurrence of zonal circulation and air temperature, but this is not observed. In this region there are observations with insufficiently long, frequently nonuniform series, which hampers a comparison. Many stations are located on seacoasts or islands, and therefore variations in temperature on them from year to year are greatly smoothed and this hinders more or less objectively the establishment of conformity of circulatory indices and temperature.

In April and May although zonal circulation remains predominant, the proportion of the meridional northern circulation and disturbance of zonality increases, and from June to August a stationary position predominates. At this time of the year interannual variations in temperature are so small that it is especial difficult to reveal conformity with the circulation.

In September the numbers of days with different forms of circulation differ little from each other, but nevertheless transition to winter conditions - predominance of zonal circulation, is noticed.

In October the predominance of zonal circulation is already sharply expressed (from 16 to 25 days per month on an average for a 10-year period), but the variation in temperature, as in preceding months, is little.

3.6. Sixth Sector

In the sixth, American sector in the winter the meridional northern circulation sharply predominates, but Fig. 46 shows that the course of the curves is rather complicated. In beginning of our century recurrence of the meridional northern circulation in January was highest, up to 27 days per month on an average for a 10-year period, and it corresponded to the lowest temperatures in Dawson and Winnipeg. In this period recurrences of the basic winter types of circulation (11, 12 and 5) were close to the perennial average. In the period near 1921-1930 the number of days with meridional circulation considerably decreased, and recurrence of Type 12 fell in comparison to the preceding period three times while recurrence of Types 5 and 7 increased, and the temperature in Dawson and Winnipeg increased. A secondary maximum of recurrence of the meridional northern circulation at the end of the 1930's and beginning of the 1940's corresponds in contrast to that which was found near the period of 1911-1920, the highest temperatures in Dawson and Winnipeg. From Table 10 it is clear that in these years Types 11, 12 and 5, which is replaced by Type 7, are smaller in proportion.

In February the character of the circulation is the same as that in January, but with a comparison of temperature with recurrence of the meridional northern circulation there were revealed the following differences. In Dawson the variation in temperature in the beginning of the century is parallel to the variation in number of days with meridional northern circulation, which, possibly, is connected with a certain increase in recurrence of zonal circulation. Variation in temperature in Dawson and Winnipeg is opposite, and consequently, the role of the meridional northern circulation in more southern latitudes is already different from that in the northern.

In March and April, although the meridional northern circulation remains predominant, the recurrence of it as compared to the winter months decreases, and the number of days with remaining forms of circulation is increased. In connection with this both in March and in April the conformity between the course of recurrence of meridional northern circulation and temperature of Dawson is observed only in basic features: the highest temperatures correspond to a small recurrence of the meridional northern circulation and the lowest - to great recurrence.

In Winnipeg just as in February, connection between temperature

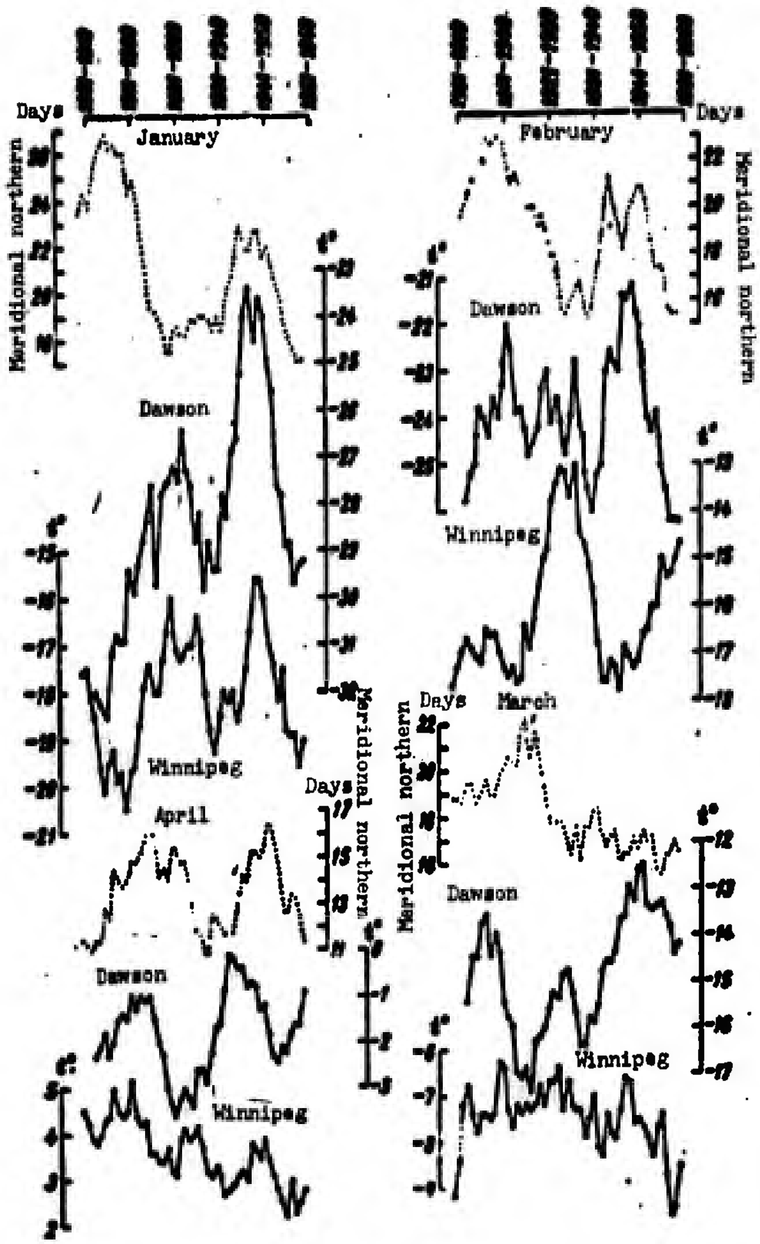

Fig. 46. Number of days with meridional northern circulation and the air temperature according to moving 10-year periods. Sixth sector. January, February, March, April.

and circulation is weakly expressed.

From May the meridional northern circulation is not predominant, and the numbers of days with different forms of circulation are distributed more evenly than in the preceding months. From June to August there predominates a meridional southern circulation, In September and October there begins transition to a winter character of the distribution of forms of circulation with predominance of a meridional northern, especially in November and December. However in not one of these months is there observed good conformity between temperatures and circulatory characteristics. In the warm period of the year it is difficult to establish such conformity objectively because of small variations in temperature and in other months because of the more or less identical proportion of various forms of circulation.

4. Appraisal of Nonrandomness of the Change in Indices of Circulation

In Chapter II there was discussed the method and given the criterion of the appraisal of nonrandomness in a series of meteorological observations. In Chapter III with the help of this criterion it was shown that the change in the course of the moving 10-year mean temperatures exceed the bounds of the random change. In this chapter one should check whether or not changes in the moving 10-year numbers of days have a random character with a certain circulatory index. Given below for selection are certain results of this check.

For the second sector an appraisal was performed of nonrandomness of the course of zonal circulation in January and February (Fig. 38) and meridional northern in June (Fig. 39). Calculations showed that probability of the fact that the course of the circulatory curve is nonrandom in January is 95.5%, in February 98.8%, and in June 99.95%.

For the fourth sector curves were checked of the course of meridional northern circulation in January and February (Fig. 44) and in November (Fig. 45). Results of the check showed that probability of nonrandomness of the course of these curves in January and February is 99.95%, in November 97.2%.

Generalizing all the above stated, it is possible to sum up certain results. Circulation of the atmosphere is an important factor of the formation of climate, but, inasmuch as this factor is not the primary one and only intimately connected with solar radiation and the character of the underlying surface, full conformity between the change in temperature with time and circulatory indices should not be expected. Basically the connections between them in winter are expressed better than in the warm period of the year. The reason for this is that in winter contrasts of temperatures between low and high latitudes, and also between the ocean and the mainland are greater than they are in the summer. In the summertime the role of the radiation factor considerably increases, and in connection with

Table 13. Number of Days in a Month with Different Forms of Circulation (on the Average for a 10-Year Period)

Sector	Month	Form of circulation	Number of days	
			least	greatest
I	January	Zonal.	9	16
II	June	Meridional northern. . . .	6	16
III	February	Stationary position. . . .	10	21
IV	January	Meridional northern. . . .	15	25
V	June	Stationary position. . . .	5	15
VI	January	Meridional northern. . . .	17	27

that the interannual variability of temperatures decreases and the conformity between conditions of temperature and forms of circulation, as a rule, weakens.

Objective judgement on the degree of conformity of air temperature and forms of circulation (with parallel or mirror course of compared values) is possible only when variations in their values from decade to decade will be sufficiently great. Great changes in temperature rate are well-known. In order to give an idea of the variations in number of days from a certain form of circulation, let us cite several examples (Table 13).

As can be seen, in the same month of the year variations in the number of days with the same form of circulation can reach 7-11 days, i.e., of the order of 25-30% of all days of the month.

In those periods when a relatively small number of days with the basic form of circulation for the given sector and month of the year is replaced by a form whose course is the same with respect to the first, and usually the connection (direct or reverse) of these forms of circulation with the course of temperature is well defined; with uniform (by number of days) distribution of three or four forms the resultant effect of their influence on temperature can appear different in different cases and the connection with temperature weakens.

Thus far there has been discoussion of the complexity of objective exposure of the connection between the change in air temperature and circulatory indices, which is caused by the very nature of distribution of temperature and forms of circulation with time. However, a great deal of difficulties were introduced into the investigation and imperfection of the typification of atmospheric processes. Thus, for example, in the course of the work it was clarified that basically the connection between the character of circulation and temperature could be established in the northern and middle latitudes (to the north of 50° N. Lat.) and only sometimes up to 45° N. Lat. (Kazalinsk) and 40° N. Lat. (New Haven). To the south the relationships are noted only in certain months. This is partially caused by the fact that the amplitude of variations in temperature from year to year in the south is less.

There is basis to assume that the worst connections in the east (northern parts of the fourth, fifth and sixth sectors) are partially caused by lesser study of these regions in a synoptic relation, in any case in earlier years, in consequence of which the number of days with defined types of weather could not always be determined correctly.

At the same time it is possible that essentially it is impossible to reduce the entire variety of atmospheric processes to a limited number of types uniform for the whole hemisphere. The same processes in a definite sector of the hemisphere can be combined with different processes in other sectors, which is shown in several works of Girs, Dzerdzeyevskiy and others.

5. Indices of Circulation

The imperfection of many typifications of atmospheric processes, including the typifications of Dzerdzeyevskiy used in the present work, consists in that they do not consider the intensity of the processes. For this purpose it is necessary to use indices of circulation.

Different indices are used as indices of circulation. Thus, for example, Rossby used differences in pressure between definite latitudes as indices of zonal circulation. Vitel's (1947) proposed for the characteristic of intensity of circulation in the given region a total index, considering the mean depth of cyclones and mean power of anticyclones. Lamb and Johnson (1959) used as indices of circulation, along with differences in pressure between definite latitudes, also indices of latitudinal displacements of basic centers of circulation. As the index of atmospheric circulation Kats (1954, 1955) took the specific flow of air mass in a definite layer per unit of time. The index of general circulation is characterized by the relation of indices of zonal and meridional circulation. The index of Kats can be obtained by means of simple calculations of the number of crossings of isobars with parallels and meridians for any territory and different levels.

In the works of Girs (1960) and Kats (1960) there is given a sufficiently complete survey of other indices proposed by various authors, and their merits and deficiencies are noted. Therefore, there is no need to dwell on this question, and one should only note that continuing search in this direction indicates the insufficient satisfactoriness of the proposed indices.

The most contemporary work considering the many deficiencies of preceding works is that of Kats (1960), in which he proposes a system of quantitative physical indices for study of the mean perennial characteristics of circulation and their concrete manifestations in different form and intensity. Measure for an appraisal of the general circulation of the atmosphere is the quantity of air transferable above a region, and as quantitative indices of circulation the mean intensity of mass air transfer in latitudinal (zonal index) and meridional (meridional index) directions and also index of the number of days with meridional processes are accepted.

Unfortunately, we could not use the classification of macroprocesses by indices of Kats, since it is produced by him only for the period from 1938 and cannot serve for determining the connections with variations in temperature during 70-80 years. Furthermore, it is developed only for the Atlantic-Eurasian sector.

Mandel' (1966a, 1966b) shows the possibility of approximate calculation of the intensity of zonal circulation only according to data of surface observations, and this permitted him to restore a series of mean monthly values of intensity of zonal circulation in the Atlantic-Eurasian sector since 1891. The connection of this series with the mean monthly temperature of air (by moving 10-year periods) is shown in Fig. 47. Shown on this figure the connection of the temperature in Berlin with values of the Iceland-Azore interlatitudinal gradient and the temperature located further eastward of Lugansk with the mean interlatitudinal gradient of two profiles Iceland-Azore and Murmansk-Nicosia, and for a comparison with the temperature of Tomsk there is taken an average of three profiles, the two indicated above and the Salekhard-Tashkent profile. As can be seen from Fig. 47, the connection of the temperature with the index of circulation of Kats is rather good.

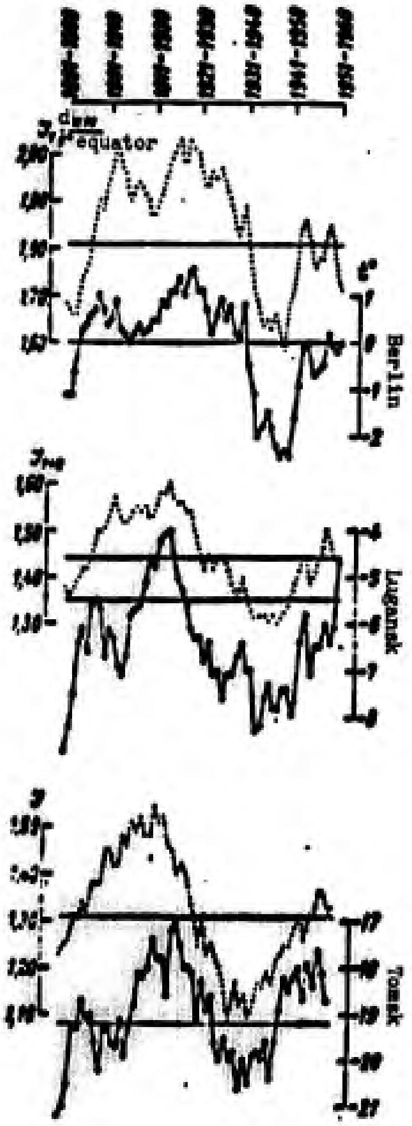

Fig. 47. Course of zonal indices (quotients J_1 and J_{1+2} and total J) and air temperatures along moving 10-year periods.

Despite, however, the importance of the use of indices characterizing the intensity of circulation, at present it is still impossible to use them for establishing the connection with temperature for the whole hemisphere because of the fact that investigation is conducted only in one sector, but in this sector there is still need of further improvement.

In this chapter the presence of the connection of atmospheric circulation with air temperature and the character of this connection are shown. At the same time deficiencies of the used typification of atmospheric processes are evident, resulting in the fact that with the help of this typification it is difficult to establish the connection with temperature to the south of 45-40° N. Lat., also in the southern part of Eastern Siberia (to south of 50° N. Lat.) and in the Far East. In certain cases it was possible only to ascertain the discrepancies between circulation and variation in temperature, the explanation of which at this stage of the work was impossible to give. It is possible that this is connected with the change in borders of sectors in various parts of the period studied.

For a more thorough study of the connection of atmospheric circulation with air temperature development is necessary of the typification taking into account the intensity of atmospheric processes and with the introduction of such indices which would permit revealing this connection at least in the whole temperate zone.

This represents already the following stage of the work.

CHAPTER V

CYCLIC RECURRENCE VARIATIONS IN AIR TEMPERATURE

1. Introductory Remarks

At present it is possible to consider sufficiently founded the connection of large-scale variations observed in the troposphere with cyclical variations in solar activity of 11, 22 and 80-90 years in duration.[1]

Questions of the influence of solar activity on processes in the troposphere and climate are studied by an enormous quantity of investigations. Among them it follows especially to note the works of L. A. Vitel's, who introduced a perceptible contribution by his long-term investigations into the development of this problem (see Vitel's, 1946, 1948, 1949, 1951, 1956, 1957, 1959, 1960, 1960a, 1962, 1963, 1965).

A sufficiently complete survey and critical remarks for the most part of the works devoted to the sun-troposphere problem are expounded in the monographs of Eygenson (1963), Rubashev (1964) and Sazonov (1964) published in recent years.

An important result of investigations of heliogeophysical relationships is the law of accentuation of troposphere processes under the influence of changes in solar activity. The essence of it (in the final editing of Vitel's, 1948) consists in that the increase in solar activity causes an increase in baric contrasts, i.e., a deepening of cyclones and power increase in anticyclones. The ambiguous influence of solar activity on baric circulatory and thermal conditions of the atmosphere causes a great diversity in the

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[1] There are assumption about the existence of cycles of higher order (180, 350, 400, 600 years, etc.), but, revealed only by indirect data, they remain as yet hypothetical.

manifestations of helioclimatic connections with time and space, the change of their sign or even the full disappearance in certain periods. This question in recent years has been allotted even more attention (Vitel's, 1960; Sleptsov-Shevlevich, 1963; Troup, 1962; Berlage, 1961, and others) in view of the fact that with cyclic recurrence of solar activity there finally began to be connected in one way or another almost all super long-range forecasts of variations in climate, but one of the stumbling blocks in this connection is its instability.

In the next section of this chapter data are given of manifestations of 11-year cyclic recurrence in the course of temperature in certain regions of the Earth.

2. Eleven-Year Cycle of Variations in Temperature and an Appraisal of Its Reality

In the perennial variation of mean monthly air temperatures, smoothed by means of moving averaging, the cyclical character of their change is well noticed. The duration of these cycles of variations in temperature and their amplitude are changed with the course of time. However, in a number of cases, for example, in the course of the 5-year moving mean monthly temperatures, it is possible to notice prolonged periods of time with cyclical variations with a duration of about 11 years. A comparison of such variations in temperature with variations in solar activity (annual Wolf numbers),[1] also averaged by moving 5-year periods, are given on Figs. 48a-48d.

On these graphs it is possible to note the direct or reverse relationship between the course of temperature in different months and solar activity in most cases during the years of increase in solar activity in secular variation (17-20 cycles); outside this period the connection is absent or has a reverse sign.

On the map of the Earth (Fig. 49) there are 80 stations according to which graphs of 5-year moving mean temperatures[2] were analyzed for all months of the year and the year as a whole. On the map there are stations, at which in some months (are shown by series with circles by Roman numerals) there are revealed 11-year variations in the course of 5-year moving temperatures. The number of such stations is about 20% of the total number of investigated stations. Of all the number of investigated stations and months (80 × 13 = 1040)

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[1] Here and further for comparisons there were used only annual Wolf numbers, since their monthly values are less than stable, while the character of the course of the numbers by months is approximately the same.

[2] Results of moving averaging of temperature from nine stations prior to 1940 (Arkhangel'sk, Irkutsk, Blagoveshchensk, Kiev, Leningrad, Moscow, Odessa, Yakutsk, Sverdlovsk) were placed at our disposal by Prof. B. L. Dzerdzeyevskiy.

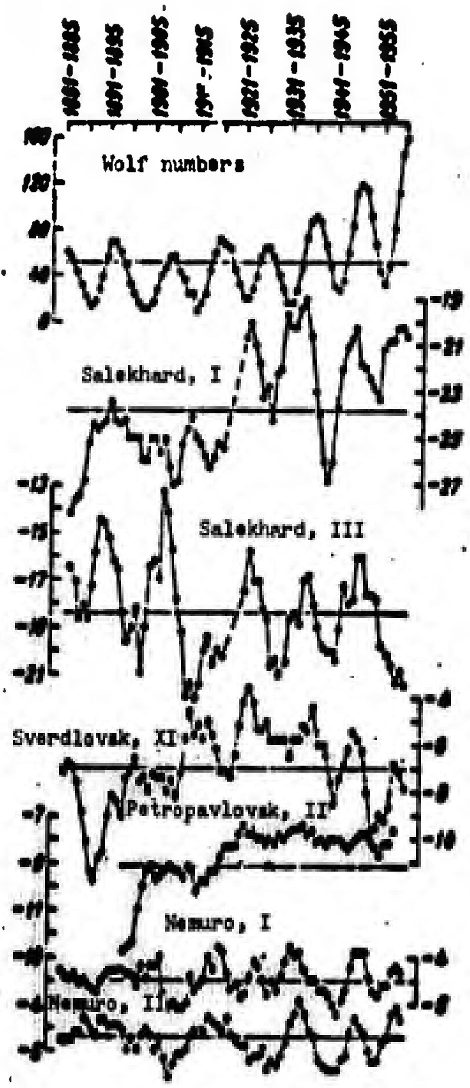

Fig. 48a. Moving 5-year mean Wolf numbers and temperatures.

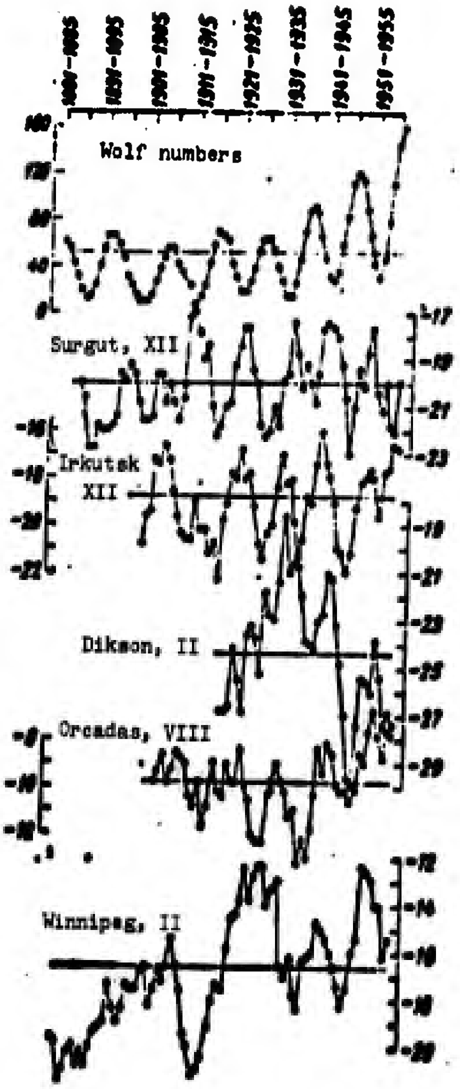

Fig. 48b. Moving 5-year mean numbers of Wolf and temperatures.

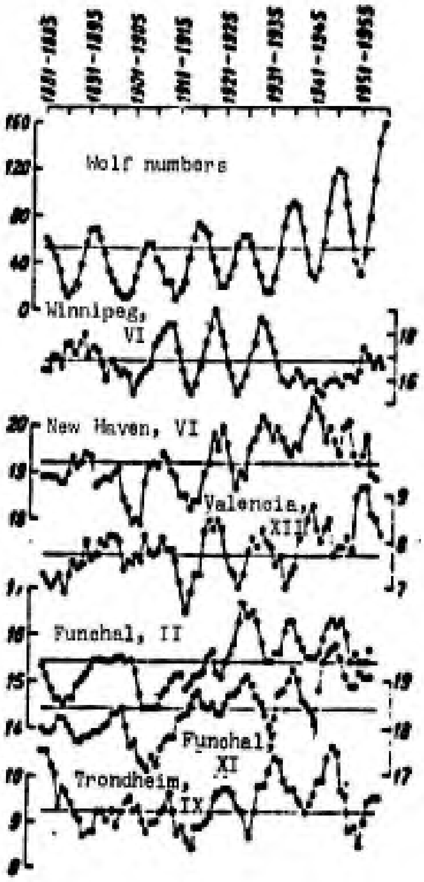

Fig. 48c. Moving 5-year mean numbers of Wolf and temperatures.

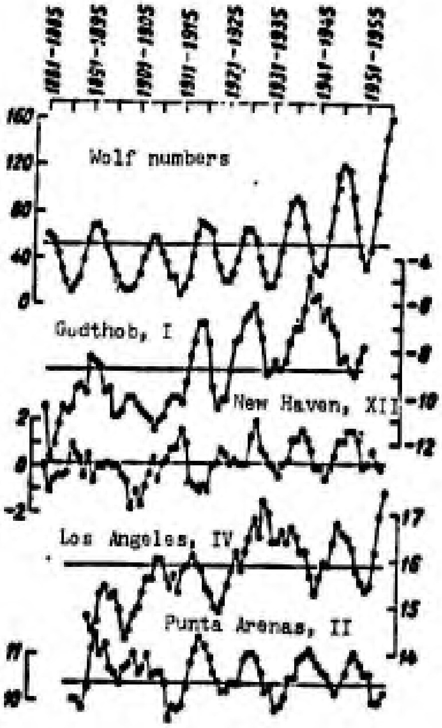

Fig. 48d. Moving 5-year mean Wolf numbers and temperatures.

the 11-year summer cyclic recurrence was observed by little more than 2% months.

However, the presence of synchroism of variations in temperature and solar activity during three-four 10-year periods cannot be considered an accidental phenomenon, even if it is observed only in separate regions and at different months of the year. It is impossible to forget the possibility of the appearance of false cyclic recurrence with moving averaging. But, as was shown in Chapter II, the danger of false cyclic recurrence is eliminated if the length of the cyclic recurrence will exceed the triple period of averaging. With 5-year averaging the most reliable will be cycles of over 15 years. Reality of the developed 11-year cyclic recurrence therefore needed additional confirmation, and there appeared moving averaging of investigated temperatures of 3 and 4 years with which the 11-year cyclic recurrence is also clearly distinguished.

In the example of the station Funchal (Madeira Islands) the reality is estimated of the connection between variations in temperature in November and solar activity for the period when this connection clearly appeared, i.e., from 1910 to 1955 (Fig. 48c).

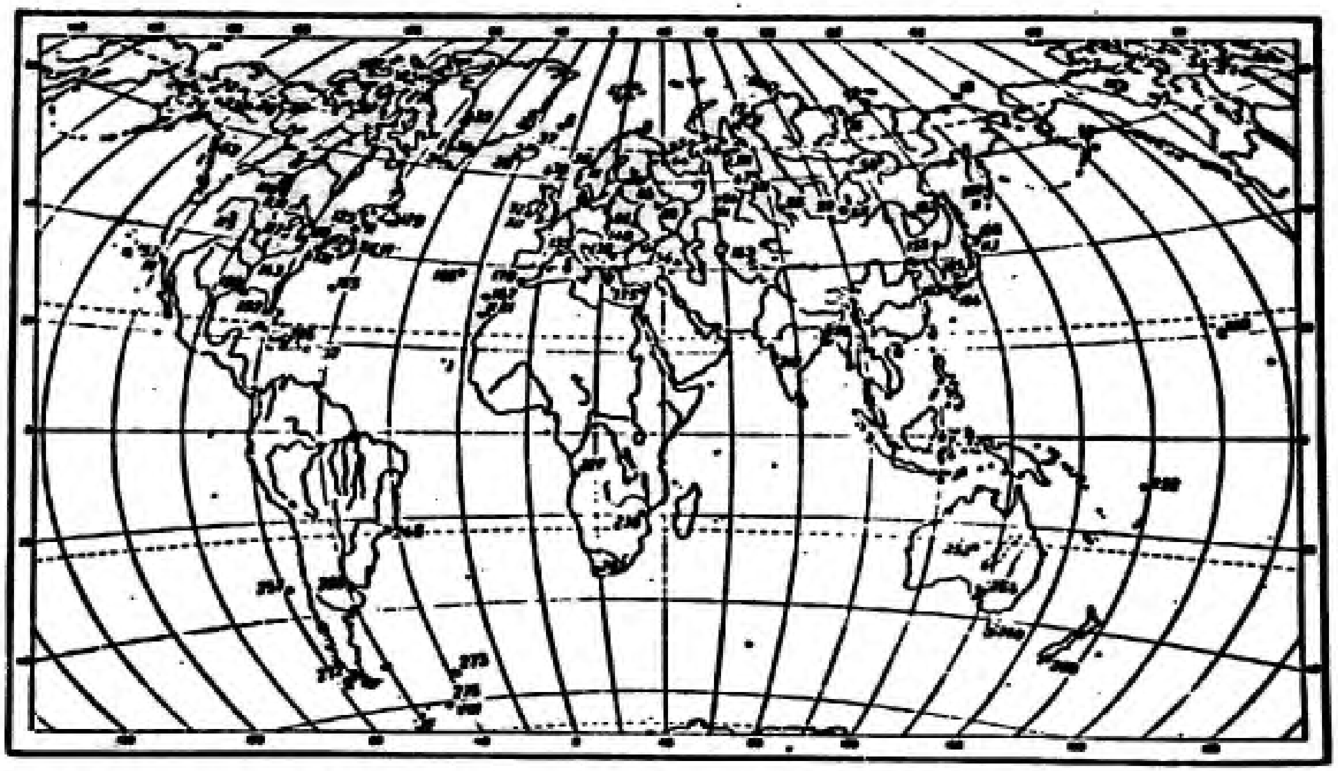

Fig. 49. Map of stations according to data of which the 5-year moving mean temperatures were investigated. See the list of stations in Appendix 1.

Table 14

	Branch of growth	Branch of drop
Number of cases of increases. . . .	19	5
Number of cases of decreases. . . .	3	13
Difference between number of increases and decreases d	16	-8
Probable error f.	1.58	1.42
Ratio d:f	10.1	5.3

For an appraisal of the reality of this connection there was used the criterion of Omshanskiy, propagated by Drozdov and Pokrovskaya (1962) in a series of moving averaging.

With the use of this criterion on the graph of the course of 5-year moving temperatures there are years of minimum and maximum of solar activity, and then the number of increases and decreases of smoothed values of temperature separately for branches of growth and drop in solar activity is calculated; then the probable error for the sum of all increases in series of the ascending branch and, accordingly, lowerings in series of the descending branch is determined from the expression

$$f_{u} = 0,337 \sqrt{\Sigma(n-m)}.$$

where $\Sigma(n-m)$ is the number of cases on the ascending or descending branches of the solar activity.

In the examined case of 5-year averaging this formula can be used with identification of a 5-year period of averaging with the length of a semicycle of solar activity. Then calculations for temperature of November in Funchal can be reduced in the table (Table 14).

To establish the distinction of the given series from the random it is sufficient that the ratio d:f ≥ 4.0. For the branch of growth this ratio (10.1) considerably exceeds the critical figure, but for the branch of drop the excess is not so great. This is probably connected with allowed identifying of the length of ascending and descending branches with the 5-year series.

The criterion used for analysis of smoothed series and cyclical phenomena differs by the limiting simplicity of calculations and minimum expenditure of time, not lowering, however, its reliability.

To estimate the reality of the connection between variations

Table 15. Recurrence of the Shift in Phases Between Variations of 5-Year Moving Mean Monthly Air Temperatures (Fig. 48) and Annual Wolf Numbers

Phase shift (number of years)	Whole series				Part of series			
	maximum		minimum		maximum		minimum	
	number of cases	%	number of cases	%	number of cases	%	number of cases	%
-8	—		1	1,1	—	—	—	—
-7	1	1,2	3	3,3	—	—	1	1,5
-6	15	17,2	13	14,3	11	17,2	9	13,6
-5	14	16,0	8	8,8	13	20,3	8	12,1
-4	11	12,7	14	15,4	7	10,9	10	15,1
-3	5	5,7	3	3,3	1	1,6	1	1,5
-2	8	9,2	7	7,7	7	10,9	5	7,6
-1	10	11,5	15	16,6	9	14,1	13	19,7
0	9	10,3	16	17,7	9	14,1	15	22,7
1	4	4,6	1	1,1	3	4,7	1	1,5
2	5	5,7	3	3,3	4	6,2	2	3,1
3	0	0,0	3	3,3	—	—	1	1,5
4	1	1,2	1	1,1	—	—	—	—
5	1	1,2	2	2,2	—	—	—	—
6	1	1,2	—	—	—	—	—	—
7	1	1,2	—	—	—	—	—	—
8	0	0,0	—	—	—	—	—	—
9	1	1,2	—	—	—	—	—	—
Sum	87	100	91	100	64	100	66	100
Quantity of gradations	15		14		9		11	
σ	2,7		2,7		3,8		3,5	

of temperature and solar activity at all other stations where this connection is revealed, Drozdov proposed an even simpler method whose essence is discussed by him in § 2 of Chapter II.

According to this method, by the graphs (Fig. 48) there was determined the phase shift (number of years) between extrema of 11-year cycles of solar activity and temperature. For great objectiveness of the appraisal all stations are taken at which in some periods and in different months of year variations close to the 11-year cycle were revealed. For these stations there are calculated phase shifts (in years) for years of maxima and minima of solar activity according to graphs of the 5-year moving mean values of temperature and Wolf numbers. Results of the statistical analysis of these are given in Table 15. In this table the phase shift, expressed by negative numbers, signifies the number of years at which extrema of temperature will lag behind extrema of Wolf numbers; a positive phase shift signifies the lead of extrema of Wolf numbers by temperature extrema. As can be seen from the table, recurrence of such leads is small and does not exceed the doubled mean quadratic error.

In Table 15 there are given two variants of calculations. In the first one all curves of temperature were examined in which variations were revealed with cyclic recurrence of about 11 years irrespective of whether this cyclic recurrence was observed during several cycles in succession or was disturbed, and then again was reestablished in that same phase or reversed phase. Such cases are examined on the left side part of Table 15 entitled for brevity

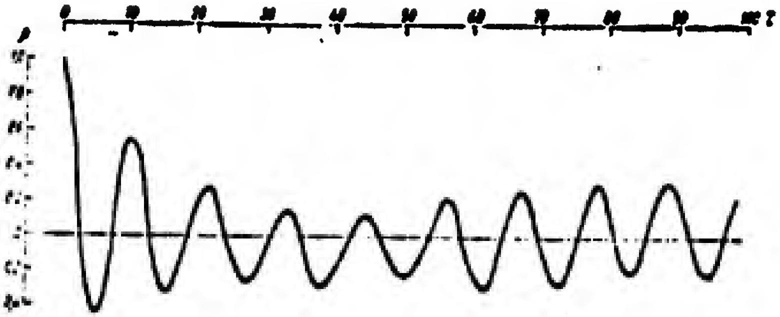

Fig. 50. Correlation function of Wolf numbers.

"Whole series." On the right side of the table ("Part of the series") there were examined only periods when variations in temperature occurred in phase or reversed phase with variations of Wolf numbers.

As can be seen from the table, even during analysis of variations of the whole series both during years of the maximum and during years of the minimum, the greatest recurrence is with coincidence (zero gradation) or lag in temperature by 1-2 (in phase) and 4-6 years (in reversed phase). For these gradations recurrence of deviations from the mean value exceeds 4-5σ, which corresponds to the value of probability of chance of less than 0.006%. Analysis of separate periods taken from predominate variations in temperature (right side of Table 15) gives even clearer results: during the years of the maximum the recurrence of deviations from the mean value of coincidences and lags in phases by 1 year is about 4σ, and the recurrence of deviations of lags by 5-6 years is about 5σ; during the years of the minimum of Wolf numbers respectively higher than 5σ and about 4σ, the recurrence of deviations of gradation is 2, and 3 — when less than 3σ.

Thus confirmed statistically is reality of the connection between variations in solar activity and air temperature at different points of the Earth. The theory of the mechanism of such a connection is still not created. It is possible to assume that among the great number of factors determining variations in air temperature, solar activity in certain periods acquires a dominating influence, which subordinates the 11-year rhythm of variation in atmospheric circulation and in terms of it variations in climate in a certain region of the Earth.

Figure 50 shows the correlation function of solar activity (annual Wolf numbers). The form of this function — cyclical curve with a period of about 11 years — indicates that variations in solar activity are close to periodic. If this is so, then the assumption is quite practical of the fact that such stable rhythmic variations cannot fail to cause resonance in the atmosphere during certain conditions of circulation of the atmosphere.

We made an attempt to analyze conditions of atmospheric circulation in the period when variations in temperature and solar

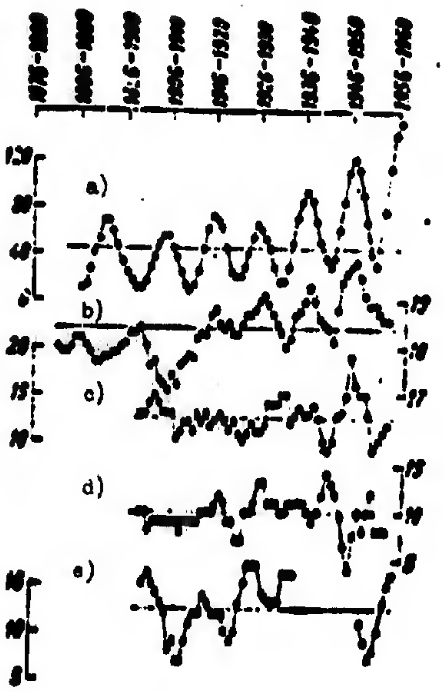

Fig. 51. Five-year moving mean. a — Wolf number, b — air temperature in Funchal (November), c — number of days with zonal western circulation, d — number of days with disturbance of zonality, e — recurrence of winds of the northern quarter in Funchal.

activity almost are synchronous. For this purpose there was taken station Funchal (Madeira Islands) where circulation of the atmosphere most frequently is caused by the Azores High.

As can be seen from Fig. 51, variations in the number of days with zonal western circulation (after Dzerdzeyevskiy) during the years close to the summit of the secular cycle of solar activity are synchronous with variations in solar activity. In the period of low (in secular variation) solar activity variations in the number of days with zonal western circulation are insignificant. An Analogous picture is observed in variations in the number of days with disturbance of zonality, but the course of the curve is opposite that of the preceding.

It should be noted that the moving 5-year mean values of generalized groups of types of Dzerdzeyevskiy circulation were calculated for the Atlantic sector according to data of the author of typification. However, this typification is most effective in moderate and high latitudes; furthermore, recurrence of types by sectors is calculated with respect to the central meridian of the sector, but Funchal is on border of the sectors. Therefore, in addition to the recurrence of types of circulation there were analyzed synoptic conditions above the region of the Madeira Islands in November from 1900 to 1960; 1940, 1941, 1944-1948 were excluded, since it was not possible to find synoptic maps.

As a result of statistical analysis of the data, it is clarified that in November the most frequently repeated is the type of weather of the eastern periphery of the anticyclone with predominant wind direction of the northern quarter of the horizon.

Variations in recurrence of these winds, just as those of temperature, are synchronous with variations of solar activity (Fig. 51). In other words, with an increase in solar activity above the regions examined recurrence of anticyclones and northern winds is increased and there is an increase in air temperature; with a decrease in solar activity in Funchal, recurrence of the northern winds decreases and the air temperature drops.

It is possible to try to explain this at first glance by the paradoxical phenomenon proceeding from results of the investigation

Sazonov (1964) of the zone of anticyclogenesis. The most active zone of anticyclogenesis is disposed above the eastern regions of the oceans, where with intrusion into the atmosphere of solar corpuscular stream atmospheric pressure increases at all altitudes in the troposphere. With this there will be formed powerful anticyclones in which high temperatures are observed as a result of descending movements. As a result of this, at the station Funchal, in November during the years of increased solar activity warm northern winds are observed. Why such synoptic conditions are observed, namely, in November and what hinders manifestation of solar activity in other months is subject to special investigation.

3. Analysis of Variations in Temperature by the Periodoscope Method

Numerous investigations of the connection between variations of hydrometeorological phenomena and solar activity confirm the presence of such a connection, although the closeness of it is considerably weaker than it is in the above-mentioned examples.

Attempts were made to estimate the dimensions of variations of indices of circulation of the atmosphere, ice cover, and hydrometeorological elements caused by variations in solar activity.

Thus Maksimov (1955) found that for indices of atmospheric circulation the solar – caused variation is on an average of 26%, and for ice cover it is 16% of the amplitude of variations of these factors.

According to other data (Druzhinin and others, 1964), the quantity of variations of hydrometeorological elements caused by the influence of solar activity reaches 40%. However, this value cannot be considered sufficiently founded due to the tactless method of its determination (the authors operate by integral curves of solar activity and hydrometeorological elements, on which points of fracture are somewhat arbitrarily determined, considering them appropriate critical points on the curve of solar activity).

In the present investigation of perennial variations in temperature an attempt is made to reveal the hidden cyclic recurrence and to estimate quantitatively the influence of solar activity on the magnitude of the amplitude of variations in temperature and also to reveal the presence of other rhythmic influences on the variation of temperature.

For this purpose there is used the rather simple method of periodogramanalysis (periodoscopes) proposed by N. Carruthers. The essence of this method is discussed in § 1 of Chapter II.

By the method of periodoscope decomposition of a series of air temperature for the following nine stations of the Earth was performed: Leningrad, Sverdlovsk, Salekhard, Kazalinsk, Barnaul, New Haven, Dawson, Ivigtut, Funchal.

By the same means series of solar activity (Wolf number) and ice cover of the Barents Sea were investigated.

Periodoscope curves were constructed for values of intervals of averaging u equal to 2, 3, 4, 5 and 8 years, which made it possible to analyze the variation in the interval from 3u to 6u observations, i.e., from 6 to 48 years.

For the investigation of series of temperature chiefly months of the cold period of the year were used in which the amplitude of variations is considerable and in the variations themselves there more frequently appears some cyclic recurrence.

As a result of calculations carried out there were obtained more than 200 decomposition curves. During the analysis of them there are distinguished curves on which in some time periods evident cyclic recurrence is traced. Then for these periods the average length of cycles of variations and their amplitude were determined approximately. Let us explain this with an example.

Figure 55 gives periodoscope curves of temperature of February for Leningrad. On curves u = 3 and u = 4 in the period 1900-1940 ordered variations are distinguished with length L of about 11 years (3.5 cycles). We obtain their mean amplitude A obtain as the arithmetic mean from amplitudes of every cycle. For u = 3 the $\left(\frac{8+9+16}{3}\right) = 11^{\circ}$, u = 4 $\left(\frac{9+9+8}{3}\right) = 9^{\circ}$. Further according to Table 1 from Chapter II for values L:u we find the coefficient R:

for u = 3 L:u = 3.7, R = 3.48;
for u = 4 L:u = 2.8, R = 1.97;

dividing the values found of amplitude A by the corresponding values of R, we obtain the real value of the amplitude of 11-year variations: for u = 3 Ap = 3.1°, for u = 4 Ap = 4.5° or, as an average, Ap = 3.8°.

For checking the effectiveness of the method periodoscope analysis was used on the series of Wolf numbers.

Figure 52 gives periodoscope curves of Wolf numbers for u = 2, 3, 6 and 8. It is not difficult to note on curves u = 2 and u = 3 the clearly distinguished 11-year cycle of variations with a monotonously variable amplitude from the minimum in the period of 1795-1825 to the maximum in the 1950's. Secondary maximum and minimum of amplitude of variations of Wolf numbers can be noted during 1830-1840 and 1900-1910 respectively. This reflects a change in Wolf numbers in the secular cycle of variations in solar activity.

Furthermore, on curve u = 8 starting from the 1820's and up to recent years of the current century the 23-24-year cycle, confirmed by the curve u = 6, is well isolated.

Thus with the help of the periodoscope well-known cycles of variations of Wolf numbers are isolated, which testifies to the sufficient reliability of the method. The same is confirmed by

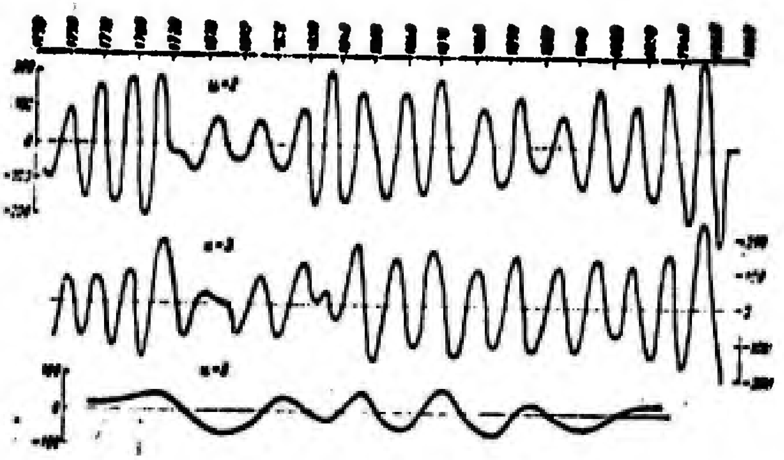

Fig. 52. Periodoscope curves of Wolf numbers.

periodoscope curves of seasonal (April-August) ice cover of the Barents Sea, on which variations are distinguished when u = 3 and u = 4 with a period of about 14 years with fading amplitude (Fig. 53a and b).

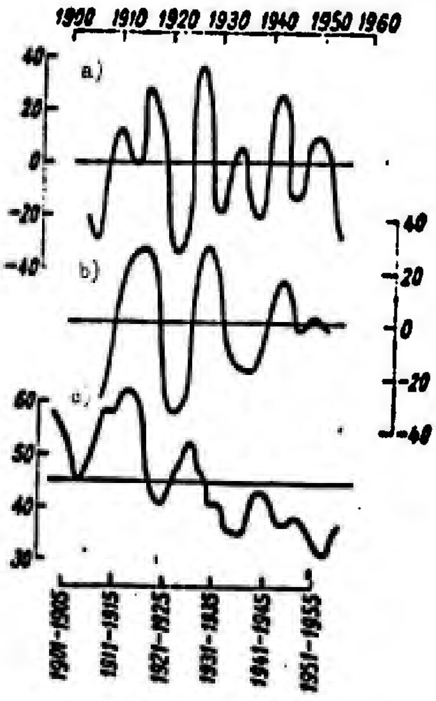

Fig. 53. Periodoscope curves of ice cover of the Barents Sea.

A 14-year cycle of variations of ice cover of the Barents Sea is quite apparent on graphs of the 5-year moving mean (Fig. 53c).

Given below is an analysis of periodoscope curves of air temperature for different stations of the Earth. Some of these curves are represented on Figs. 54-58.

Leningrad (1805-1960 November-March). The most interesting curves are obtained for February (Fig. 55). With u = 8 the curve gives cyclical variations with a period of about 25 years and mean amplitude of 3.8°; this is confirmed by the curve u = 5. On curves u = 3 and u = 4 there are clearly isolated (approximately since 1890) cycles of 11-year variations with an amplitude of about 4°, which are disturbed after 1940.

On curve u = 2 the amplitude of variations in certain periods reaches 6-7°, but the magnitude of it and the period of variations are extremely variable.

Thus variations in temperature in February, at least in the current century, are caused by variations of two cycles with periods

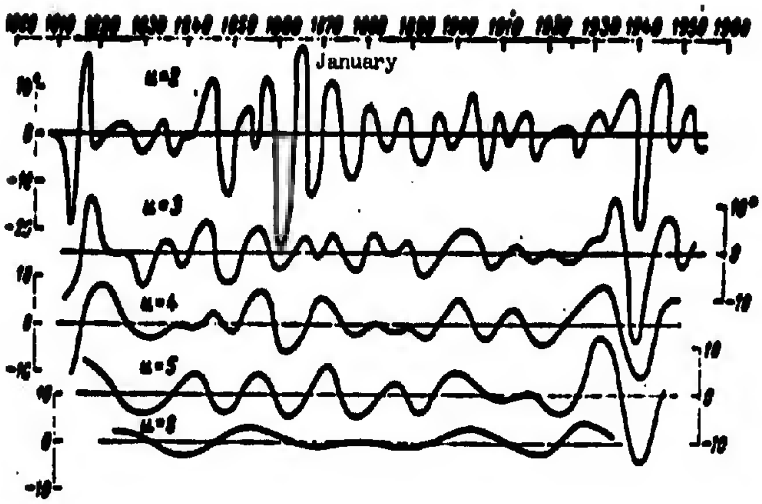

Fig. 54. Periodoscope curves of temperature. Leningrad. January.

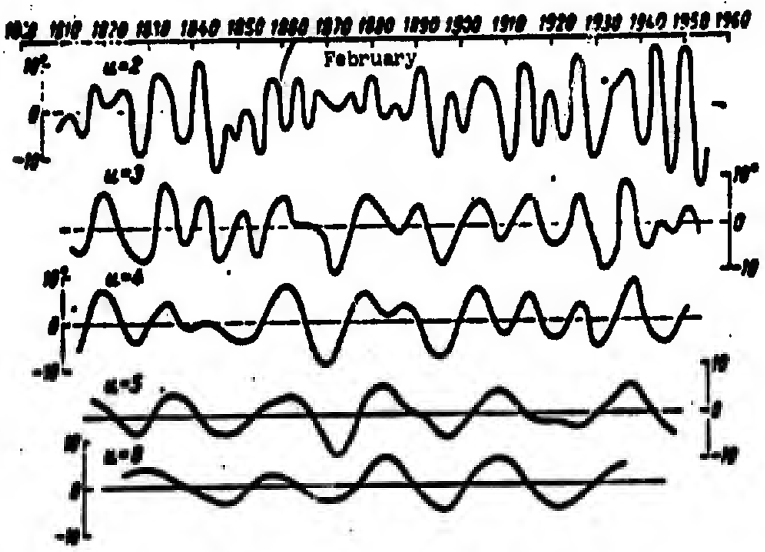

Fig. 55. Periodoscope curves of temperature. Leningrad. February.

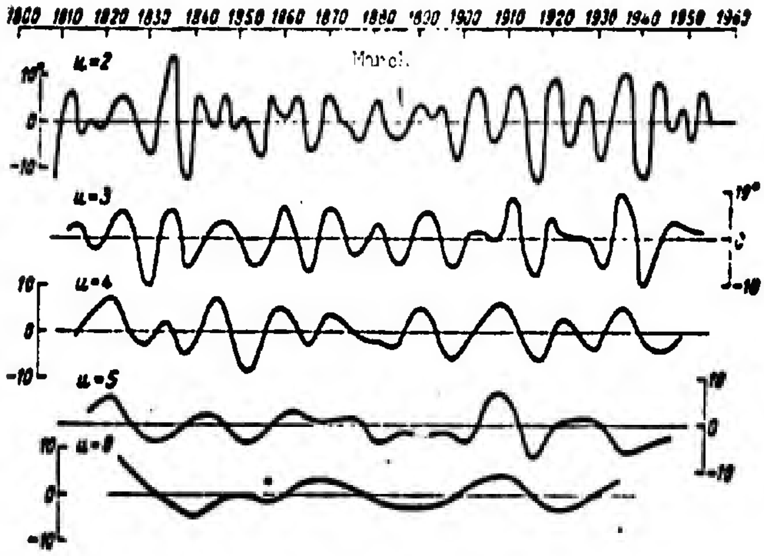

Fig. 56. Periodoscope curves of temperature. Leningrad. March.

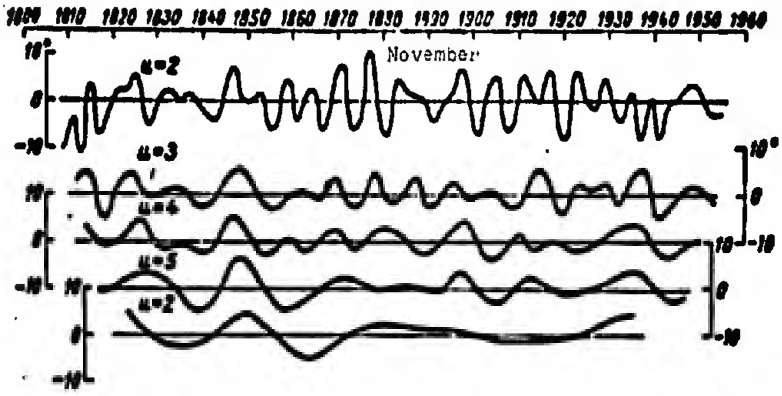

Fig. 57. Periodoscope curves of temperature. Leningrad. November.

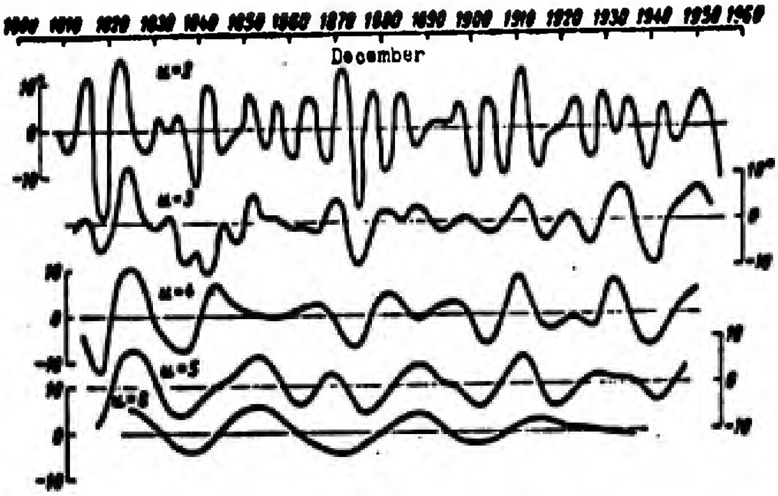

Fig. 58. Periodoscope curves of temperature. Leningrad. December.

close to the solar (11 and 25 years) and by variations of a nonsystematic character with great amplitude. Superposition of the latter on cyclical variations creates observed nonperiodic changes in temperature.

In March (Fig. 56) there is also revealed a 11-year cycle on curves u = 3 and u = 4 from the beginning of the period to the 20's of the current century.

In the remaining months the cyclic recurrence in variations in temperature does not appear, except as on curves u = 2 on which in all months (from November to March) variations are noticeable with a period of about 7 years (from 6 to 8) and a variable amplitude consisting on an average of about 4° (Figs. 57 and 58).

A special form of cyclic recurrence is represented by the curve u = 8 in December; this is sinusoidal curve with monotonously diminishing amplitude and length of the period (from 35 to 30 years) which creates the impression of damped oscillations induced by some simultaneous impulse (Fig. 58). Similar variations are encountered in different months of the year at other stations.

Sverdlovsk (1881-1960, October-February, July). Variations with a period of 6-8 years in October, November, January and July with variable amplitude are distinguished on curves u = 2. Curves u = 3 and u = 4 indicate damped oscillations in November with diminishing amplitude (from 6 to 2°) and a period from 13 to 10 years. Eleven-year cycles are clearly distinguished in December (u = 2) and especially in February (u = 2, u = 3, u = 4) when the amplitude of oscillations (on an average of 5°) attains the greatest value (Fig. 59).

Salekhard (1881-1960, June, November, April, January, February). On the curve u = 2 there are oscillations of variable amplitude with

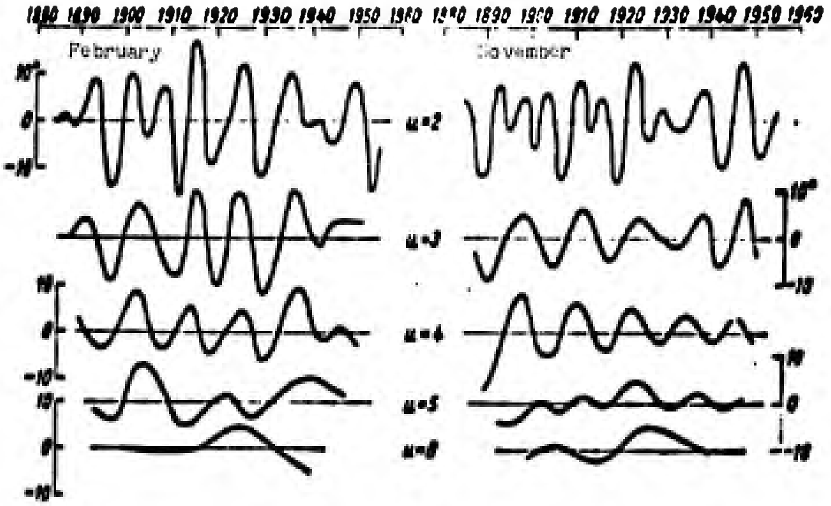

Fig. 59. Periodoscope curves of temperature. Sverdlovsk. February, November.

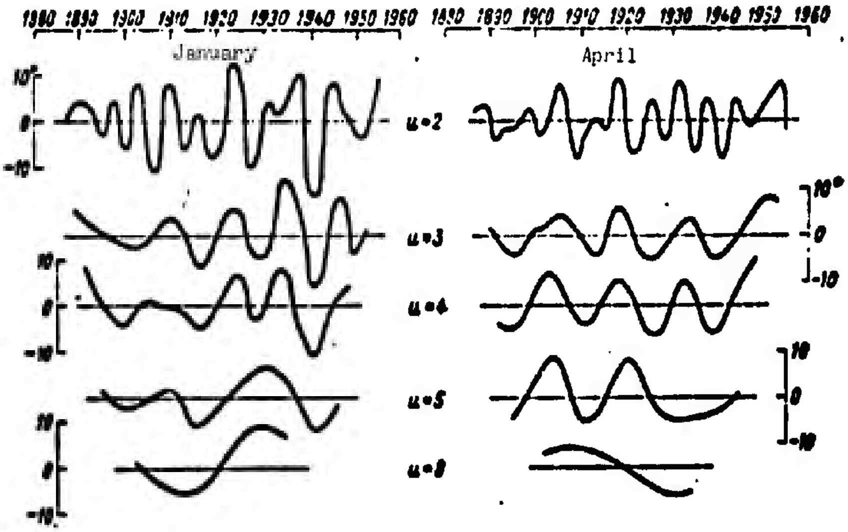

Fig. 60. Periodoscope curves of temperature. Salekhard. January, April.

a period of 6-8 years since 1920 in November and in remaining months, prior to 1920. Curves u = 3, u = 4 show the 11-year cycle in January approximately since 1910 with an amplitude of about 3°, and in April there is noted a 14-15-year cycle approximately with the same amplitude (Fig. 60).

Kazalinsk (1881-1960, November-March). On curve u = 2 there are noted oscillations with a period of 6-8 years from January to March with variable amplitude; on curves u = 3 and u = 4 there are three cycles of oscillations (to 1930) with a period of 13 years and amplitude of about 4°.

Winnipeg (1881-1960, November-March). On curves u = 2 the 6-8-year cyclic recurrence is preserved during almost the entire investigated period in January and less stably in November. On curves u = 2 and u = 3 there is a 10-12-year cyclic recurrence in March with an amplitude of about 4°.

New Haven (1800-1960, November-March, July). On curve u = 2 a cyclic recurrence with a period of about 7 years is in all months except January and February, and a 11-year cycle is in February (u = 3, u = 4). In January with u = 8 cyclic recurrence is noted with more or less constant amplitude (about 1°) and a fading period from 40 to 24 years; on curve u = 5 the cyclic recurrence is 20-18 years with an amplitude of about 2.5° (Fig. 61).

Ivigtut (1881-1960, November-March). On curve u = 2 there are cycles with a period of about 7 years in November, December and February. Solar cycles (11 years) are apparent in January (u = 3, u = 4) and not quite as clear in December (u = 4). In February there is a well-marked (u = 4, u = 5) cycle of 14 years, analogous to the cycle of ice cover of the Barents Sea (Fig. 62).

Funchal (1881-1960, November-February), lying in the low latitudes, is taken for investigation in view of the presence in the course of the temperature (by a 5-year moving mean) in November and February of a clearly marked 11-year cycle of variations approximately from 1920 to the middle 1950's. The presence of these cycles in the indicated period was confirmed well by periodoscope curves u = 2 and u = 3 in November and February, and the amplitude of variations is about 1.5°, which fully corresponds indeed to the observed amplitude (Fig. 63).

The above-mentioned examples of decomposition of series of temperature on the components visually demonstrate the complexity and diversity of variations in temperature in different parts of the Earth.

These variations are the result of the superposition of series of variations with different amplitudes, periods and phases. Certain systematics in the character of the oscillations is revealed only in those cases when the period of them on the average is 6-8, 11, 14

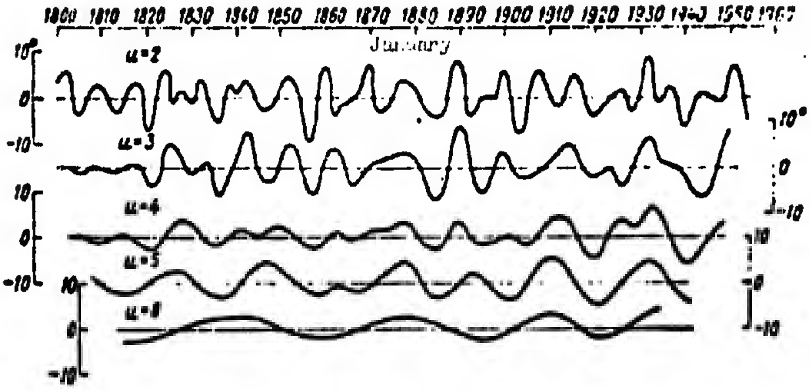

Fig. 61. Periodoscope curves of temperature. New Haven. January

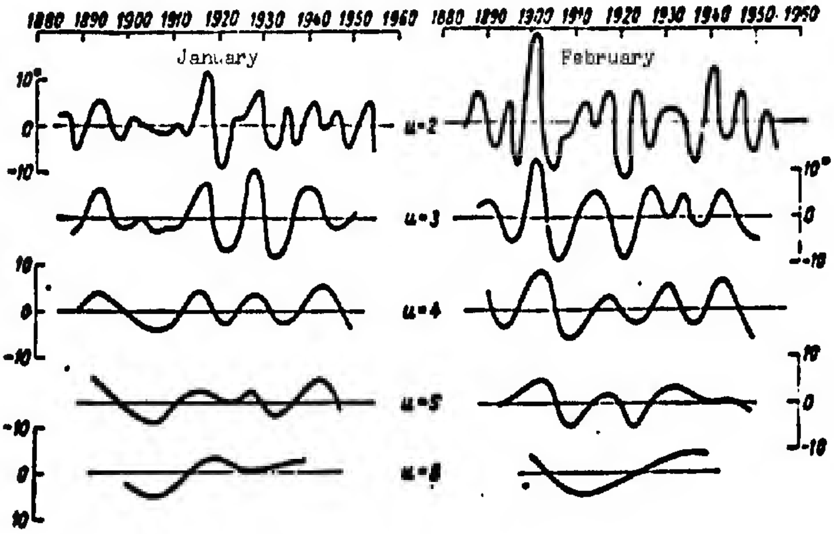

Fig. 62. Periodoscope curves of temperature. Ivigtut. January, February.

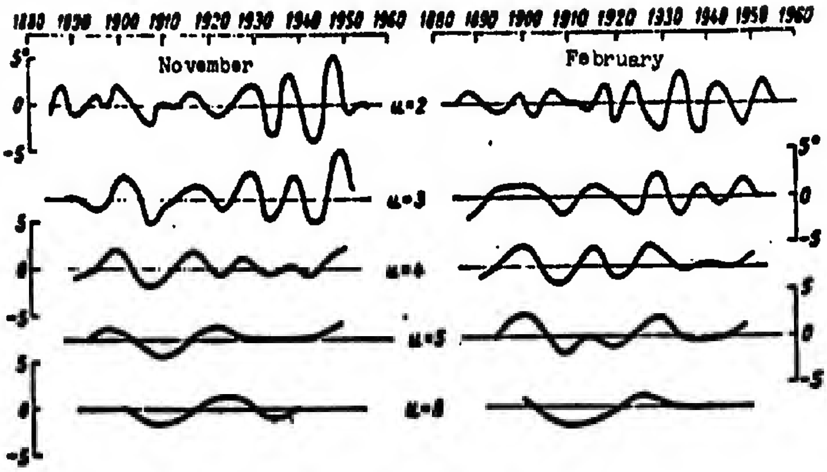

Fig. 63. Periodoscope curves of temperature.
Funchal. November, February.

and occasionally 23-24 years. In the remaining mass of periodoscope curves it is impossible to find some systematics in the oscillations.

Occurring most frequently are variations with a period of about 6-8 years. Such variations are revealed in almost all months (chiefly in winter) and at different stations. The amplitude of the variations changes in wide limits, and coordination of the variations at different stations is not observed.

The existence of variations with a period of 6-8 years are indicated in literature, but the most founded can be considered the 7-year period of variations of different hydrometeorological phenomena revealed by Maksimov (1953, 1957).

The reason for such short-period (6-8 years) variations in the atmosphere of high latitudes is, according to Maksimov, the interaction of atmospheric polar tide with a period of about 14 months and 12-monthly seasonal changes of circulation of the atmosphere. As a result of the interaction of these two various-period and different (in their origin) phenomena a 7-year cycle of change in seasonal variations in the atmosphere of high latitudes appears.

The basic result of the influence of the "polar tide" on the baric-circulatory conditions of the atmosphere is the accentuation of basic peculiarities of seasonal variation in circulation of the atmosphere and weather in high latitudes of Earth, which is variable with time (from 6 to 8 years) and different in different longitudes of Earth.

Variations in atmospheric pressure caused by polar tide make up about one-third seasonal changes of atmospheric pressure taking place, and, consequently, seasonal changes of circulation of the atmosphere.

The 6-8-year cycles of variations in temperature, prominent on periodoscope curves in certain periods have considerable (up to 6°)

amplitude, but in others they completely fade, just as the 7-year variations of Maksimov.

The amplitude of 11-year cycles of variations noted in certain periods on periodoscope curves at the investigated stations (except Funchal) is on an average of 4°, but in certain periods it attains 6-7°; in Funchal the amplitude of variations is about 1.5°. The indicated values make up approximately 15 to 40% of the mean amplitude of the natural series of temperature. The "contribution" of 6-8-year variations is of the same order. The remaining part of the amplitude of variations in temperature is created by other influences of a nonrhythmic character or disturbance.

4. Method of Autocorrelation

For exposure of periodicity in variations of a certain element there is frequently used the method of autocorrelation or correlation functions. This method gives only a tentative appraisal of the periodicity of variations and their amplitudes, but its main advantage is that there are introduced no hypotheses with respect to the form of the correlogram and frequency of variations.

We calculated experimentally with the help of an electronic computer the autocorrelation of the mean monthly temperature of Leningrad for all months of the year for the period from 1752 to 1964 with a shift in time intervals τ from 1 to 100 years. The appropriate correlation functions for certain months of each season are represented in Fig. 64, from which it is clear that correlograms of mean monthly temperatures of Leningrad represent curves with insignificant variations near a zero value (on an average the coefficient of correlation ρ is changed from 0.1 to -0.1 and in rare cases reaches the value ±0.3).

However, if even at small ρ some periodicity on the correlogram is repeated several times, i.e., there is observed systematics of variations and one should pay attention to it. According to the criterion Veynberg (1929), probability of the appearance of one maximum in a random series is 1/3 and n maxima, $(1/3)^n$ respectively. In the examined correlogram there are maxima $\rho = 0.11; 0.12; 0.14$ respectively at $\tau = 7; 14; 21$ and minima $\rho = 0.05; 0.07; 0.06$ at $\tau = 4; 11; 18$.

The probability of appearance of three maxima for the random series is equal to $(1/3)^3$, i.e., one case out of 27. It is possible, apparently, to consider that the 7-year periodicity is real and is nonrandom, but it is expressed weakly and unstable.

As was already noted above, by means of periodoscopic analysis there is also a 7-year cyclic recurrence in January, but, as can be seen from Fig. 7, the value of the amplitude of variations is unstable and is changed in wide limits. The coefficient of correlation has the greatest value at $\tau = 44$ years, when $\rho = -0.18$.

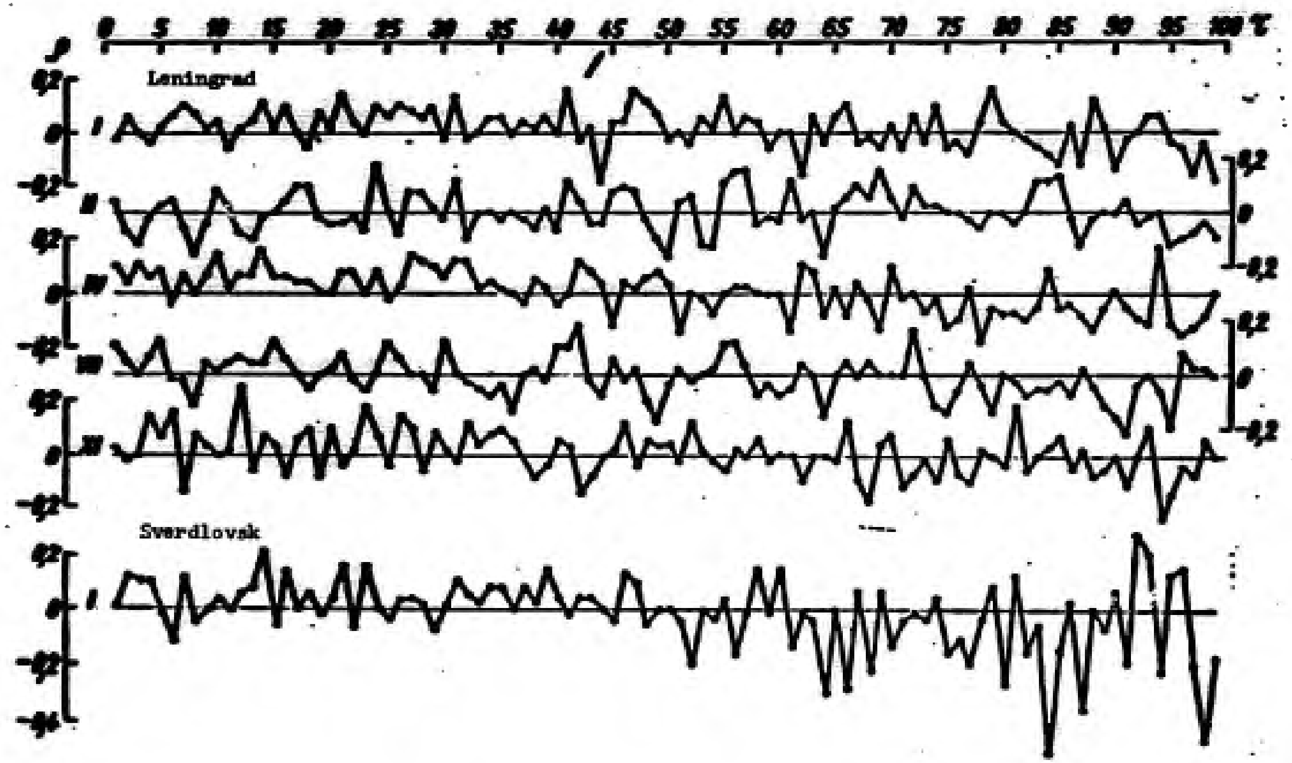

Fig. 64. Correlation function of temperature. Leningrad, 1752-1964.

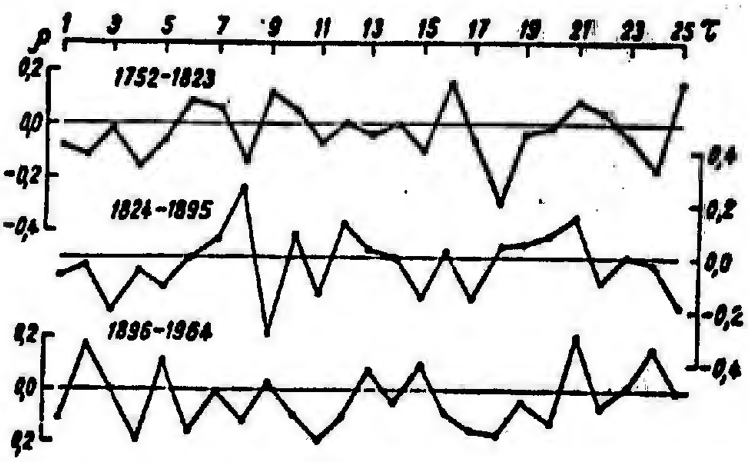

Fig. 65. Correlation function of temperature. Leningrad 1752-1823, 1824-1895, 1896-1964.

Considering the unstable character of variations in temperature with time, for the exposure of variations in separate periods there is calculated the autocorrelation of the mean monthly temperature of January for periods 1752-1823, 1824-1895 and 1896-1964 (Fig. 65).

As it can be seen from this figure, the seven-year cyclic recurrence, manifested on the correlogram of the whole period (Fig. 64) with separation into shorter time intervals, is distinguished only in the period 1824-1895 in the form of an 8-year cyclic recurrence ($\rho = 0.25$; $\rho = 0.11$). With division of the series into four periods (1752-1799, 1800-1847, 1848-1895, 1896-1964), configuration of the correlogram, naturally, was changed (Fig. 66), and quantity ρ in separate periods increased. All of this reflects the fact of instability in variations in temperature, change from period to period of their duration, phases and amplitudes. Due to this the study of correlation functions of meteorological elements are apparently, more fruitful with the use of not very long series of observations, but are sufficient for autocorrelating with a shift τ at least of 25 years. The increase in value of τ decreases the number of correlated pairs of values and, according to Brooks and Carruthers (1963), further calculations are inexpedient if the number of pairs decreases to 35. Thus for exposure of cyclic recurrence with a duration up to 23-24 years, a series of not less than 60 years is needed. However, an experiment of performed calculations showed that the minimum number of correlated pairs 35 is insufficient for producing reliable results. This is especially noticeable in the example of Sverdlovsk (Fig. 64). Despite the series of observations is 133 year, already with a shift to $\tau = 50$ years values of ρ noticeably increase and reach clearly oversized values with the residual number of pairs of 50-55. An estimate of the accuracy of coefficients of correlation for a decreasing number of pairs, according to Brooks and Carruthers, is produced by means of division of each coefficient ρ on the magnitude of its error σ, which for the random series is approximately estimated by the expression

$$\sigma_{\rho\tau} = \frac{1}{\sqrt{N-\tau-1}}.$$

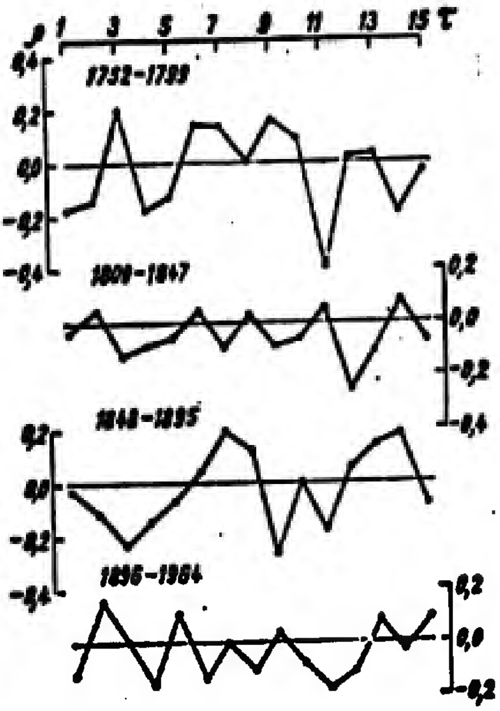

Fig. 66. Correlation function of temperature. Leningrad. 1752-1799, 1800-1847, 1848-1895, 1896-1964.

For example, for Sverdlovsk in January:

at $\tau = 14$ $\rho = 0{,}23$; $\sigma = 0{,}09$; $\rho : \sigma = 2{,}64$,
at $\tau =$ [illegible] $\rho = 0{,}18$; $\sigma = 0{,}12$; $\rho : \sigma = 1{,}50$,
at $\tau =$ [illegible] $\rho = 0{,}24$; $\sigma = 0{,}14$; $\rho : \sigma = 1{,}75$.

i.e., significance of the last highest coefficient of correlation is approximately one and a half times less than that of the first. This circumstance must be considered during the analysis of correlation functions and estimate of the significance of coefficients of correlation.

A more strict and acceptable criterion of magnitude of the shift should be considered the criterion of Blackman and Tukey (1958), according to which the maximum magnitude of the shift should not exceed 1/3 the number of observations in the series (i.e., in case of Sverdlovsk the shift should not be more than 45 years).

Further, the selection of the period for autocorrelation is connected not only with its duration but also with a definite epoch of atmospheric circulation and phase of solar activity. However, epochs of uniform atmosphere circulation cover too short of autocorrelation periods for calculation (20-25 years), and therefore in one investigated period there are included two-three circulatory epochs that can level the variations not coinciding in phase or, conversely, can create random cycles with excessive correlations. In this case it is possible, probably, to use the calculation of autocorrelation for the moving period, displacing the initial 60-70-year series by 5-10 years in every subsequent calculation of autocorrelation. But such bulky calculations are expedient only in the presence of quite high coefficients of autocorrelation in the series, which is not observed in the series of mean monthly temperatures.

In connection with this it is inexpedient to use diverse variants of the determination of spectral density in similar series of observations. As calculations of spectral density made by us on a computer for several stations showed, the spectrogram in comparison with the correlogram does not give fuller information about variations of temperature, but the program of its calculation is considerably more complicated, and, consequently, the possibility of miscalculation is greater.

5. Conclusions

The given examples are sufficient in order to arrive at a conclusion concerning the fact that any of the methods of detecting periodicity in nonstationary variations in meteorological elements has limited application. With a very correct approach and with the use of several methods (for example, periodoscopes and correlation functions), it is possible to reveal periods in the initial series in which variations in the form cycles of definite duration having some physical foundation predominate. However, even this is not always possible to do.

Let us explain this with examples. On curve u = 2 of the periodoscope of January (Leningrad, Fig. 54) in the second half of the 19th Century there are 6-8-year variations with a mean amplitude of about 4°. On the correlogram (Fig. 66), 1848-1895) also the 6-8-year cyclic recurrence has the greatest ($\rho = 0.2$) coefficient of correlation. Another example is in February periodoscope curves u = 5 and u = 8 give during the whole period (1805-1964) cyclical variations with a period of about 24-25 years and an amplitude of over 3° (Fig. 55). The correlation function (Fig. 64) also confirms the existence of this cycle by the maximum coefficient of correlation ($\rho = 0.2$). However, in the same month the clearly distinguished 11-year cyclic recurrence in the 20th Century (u = 3; u = 4) is not absolutely confirmed by the correlogram (Fig. 64).

In Table 16, for a comparison of the value of mean cycles there are given variations revealed with the help of the periodoscope and correlogram. As follows from this table, in 8 cases out of 11 both methods give similar values, but in three cases (27%) the correlogram does not confirm cyclic recurrence revealed by the periodoscope, apparently, due to the overlapping influence of disturbances and variations with noncoincident phases.

Here we will not touch upon the question of the 2-year cycle of

Table 16. Duration Cycles Determined with the Help of the Periodoscope and Correlogram

Period in which cyclic recurrence was observed (years)	Month	Mean duration cycles (in years)	
		periodoscope	correlogram
Leningrad			
1848—1895	I	7	6—7
1805—1960	II	25	24
1895—1960	II	11	—
1895—1960	III	7—8	—
1805—1895	III	11	10—11
1850—1960	XI	6—7	6
1850—1960	XII	6—7	6
Sverdlovsk			
1881—1960	I	7	7
1881—1960	II	11	11
1881—1960	XI	12	12
1881—1960	XII	9—10	—

Note: The dash "—" signifies the absence of appropriate significant value on the correlogram.

variations (or 26-monthly), which recently began to appear in works of many researchers (Pokrovskaya, 1959, 1960; Veryard, Ebdon, 1961; Landsberg 1962; Landsberg, Mitchell and others, 1963, and others). This cycle can be more quickly attributed to variations in annual conditions than climatic, and it will be examined in appropriate investigations.

It is necessary only to note that the 2-year cycle of variations of different meteorological indices and phenomena are usually associated with natural fluctuations of the atmosphere, i.e., with its natural fluctuations conditioned by a different thermal balance of continents and oceans, the replacement of seasons and other geophysical causes.

In the opinion of Vitel's (1957), those variations in solar activity, which enter into resonance with natural fluctuations of the atmosphere, intensify them and thus appear most clearly in the atmosphere. However, because of the complexity of such interaction and the presence of nonresonating variations, it is impossible to expect a unique reaction of the atmosphere on variations in solar activity with time and space. From all this it follows that the presence of self-oscillation systems in the atmosphere creates an additional complication of the manifestation of external influences.

In connection with this, there is special importance in the question of the isolation and calculation of possible periods of natural fluctuations in the atmosphere, depending upon different physicogeographic conditions.

In his time Lineykin (1953) proposed a schematic (in the first approximation) explanation of physical causes of self-oscillation process and gave a mathematical setting of the question with an account of the scheme of the general method of determining periods of self-excited oscillations. A more detailed investigation by Lineykin of the basic system of equations was encountered on as yet unsolved mathematical difficulties.

Everything said above quite visually illustrates the very relative stability of variations in atmospheric circulation and climate and then only in individual periods. Therefore, any forms of statistical analysis and harmonic analysis of series of meteorological observations can give a concept only of variations observed in the past, the change in their amplitude, period and phase, and the appearance and disappearance of these variations.

But not one of the methods of the search of periodicity or cyclic recurrence of variations in the series of empirical values can give reliable information on forthcoming variations and changes in parameters until the nature of these variations and causes of their change are uncovered.

Certain researchers, in particular, Maksimov (1965), have great hopes for methods of forecast of variations in natural series founded on their harmonic analysis. In the opinion of Maksimov, this direction becomes especially long-term in connection with the application of electronic frequency analyzers for spectral analysis of natural series. He correctly notes that with the use of harmonic analysis, for a forecast a physical interpretation of obtained results is obligatory, without which even the most exact mathematical presentation of the series does not remove the formal essence of such methods.

To this one should add that possibilities of physical interpretation of results of any mathematical analysis of series of observations, with the contemporary level of our knowledge on causal effect relationships in the system Earth — atmosphere — Sun, as yet are still very limited. In essence, all forecasts of variations of climate in several 10-year periods are based on the extrapolation of empirically established solar-atmospheric relationships. But until the physical essence of this phenomenon is studied, it is impossible to guarantee the high justification of such forecasts.

In conclusion of this chapter one should note that for cyclical variations in air temperature, revealed by one means or another it is as yet not possible to establish some regularity of their appearance and disappearance with time and space. Further expansion and deepening of investigations of causes of variations in climate is necessary; it is impossible to forsee dimensions of these variations, not knowing, where, when and with what they are generated.

The development of computer technology opens up great possibilities for the expansion of such investigations on the basis of the use of the most correct methods of statistical analysis of time series and gradual expansion of physical prerequisites and regularities of their variations.

CHAPTER VI

METHODS OF ESTIMATE OF THE CHANGE IN TEMPERATURE IN A PLANETARY SCALE AND TREND OF ITS FURTHER VARIATION

1. Regularities in the Spatial Change in Temperature

In connection with the establishment of the fact of the change in climate in the last 10-15 years there was conducted an animated discussion about whether during the years of warming the air temperature at the earth's surface was increased over the entire planet as a whole, whether warming, observed in various parts of the Earth in the 1920's and 1930's ceased, and what are the trends of variations in temperatures in the immediate decades.

Let us try to express our point of sight on these questions on the basis of material investigated by us.

In a number of works concerning the question of the change in climate it was shown that although the character of the change is preserved in vast territories, nevertheless in regions of the Earth quite remote from each other phases of increases and decreases in temperature do not coincide and, in certain cases, are almost opposite. Thus in the work of Rubinshteyn (1946) it was shown that in certain months of the year (January, May, September) there is observed a mirror-like nature in the course of moving 10-year mean temperatures on the western seacoast of Greenland and the Murmansk seacoast. Given in the same work are maps of deviations of mean monthly temperatures for the decade 1929-1938 from the perennial means, from which it is very clear that in January and February deviations in temperature in the month of the Ob' River are positive, and in Central Asia in the region of the Aral Sea they are negative. Numerous examples confirming that said above can be found by examining graphs of moving mean temperatures in the work of Rubinshteyn (1956). Finally, by analyzing data for the entire Earth, Polozva and Rubinshteyn (1963) generalized in former works conslucions and came to the conclusion that in January (other months were not examined) every latitudinal zone between 80° and 40° N. Lat. is divided in a meridional direction into two parts, the course of temperature in which in its basic outlines is opposite to each other.

In Chapter III of this work, on the basis of analysis of vast material there were isolated regions in which moving 10-year mean temperatures have synchronous course.

In order to give a quantitative appriasal of the connection between air temperature of various parts of the territory of the USSR there were compiled isocorrelate[1] maps on the basis of series of observations not smoothed by 10-year periods. Some of these maps, published in the work of Rubinshteyn (1956), with sufficient exactitude determine the region inside which temperatures are closely connected with each other (positive connection), region, among which the connection between temperatures is actually absent, and regions where the connection is opposite.

For the purpose of a more detailed study of connections between temperatures of different points of the earth's surface, isocorrelates were plotted for polar and moderate zones of the northern hemisphere and partially for the subtropical zone (Figs. 67 and 68). January and May were selected in view of the fact that in the territory of the Soviet Union the distribution of regions of positive and negative isocorrelates in these months has the most contrast in relation to one another. Let us indicate for example the course of correlation coefficients of Moscow — Barnaul during one year:

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0,45	0,49	0,20	–0,20	–0,55	–0,45	–0,32	–0,23	–0,27	0,30	0,22	0,32

Analysis of Figs. 67 and 68 leads to the following conclusions.

1. In winter isocorrelates extend in Eurasia in a latitudinal direction, apparently, in connection with the influence of the Asian anticyclone. At great distances from Moscow (Sea of Japan, America), as the center of correlation the zonality of the course of the isocorrelates is weakened, and in certain places is entirely inconspicuous.

2. In the north in the extensive region covering the Central Arctic, Greenland, Chukchi Sea, Kamchatka and Alaska, coefficients of correlation with temperatures of January in Moscow are negative.

3. In May the distribution of isocorrelates sharply differs from that of January. They extend in a meridional direction; eastward and west from the regions with negative coefficients, after which again the coefficients of correlation become positive but already smaller in magnitude. The relationship of temperatures of Moscow with the polar zone is practically absent.

4. It is noteworthy that on the border of the regions where there occurs replacement of the sign of correlation, lines in January

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[1] Isocorrelates are lines along which correlation coefficients are identical with respect to some selected point.

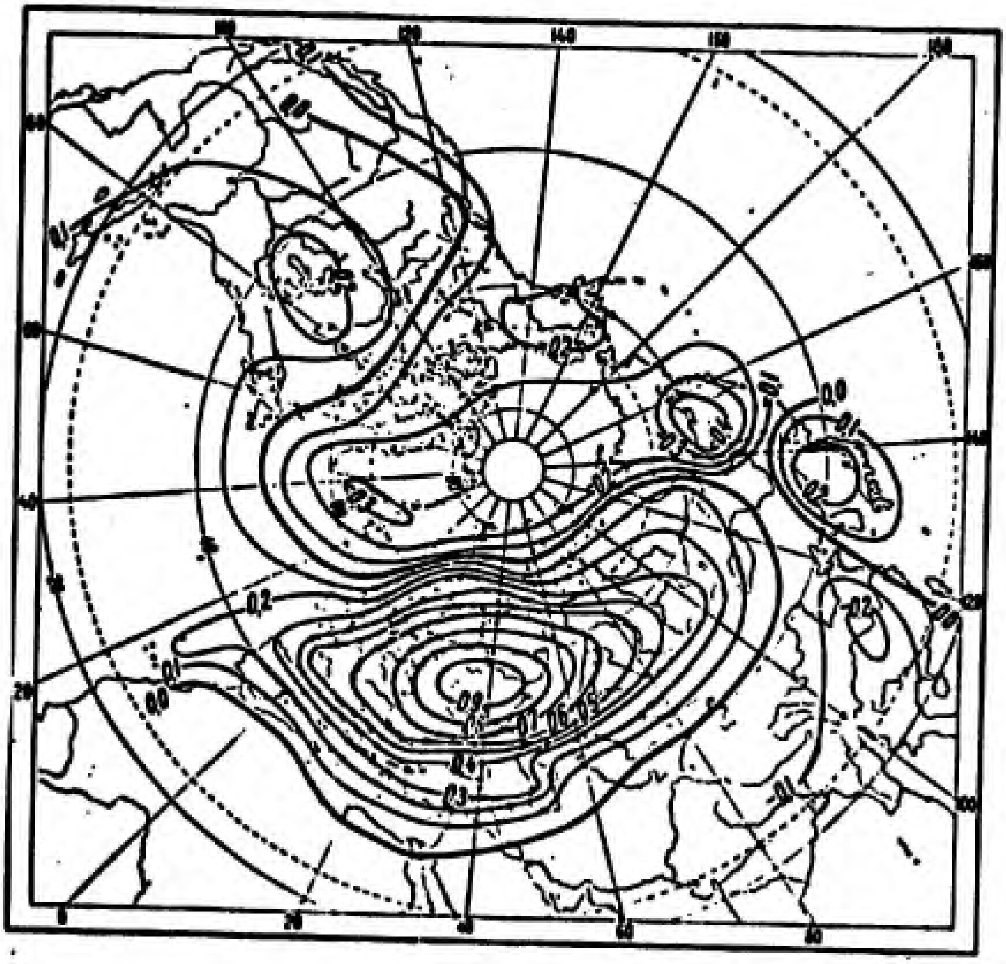

Fig. 67. Isocorrelates with respect to the temperature of Moscow. January.

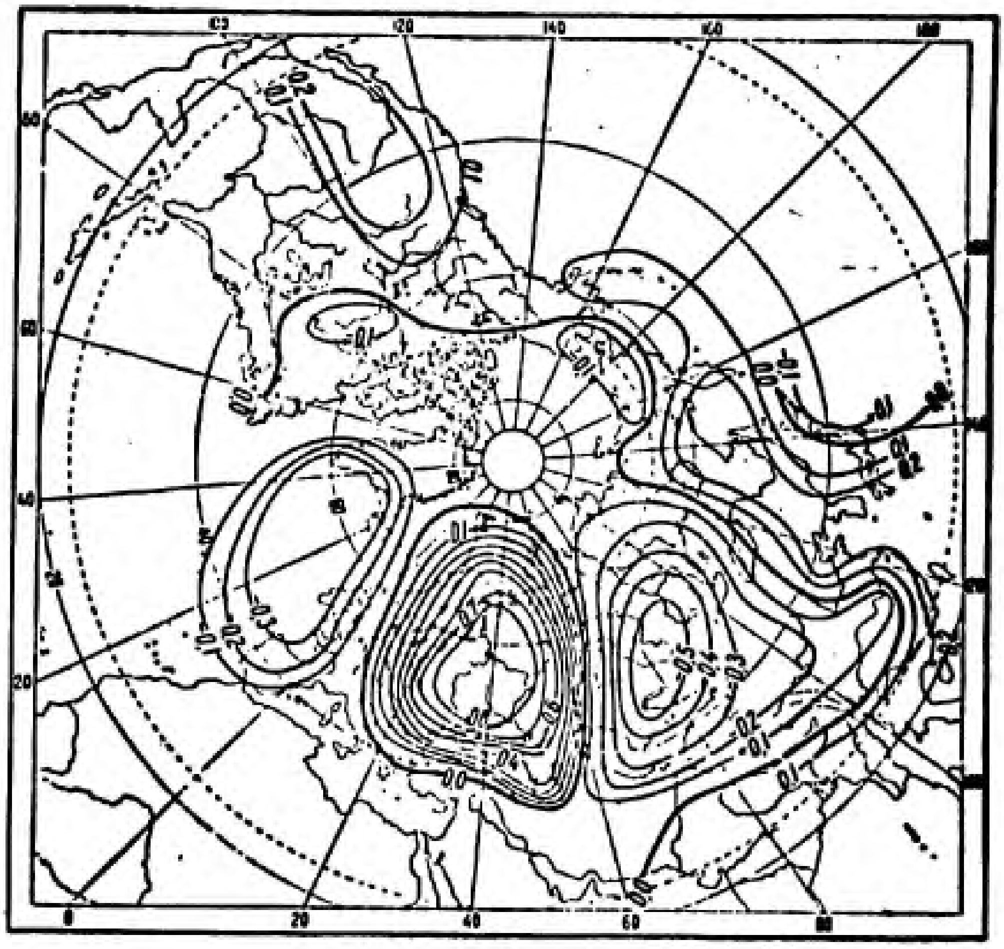

Fig. 68. Isocorrelates with respect to the temperature of Moscow. May.

and especially in May are condensed. The reason for this consists in the following. The connectivity of temperature series inside some region is caused by the presence of macroscale circulatory processes covering this region. It is understandable that the borders of the region change from case to case, and points which in separate years are inside the region, in other years turn out to be outside it; this creates in boundary regions a correlation close to zero.

5. With distance from Moscow coefficients of correlation, as a rule, series were used with a duration of 50-70 and sometimes and 80 years. Only in insufficiently studied regions was there included in the investigation an insignificant number of stations with series of smaller duration, but not less 30 years.

It follows from this that with the length of the series of 60-70 years coefficients of correlation of about ±0.25 have a level of significance of 5%, i.e., in 95% of the cases they can be considered real; with the length of the series at 45 years they have a significance of 10%. 30-year series have such significance only with coefficients not lower than ±0.31. Figures 67 and 68 show that in almost the whole territory studied the coefficients of correlation actually reflect the existing relationships of temperature at the different stations.

Let us illustrate these relationships in a concrete example.

As can be seen from the course of the isocorrelate, in January the coefficient of correlation of temperature of Moscow — Novosibirsk is ±0.5, in May the isocorrelate 0.5 passes through Sverdlovsk, in Novosibirsk the relationship of temperature with Moscow is already reverse, and coefficient of correlation is equal to -0.5. This means that in January signs of deviations of mean monthly temperatures from perennial means in Moscow and Novosibirsk in approximately 75% of the years coincide, and in May in 75% of the years they are different. In May the coincidence of signs of deviations in 75% of the years should be observed at a considerably closer distance to Moscow, at Sverdlovsk, where isocorrelate 0.5 passes.

Let us check this relationship, using, instead of Novosibirsk, Barnaul, where the series of observations are longer and more uniform. The coefficient of correlation of temperature of Moscow — Barnaul is equal in January to ±0.45 and in May, -0.55. Comparing signs of deviations of mean monthly temperature from the perennial average in Moscow and Barnaul for corresponding years during 70 years, we see that in January in 70% of the years these signs coincide, and in 30% they are opposite; in May they coincide in only 33% of the cases and are different in 61%, and in 6% of the cases at one of the stations deviation from perennial mean is 0° and therefore was not included in counting. In addition let us give relationships of deviations in temperatures from the perennial means in Moscow and Barnaul during years with especially high and low temperatures (Table 17).

Table 17. Deviations of Mean Monthly Temperatures from the Perennial means

Years	Moscow		Barnaul
	January		
1893	−11,2°		−10,5°
1940	−9,0		−6,4
1932	+6,4		+5,4
1949	+6,6		+6,2
	May		
1883	+2,1		−3,0
1897	+4,7		−2,6
1898	+3,1		−5,1
1912	−3,3		+1,6
1917	−4,2		+3,8

Undoubtedly, the distribution of isocorrelates can indicate where one should expect a change in temperature of the same sign and where of the opposite sign.

In order to represent more graphically the distinction in the course isocorrelates in January and May, let us construct on the basis of data of Figs. 67 and 68 a correlation function for the section along 55° N. Lat. between 50° W. Long. and 130° E. Long.; on the remaining part of this latitudinal range correlation coefficients are either small or (on oceans) almost not studied. On Fig. 69, where there are depicted correlation functions for January and May the asymmetry of branches of correlation curve westward and eastward from Moscow is clearly seen.[1] The same correlation coefficient is attained in January to the east of Mowcow at greater distances than that to the west. This is connected with the character of circulation in the presence of the Asian anticyclone (the great contrast between temperatures of the sea and land, strong zonal transfers of air). The correlation function in May is also asymmetric, but the character of its asymmetry is different. In the region where coefficients of correlation exceed ±0.30, the asymmetry has the same character as it does in January, although quantitatively it is somewhat weaker. Thus in May in this region the connection of the temperature of Moscow with eastern regions closer than that with western at the same distances. In regions more remote from Moscow the decrease in coefficients and transition of them to negative values in the east occur faster, and the actual coefficients attain larger negative values than those in west. It is possible that in the Northern Atlantic coefficients of correlation attain -0.40, but, since for the ocean there is no data, on the map such an isocorrelate

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[1] The value of this asymmetry is easily estimated if one were to bend the curve along the vertical axis, passing along the lontitude of Moscow.

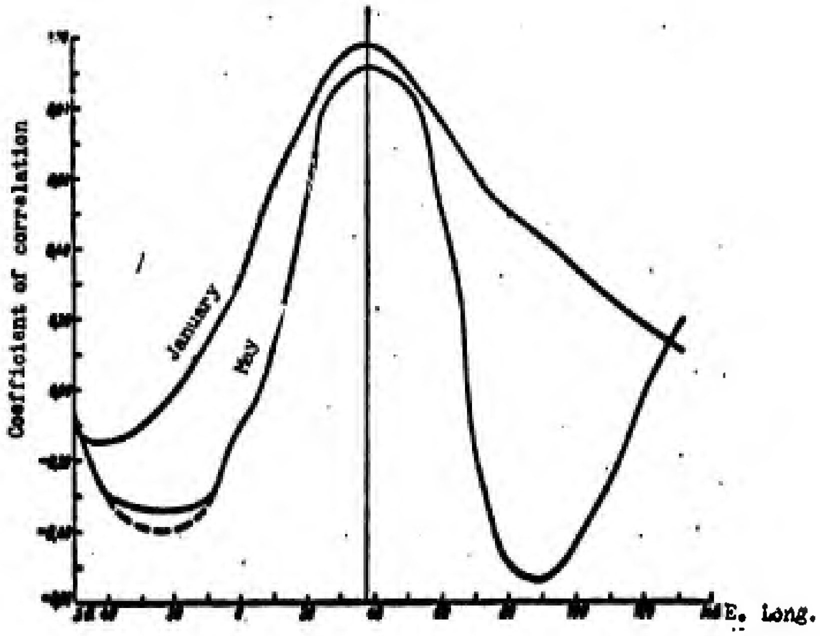

Fig. 69. Correlation function with respect to the temperature of Moscow. Section of isocorrelates along 55° N. Lat.

is not drawn, and on Fig. 69 it is given by a dotted line. Distribution of isocorrelates in May shows that during this time of the year meridional transfer of air masses play a great role.

It is further necessary to clarify the dependence of character of the correlation function from the selection of the center, with respect to which coefficients of correlation are calculated.

Isocorrelates with respect to Barnaul, calculated for the territory of the Soviet Union can serve for this purpose. Barnaul was selected as the center for that reason that it in winter is in the zone of so powerful a center of action as the Asian anticyclone. Isocorrelates with respect to Barnaul were published by Rubinshteyn (1962). They are reproduced on Figs. 70-81 with considerable more precise definitions in the north and east of the country. These more precise definitions are connected with the fact that in the indicated regions it was found possible due to the accumulation of material to use a series of stations which earlier had too short a series and was not included in the examination. In that work there was used a series of observations, as a rule, only up to 1950.

As can be seen from Figs. 70, 71, 80, and 81, in the north in the cold period of the year (from November to February) regions with large negative correlation coefficients with respect to Barnaul are revealed.

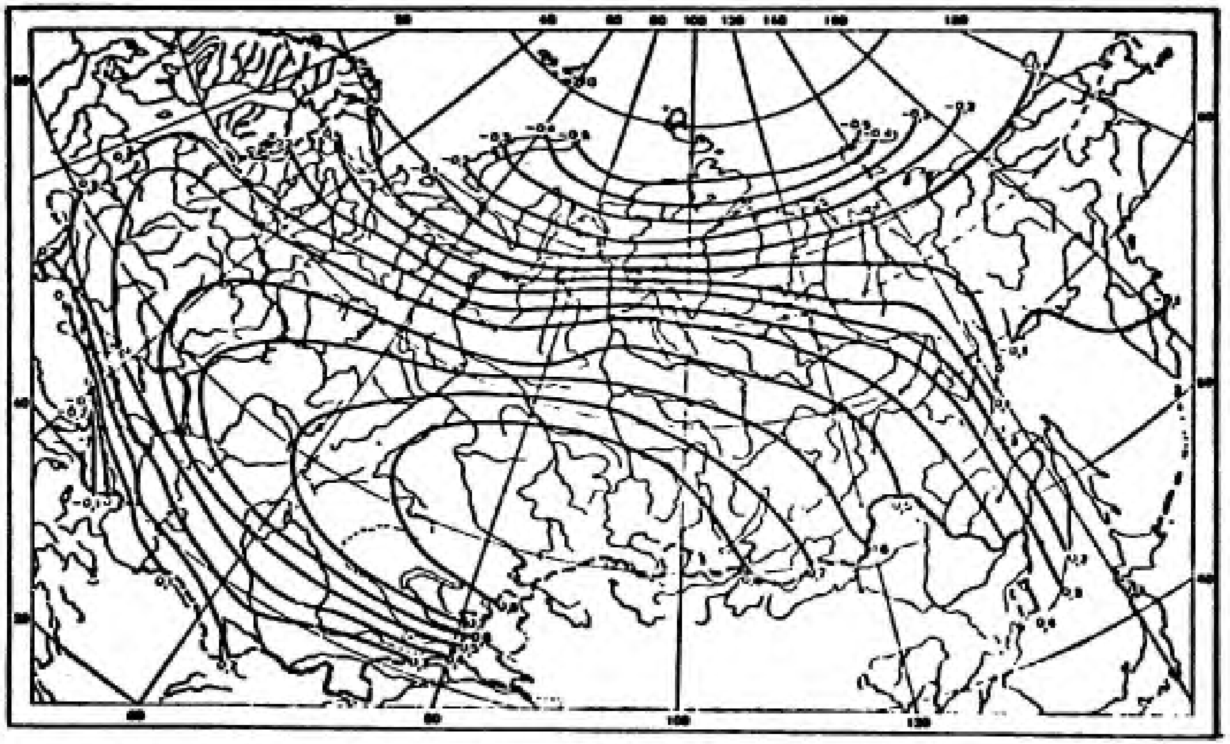

Fig. 70. Isocorrelates with respect to the temperature of Barnaul. January.

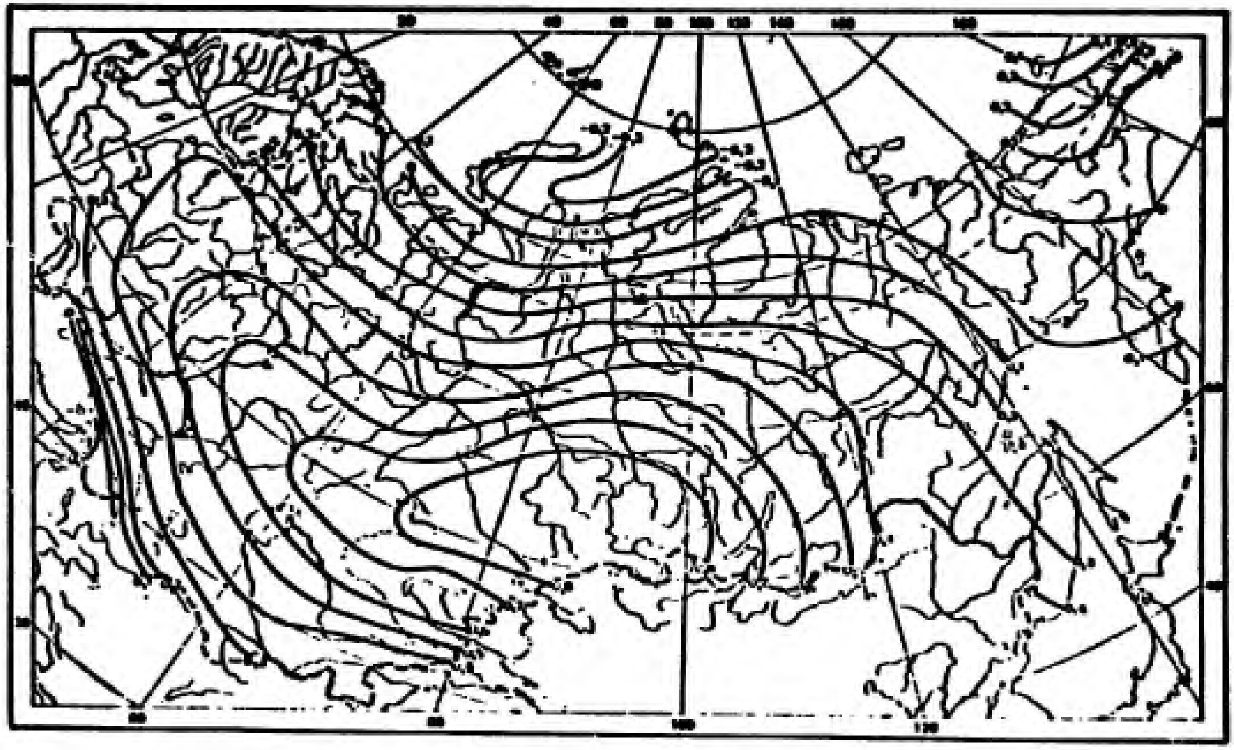

Fig. 71. Isocorrelates with respect to the temperature of Barnaul. February.

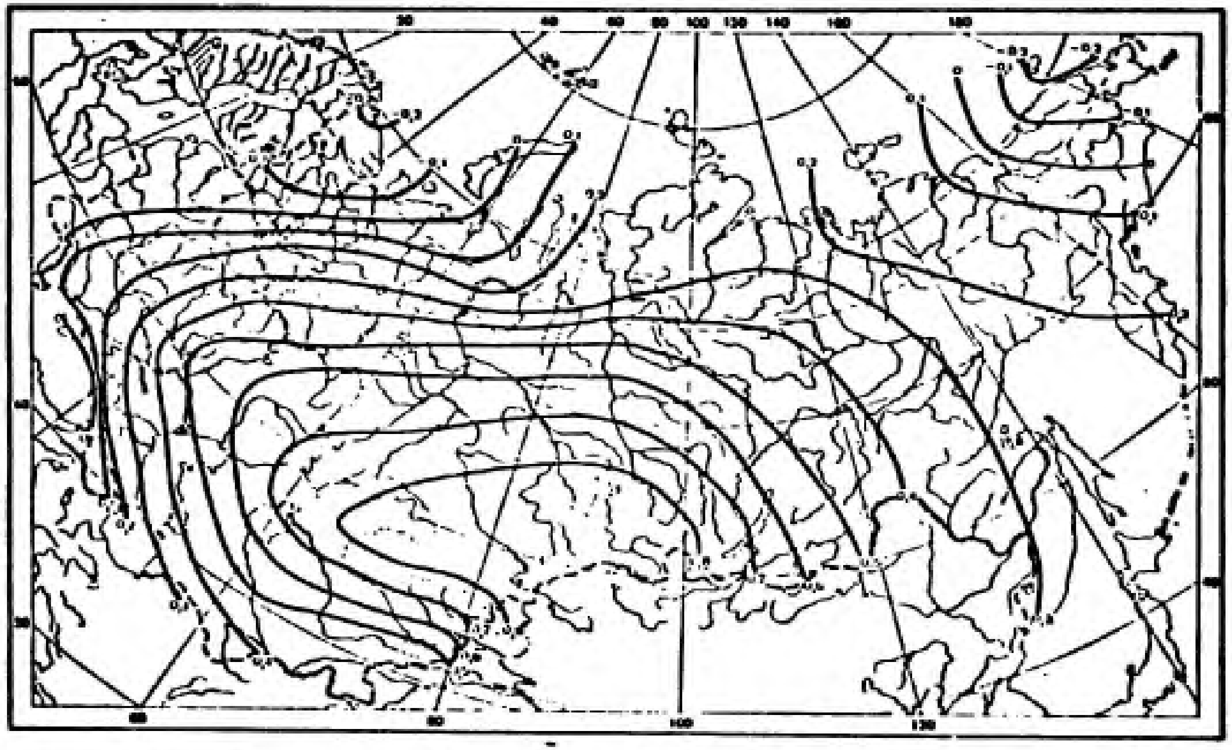

Fig. 72. Isocorrelated with respect to the temperature of Barnual. March.

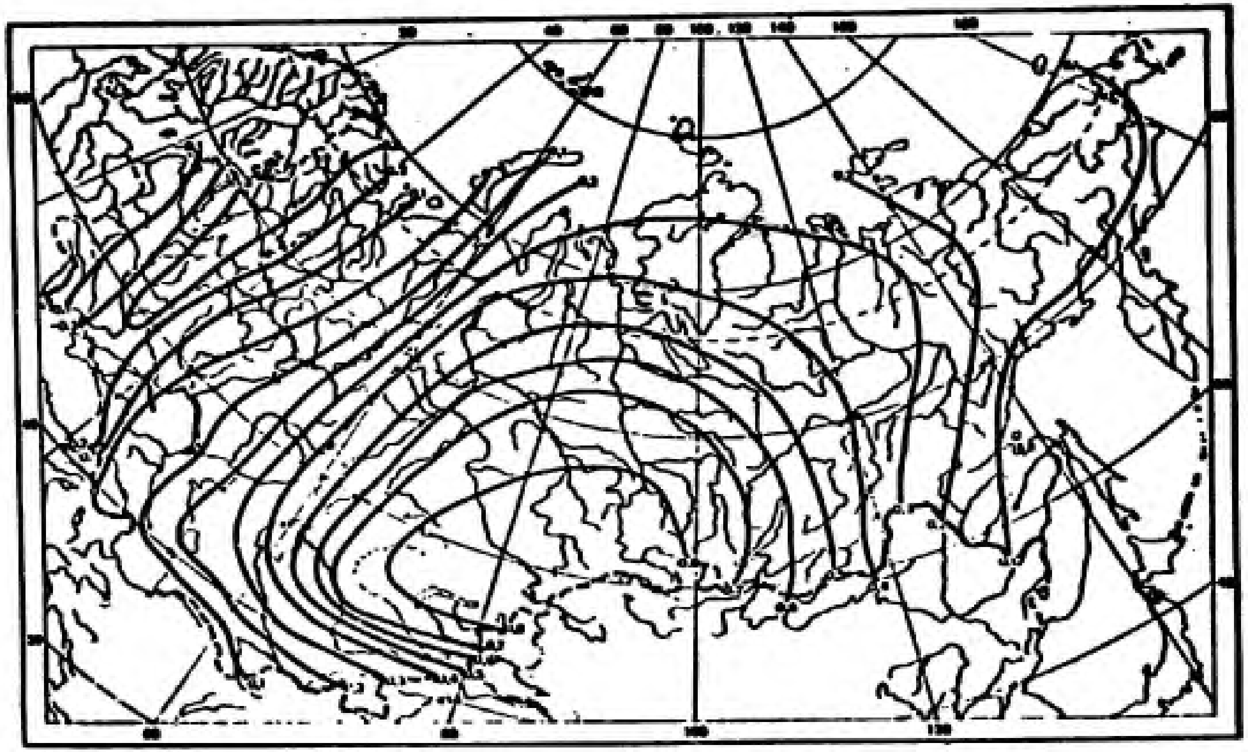

Fig. 73. Isocorrelates with respect to the temperature of Barnaul. April.

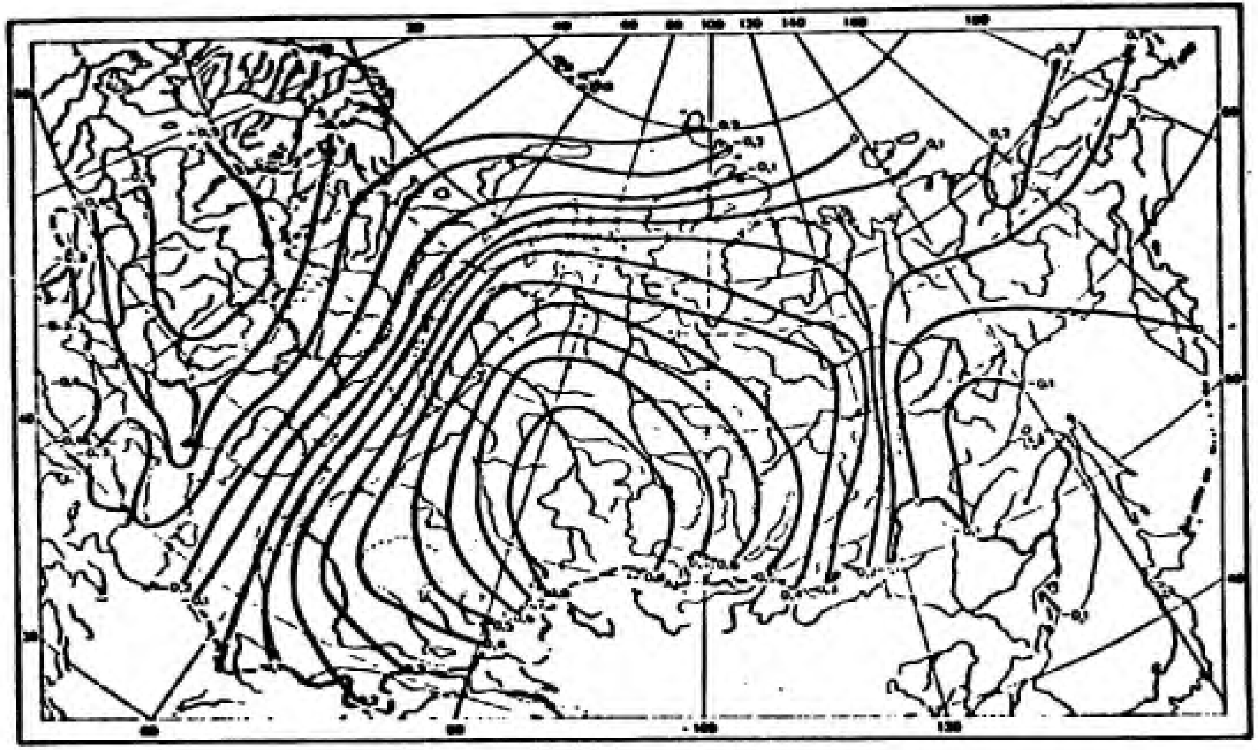

Fig. 74. Isocorrelates with respect to the temperature of Barnaul. May.

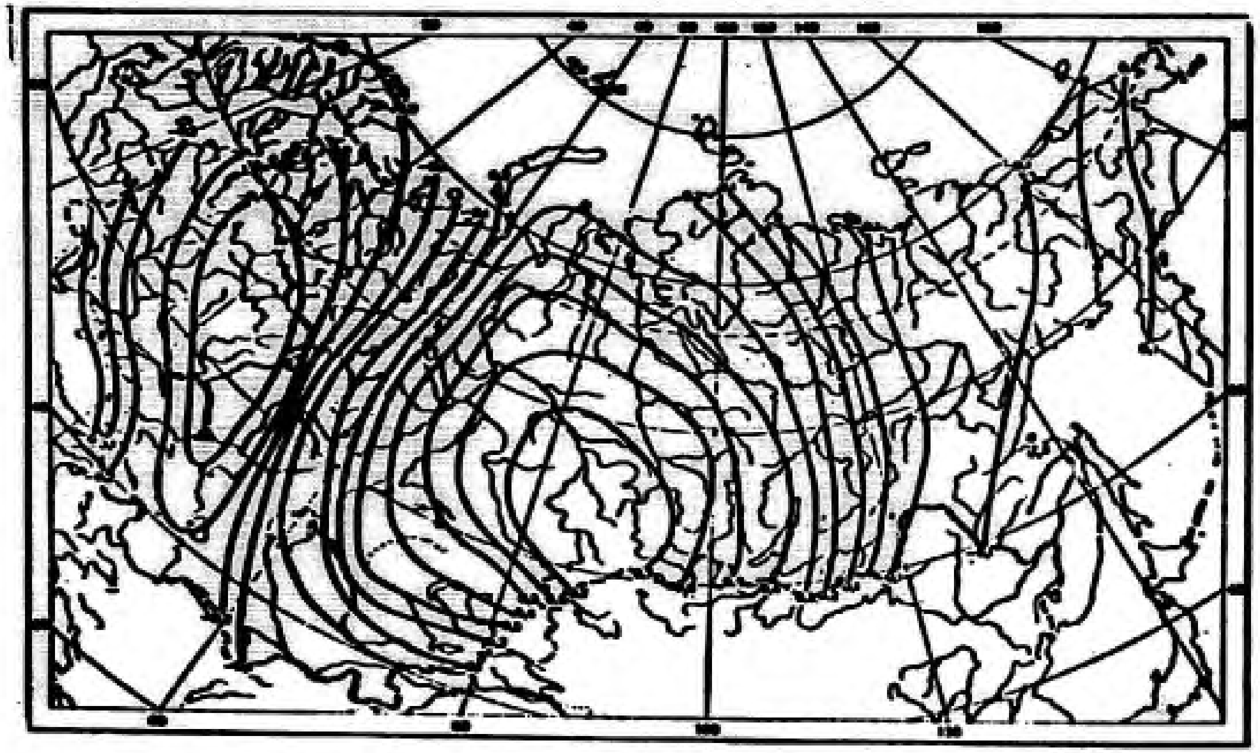

Fig. 75. Isocorrelates with respect to the temperature of Barnaul. June.

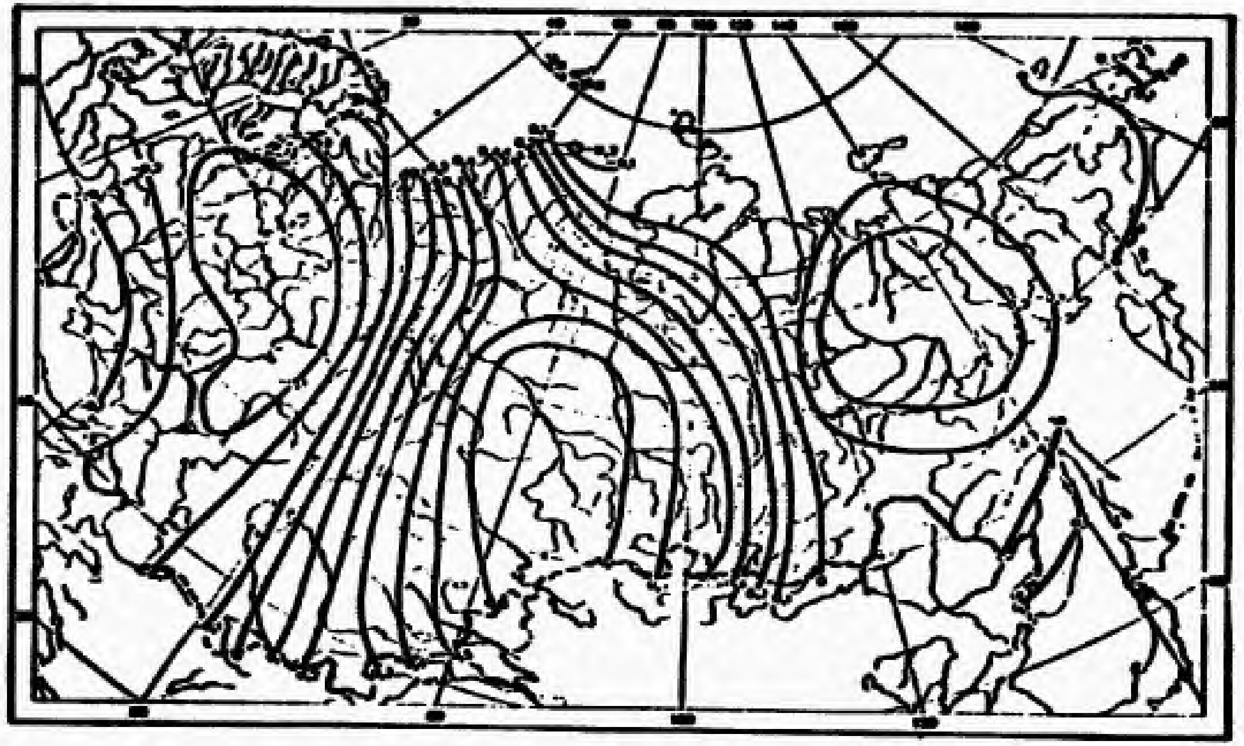

Fig. 76. Isocorrelates with respect to the temperature of Barnaul. July.

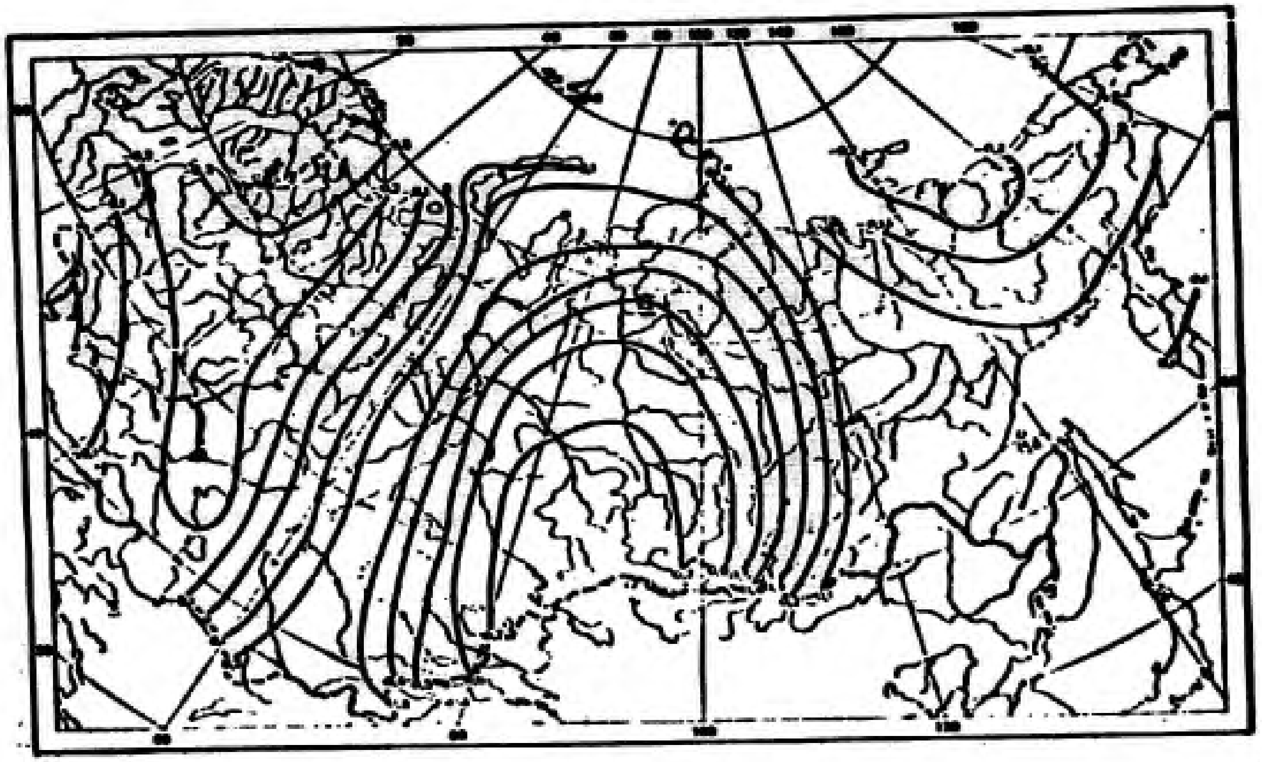

Fig. 77. Isocorrelates with respect to the temperature of Barnaul. August.

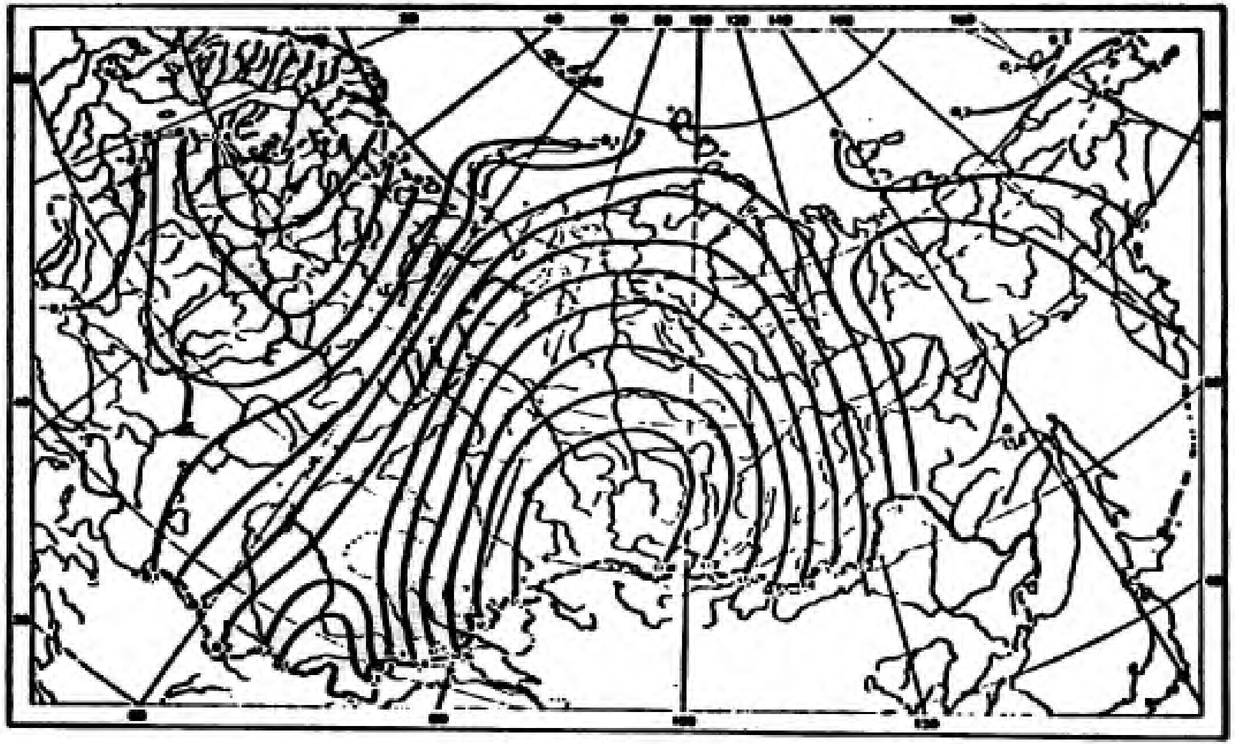

Fig. 78. Isocorrelates with respect to the temperature of Barnaul. September.

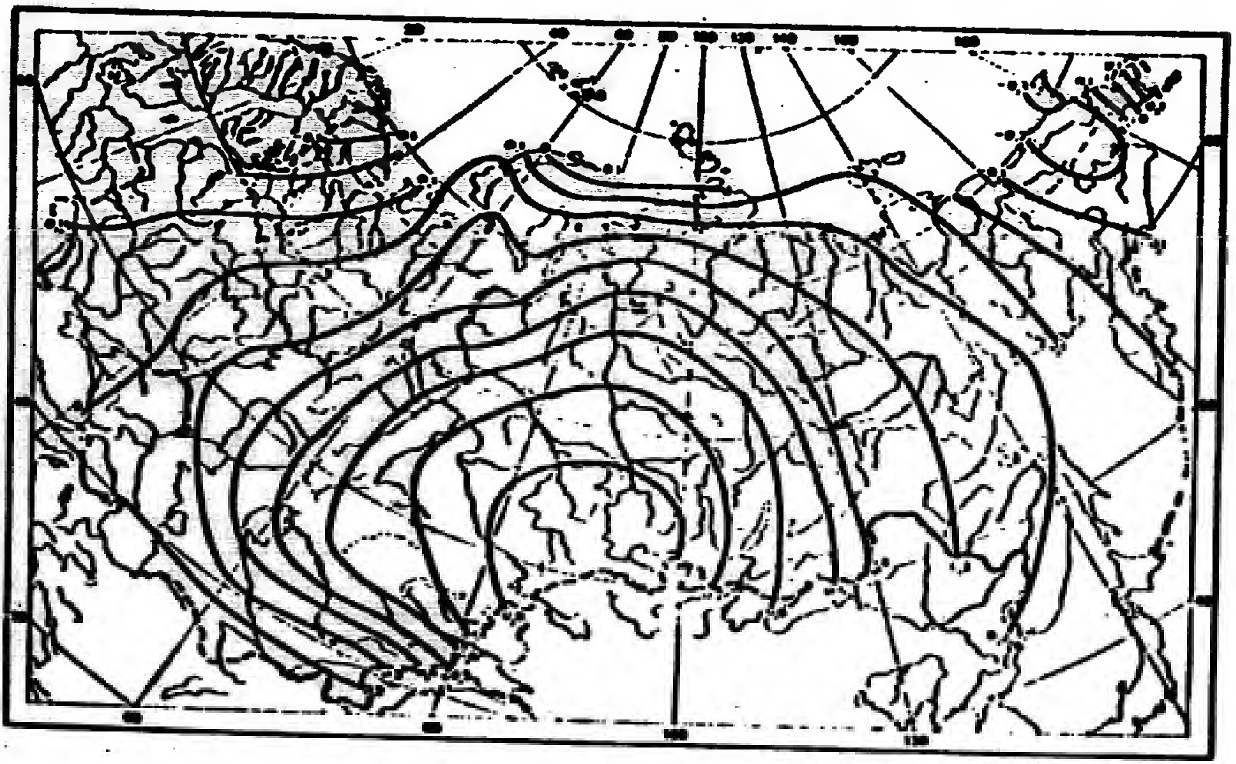

Fig. 79. Isocorrelates with respect to the temperature of Barnaul. October.

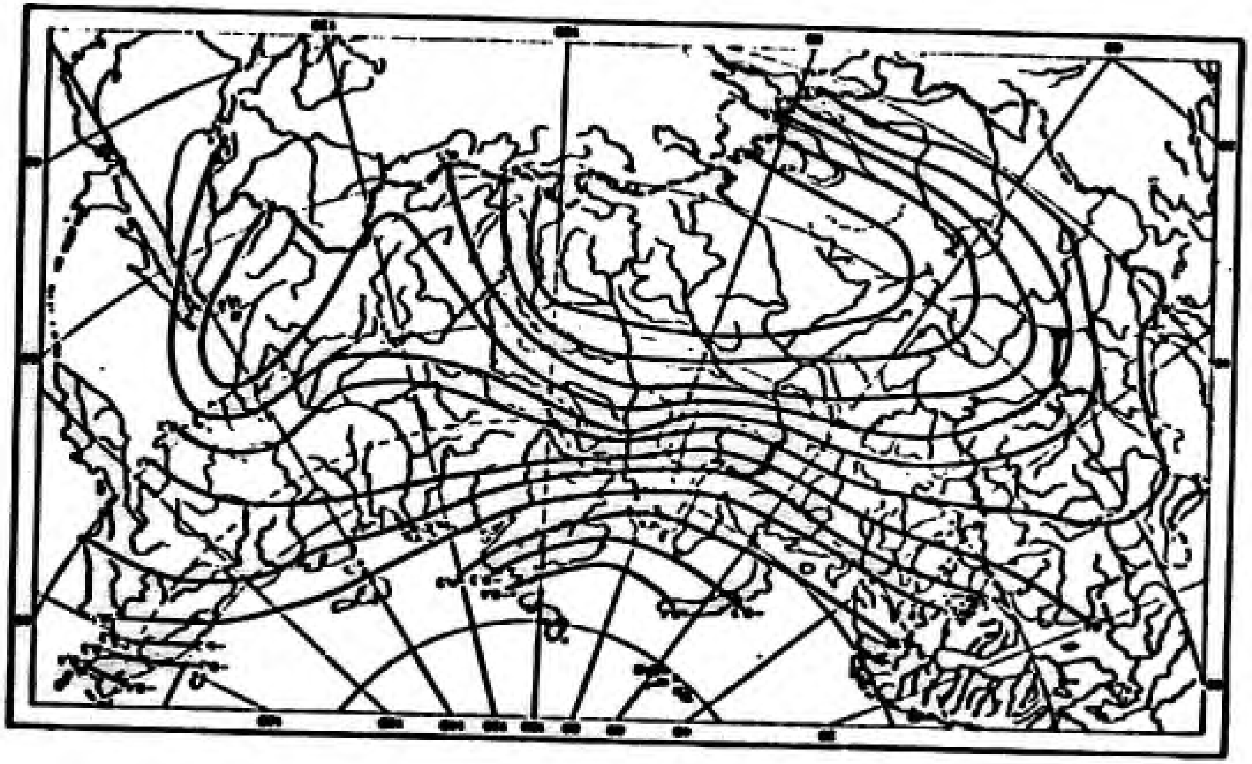

Fig. 80. Isocorrelates with respect to the temperature of Barnaul. November.

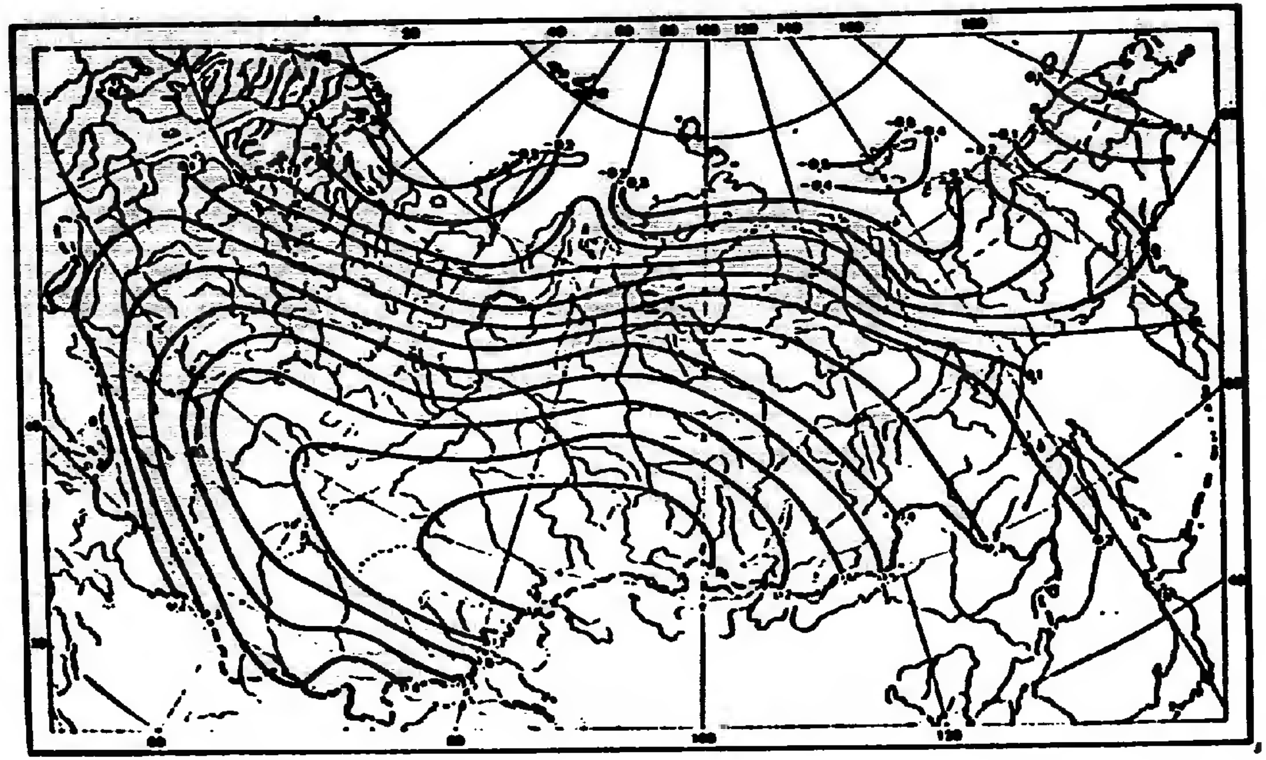

Fig. 81. Isocorrelates with respect to the temperature of Barnaul. December.

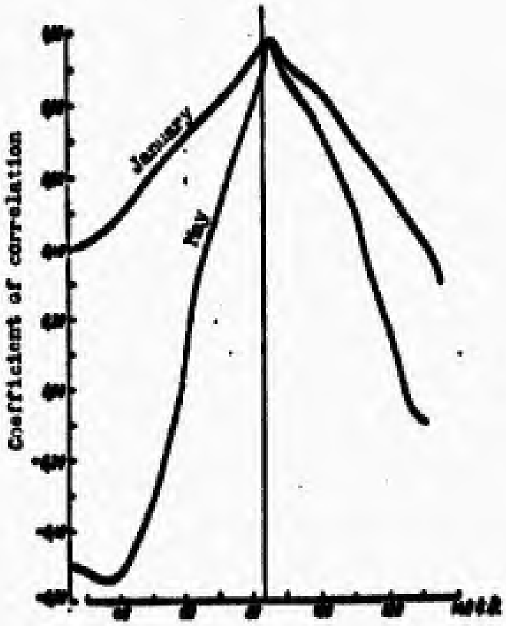

Fig. 82. Correlation function with respect to the temperature of Barnaul. Section along 53° N. Lat.

Analyzing the form of correlation functions for the section of about 53° N. Lat. with respect to Barnaul (Fig. 82) and comparing them with corresponding data of Fig. 69, we see that in January only in a small part of the territory, where coefficients of correlation are more than 0.80, does the asymmetry of the correlation curve have the same character as that with respect to Moscow, and at greater distances from Barnaul westward the coefficients of correlation are greater than those eastward at the same distances from the center. In May the asymmetry of correlation curve with respect to Barnaul in the whole territory is of the same character as that with respect to Moscow, but it is expressed somewhat sharper. It is necessary to consider that latitudinal sections for which correlation functions are plotted with respect to Moscow and Barnaul are unequal. Comparing the closeness of the connection of stations located at the same distances westward from the centers of correlation, we find that in January the coefficients of correlation with respect to Barnaul are greater than those with respect to Moscow. This is caused by the influence of the Asian anticyclone, which in various years is unequally developed in intensity and does not always render great influence on regions to the west of Moscow. Eastward from Moscow and from Barnaul at the same distances the coefficients of correlation are practically identical.

In May the picture changes considerably: western branches of correlation curves show that at the same distances from the centers the coefficients of correlation with respect to Moscow are greater than those with respect to Barnaul, and the eastern branches in their greater part have a reverse course. The cause of this is the destruction of the winter anticyclone in the western part of the country and the intensification of the meriodional air transfer, whereas in the east the role of the winter character of the circulation is still important.

For the characteristic of changes in position which isocorrelates undergo during a year, on Fig. 83 positions of 0.5 isocorrelates for all months of the year are plotted. Barnaul (and not Moscow) is selected as center because in all months of the year the 0.5 isocorrelate is within the Soviet Union with the exception of a small part of it in the south of the country.

Analysis of Fig. 83 permits drawing the following conclusions.

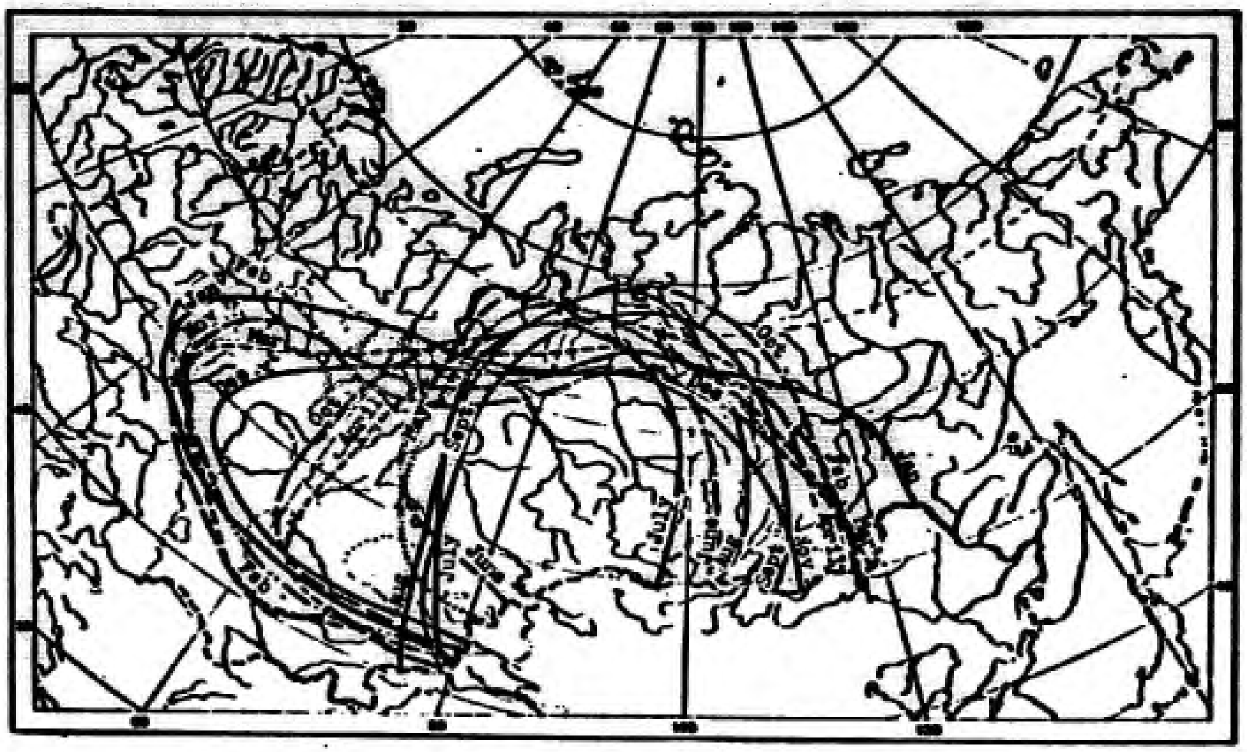

Fig. 83. Position of 0.5 isocorrelate with respect to the temperature of Barnaul in all months of the year.

1. In the west the annual course of the 0.5 isocorrelate is distinguished by a well-known regularity. The farthest advanced to the west of isolines in winter are from December to February;[1] then come isolines for months symmetric in the annual course, March and November, April and October; and the nearest of all to Barnaul and sufficiently close to one another are isolines of the warm period, from May to September.

2. Eastward from Barnaul the location of 0.5 isocorrelates in various months of year has another character. Further all on east there is advanced the isocorrelate in January, in the remaining months of the cold part of the year 0.5 isocorrelates are close to one another, 0.5 isolones in the period from May to September are distributed more or less regularly and nearer to Barnaul than they are in winter. The reason that 0.5 isocorrelates do not extend further to the east is because of presence in the Far East of an infependent circulation of a special type, the monsoon, whose connection with respect to temperature characteristics with the central part of the continent is expressed comparatively weakly, and the coefficients of correlation do not reach 0.5.

3. In the north and, apparently, in the south isocorrelates are located very densely, where in the cold part of the year they are nearer to the center than in the warm period. It is clear that here the predominant air transfers in various seasons are effective. It is difficult to analyze this question more in detail, using only terrestrial data. This is a subject of special investigation, which has both theoretical and practical (prognostic) importance.

As was already said earlier, isocorrelate maps of the northern hemisphere are compiled only for two months – January and May. Presnetation of the annual course of coefficients of correlation in various parts of the northern hemisphere is given in Table 18, where for the selected points coefficients are given of correlation for all months of the year.

Analysis of Table 18 shows, first of all, that the annual course of coefficients of correlation is insufficiently smooth. Since in this table there are data for long a series of observations (only for Jan Mayen Island 21 years is used) one should consider that coefficients of correlation, as a rule, are determined with sufficient accuracy, and their small values indicate that a connection is practically absent.

In great expanses, as data of Nant, Barnaul, Petropavlosk-Kamchatkiy and Niigatar show, according to values of coefficients of correlation May there is indeed one of the most contrast months with respect to January according to the character of the relationship. On Kamchatka a somewhat greater contrast is observed in October. Since in Dawson, Upernavik and Jan Mayen Island in summer months the

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[1] The section along the parallel corresponding to the latitude of Barnaul.

Table 18. Correlation Coefficients with Respect to the Temperature of Moscow.

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Nant	0,30	0,38	0,37	−0,16	−0,28	−0,10	−0,09	−0,17	−0,04	−0,10	0,25	0,12
Jan Mayen	−0,36	−0,21	−0,11	−0,05	0,05	−0,15	0,18	0,13	0,02	−0,09	−0,02	−0,30
Stikkisholmur	−0,25	−0,24	−0,07	−0,27	−0,30	−0,05	0,04	0,11	−0,27	−0,61	−0,19	−0,26
Upernavik	−0,22	−0,52	−0,08	−0,15	0,05	0,05	0,03	0,01	0,30	−0,13	0,06	0,002
New Haven	0,22	0,13	0,17	0,22	0,02	−0,24	−0,09	0,25	−0,35	−0,34	0,02	0,11
Dawson	−0,22	−0,09	0,05	−0,04	0,02	0,05	0,01	−0,02	0,31	0,21	0,31	0,11
Petropavlovsk-Kamchatskiy . . .	−0,27	0,09	0,21	0,19	0,23	0,04	0,05	0,16	0,12	0,33	−0,06	−0,21
Niigata	0,25	0,13	0,20	0,21	−0,12	−0,15	0,02	0,13	−0,04	−0,03	0,01	0,02
Yakutsk	0,16	0,03	0,12	0,14	0,30	0,18	0,33	0,15	0,16	0,25	−0,06	0,04
Barnaul	0,45	0,49	0,20	−0,30	−0,55	−0,45	−0,32	−0,23	−0,27	0,30	0,22	0,32

coefficients of correlation are close to zero, and it is not necessary to discuss the contrast of them with respect to January. In Stikkisholmur (and also in Yaktusk) in all those months when coefficients are more or less considerable, they have the same sign. Deserving attention are the comparatively large coefficients of correlation in the autumn months (Dawson, New Haven, Stikkisholmur, Petropavlosk-Kamchatkiy).

Isocorrelate maps and correlation functions characterize to a certain degree the influence of the Asian and anticyclone on the closeness of the connection between temperatures of different parts of the Soviet Union. It is interesting to trace the role of the Icelandic action center.

Table 19 shows that correlation coefficients between temperatures of Stikkisholmur and New Haven in all months of the year are positive, whereas with Moscow and Leningrad almost in all months these coefficients are negative and in their value of own, as a rule, they are larger. It is important that the largest values of them in the annual course are observed in October (and with New Haven also in August).

Table 19. Correlation Coefficients with Respect to Stikkisholmur

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
New Haven	0,34	0,24	0,21	0,12	0,30	0,22	0,15	0,40	0,34	0,44	0,34	0,18
Leningrad	−0,09	−0,21	0,02	−0,21	−0,20	0,00	0,10	0,14	−0,25	−0,52	−0,11	−0,08

It is necessary to note the fact of the insignificant relationship between the temperature regime in regions of the Icelandic and Azore centers of action. Correlation coefficients between temperatures of Stikkisholmur and Ponta Delgad in January and May are equal to -0.12 and ±0.04 respectively. The complicated character of relationships of temperature regime of the Icelandic action center with America and Europe is caused by the character of circulation, which here is not examined since it does not have a direct relation to the present work.

Correlation relationships revealed between temperatures of various parts of the polar and temperate zones of the northern hemisphere permit revealing many regularities in the character of spatial change in temperature regime in these parts of Earth. In particular, the transition from large positive correlation coefficients through their zero to negative values with indubitableness once again shows that the direct cause of the change in the temperature regime is due to changes in character in the atmospheric circulation, since only with the help of the circulation is redistribution possible on the Earth of heat, accumulated in the low latitude, in particular, in the World ocean, and cold flows of air proceeding from the polar regions.

Although for the southern hemisphere isocorrelate maps are not made due to an insufficient quantity of stations and short duration of many series of observations, it is doubtful whether there are the same regularities there in the connectivity of series of observations in various parts of the hemisphere, and perhaps, only dimensions of regions having the same sign of connection will differ from the analogous regions of the northern hemisphere.

In spite of the important contribution which the analysis of isocorrelate maps introduces into the investigation of the change in the temperature regime, these maps still do not make it possible to judge if air temperature totally in the whole hemisphere simultaneously increased or decreased with an increase or decrease in temperature in the center of the correlation. First of all the relationships between centers of correlation located in temperate zone with the tropic (partially with subtropical) zone are almost absent, and it is clear that the shift of the center of correlation from one point of the temperate zone to another point of the same belt will not facilitate calculation. Considering the dimension of the area of low latitudes and also the fact that the temperature regime there is subjected to considerable variations from one 10-year period to another (as this was shown in our former works and in Chapter III of this work), it is impossible to disregard data for this area with a total appraisal of the increase or decrease in temperature of the hemisphere.

It would have been possible to calculate for low latitudes correlation coefficients with respect to any point in the subtropical or tropic zone and to examine it independently. But calculation of warming or cooling totally for the whold hemisphere with the help of the distribution of isocorrelates, even if it is possible, is very complicated, and mainly it is doubtful whether it will be sufficiently accurate.

It is necessary to try to find another approach to the solution of the question about the change in temperature regime of whole hemisphere on the whole.

2. Appraisal of the Change in Air Temperature of the Northern Hemisphere (as a Whole) for Individual Months and Years with Respect to Its Perennial Mean Temperature

It has been more than 100 years since Dove (1840-1859) carried out an investigation (classical for his time) on the distribution of deviations in temperature in individual years from the perennial mean in various parts of the Earth. As is known, he arrived at conclusions which are sometimes called Dove's laws. They can be formulated in the following way: 1) a deviation in temperature from the perennial mean, noted in any year at a given point, usually spreads in more or less an extensive territory, 2) considerable deviations from the mean in one region are compensated by deviations of the opposite sign in another region. It is understandable that at that time Dove could reveal only general regularities of the distribution in temperature, but for a more or less acceptable quantitative solution to the problem hea has extremely insufficiently initial data.

Half a century later, at the beginning of our centruy, the same question was the subject of several works of Arktovskiy (1909, 1914). The works of Arktovskiy, essentially, are the continuation of works of Dove. Arktovskiy arrived at the conclusion that there exist two sources where deviations in annual temperatures from the perennial mean values appear. From these sources deviations spread to considerable expanses. He investigated the period of 1891-1900 and for this period such sources were, in his opinion, the polar regions and Australia. At the same time he recognized that in other years these sources can be displaced. Arktovskiy tried also to find the cause of the appearance of deviations of temperature in individual years from the mean and studied the relationship of them with solar activity.

Since then there has passed still a half a centruy, but the problem formulated by Dove is not solved now, despite the fact that we have an immeasurably greater initial material than that of Dove.

The basic difficulties of resolution of the problem are the lack of data for oceans. This led to the necessity to refuse resolution of the problem for the planet as a whole and to be limited by an attempt of its schematic solution for the northern hemisphere.

Initial data served as maps of an atlas with isolines of deviations in air temperature from the perennial average for the period of 1881-1940 in the northern hemisphere (1961, 1962). For calculations a series of maps was selected for those months and years when in extensive territories there were observed intense deviations in temperature of a certain sign from perennial values. By means of leveling areas were calculated separately where the temperature was higher and lower than the perennial mean, and then on each of these areas the amount of deviation of temperature from the perennial was considered.

For an explanation of the method of calculation let us turn to Appendices II-VIII. In December of 1917 there were observed large positive deviations of temperature in the northeast of the European territory of the Soviet Union. In order to calculate the excess in temperature above the mean in this region, areas of rings were determined where deviations are from 2° to 3°, from 3° to 4°, etc. The excess in temperature in areas of each of the rings was considered 2.5°; 3.5°, etc. respectively per unit of area. But in the region where deviations exceeded 7° the deviation in temperature should not necessarily be considered 7.5°. To determine its most probable value there were used originals of deviation maps with values of deviations for separate stations plotted on them. Especially needed in a more precise definition are coefficients for the calculation of deviations of temperature in areas occupied by oceans and in the insufficiently studied parts of the territory of continents. These coefficients were always determined by orginals of maps taking into account data all nearby stations. Thus, for example, to the south of Greenland in the region of the Atlantic inside the closed 1° line deviation from the perennial mean was taken not 1.5° but only 1°, and inside the ring 0-1°, not 0.5° but only 0.2°. Analogously in Africa in the area inside the closed 1° line the deviation was considered not equal to 1.5°, but only 1.2°. With the help of the above-indicated mehtod series of maps of deviations in air temperature in the northern hemisphere was compiled. Some of these maps are given as examples in the Appendix II-VIII.

Results of analysis for three years (1917, 1921 and 1931) are given in Table 20.

Table 20. Deviations in Air Temperature from the Perennial Means for the Northern Hemisphere

Year	I	II	III	IV	V	VI	VII
1917	−0,14	−0,14	−0,38	−0,23	−0,34	−0,01	+0,08
1929	−0,04	−0,13	+0,07	+0,03	−0,05	−0,06	−0,07
1931	+0,41	+0,10	+0,36	+0,26	+0,03	+0,44	+0,03

Year	VIII	IX	X	XI	XII	Year
1917	−0,08	−0,19	−0,40	−0,22	−0,65	−0,25
1929	+0,07	+0,09	+0,01	+0,04	−0,23	+0,06
1931	+0,34	+0,27	+0,36	+0,34	+0,42	+0,28

An analysis of this table shows important distinctions in the character of distribution of temperature in each of these three years. In 1917 in all months except May and June and also as an average for the year, the temperature of the hemisphere was lower than that of the perennial mean. Negative deviations attained especially large values in the period of March-May and October to December. From June to August there was carried out almost full compensation of temperature between regions of positive and negative deviations from the perennial mean. In 1929 such a compensation was observed almost in all months of the year and also as an average for the year. Thus in these months of 1917 and also as an average almost in all months of 1929, the temperature of the northern hemisphere was close to the perennial average.

In 1931 the excess the temperature as compared to the perennial average is observed in all months of the year and as an average for the year where, with the exception of May and July, it reaches considerable values. It is interesting that in certain summer months (June, August) it is just as great as it is in winter.

The distribution of positive and negative deviations, as can be seen from maps of temperature deviations, is very complicated, and without exact computation it is not always possible to decide whether in a given month the northern hemisphere was, as a whole, warmed or cooled. A characteristic example can be February of 1929. It is known that it was very cold almost on the entire mainland of Eurasia, especially in Europe. Low temperatures were also observed in North America. In spite of this, calculations showed (Table 20) that the temperature of the whole hemisphere was lower than the perennial mean by only 0.13°. This occured due to positive deviations from the perennial mean in low latitudes (Atlantic, part of Africa, Arabia). The warm Arctic in this case has lesser importance, since the deviations from the perennial mean, although there they attain considerable values, the area occupied by them is comparatively small.

Although with the construction of maps of temperature deviations in oceans data of observations on vessels were considered, nevertheless, there was doubt in the accuracy of the drawing of isolines on oceans, and also in Africa, Central Asia, Arabia, and therefore it is considerably important to clarify whether figures of Table 20 reflect the real relationships of positive and negative deviations in temperature of the northern hemisphere. An exact answer to this question is difficult to give, but certain considerations are in favor of a positive answer.

Thus, for example, the increase or decrease in temperature of the northern hemisphere as an average for the year can be calculated by months, but can be obtained as an average value from 12 months.[1] A check showed good consent of values of the annual increase or decrease in temperature calculated by both methods, which indicates satisfactory accuracy of isolines of deviations on monthly maps.

As to the fact that figures given in Table 20 reflect real relationships, systematics in the course of deviations during the year indicates that in 1931 in all months of the year an increase in the perennial mean is observed, and in 1917 in all months except January and December there is a decrease in temperature. For 1929 almost in all months very insignificant deviations in temperature are characteristic of the northern hemisphere from the perennial mean.

By applying the described method of calculation of the deviation in temperature of the northern hemisphere from the perennial mean for a series of years, one can determine the magnitude of increase or decrease in temperature of the northern hemisphere from one decade to another, etc.

Such calculation requires, however, much expenditure of labor and in the given stage of the investigation of the change in

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[1] Given in the table are values of annual deviation in temperature from the perennial mean obtained by means of calculation on annual maps of deviations.

temperature was not carried out. It is impossible as yet to conduct it for the southern hemisphere, since maps of temperature deviations from the perennial mean for the southern hemisphere have not been compiled. Thus, in spite of the great perspectivity of this method, at present an appraisal of the change in temperature in a planetary scale by this method is not feasible, and we must be satisfied for this purpose with methods which are less exact, especially in oceans.

3. Question of the Temperature Drop After the Period of 1921-1940

Authors engaged in the study of this question used one of following methods. Callendar (1961) calculated for various latitudinal zones and for separate parts of the Earth (Africa, Southern America, etc) deviations of 5-year mean annual temperatures, and also moving 20-year means from the perennial means (1901-1930) for the period from 1880 to 1960, and he also compared for latitudinal zones mean temperatures for periods 1921-1950 and 1891-1920.

Mitchell (1963) calculated deviations of 5-year mean temperatures (from 1840 to 1960) from the mean for the 5-year period 1880-1884 for the year and for winter, summed up along latitudinal zones for the whole Earth and also separately for various latitudinal zones. Furthermore, he calculated differences of the mean annual temperatures along latitudinal zones for periods 1890-1919 and 1920-1949. All these calculations led to the conclusion of the increase in temperature on the Earth as a whole, consisting, as already was shown in Chapter III, according to Willett and Mitchell, of about 0.4° for regions from 60° N. Lat to 50° S. Lat. and about 0.6° for the zone from 60° to 20° N. Lat. In the tropic zone from 20° N. Lat. to 20° S. Lat. it is about 0.4°, and in the southeren hemisphere (of 20 to 50° S. Lat.) the increase in temperature was less, about 0.1°. Values of the increase in temperature obtained by Callendar differ little from those mentioned above.

We did not consider it expedient to conduct the same calculations on our more extensive material, since it is doubtful whether it is possible to expect results differing essentially from those obtained by these authors.

But if zonal-integrated mean temperatures in the first approximation are sufficient in order to estimate the general trend of the variation of temperature on the Earth as a whole, then they are unfit for the characteristic of the distribution of regions of increase and decrease in temperature inside the same latitudinal zone. This was already well apparent from the work of Rubinshteyn (1946), where there are given for the northern hemisphere maps of deviations in temperature from the perennial mean for the 10-year periods 1919-1928 and 1929-1938, and also from the work of Polozova and Rubinshteyn (1963) where it was shown that according to the course of temperatures each latitudinal from 80° N. Lat. to 40° N. Lat is divided into two parts.

Mitchell (1963) provided maps of the distribution of differences in temperature for winter and the year for periods 1900-1919 and 1920 to 1939, 1920-1939 and 1940-1959, 1940-1949 and 1950-1959. In the work of Polozova and Rubinshteyn (1963) analogous maps are given for January and April for periods 1941-1960 and 1921-1940, and also for periods 1951-1960 and 1941-1950.

It is clear that maps for the entire winter as a whole camouflage certain important peculiarities of the distribution of differences in temperature, since in the same regions in two adjacent months in comparable periods there can be difference in temperatures of opposite signs.

The time arrives to turn to an analysis of the warming and temperature drop for each month separately, since this will facilitate for future researchers coordination of the change in temperature with circulation and other factors affecting the variation of meteorological elements with time.

Given on Figs. 84-90 is a geographic distribution of differences in mean temperatures for the 20-year periods 1921-1940 and 1941 to 1960 for those months in which differences in their value represent the greatest interest (November-May). These differences permit judging in what months of year in what regions of the Earth is the temperature drop expressed the sharpest.

Not analyzing in detail Figs. 84-90, let us indicate only certain characteristic peculiarities of isolines of differences in temperatures.

It is known that there was a very great increase in the temperature of Greenland in the 1920's and 1930's. In the subsequent 20-year period almost all of Greenland cooled in the period of November-December, February-May. In January in a great part of it there was no temperature drop.

In November and December after 1940 the temperature dropped almost all over Eurasia and in the west of North America, where in November the greatest temperature drop (more than 2°) was observed not in the Arctic but in the Soviet Union, to the south of the Arctic Circle, and in December it extended partially to Alaska.

It is characteristic that in the eastern part of North America the temperature in the 20-year period 1941-1960 is higher than that in the preceding period. In January the region of the temperature drop in Eurasia considerably decreased, and the greatest decrease in temperature was observed in Scandinavia. The region of increase in temperature in North America is approximately the same as it is in preceding months, so that the contrast in the course of the temperature with Eurasia, which was the case in the preceding months, vanishes. In February regions enveloped by a temperature drop were increased, where for the first time the region of the greatest temperature drop (over 2°) extended to the Arctic – from Spitsbergen to the Novosibirsk Islands. In March again there is a contrast between the temperature drop in Eurasia and the

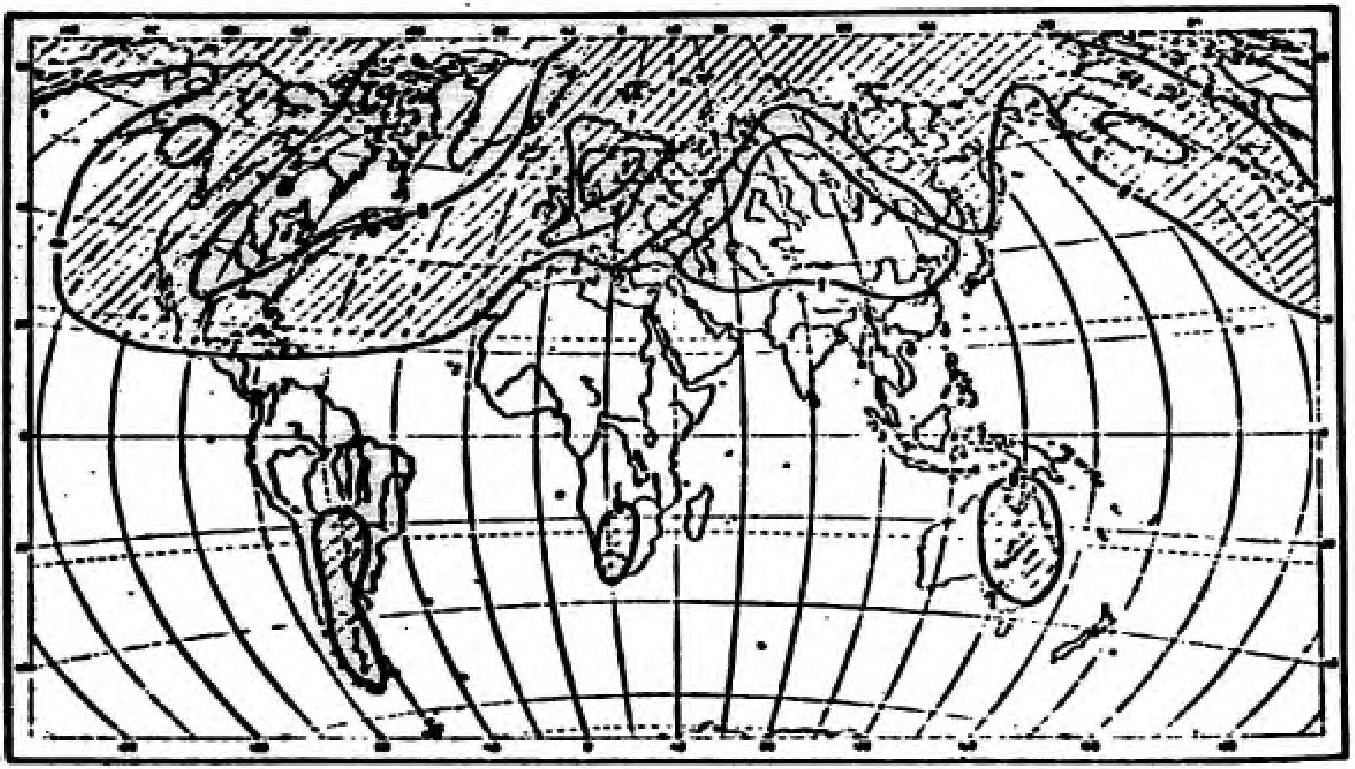

Fig. 84. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. January

Fig. 85. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. February.

Fig. 86. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. March.

Fig. 87. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. April.

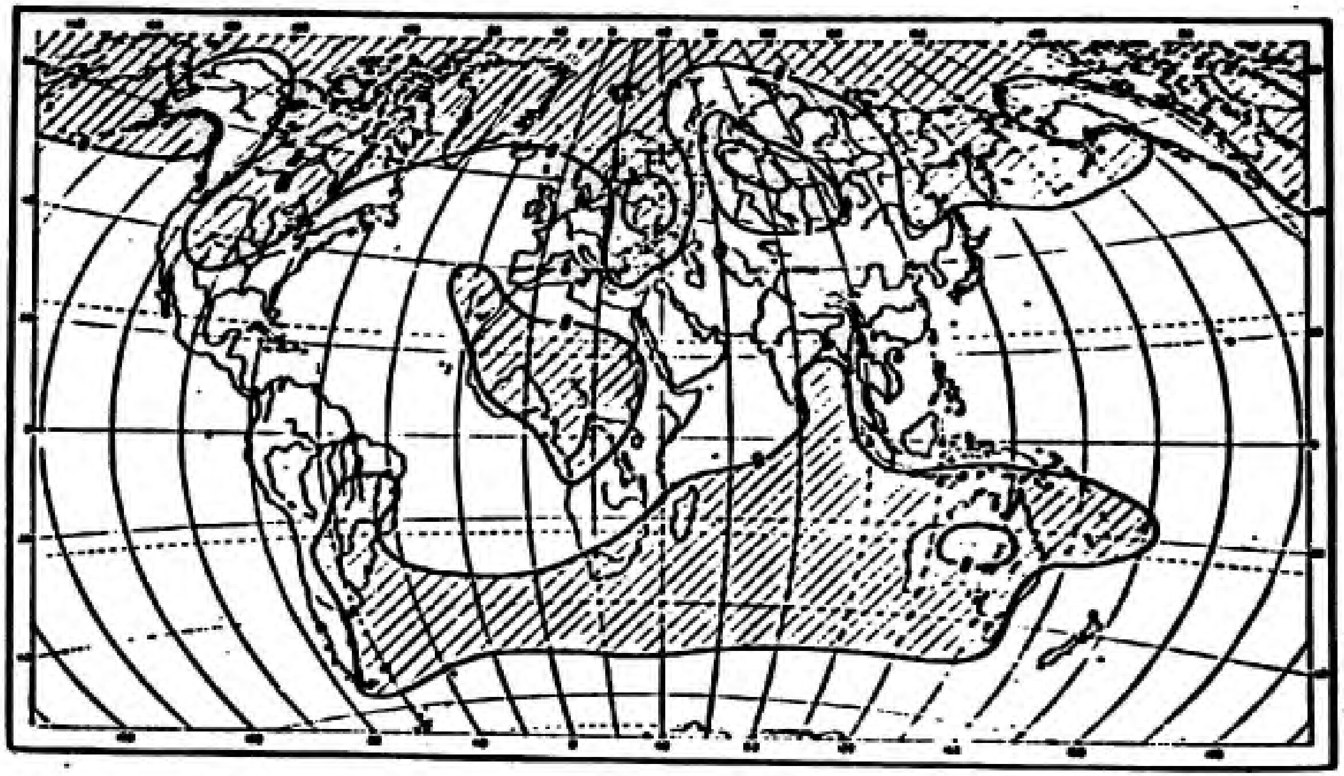

Fig. 88. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. May.

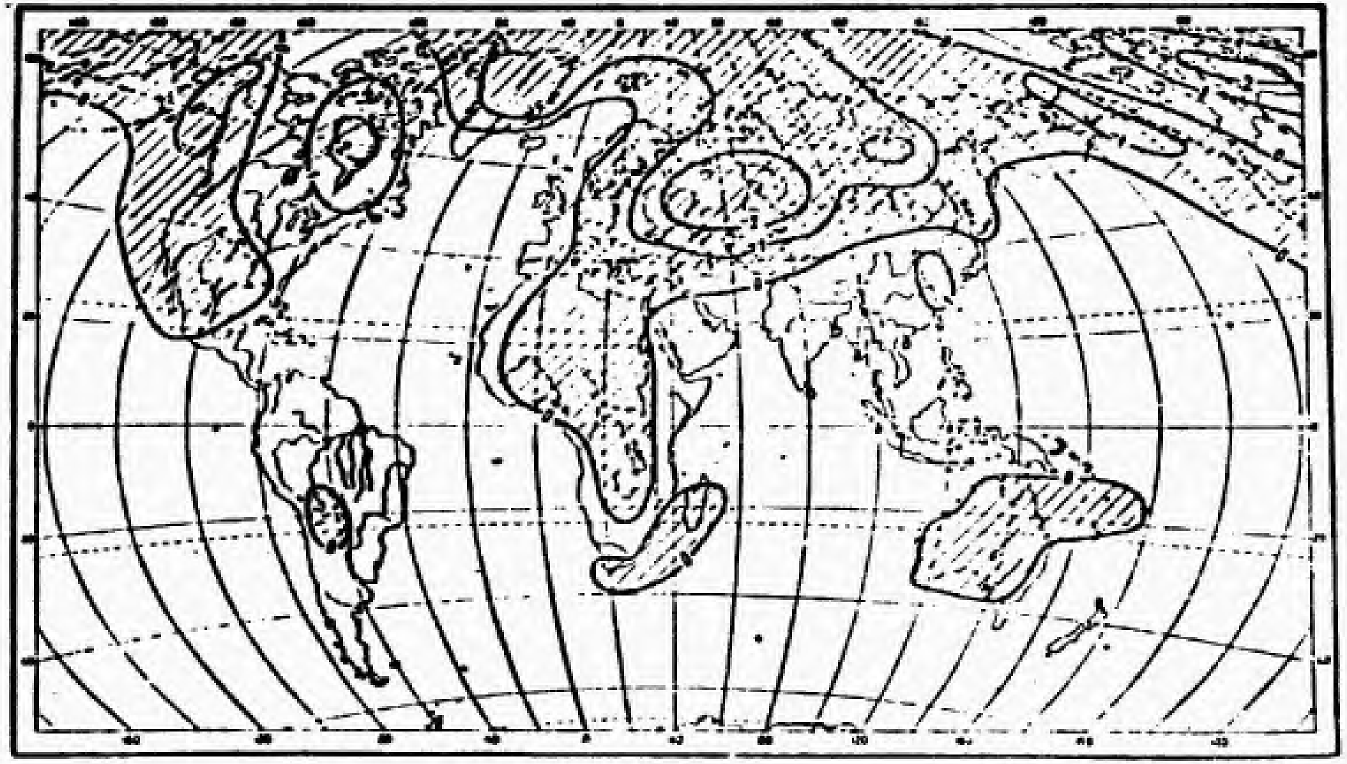

Fig. 89. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. November.

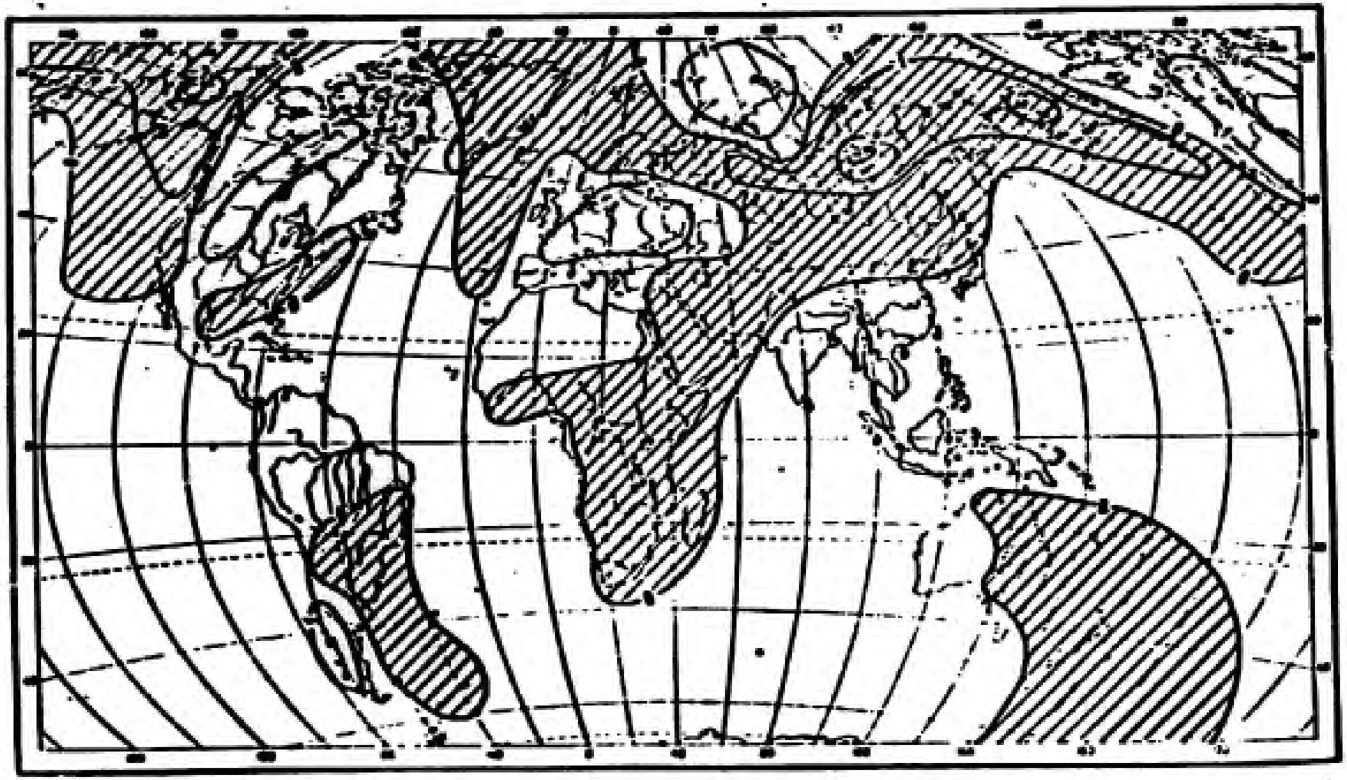

Fig. 90. Differences in temperatures for the 20-year periods 1921 to 1940 and 1941-1960. December.

continuing warming of a considerable part of North America. In April this contrast is preserved but with a reversed sign — in the northeast part of North America it cooled 1°-2°, whereas in Eurasia in separate regions there is observed an increase in temperature of 1°-2°. In May the contrast between temperature in North America and certain parts of the Soviet Union retains the same sign, but in North America the temperature drop is considerably less in its value than the warming in the corresponding regions of the Soviet Union.

The lowering of temperature in the period 1941-1960 as compared to the preceding 20-year period is observed in low latitudes of the northern and southern hemispheres.

The temperature dorpped considerably in May in large areas of Africa, Australia, partially in South America and in the oceans, and in March and November — in Africa and Australia. In contrast to this in January the distribution of differences of temperature for comparable periods show that in the entire territory of Africa and partially South America and Australia a temperature rise continues in the period 1941-1960.

It is of interest to clarify during what years in the period 1941-1960 did lowering of the temperature occur. This will give an idea of the stability of the temperature drop in this 20-year period.

In order to answer this question, let us turn to Figs. 91-97 on which differences in mean temperatures are given for the decades of 1951-1960 and 1941-1950 for those months of the year when they are the greatest.

Analyzing these figures, it is necessary to note the following peculiarities of the course of the isolines on the maps.

The decade 1951-1960 in October is considerably colder than the previous decade in the north of the Asian part of the Soviet Union where the difference reaches 4-5° (Fig. 95). In November also in certain parts of the Soviet Union there are regions where the drop in temperature, as compared to the 1940's, exceeds 3° and in certain places even 4° (Fig. 96). In January just as considerable in value a drop in temperature is observed in North America, in February — in Alaska and the Soviet Union.

An important peculiarity of the decade 1951-1960 is the temperature drop of the Atlantic, especially in the tropic latitudes and in the southern hemisphere (October-December, February-March). Since in the sum for 20 years (1941-1960) the tropic and South Atlantic are nevertheless, warmer than that in the period 1921-1940, ti is clear that years 1941-1950 were very warm in these regions.

Attracting attention in the period 1951-1960 is the temperature drop of the ocean in all the examined months of the year except February.

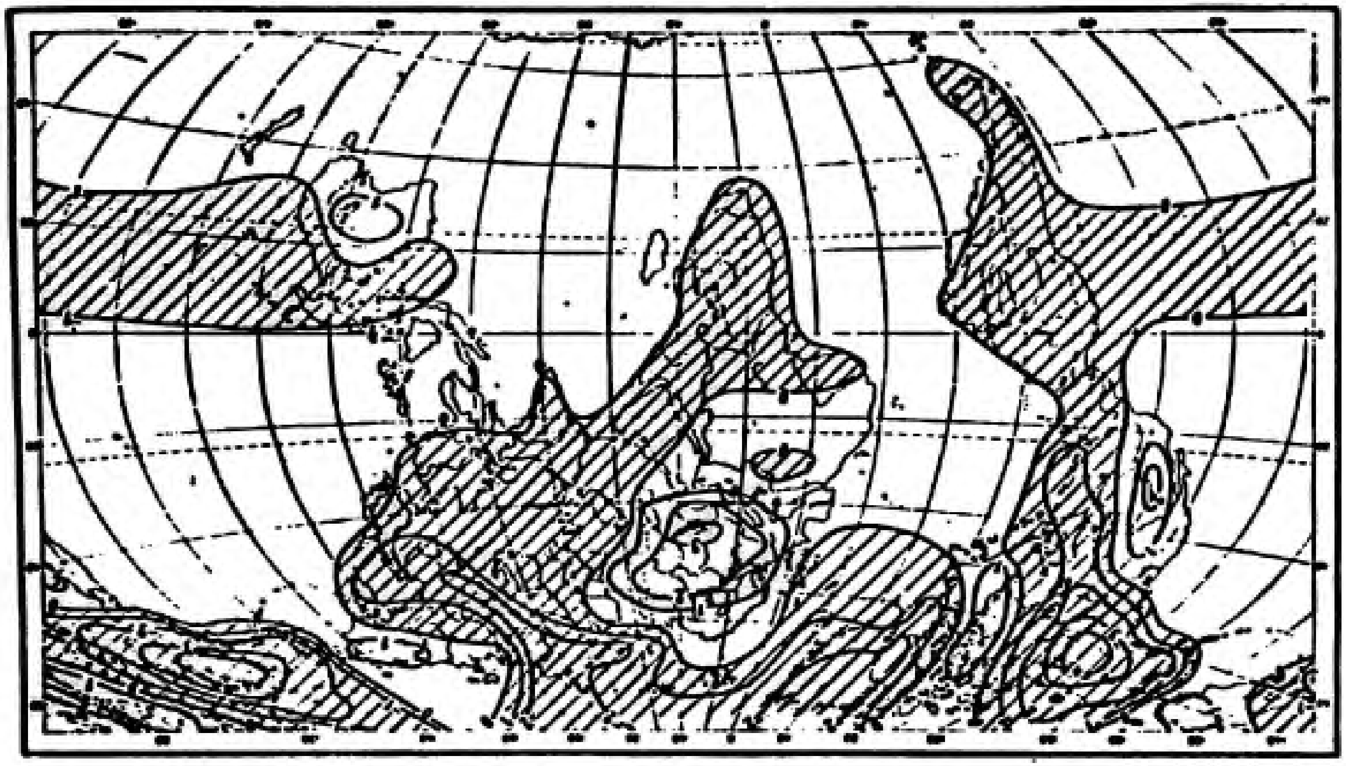

Fig. 91. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. January.

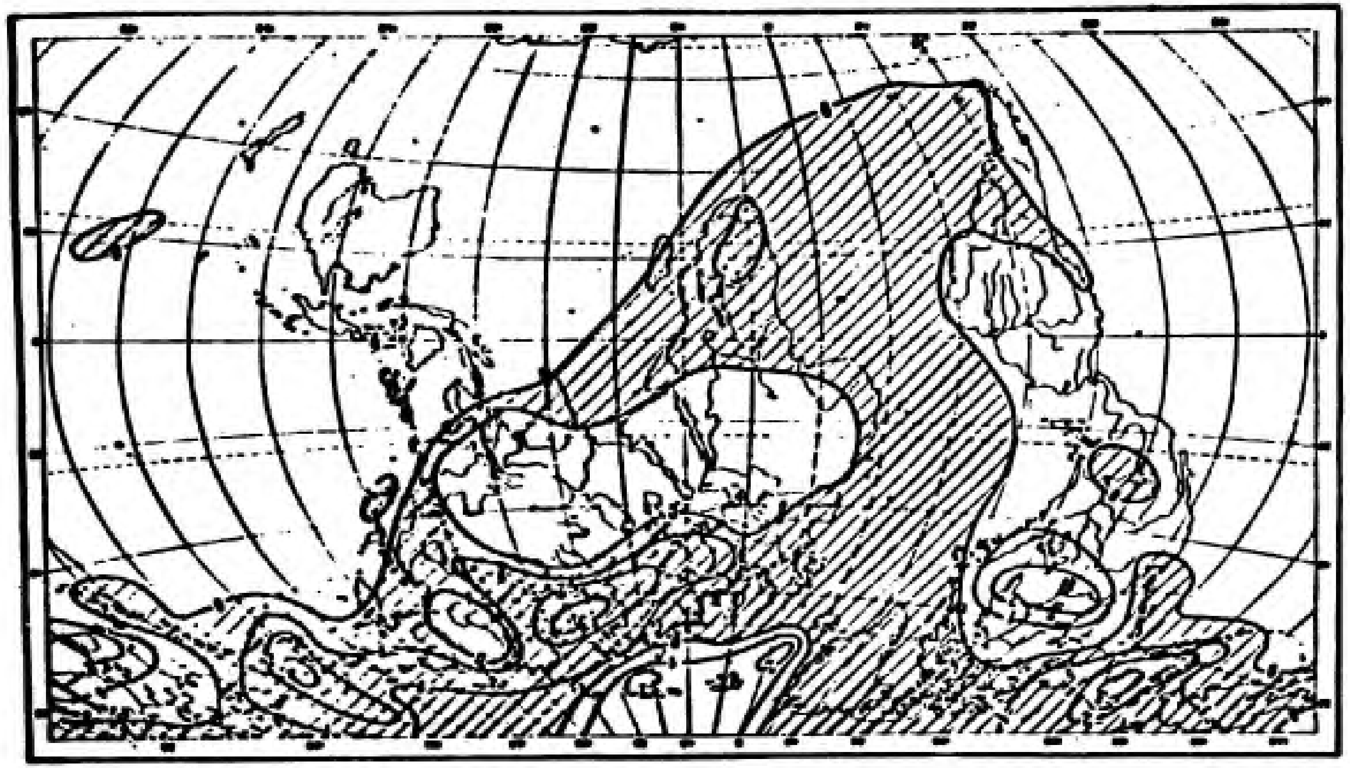

Fig. 92. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. February.

Fig. 93. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. March.

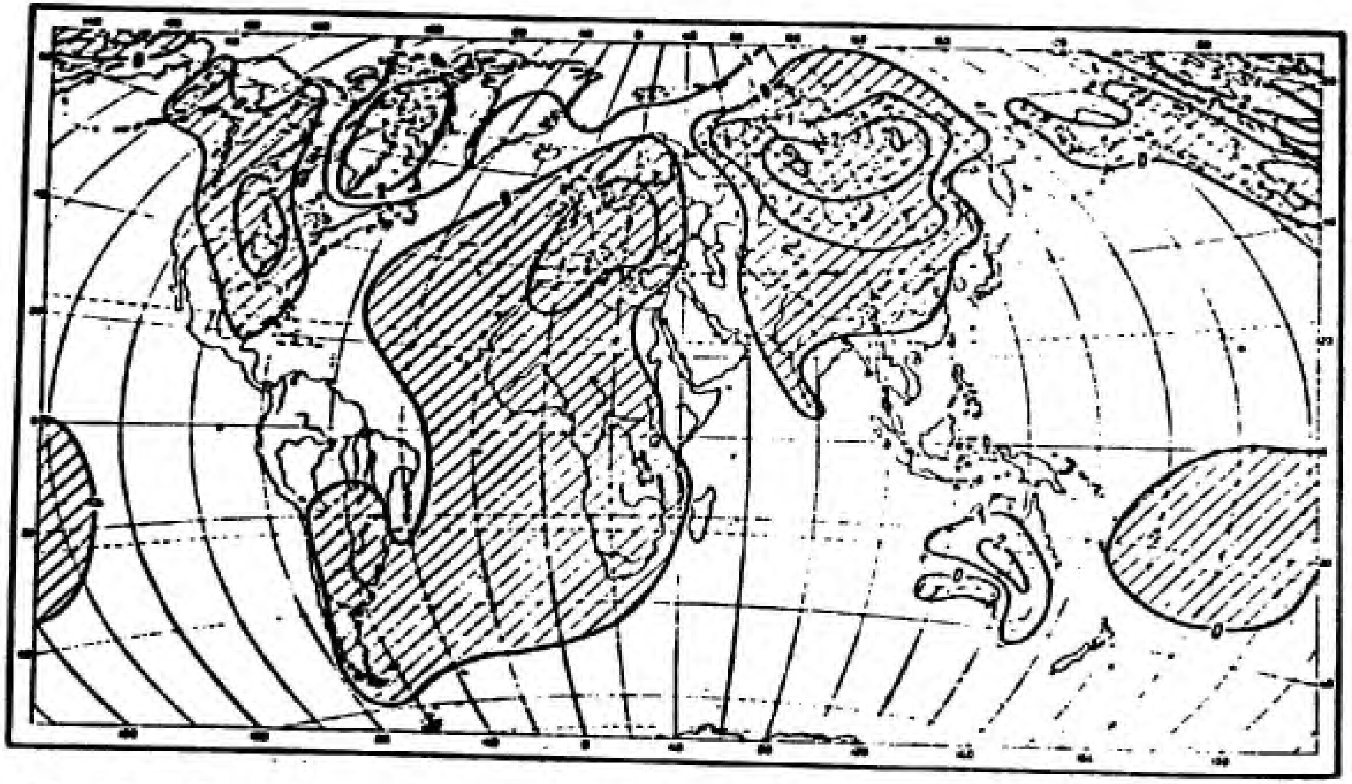

Fig. 94. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. April.

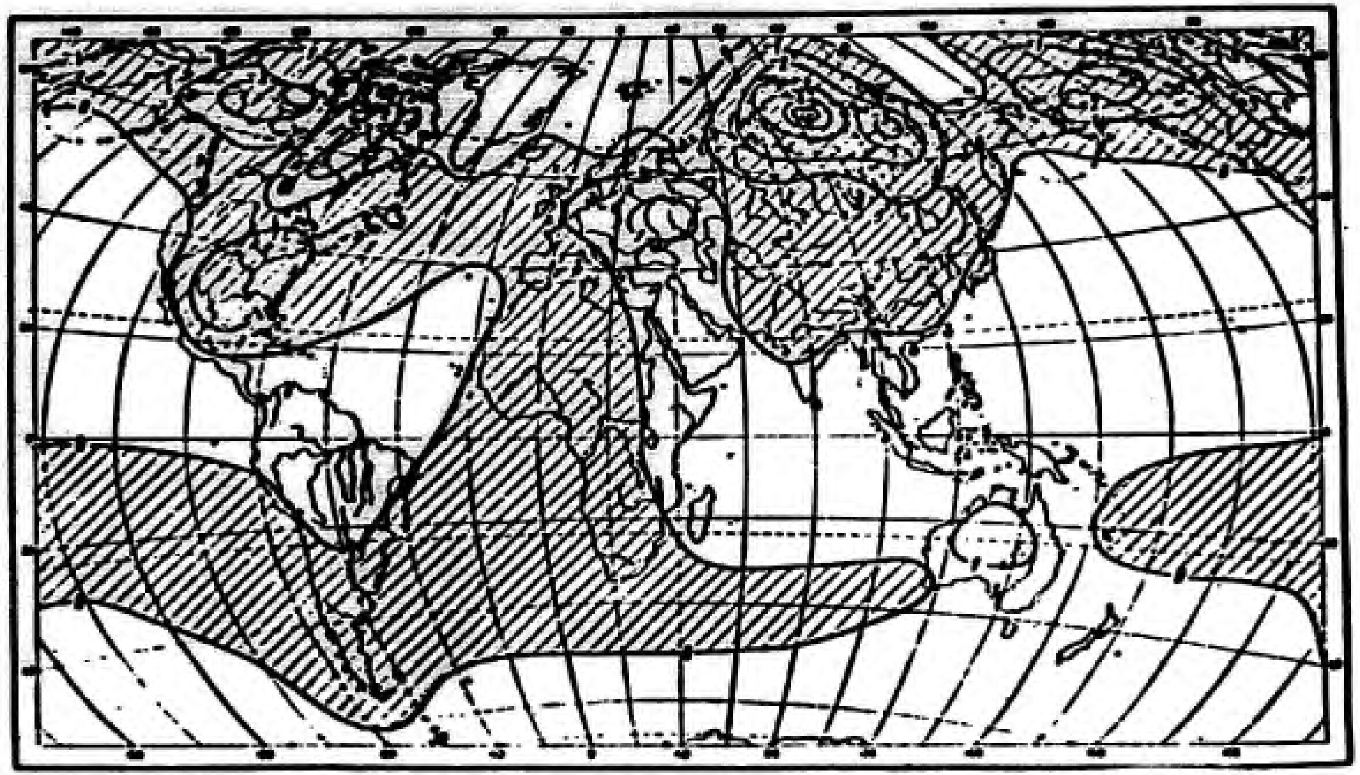

Fig. 95. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. October.

Fig. 96. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. November.

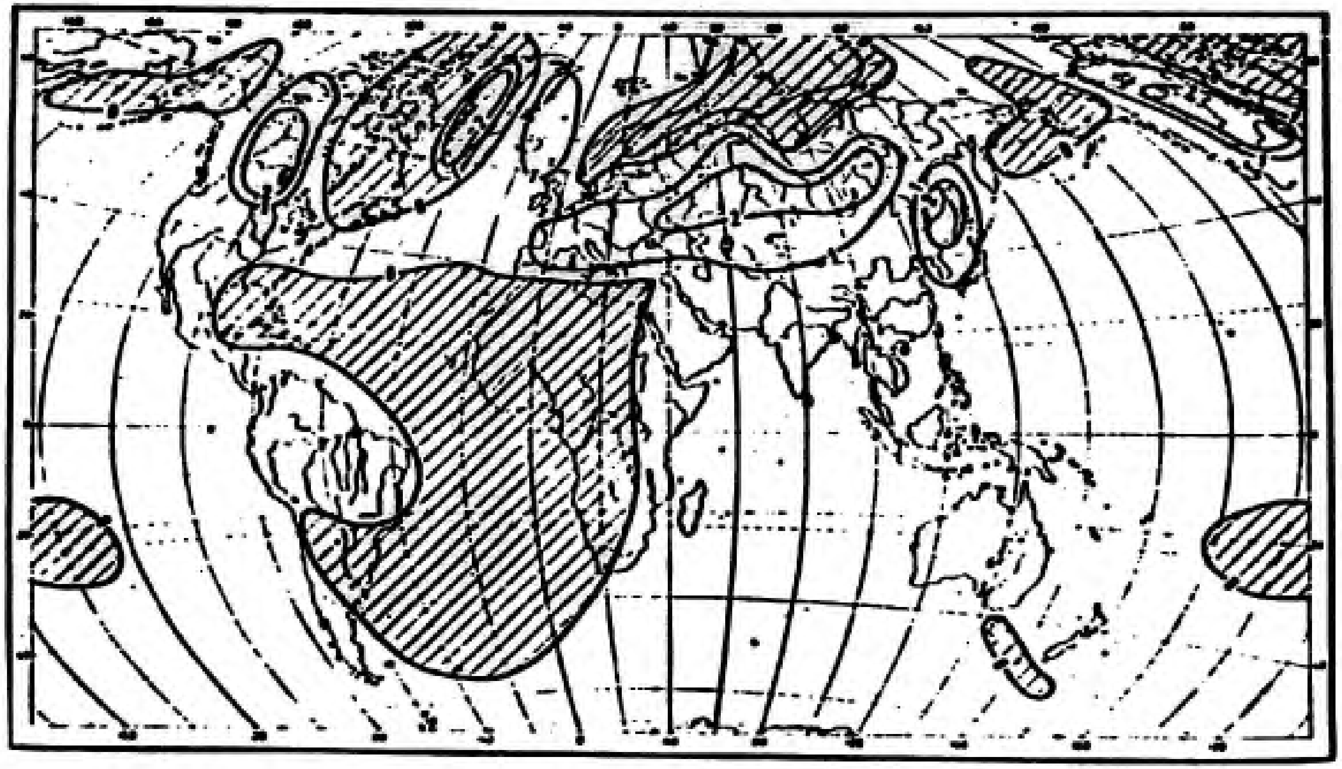

Fig. 97. Differences in temperatures for the 10-year periods 1951 to 1960 and 1941-1950. December.

Maps of mean annual temperatures are also of interest but differences in annual temperatures are usually less than diff. in mean monthly temperatures, and therefore with their calculation there is need of the appropriate accuracy. Schematic maps of differences in temperatures for the periods 1930-1939 and 1881-1890 and also differences for the periods 1951-1960 and 1930-1939 are given in Chapter III.

It is well-known that Mitchell (1963) also constructed a map of differences in temperatures almost for the same periods which are examined in this work, but they are not fully comparable with our maps, first, for the reason that Mitchell gives differences for the winter and not for each month separately; secondly, because his isolines are drawn every 1° F while ours are 1°C; and thirdly, periods for which differences are calculated are displaced one year. Furthermore, the construction of such maps represents a creative process, and every author puts into it his own individual approach.

Figures 84-97 pertain basically to the cold part of the year when, as is known, there was observed the greatest warming of the 1920's and 1930's. From differences for 20-year periods the conclusion can be made that in the majority of the examined months considerable expanses in the period 1941-1960 became colder then they did in the preceding 20-year period, but above the ocean, apparently, in the majority of the months the temperature did not decrease. Considering their large area and the insufficient knowledge of the temperature regime on oceans, it is difficult to give a final conclusion whether the atmosphere cooled above all the entire Earth as a whole. As was already noted earlier, zonal-integrated trends in the change in temperatures from the period 1890-1919 to the period 1920-1949 show a temperature rise from the first 30-year period to the second. However, the lowering of temperatures in the 1950's with respect to the 1940's, especially in oceans, can lead to a lowering of the value of zonal trends of a temperature rise and in certain zones of the sourthern hemisphere to a change in signs of these trends.

4. Trends of Further Change in Climate

Discussions about causes affecting the change of climate do not cease with the time of establishing this fact. Recently, a majority of the researchers no longer doubt the existence of the causal-effective relationship between variations in solar activity, the change in circulation of the atmosphere and ocean, and the climate, although the mechanism of this relationship has not been explained as yet.

Along with this one of the possible causes of the total planetary warming certain researchers (Callendar, 1938, 1961; Plass, 1959) consider to be the increase of in content of carbon dioxide in the atmosphere and heat from energy produced by humanity. According to their calculations during the last 100 years the total planetary temperature was increased 0.5°; if the burning of fuel continues at the same intensity, then by 2000 the mean planetary temperature will be increased 2° (with respect to the middle of the

19th Century).

Budyko (1962) calculated that the relationship between radiation balance for the whole surface of Earth and quantity of produced energy is 49:0.02. If the yearly increase in production of energy on Earth reaches 10%, then the total amount of it will exceed the value of the radiation balance earlier than every 100 years, and then solar radiation no longer will be the main climate-generating factor; the main source of heat on the earth's surface will become energy produced in the process of the activity of humanity.

The assumed increase in content of carbon dioxide in the atmosphere, according to considerations of Krauss (1960), in the beginning will cause warming and an increase in aridity and later an increase in humidity and decrease in turbulence of the atmosphere, which will cause the formation of smoky fog ("smog") similar to that which is sometimes observed in the region of London. Serious criticism and proof of uncertanties in the theory of variations in climate under the influence of variations of the content of carbon dioxide in the atmosphere are given Möller (1953). He showed that a change in the CO_2 content should not absolutely cause a change in temperature, since it can be compensated by other factors. For example, an increase in radiation balance under the effect of the increase in concentration of CO_2 by 10% can be completely compensated by a change in the content of steam by 3% or cloudiness of 1%, which does not emerge beyond the limits of errors of measurements of these values.

The insignificant influence of the increase in the atmosphere of the CO_2 content on the change in temperature is indicated by the diverse directivity of trends of the variation in temperature even in adjacent months, as can be seen from the figures of Chapter III.

However, it is impossible not to consider the possibility of further and more intense growth in the atmosphere of the content of carbon dioxide. In order to estimate the degree of its influence on the increase of the total planetary temperature and to provide a comparison of data, exact quantitative measurements of the CO_2 content in air are needed which would be produced by standard instruments and methods. Such observations were started during the International Geophysical Year (IGY) in (1960) Kessling.

Certain researchers, being based on empirically established relationships of the circulation of the atmosphere with secular variation of solar activity, make attempts of superlong-term prognostication.

L. A. Vitel's (1962), taking as a basis of the secular cyclic recurrence of solar activity and epochs established by him of simple anomalies of Wolf numbers, expressed considerations on the trend of future variations in solar activity and atmospheric processes connected with them. The expected transition to the epoch of lower solar activity (last three decades of the current century) will be characterized by conditions of atmospheric circulation closer to the epoch prior to the warming of the Arctic, i.e., considerable weakening of the total circulation of the atmosphere will be observed, main routes of cyclones will be displaced to the south, the power of Arctic intrusions will be increased, and there will be an increase in ice cover of the Arctic Seas. In connection with this the continentality of the climate of Europe and Western Siberia will be increased, and the temperature of winter months will drop.

Gris (1963), in generalizing the results of his former investigations and present work, considered it possible to formulate the following prognostic considerations. The connection between secular and 11-year cycles of solar activity, on the one hand, and variations in atmospheric circulation, on the other, permits assuming that in the next 30-40 years (branch of thd drop of the secular cycle) the recurrence of processes of the western form of circulation (increase in zonality) will exceed the norm, i.e., there will be observed a weakening in the interlatitudinal exchange, an increase in contrasts between high and low latitudes, and a temperature drop in the high and moderate latitudes.

Considering the influence of the branch of the growth of the 11-year cycle of solar activity, it is possible to expect that from 1965 to 1970 the recurrence of processes of zonal circulation is somewhat decreased, and on the branch of the drop in the 11-year cycle in the period of 1970-1976 the zonal circulation should be activated.

In the work of Maksimov and Smirnov (1965) there is given a long-term forecast of variations of basic forms of atmospheric circulation (after Vangengeym and Girs) for the Atlantic and Pacific Ocean sectors of the northern hemisphere for the forthcoming 10-year period (to 1976). For the formulation of prognositc equations the authors used results of harmonic analysis of perennial (1900-1960) indices of the circulation of the atmosphere. The change in the number of days with a certain type of circulation was determined taking into account the influence of variations in solar activity (11 and 80-year cycles), long-period lunar tide in the ocean (19-year cycle) and the position of the pole of rotation of Earth (7-year cycle).

The equations formulated are used by the authors for the determination of indices of circulation (annual recurrence of types of circulation) for the whole period of observations and for the subsequent 15 years. The observed data calculated by them on dependent material will agree quite satisfactorily (coefficient of correlation is 0.61-0.84), but the authors correctly note that the data predicted by them cannot give such good connection with independent values.

On this basis the authors prognosticate recurrence of forms of circulation in the Atlantic and Pacific Ocean sectors, detailing peculiarities of the course of every type for periods 1965-1967, 1968-1973, 1974-1976 and even for 1982-1987. In this last period a deep minimum of meridional circulation is expected, which should lead to a "sharp accentuation of the continentality of the climate in the Atlantic zone of the Earth".

Analogous treatment of consequences of the change of circulation in other periods is not given.

Authors of the given article correctly note that the good similarity of curves (obtained by them) of observed values and calculated (on the basis of the same series) still does not guarantee success of the forecast of the basic forms of circulation; however, considering the inertness of the wave processes, they count on the satisfactory accuracy of the forecast.

Rodwal'd (1958) predicts warming by examining the contemporary warming as a return to normal climatic conditions, i.e., to the warmer climate of the early Middle Ages. Assuming that the phase of recession of glaciers (in 1850-year cycle) of the Earth started at the end of the 18th Century, Shnitnikov expects that during the next 14-15 centuries the retreating of glaciers will continue, and this is connected with the increase in the total planetary temperature.

Thus till now there has been no single opinion about the forthcoming changes of climate. This is understandable because the role of different factors causing variations in circulation of the atmosphere and climate too is little known to us, and the mechanism of influence on the atmosphere of external factors is unknown. Hence there is impossibility of physically founded forecasts of circulation characteristics. All contemporary attempts of superlong-term prognostication, essentially, are the bases in the extrapolation of empirically set connections with solar activity. In reality the course of atmospheric processes differs by the nonstationarity: a certain cyclic recurrence can be observed during some period, then it can vanish or change the wavelength. Therefore, it is difficult to anticipate when cyclical variations will appear or will cease and how long they will continue.

From the preceding account it is clear that the superlong-term forecasts of Vitel's, Girs, and Maksimov for several decades or even several years are based on forecast of the character of the atmospheric circulation, which in turn is based on the relationship of the circulation with solar activity. In Chapters IV and V it was established that the change in air temperature indeed to a considerable degree is connected with different indices of circulation and solar activity; however, the mechanism of these relationships is complicated and, furthermore, on the course of temperature is affected by other factors.

As a result the course of even 10-year mean temperatures is not always linked well with the course of indices of circulation, just as the course of the 5-year mean with the course of solar activity. It is all the more difficult to expect that the forecast of temperature for 3-5 years, founded on the forecast of circulation, will be more or less satisfactory.

Considering the nonstationary character of atmospheric processes leading to perennial variations in temperature, we do not risk using in the determination of the trend in further variation in temperature connections the revealed at present of it with the character of circulation and variations in solar activity.

On the basis of that said above we will try, not arriving at any hypotheses, to give certain considerations about the course of temperature in the next several decades.

Until now the change in the variation in temperature by 10-year moving mean monthly temperatures was analyzed. This permitted revealing the presence of the change in temperature regime, monotonously directed or oscillatory with wavelengths of more than 10 years. It is important, however, to know the character of the trends, and in the case of a wave-like change in the curve to determine approximately the order of the wavelengths remaining with averaging for longer intervals of time. Figures 98-109 show the character of temperature curves with moving averaging by 35, 50 and 80 consecutive members of the series. The selection of stations whole temperatures are represented on these figures is done according to the following principle.

Moving 35-year mean temperatures are given for stations having a duration of a series of temperature of not less than 80-85 years, and only in regions little exposed in a meteorological respect were the series selected somewhat shorter. Moving 50-year series are given for stations with observations of more than 100 years, and 80-year series – more 200 years. Series were used which were as uniform as possible or with ocrrections excluding heterogeneity.

Given on Figs. 98-102 is the course of the 35-year moving mean temperatures for all months of the year and as an average for year for stations with a very long series of observations (Leningrad, New Haven, Barnaul) and for stations Upernavik and Salekhard having observations of 80-85 years but differing by very great changes in temperature – record-breaking in a planetary scale.

On Figs. 103-106 there are given 35-year moving mean temperatures for a series of stations only for certain months of year and as an average for the year, since it was inexpedient to analyze 35-year mean temperatures for those months for which the 10-year moving means were already stable.

Let us turn to an analysis of the course of moving mean temperatures. According to the character of the course of 35-year moving means in <u>January</u>, the stations are divided into four groups.

The first group is Upernavik and Salekhard. Characteristic for them is a sharp increase in temperature from the beginning to the end of the period. In the period of 1882-1916 the mean temperature of January in Upernavik was -22.5°, and in the period of 1926-1960 only -17°; in Salekhard it was during 1882-1916 -25.5° and during 1923-1957 -21.8° respectively.

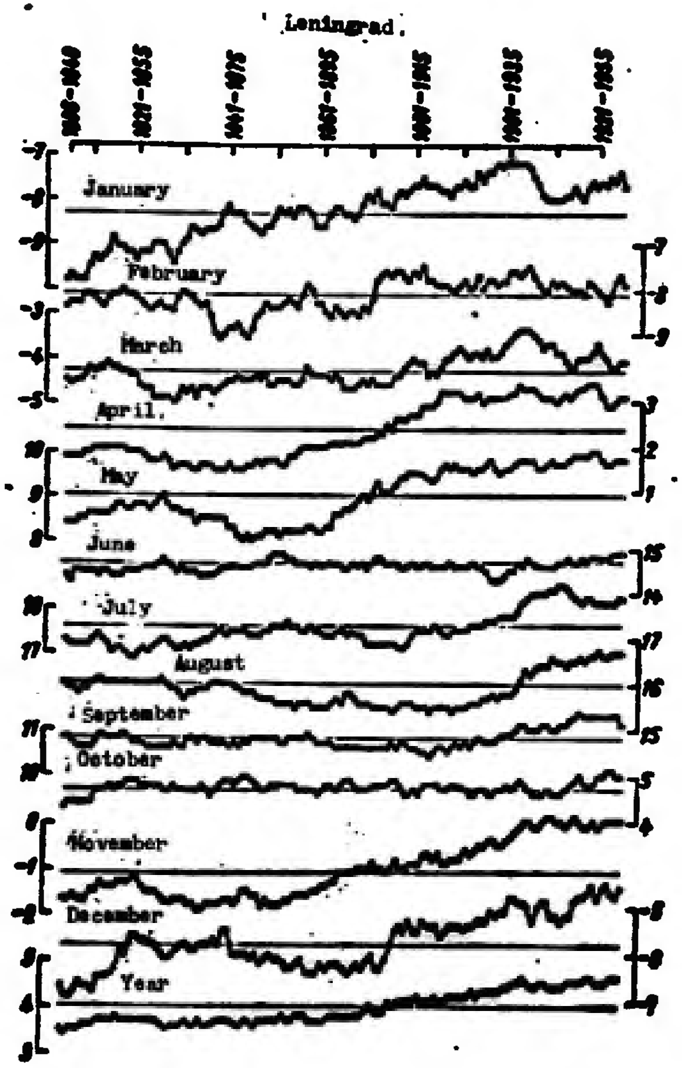

Fig. 98. Moving 35-year mean temperatures. Leningrad.

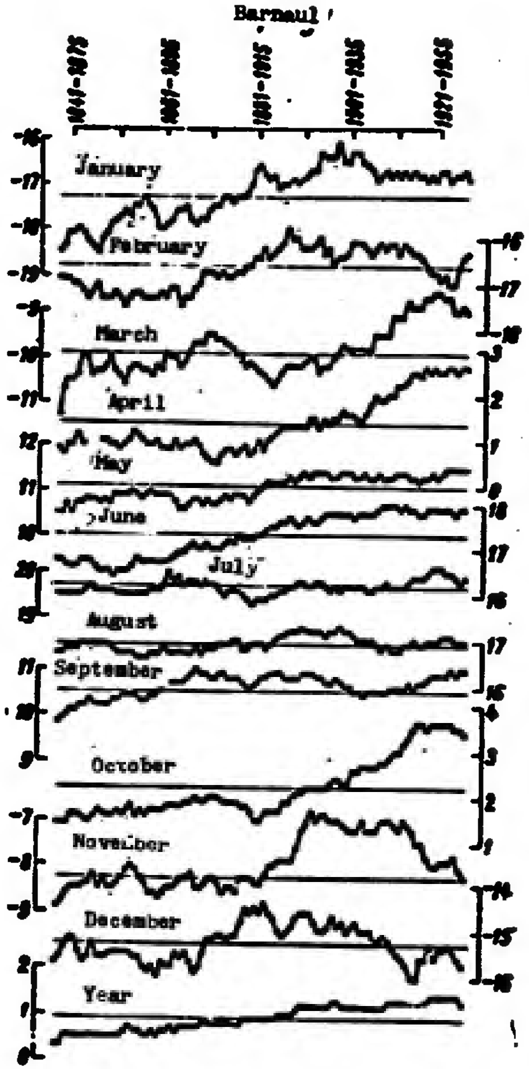

Fig. 99. Moving 35-year mean temperatures. Barnaul.

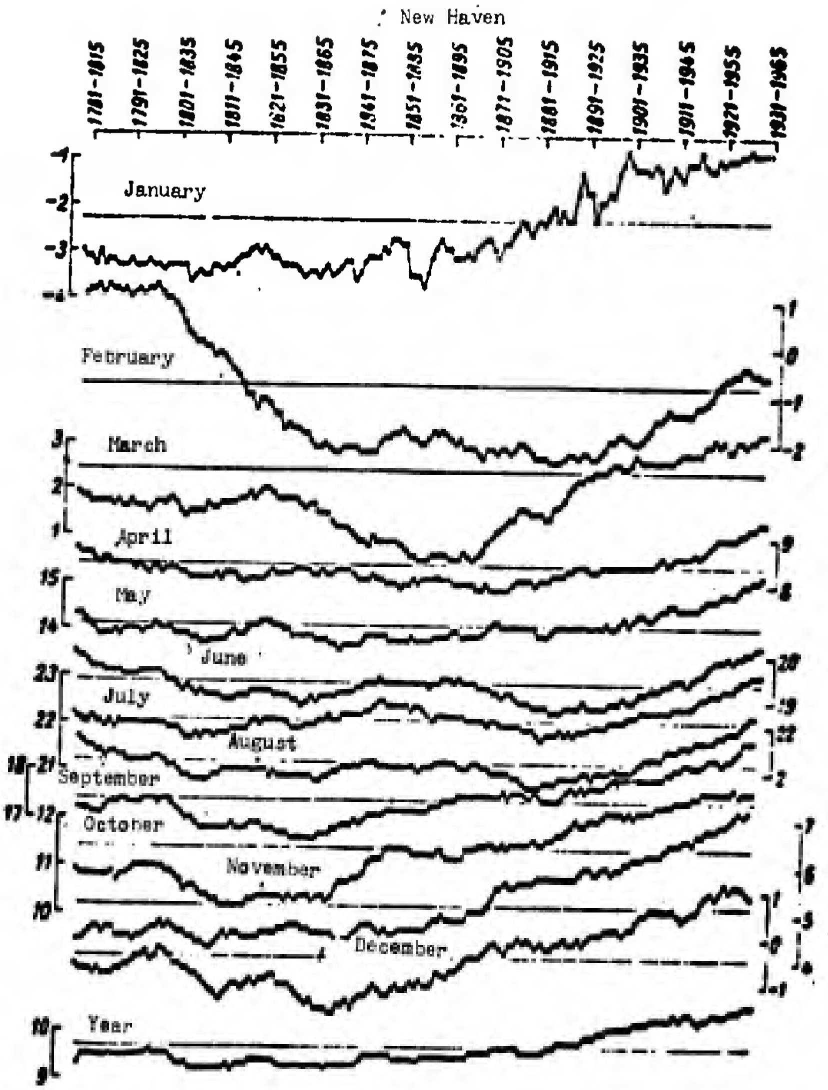

Fig. 100. Sliding 35-summer average temperatures. New Haven.

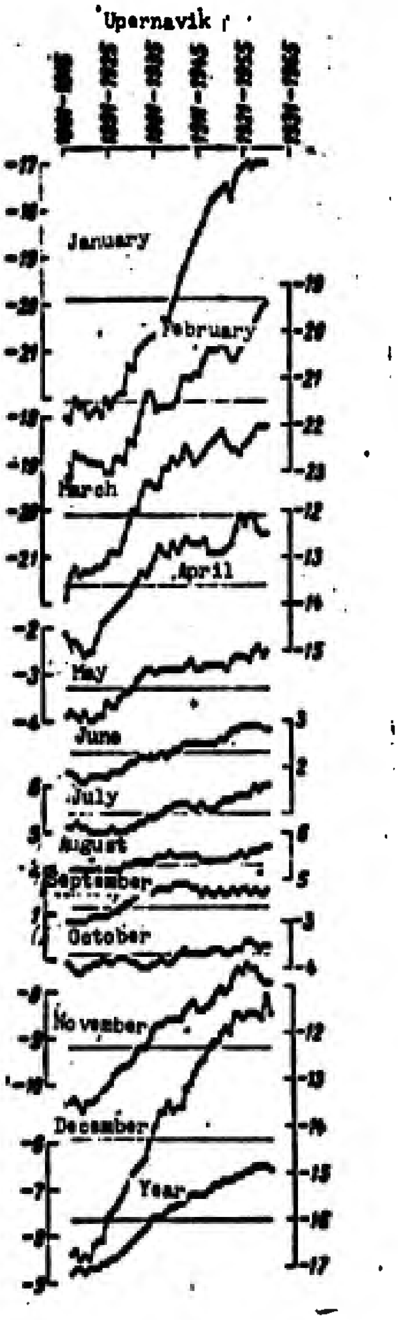

Fig. 101. Moving 35-year mean temperatures. Upernavik.

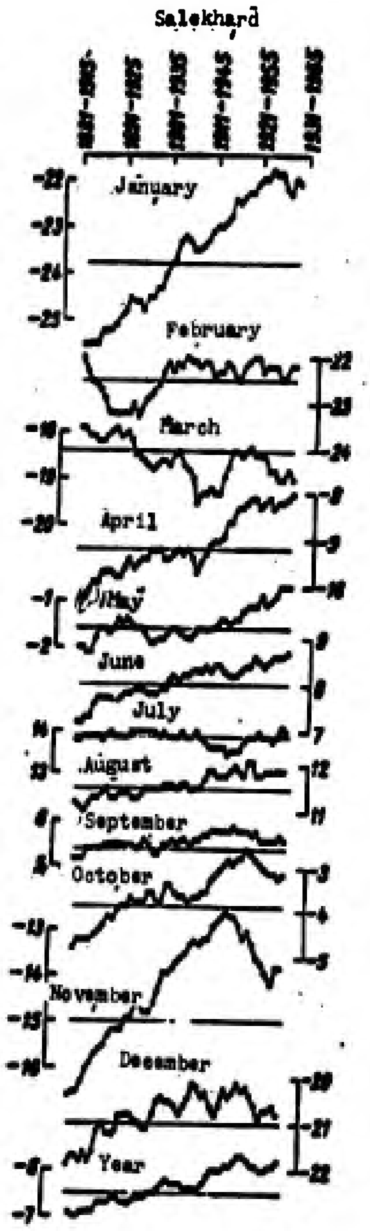

Fig. 102. Moving 35-year mean temperatures. Salekhard.

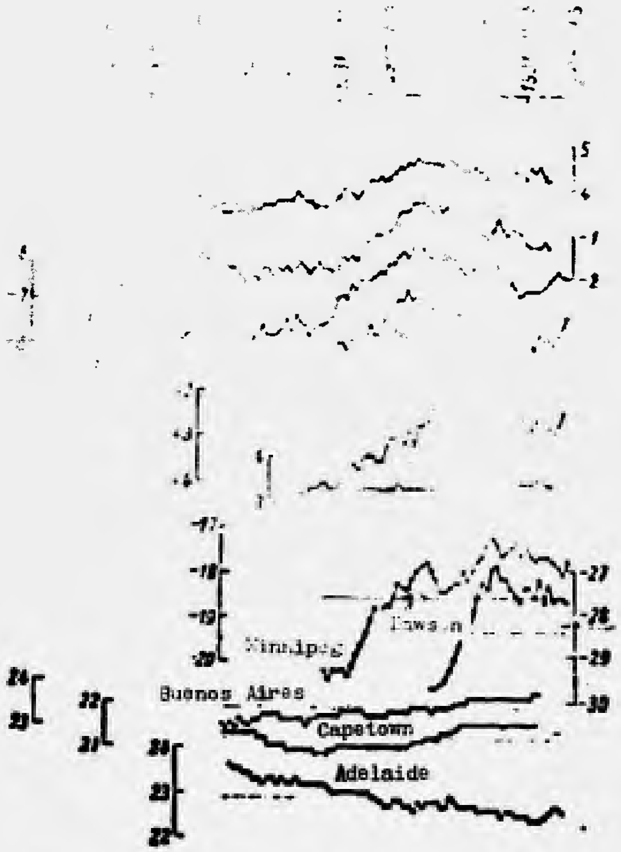

Fig. 103. Moving 35-year mean temperatures. January.

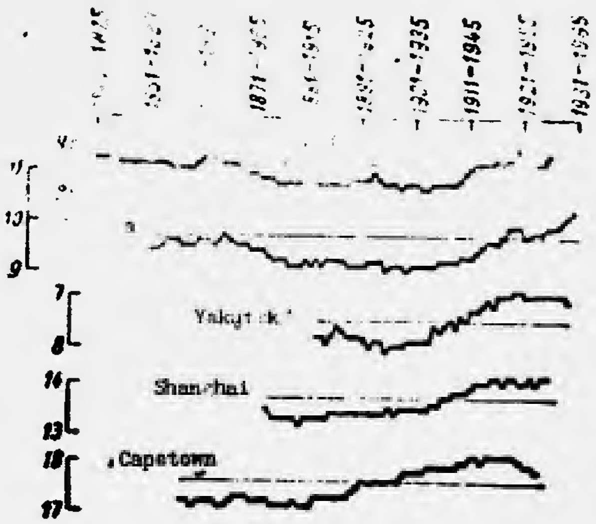

Fig. 104. Moving 35-year mean temperatures. April.

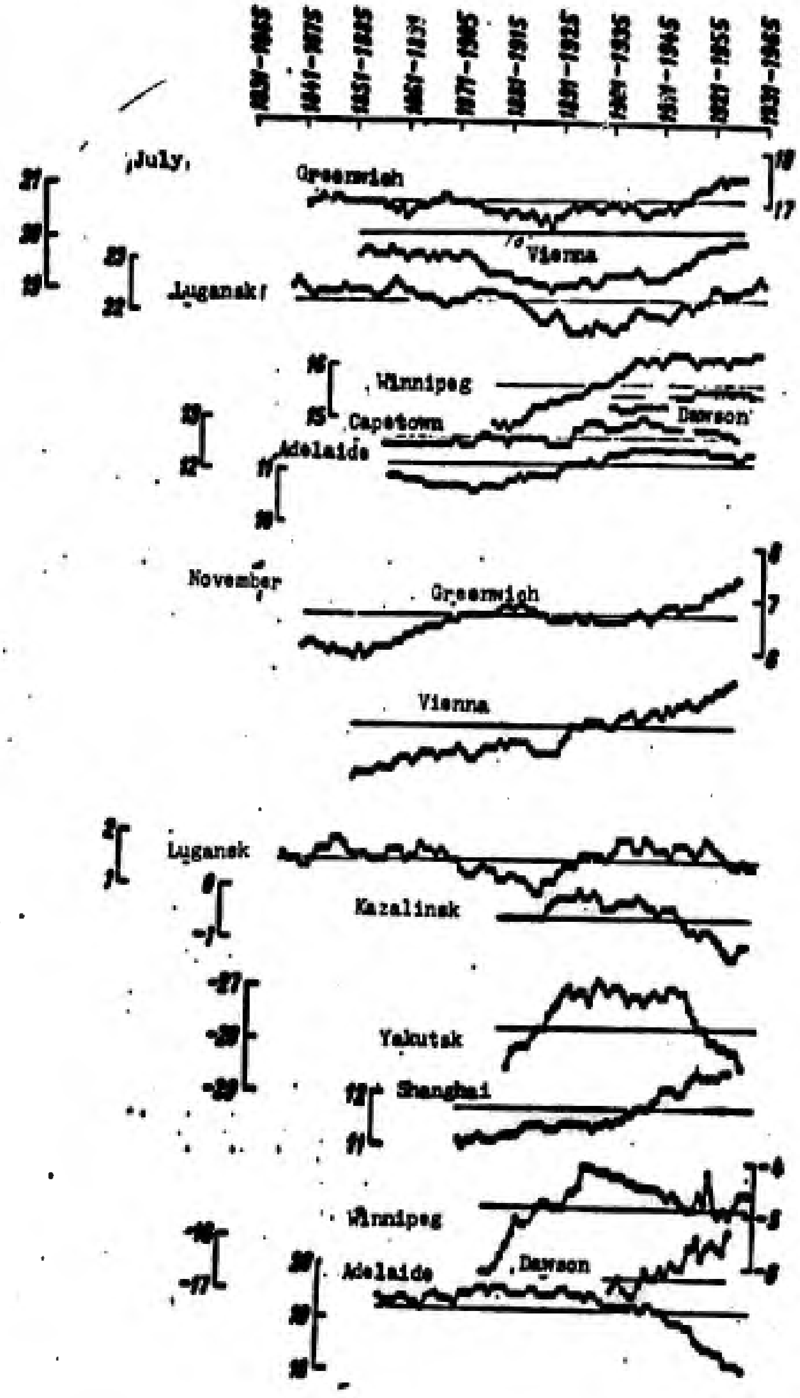

Fig. 105. Moving 35-year mean temperatures. July, November.

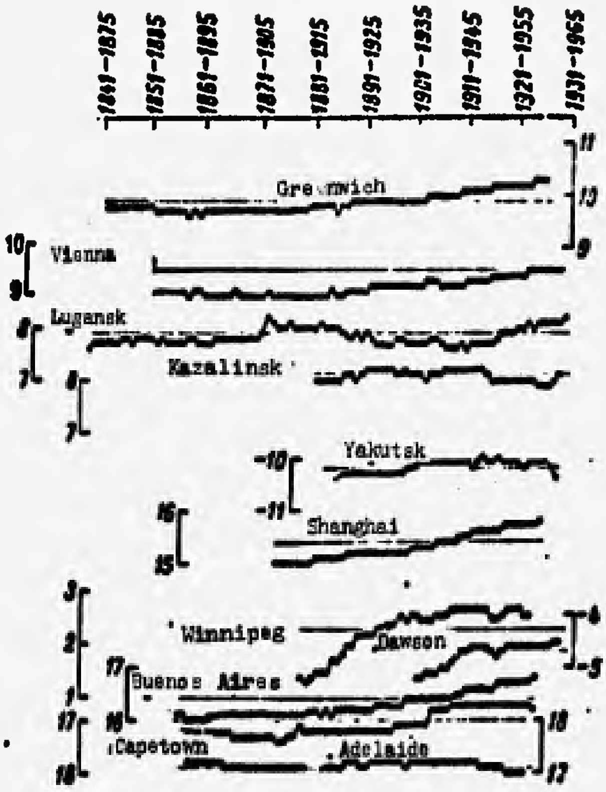

Fig. 106. Moving 35-year mean temperatures. Year.

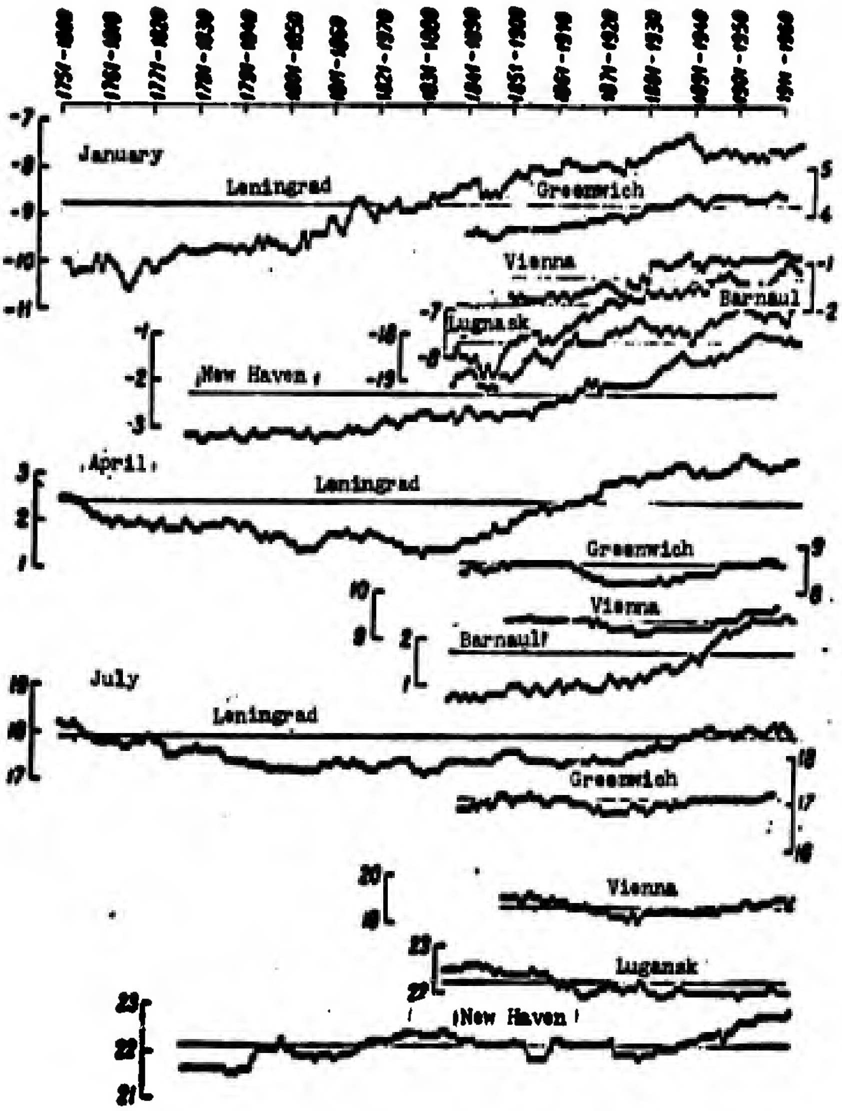

Fig. 107. Moving 50-year mean temperatures. January, April, July.

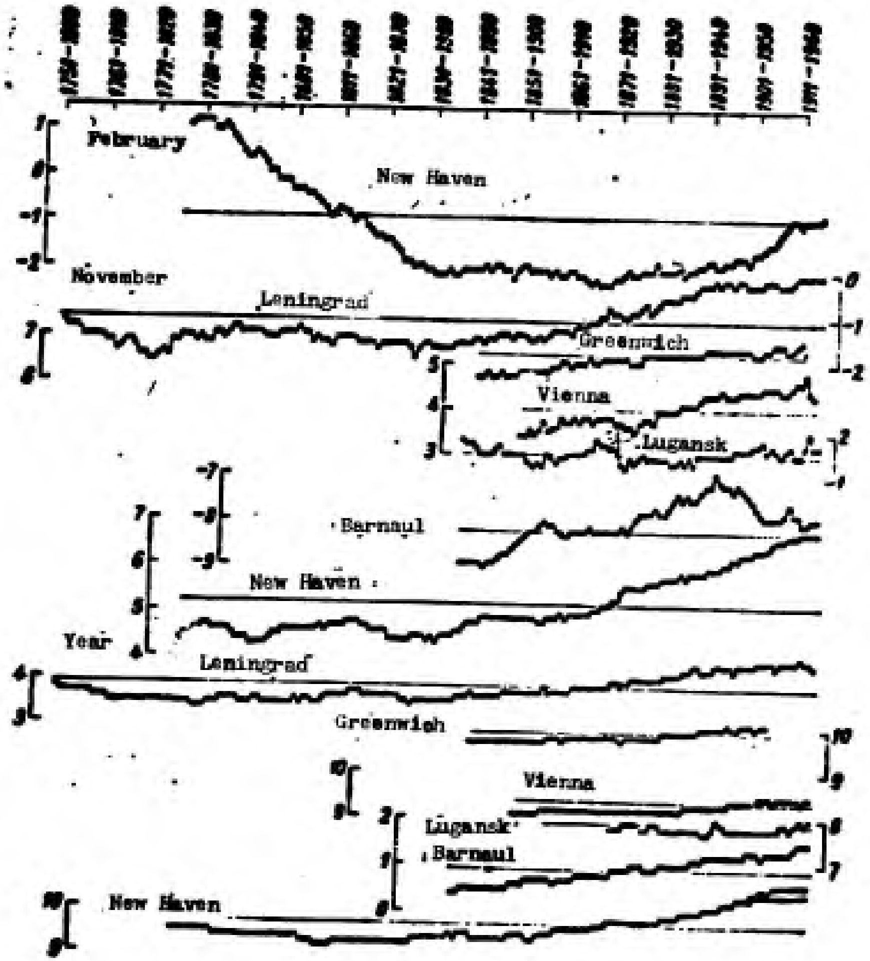

Fig. 108. Moving 50-year mean temperatures. February, November, year.

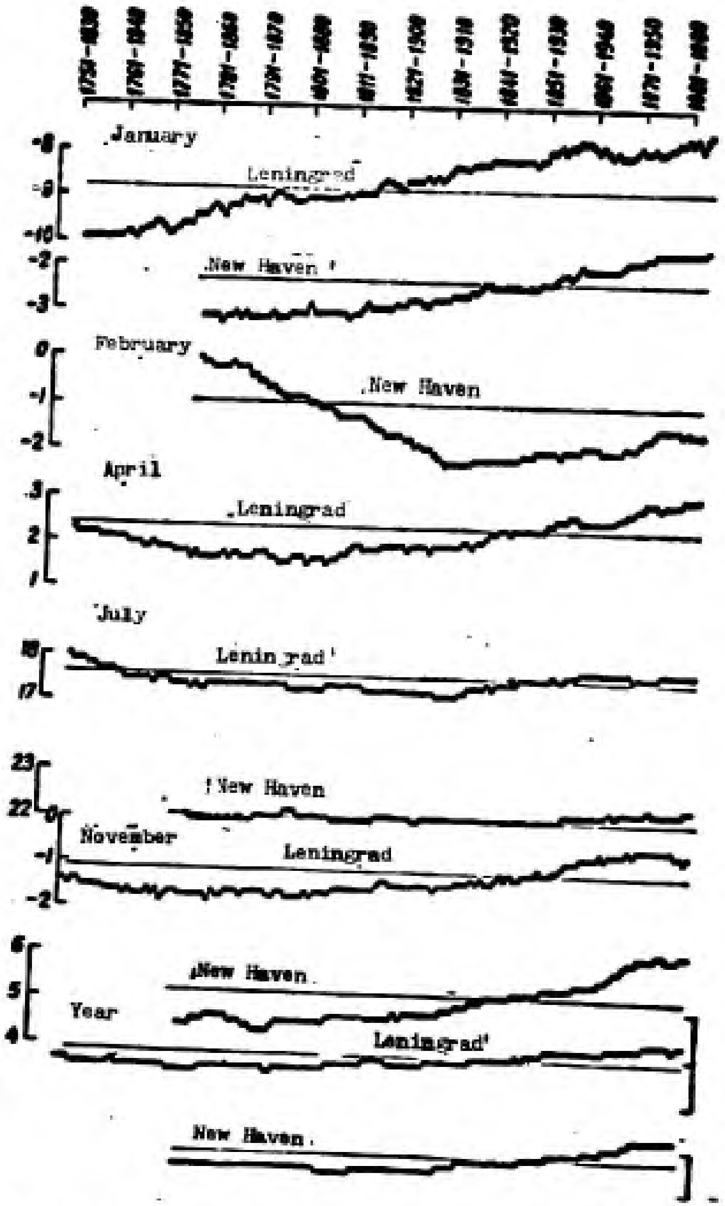

Fig. 109. Moving 80-year mean temperatures. Leningrad. New Haven.

To the second group can belong a series of stations of the moderate zone located in Europe, Asia and America. In it are included the stations Leningrad, Greenwich, Vienna, Lugansk, Barnaul, Yakutsk, New Haven, Winnipeg and Dawson. For them an increase in temperature in the second part of the period as compared to the first is characteristic, and, although toward the end of the period there is observed a certain lowering of the temperature; nevertheless, it remains higher than the perennial mean temperature. Thus, for example, in Leningrad the mean temperature of January for the period 1752-1786 was -10.5°, in the period of 1904-1938 it was -7.1°, and from 1930 to 1965, -7.2°. In Barnaul in the period of 1846-1880 the temperature of January was equal to -19.5°, in the period 1898-1932, -17.6°, in the period 1930-1964, -17.8°. Kazalinsk does not quite belong to this group of stations, since after the increase in temperature in the middle of the series of observations the temperature again drops and at the end of the period it is the same as it was in the beginning.

The third group consists of stations located in comparatively low latitudes of the northern and southern hemispheres, Shanghai, Buenos Aires, Capetown, which with general stability of the means have a trend toward the increase in temperature toward the end of the period. Opposite as compared to this, the course of temperature with the lowering of the temperature toward the end of the period is observed in Australia, in Adelaide, which one should refer to the fourth group; such a course in temperature is typical for greater part of Australia.

In February, just as in January, the temperature of Upernavika is sharply increased rom the beginning to the end of the period, but in New Haven and Yakutsk the course of temperature is basically opposite to the course of it in January, i.e., toward the end of the period of temperature it is lower than in the beginning of it. In Adelaide in February, as in January, a decrease in temperature toward the end of the period is observed.[1]

In April there is basically noticed the same trend toward an increase in temperature as in January. Only in Winnipeg and Adelaide, judging by the moving 10-year mean (see Chapter III), is the trend toward a decrease in temperature noticable.

In July all stations, including Adelaide, show an increase in temperature.

In November in Leningrad, Greenwich, Vienna, Shanghai, and New Haven, one can see a considerable increase in temperature toward the end of the period. The other group of stations — Kazalinsk, Barnaul, Yakutsk, Winnipeg, Adelaide — is characterized by a decrease in temperature toward the end of the period.

On the average for the year the temperature at a series of stations was basically increased. The exception includes the stations Lungansk, Kazalinsk, Yakutsk and Adelaide, where the 35-year mean annual temperatures during the whole period of observations are almost constant.

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[1] Data are not represented for February in Yakutsk and Adelaide on the graph.

At first glance it can appear that stations characterized by an analogous course in temperature are located unsystematically. It is necessary, however, to remember that they are representatives of large territories inside which the course of temperature is well correlated.

Examination of Figs. 98-106 leads to the conclusion that in vast areas of the Earth trends toward the increase in temperature are observed: apparently, cycles of variations with a wavelength of more than 35 years exist. Hence it appears necessary to trace the course of the moving 50 and 80-year mean temperatures for specially long series of observations. From Figs. 107-109 it is clear that in January, April, November and on the average for the year in Leningrad there is revealed the clearly expressed trend toward an increase in the 50 and 80-year mean temperatures. Let us show for its characteristics that the 80-year mean temperature of January in the period 1752-1831 was -9.9°, and in the period 1885 to 1964, only -7.5°. In July the lowest 50 and 80-year mean temperatures were observed in the middle of the 19th Century and the highest, in the beginning and at the end of the whole period of observations, but the difference in temperatures in the period of the highest mean values is considerably less than it is in winter. In New Haven in January, November and on the average for the year the course of 50 and 80-year mean temperatures is the same as that in Leningrad, i.e., there is a trend toward the increase in temperature.

Besides the course of temperature in Leningrad and New Haven characterized above, it is possible to note peculiarities of the change in temperature and at other stations. Thus in January there is seen a trend toward an increase in 50-year mean temperatures in Lugansk, Barnaul, Greenwich and Vienna and in Barnaul also in April. In July in Lugansk the 50-year mean temperatures have a trend toward lowering, and in November they are stabilized near the perennial mean.

On the average for the year 50-year temperatures in Lugansk are very stable, and in Barnaul they reveal a trend toward an increase, signaling the presence of temperature waves with a length of more than 50 years.

Figures 98-109 permit expressing certain considerations about the probable course of mean monthly temperatures of the next 35-year periods.

These considerations are given further for few stations, since by far not in all parts of the Earth are there long and, moreover, more or less uniform series of observations, especially in the wouthern hemisphere. At the same time it is necessary to consider that each of the stations for which there is given a tentative forecast of mean monthly temperatures for the next decade is characteristic for extensive regions, and everything said about mean temperatures of the next 35-year period pertains to regions whose borders can be judged according to Chapter III.

Leningrad. From Fig. 98 it is clear that 35-year mean temperatures in January, April, May, November and December, and also on the average for the year, at present have large positive deviations from the perennial (for the whole period of observations in Leningrad) mean, and there are no bases to expect that in the following 35-year period they will be lower than this mean.

In February, March, July, August and September it is possible to expect only small deviations from the perennial mean to either side. In June and October the 35-year mean temperatures are very stable; the temperature of the warmest and the coldest 35-year period for the whole period of observations were different only by 0.6-0.7°, and there is no basis to consider that subsequently there will be any considerable deviations from the perennial average.

Salekhard. At the present 35-year mean temperatures in January, April, October, November and on the average for the year are very high as compared to temperatures at the end of the last centruy (Fig. 102). Although in all the months shown except January in the last period there began a decrease in temperature, nevertheless, in the forthcoming 35-year period it is doubtful whether temperatures will fall lower than the perennial mean. In February and March the 35-year temperatures in the last decades are close to the perennial mean. In the future it is possible to expect either values of temperatures close to the perennial or below them.

In May, June, August and September the 35-year temperatures will, apparently, insignificantly vary near the mean perennial to either side, and it is possible to expect a lowering of the temperatures lower than the perennial in December. The stablest with respect to temperature by month is July, when the temperature of the warmest and the coldest 35-year periods were different by only 0.5°. From these limits there will not emerge, apparently, and the mean temperature of the next 35-year period.

Barnaul. Figure 99 shows that almost in all months the 35-year mean temperatures have recently held at a level higher than that of the perennial mean, but the value of the excess of this mean and peculiarities of the course of the curve are unequal. In January, May June and on the average for the year stabilization of mean temperatures at a level somewhat exceeding the mean perennial is seen. In these months it is possible to expect with identical probability both a small increase and a decrease down to the perennial mean and even somewhat lower than it. In March, April and October the positive deviation of the 35-year mean from the perennial value is very considerable, and in these months in the forthcoming 35-year period temperatures, apparently, will remain higher than those of the perennial mean. In February, September and December it is possible to expect relatively small fluctuations on both sides with respect to the perennial mean. In July and August the 35-year means are very stable and will remain the same in the future. Temperatures of November have a unique course; at present the 35-year means are close to the perennial value, and there is base to assume that subsequently the temperatures will drop.

From foreign stations let us analyze temperatures of Upernavik and New Haven.

Upernavik. All months of the year and the mean annual temperature reveal a trend toward an increase in temperatures from the beginning of the period of observations to its end. Especially great is a temperature rise in winter – from November to April and on the average for the year. In these months there is hardly any doubt that in the nearest 35-year period the means will be higher than the perennial mean, even in the case when lowering of temperature proceeds at that same rate as does its increase in the 20th Century. In the period from May to October in the future insignificant variations in temperature on both sides of the perennial mean are possible.

New Haven. The course of 35-year temperatures in New Haven is characteristic in the respect that in all months of the year and on the average for the year in the 19th Century there is observed an increase in temperatures as compared to the second half of the 19th Century. Earlier than this time the temperatures are held lower than the perennial mean or near it. An exception is February, where in the beginning of period of observations the temperatures were very high. It can be expected that in those months in which temperatures at present are considerably higher than the perennial (January, March, October, November and December), the temperatures will hold at a higher level than that of the perennial mean, and in others months variations near this mean are possible.

The material examined permits making the conslusion concerning the existence in the course of the temperature of variations with a duration of more than 10, 35, 50 and even 80 years. The 80-90-year (secular) cycle (revealed by certain researchers) in the course of different natural phenomena, and, in particular, the recurrence of severe winters in Europe (Easton,[1] Köppen), does not appear in the course of the temperature (50-year moving mean). As can be seen from Figs. 98-109, in the great expanses of the Earth, in any case in the cold part of the year (northern hemisphere), according to the 35, 50 and 80-year mean, a temperature rise is observed. Frequently there are attempts to connect this with the growth of cities ("urbanization"). Undoubtedly, this plays a certain role in the increase in temperature, but this role is not considerable enough to cause the observed changes in temperature. Numerous investigations showed that with a correct location in a city of a station and with normal installation of the instruments, the temperature in the city exceeds the temperature of the surrounding terrain by approximately 0.5-1.0°. The surplus of heat to a considerable extent is carried out by local circulation beyond the city. But, as one can see from the material given in the present work, the order of observed changes in temperature is considerably greater. Furthermore, if the basic cause of temperature rise was

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[1] This name is unverified [Trans. Ed. Note].

"urbanization", then this would condition the analogous course of temperature in the adjacent months, which in fact is not observed. This shows that the influence of other factors (in the basic circulatory factors) exceeds the influence of the growth of cities.

It is impossible to forget the fact that the greatest changes in temperature in many cases are basically concentrated in the high latitudes where large cities are very few.

One should not assume, however, that in periods of warming all years are warm. It is possible to give as many examples as desired of great contrasts of temperatures in adjacent years. For example, in January in Leningrad, there was observed the following mean temperatures:

Year	1925	1926	1929	1930	1949	1950	1962	1963	1965	1966
t°	–0,5	–12,9	–10,3	–0,9	–2,2	–13,9	–3,2	–12,9	–5,3	–14,9

But the period of warming differs by a predominance of warm winters. The level of temperatures in cold winters in the period of warming was higher than that in the preceding century; thus in the coldest Januarys of this century in 1942 and 1966 the mean temperature was -18.7° and -14.9° respectively, and in 1809, 1814, 1861 and 1862, -18.6°; -21.4°; -17.5° and -17.3°. An analogous picture is observed in February and December, i.e., in all the winter months.

In conclusion one should note that during the last 20-25 years the investigation of the problem of the change in climate, in which scientists of a number of countries have been engated, has made considerable progress. But there is still much work ahead for the complete opening of the physical causes and mechanism of the relationship Sun — atmosphere — ocean — climate, since only in this case is it possible to look forward in giving a sufficiently founded superlong-term forecast of the change in climate.

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APPENDEX I

LIST AND MAP OF METEOROLOGICAL STATIONS WHOSE DATA ARE USED IN THE WORK

List of Meteorological Stations

North of 80° N. Lat.

1. Bukhta Tikhaya

80-70 N. Lat.

2. Barrow
3. Arctic Bay
4. Upernavik
5. Myggbukhta
6. Jan Mayen
7. Barentsburg
8. Varde
9. Malyye Karmakuly
10. Vaygach
11. Mys Zhelaniya
12. Dikson
13. Uyedineniya Island
14. Khatanga
15. Mys Chelyuskin
16. Kyusyur
17. Katel'nyy
18. Chetyrekhstobovoy Island
19. Wrangel Island

70-60 N. Lat.

20. Nome
21. Bethel
22. Tanana
23. Fairbanks
24. Valdez
25. Fort Yukon
26. Dawson
27. Aklavik
28. Fort Good Hope
29. Hay River
30. Chesterfied
31. Resolution
32. Gothob
33. Jakbskhavn
34. Ivigtut
35. Angmagsalik
36. Stikkisholmur
37. Grims Ey
38. Tórshavn
39. Trondheim
40. Skomver
41. Haparanda
42. Kola
43. Kem'
44. Arkhangel'sk
45. Troitsko-Pechorsk
46. Salekhard
47. Surgut
48. Tarko Sale
49. Turukhansk
50. Tura
51. Olekminsk
52. Vilyuysk
53. Zhigansk
54. Yakutsk
55. Verkhoyansk
56. Oymyakon
57. Srednekolymsk
58. Markov
59. Anadyr'
60. Uelen

60-50 N. Lat.

61. Dutch Harbor
62. Kodiak
63. Sitka
64. Masset
65. Barkerville
66. Edmonton
67. Prince Albert
68. Ou' Appel
69. Churchill
70. Fort Hope
71. Mussonee
72. Valencia
73. Edinburgh
74. Greenwich
75. Utrecht
76. Dublin
77. Mandal
78. Oslo
79. Copenhagen
80. Berlin
81. Uppsala
82. Riga
83. Vilnius
84. Minsk
85. Leningrad
86. Kiev
87. Bogoroditskoye-Fenino
88. Moscow
89. Tot'ma
90. Oktyabri'skiy Gorodok
91. Kazan
92. Kirov
93. Orenburg
94. Sverdlovsk
95. Tobol'sk
96. Barnaul
97. Tomsk
98. Yenisesk
99. Irkutsk
100. Kirensk
101. Nerchinskiy Zavod
102. Blagobeshchensk
103. Bomnak
104. Ayan
105. Nikolayevsk na Amure
106. Aleksandrovsk on Sakhalin Island
107. Okhotsk
108. Ust'-Khayryuzovo
109. Petropavlovsk-Kamchatskiy
110. Klychi
111. Nikol'skoye

50-40 N. Lat

112. Victoria
113. Winnemucca
114. Boise
115. Sheridan
116. Winnipeg
117. Omaha
118. Marquette
119. White River
120. Toronto
121. New York
122. Montreal
123. New Haven
124. Blue Hill
125. Eastport
126. Anticosti Island
127. Charlottetown
128. Sable
129. Saint Johns
130. Madrid
131. Nant
132. Paris
133. Marseille
134. Rome
135. Vienna
136. Zagreb
137. Belgrade
138. Sofia
139. Sulina
140. Odessa
141. Nikolayev
142. Sevastopol'
143. Samsun
144. Lugansk
145. Poti
146. Pyatigorsk
147. Tbilisi
148. Baku
149. Fort Shevchenko
150. Krasnovodsk
151. Kazalinsk
152. Kzyl Orda
153. Tashkent
154. Alma Ata
155. Vladivostok
156. Nemuro

40-30 N. Lat.

157. Los Angeles
158. San Diego
159. Yuma
160. El Pass

161. Amarillo
162. Ashville
163. Charleston
164. Hatteras
165. Saint George
166. Ponta Delgada
167. Funchal
168. Lisbon
169. Casablanca
170. Gibraltar
171. Palma
172. El'Goléa
173. Biskra
174. Alexandria
175. Nicosia
176. Beirut
177. Bayram Ali
178. Quetta
179. Lahore
180. Hank'ou
181. Tientsin
182. Shanghai
183. Nagasaki
184. Kagosima
185. Sakai
186. Kyoto
187. Niigata

30-20 N. Lat.

188. Mazatlan
189. Monterey
190. New Orleanss
191. Mérida
192. Key West
193. Aoulef
194. Helwân
195. Aswân
196. Bushehr
197. Allahabad
198. Calcutta
199. Chünhsien
200. Hong Kong
201. Tainan
202. Tayoki
203. Honolulu

20-10° N. Lat.

204. Mexico City
205. Port Au Prince
206. Caracas
207. San Juan
208. Trinidad
209. Kano
210. Khartoum
211. Aden
212. Bombay
213. Madras
214. Port Blair

10-0° N. Lat.

215. Georgetown
216. Freetown
217. Akkra
218. Logos
219. Bangui
220. Wau
221. Entebbe
222. Colombo

0-10° S. Lat.

223. Quixeramobim
224. Ascension (Ascension Island)
225. Port Gentil
226. Pointe Noire
227. Luanda
228. Nairobi
229. Port Victoria
230. Jakarta
231. Moreby
232. Funafuti

10-20° S. Lat.

233. Lima
234. Corumbá
235. Salvador
236. Maun
237. Salisbury
238. Beira
239. Tananarive
240. Darwin
241. Papeete
242. Suva
243. Apia

20-30° S. Lat.

244. La Quiaca
245. Goya
246. Rio de Janeiro
247. Windhock
248. Kimberley
249. Bulavayo
250. Durban
251. Onslow

252. Alice Springs
253. Brisbane
254. Nouméa
255. Raoul
256. Rarotonga

30-40° S. Lat.

257. Juan Fernandes
258. Santiago
259. Cordova
260. Buenos Aires
261. Mar del Plata
262. Capetown
263. Perth
264. Adelaide
265. Sitka
266. Auckland

40-50° S. Lat.

267. Sarmiento
268. Hobart
269. Dunedin
270. Wellington
271. Chatham Island

50-60° S. Lat.

272. Punta Arenas
273. Gritviken[1]
274. Campbell

60-70° S. Lat.

275. Orcadas

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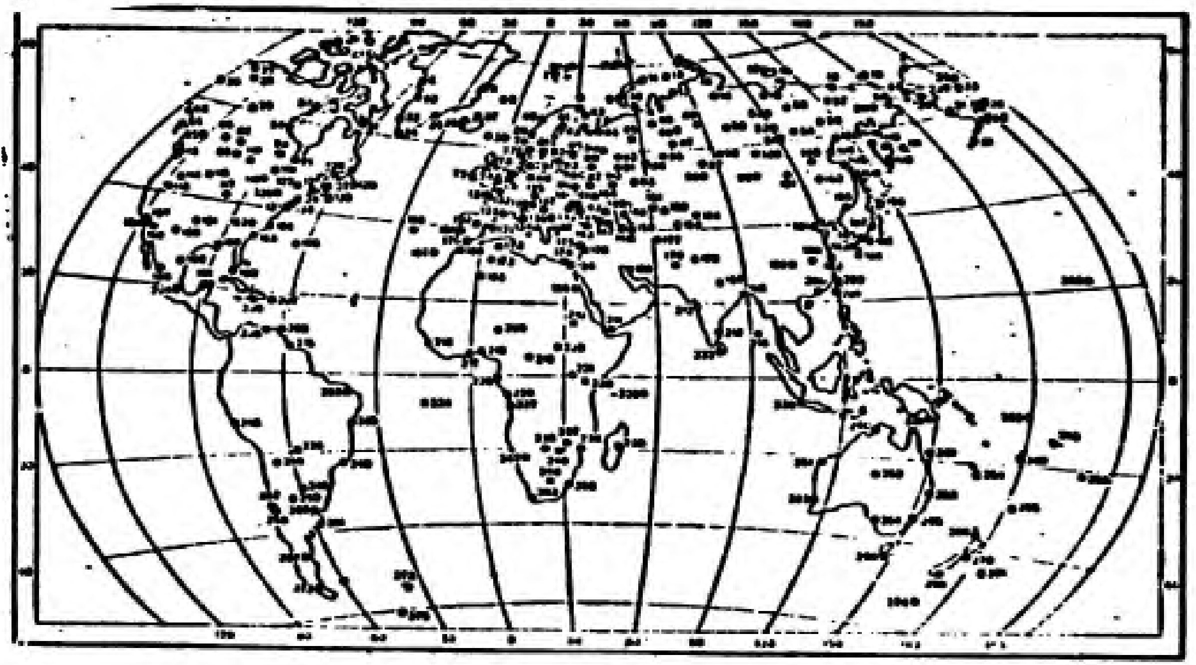
[1] This station (near South Georgia) is unverified [Trans. Ed. note].

Map of Meteorological Stations



U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.