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IMPACT OF CARBON DIOXIDE ON CLIMATE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 5-17

[Article by M. I. Budyko, corresponding member USSR Academy of Sciences, and N. A. Yefimova, doctor of geographical sciences, State Hydrological Institute, manuscript submitted 18 Aug 80]

[Text]

Abstract: A study was made of the dependence of climatic conditions on the concentration of atmospheric carbon dioxide on the basis of data on climates of the geological past. The change in the mean annual air temperature at the earth's surface with a doubled carbon dioxide concentration is estimated. Approximate data are given on the change in the quantity of precipitation on the land in the high and middle latitudes for these conditions.

The problem of the impact of atmospheric carbon dioxide on climate was studied in two cycles of investigations. The first of these was devoted to a clarification of the relationship between climatic changes in the geological past and variations in the CO_2 concentration in the atmosphere. Investigations in this direction were initiated late in the 19th century in studies by Arrhenius [14] and Chamberlin [22].

In the second cycle a study was made of the influence of an increase in the CO_2 concentration caused by man's economic activity on modern climate. These investigations, initiated in the 1930's by Callender [19], have now acquired great importance in relation to long-range anthropogenic changes in global climate.

Until recently the studies of these cycles were poorly tied in together, which limited the possibilities for clarifying the influence of carbon dioxide on climate. During recent years ways were found to make a joint study of the two problems [3, 6].

This paper gives materials on the impact of carbon dioxide on climate of the geological past, whose use makes it possible to clarify the patterns of modern changes in climate.

Sensitivity of climate. In a quantitative explanation of climatic changes it is necessary to know its sensitivity to variations in external climate-forming factors. In particular, for an explanation of the dependence of climate on the atmospheric CO_2 concentration it is necessary to evaluate the sensitivity of climate to changes in the heat influx caused by variations of atmospheric transparency for long-wave radiation.

Until recently in determining the sensitivity of climate use was made primarily of computations with models of the theory of climate. Since all existing climatic models contain different simplifications, the accuracy of such computations has remained unclear, as a result of which the conclusion is sometimes drawn that there are no adequately reliable evaluations of the sensitivity of climate to changes in the heat influx.

During recent years considerable progress has been attained in this field as a result of the use of a series of empirical methods for evaluating the sensitivity of climate to changes in the heat influx, based on the use of data on changes in climate in the geological past, on modern changes in climate and on seasonal changes in the meteorological regime. All these different and completely independent approaches give close results in evaluating the parameters characterizing the sensitivity of climate. These results agree well with data from computations of sensitivity using models of the theory of climate, including detailed models of general circulation of the atmosphere and schematic energy models of the thermal regime with determination of their parameters on the basis of sufficiently reliable empirical materials. Among the general characteristics of the impact of carbon dioxide on climate it is common to use the parameter ΔT_{mean}, the change in mean global air temperature at the earth's surface with doubling of the CO_2 concentration in comparison with its value for the end of the pre-industrial epoch. On the basis of a comparison of the results of computations of this parameter using different models of the theory of climate a commission of the United States Climate Council under the chairmanship of J. Charney concluded that its value is 3±1.5°C [20]. This conclusion coincides with the conclusion drawn in other studies made recently, where in determining the parameter ΔT_{mean} use was made of the results of computations based on the application of both theories of climate and empirical methods [5, 6].

Table 1

Change in Mean Air Temperature With Doubling of the Atmospheric CO_2 Concentration

Simplified models of climatic theory	Models of general circulation of atmosphere	Modern climatic changes	Climatic changes in geological past
1. 2.4°C (1967)	5. 2.9°C (1975)	8. 3.3°C (1977)	9. 3.5°C (1979)
2. 2.5-3.5°C (1974)	6. 2.0°C (1979)		10. 3.4°C (1980)
3. 2.0-3.2°C (1977)			
4. 3.3°C (1979)			

The results of ΔT_{mean} computations are given in Table 1, which for each evaluation of the ΔT_{mean} parameter gives the years of publication of the corresponding studies.

The first of these evaluations, obtained in a study by Manabe and Wetherald [26], pertains to conditions for the earth as a whole and includes no allowance for the feedback between the temperature field and the area of the polar snow-ice cover. Since this feedback is positive, that is, intensifying the sensitivity of the thermal regime to changes in the heat influx, the corresponding value of the ΔT_{mean} parameter must be somewhat reduced. This feedback was also not taken into account in the detailed computations of Augustsson and Ramanathan [15] (evaluation 3). Evaluation 2 was based on computations of the distribution of the mean latitudinal temperatures made taking the mentioned feedback into account [2]. Evaluation 4 was obtained by Ramanathan, et al. [29], also with allowance for this feedback.

Evaluations 5 and 7 were found in the studies of Manabe and Wetherald [27, 28]. In the first of these studies computations were made of the changes in the mean latitudinal values of elements of the meteorological regime with an increase in the atmospheric CO_2 concentration, relating to mean annual conditions. In the second study a more general problem was solved, including computations of both latitudinal and longitudinal changes in the meteorological elements for an idealized topography of the continents and oceans. Evaluation 6 was obtained in an investigation by Manabe and Stouffer, in which the authors took into account the real distribution of the continents and oceans as well as the annual variation of meteorological elements [25]. In these studies use was made of a detailed model of general circulation of the atmosphere, including allowance for the principal feedbacks between climatic elements, including the feedback between the thermal regime and the snow-ice cover.

Evaluation 8 is based on an analysis of empirical data on modern climatic changes [5]. Evaluations 9-10 were obtained using data on climatic change in the geological past [5, 6], when these changes were dependent on additional feedbacks between the albedo of the earth's surface and the thermal regime, which do not have great importance for the modern change in climate. Among these additional relationships are the mutual relationships between the thermal regime and changes in the area of the continental glaciations and albedo of the surface of the continents occupied by a vegetation cover [11, 21], which increase the sensitivity of the thermal regime to variations in CO_2 concentration. In [5, 6], on the basis of approximate computations, it was assumed that the influence of these feedbacks increases the ΔT_{mean} value by approximately 1°C. This correction was taken into account in determining the values of the ΔT_{mean} parameter in the fourth column of the table for ensuring comparability of these evaluations with the evaluations relating to the conditions of modern change of climate.

Table 1 shows that the mean value of the parameter ΔT_{mean}, determined by different methods, is close to 3°C; the maximum deviation of individual evaluations from this value does not exceed 1°C. Computations of the mean deviation of individual evaluations from the indicated ΔT_{mean} value make it possible to assume that its probable error is about 15%.

It is obvious that the problem of determining the change in the mean planetary air temperature with an increase in the CO_2 concentration is not the whole of the problem of the influence of carbon dioxide on climate. In order to answer practical questions concerning modern changes in climate it is necessary, in particular, to have materials on change in the temperature of the lower air layer at different latitudes and longitudes for definite seasons. It is also necessary to evaluate the changes in the precipitation sums on the continents.

In answering these questions it is possible to use two methods: computations using different models of the theory of climate and an analysis of data on the climates of the past relating to warmer epochs. It has already been repeatedly noted that it is extremely desirable to make simultaneous use of both these methods since the accuracy of each of these methods is limited and is usually inadequately known. With matching of the results of the two independent approaches it can be hoped that these results will be adequately reliable [4, 6].

Paleoclimatic data. Returning to the problem of the use of empirical data for studying the influence of an increase in the concentration of CO_2 on climate, we should note the possibility of the use for this purpose of materials on the modern change of climate, on the meteorological regime in the epoch of the climatic optimum of the Holocene, during the interglacial epochs and during the Tertiary [6, 10, 24].

The importance of these materials for solving the indicated problem varies. The climatic change during the last century was only partially dependent on the increase in the CO_2 concentration; the warmings of the Holocene and interglacial epochs evidently were determined for the most part by variations of elements of the earth's orbit and the inclination of the earth's axis. Although it has been established in studies of the theory of climate that changes in the heat influx to the earth-atmosphere system caused by different factors lead to similar climatic changes [28], the indicated difference can be a source of additional errors in a study of the dependence of climate on the CO_2 concentration.

Among the already enumerated forms of climatic change in the past it is the Cenozoic cooling which is most closely associated with variations in the CO_2 concentration and data on this cooling are of special value in a study of the dependence of climate on the atmospheric carbon dioxide content. This value increases considerably due to the great interval of change in mean temperature at the earth's surface in the course of the Cenozoic era, which is about 10°C. Such a value, much greater than the ranges of temperature variations during the time of the other enumerated warmings, corresponds to a change in the CO_2 concentration in an interval which is approximately equal to the anticipated increase in the CO_2 concentration under the influence of economic activity in the course of the coming centuries.

The use of data on climatic changes during the Tertiary period for a study of the dependence of climate on the CO_2 concentration involves a number of difficulties. In particular, in the Paleogene the form of the oceans and continents differed appreciably from their modern form, which could lead to additional climatic changes not associated with variations in the atmospheric content of carbon dioxide. These changes, however, evidently were of a regional character and exerted little influence on variations in mean annual temperature [2]. In the Neogene the form of the earth's surface was close to that of the present day, which facilitates the use of paleoclimatic data for this time for a study of the dependence of interest to us.

Other difficulties in the use of paleoclimatic data are related to the limited detail of materials on the concentration of carbon dioxide in the past, which are available only for entire divisions of geological periods, the inadequately clarified accuracy of these data, the schematic nature and limited accuracy of paleoclimatic materials. The existence of these difficulties gives the results of study of the dependence of climate on the CO_2 concentration on the basis of paleoclimatic data an approximate character and requires their detailed checking. One of the ways to carry out such checking is a comparison of available data on variations in the concentration of carbon dioxide with changes in the thermal regime in the Tertiary. The results of such a comparison are given in the next section.

In order to use paleoclimatic data in a study of the dependence of the thermal regime on the carbon dioxide concentration in the atmosphere it is necessary to determine as precisely as possible the changes in this concentration in the past in comparison with the modern epoch.

In [3,8] the values of the CO_2 concentration for different divisions of the Tertiary times were found using materials published by A. B. Ronov on the rate of deposition of calcareous sediments. These materials do not include data for the modern epoch.

The corresponding value, which we will denote S_0, can be found by the extrapolation method using data for divisions of the Tertiary and Cretaceous periods. Such computations made it possible to find a S_0 value of $0.05 \cdot 10^{15}$ g/year [3]. Recently A. B. Ronov somewhat refined the rates of carbonate formation for the Pliocene. Computations made with allowance for this refinement, according to data for the Tertiary and Cretaceous periods, give $S_0 = 0.07 \cdot 10^{15}$ g/year. Extrapolation of the values for the last two divisions of the Tertiary on the basis of the refined data published by A. B. Ronov gives $S_0 = 0.045 \cdot 10^{15}$ g/year. The corresponding value, which can be found using data published by Bowen [17], has this same order of magnitude.

On the basis of the evaluations cited here it can be postulated that the S_0 value falls in the interval $0.045-0.07 \cdot 10^{15}$ g/year. This makes it possible not to change the earlier adopted evaluation of this value, equal to $0.05 \cdot 10^{15}$ g/year.

Table 2 gives the carbon dioxide concentration values determined with allowance for this value in comparison with its modern value in the Tertiary period and in the Upper Cretaceous. It can be concluded from the data in Table 2 that in the Pliocene the CO_2 concentration was greater than the modern level by almost twice and in the Miocene by almost a factor of 4. It must be remembered that the changes in the carbon dioxide concentration during the last hundred million years had a more complex structure, which is only partially characterized by the six mean values cited here, relating to long time intervals. Evidently, in the past there were repeated briefer variations of the CO_2 concentration and the thermal regime.

Thermal regime. The most detailed investigations of the influence of carbon dioxide on the thermal regime by means of models of general circulation of the atmosphere were made in the studies of Manabe and Stouffer [25] and Manabe and Wetherald [28]. The results of these studies do not completely coincide. Whereas the values of the ΔT_{mean} parameter obtained in the second of them agree well with the conclusions of a number of theoretical and empirical studies, the ΔT_{mean} value found by Manabe and Stouffer is somewhat less than the results of other modern investigations. It is worth noting, as indicated by Table 1, that this value is lower than the values of the ΔT_{mean} parameter obtained in the absence of allowance for the feedback between the thermal regime and the snow-ice cover, which, as noted above, increases the sensitivity of climate to the values of the CO_2 concentration. From the preliminary communication on the investigation by Manabe and Stouffer [25] it is difficult to explain the reason for such a discrepancy, which scarcely is dependent on the different detail of the used climatic models and evidently is associated with a noncoincidence of the parameterization of the studied processes in [25] and [28]. Until this problem is clarified we limit ourselves to a comparison of the results of a recent study by Manabe and Wetherald [28] with paleoclimatic data.

Figure 1 gives the differences in the mean latitudinal temperature at different latitudes, according to Manabe and Wetherald, with a doubling of the CO_2 concentration in comparison with its modern value (MW curve). This graph also shows the results of determination of temperature for the middle of the Pliocene at different latitudes in the northern and southern hemispheres according to materials from empirical investigations generalized by I. I. Borzenkova, M. V. Muratova and I. A. Suyetova. The mean latitudinal temperature values for the temperate and high latitudes for which there were groups of uniform data are represented in the form of two segments of continuous lines. For the lower latitudes it was possible to use data from temperature measurements only in four regions. These data are represented in the form of dots. The dashed line corresponds to the mean temperature distribution according to empirical data.

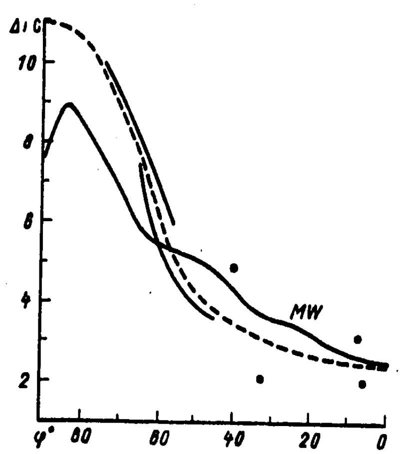

Fig. 1. Dependence of change in air temperature (ΔT) on latitude with doubling of CO_2 concentration.

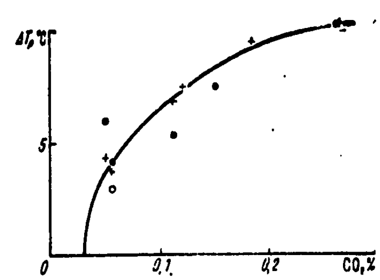

Fig. 2. Change in mean global air temperature (ΔT_p) with different CO_2 concentrations.

It follows from the indicated materials that the mean air temperature for the earth at the earth's surface in the Middle Pliocene was above the present-day level by 2.9°C. This value almost coincides with the ΔT_{mean} value found by Manabe and Wetherald. We note that in the Pliocene the thermal regime was influenced by the feedback between temperatures and reflectivity of the continents, dependent on the state of the vegetation cover, which was not taken into account in the study by Manabe and

Wetherald. Allowance for this feedback increases the value of the parameter ΔT_{mean} by approximately 0.5°C [11], as a result of which the ΔT_{mean} values in these two computations are equal to 2.9 and 3.5°C. It is obvious that these values agree quite well.

It is worth noting, as indicated in Fig. 1, that the dependence of the ΔT value on latitude according to empirical data and according to the computations of Manabe and Wetherald is very similar. It can be noted that the empirical data indicate a somewhat more considerable increase in the ΔT difference with latitude in comparison with the results of theoretical computations.

In order to clarify the dependence of the thermal regime on the changes in the CO_2 concentration in a broad range of its values it is possible to use data on paleotemperatures during the last hundred million years, during which the CO_2 concentration decreased almost tenfold. In earlier studies [6, 9] for this purpose use was made of materials from the investigations of V. M. Sinitsyn [12, 13], which up to the present time are the sole source providing information on the thermal regime of a considerable part of the earth's surface during the entire Phanerozoic. A comparison of the air temperature maps constructed by V. M. Sinitsyn with the materials of later investigations makes it possible to assume that for the Tertiary period and the Mesozoic era V. M. Sinitsyn somewhat exaggerated the temperature differences of the past in comparison with the modern epoch in the high and middle latitudes and understated these differences in the low latitudes. However, the mean air temperature differences for the northern hemisphere, computed using the V. M. Sinitsyn maps, are quite reliable, as can be seen, in particular, from the data in Fig. 2.

Table 2

Relative Changes in CO_2 Concentration

Division	Absolute age of beginning and end of division, millions of years	Rate of deposition of carbonates, 10^{15} g/year CO_2	Concentration of CO_2, %
Pliocene	2-9	0.09	0.055
Miocene	9-25	0.18	0.110
Oligocene	25-37	0.08	0.050
Eocene	37-58	0.31	0.185
Paleocene	58-66	0.20	0.120
Upper Cretaceous	66-101	0.44	0.265

This figure, in the form of dots, shows the values of the noted difference from the maps constructed by V. M. Sinitsyn for the Pliocene, Miocene, Oligocene, Eocene-Paleocene and Upper Cretaceous in dependence on the corresponding concentrations of carbon dioxide. The circle represents the similar value for the Pliocene, computed using the data in Fig. 1.

The empirical values for temperature change can be compared with the results of theoretical computations. In these computations it was assumed, in accordance with the results of several modern investigations, that with a constant albedo a doubling of the CO_2 concentration leads to an increase in the mean air temperature at the earth's surface by 2.5°C. Since over the course of a hundred million years the earth's albedo changed, these changes must be taken into account in determining air temperatures in the geological past.

One of the reasons for change in albedo was the increasing aridity of the continents, which occurred at the end of the Pliocene and the Pleistocene. As noted above, this led to a decrease in the mean air temperature by approximately 0.5°C.

The second reason was the appearance and gradual increase in the area of the snow and ice covers in the high latitudes. Although the influence of these covers on the thermal regime is taken into account in most modern theories of climate, the accuracy of such computations is usually rather limited due to the schematic nature of the parameterization of the corresponding processes.

The influence of snow and ice covers on the thermal regime of the past can be evaluated on the basis of the following empirical data.

It follows from materials from satellite observations [23] that in the high latitudes of the northern hemisphere in summer in the region free of ice the albedo of the earth-atmosphere system is about 0.40, whereas the mean albedo of the zone with an ice cover is approximately 0.55. Taking into account the difference in these values and the area of permanent and seasonal snow and ice covers, as well as the ratio of the radiation values in the zone of the snow and ice cover and its mean global value, on the basis of data on the sensitivity of mean temperature to change in the heat influx it can be found that the now existing snow and ice cover decreases the temperature of the lower air layer for the entire earth by approximately 2°C.

It is known that the snow and ice cover in the high latitudes already developed in the Paleogene in the form of mountain glaciations which occupied a relatively small area and exerted no substantial influence on global climate. In the Miocene this cover occupied a considerable part of the territory of Antarctica, which, as indicated by computations, could reduce the mean global temperature by 0.2-0.3°C. A considerable broadening of the snow and ice cover occurred in the Pliocene and especially at the end of the Pliocene, when extensive zones of sea ice developed and the seasonal snow cover on the continents expanded.

An increase in the area of the land as a result of a decrease in ocean levels due to the formation of continental glaciers could also exert some influence on the earth's albedo. Since the mean albedo of the surface of the continents was greater than the albedo for the oceans, for this reason with the development of large glaciations there was a decrease in mean temperature. An approximate evaluation shows that all other conditions being equal, such a decrease for the modern epoch is about 0.3°C in comparison with the Paleogene. This value, however, can scarcely be included in computations of changes in mean temperature because it is only part of the variations of temperature due to the advance and retreat of sea waters as a result of rising and subsidence of the earth's surface, which it is difficult to estimate with sufficient accuracy for the earth as a whole.

Limiting ourselves to allowance for the first two temperature differences, caused by variations in albedo, using the data in Table 2 it is possible to compute the temperature changes for all the divisions of the Tertiary and Upper Cretaceous.

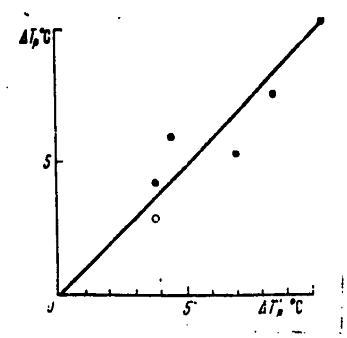

Fig. 3. Comparison of changes in mean global air temperatures found using empirical data (ΔT_p) and results of computations of these changes on the basis of the CO_2 concentration ($\Delta T'_p$).

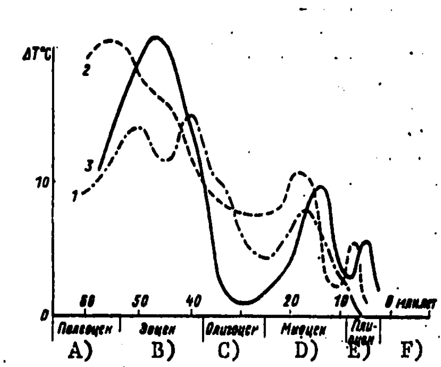

Fig. 4. Temperature change in the geological past in comparison with modern epoch.

KEY:

A) Paleocene
B) Eocene
C) Oligocene
D) Miocene
E) Pliocene
F) millions of years

Differences in Mean Temperature in Geological Past in Comparison With Present Epoch

Divisions	Pliocene	Miocene	Oligocene	Eocene	Paleocene	Upper Cretaceous
Temperature differences, °C	3.7	6.9	4.3	9.1	7.5	10.4

The results of these computations are given below.

The represented temperature differences consist of a temperature increase as a result of changes in the greenhouse effect caused by variations in the CO_2 concentration and the temperature increase as a result of changes in albedo of the earth-atmosphere system. In the computations of the second of these values it was assumed that it is equal to 2.5°C for the Oligocene and earlier time intervals, 2.2°C for the Miocene and 1.5°C for the Pliocene (the value for the Pliocene is the mean value for that time interval during which the albedo appreciably changed). These temperature differences are represented in Fig. 2 in the form of crosses.

The solid curve drawn on the basis of these data agrees well with empirical materials.

A similar conclusion can be drawn from Fig. 3, which shows the relationship between the temperature differences found on the basis of empirical data (ΔT_p) and the difffereces obtained as a result of the mentioned ($\Delta T'_p$) computations. Such an agreement is evidence, in particular, of the reliability of the V. M. Sinitsyn materials used in this case.

The greatest discrepancy between the data published by V. M. Sinitsyn and the results of computations are for the Oligocene. This discrepancy is probably attributable to the fact that V. M. Sinitsyn, on the basis of the limited data available at the time he made his investigations (1940's-1950's), could not discriminate relatively brief climatic variations against the background of the general trend of temperature change at the end of the Mesozoic era and the Tertiary period. In this connection he did not detect a marked cooling in the Oligocene which could be observed using data on variations in the CO_2 concentration and which can be clearly detected on the basis of the newer materials on the thermal regime of the Tertiary cited below.

Figure 1 shows that the changes in air temperature in the low latitudes are relatively small during climatic variations. Accordingly, in an empirical investigation of climatic changes it is of great importance to have data on the increase or decrease in temperature in the middle and high latitudes, where the temperature variations are great in absolute value and they can be detected more easily.

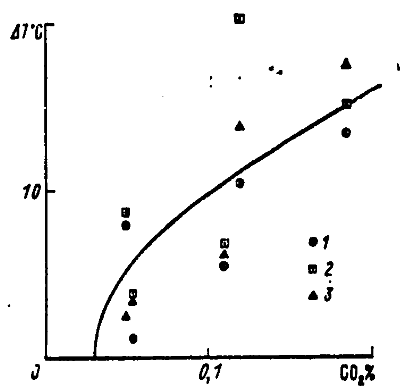

Fig. 5. Change in air temperature (Δ T) with different CO_2 concentrations. 1) according to data from Axelrod and Baily, 2) Shackleton and Kennett, 3) Buchart

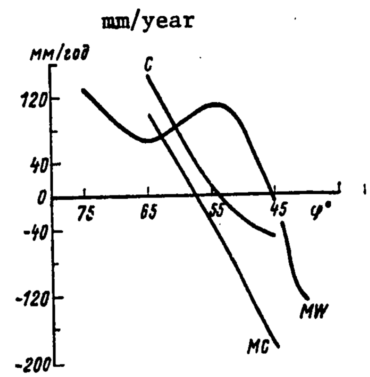

Fig. 6. Change in precipitation with doubling of CO_2 concentration. MW -- data from Manabe and Wetherald, C -- data from Sinitsyn, MC -- data from Muratova and Suyetova.

Figure 4 gives data on the temperature differences in comparison with the modern epoch, computed using materials from three investigations: Axelrod and Baily [16] (computations of paleotemperatures on the basis of palynological data for the most part for western North America, curve 1), Shackleton and Kennett [30] (isotopic analysis of remnants of marine organisms in the oceans of the southern hemisphere, curve 2), Buchart [18] (isotopic analysis of remnants of marine organisms in the southern part of the North Sea, curve 3).

By comparing the data in Fig. 4 with the changes in the CO_2 concentration cited in Table 2, one can note the good qualitative agreement of these independent materials.

Thus, in particular, on all three curves one can note a warming occurring in the Eocene in comparison with the Paleocene. On all the curves there is a marked cooling in the Oligocene, temperature maximum in the Miocene, a lesser maximum in the Eocene, a cooling in the Pliocene in comparison with the Miocene. Some differences in the position of the indicated temperature maxima and minima, established on the basis of materials from different investigations, are attributable to the incomplete agreement of the time scales of each investigation, the accuracy of which is limited.

In addition to the principal patterns of the thermal regime of the Tertiary, from the data presented in Fig. 4 it is possible to find more detailed features of climatic variations. For example, on two curves after the temperature maximum in the Miocene one can note a relatively brief second temperature increase in the Neogene. Since the time scale of this climatic variation is less than the duration of the divisions of the Tertiary, it is impossible to compare this change in the thermal regime with available data on the atmospheric content of carbon dioxide.

Since data on paleotemperatures, from which Fig. 4 was constructed, in contrast to the materials of V. M. Sinitsyn, pertain to individual limited regions, their dependence on variations in the CO_2 concentration is complicated by the influence of a number of additional factors. Nevertheless this dependence is adequately clear, as is indicated in Fig. 5, where the mean temperature differences, determined for each division of the Tertiary period from the three curves represented in Fig. 4, are compared with the CO_2 concentration.

It follows from the data in this figure that with an appreciable scatter of individual points there is a clear dependence between the considered values, which is described satisfactorily by a line corresponding to the curve in Fig. 2 with an increase in its ordinates by a factor of 1.7.

Such an increase can be attributed to the fact that the data represented in Fig. 5 relate to the temperate latitudes, where the temperature changes are greater than their mean global values, represented in Fig. 2.

The good qualitative and quantitative agreement in temperature changes determined by empirical methods and found from materials on variations in the CO_2 concentration makes it possible to conclude that there is an adequate reliability of data on the concentration of carbon dioxide, a satisfactory accuracy of materials on paleotemperatures and correctness of the evaluations of the sensitivity of the thermal regime to changes in the quantity of atmospheric CO_2 used here.

For a more detailed characterization of changes in the thermal regime caused by an increase in the mass of carbon dioxide it is necessary to construct maps of air temperature for different CO_2 concentrations. In studies on the theory of climate such maps, based on allowance for the real form of the continents and oceans, for the time being have not been constructed. In an earlier investigation [9] the V. M. Sinitsyn air temperature maps, relating to the Early-Middle Pliocene, were used for this purpose. It was assumed that these maps correspond to the condition of an increase in the CO_2 concentration by a factor of approximately 2.

A detailed investigation of the studies of V. M. Sinitsyn shows that in the geochronological scale which he used the Pliocene was more prolonged and also takes in the latter part of the Miocene in the modern geochronological scale. Accordingly, his climatic maps for the Early-Middle Pliocene relate to a higher level of CO_2 concentration falling in the interval of its increase by a factor of 2-4 in comparison with modern conditions. Evidently, the data of V. M. Sinitsyn for the Late Pliocene, which corresponds to the chronology of the Pliocene in its modern definition, are closest to a double increase in CO_2 concentration.

We note that the use of paleoclimatic data for reconstruction of the meteorological regime in the case of a doubled CO_2 concentration involves special difficulties because in the Pliocene there was a relatively rapid change in the albedo of the earth's surface. Therefore, using data on climates of the past it is easier to study the climatic conditions for higher CO_2 concentrations when the albedo of the earth's surface was more constant. In particular, it is worth noting the possibility of using for this purpose data for the Miocene, which correspond to an increase in the concentration of carbon dioxide by a factor of approximately 4 in comparison with the present-day level.

A comparison of new paleoclimatic maps for the Miocene and their comparison with similar maps constructed using models of general circulation of the atmosphere can have great importance for clarifying the influence of the CO_2 concentration on climate.

Precipitation. It follows from simple physical considerations that with an increase in the CO_2 concentration the quantity of precipitation falling on the earth's surface increases. In particular, it was established long ago that evaporation from the surface of water bodies and from the surface of the land under conditions of adequate moistening is proportional to the radiation balance value and in the first approximation is equal to the value of this balance, divided by the latent heat of vaporization [1].

Since with an increase in the concentration of carbon dioxide the radiation balance of the earth's surface increases, there is a corresponding increase in total evaporation and the sum of precipitation equal to it for the earth as a whole. This dependence can be investigated approximately on the basis of use of the heat balance equation for the earth's surface [7].

However, it is evident that in individual regions of the earth with an increase in the CO_2 concentration the quantity of precipitation can both increase and decrease in accordance with changes in atmospheric circulation and other factors.

For practical purposes data on variations of the precipitation regime on the continents are most necessary.

In computations of the precipitation regime, as well as in determination of changes in air temperature for conditions of a considerable increase in the quantity of atmospheric carbon dioxide, it is possible to use two methods: detailed models of the theory of climate and paleoclimatic data relating to epochs with a higher CO_2 content in atmospheric air.

Figure 6 shows the results of determination of the differences in the mean latitudinal annual sums of precipitation falling on the continents of the northern hemisphere for a doubled CO_2 concentration and precipitation sums with a pre-industrial level of the quantity of carbon dioxide. The MW curve is based on materials of the latest investigation of Manabe and Wetherald [28]. The curve C was constructed using the data published by V. M. Sinitsyn for Eurasia, which relate, according to his nomenclature, to the Late Pliocene. The curve MC corresponds to the mean latitudinal values found using the research materials of M. V. Muratova and I. A. Suyetova, who on the basis of paleobotanic data computed the mean annual sums of precipitation in ten regions of the temperate latitudes of Eurasia and North America for the Middle Pliocene.

Figure 6 shows that the results of all three investigations are in satisfactory agreement. They all indicate an increase in the precipitation sums in the higher latitudes and a decrease in precipitation in the lower latitudes.

The great absolute values of the considered difference warrant attention. In most cases this difference is 10-30% or more of the quantity of falling precipitation.

The difference between the curves in Fig. 6 can be attributed in part to a noncoincidence of the regions to which the corresponding data pertain, and in part to the errors of each of the methods for determining the values of precipitation change.

It can be assumed that the agreement between these curves is adequate for determining the general pattern of change of the precipitation sums in the middle latitudes of the continents with an increase in the CO_2 concentration. However, for many practical purposes it is necessary to have more precise and detailed information on the dependence of the precipitation regime on the concentration of carbon dioxide, obtaining which is a task of future investigations.

The principal conclusion from the materials presented here is that it is now possible to study the influence of the carbon dioxide concentration on climate by two independent methods: theoretical and empirical.

The satisfactory agreement of the results of application of these methods for determining the change in temperature and precipitation with an increase in the CO_2 concentration indicates a correspondence between these evaluations and the conditions of real climate.

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TELESCOPED SCHEME FOR HYDRODYNAMIC SHORT-RANGE WEATHER FORECASTING

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[Article by V. M. Kadyshnikov, candidate of physical and mathematical sciences, USSR Hydrometeorological Scientific Research Center, manuscript received 27 May 80]

[Text]

Abstract: A scheme for short-range forecasting of meteorological elements is proposed on the basis of telescoping with a one-sided influence. Some results of its operational testing are presented. The merits and shortcomings of different methods for evaluating a hydrodynamic forecast of pressure fields are discussed.

An important and obvious reserve for increasing the quality of hydrodynamic short-range weather forecasts is a reduction of the spatial (horizontal) steps in numerical schemes. If in this case we do not wish to impose qualitatively new requirements on the speed of computers, the extent of the region of the forecast must be reduced; indeed, even with retention of the number of computation points, the computation time with the use of explicit finite-difference schemes increases by as many times as the grid interval decreases. However, a decrease in the dimensions of the region makes it necessary to desist from physically inadequate boundary conditions at its lateral boundaries. In actuality, in the case of an ordinary regional forecast for a time of 24-36 hours for a region measuring about 20 x 20 points with a distance of 300 km between them it is possible, for example, to consider the boundary values of the meteorological elements to be constant with time. The errors arising as a result of this (under the condition of absence of computational instability associated with incorrect stipulation of the boundary conditions), manifested in presence of rapid reflected waves of a great amplitude propagating within the computation region with the velocity of synoptic formations, are not reflected in the quality of the forecast in some internal region. With the same number of points, but with a decrease in the distance between them by a factor of 2-3 the internal region, free of such errors, virtually disappears. This can be avoided only by stipulating physically adequate conditions on the boundaries, that is, if at some boundary point using the computation algorithm it is necessary to stipulate some function, it must be assigned a true value. But since such are unknown, they must first be found by solving first the problem of forecasting for a larger region which includes the boundary points of our region with a small interval as internal boundary conditions. This can be a regional or hemispherical forecast. The resulting forecast in the fine grid can in turn be regarded as auxiliary, giving the boundary conditions for computing the forecast in a still finer grid, being internal relative to that just used.

Such a problem of the successive precomputation of meteorological elements with the use of embedded grids with decreasing intervals with the use as boundary conditions of the values of the elements already computed using the coarser grid is called the telescoping of the forecast. This idea and the term itself for the first time were proposed in [21].

If reference is to the telescoping of a barotropic forecast, the problem of specifically what functions must be stipulated at what boundary points (all the functions are known to us at each boundary point from the forecast for a large territory) is solved simply. For the first time it was investigated by Charny [18], who at the points of inflow stipulated normal velocity and vorticity, and at the points of outflow -- only the normal velocity. The correctness of the corresponding problem follows [16] from the theory of characteristics. In a one-dimensional case there are other formulations of the problem of a barotropic forecast for a limited territory. In a two-dimensional problem this matter was studied in detail in [4]. However, not all the theoretically possible formulations are satisfactory on a practical basis. In [7], for example, it was shown that the replacement of normal velocity in the Charny problem by divergence can lead to negative results.

The situation is different in a baroclinic case. It was demonstrated in [6] that depending on the vertical velocity profile at a boundary point, that is, on the totality of its values at the levels of breakdown of the atmosphere into computation layers, at this point it is possible to stipulate definite combinations of values of the sought-for functions at different levels, determining the others from solution of the equations (in this case, in particular, the entire profile of any function cannot be stipulated at the outflow points). But the problem of determining the corresponding combinations is too unwieldy: at each point in each time interval it is necessary to solve the full problem of the eigenvalues for a matrix whose order is proportional to the number of levels in the model; its elements are dependent on the coefficients of the problem and the normal velocity values at different levels. A similar conclusion for a continuous model -- it is impossible to stipulate certain meteorological elements (as a function of altitude) at the points of inflow and certain others at the points of outflow -- was drawn still earlier in [15].

It should not be thought that since computations for the internal region differ only with respect to the dimensions of the grid used, solutions for both problems (for the external and internal regions) virtually coincide at common points, so that at all boundary points it is possible to stipulate all functions. This is impossible even under the condition that the initial fields in the small grid are obtained by a simple interpolation of the corresponding fields with the coarse grid. In addition, one of the purposes of telescoping is allowance, already in the initial data, for more detailed information on meteorological fields, including microscale information; then, very frequently in the telescoping procedures the scheme includes physical factors not at all taken into account in forecasts in a coarser grid or taken into account less completely; finally, the forecast for the large area, used as the auxiliary in the stipulation of physically adequate boundary conditions for forecasting for the smaller, internal region, can be prepared using a scheme differing considerably in computational respects (number of levels, altitudinal boundary conditions, finite-difference algorithm, etc.) from the scheme for making forecasts for the small territory.

Thus, it is impossible to stipulate everything on the boundary of the small grid because the data potentially intended for this purpose are not solutions of the problem in the fine grid. At the same time it is virtually impossible to determine specifically what should be stipulated.

Accordingly, one can understand the interest in the literature [20, 21, 24, 25, 27, 28] with respect to the problem of "interaction" of the values of the meteorological elements at the boundary points of the fine grid obtained from computations made with the coarse grid with the values within the fine grid. In a number of these studies the problem in a barotropic case is also formulated. And although, as indicated above, in a barotropic scheme it is possible to get by without a precise formulation of the boundary conditions, such investigations are considered useful in the working out of empirical rules, which are possibly suited for a baroclinic case as well.

And nevertheless, apparently, all the practical results in this field are very closely related to specific finite-difference schemes for the integration of differential equations.

We will employ the Lax-Wendroff scheme [23], for the first time used in solving the barotropic forecasting equations in [13, 22]. A detailed description of the scheme can be found in [13]. It can also be used directly in an integration of baroclinic prognostic equations [14]. However, we will apply it only to "plane" nonstationary equations derived already after vertical discretization of the equations. It is known that the Lax-Wendroff scheme has great merits [14]: being explicit, it is stable and if it distinguishes disturbances, only in the most insignificant degree, which enables it, in particular, to describe well cases with large gradients. This is attributable to the fact, as demonstrated in the linear variant in [12], that the difference system of equations, having a higher order than the differential system, precisely describes the propagation of these same waves, like the differential system, plus some additional, rapidly attenuating waves.

It goes without saying that all these properties appear only under the condition that the vertical discretization of equations was selected in such a way that the forecasting problem for the derived system of plane equations is correct, that is, the solution exists uniquely and is continuously dependent on the input data. In the literature proper attention has not yet been devoted to this problem: for solution of the baroclinic problem use is made of methods whose merits were investigated in the example of the equation of advection, or in the best case, a system of barotropic equations. Moreover, a quasilinear system of evolutionary equations in first-degree partial derivatives, which is obtained after vertical discretization and exclusion of some functions from it by means of diagnostic expressions, may not be hyperbolic, that is, by means of canonization it will be impossible to reduce it to a system consisting of individual systems of "barotropic" equations with different velocities of "gravitational" waves. Since the problem of forecasting for such a system of equations is not correct, there is no method by which its solution is possible.

If the discretization of equations has already been selected on the basis of one consideration or another, it is exceedingly difficult to check whether the derived system of first-degree equations is hyperbolic, even with a fixed wind profile and temperature stratification: it is necessary to be convinced that in the already mentioned matrix (reference is to the formulation of boundary conditions) all the eigenvalues are real and that it has a full set of eigenvectors. It is all the more impossible to check the selected discretization from the point of view of correctness of the corresponding problem in the entire phase space of solutions, that is, for any profiles of the mentioned meteorological elements. It was demonstrated in [8] how it is possible to formulate such discretizations which will knowingly yield a positive result. We will use precisely such a discretization without pretense to the conservation of energy or any other integral characteristics present in an undiscretized system of equations because in our opinion their retention is not of great practical value: integral properties by no means guarantee differential properties, which in essence are the purpose of numerical model-

The initial system of equations is written in the form [9]

$$u_t + uu_x + vu_y + \omega u_\zeta = -\Phi_x + lv + Ku\sqrt{u^2+v^2}, \qquad (1)$$

$$v_t + uv_x + vv_y + \omega v_\zeta = -\Phi_y - lu + Kv\sqrt{u^2+v^2}, \qquad (2)$$

$$-RT = \Phi_\xi \quad (\xi = \ln\zeta), \qquad (3)$$

$$T_t + uT_x + vT_y = \Gamma\omega \quad \left(\Gamma = \frac{RT(\gamma_a - \gamma)}{g\zeta}\right), \qquad (4)$$

$$-(u_x + v_y) = \omega_\zeta, \qquad (5)$$

where u, v, ω are components of the velocity vector along the x, y, ζ axes, Φ is geopotential, T is temperature, l is the Coriolis parameter, R is the gas constant, g is the acceleration of free falling, γ and γ_a are the vertical and dry adiabatic vertical temperature gradients, K is the drag coefficient, different from zero only at the underlying surface (it was assumed that $K|_{\zeta=1} = 1.71\cdot10^{-4}\text{m}^{-1}/T|_{\zeta=1}$)

The boundary conditions for ζ are

$$\omega = 0 \quad \text{with } \zeta = 0, \qquad (6)$$

$$\Phi_t + u\Phi_x + v\Phi_y = c^2\omega + uL_x + vL_y \ (c^2 = RT) \quad \text{with } \zeta = 1, \qquad (7)$$

where L is the geopotential of the underlying surface above sea level. The sense of the lower boundary condition (bearing in mind that it was written for ζ = 1) is that we take the slope of relief into account, but not its elevation.

The vertical structure of a 5-level atmospheric model which we will use in a finite-difference solution of the problem (1)-(7) is as follows: at the main levels 300, 500, 700, 850 and 1000 mb (their numbers are 1, 3, 5, 7, 9) the geopotential and horizontal velocity components are determined; at the intermediate levels 400, 600, 775 and 925 mb (their numbers are 2, 4, 6, 8) the vertical velocity and temperature are determined. In addition, with ζ = 1 in accordance with the boundary condition we also determine the vertical velocity. It is not necessary to determine $T|_{\zeta=1}$. Otherwise there would be 5 T values. After discretization of the model in accordance with (3) they would be expressed through 5 Φ values using a degenerate matrix (otherwise all Φ could be expressed through T, that is, through Φ_ξ, which is impossible). Accordingly, $T|_{\zeta=1}$ is a linear combination of the already introduced four T values.

The convective derivatives in the equations of motion (1), (2) are frequently omitted in a forecast. In actuality they are usually small. Although we will not neglect the corresponding terms, taking into account their role in frontal zones, we will carry out the theoretical analysis of vertical breakdown in the text which follows without them. In the analysis we will also assume that the parameters Γ and c^2 dependent on the sought-for functions are always positive.

Guided by the derivatives of ζ in the hydrostatic equation (3) and the continuity equation (5), we will write the equations of motion (1) and (2) and the continuity equation (5) at the main levels and the hydrostatic equation (3) and heat influx equation (4) at intermediate levels. In accordance with [8] we will assume that

$$-RT_{2i} = (\Phi_{2i+1} - \Phi_{2i-1})/(\xi_{2i+1} - \xi_{2i-1}) \quad (i = 1, 2, 3, 4), \tag{8}$$

$$-D_{2i-1} = (\omega_{2i} - \omega_{2i-2})/(\zeta_{2i} - \zeta_{2i-2}) \quad (D \equiv u_x + v_y, \quad i = 1, 2, 3, 4);$$
$$-D_9 = (\omega_9 - \omega_8)/(\zeta_9 - \zeta_8). \tag{9}$$

To these nine equations it is necessary to add equations (1) and (2), written at the levels 1, 3, 5, 7, 9, equation (4) written at the levels 2, 4, 6, 8, and also the boundary conditions (6), (7). A system of 25 equations is derived for the 25 initial functions.

In [8] a model with such a vertical structure was not analyzed in detail from the point of view of correctness of the forecasting problem for the corresponding system of plane equations; only the final result was cited. The writing of the hydrostatic equation in a logarithmic coordinate system was also not proposed. Accordingly, we will now check to see if the formulated problem is actually correct.

Our purpose is to demonstrate that the evolutionary (soluble relative to the derivatives of t) system of plane equations which is derived, if Φ_1, Φ_3, Φ_5 and Φ_7 are excluded by means of (8), and if (9), with (6) taken into account, is used to exclude ω_2, ω_4, ω_6, ω_8 and ω_9, that is, a system of 15 equations, is hyperbolic. Since the hyperbolicity of our two-dimensional system of equations and the corresponding one-dimensional system exist simultaneously, we can limit ourselves to a one-dimensional case and equation (2) can be excluded from consideration [8]. In addition, in equations (1), (4) and (7), from which it is now necessary to exclude all ω and Φ, except Φ_9, we omit all the nondifferential terms, bearing in mind that the type of system of first-degree differential equations is determined by the matrix of coefficients with derivatives of x.

Thus, we derive a system of ten evolutionary one-dimensional equations (the prime denotes differentiation for x)

$$\frac{\partial u_{2i-1}}{\partial t} = -uu'_{2i-1} - R\sum_{k=i}^{4} b_{2k} T'_{2k} - \Phi'_9 \quad (i=1, 2, 3, 4, 5),$$

$$\frac{\partial T_{2i}}{\partial t} = -uT'_{2i} - \Gamma_{2i}\sum_{k=1}^{i} a_{2k-1} u'_{2k-1} \quad (i=1, 2, 3, 4), \tag{10}$$

$$\frac{\partial \Phi_9}{\partial t} = -u\Phi'_9 - c^2 \sum_{k=1}^{5} a_{2k-1} u'_{2k-1},$$

where

$$b_{2k} = \xi_{2k+1} - \xi_{2k-1}, \quad a_{2k-1} = \zeta_{2k} - \zeta_{2k-2}.$$

Its hyperbolicity is equivalent to the correctness of the Cauchy problem for it and accordingly to the forecasting problem if the boundary conditions are properly formulated.

This system of equations is hyperbolic at any point in the phase space of solutions if in the matrix of coefficients on the right-hand side with any values of the corresponding parameters all the eigenvalues are real and it has a full set of eigenvectors. It might be added that this cannot be checked directly. But it follows from the definition of hyperbolicity that such a system can be canonized (at each point in its special way), introducing new φ_k functions such that for each of them the following equation will apply

$$\varphi_{k_t} + \lambda_k \varphi_{k_x} = 0 \quad (k=1, 2, \ldots, 10),$$

and all λ_k are real.

It therefore follows that if a problem periodic with respect to x is formulated, at each point in phase space there is a positively determined quadratic form whose integral does not change with time. It was demonstrated in [8] that if, on the other hand, a system of type (10) is not hyperbolic, no positively determined quadratic form is retained in it. Thus, to demonstrate the hyperbolicity of system (10) means to indicate for it some positively determined quadratic form remaining in the periodic problem.

We will multiply the equations (10) (respectively) by

$$(au)_{2i-1} \quad (i=1, 2, 3, 4, 5); \quad \left(\frac{R}{\Gamma} bT\right)_{2i} \quad (i=1, 2, 3, 4); \quad \frac{\Phi_9}{c^2}.$$

We add them and integrate the sum for the periodicity region. At any fixed point in the phase space of solutions, that is, with "frozen" values of the coefficients, the integral of the advective derivatives becomes equal to zero. The remaining terms on the right-hand side with an accuracy to the factors have the form $f_x\varphi$ (f and φ are the sought-for functions). It is easy to confirm that the term $f\ _x$ corresponds accurately to each such term with the same coefficient. Accordingly, the entire right-hand side disappears after integration. At the left we obtain

$$\frac{\partial}{\partial t}\int\frac{1}{2}\left[\sum_{i=1}^{5}(au^2)_{2i-1}+\sum_{i=1}^{4}\left(\frac{Rb}{\Gamma}T^2\right)_{2i}+\frac{\Phi_9^2}{c^2}\right]dx.$$

Thus, for system (10) we found a positively determined quadratic form whose integral is retained. It is easy to understand its sense: beneath the integral is the difference analogue of energy for a simplified (without convective derivatives, mountains and friction) system of equations before its vertical discretization under the condition of "freezing" of the coefficients:

$$\frac{1}{2}\left\{\int_0^1\left[u^2+\frac{1}{c^2}(\Phi|_{\zeta=1})^2\right]d\zeta+\int_{-\infty}^{0}\frac{R}{\Gamma}T^2d\xi\right\}.$$

This follows from (8) and (9) if it is required that the Newton-Leibnitz theorem on the determined integral be satisfied.

We note that the result obtained in no way is related to the specific number of levels in the model. It is a corollary of the discretization formulas (8), (9). We also note that the considered "energy" has no relationship to the true energy of the problem (1)-(7), also examined without allowance for convective derivatives, mountains and friction. In order that there be a quadratic integral for the corresponding nonlinear problem, it is necessary to take the convective derivatives into account, but at the same time it is necessary to replace the boundary condition (7) by the condition $\omega = 0$ and consider the $\zeta\Gamma$ parameter to be constant with height. For example, an energy conservation law is derived in [10].

We note that the velocity values in the advective derivatives remained arbitrary, that is, they can be selected in any way, using only approximation considerations as a point of departure. The convective derivatives in equations (1), (2) were also not determined. With respect to vertical velocity, it can be assumed, for example, that $\omega_{2i-1} = 1/2(\omega_{2i-2} - \omega_{2i})$ (i = 1, 2, 3, 4), and the derivatives of ζ with i = 1, 5 are replaced by one-sided differences, but with i = 2, 3, 4 -- by central differences.

As already mentioned, we will solve the system of plane equations by the Lax-Wendroff method. It goes without saying that it need not be reduced to the form (10), which we require for demonstrating correctness. We will take equations (1), (2) and (4) directly and supplement them in each time interval by the expressions (8) and (9).

The telescoping of the forecast was accomplished in the following way. First for a territory measuring 20 x 24 points with a horizontal interval 300 km (taking in approximately Europe; the corresponding L(x,y) was taken from [19]) and a time interval of 12 minutes a forecast is computed 24 hours in advance. In this case the time-constant tendencies of geopotential at the lateral rows of points and the geostrophic wind at them, computed using data on geopotential in the two lateral rows, are stipulated from the known geopotential values at the final time of the forecast. The initial wind is stipulated geostrophic. Thus, information is required on geopotential at the initial moment in time everywhere and in the two lateral rows after a day. The "matching" of the stipulated boundary values with the computed internal values was accomplished as in [20]: in each time interval the values of all the "evolutionary" variables at the points of the first internal row are corrected using the formula

$$\overline{f}_2 = \frac{1}{2} f_2 + \frac{1}{4} (f_1 + f_3)$$

(point 1 is a boundary point, reckoning is inward from the boundary along the normal).

During the computations each four hours the values of all the meteorological elements at points which are boundary points for the internal region subject to telescoping (it is situated at the center of the first region) are stored. Upon completion of the computations a forecast begins for the internal region for this same time. The number of points in it is the same, but the interval in horizontal coordinates and time is half as great. In such new computations the tendencies at the boundaries are "piecewise-constant" in time: they are changed each 4 hours. The initial and boundary values in the denser grid of points are obtained from the corresponding values in the coarse grid by simple linear interpolation. The matching is accomplished the same as before.

By way of trial runs we computed 12 examples with the use of the actual (including the future values at the boundaries) initial data. The results were good. Without discussing these in detail, we will examine a table in whose upper part there are some results yielded by the scheme in comparative tests under operational conditions in July-November 1979 carried out by the test laboratory of the USSR Hydrometeorological Center. Objective analysis [1] was used, and the results of 36-hour forecasts in accordance with the scheme in [3] were taken as the future values at the boundaries of the first region with a 300-km interval.

Unfortunately, the results are not entirely comparable: ε, R and S_1 for the telescoped scheme were computed using 37 points, whereas for the other schemes 50 points were used, including these 37; in addition, S_1 for these three schemes was determined using a greater number of cases -- 67.

With respect to the relative error ε the telescoped scheme is appreciably poorer than the others. In our opinion, however, an exaggerated importance is attached to this evaluation, highly dependent on the quality of the forecast of the background, which is of little importance. For the weatherman-forecaster the gradients of the isohypses (wind) and the position of the pressure centers (the vertical gradients of pressure fields-temperature should also be evaluated) are far more important. S_1 is widely (and frequently by itself) used abroad as a statistical evaluation of a forecast of horizontal gradients. We note in passing that the other evaluations used abroad are not dependent on the background. The data in this part of the table show that S_1 is related most closely to the synoptic evaluation Δr (the schemes are arranged in the order of an increase in Δr; what place they would occupy with respect to ε, R and S_1 is shown; the N value characterizes the degree of difference of the corresponding arrangement of places from the initial place): the arrangement of the schemes with respect to S_1 and Δr is identical.

Distribution of Prognostic Schemes by Places in Dependence on the Quality Criterion (Schemes: T -- Telescoped, SHD -- Synoptic-Hydrodynamic [11], S -- Synoptic Operational Forecasts, R -- Regional Variant of Scheme [3], SIB -- Computation Center of the Siberian Department of the USSR Academy of Sciences [5], AMER -- United States National Meteorological Center [26], Q -- Quasigeostrophic [2])

Scheme	Δr	$\delta\Delta r$	ε			R			S_1			% of predicted new formations
For 33 forecasts of surface pressure for 24 hours in July-November with 44 pressure centers												
T	220	56	0,85	4	3	0,68	4	3	49,1	1	0	58
SHD	276	17	0,68	2	0	0,76	2	0	50,8	2	0	47
S	293	16	0,66	1	2	0,81	1	2	51,7	3	0	53
R	309		0,74	3	1	0,72	3	1	51,8	4	0	37
		N			6			6			0	
For 34 forecasts of surface pressure for 24 hours in March-May 1976 with 40 pressure centers												
S	292	30	0,75	3	2	0,72	3	2	49,3	2	!	59
SIB	322	2	0,93	5	3	0,69	4	2	52,9	4	2	50
AMER	324	6	0,64	1	2	0,80	1	2	45,6	1	2	59
SHD	330	35	0,70	2	2	0,73	2	2	50,0	3	1	41
Q	365		0,85	4	1	0,65	5	0	54,8	5	0	59
		N			10			8			6	
Same, but for forecasts for 36 hours (the quasigeostrophic scheme was not evaluated)												
SIB	370	28	1,12	4	3	0,68	2	1	58,7	2	1	55
AMER	398	7	0,65	1	1	0,71	1	1	51,8	1	1	61
SHD	405	28	0,83	2	1	0,60	4	1	62,2	3	0	57
S	433		0,88	3	1	0,62	3	1	62,7	4	0	71
		N			6			4			2	

Notations. Δr -- error (in km) in forecast of position of pressure centers, $\delta\Delta r$ -- difference in Δr between adjacent schemes; the first number in the ε, R, S_1 columns denotes the relative error, correlation coefficient and gradient error respectively (their determination was given in [17]), the second number is the place for the corresponding index, the third number is the deviation from the initial place with respect to Δr; N is the sum of the deviations.

In order to confirm the presence of a relationship between these two highly important characteristics, in this same table we give data obtained using materials from other tests [17]. Although the distribution of schemes with respect to Δr and S_1 now does not coincide (a precise coincidence in all cases, to be sure, is impossible: S_1 characterizes the structure of the entire field, and Δr characterizes only the position of singularities), the N value shows that here they are closest to one another.

From this point of view the telescoped scheme yielded fair results. It is considerably superior to other schemes with respect to Δr. The synoptic scheme is inferior to it even with respect to the prediction of new formations (as can be seen from the middle and lower parts of the table, in the tests of 1976 forecasts using other schemes did not surpass it in this respect).

We note that despite the prevailing opinion that the forecasts of the United States National Meteorological Center are the best with respect to all indices, in actuality this is not the case. The scheme developed by the Computation Center of the Siberian Department USSR Academy of Sciences gives better results with respect to the highly important synoptic characteristic Δr. Whereas in a forecast for 24 hours it surpasses the two subsequent schemes insignificantly, evidently within the limits of accuracy of the evaluations (and with respect to S_1 is appreciably inferior to them), in a forecast for 36 hours it is superior to all the schemes with a greater interval, although, to be sure, it occupies second place with respect to S_1. The poor ε value for this scheme is attributable simply to an unsuccessful forecast of the background.

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PREDICTION OF MEAN MONTHLY AIR TEMPERATURE FIELDS OVER THE NORTHERN HEMISPHERE USING AN AUTOMATED GROUP ANALOGUE SCHEME

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[Text]

Abstract: The article describes an automated scheme for adaptive statistical forecasting making use of the group analogues method. The authors describe the results of its application in numerical experiments for the long-range prediction of air temperature over the northern hemisphere. The authors discuss the form of representation of forecasts, including probabilistic, and give some evaluations of the success of experimental forecasts based on operational data.

Long-range weather forecasting is one of the principal aspects of modern meteorology [13], being of great importance for the national economy. Scientists in different fields of specialization are working on this problem, including those basing their work on the similarity principle [1, 16, 17]. Since with the passage of time the technical possibilities of automatic numerical schemes are broadening and the volume of archival data is increasing, the analogues method is still retaining its timeliness. Objective methods for the selection of analogues are being developed to an increasing degree, are being based on the methods of mathematical statistics and are being applied with the use of electronic computers [3].

One of the realizations of such an approach is the GRAN (group analogues) approach, described in the publications [4, 5]. The scheme developed for the M-222 computer is completely automated and standardized, as a result of which it can be used, in particular, not only in a forecasting regime, but also in a diagnosis regime, for example, in the meteorological interpretation of numerical (hydrodynamic) forecasts [9]. The scheme has found extensive application in solution of problems of a research nature. For example, on its basis it has been possible to obtain evaluations of predictability (within the framework of the analogues method) of some meteorological features [6, 10]; the prognostic information yield of individual predictors and their systems has been evaluated [8]; studies were made of a number of problems related to optimization of parameters of the scheme [7]. As a prognostic system the GRAN scheme is also suitable for practical forecasting.

Without repeating the detailed description of the scheme [4], we will only mention that the forecast is constructed here as a statistical description of a sample (group) of analogues, making it possible to formulate the forecast in a categorical and in a prognostic form. The sample of analogues is formed from archival data on the basis of the stipulated criterion of similarity of the characteristics of atmospheric processes designated at the input into the scheme. It goes without saying that the choice of the indicated criterion, like the content of the information on processes which is taken into account, to a considerable degree predetermine the success in solution of the formulated problem.

It should be noted that this scheme in all stages of preparation of the forecast affords the researcher information on the prognostic significance of the predictors used [11]. It is important that such information was provided for when using the scheme not only in a retrospective regime (for example, evaluations of the success of experimental forecasts on the basis of archival material), but also on a real time scale [12]. In obtaining and analyzing this sort of evaluations use was made of one of the problems in the experiments described below, directed to the development of a method for the long-range forecasting of air temperature over the northern hemisphere.

Since a decisive role in the formation of the large-scale fields of meteorological elements is played by thermal and circulatory factors, in the investigation use was made of data on the hemispherical fields of air temperature T_0 and pressure P_0 at sea level (1891-1976), and also on the fields of geopotential H_{500} at the 500-mb level (1949-1976).

It should be especially emphasized that this information does not seem to us to be adequate for successful solution of the forecasting problem, but only reflects our real possibilities at this stage in the research.

The initial information on the meteorological fields was represented in such a way as to ensure the possibility of a quantitative comparison of the processes (including with respect to their intensity) at different spatial-temporal scales. For this purpose we carried out averaging (denoted below by the operator E) of data along the circles of latitude of the Atlantic-European sector 40°W-100°E (conventional notation E^{λ}, AES) and over the area of large regions of the northern hemisphere (E^R, NH). Such averaging was carried out for the T_0 and P0 fields stipulated by the values at the points of intersection of a regular grid, but also the fields of the zonal (Γ_{λ}) and meridional (Γ_{φ}) components of their horizontal gradients. In addition, a study was made of the generalized parameters, to wit: the Ye. N. Blinova circulatory indices at the ground level (IP) and at the 500-mb level (IH), the characteristics of the high-level frontal zones in the northern (FZ_n) and southern (FZ_s) hemispheres, computed on an electronic computer on the basis of H_{500} diurnal data [2].

An analysis of the information content of the characteristics of the temperature and circulation regimes for the forecasting of temperature was accomplished in the process of two experiments (we will call them "experiment 1" and "experiment 2" respectively). In experiment 1 we used surface data on air temperature and pressure at sea level since 1891. Experiment 2 was broadened by the inclusion of data on

H_{500}, but the duration of the analyzed period was only 28 years (1949-1976). In accordance with the real possibilities (in particular, the speed of the M-222 electronic computer and computer time availability) for numerical experiments, a limited set of systems to be taken into account was stipulated on an a priori basis (Table 1).

The table shows that among the predictors we included the diurnal and mean monthly data (the latter are indicated in the table by the upper horizontal line over the designation of the element). The diurnal data were introduced for describing the initial conditions (state of current atmospheric processes at the ground level and at the 500-mb level on the last day of the compared months). In addition, the diurnal data in the form of 30-day segments of time series of circulation indices (IH, IP) and temperature at Moscow (TM), in our opinion, must characterize the tendency in the development of processes in the considered month (in the table they are supplied with the subscript "d").

All the data are represented with a time interval of 5 days (72 observations for each year). In the case of mean monthly data use was made of 30-day moving means. For temperature (due to the lack of diurnal data for the northern hemisphere for a long period) such means were obtained by linear interpolation of the mean monthly values.

The values of the parameters of the scheme (maximum number of analogues used, "threshold" of similarity, type of weighting function), which to a considerable degree determine the effectiveness of its use, were selected as a result of several specially undertaken studies of a methodological character [11]. With respect to the similarity indices, for the considered meteorological features we made use of Euclidean distance [8], since the experiments included only vectors with uniform components (horizontal field or segment of a time series of one meteorological element).

The testing period included the last 10 years (1967-1976). In experiment 1 the analogues were selected from the remaining part of the archives (1891-1966), whereas in experiment 2, due to the substantially lesser volume of observations in the archives the analogues in each case were selected from the entire series (1949-1976) with the exception of the tested year. In accordance with the local stationarity hypothesis [7], the analogues in the archives were selected with displacement in the limits of a month from calendar dates corresponding to the initial situation. This made it possible to increase the volume of the accessible observations and improve the quality of the analogues by taking into account processes occurring in adjacent calendar periods.

The experimental forecasts were compared for the winter and summer seasons. According to evaluations made earlier [8, 9], allowance for the long-term prehistory of development of atmospheric processes (within the framework of the information used) exerts an insignificant influence on the success of the forecasts. Therefore, in this investigation the choice of analogues was made on the basis of the characteristics of only one initial month (the data cutoff time was the last day of this month). As such a month for winter we chose December, and for summer --

June. The prediction was made with zero (in winter, for January, and in summer, for July) and one-month (for February and August respectively) advance times.

The prediction method was tested for three different territories: the extratropical zone of the northern hemisphere (72 points of a regular geographic grid in the zone 35-70°N), the lowland territory of the USSR (26 points of grid intersection) and seven administrative regions of the USSR [12]. A prediction was made for the normalized air temperature anomalies, the deviations from the mean long-term values, expressed in fractions of the standard deviation σ; the mean and σ were computed for the 30-year period (1931-1960) recommended in [18]. The total number of tested variants was 120 and the total number of evaluated forecasts was 1,080 (600 for winter and 480 for summer). Success evaluations were made for each forecast and as a whole for the entire period of the tests both for individual components of the predictants and as an average for the predicted vector.

It should be emphasized that no preliminary sorting-out of the predictors was made and therefore all the evaluations can be considered as obtained in an independent sample. Evaluations of the quality of the probabilistic forecasts are computed outside the GRAN scheme [14, 15] and will not be considered here.

It was found that the mean success of the methodological forecasts for different makeup of the information used was very stable. In Table 2, for some systems of predictors, we give one of the evaluations of quality of the categorical forecasts -- the mean square error δ (in the prediction of the normalized anomalies it was expressed in fractions of σ and was adequate at each field point to the relative error ε, and as an average for the field to the widely used criterion Q employed by long-range forecasters [1]). As a comparison, here we have also given the corresponding evaluations of climatic and random forecasts, as well as evaluations of the "optimum" analogues, which are selected a posteriori directly prior to the observed state of the forecasted phenomenon and characterize the "special predictability" of the temperature fields considered in this case. The methods for obtaining them are described in greater detail in [12]. The table shows that the errors in the methodological forecasts, averaged for the test period, for all the predictants are less than the random errors, do not attain the levels of "optimum" errors and as a whole are comparable to the evaluations of climatic forecasts.

The geographical distribution of evaluations of the quality of experimental forecasts for the territory of the northern hemisphere can be judged from maps of values of the mean square error δ and the success in forecasting the sign of the ρ anomalies (Fig. 1). Here we have defined (shading) regions of "successful" forecasts, corresponding to the arbitrary criteria $\delta < 1$ and $\rho > 0$. The figure includes the results for the system of predictors X1 (experiment 1) for a forecast for a month in advance for two seasons.

Similar maps for the system of predictors X4 and a zero advance time reveal a definite similarity in the geographical distribution of regions of "successful" forecasts, which can be regarded as indirect evidence of their stability. In this case the main territory of the Soviet Union does not fall in these regions and this is evidently attributable to the relatively great difficulty in making a forecast for these regions.

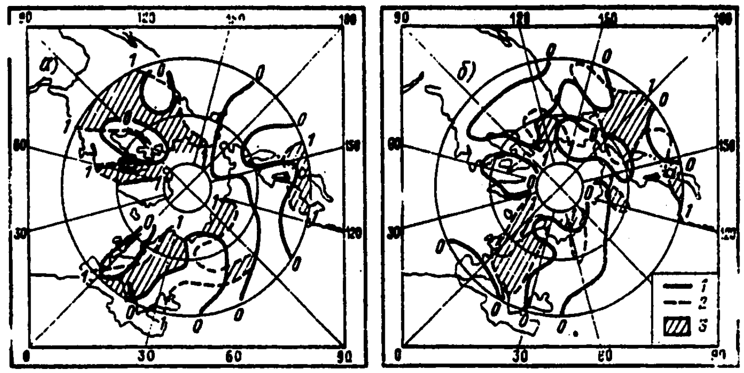

Fig. 1. Region of successful forecasts of mean monthly air temperature over northern hemisphere (35-70°N). a) winter (February); b) summer (August). 1) $\rho = 0$; 2) $\delta = 1$; 3) $\rho > 0$, $\delta < 1$.

Table 1

Group of Predictors for Numerical Experiments for Predicting Air Temperature

Meteorological information	File: characteristic	File: dimension	File: territory	Experiment 1 (1891—1966): X0	X1	X2	X3	Experiment 2 (1949—1976): X4	X5	X6	X7	X8	X9
Air temperature	$E^R\overline{T}$	27	NH	+	+		+	+	+	+	+	+	+
	$E^\lambda\ \Gamma_\lambda\ \overline{T}$	14	AES				+						
	$E^\lambda\ \Gamma_\varphi\ \overline{T}$	14	AES				+					+	+
	TM_d	30	Moscow				+						
Circulation at ground level	$E^R P$	27	NH		+	+	+				+	+	
	$E^\lambda\ \Gamma_\lambda\ P$	11	AES			+	+						
	$E^\lambda\ \Gamma_\varphi\ P$	11	AES			+	+						
	IP_d	30	NH			+	+				+	+	
Circulation at 500-mb level	$E^R H$	27	NH					+					
	$E^R\overline{\Pi}$	27	NH						+			+	+
	$\Phi З_c$	36	NH							+	+	+	+
	$\Phi З_ю$	36	NH							+	+	+	+
	IH_d	30	NH							+	+	−	+

C = N; Ю = S

In evaluating the results of these numerical experiments the conclusion can be drawn that the group analogues method when there is an informative system of predictors has a definite advantage in comparison with a climatic and especially a random forecast. Accordingly, there is a need for further investigations for seeking and analyzing the characteristics of atmospheric processes which must be taken into account in the evaluation of similarity, that is, for improvement in the system of predictors. Nevertheless, taking into account the real readiness of the GRAN scheme for use in routine work and for the purpose of accumulating prognostic experience, since 1979 attempts have been made to prepare forecasts on the basis of group analogues in a routine regime.

Table 2

Comparative Evaluations of Success (Mean Square Error δ) of Experimental Forecasts of Field of the Normalized Anomalies of Mean Monthly Air Temperature Over Different Territories in the Northern Hemisphere With Zero (τ = 0) and Monthly (τ = 1) Advance Times

Prediction method	Winter (1967—1976)						Summer (1967—1974)					
	35—70° N		USSR, plain		USSR, 7 regions		35—70° N		USSR, plain		USSR, 7 regions	
	τ=0 Jan	τ=1 Feb	τ=0 Jan	τ=1 Feb	τ=0 Jan	τ=1 Feb	τ=0 Jul	τ=1 Aug	τ=0 Jul	τ=1 Aug	τ=0 Jul	τ=1 Aug
Experiment 1												
Analogue group X0	1,17	1,41	1,33	0,94	1,03	0,81	1,46	1,46	1,24	0,91	0,80	0,83
Analogue group X1	1,16	1,41	1,31	1,02	1,02	0,86	1,57	1,51	1,23	1,16	0,77	0,83
Random forecast	1,46	1,65	1,43	1,24	1,11	1,00	1,72	1,68	1,67	1,28	0,94	1,07
Climatic forecast	1,16	1,40	1,27	0,96	1,00	0,83	1,56	1,48	1,21	1,09	0,78	0,80
Special predictability (analogue group Y)	0,96	1,19	0,55	0,39	0,38	0,24	1,31	1,28	0,62	0,53	0,30	0,37
Experiment 2												
Analogue group X4	1,08	1,32	1,33	0,89	1,05	0,73	1,32	1,33	1,22	1,11	0,79	0,79
Analogue group X8	1,08	1,31	1,27	0,98	1,03	0,84	1,28	1,28	1,29	1,08	0,84	0,79
Random forecast	1,43	1,60	1,45	1,26	1,10	1,01	1,65	1,64	1,45	1,31	0,94	0,97
Climatic forecast	1,05	1,24	1,19	0,91	0,95	0,77	1,30	1,31	1,20	1,06	0,77	0,77
Special predictability (analogue group Y)	0,88	1,12	0,55	0,44	0,41	0,35	1,14	1,08	0,70	0,63	0,77	0,77

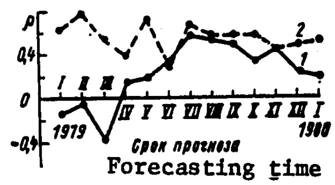

Fig. 2. Success of experimental categorical forecasts of sign of anomaly of mean monthly air temperature over northern hemisphere. 1) evaluations of forecasts based on routine data with month advance period (complex of predictors X0), 2) evaluations of individual predictability.

Since the effectiveness of different systems of predictors (within the framework of the used information) is approximately identical, for operational tests we selected the simplest variants in which the mean monthly smoothed fields (for 27 regions in the northern hemisphere) are used as initial information: only for air temperature (X0) and in combination with the surface pressure field (X1' in contrast to system X1, where the P_0 field was used for the last day of the month).

As the predictants we also included the field of normalized air temperature anomalies, smoothed over an area of 42 approximately equal-area squares in the zone 30-80°N. The evaluations of success of forecasts obtained for this variant for the main test period (1967-1976) are given in Table 3. We note that at the present time the preparation of forecasts by the proposed method under operational conditions is technically feasible only for a month in advance. Accordingly, evaluations of forecasts for a zero advance time are not given in this case.

The table shows that the mean evaluations for the test period differ substantially from the results in Table 2. We note that in individual, evidently extremal years the relative errors ε of both methodological and climatic forecasts increase sharply, indicating an increased difficulty in predicting such processes. Judging from the cited evaluations, some preference must be given to the system X0 in predictions for the territory of the northern hemisphere. Figure 2 shows the success of the forecasts using this system prepared on the basis of operational data for 1979.

A comparison of these evaluations with the evaluations for "optimum" analogues indicates that in the second half-year the forecasts to all intents and purposes attained a success "ceiling" which was the maximum possible within the framework of the existing archives. It must be remembered that analogues to the predictant were not selected using the ρ criterion, but instead the Euclidean distance δ, so that in the sense of the evaluation ρ curve 2 cannot be optimum, which is indicated, in particular, by the results for June 1979.

The content of the prognostic information issued using the GRAN scheme is shown in Table 4 in the example of a forecast of the normalized air temperature anomalies for seven regions of the USSR (a predictant of minimum dimensionality was selected). This information contains a climatic forecast (evaluations of "unconditional climatology," obtained for the entire period from which the selection of

Table 3

Evaluations of Quality (Relative Error ε and Success With Respect to Sign of ρ Anomalies) of Forecasts of the Normalized Anomalies of Mean Monthly Air Temperature for 42 Regions of the Northern Hemisphere With Advance Time of One Month

Month	Evaluation	Prediction method	Years (1967—1976)										
			1	2	3	4	5	6	7	8	9	10	Mean
February	ε	Analogue group X0	0.92	0.78	1,33	1,15	0.88	1,66	1.01	2,36	0.98	1,28	1,31
		Analogue group X1	0.90	0,79	1,36	1,10	0,92	1,62	1,02	2,40	0,88	1,28	1,31
		Climatic forecast	0.81	0.75	1,44	1,13	0,86	1,59	0.97	2,40	0,81	1,28	1,30
	ρ	Analogue group X0	—0,05	0.05	0.29	0,09	0,29	—0,05	—0.05	0,33	—0,29	0.14	0,08
		Analogue group X1	0.09	—0,09	0,38	0,19	—0,29	—0,05	0,00	—0,19	—0,33	0,33	0,00
August	ε	Analogue group X0	0.96	1,02	1,04	1,26	1,24	1,48	1,23	1,19			1,19
		Analogue group X1	1,01	1,16	1,10	1,26	1,27	1,64	1,22	1,23			1,25
		Climatic forecast	0,97	1,04	1,00	1,33	1,23	1,57	1,24	1,23			1,21
	ρ	Analogue group X0	0,09	0.05	0,09	0,19	0,09	0,09	0,00	0,09			0,09
		Analogue group X1	—0,14	—0,29	—0,19	0,19	0,00	—0,09	0,05	0,09			—0,05

Table 4

Fragment of Computer Prediction (Using GRAN Scheme) of Normalized Anomaly of Mean Monthly Air Temperature, Averaged for Area of Seven Administrative Regions in the USSR (Advance Time — One Month, Number of Analogues in Sample — 10)

Unconditional Climatology Evaluations (Statistical Characteristics of Initial Sample of Predictant)

№ of region	Mean	Standard deviation	max	min	Distribution quantiles						
					12,5%	25%	37,5%	50%	62,5%	75%	87,5%
1	−0,25	0,85	1,59	−1,97	−1,35	−0,90	−0,43	−0,21	−0,02	0,35	0,74
2	0,05	0,83	1,58	−2,26	−0,93	−0,49	−0,15	0,16	0,39	0,72	0,98
3	−0,03	0,79	1,27	−2,07	−0,81	−0,46	−0,24	0,01	0,26	0,51	1,03
4	−0,02	0,96	2,04	−2,80	−1,09	−0,68	−0,32	0,25	0,47	0,70	0,92
5	−0,17	0,81	1,70	−2,87	−1,05	−0,62	−0,36	−0,10	0,15	0,37	0,68
6	−0,09	0,78	1,56	−1,95	−1,06	−0,61	−0,22	−0,05	0,15	0,39	0,83
7	−0,15	0,68	1,51	−1,62	−1,03	−0,70	−0,42	−0,17	0,06	0,39	0,71

Equiprobable Gradations of Predictant for NGY = 5 (p = 0.200)

№	Limits to right					Middle of gradations				
	1	2	3	4	5	1	2	3	4	5
1	−1,1	−0,4	−0,1	0,5	4,0	−1,43	−0,59	−0,21	0,21	0,90
2	−0,6	−0,1	0,4	0,8	4,0	−1,06	−0,40	0,16	0,49	1,05
3	−0,6	−0,2	0,2	0,6	4,0	−0,94	−0,35	0,01	0,38	1,08
4	−0,9	−0,2	0,4	0,8	4,0	−1,13	−0,58	0,25	0,56	0,98
5	−0,7	−0,3	0,1	0,5	4,0	−1,22	−0,53	−1,10	0,30	0,75
6	−0,7	−0,2	0,1	0,6	4,0	−1,13	−0,49	−0,05	0,29	0,94
7	−0,8	−0,4	0,0	0,5	4,0	−1,08	−0,56	−0,17	0,27	0,76

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Evaluations of Dynamic Climatology (Adaptive Prediction for Sample of Analogues)

№	Statistical characteristics				Distribution quantiles						
	mean	standard deviation	max	min	12,5%	25%	37,5%	50%	62,5%	75%	87,5%
1	—0,24	0,92	1,20	—1,72	—1,53	—1,17	—0,44	—0,10	0,18	0,45	0,82
2	—0,27	0,89	1,24	—2,10	—1,42	—0,70	—0,45	—0,24	—0,00	0,47	0,77
3	—0,26	0,96	1,23	—1,92	—1,72	—1,05	—0,52	—0,01	0,15	0,30	0,92
4	—0,17	0,91	1,16	—2,36	—1,10	—0,72	—0,43	—0,09	0,42	0,54	0,78
5	—0,31	0,83	0,86	—1,91	—1,10	—0,87	—0,63	—0,56	0,25	0,51	0,73
6	—0,25	0,79	0,80	—1,59	—1,31	—1,19	—0,50	0,06	0,25	0,38	0,51
7	—0,36	0,72	0,59	—1,62	—1,25	—0,97	—0,81	—0,40	0,13	0,24	0,51

Precomputed Probability Distributions for Five Equiprobable Gradations

№	Limits to right					Probabilities				
	1	2	3	4	5	1	2	3	4	5
1	—1,1	—0,4	—0,1	0,5	4,0	0,248	0,158	0,099	0,256	0,239
2	—0,6	—0,1	0,4	0,8	4,0	0,310	0,291	0,051	0,250	0,098
3	—0,6	—0,2	0,2	0,6	4,0	0,309	0,149	0,194	0,157	0,191
4	—0,9	—0,2	0,4	0,8	4,0	0,202	0,241	0,207	0,255	0,094
5	—0,7	—0,3	0,1	0,5	4,0	0,257	0,358	0,000	0,099	0,286
6	—0,7	—0,2	0,1	0,6	4,0	0,359	0,047	0,098	0,402	0,094
7	—0,8	—0,4	0,0	0,5	4,0	0,359	0,147	0,052	0,346	0,096

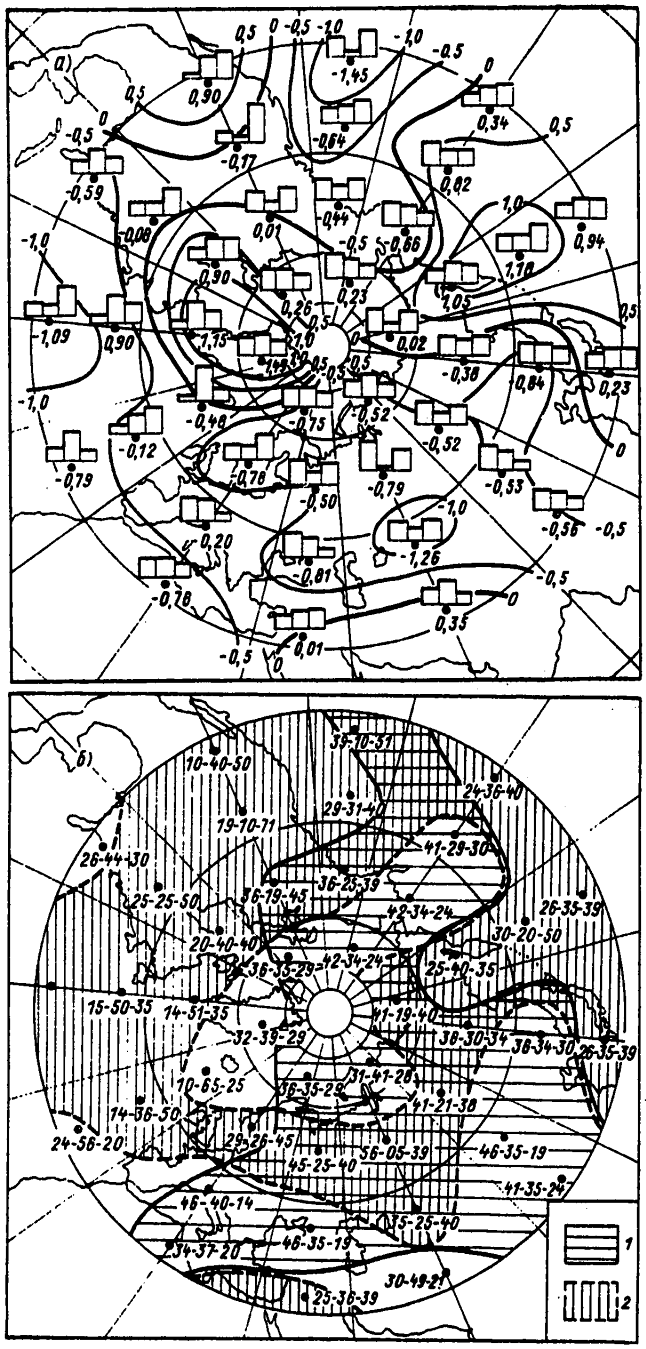

Fig. 3. (see top of next page)

Fig. 3. (see preceding page) Probabilistic forecast of normalized air temperature anomalies over the northern hemisphere based on three equiprobable gradations (forecast for January 1980 for a month in advance using the set of predictors X1').

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analogues is allowed, in this case 1891-1976) and an adaptive forecast on the basis of a sample of analogues (in this case with use of the system of predictors X1').

These two parts of the forecast are similar in content and are represented in terms of a full detailed statistical description of the corresponding samples through the statistical characteristics and distribution functions. The latter are given in the form of quantiles for stipulated probability levels and probability densities for the introduced gradients of the predictants. Here a categorical analysis corresponds to the one column "Mean" in the adaptive forecast.

Since probabilistic forecasts for the time being are not yet generally accepted, it is of interest to examine possible forms of their graphic representation. Figure 3 shows two variants of graphic representation of a probabilistic forecast of the distribution of normalized air temperature anomalies for the northern hemisphere. The basis for this table was a forecast for three equiprobable gradations, which can be interpreted as the gradations "below the norm," "near the norm" and "above the norm" respectively. The limits of the gradations were determined individually for each predictant as 33.3% quantiles of the unconditional distribution (with five gradations these are 20% quantiles, as, for example, in Table 4).

The histograms (Fig. 3a) show the precomputed probability distributions of the considered gradations at each field point. The numerical values corresponding to them are given in Fig. 3b. It is also useful to remember that for a climatic forecast all the probabilities would be equal to 1/3 and the histograms would have the form of a rectangle with the height 1/3. Figure 3b also shows regions where the predicted probability of the gradations "below the norm" and "above the norm" is greater than the climatic probability. We note that there are regions where the formed sample of analogues indicates an increased probability of occurrence of anomalies of both signs (corresponding to the area of cross-hatching). It is understandable that here the uncertainty of the categorical forecast (which would give a value close to the norm) is substantially higher. This can be attributed to the inadequately high quality of the selected analogues (in particular, due to the incomplete description of the initial state). It is possible that the forecast for these regions requires additional refinement (for example, by using analogues with a different system of predictors).

We emphasize in conclusion that these results reflect only the current level of use of the GRAN scheme for long-range forecasting. Further prospects may be afforded by the discrimination of regions responsible for the formation of weather conditions in specific regions and with the formation of group analogues with "regional" systems of predictors. As a result, a forecast for global territories (northern hemisphere or the USSR) will be formed by combining regional forecasts. Clearly such an approach involves solution of optimization problems in each current situation, which is possible with sufficiently high-capacity computers. In addition, later, in seeking analogues, allowance must be made for data on the underlying surface (ocean temperature and ice content, snow cover, etc.), atmosphere-ocean interaction, global cloud cover, etc.

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MODEL OF CLOUD COVER ON A STATIONARY FRONT

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[Text]

Abstract: Using numerical methods applied on an electronic computer it was possible to formulate a model of cloud cover formation on a stationary front. An evaluation was made of the influence of the temperature difference between warm and cold air, relative humidity of warm air, depth of the trough in which the front is situated, on the characteristics of frontal cloud cover: the altitude of its boundaries, horizontal extent, vertical liquid-water content profile, quantity of precipitation falling from a cloud, etc. It is shown that the model explains the principal features of the distribution of temperature with altitude and horizontally in frontal zones (in particular, the formation of a frontal temperature inversion).

It follows from earlier investigations [2, 4, 7] that the processes of redistribution of heat and moisture, as well as the formation of cloud cover, are influenced to the greatest degree by vertical movements, turbulent exchange and advective receipts of heat and moisture. As is well known, fronts are situated in troughs and therefore a convergence of air currents generated by the ascending movement of air, caused by turbulent friction, is associated with them. This, in turn, is accompanied by frontal cloud cover. The role of turbulence is great and generally recognized in the atmospheric boundary layer. However, in frontal zones under the influence of a horizontal temperature gradient there is a substantial wind shear and the generation of the energy of turbulent fluctuations is observed not only in the boundary layer, but also in the entire troposphere. However, if it is taken into account that the cloud formation process also favors an intensification of turbulent exchange (according to the experimental data in [8], the turbulence coefficient in clouds is greater than outside them and has an order of magnitude of several tens of meters per second), it becomes obvious that turbulence must be taken into account in formulating models of frontal cloud cover within the limits of the entire troposphere.

Although during recent decades less attention has been devoted to the study of fronts than during the first decades after the discovery of this phenomenon, nevertheless studies [1, 3, 6, 9-21] have been made along these lines. These have developed and deepened our concepts concerning the mechanisms of formation and structuring of frontal zones and the cloud systems associated with them.

This article is a development of [1, 2, 9]. In this article numerical methods are used in modeling the steady fields of frontal cloud cover, vertical movements and temperature under the influence of advective and turbulent influxes of heat, moisture and momentum, as well as the phase transitions of water vapor and the heat of condensation. In contrast to the mentioned studies, we do not stipulate the characteristics of turbulent exchange, these being extracted from the equation for the balance of turbulent energy and expressions established in similarity theory. In order to determine the wind velocity components use was also made of more complete equations (with conservation of inertial terms) than in studies made up to the present time.

Initial Equations and Expressions

Assuming that all the meteorological parameters and other characteristics do not change in the direction parallel to the front (plane problem) and in time (stationary front), we write the initial system of equations in the following form:

$$u \frac{\partial \Pi}{\partial x} + w \frac{\partial \Pi}{\partial z} = \frac{\partial}{\partial z} k \frac{\partial \Pi}{\partial z}, \tag{1}$$

$$\Pi = T + \gamma_a z + Lq/c_p, \tag{2}$$

$$u \frac{\partial s}{\partial x} + w \frac{\partial s}{\partial z} = \frac{\partial}{\partial z} k \frac{\partial s}{\partial z} - \frac{1}{\rho} \frac{\partial Q_k}{\partial z}, \tag{3}$$

$$s = q + \delta, \tag{4}$$

$$u \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial z} = 2\,\omega_z (v - v_g) + \frac{\partial}{\partial z} k \frac{\partial u}{\partial z}, \tag{5}$$

$$u \frac{\partial v}{\partial x} + w \frac{\partial v}{\partial z} = -2\,\omega_z (u - u_g) + \frac{\partial}{\partial z} k \frac{\partial v}{\partial z}, \tag{6}$$

$$\frac{\partial \rho u}{\partial x} + \frac{\partial \rho w}{\partial z} = 0, \tag{7}$$

$$u \frac{\partial b}{\partial x} + w \frac{\partial v}{\partial z} = \alpha_b \frac{\partial}{\partial z} k \frac{\partial b}{\partial z} - \frac{cb^2}{k} + k \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 + \left(\frac{\partial w}{\partial z} \right)^2 - \frac{g}{T} \frac{\partial \Theta}{\partial z} - 0{,}62 \frac{\partial q}{\partial z} \right], \tag{8}$$

$$\frac{dk}{dz} = \frac{k}{b} \frac{db}{dz} + \sqrt{c}\,\varkappa\,\sqrt{b}. \tag{9}$$

Here u, v, w are the projections of wind velocity onto the x-, y- and z-axes (the x-axis is directed along the normal to the front, in the direction of the cold air and the z-axis is directed vertically upward); T is air temperature; γ_α is the dry adiabatic gradient; L, c_p are the specific heat of condensation and heat capacity of air; Q_k is the flow of water droplets and ice crystals under the influence of gravity; q, δ are specific humidity of air and the liquid-water content of the cloud; s is the specific moisture content of cloud air; u_g, v_g are the components of the geostrophic wind along the x- and y-axes; $2\omega_z$ is the Coriolis parameter; ρ is air density; b, k are energy and the turbulence coefficient; g is the acceleration of free falling; θ is potential temperature; $\varkappa = 0.40, \alpha_b \approx 0.73$, c ≈ 0.046 are constants.

The equations for the inflow of heat (1) and moisture transfer (3) were written taking into account [7, 8]. The form of equation (3) indicates that in addition to advective, convective and turbulent moisture influxes we have taken into account the falling of droplets under the influence of gravity. The expression for the flow of water droplets and ice crystals has the form [8]

$$Q_k = -\rho(s - q_m)\tilde{v}, \qquad (10)$$

where $\tilde{v}$ is the mean weighted (by mass) velocity of falling of cloud elements, q_m is the specific saturation humidity.

For $\tilde{v}$ we used an expression cited in [5],

[B = upper; H = lower]

$$\tilde{v} = v_m \exp\left(-\beta \frac{z - z_H}{z_B - z_H}\right), \qquad (11)$$

where v_m is the maximum $\tilde{v}$ value, which can be attained at the lower boundary of the cloud z_{low}, z_{up} is the upper cloud boundary, β is a parameter characterizing the decrease of $\tilde{v}$ with altitude.

In a cloud system (1)-(9) is supplemented by the expression

$$q = q_m = 0{,}622\,\frac{E(T)}{P}, \qquad (12)$$

where E(T) is the saturating pressure of water vapor, P is air pressure, which is computed using the principal equation of statics.

The sought-for functions satisfy the following boundary conditions:

a) at the earth's surface (z = 0) $\quad u = v = \frac{\partial b}{\partial z} = 0,$

$$T(x, 0) = \bar{T} - \frac{\Delta T}{2}\,\mathrm{th}\,\frac{x}{D_T}, \qquad (13)$$

$$f(x, 0) = \bar{f} - \frac{\Delta f}{2}\,\mathrm{th}\,\frac{x}{D_f}, \qquad (14)$$

(15)

where T_1, T_2 are the air temperatures near the earth's surface in the warm ($x \to -\infty$) and cold ($x \to +\infty$) air masses; f_1, f_2 are the relative air humidities with these same values x; D_T, D_f are parameters with the dimensionality of length, characterizing the rate of change in temperature and relative humidity along the x-axis in the frontal zone,

$$\overline{T}=\frac{T_1+T_2}{2},\ \Delta T=T_1-T_2,\ \overline{f}=\frac{f_1+f_2}{2},\ \Delta f=f_1-f_2;$$

$$u_{g0}^{(1)}=u_{g0}^{(2)}=u_{g0}=\text{const}, \tag{16}$$

$$v_{g0}=\overline{v}_{g0}+\frac{\Delta v_{g0}}{2}\ \text{th}\ \frac{x}{D_v}, \tag{17}$$

where $u_{g0}^{(1)}$, $v_{g0}^{(1)}$ are the velocity components of the geostrophic wind along the x and y axes with $x\to-\infty$; $u_{g0}^{(2)}$, $v_{g0}^{(2)}$ are the same wind velocity components with $x\to+\infty$; D_v is a parameter with the dimensionality of length, characterizing the rate of change of the component v_{g0}; $\overline{v}_{g0}=\frac{v_{g0}^{(1)}+v_{g0}^{(2)}}{2}$, $\Delta v_{g0}=v_{g0}^{(2)}-v_{g0}^{(1)}$;

b) at the level of the tropopause $z = z_\infty$

$$T(x, z_\infty)=T(z_\infty)=\text{const}, \tag{18}$$

$$q(x, z_\infty)=q(z_\infty)=\text{const}, \tag{19}$$

$$b(x, z_\infty)=b(z_\infty)=0, \tag{20}$$

$$u(x, z_\infty)=u_g(z_\infty)=u_{g0}, \tag{21}$$

$$v(x, z_\infty)=v_g(x, z_\infty)=v_{g0}(x)\frac{T(z_\infty)}{T(x,0)}+\frac{gT(z_\infty)}{2\omega_z}\int_0^{z_\infty}\frac{1}{T^2}\frac{\partial T}{\partial x}dz; \tag{22}$$

c) at a sufficiently great (theoretically with $x\to-\infty$) distance from the front in a warm air mass

$$T(-\infty, z)=T_\infty(z)=T_1-\gamma_1 z, \tag{23}$$

$$q(-\infty, z)=q_\infty(z)=f_1 q_m(z), \tag{24}$$

where γ_1, f_1 is the vertical temperature gradient and the relative humidity in the warm air.

The expressions (14), (15) and (17) for a change in temperature, relative humidity and the component of the geostrophic wind near the earth's surface in dependence on x are in satisfactory agreement with the experimental data. These expressions ensure a continuous conversion from the T_1, f_1 and $v_{g0}^{(1)}$ in warm air to the T_2, f_2 and $v_{g0}^{(2)}$ values of the corresponding meteorological parameters in the cold air. The rate of change of the meteorological parameters near a surface front (that is, near x = 0) is determined by the parameters D_T, D_f and D_v: the lesser their values, the more rapid is the change in the corresponding meteorological parameter in the frontal zone and the lesser is the width of the frontal zone itself. With the symbols and notations adopted in (14) and (17) the differences $\Delta T = T_1 - T_2$ and $\Delta v_{g0} = v^{(2)}_{g0} - v^{(1)}_{g0}$ are always positive, since $T_1 > T_2$, and $v^{(2)}_{g0} > v^{(1)}_{g0}$ (in a clearly expressed, unmasked trough $v^{(2)}_{g0} > 0$ and $v^{(1)}_{g0} < 0$). The trough in which the front is situated is the deeper the greater the difference Δv_{g0}. [In accordance with the adopted terminology the term "front" will be applied to the line of intersection of a frontal surface with the horizontal plane.]

Results of computations. In carrying out most of the computations we assumed $T_1 = 20°C$, $\gamma_1 = 0.7°C/100$ m, $u_{g\,0} = 0.2\omega_z = 1.12 \cdot 10^{-4}$ sec^{-1}, the coefficient $\beta = 3$, the mean weighted rate of falling of cloud droplets $\tilde{v} = 13$ cm/sec (such a rate corresponds to the modal radius of droplets $r_m = 3$ m), $v^{(1)}_{g0} = -v^{(2)}_{g0}$, a roughness parameter $z_0 = 1$ cm (this parameter appears with stipulation of the turbulence coefficient at the ground: $k_0 = az_0$).

The rate of vertical movements and the field of liquid-water content of the cloud cover forming in the frontal zone are dependent on such parameters as ΔT, $\Delta v_{g\,0}$, f_1, D_v.

The results of the computations of vertical velocity at different distances x from a surface front and altitudes z with different ΔT values are given in Table 1. According to these data, with fixed x and ΔT the vertical velocity increases with an increase in z (for example, with x = 100 km and ΔT =5°C from 0.09 cm/sec at an altitude of 0.3 km to 2.75 cm/sec at 5 km). In warm air ($x<0$) and over a surface front (x = 0) vertical velocity is virtually not dependent on ΔT. With $\Delta T = 0°C$ at a fixed altitude the w field is symmetric relative to the front and the frontal surface in this case coincides with the vertical plane and at all altitudes the w maximum is attained with x = 0 (at the front). With an increase in contrast (ΔT) in temperatures the slope of the frontal surface decreases, with an increase in altitude the front is more and more displaced in the direction of the cold air and at the same time there is impairment of symmetry of the w field relative to the plane x = 0. For example, with ΔT = 5°C the vertical velocity at all altitudes with x = 100 km is greater than with x = -100 km (at an altitude of 1 km it is equal to 0.27 and 0.54 cm/sec, at an altitude of 3 km -- 0.34 and 2.65 cm/sec respectively). With ΔT = 10°C the w field is displaced still more in the direction of the cold air (because of this the vertical velocity at a distance x = 300 km with ΔT = 10°C at all altitudes is greater than with ΔT = 5°C). However, also in the presence of a temperature contrast ($\Delta T > 0$) the w maximum is attained over a surface front (with x = 0). Qualitatively this is attributable to the fact that the most substantial convergence of wind velocity is observed in the lower layer near a surface front (x = 0); the vertical velocity generated by this convergence exceeds the velocity arising under the influence of wind convergence at higher levels (where a front with high x values are found). This also explains the weak dependence of w on ΔT with $x \leqslant 0$.

Since wind convergence is dependent on the D_v parameter, its change is accompanied by a change in w. An increase in D_v from 50 to 100 km is accompanied near the surface front by a decrease in w by a factor of approximately 2 (with the values of the parameters used in Table 1 the vertical velocity near x = 0 decreases from 0.91 to 0.44 cm/sec at an altitude of 0.3 km, from 4.13 to 2.05 cm/sec at 1 km, from 4.24 to 2.08 cm/sec at 4 km).

Table 1

Vertical Velocity Values (cm/sec) with $\Delta v_{g\ 0}$ = 20 m/sec, $u_{g\ 0} = 0$, f_1 = 70%, $D_T = D_V$ = 50 km

x км	z км							
	0,3	0,5	1,0	2,0	3,0	4,0	5,0	6,0
				ΔT=0°C				
—100	0,10	0,18	0,27	0,31	0,34	0,36	0,38	0,40
0	0,91	2,68	4,13	4,21	4,23	4,24	4,25	4,26
100	0,10	0,18	0,27	0,31	0,34	0,36	0,38	0,40
300	0,00	0,00	0,00-	0,00	0,01	0,02	0,03	0,05
				ΔT=5°C				
—100	0,10	0,18	0,27	0,31	0,34	0,36	0,38	0,40
0	0,91	2,68	4,13	4,21	4,23	4,24	4,25	4,26
100	0,09	0,16	0,54	1,77	2,65	2,72	2,75	2,77
300	0,00	0,00	0,00	0,02	0,11	0,29	1,04	1,27
				ΔT=10°C				
—100	0,10	0,18	0,27	0,31	0,34	0,36	0,38	0,40
0	0,91	2,68	4,13	4,21	4,23	4,24	4,25	4,26
100	0,15	0,63	1,30	1,72	1,73	1,74	1,75	1,75
300	0,00	0,00	0,07	0,51	1,09	1,51	1,87	1,92
500	0,00	0,00	0,00	0,05	0,12	0,45	0,71	1,34

It is also physically obvious that the greater the difference $\Delta v_{g\ 0}$ of the components of the geostrophic wind parallel to the front, the greater is the wind velocity convergence (since the deviation of the wind from the geostrophic is proportional to v_g) and, accordingly, the greater is the vertical velocity. According to computations, an increase in $\Delta v_{g\ 0}$ from ~10 to 20 m/sec is accompanied (with $D_T = D_V$ = 50 km, f_1 = 70%) by an increase in the maximum w values observed in the upper troposphere) with x = -100 km from 0.19 to 0.41 cm/sec, with x = 0 from 2.12 to 4.28 cm/sec, with x = 100 km -- from 0.19 to 0.41 cm/sec (ΔT = 0), from 1.47 to 2.78 cm/sec (ΔT = 5°C) and from 1.14 to 1.77 cm/sec (ΔT = 10°C), with x = 300 km -- from 0.90 to 1.33 (ΔT = 5°C), from 1.08 to 1.97 cm/sec (ΔT = 10°C), with x = 500 km -- from 1.01 to 1.39 cm/sec (ΔT = 10°C).

The distribution of the liquid-water content of clouds is in agreement with the distribution of vertical velocities. The distribution of cloud liquid-water content is influenced not only by vertical movements, but also turbulent exchange and the heat of condensation. The thickest cloud cover is formed in the neighborhood of the surface front ($x \approx 0$). Figure 1 shows the dependence of the absolute liquid-water content of a cloud on altitude with x = 0 and different f_1 and D_V. The cloud cover is the thicker the greater the relative humidity of the warm air. With f_1 equal to 60-70% only middle- and upper-level cloud cover with a liquid-water content not exceeding 0.1 g/m^3 is formed. Fronts with such a cloud cover are observed, for example, in summer in Central Asia.

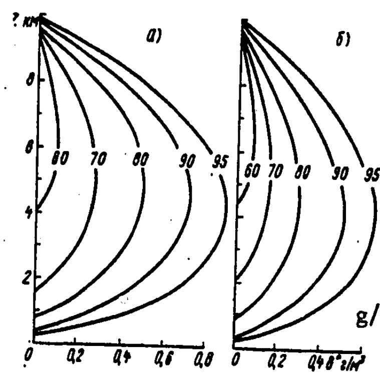

Fig. 1. Distribution of absolute liquid-water content of cloud with altitude for different f_1 and D_v and fixed x = 0, ΔT = 10°C, $\Delta v_{g\ 0}$ = 20 m/sec, v_m = 13 cm/sec, Δf = 0. a) D = 50 km; b) D_v = 100 km. The figures on the curves are $f_{1\%}$ values

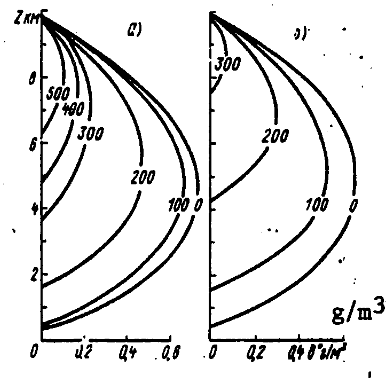

Fig. 2. Distribution of absolute liquid-water content with altitude with different x and ΔT and fixed $\Delta v_{g\ 0}$ = 20 m/sec, v_m = 13 cm/sec, $f_1 \cong$ 90%, Δf = 0, D_v = 50 km. a) ΔT = 10°C; b) ΔT = 5°C. The figures on the curves are values x (in km).

In the case of a high relative humidity (80-95%) thick stratonimbus cloud cover is formed with maximum values of liquid-water content (observed in the middle troposphere) of about 0.6-0.8 g/m³. Since with an increase in D_v the vertical velocity over the surface front decreases, the transition from the distribution of absolute liquid-water content shown in Fig. 1a (D_v = 50 km) to the distribution in Fig. 1b (D_v = 100 km) is accompanied by a decrease in the liquid-water content of the cloud (with f_1 = 80% the maximum liquid-water content δ_m^* is 0.50 g/m³ with D_v = 50 km and 0.29 g/m³ with D_v = 100 km).

Figure 2 makes it possible to trace the boundaries, thickness and vertical profile of liquid-water content of frontal clouds as a function of distance to a surface front. The thickest cloud cover is formed near a surface front (x = 0 and x = 100 km). With increasing distance from the surface front the lower boundary of the cloud cover increases (if ΔT = 10°C, then from 330 m with x = 0 to 1670 m with x = 200 km and 3650 m with x = 300 km), whereas the liquid-water content decreases (with this same ΔT = 10°C the maximum δ_m^* value is from 0.72 g/m³ with x = 0 to 0.47 g/m³ with x = 200 km and 0.22 g/m³ with x = 300 km).

The temperature difference ΔT between the warm and cold air (near the ground) exerts the greatest influence on the horizontal extent of the cloud system and the slope of the frontal surface. Near the surface front ($x \approx 0$) the characteristics of the cloud cover with ΔT = 10°C (Fig. 2a) and ΔT = 5°C (Fig. 2b) are close to one another (the altitude of the lower boundary is about 330 and 450 m, δ_m^* -- 0.72 and 0.67 g/m³ respectively). However, already with x = 100 km and especially with x ≥ 200 km there is a substantial difference in the parameters of cloud cover with $\Delta T = 10°C$ and $\Delta T = 5°C$. For example, with x = 200 km the altitude of the lower boundary is 1670 m in the first case and 4300 m in the second, δ^*_m -- 0.47 and 0.25 g/m^3. With an increase in ΔT, as follows from Fig. 2, the extent of the cloud system along the x-axis (perpendicular to the front) increases: with $\Delta T = 5°C$ it is 330 km, with $\Delta T = 10°C$ — 620 km.

Such a change in the horizontal dimension of the cloud system is closely related to the slope of the frontal surface. We will evaluate it on the basis of the altitude of the lower boundary of cloud cover at a stipulated distance from the surface front.

According to Fig. 2, the tangent of the slope of the frontal surface at different distances from the surface front is as follows:

x km	0–100	100–200	200–300
$\Delta T = 5°C$	$1.20 \cdot 10^{-2}$	$2.65 \cdot 10^{-2}$	$3.30 \cdot 10^{-2}$
$\Delta T = 10°C$	$0.27 \cdot 10^{-2}$	$1.20 \cdot 10^{-2}$	$1.90 \cdot 10^{-2}$

According to these data, the slope of the frontal surface has the same order of magnitude (10^{-2}–10^{-3}) as according to experimental data. These results are in qualitative agreement with the well-known thesis of the Margules theory: the slope of the frontal surface decreases with an increase in the contrast of temperatures ΔT of air masses. There should not be a complete quantitative correspondence between the Margules theory and our data because the Margules formula (according to which the slope of a frontal surface is inversely proportional to ΔT) was obtained for the case of geostrophic movement and absence of an influence of the heat of condensation, turbulence and vertical currents on the temperature field.

Table 2

Water Reserve (kg/m^2) of Frontal Clouds With Different ΔT, f_1 and x and Fixed Δv_{g0} = 20 m/sec, $\Delta f = 0$, $D_i = D_T = 50$ km Without Allowance (Numerator) and With Allowance (Denominator $v_m = 13$ m/sec) for the Falling of Precipitation

ΔT°C	f_1 %	x km: 0	100	200	300	400	500
10	80	24,70 / 3,03	23,39 / 2,33	11,76 / 1,02	4,26 / 0,30	1,44 / 0,19	0,36 / 0,04
	90	35,82 / 4,49	34,14 / 4,00	18,66 / 2,59	6,13 / 0,95	2,43 / 0,55	0,72 / 0,23
		42,19 / 5,87	40,09 / 5,51	24,94 / 3,99	9,69 / 1,92	3,45 / 0,89	1,14 / 0,49
5	80	23,67 / 2,79	20,08 / 1,52	7,49 / 0,35	2,22 / 0,03	—	—
	90	30,45 / 4,25	27,76 / 2,89	12,89 / 1,10	3,34 / 0,13	—	—
	95	39,7 / 5,62	36,61 / 4,43	19,51 / 2,12	3,78 / 0,34	—	—

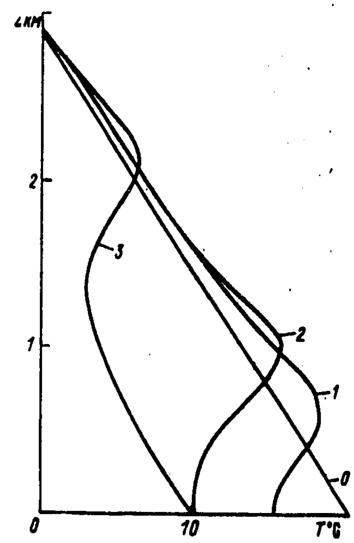

Fig. 3. Vertical temperature profiles at different distances from surface front. 0) $x = -\infty$; 1) $x = 0$; 2) $x = 100$ km; 3) $x = 200$ km. $\Delta v_{g\,0} = 20$ m/sec, $v_m = 13$ cm/sec, $f_1 = 90\%$, $\Delta f = 0$, $D_v = D_T = 50$ km.

Moreover, we should note the change in slope of the frontal surface as a function of distance x to the surface front. In the diagrams given in monographs and textbooks (beginning from the first studies of the founders of frontological analysis V. Bjerknes, T. Bergeron and others) a frontal surface is represented in such a way that its slope with an increase in x decreases (at a sufficiently great distance the frontal surface in these diagrams is horizontal). However, according to our data cited above the slope of a frontal surface increases with increasing distance from the surface front (for $\Delta T = 5°C$ from $1.20 \cdot 10^{-2}$ in the interval $x = 100$ km to $2.65 \cdot 10^{-2}$ and $3.30 \cdot 10^{-2}$ in the intervals 100-200 and 200-300 km). This is attributable to the fact that with an increase in x the horizontal difference in temperatures between the warm and cold air decreases. With such a change ΔT with height the slope of the frontal surface must increase with an increase in x. The results of modeling confirm this conclusion. [It is true that it is not entirely clear why earlier no attention was given to this circumstance since on the basis of the Margules formula and the fact that ΔT decreases with height it would have been possible to draw the very same conclusion.]

It is of interest to evaluate the quantity of precipitation falling from frontal clouds. For this purpose computations were made of the water reserve in clouds (the mass of droplet water in a column of a unit section falling below the lower and upper cloud boundaries) without allowance for ($\tilde{v} = 0$) and with allowance for ($\tilde{v} \neq 0$) the falling of cloud elements. The results of the computations are presented in Table 2. It can be seen that the water reserve of a cloud system is dependent on f_1, x and ΔT (it increases with an increase in f_1 and ΔT and decreases with increasing distance from the surface front. The falling of precipitation exerts a great influence on the water reserve of clouds. Thus, near the surface front ($x \approx 0$) with f_1 = 90% and ΔT = 10°C the water reserve of a cloud decreases under the influence of precipitation from 35.82 to 4.49 kg/m^2. This means that from such a cloud during the entire time of its existence a quantity of precipitation equal to 35.82 - 4.49 = 31.33 kg/m^3 falls, that is a layer of water with a thickness of about 31 mm. With an increase in distance from the surface front the quantity of precipitation decreases. For example, at x = 400 km and with the same f_1 and ΔT only 2.43-0.55 = 1.88 mm of precipitation falls.

The heat of condensation released in the process of cloud cover formation exerts a substantial influence on the distribution of temperature with height. Figure 3 shows the vertical temperature profiles in a warm air mass (with $x = -\infty$) and at three distances (x = 0, x = 100 and x = 200 km) from a surface front. Over the surface front (x = 0) and at a small distance from it (x = 100 km) a temperature inversion begins with a low height (100-200 m). With x = 200 km the frontal temperature inversion is situated in the layer from 1400 to 2100 m.

The vertical temperature gradients in the layer adjacent to the frontal inversion from above exceed the moist-adiabatic values. As a result convective movements can develop in the main mass of stratiform clouds and these in turn lead to the formation of convective cloud cover -- a phenomenon which is frequently observed [19-21] in frontal zones.

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EVALUATION OF THE EFFECTIVENESS OF ANTIHAIL PROTECTION IN BULGARIA

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[Text]

Abstract: Making use of the physicostatistical method for evaluating the effectiveness of antihail protection, on the basis of observational data for the territory of the People's Republic of Bulgaria protected against hail, the authors have derived a regression equation relating the area of hail falling to the energy of atmospheric instability. It is shown that the breakdown of data into four classes with respect to the intensity of hail events results in a decrease in the mean square error.

In order to test the least squares method proposed in [1] for computing the predictable losses from hail in a protectable area under the condition of absence of protection we employed an approach to evaluation of the economic effectiveness of hail protection developed in [5]. In this approach the loss from hail is characterized by the area of crops damaged by hail (P, in hectares), and as the predictor of loss we propose use of instability energy $\Delta T_{\Sigma} = \Delta T_{500} + \Delta T_{700}$ (in which the $\Delta T_{500,\,700}$ is the difference between the curves of state and stratification at the altitudes 500 and 700 gPa).

The curve of state was computed taking into account the displacement of the cloud medium with ambient air in the layer below 850 gPa and wind convergence in the surface layer [4].

In the computations we employed tabulated data for P and in some cases the data series was lengthened by adding days with unsuccessful modification efforts. In order to ascertain the predictable value of crop area damaged by hail P^* we constructed the linear prognostic relationship

$$P^* = \overline{P} + \alpha\,(\Delta T_{\Sigma} - \overline{\Delta T_{\Sigma}}). \qquad (1)$$

For determining α in place of P^* and ΔT_Σ we substituted the values from [5] and minimized the sum of the squares of the deviations of the real value from the predicted value:

$$\Delta = \sum_i [P_i - \overline{P} - \alpha (\Delta T_\Sigma - \overline{\Delta T_\Sigma})]^2 = \min. \tag{2}$$

By equating the derivative $d\Delta/d\alpha$ to zero, we find

$$\alpha = K_{\Delta T_\Sigma P} \sigma_P / \sigma_{\Delta T_\Sigma}. \tag{3}$$

Here K_{xy} is the correlation coefficient between x and y; σ_P, $\sigma_{\Delta T_\Sigma}$ are the standard deviations. The line denotes averaging.

In the first variant of the computations the coefficients of equation (1) were determined directly from data on the energies and areas of hail falls during some months and the prognostic equations derived in this way were checked using the materials for the same month or other periods. The results of the computations are given in Tables 1 and 2. We should note the rather high correlation between P and ΔT_Σ. Table 2 gives the results of computations of the predicted area of damaged crops using the derived prognostic relationships (1).

In general, the use of the prognostic relationships for a teaching sample (for these same periods) gives a lesser relative mean square error than for control samples (for other periods). The only exception is the prediction for July using combined data for May and June. The use of the prognostic relationship for May in the prediction for June, July and August leads to a relative mean square error of more than 100%.

Table 2 also gives the mean values of the absolute positive and negative errors $\Delta P_\pm = \overline{(P - P^*)}_{P^* > P,\ P^* < P}$ and the frequencies of the positive and negative differences $P - P^*(n_\pm)$, and also $n_{<0}$) -- the number of negative P^*. In general, the positive and negative errors for the teaching samples were distributed more symmetrically than for the control data. For the latter an exaggeration of the areas of the hail falls in the forecast was also more probable.

A comparison of individual predicted and real values reveals the presence of negative area values for small real areas. The presence of negative values of the predicted areas is evidence of the unsatisfactoriness of use of relationships of type (1). This is evidently associated with several factors. First, a linear forecast of type (1) is optimum only for normally distributed values, which is evidently poorly satisfied for the areas. Second, the linear correlation between instability energy and the areas of damaged crops poorly reflects the empirical fact, following from the primary data, that a change in instability energy by several degrees leads to a change in area by one-two orders of magnitude. Third, evidently, there is not a sufficiently close correlation between convective activity in the different months of one year and one and the same month of different years. Fourth, the physics of hail formations from different clouds evidently can differ greatly, as a result of which there are systematic, not random differences between the losses from hail falling from different clouds.

It is therefore of interest to carry out a classification of the data not with use of a time criterion, but on the basis of the intensity of convective activity and the areas of hail falls.

Taking into account everything stated above, we made a second series of computations. In order to exclude systematic differences between situations with different ΔT_Σ and P all the cases were divided into four classes:

I -- weak hail falls; $P < 10^2$ hectares, number of cases $n_1 = 16$; $5.8°C < \Delta T_\Sigma < 7.0°C$.

II -- average hail falls; 10^2 hectares $< P < 10^3$ hectares; $n_2 = 51$; $5.9°C < \Delta T_\Sigma < 10.2°C$.

III -- strong hail falls; 10^3 hectares $< P < 10^4$ hectares; $n_3 = 28$; $9°C < \Delta T_\Sigma < 13.8°C$.

IV -- catastrophic hail falls; $P > 10^4$ hectares; $n_4 = 4$; $\Delta T_\Sigma > 16°C$.

Above we have indicated the intervals of change ΔT_Σ with breakdown of data on the basis of areas of hail falls. In order to evaluate with what degree of reliability there is a ΔT_Σ breakdown with a breakdown with respect to P, after a data analysis we introduced the following instability energy values separating different classes of data: weak hail falls $\Delta T_\Sigma < 6.9°C$; average hail falls $7°C < \Delta T_\Sigma < 10°C$; strong hail falls $-10°C < \Delta T_\Sigma < 14°C$; due to the small number of cases of catastrophic hail falls they could not be separated from strong hail falls on the basis of the ΔT_Σ criterion. Proceeding on the basis of our data it can be assumed that catastrophic hail falls occur with $\Delta T_\Sigma > 14-15°C$.

As a measure of the reliability of separation using the ΔT_Σ criterion we will employ the values $\omega = 1 - \rho/n$, where ρ is the number of cases when on the basis of area a particular case belongs to one class, whereas according to instability energy it belongs to another; n is the number of cases in the class. Elementary estimates have shown that the probability of a breakdown by instability energy between weak and average hail falls is 94%, between average and weak -- 90%, between average and strong -- 90%, between strong and average -- 75%.

In order to take into account the first two comments made above, the prognostic equation in the second series of computations was used in the following form:

$$\ln P^* = \beta(\Delta T_\Sigma - \overline{\Delta T_\Sigma}) + \overline{\ln P}; \quad (4)$$

$$\beta = K_{\Delta T_\Sigma \ln P} \, \sigma_{\ln P} / \sigma_{\Delta T_\Sigma}. \quad (5)$$

The coefficients of equation (4) and the results of computations for the teaching samples are given in Table 3. In contrast to Table 2, the negative prognostic values have completely disappeared. Due to the use of stratification data it was possible to achieve a considerable decrease in the absolute and relative mean square errors (for average and strong hail falls -- up to 40%). The relatively low correlation coefficient ($K_{\Delta T_\Sigma \ln P} = 0.19$) for weak hail falls is attributable to the fact that with low instability energies there is a strong variability of the areas of hail falls. This in turn is partially attributable to the spottiness of the falling of hail when there are weak hail falls, which makes it difficult to ascertain their areas on the basis of data from the state warning service.

Table 3 also gives the mean absolute errors and their frequencies. The different areas when the forecast gives lesser and greater values than the real extents are observed with an approximate equal probability, but in absolute value the excess of the real values over the computed values is greater than the excess of the computed values over the real values. This means that a prognostic equation of type (4) with a high probability will understate the area of the damaged crops for individual hail falls.

On the basis of this investigation it was possible to recommend the following formulas for determining the predicted area of sown crops damaged by hail in the Byrdarskiy polygon:
P^* (hectares) = $1.224\ e^{0.506\Delta T_\Sigma}$ for $\Delta T_\Sigma < 6.9°C$ (weak hail),
where P^* (6.9°C) = 40 hectares;
P^* (hectares) = $11.176\ e^{0.439\Delta T_\Sigma}$ for $7°C < \Delta T_\Sigma < 10°C$ (average hail),
where P^* (7°C) = 224 hectares; P^* (10°C) = 906 hectares;
P^* (hectares) = $66.948 e^{0.3292\Delta T_\Sigma}$ for $10°C < \Delta T_\Sigma < 14°C$ (strong hail),
where P^* (10°C) = 1801 hectares; P^* (14°C) = 6719 hectares.

Due to the small number of cases of catastrophic hail falls it is impossible to obtain prognostic equations. On the basis of data for the Byrdarskiy polygon it can be assumed that if $\Delta T_\Sigma = 14°C$ it is necessary to expect area of damage greater than 10^4 hectares.

The derivation of similar formulas for computing the losses (in rubles) was not accomplished because the cost of agricultural production can vary from year to year.

The adopted classification of hail falls to a certain degree is of an arbitrary character due to the arbitrariness of choice of the separating values of the areas and differs from the classification proposed in [6], where the processes are divided into weak, medium and high energy phenomena ($\Delta T_\Sigma < 9°C$; $9°C < \Delta T_\Sigma < 12°C$; $\Delta T_\Sigma > 12°C$ respectively). If data are classified on the basis of ΔT_Σ in accordance with [4, 6], it is possible to achieve a fair separation also with respect to areas, but in each of the groups there will be cases with areas differing by a factor of more than 10. Such a situation cannot be met since it is natural that processes with an approximately equal instability energy resulted in close areas of hail falls if the hail processes developed over territories with a similar arrangement of agricultural fields.

The data classification which we used is in some correspondence with the analysis made in [5], according to which there is complete suppression of processes with ΔT_Σ = 6-8°C; it is also possible to achieve complete suppression of some processes with ΔT_Σ up to 10°C; the suppression of processes with $\Delta T_\Sigma < 12°C$ is partially possible, but it is impossible to suppress those with $\Delta T_\Sigma > 12°C$. According to [5, 6], with $10°C < \Delta T_\Sigma < 12°C$, and in some cases also with $12°C < \Delta T_\Sigma < 14°C$, by means of modification it is possible to suppress hail only from some of the totality of hail-dangerous clouds, specifically, from clouds from which weak hail falls, which gives a small contribution to the total losses. Comparing these data with our classification, it can be asserted that modification will be completely successful if an area of hail fall from them of less than 100 hectares is

Table 1

Parameters of Prognostic Expression (1)

Time period for which coefficients of equation (1) were determined	Length of data series	$\sigma_{\Delta T_\Sigma}$ °C	σ_P га hectares	r га °C hectares	$\bar{P}$ га hectares	$\overline{\Delta T_\Sigma}$ °C	$K_{\Delta T_\Sigma P}$	Time period for which prognostic expression is used	Notes
May	18	1,84	626,3	305,7	660	3,10	0.90	May, June, July, August	All parameters were computed from shortened data series. The prognostic expression was applied to the shortened data series
June	43	2,8	4319	1359	2195	9,73	0,87	June	Full set of data was used
July	25	2,2	2461	1036	1767	8,82	0,93	July	Full set of data was used
August	11	2,5	4852	1819	1832	8,71	0,91	August	Same
May+June	42	2.5	4245	1126	1446	8,74	0,87	May+ June, July, August	Parameters were computed from shortened data series, The prognostic expression was applied to the shortened data series

Table 2

Results of Computations Using Equation (1)

"Teaching" month	Control month	$\bar{P}^*$ hectares	σ hectares	δ	$n_{<0}$	n_+	n_-	ΔP_+	ΔP_-
May	May	748	318	0,48	2	8	10	508	563
May	June	1073	3527	1,73	0	11	13	2641	498
May	July	853	2003	1.17	0	12	7	1504	266
May	Aug	1488	5758	1,88	3	5	6	2025	1026
June	June	2530	1426	0,65	12	17	26	2995	1319
July	July	1765	918	0,52	6	14	11	660	836
August	Aug	1830	1712	0,93	4	5	6	1668	1387
May + June	May+ June	1447	1818	1,26	15	21	21	1303	1306
May+ June	July	1500	758	0,44	4	11	8	609	541
May+June	Aug	1701	3171	1.73	2	4	2	2403	720

Note. $\sigma = \sqrt{\Delta}$ is the mean square forecasting error, $\delta = \sigma/\bar{P}^*$ is the variation coefficient.

expected; modification makes it possible to prevent the falling of hail from clouds, the expected area of hail falls from which is more than 100, but less than 10^3 hectares. If the anticipated area of the hail falls is more than 10^3, but less than 10^4 hectares, in some cases it is possible to lessen the intensity of hail falls from individual clouds. However, if the anticipated area of hail falls exceeds 10^4 hectares, the method employed does not yield a positive result.

From the point of view of the physics of hail falls, what has been said above can be interpreted as follows. For weak processes ($P < 100$ hectares, $\Delta T_\Sigma < 6.9°C$) the hypothesis of a competition of natural and artificial hailstones during modification work is applicable. For processes of intermediate intensity (10^2 hectares $< P < 10^3$ hectares, $7°C < \Delta T_\Sigma < 10°C$) this hypothesis is not applicable to all clouds. For strong processes (10^3 hectares $< P < 10^4$ hectares) this hypothesis is entirely inapplicable to any cloud, but in some clouds hail is partially formed by a mechanism which allows the attenuation of a hail fall by the creation of a competition of hail nuclei, but at the same time a hail growth mechanism is operative in the cloud to which the competitive modification mechanism is inapplicable. Finally, for catastrophic hail falls the competitive modification mechanism is completely inapplicable.

Table 3

Parameters of Equation (4) and Results of Computations

Data class	$\overline{P}$ hectares	$\overline{\ln P}$	$\overline{\Delta T_\Sigma}$ °C	$\sigma_{\ln P}$	$\sigma_{\Delta T_\Sigma}$ °C	$K_{\Delta T_\Sigma \ln P}$	β	$\overline{P}^*_{2a}$	σ_{2a}	δ	n_+	n_-	ΔP_+	ΔP_-
I	41	3,42	6,4	0,85	0,32	0,19	0 506	31	27	0,66	8	8	14	33
II	391	6,02	8,0	0,76	1,08	0,67	0,439	376	208	0,41	23	28	142	242
III	6912	7,79	10,9	0,60	1,43	0,78	0,329	5162	1133	0,38	16	12	495	1122

The ideas set forth here agree with the computations of hail growth made in [2, 3], according to which for clouds with not excessively strong ascending currents hail is formed by the classical quasi-one-dimensional mechanism allowing modification by the competition of artificial and natural hail nuclei. In the case of clouds with strong ascending currents this hail-forming mechanism ceases to be operative and hail grows for the most part at the cloud periphery with movement along cyclic trajectories, the number of which is determined by cloud dynamics, not by cloud microphysics. With intermediate velocities of the ascending flow a contribution to hail formation can be made by both mechanisms.

It can therefore be postulated that the classical quasi-one-dimensional theory of hail growth is completely applicable to weak processes and to some processes of intermediate intensity. Both hail-formation mechanisms are operative in some processes of intermediate and strong intensity and modification makes it possible to suppress only one of them. In the remaining strong processes and in all processes leading to catastrophic hail falls the cyclic mechanism of hail growth is operative and the usual method for lessening their intensity by the introduction of crystallizing reagents in them is inapplicable.

Thus, our investigation indicated that the classification of data on the basis of the intensity of hail falls or on the basis of convective activity can substantially increase the reliability of the formulas for predicting those areas of hail falls in a protected territory which would exist in the case of absence of hail protection.

It is desirable that the derived formulas be checked on the basis of control data for the Byrdarskiy polygon and the entire approach to computations of the predictable loss -- for other regions.

It is also desirable to carry out physical measurements in hail clouds for the purpose of confirming and refining the proposed classification of hail falls.

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UDC 551.(553.21:576)(267)

VARIATIONS IN THE INTENSITY OF THE INDIAN SUMMER MONSOON ACCORDING TO CLOUD COVER DATA FROM SATELLITES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 55-61

[Article by A. K. Devan, Moscow State University, manuscript received 19 Dec 80]

[Text]

Abstract: On the basis of a spectral analysis of time series of daily cloud cover observations from satellites in the summer of 1974 a study was made of the characteristics of variations in the intensity of the summer Indian monsoon. The results of an analysis confirm the facts known earlier concerning the presence in the monsoon of variations of a global scale with a period of 2-3 weeks and variations of a synoptic scale with a period of 3-10 days. In processes at a synoptic scale it is possible to discriminate two types of variations with a period of 3-6 days, associated with monsoonal depressions and weak systems (monsoon lows), and with a period of 7-10 days, associated with deep depressions and storms. On the basis of a spectral analysis of the spatial-temporal characteristics of a monsoon it was possible to define two types of waves in a monsoon: synoptic waves, moving to the west, and also waves moving to the west and south, associated with variations having a 13-17-day period. The macroscale variations of a monsoon occur under the influence of the latter two types of global waves on a quasistationary monsoonal system.

The variations in intensity of the Indian summer monsoon are examined in this article on the basis of observations of cloud cover from satellites with use of spectral analysis of stationary random processes.

Only a few studies [2, 6, 9, 10] have been devoted to monsoonal variations. A more detailed study of this problem in comparison with earlier investigations, and also the use of satellite data on cloud cover in the analysis, has made possible the additional detection of some important peculiarities in the spatial-temporal characteristics of the summer monsoon.

Characteristics of Data and Processing Method

The material used in this study consisted of daily photographs of cloud cover from satellites during the summer (April-October) 1974 for the northern and southern hemispheres [8]. The region selected for the investigations, bounded by 20°S and 35°N and 40 and 120°E, was broken down into squares with sides 5° in latitude and longitude. A total of 176 such squares were defined. The quantity of clouds in each of the squares was estimated in tenths (the case of presence of a continuous cloud cover was assigned the value unity) on the basis of daily photographs from a satellite. These data formed a time series of 178 daily cloud cover observations.

In order to ascertain the temporal characteristics of processes whose duration varies from several days to a month it was necessary to discriminate low-frequency variations. For this purpose a cosine filter was used in filtering variations with periods $T > 50$ days. The temporal characteristics were determined by means of spectral analysis in accordance with [3, 5]. Using these data we computed the autospectra, cross-correlation spectra, cross-coherencies of processes, and also the phase differences between processes for the squares situated in the considered region. The spectral analysis algorithm included a fast Fourier transform (FFT), whose fundamental principles were formulated by Cooley and Tukey [7]. The simplest application of this method is obtained when the number of terms in the series is a power of 2. In the particular analysis 25 terms were excluded from both the beginning and end of the time series. Thus, the working time series includes 128 (2^7) cases. The computations were made using a BESM-6 electronic computer.

Results of Investigations

Using the method described above, we computed the spectra of cloud cover time series for 176 5° squares in the considered territory.

An analysis of cloud cover spectral density functions for each square shows that the spectra have extrema (peaks) of variations with several periods varying from 3 to 25 days. A study was made of the frequency of recurrence of cases of the presence of peaks for all frequencies. It was found that the greatest frequency of peaks in the spectra falls in two ranges of periods: 2-3 weeks and 3-10 days.

Adhering to the A. S. Monin classification [4], in atmospheric processes, in accordance with their scale, it is possible to discriminate two types: global and synoptic. In this study processes with periods of variations 2-3 weeks are considered global and variations with periods 3-10 days are considered synoptic.

It should be noted that in the cloud cover density spectra relating to a synoptic scale there are two maxima of the frequency of recurrence of peaks: about 4 and about 8 days. This indicates that in the synoptic process there are two types of main variations: variations with periods of 3-6 days, associated with tropical depressions and weak low-pressure systems (monsoon lows) and variations with periods of 7-10 days, associated with extensive tropical depressions and storms.

Variations with periods 2-3 weeks (processes on a global scale). The cloud cover dispersions were computed in an investigation of monsoonal variations with a period of 2-3 weeks (Fig. 1a).

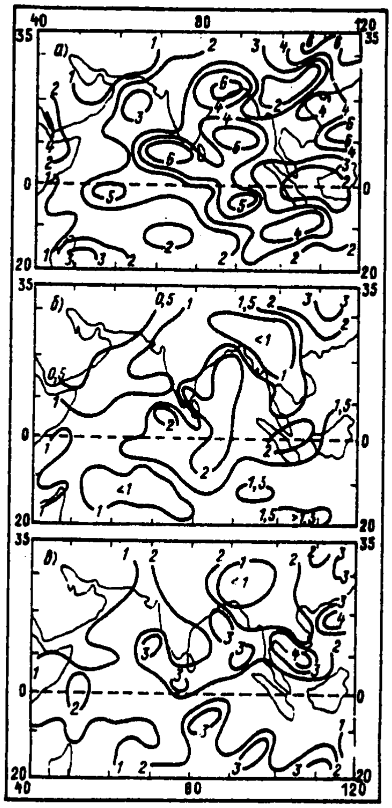


Fig. 1. Maps of dispersion of cloud cover with periods of 2-3 weeks (a), 3-6 days (b) and 7-10 days (c).

By analyzing the map in Fig. 1a it is possible to detect the peculiarities of the geographical distribution of activity of processes at this scale.

The greatest variations of a monsoon with a great amplitude, reflected in the cloud cover field, occur over some regions which are the most active regions of the monsoon.

For example, a region with a high dispersion of cloud cover, situated to the north of 18°N, corresponds to the region of the Indian monsoon in the period of alternation of its active and weak phases. This region includes the northern part of the Bay of Bengal and is bounded by the mountain ranges and desert region of Northwestern India.

The second region of a high cloud cover dispersion is situated to the south of 15°N. In this region the maximum dispersion values are observed over the central part of the Bay of Bengal (10-15°N), the South China Sea (10-15°N) and the southeastern part of the Arabian Sea (5-10°N) and are determined by the intensification of cyclonic activity in these regions. Over the southwestern part of the Bay of Bengal, near the equator, there is also a high dispersion value caused by the position of the ICZ here.

The third region of high dispersion is observed over southern and southeastern China and in all probability is associated with variation of cloud cover during the passage of extratropical fronts.

Still another region of relatively high dispersion is situated in the southern hemisphere near the equator in the form of a narrow zone with three maxima between longitudes 55 and 60, 90 and 95, 105 and 110°E. The first two maxima are situated in the latitude zone 0-5°S, and the last in the zone 5-10°S. This region of a relatively high dispersion corresponds to the position of the southern branch of the ICZ.

Thus, in the considered territory, on the basis of high dispersion values, it is possible to discriminate four regions in which processes of a global scale with a period of variations 2-3 weeks are most active.

In [1] it was found that in the weak phase of a monsoon the northern branch of the ICZ is displaced from the region of Central India and the northern part of the Bay of Bengal to the south and is situated over the southern part of the Bay of Bengal. In this connection it can be postulated that macroscale variations of a monsoon are also associated with the advance of the ICZ.

We note the complex distribution of the dispersion of cloud cover over the land when it is more or less zonal over the oceans. Figure 1a shows that the dispersion over the mountain regions is low. Such a distribution of dispersion reflects the characteristic thermal characteristics of the land and sea, and also the influence of the mountain ranges of Southern Asia on circulation during the period of the southwestern monsoon.

Over the Iranian Plateau and over the desert regions there is a predominance of small cloud cover, and as can be seen in Fig. 1a, the dispersion of cloud cover is also insignificant. Over the western Arabian Sea and the eastern coast of Africa there is also a low dispersion. In all probability this is attributable to the fact that over this region in the lower troposphere during summer there is a predominance of transport of warm dry air from the southern hemisphere, the so-called "Somali jet." As a result, a convergence zone is not formed here. However, the ascent (upwelling) of cold water along the Somali coast also does not favor the development of convection over this region of the ocean.

Variations with periods of 3-6 days (processes of a synoptic scale). Maps of the dispersion of cloud cover with a period of 3-6 days (Fig. 1b) and with a period of 7-10 days (Fig. 1c) were compiled for an examination of the spatial characteristics of synoptic processes.

Figure 1b shows that the region of a high dispersion is bounded by the isoline 1.5 units. In the northern hemisphere this region occupies the entire Bay of Bengal, Andaman Sea, northern Sumatra, Malaysia, South China Sea and then extends over Eastern China. Over the eastern part of the Arabian Sea the region of high cloud cover dispersion values is represented by a small sector to the south of 10°N and to the east of 70°E.

The high dispersion values over the Bay of Bengal are in accordance with the intensive cyclonic activity characteristic of this region in summer.

The variability of cloud cover over the regions of southeastern China is associated with cyclonic activity on extratropical fronts.

Figure 1b shows that over the continent there are low cloud cover dispersion values. It follows from this that weak dynamic systems, forming over the oceans, attenuate with transition to the land. This, in turn, confirms the reliability of the assertion that processes with periods of variation of 3-6 days are associated with weak depressions.

Processes of a synoptic scale with a period of 7-10 days. As already mentioned, disturbances of this class include deep depressions and tropical cyclones (storms).

An analysis of the cloud cover dispersion distribution (Fig. 1c) shows that the most active region for synoptic processes with a period of 7-10 days is bounded by the two isolines 2.0 units and is situated in the form of a narrow band along the coast of South and Southeast Asia from 60 to 120°E. Over the Bay of Bengal this zone bifurcates. One branch reaches to the northwest, onto the land, and takes in a large part of India; the other branch passes through the southwestern part of the Bay of Bengal and seemingly encircles the Hindustan Peninsula.

It is interesting to note that the first branch of this zone coincides with the paths of movement of tropical depressions and storms generated over the northern part of the Bay of Bengal. It is known that only deep depressions and storms can penetrate onto the land, whereas weak depressions rapidly attenuate with passage onto the land. Thus, the distribution of cloud cover dispersion (Fig. 1c) in the region of the Bay of Bengal is evidence that synoptic processes with a period of variations 7-10 days are associated only with tropical disturbances of a great intensity.

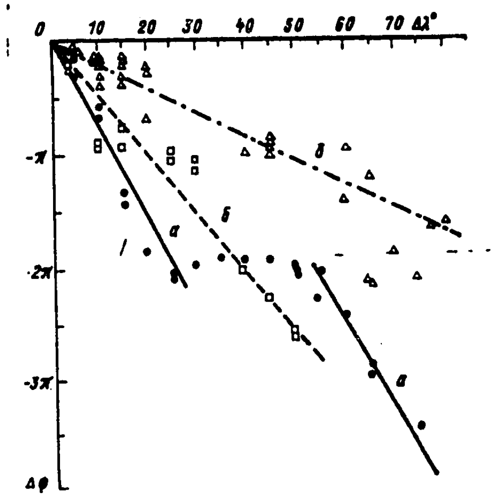
In the zone of high dispersions of cloud cover (>2) there are individual centers with maximum dispersion values. This indicates that these regions are characterized by an intensive cyclonic activity. Thus, the existence of a region of high cloud cover dispersions over the South China Sea is associated with typhoons forming under the influence of cyclonic activity over the Pacific Ocean in the Pacific Ocean branch of the ICZ.

It follows from an analysis of Fig. 1c that over the equatorial region of the southern hemisphere the activity of disturbances with a period of 7-10 days is not great, except for the region between 80-90°E. A small region of considerable dispersion in the southeast of the investigated region is evidently associated with the passage of Trade Wind fronts.

It can be seen on maps of the distribution of cloud cover dispersion for global and synoptic processes that in the northern hemisphere the dispersion values are greater than in the southern hemisphere. It follows from this that atmospheric processes in summer in the tropical and subtropical zones of the northern hemisphere transpire more intensively than in the southern hemisphere. In the summer Indian monsoon the northern branch of the ICZ is more active than the southern branch, which causes intensive tropical cyclogenesis in the zone of the northern branch of the ICZ.

We note that synoptic processes with a period of variations in the cloud cover field 3-6 and 7-10 days are intensive almost in the same regions where global processes with a period of variations 2-3 weeks are intensive.

A. V. Kislov and Ye. K. Semenov [2] discovered 2-3-week and 3-6-day variations in the cloud cover field over the Indian Ocean basin on the basis of data for the summer of 1971. The distribution of dispersions during the course of this period coincides with the distribution obtained in this study. However, variations with a period of 7-10 days were not discovered in 1971, which evidently is attributable to a weak monsoon and therefore deep depressions with a period of 7-10 days were not formed frequently.



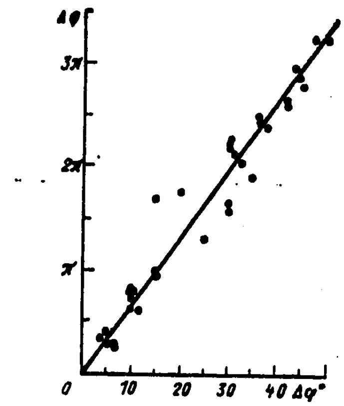


Fig. 2. Phase difference as a function of longitude. a) T = 4-6 days (along 15-20°N), b) T = 4-6 days (along 10-15°N), c) T = 13-17 days (along 10-20°N).

Fig. 3. Phase differences $\Delta\Psi$ as function of latitude along zone 80-100°E for variations with period 13-17 days.

Similar variations in monsoonal intensity were also investigated in [9, 10] by an analysis of other meteorological elements and for a different series of years. The conclusions from the above-mentioned studies confirm that the monsoonal variations considered in this article are not random for 1974 and are characteristic for the Indian monsoon.

Some spatial-temporal characteristics of monsoon. Using cross-spectral analysis we examined some spatial characteristics of a monsoon associated with its temporal variability. In order to ascertain the spatial-temporal characteristics along the circles of latitude we computed the phase difference spectra and the cross-coherency spectra for all latitude zones relative to different points in the squares in this zone. Such points were taken in the meridional zone 115-120°E. Similar computations were made along the direction of the meridian relative to points in the latitude zone 15-20°N. In an analysis of the phase difference use was made of values with a coherency exceeding 0.58 and the evaluation of the phase difference spectrum had a reliability greater than 80%.

Figure 2a shows a graph of the phase difference $\Delta\Psi$ along the circles of the latitude zone 15-20°N, and Fig. 2b -- a graph of the phase difference along the circles of the latitude zone 10-15°N for variations with periods 4-6 days. It can be seen that the phase difference decreases with an increase in the distance from the "initial" point (square) in a westward direction. This shows that there is a zonal wave of a synoptic scale which moves to the west. In Fig. 2a it should be noted that approximately from 85 to 70°E the phase differences remain constant. Such a "break" in the $\Delta\psi$ function over the continent is evidence that in this latitude zone (15-20°N) disturbances with periods of 4-6 days attenuate with transition from the Bay of Bengal onto the land. To the west of 70°E disturbances form again and move toward the west. These synoptic waves have a length of 30-40° in longitude and a phase velocity of 4-10° longitude per day. The conclusion can be drawn from this that weak disturbances move from the western part of the Pacific Ocean in a westerly direction in the form of zonal waves and the development of tropical depressions over the monsoonal region occurs as a result of the effect of a quasistationary monsoonal wave on these synoptic waves.

The phase differences were also used in studying waves associated with variations with a period 13-17 days. Figure 2c shows a graph of the phase difference change for processes in the latitude zone 10-20°N. The wave detected in the analysis moves from east to west; its length is about 100° longitude and its velocity is 6-8° longitude per day. The existence of this wave reflects the influence of Pacific Ocean systems of atmospheric circulation on the monsoon.

Table 1

Characteristics of Zonal and Meridional Waves

Period, days	Region, direction of movement	Length	Phase velocity
4-6	10-15°N, to west	40° longitude	7-10° longitude/day
4-6	15-20°N (Bay of Bengal), to west	30° longitude	4-6° longitude/day
4-6	15-20°N (Arabian Sea), to west	30° longitude	5-7° longitude/day
13-17	10-20°N, to west	100° longitude	6-8° longitude/day
13-17	80-100°E, to south	35° latitude	2-2.5° latitude/day

Figure 3 is a graph of the phase difference of processes with a period of variations 13-17 days along the longitude zone 80-100°E relative to squares in the southern hemisphere in the zone 15-20°S. The figure shows that the phase difference increases with an increase in distance from the indicated initial zone in a northward direction. This shows that in the region at the meridians of the Bay of Bengal there is a meridional wave moving from north to south. It is characterized by a wavelength of 35° latitude and a phase velocity 2-2.5° latitude per day. In the regions to the east and west of the zone 80-100°E no such a wave was observed. The characteristics of the zonal and meridional waves are given in Table 1.

The existence of a meridional wave reflects the interaction of circulation in two hemispheres. It is interesting to note that the cloud cover variations over the northern part of the Bay of Bengal are in antiphase with its variations over the equator and over Tibet (Fig. 3). This indicates feedbacks between the intensity of the northern branch of the ICZ and the southern branch and also with cyclonic activity over the Tibet region. It also follows from an analysis of Fig. 3 that cloud cover variations over the regions between 10-20°S are in the same phase with variations over the northern part of the Bay of Bengal.

An analysis of the phase differences of processes of a global scale over the meridians of Indochina indicates that processes over Indochina are in antiphase relative to processes in the equatorial region of the southern hemisphere. This indicates an alternating activity of processes in the northern and southern branches of the ICZ. This relationship between the two ICZ branches was also determined in [2].

It is difficult to explain the mechanism of variation of the macroscale monsoonal system. However, the presence of zonal and meridional waves in the monsoonal atmosphere reflects the fact that the powerful quasistationary monsoonal circulation experiences macroscale variations as a result of the effect of these two moving waves on it.

It can be concluded on the basis of these materials that the variations of the macroscale system of a monsoon are related to the global circulation system.

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KARA-BOGAZ-GOL GULF AND THE CASPIAN SEA PROBLEM

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 62-68

[Article by F. S. Terziyev and N. P. Goptarev, candidates of geographical sciences, State Oceanographic Institute, manuscript received 5 Aug 80]

[Text]

Abstract: A study was made of the influence of Kara-Bogaz-Gol Gulf on the water and salt balances, level and salinity of the Caspian Sea in connection with the separation of the gulf from the sea by a blind dam. The implementation of this measure is evaluated as one of the links in the problem of regulation of the Caspian Sea. The article sets forth the basis of the scientific program for investigating the processes of dessication of the gulf and the possible changes in the natural conditions in the gulf region.

The Kara-Bogaz-Gol Gulf, situated amidst the deserts of the eastern shore of the Middle Caspian, exerts a great influence on the water and salt balance of the Caspian Sea (Fig. 1). With the high sea level prior to the beginning of the 1930's, according to data published by B. D. Zaykov [2], the runoff of Caspian waters into the gulf often exceeded 20 km^3 annually. From the beginning of the 20th century to the present time, due to runoff into the gulf, the Caspian has lost more than 1,000 km^3 of water, which is equal to three water volumes of the Sea of Azov, or converted to a water layer, related to the mean area of the sea for the period, is about 3 m. Due to the sharp reduction in sea level beginning after 1930, the runoff of water into the gulf began to decrease considerably. In the 1940's, despite a relative stabilization of sea level in connection with erosion of the channel of Kara-Bogaz-Gol Strait, the runoff of water into the gulf increased appreciably (Fig. 2).

Beginning in 1960, and until recently, there has been an extremely stable linear relationship between the mean volume of runoff of Caspian waters into the gulf and the sea level, which is expressed by the equation

$$Q_{KBG} = 7.43\ H_B + 219.7,$$

where Q_{KBG} is the annual volume of water runoff into the gulf, km^3, H_B is the mean annual sea level at Baku.

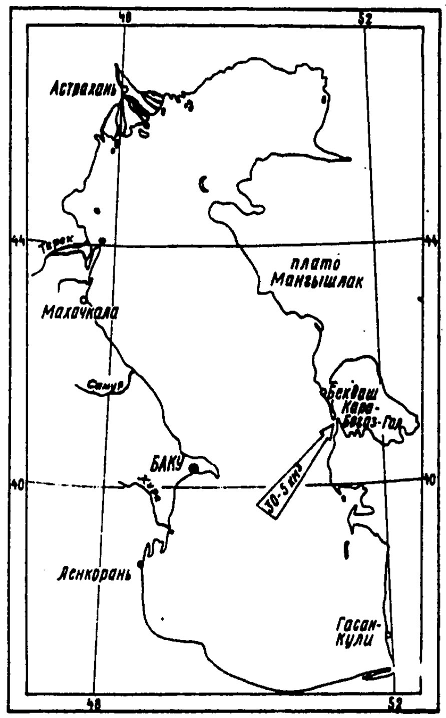


Fig. 1. Caspian Sea and Kara-Bogaz-Gol Gulf.

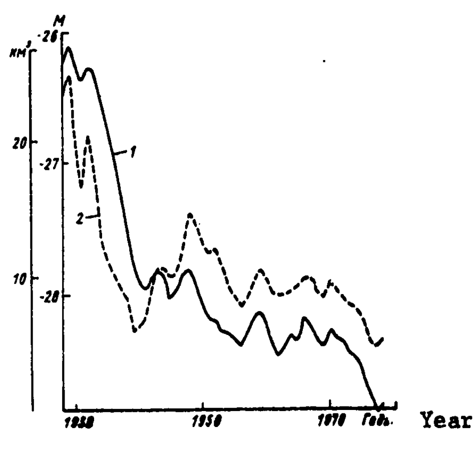


Fig. 2. Chronological variation of level of Caspian Sea (1) and runoff of water into Kara-Bogaz-Gol (2).

By the end of the 1970's the water runoff into the gulf had been reduced to 5-7 km^3/year.

The water losses during the last 50 years since the time of the sharp dropoff in the level of the Caspian Sea, expressed in a water layer, amounted to more than 1 m.

Kara-Bogaz-Gol Gulf, as a singular natural feature, long ago began to attract the attention of Russian researchers. The first scientific expedition under the direction of A. Bekovich-Cherkasskiy, sent out by Peter I in 1715 for study of the Caspian Sea, compiled the first map of the gulf with an indication of depths.

Later, in 1832-1834 and 1836, G. S. Karelin carried out numerous surveys and depth measurements of Kara-Bogaz-Gol also along the eastern shores of the Caspian Sea and on the basis of these materials drew conclusions on the reasons for the existence of a permanent current from the sea into the gulf.

Lieutenant I. D. Zherebtsov in 1847 completely explored the gulf in a steamship and made many astronomical determinations and surveys and refined prevailing concepts concerning the gulf.

Thereafter expeditionary investigations of the Kara-Bogaz-Gol and adjacent regions were made by O. A. Grimm (1874 and 1876), N. I. Andrusov (1894) and I. B. Shpindler (1897).

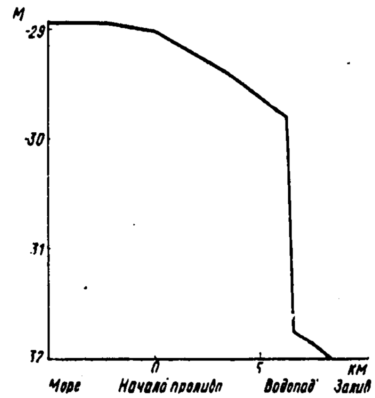
The Kara-Bogaz-Gol attracted the particular attention of researchers and industrialists as a source for the production of chemical raw material, especially mirabilite, after the results of studies of a participant on the Shpindler expedition (1897), the chemist A. Lebedintsev, became known. Already in 1910 the working of shore deposits of mirabilite had begun.

Thereafter interest in the Kara-Bogaz-Gol became still more intense. In 1918 a Kara-Bogaz-Gol Committee was established in the Academy of Sciences under the chairmanship of Academician N. S. Kurnakov, and in 1929 -- the special trust "Karabugazsul'fat" was established, as well as the All-Union Institute of Halites. At a later date the problems of the Kara-Bogaz-Gol were studied by the Institute of General and Inorganic Chemistry USSR Academy of Sciences, etc.

The Hydrometeorological Service also broadened its specialized investigations of the Kara-Bogaz-Gol, directing them to solution of practical problems in connection with the discovered close dependence of the production and refining of chemical raw materials on hydrometeorological factors: water level in the gulf and sea, water discharges through the strait, salinity, air temperature and humidity, evaporation, wind, etc. Systematic hydrometeorological observations in the gulf region have been made since the early 1920's. Despite the great efforts of researchers, the geographical, hydrochemical and physicochemical characteristics of the Kara-Bogaz-Gol have still to a large extent remained uninvestigated. The principal reason for this is the considerable variability of the gulf's regime, caused by variations in the level of the Caspian Sea, changes in the channel of the strait connecting the gulf to the sea, and in the last analysis, changes in the inflow of

Caspian waters into the gulf.

Prior to the beginning of the 1930's, when the level of the Caspian Sea was relatively stable, the area of the gulf, according to data from a number of authors, varied in the range 18,000-19,000 km^2. The sometimes observed considerable variations in sea level and water runoff into the gulf had little effect on the area of the gulf because due to the predominance of the high shores of the gulf they were reflected for the most part in the height of the level and the volume of water in the gulf.



Sea Beginning of strait Water-fall Gulf

Fig. 3. Profile of water level in Kara-Bogaz-Gol Strait (according to expeditionary investigations of the Azerbaijan Republic Administration of Hydrometeorology and Environmental Monitoring in September 1978).

Due to the later sharp reduction in sea level which occurred, the runoff of Caspian waters into the gulf decreased considerably and the area of the gulf also began to decrease. According to data published by Dzens-Litovskiy [1], in the early 1960's the area of the gulf was reduced to 10,000 km^2. These data are confirmed by surveys of the gulf from the American satellite "TIROS-5" on 22 June 1962. According to approximate computed estimates, the modern area of the gulf with an annual runoff of 5-6 km^3 of water into it should be 6,000-7,000 km^2.

With a decrease in level of the sea and a decrease in water runoff into the gulf the level differentials between the Caspian Sea and the gulf are increasing.

In the late 1930's the mean annual difference in levels between the sea and the gulf attained 60-70 cm. The passage of ships in and out of the gulf was stopped in November 1937 when at the time of a storm the depth in the strait at the bar situated before the entrance into the gulf was sharply reduced. Earlier the depth in the main channel of the strait had been maintained by dredging (about 4.5 m).

According to data from expeditionary investigations carried out by the Azerbaijan Republic Administration of Hydrometeorology and Environmental Monitoring in August-September 1978 in connection with the proposed separation of Kara-Bogaz-Gol Gulf from the Caspian Sea by a blind dam, the level differential between the sea and gulf was more than 3 m and the height of the "waterfall," that is, the difference in water levels over the sill of the strait and the water level in the gulf, was more than 2 m (Fig. 3).

As we have already noted, the Kara-Bogaz-Gol Gulf, an enormous natural evaporator, exerts a considerable influence on the water balance and level of the Caspian Sea. For example, of the total dropoff in level during the period 1970-1977 of 0.065 m more than 20% is accounted for by the runoff of water into the gulf.

The influence of the gulf on the salt balance and salinity of the Caspian Sea is less impressive, although the runoff of salts into the gulf is the principal factor in salt balance losses. With a great runoff into the gulf about 250-350 million tons of salt annually are carried into the gulf from the sea. This should lead to a decrease in sea salinity by 0.003-0.004^{o}/oo annually, that is, by 0.3-0.4^{o}/oo per 100 years.

With a runoff of 5-10 km^3 annually, 65-130 million tons will be carried into the gulf, which should freshen the sea by 0.0008-0.0017^{o}/oo per year, that is, by 0.8-1.7^{o}/oo per thousand years.

In a historically conceivable time frame there may be some increase in the salinity of the Caspian Sea as a whole due to a decrease of runoff into the gulf, but this is not a problem because with such a slow change in salinity the ecosystem could evidently adapt to it.

Thus, in the hydrological regime and hydrobiology of the Caspian Sea the Kara-Bogaz-Gol Gulf plays a negative rather than a positive role.

However, the problem of maintaining the level of the Caspian Sea at readings close to those of the present day (minus 28.5-29.0) in the interests of most of the branches of the national economy associated with the sea, under conditions of an increasing deficit of fresh water in the southern part of the country, is becoming more and more aggravated. A great many teams at scientific and planning-engineering institutes are working on this problem, which is part of the very great national water management problem.

A solution of the problem of maintaining the level of the Caspian Sea is possible in different ways, which can essentially be divided into three groups:

-- every possible saving of fresh water in the sea basin by the development and introduction of new modern methods for its use in agriculture, industry, electric power, communal management, etc.;

-- an additional delivery of water from other regions of the country into the basin of the Caspian Sea -- the transfer of some of the runoff of northern rivers, the supplying of waters from the Sea of Azov and the Black Sea;

-- a reduction in water losses in evaporation from the surface of the Caspian Sea itself and from other water bodies in its basin -- the cutting-off of the poorly productive shallow-water areas in the northern part of the sea and in other regions the reduction or total cessation of the runoff of Caspian waters into Kara-Bogaz-Gol Gulf.

Many complex, still unresolved problems arise in the course of work on projects and when carrying out scientific investigations on the above-mentioned variants of regulation of Caspian levels.

It is evident that the most radical means for ensuring hydrological and biological conditions in the Caspian Sea favorable for the national economy would be the delivery of river runoff from other basins of an appropriate volume and equivalent in natural quality. However, this variant of regulation of the sea regime can encounter great difficulties due to the high cost of shifting a considerable volume of river runoff, the ever-increasing deficit of fresh water in the southern part of the country, the need for creating large reservoirs for the long-term redistribution of water, and possible unfavorable changes in natural conditions in the regions of runoff withdrawal.

The preliminary studies made at the State Oceanographic Institute and at other scientific institutes indicated that the possible transfer of about 30 km^3 of river runoff per year from north to south should not cause any significant consequences in the northern regions of the country.

The formulation of forecasts of possible changes in natural conditions in the case of great withdrawals of river runoff in the remote future is only now being undertaken.

The variant of maintaining the level of the Caspian Sea by the waters of the Sea of Azov or the Black Sea is extremely attractive since it would make possible the freeing of great reserves of fresh water for use in the national economy and a solution of the problem of the Caspian Sea level. But very serious barriers arise on the path to implementation of this variant: the more saline and denser waters of the Black Sea, upon entry into the Caspian Sea, in the depths of the latter can form a lifeless hydrogen sulfide zone similar to that which exists in the Black Sea; animals and plants might enter the Caspian together with the waters of the Sea of Azov or Black Sea which would be harmful for the Caspian ecosystem, as has already happened after connection of the Caspian Sea with the Azov-Black Sea basin by means of the Volga-Don Canal; the salt balance of the sea could be impaired, etc.

In addition, the shifting of Black Sea waters into the Caspian Sea with bypassing of the Caucasus Range, across a number of water divides, according to the estimates of specialists, would require very great expenditures.

The simplest and cheapest means for the partial saving of water for the Caspian Sea is a restriction or complete cessation of runoff of Caspian waters into the Kara-Bogaz-Gol Gulf.

In 1977 the "Soyuzgiproprovodkhoz" institute prepared a technical-economic validation of construction of a regulating hydraulic structure in Kara-Bogaz-Gol Strait which would make it possible to control the regime of entry of water from the Caspian Sea into the gulf in the case of erosion of the bottom of the strait and ensure the continuous delivery of water into the gulf for replenishing the reserves of hydromineral raw material.

The functioning of the regulators was examined applicable to a series of variants of variations of Caspian Sea levels, dependent on the rates of increase of water consumption in the Caspian basin, the hydrometeorological conditions of the upcoming period (up to 2020), and the volume and times of shifting of runoff of the rivers of the northern and northwestern European USSR into the Volga basin.

The present-day annual volume of entry of water from the Caspian into the gulf was estimated at 6 km^3. It was assumed that with a decrease in sea level by 1985 the annual volume of runoff into the gulf would decrease to 5 km^3 with a subsequent reduction. The regulator was rated for the passage of 5 km^3 of water into the gulf each year.

During the period of construction of the structure, when the strait would be completely blocked, it was expected that there would be a water saving of 12 km^3 each two years, and during the subsequent four years, during which the natural runoff of water into the gulf would exceed 5 km^3 annually, there would be a saving of an additional 2 km^3 of water. Thus, it was assumed that the total saving would be 14 km^3. It follows from a comparison of the annual operating costs on the transfer of 1 km^3 of water from the north in the sum of 1.8 million rubles with the one-time saving of 14 km^3 of Caspian water that the saving of annual costs on transfer of the runoff of northern rivers into the Volga exceeds by a factor of approximately 3 the expenditures on construction of a regulating lock, which are estimated as a total of approximately 16 million rubles, and the operating expenditures on the regulator for the period 1982-1985.

After in-field familiarization in 1978 with the problems relating to the use of the hydromineral resources of the Kara-Bogaz Gol in the chemical industry and the influence of the gulf on the hydrological regime of the Caspian Sea, the State Oceanographic Institute, under the direction of Academician Ye. K. Fedorov, carried out additional investigations of the influence of the gulf on the sea regime. It was shown that with the clearly expressed tendency to a decrease in the level of the Caspian under conditions of an increasing consumption of fresh water in the economy of its basin the saving of Caspian water with the use of the regulating hydraulic structure is only about 10 km^3 and there will be a total increase in the level by 3-4 cm.

Thus, the construction of a regulating hydraulic structure in the Kara-Bogaz-Gol Strait with the conveyance of 5 km^3 of water per year through it in order to maintain the sea level under present-day conditions is ineffective. Accordingly, for the maximum prevention of a negative influence of the Kara-Bogaz-Gol on the level of the Caspian Sea it was recommended that provision be nade for the total cessation of the runoff of water into the gulf by the construction of a blind inexpensive dam. The implementation of this measure will exert no negative influence on the chemical industry, at least in the foreseeable future, since the present-day technology for the production of mirabilite is unrelated directly to the gulf. However, the blocking of the strait by a blind dam from the beginning of 1980 already in the first 10 years will make possible a total saving of 25 km^3 of Caspian water and the maintenance of the Caspian level at a reading above the predicted level by approximately 0.1 m. With a reading of -28.7 m, which in the technical-economic specifications of Soyuzgiprovodkhoz is deemed acceptable for fishing, the water saving will be about 7 km^3 annually. Such a water volume can give an increase in water level of 2 cm annually. With higher level readings, which can be established under favorable climatic conditions and shifting of part of the runoff of northern rivers into the Caspian, the water saving will be still greater.

If it is assumed that the cost of transfer of one cubic kilometer of river water is 60-80 million rubles, whereas the cost of construction of a blind dam in Kara-Bogaz-Gol Strait is about 2-4 million rubles, the high effectiveness of implementation of this measure becomes entirely obvious and is hundreds of millions of rubles annually.

It was decided to separate the Kara-Bogaz-Gol from the Caspian Sea by a blind dam and a number of ministries and departments were delegated to carry out a complex of scientific investigations related to maintenance of the mineral-raw material base and ecological conditions in the Kara-Bogaz-Gol region. Early in 1980 the construction of the blind dam was completed and Caspian waters ceased to flow into Kara-Bogaz-Gol.

It should be noted that the blockage of Kara-Bogaz-Gol Strait was the first step in solving the problem of maintaining the level of the Caspian, closely related to the problem of transfer of the runoff of northern rivers into the Volga basin. This problem arose long ago. Scientists and planners proceeded gradually on the path to its solution. They had opponents whose principal arguments were that the cutting-off of the gulf from the sea and its dessication would deprive industry of valuable raw material and that the deflation of salts from the dessicating gulf could exert a negative influence on the near-lying agricultural regions.

And although the reserves of the principal chemical raw material of the Kara-Bogaz-Gol, mirabilite, which already for more than 20 years has not been extracted from the brine of the gulf, are ensured for many decades to come, and some salts in the gulf (epsomite, potassium sulfate and others) can be used as fertilizers (incidentally, at Bekdash village, where the raw material of the Kara-Bogaz-Gol is loaded, vegetables, melon crops and other plants grow beautifully), the study of these matters requires the closest attention of scientists in different fields of specialization, especially oceanologists, climatologists and hydrochemists. In this connection the State Oceanographic Institute has drawn up a program for hydrometeorological investigations of the gulf and its coastal regions.

The most important objectives of these investigations are a study of the specific characteristics of the hydrometeorological regime of the dessicating saline gulf and its influence on the environment and also determination of the influence of the deflation of salts from the dessicated surface of the gulf on the salinity of the Caspian Sea and the salinization of soils in the surrounding territories. The program provides for a hydrographic investigation of the gulf, the carrying out of hydrological-hydrochemical surveys in the eastern part of the Caspian Sea, a study of the microclimatic conditions along the shores of the gulf, aerial photographic surveys of the gulf and study of the transfer of salts in the region of the gulf and other studies.

In the course of the investigations it is very important to clarify whether the basin of the dessicating gulf will serve as a source of eolian transport of salts or it will gradually be drifted-in by the sands of the surrounding desert. It is possible that the salts will be consolidated, as a result forming a solid cemented salt surface and there will be no salt transfer. It is also of interest to study the processes involved in the formation of salt dust storms and determine the tendency in development of these phenomena with dessication of the gulf (lake).

In addition to the State Oceanographic Institute, the Azerbaijan Republic Administration of Hydrometeorology and Environmental Monitoring, Main Geophysical Observatory imeni A. I. Voyeykov, Baku Division of the Transcaucasus Hydrometeorological Institute and Turkmen Republic Administration of Hydrometeorology and Environmental Monitoring should participate in implementation of the program.

In 1980 work began on reconnaissance investigations of the gulf, of adjacent regions of the coast and the Caspian Sea for the purpose of selecting points for stationary and expeditionary investigations, more precise determination of the nature and the volume of the studies, as well as coordination of actions among participants in the investigations. In the course of the investigations plans were made to carry out a reconnaissance survey of the upper part of the former Kara-Bogaz-Gol Strait from the "source" to the blind dam for evaluating the possibility of its drifting-in with sand from the shore and filling-in with marine sediments, carry out an aerovisual survey of the landscape features of the coastal zone of the gulf, take samples of soils and aerosols on several profiles along the normal from the shore of the gulf for determining the salt composition.

Studies for implementation of the research program must begin without delay since the process of dessication of the gulf will develop very intensively. The investigation of the process of dessication of the gulf and the phenomena associated with it is of great scientific and practical importance, especially in a study of similar processes with the cutting-off of other regions of the Caspian Sea, shoaling of individual gulfs and estuaries of the Aral Sea and other seas.

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VARIABILITY OF ICE CONDITIONS ON SHIP NAVIGATION ROUTES

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[Article by A. Ya. Buzuyev, candidate of geographical sciences, and V. Ye. Fedyakov, Arctic and Antarctic Scientific Research Institute, manuscript received 11 Jul 80]

[Text]

Abstract: On the basis of the results of generalization of shipboard and aerial observations it was possible to compare the scales of variability of characteristics of the ice cover directly on the path of movement of a ship and in the navigation region as a whole. The influence of nonuniformity in the distribution of the ice cover on the rate of movement of ships was demonstrated. The results are of great importance in the scientific-operational support of navigation in the ice.

The ice cover on the sea surface has an extremely nonuniform distribution. Accordingly, an important task of scientists specializing in the study of ice is an investigation of the scales of spatial nonuniformity of the characteristics of the state of ice (thickness, continuity, hummocking, etc.).

It was possible to achieve definite successes in this direction by using data from aerial reconnaissance and especially instrumental observations, as well as materials from ice-measuring surveys. The statistical processing of these data made it possible to clarify the patterns of distribution of most characteristics [1, 3, 8, 10] as a whole for arctic seas (or individual regions).

There has been considerably less study of the scales of nonuniformity of the ice cover along a ship navigation route. The values of the ice characteristics registered from a ship can differ substantially from data obtained by aerial reconnaissance [2]. This is attributable to the fact that at each moment in time navigators select the easiest route through the ice. An influence is also exerted by the difference in the scale of generalization of ice characteristics in shipboard and aerial ice observations.

A study of the nonuniformity in distribution of the ice cover along a navigation route is of fundamental importance because it makes possible an objective evaluation of navigational ice conditions with the use of traditional sources of information on ice conditions in a particular region. It is also of more than a little importance to evaluate the influence which the nonuniformity of distribution of the ice cover exerts on the movement of ships. However, until recently there have been insufficient field observational data for a study of the considered problems. An influence is also exerted by the lack of methods for the continuous registry of the rate of movement of a ship in the ice, the complexity in ascertaining the position of a ship during movement along variable courses and at different speeds, the absence of instrumental methods for observing the state of the ice from aboard a moving ship, etc.

In the spring of 1978, during navigation along the entire route of the Northern Sea Route, specialists of the Arctic and Antarctic Scientific Research Institute carried out continuous observations which for the first time were accompanied by the continuous registry of coordinates (the icebreaker carried a "Magnavox" satellite navigational system) and registry of the rate of continuous movement. [This study was made by an understudy of senior assistant L. A. Shamkin, who kindly furnished us the results of this registry.] This article is devoted to a discussion of the results.

In case of necessity use has been made of data from observations made during recent years and in other seasons. It should be particularly emphasized that on the expeditions of the Arctic and Antarctic Scientific Research Institute shipboard ice observations provide for the registry of the characteristics of ice both on the path of movement and in the range of visibility [6]. On the navigation route (in a zone constituting 1.5-2.0 ship's hull forward along the course and 2-3 ship's width on either side) a determination is made of the characteristics of ice exerting a direct influence on the ship's hull. Within the limits of visibility an evaluation is made of ice conditions in the navigation region. In this case the width of the zone is dependent on the height of the place of observations and meteorological conditions and is usually about 2 miles.

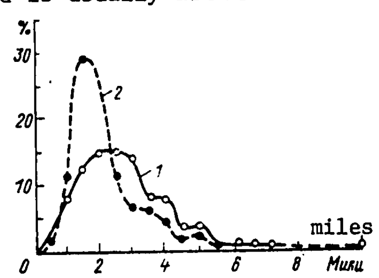

Fig. 1. Distribution of extent of sectors with uniform ice conditions during the spring (1) and summer (2) periods.

Ice continuity is one of the principal navigational indices. During the winter the local changes in continuity are not great and therefore its values along the navigation route agree fairly well with data on ice continuity within the range of visibility (Table 1). During spring there is an increase in the nonuniformity of distribution of the ice cover over the sea surface. This results in an appreciable discrepancy between ice continuity in the visibility zone and directly along the path of movement. These discrepancies are most important during summer when the continuity registered over the navigation region corresponds to the spectrum of this characteristic along the path of ship movement (Table 1).

The seasonal characteristics of distribution of local zones of ice continuity are also reflected in the frequency of recurrence of the extent of these zones (Fig. 1). During the spring the mean extent of zones of uniform ice along the navigation route is 3.0 miles and in general agrees with the results of investigations made by N. A. Volkov, A. V. Bushuyev and V. S. Loshchilov. Whereas in summer the most probable extent of a zone of identical continuity is 1.5 miles [2], in the spring it increases to 2.5 miles (see Fig. 1).

The processing of data from shipboard ice observations indicated that the mean extent of uniform sectors differentiated with respect to ice age, continuity and predominant forms, remains stable (Table 2). The mean extent of sectors of navigation in ice of one age type (with constant values of the remaining elements) is 2.9 miles with a standard deviation of 2.2 miles, whereas in "mixed" ice (consisting of ice of different ages) these values are 3.1 and 2.0 miles respectively.

Another important characteristic of ice is hummocking. The probability of the coincidence of hummocking registered within the limits of visibility and directly along the path of movement decreases rapidly during the spring with an increase in hummocking (Table 3). The route of an icebreaker is always selected through sectors of more even ice. For example, with hummocking within the visibility range of 3-4 scale units almost 40% of the route is in relatively even ice with a hummocking of less than 2 scale units. Such a situation is attributable to the fact that in spring sectors of younger and more even ice are preserved and these are used by navigators. In the summer this ice, as a result of thawing and deformation, is destroyed and hummocking on the navigation path is only 0.5 scale unit lower than for the region of movement as a whole.

The general patterns of distribution of ice by horizontal dimensions (forms), computed on the basis of data from visual evaluations from aboard an icebreaker, agree fairly well with the results of investigations made by Yu. A. Gorbunov and S. M. Losev [8] using data from an aerial photographic survey (Table 4).

Thus, with the existing system of visual ice observations there are differences between data from aerial reconnaissance (which characterizes ice conditions in the navigation region) and ice conditions along the ship's path.

In particular, they are manifested in such important ice characteristics as hummocking and continuity. At the same time, the distributions of predominant dimensions of ice formations registered from a ship agree with data for arctic seas. The considered differences are a result of the spatial nonuniformity in the distribution of essentially all characteristics of the ice cover. Depending on the season, the nonuniformity in the distribution of the ice cover has its special characteristics. Accordingly, a study of the patterns of distribution of ice cover characteristics on the basis of observations from shipboard is of great importance.

Unfortunately, the lack of data did not make it possible to compare the scales of variability of ice compression directly on a ship's path and in the navigation region as a whole.

In solving a wide range of problems, especially in formulating the methodological principles for the preparation of navigation recommendations, a factor of great importance is a quantitative evaluation of the influence which the variability of the characteristics of the ice cover exerts on navigation.

For the case of movement of a ship in continuous ice, when ice thickness (H) is a decisive characteristic, the procedures for taking into account the nonuniformities in its distribution were examined earlier in [5]. It is considerably more difficult to solve this problem for ice conditions when the characteristics of navigation are determined by a combination of characteristics; each has its own patterns of variability. As a result of their total effect the rate of movement of the ship, even in uniform ice (V), varies in a wide range. [Ice whose characteristics vary in the range of the accuracy of observations [6] is called "uniform."] Therefore, up to the present time in the study of the dependence of the ship's speed on thickness, continuity and hummocking use is made of data on mean rates of movement ($\bar{V}$) through sectors with uniform ice. The extent of sectors is read from the navigational chart and the time required for passing through them is registered when making ice observations. The magnitude of the errors in determining mean speed with such an approach is evaluated using the known expression

$$\frac{\Delta V}{V} = \sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta t}{t}\right)^2} \quad \text{or} \quad \varepsilon_V = \sqrt{(\varepsilon_L)^2 + (\varepsilon_t)^2}, \qquad (1)$$

where ε_V, ε_L, ε_t are the relative errors in speed, distance and time respectively; Δt is the time required for passage through a sector with uniform ice of the length L; Δt, ΔL is the accuracy in determining time and the length of a sector with uniform ice (respectively) when making ice observations.

The numerical values of the ΔL parameter are dependent on the method for determining the coordinates. During the period of the spring navigation along the Northern Sea Route in 1978 $\Delta L \pm 0.5$ mile and the Δt values in visual ice observations were ±1.0 minute. Taking into account that the mean extent of sectors with uniform ice conditions is 3.0 miles, the relative error in determining the mean speed ε_V, computed using formula (1), is 18%. It is clear that with a lesser accuracy in determining the coordinates the value of the relative error will be greater.

In studying the dependence V = f(H) use was also made of discrete measurements of a log-sight. They are made at the times of steady movement of the ship and also do not give any idea concerning the scales of variability of speed along each of the sectors with a uniform ice cover. In studying the variability of the ship's speed in the ice it is necessary that it be registered continuously. As noted above, such registry was obtained for the first time in the spring of 1978.

It should be stated here that the nonuniform distribution of the ice cover along the navigation route, even in the case of movement without stopping, forces navigators to change the operating regime of the engine regularly by means of the control system. Information on the total usable power at each moment in time is lacking. It can only be noted that all records apply to cases when the restrictions on power were 70-100% of the nominal power.

Due to the fact that this model of the ice log registered only the speed modulus, first cases were discriminated on the tape when the movement of the icebreaker was without stops (in the case of an autonomous voyage and with towing of the ship at the stern). In the processing use was made only of those sectors with a distinct record on which the time marks were made by the observer at the beginning and end of the sector. Discrete speed values with an interval of about 2.5 minutes were registered for each sector. The choice of the interval was tied in with the marking of the recording tape. The speed values were read at the points of intersection of the record line with the grid verticals on the tape. In individual segments, where the quality of the record was low ("bursts" at the zero and maximum values, "fused" record) the speed readings were taken from a curve reproducing a smooth curve of changes in speed.

The processing of the discrete speed values obtained in this way provided for the introduction of two corrections. The first correction (in the "0" place) to the record was at the time when the ship stopped (wedging in the ice, stopping for technical or organizational reasons). The second correction ("instrumental") was determined from the results of a comparison (Fig. 2a) of synchronous determinations of the rate of movement according to the ice log (y-axis) and log-sight (this simple device gives reliable results when making discrete measurements of speed during steady movement).

An indicator of the reliability of the data obtained in this way is the fairly good agreement of the mean rates of movement in all the sectors of uniform ice, computed using both the registry results (x-axis) and the extent of the sectors and the time required for the ship to pass through them (Fig. 2b).

Still another circumstance can be noted from the graphs: both with autonomous movement and with towing of the ship the minimum rate of continuous movement (without stops) is identical and equal to 5 knots. However, it is known that in studies related to investigation of the resistance of ice to a ship's movement the minimum rate of stable movement is assumed to be equal to 1.5-2.0 knots [7]. The reason for such significant differences is the spatial nonuniformity in the distribution of ice cover characteristics. In our case reference is to stable movement in sectors of a considerable extent ($\bar{L} \simeq 3.0$ miles), with a natural nonuniform distribution of the characteristics of state of the ice on the navigation path. In the second case the movement takes place in continuous even snow-free ice in which the scales of variability of the principal ice characteristic -- its thickness -- are commensurable with the accuracy in its determination.

The conclusion that the minimum rate of ship movement without a stop under natural conditions is about 5 knots is of great importance in the formulation of navigational recommendations.

Table 1

Relationship Between the Extent of Sectors With Different Ice Continuity Along the Navigation Path (C_{route}) and in Visibility Limit (C_{vis}) in Different Periods of Arctic Navigation (C_{route}/C_{vis} in Percent)

C_{vis}, units	C_{route}, units								
	0-3	4-6	7-10	0.3	4-6	7-10	0-3	4-6	7-10
	Fall-winter period			Spring period			Summer period*		
0-3	100	-	-	100	-	-	100	-	-
4-6	5	95	-	96	4	-	70	28	2
7-10	-	-	100	22	5	73	27	45	28

* According to data from V. Ye. Borodachev [2].

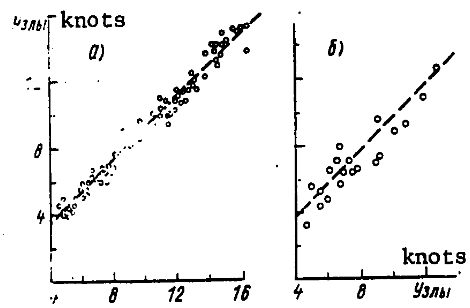

Fig. 2. Comparison of ship's speed, measured with ice log (y-axis) and log-sight (a) and mean rate of movement by sectors, determined from coordinates (y-axis) and computed using record (b).

The data obtained in the continuous registry of the rate of movement, after the introduction of corrections, were processed in the following way. For each sector of uniform ice we computed the mean values of the rate of movement $\bar{V}$ and the standard deviations σ_V. Then the entire mass of data was grouped by ranges of mean speeds and standard deviations (Table 5) and then the correlation functions were computed for each group. As a result of the computations it was found that with an interval between measurements t = 2.5 minutes the correlation between successive measurements virtually disappears and they can be regarded as independent random values. Accordingly, the number of discrete measurements n which will ensure a determination of $\bar{V}$ with a stipulated accuracy can be computed approximately using the expression

$$n = \left(\frac{Z_\alpha \sigma}{\Delta}\right)^2, \qquad (2)$$

where n is the number of discrete measurements; Δ is the stipulated error in determining the rate of movement; σ is the standard deviation; Z_α is a parameter determined from the tables in [11] using the stipulated probability value (α).

Table 2

Mean Extent of Sectors With Uniform Characteristics of Ice Cover State in Spring

Characteristic	Mean extent L, in miles	Number of sectors, n	Standard deviation σ_L, miles
Ice continuity, units			
0-3	4.7	27	1.9
4-6	2.7	35	1.4
7-8	2.1	20	1.0
9	3.9	48	2.6
9-10	3.4	103	2.4
10	2.5	279	2.1
Predominant forms [9]			
Extensive and large fields	1.9	229	1.3
Large fields, fragments	3.5	305	2.8
Fragments of fields, large broken ice	3.1	246	1.9
Large-small broken and ground ice	3.5	60	1.9

Table 3

Relationship Between Extent of Sectors With Different Ice Hummocking on Navigation Route (T_{route}) and in Visibility Limit (T_{vis}) in Spring (T_{route}/T_{vis} in Percent)

T_{vis}, units	C_{route}, units				
	0-1	1-2	2-3	3-4	4-5
0-1	97	(3)		-	-
1-2	44	54	(2)	-	-
2-3	24	48	25	(3)	-
3-4	22	16	32	30	-
4-5	(23)	(3)	(3)	(51)	(20)

Note: Approximate data are given in parentheses.

For example, for $\alpha = 0.95$, $\Delta = 0.8$ knot, $\sigma = 1.5$ knot the necessary number of speed determinations will be $n \sim 14$ and under the condition that the mean extent of a uniform sector is ~ 3 miles the discreteness of the measurements will be ~ 1.6 min.

Table 4

Distribution of Ice Cover by Forms in Spring-Summer

Forms of ice cover [9]	Path in miles in ice of given forms L_{form} (shipboard observations)	$L_{form}/\sum L_{form}$	Frequency of recurrence of floes by horizontal dimensions (air photo survey materials [8])
Extensive and large fields	456	0.18	0.26
Large fields, fragments	1085	0.43	0.42
Field fragments, large broken ice	750	0.30	0.24
Large-small broken and ground ice	213	0.09	0.04

Table 5 shows that the presence of an ice cover leads to appreciable variations in the rate of movement without stops even in sectors of uniform ice. And only under easy ice conditions ($\overline{V}$ = 11 knots) does the dispersion of velocity decrease appreciably.

The wide range of combinations of ice cover characteristics and the lack of instrumental methods for their evaluation from shipboard do not make it possible, for each moment in time, to discriminate the contribution of individual elements of the state of ice to the change in total resistance of the ice to ship movement. However, the results of continuous registry of the rate of movement make it possible to note some general features of the nature of ship movement in the ice. As might be expected, the variability of the ship's speed in the ice (the standard deviations σ_V were used as its index) is determined by the peculiarities of ice conditions.

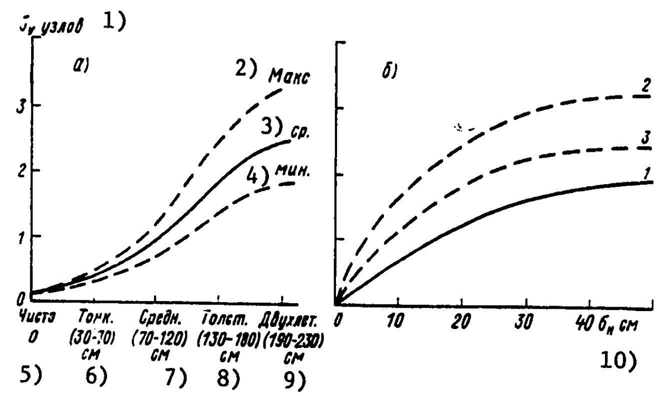

Fig. 3. Change in standard deviation of ship's speed σ_V in large fields of different age (a) and different forms (b) of drifting ice with total continuity $\geqslant$ 9-10 units, hummocking $\leqslant$ 1-2 units and compression $\leqslant$ 0-1 unit. 1) broken and ground ice with inclusion of fragments; 2) fragments of fields, broken ice with inclusion of fields; 3) large and extensive fields.

KEY:

1) knots
2) Max
3) Mean
4) Min
5) Clear
6) Thin
7) Medium
8) Thick
9) Two-year
10) n

Table 5

Distribution of Standard Deviation of Speed σ_V as Function of Mean Speed $\overline{V}$ in the Sectors With Uniform Ice Conditions (in Percent of Total Number of Observations)

$\overline{V}$ knots	Autonomous			With Towing		
	$\sigma_V < 1$	$1 \leqslant \sigma_V < 2$	$2 \leqslant \sigma_V \leqslant 3$	$\sigma_V < 1$	$1 \leqslant \sigma_V < 2$	$2 \leqslant \sigma_V \leqslant 3$
5-7	4	30	66	1	37	61
8-10	3	18	79	3	55	41
$\geqslant$11	24	34	42	27	30	43

In the spring period, when the thawing process has not yet begun and the predominant ice continuity is not less than 9-10 units, the σ_V value is in definite dependence on the age type of ice (Fig. 3a). In addition, there is an interrelationship between the variability in ice thicknesses, computed with allowance for hummocking [5], and the σ_V value (Fig. 3b).

It should be noted that the indicated dependences are characterized by a considerable scatter of data, the scale of which is indicated in Fig. 3a.

The patterns of changes $\sigma_V = f(H, C, T)$, considered above, are based on data of limited volume and possibly will be refined with the development of techniques for the continuous registry of a ship's speed and coordinates in the ice. Particular attention must be given to investigations of cases of ship movement with stops caused by ice conditions. However, even now a definite conclusion can be drawn that with the existing system of ice observations from a ship the patterns of change of mean speed in sectors with uniform ice conditions must serve as a basis for solving operational problems and formulating navigation recommendations.

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INFLUENCE OF ERRORS IN STATISTICAL CHARACTERISTICS ON THE ACCURACY OF OPTIMUM INTERPOLATION

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[Article by B. R. Nezhikhovskiy, State Hydrological Institute, manuscript received 28 May 80]

[Text]

Abstract: Formulas are derived for evaluating the error in optimum interpolation using one coordinate in which the degree of reliability of the statistical characteristics used in the interpolation is taken into account. In the example of interpolation of the corrections to the curve for water discharge in a river it was possible to compare the accuracy of linear and optimum interpolation. It is shown that with relative mean square errors of statistical characteristics of about 30% and less optimum interpolation gives a higher accuracy.

The optimum interpolation method, developed by L. S. Gandin [2], is now used extensively in the objective analysis of meteorological fields. In hydrology this mathematical procedure has not yet come into wide enough use, despite the fact that the studies of G. A. Alekseyev [1], I. F. Karasev [3, 4] and V. A. Rumyantsev [5] have demonstrated the possibility of its use in different types of hydrological computations. The practical application of optimum interpolation in hydrology is hindered primarily by the poor study of the statistical structure of the fields of hydrological elements and also the considerable nonuniformity (nonstationary character) of these fields. As a result of the unreliability of the statistical characteristics necessary for computing the interpolation coefficients the actual error in optimum interpolation can be greater than the error theoretically established by L. S. Gandin on the assumption that the statistical characteristics are extremely precise.

Below we give the derivation of refined formulas for evaluating the errors in optimum interpolation in which allowance is made, among other things, for the influence of the unreliability of statistical characteristics (mean value $\bar{f}$, autocorrelation function $r_f(\tau)$ and measure of measurement error η_f) on the interpolation results. The problem is solved for the case of optimum time interpolation, although all the computations are also correct for spatial interpolation using one coordinate.

Optimum time interpolation of hydrological elements is usually carried out using the formula

$$\hat{f}(\tau) = \bar{f}(\tau) + a_1(\tau)\overset{0}{f}_1 + a_2(\tau)\overset{0}{f}_2, \qquad (1)$$

where $\overset{0}{f}_1 = f_1 - \bar{f}_1; \qquad \overset{0}{f}_2 = f_2 - \bar{f}_2.$

Here $\hat{f}(\tau)$ is the result of interpolation for the time τ (the immediately preceding measurement is used as the point of beginning of time reckoning); f_1 is the result of this preceding measurement; f_2 is the result of the next subsequent measurement; $\bar{f}(\tau)$, $\bar{f}_1$ and $\bar{f}_2$ are the values of the means at the time τ, and also at the times of the preceding and subsequent measurements; $a_1(\tau)$ and $a_2(\tau)$ are interpolation coefficients determined from the statistical characteristics of the element f and the errors in its measurement (the formulas for computing the coefficients were given in [2]).

In those cases when the statistical characteristics used in formula (1) contain errors the interpolation result $\hat{f}(\tau)$ differs from the actually optimum value $\hat{f}_{true}(\tau)$, corresponding to interpolation on the basis of the true statistical characteristics. In this case the error in optimum interpolation can be represented in the form of the sum of two terms:

[И = true; Д = add] $$\delta(\tau) = \hat{f}(\tau) - f(\tau) = [\hat{f}(\tau) - \hat{f}^{И}(\tau)] + [\hat{f}^{И}(\tau) - f(\tau)] = \delta_{Д}(\tau) + \delta_0(\tau), \qquad (2)$$

where $f(\tau)$ is the actual value of the element f at the time τ; $\delta_0(\tau)$ is the principal error in optimum interpolation (that is, the error in interpolation with true statistical characteristics); $\delta_{add}(\tau)$ is the additional error caused by inaccuracy in the statistical characteristics.

Omitting the proof, we note that the terms δ_0 and δ_{add} in expression (2) are not correlated with one another. Accordingly, squaring the right- and left-hand expressions (2) and carrying out the averaging operation, we have

$$\overline{\delta^2(\tau)} = \overline{\delta_0^2(\tau)} + \overline{\delta_{Д}^2(\tau)}. \qquad (3)$$

Expression (3) expresses an important rule: the mean square of the actual error in optimum interpolation is equal to the sum of the mean square of the principal error in optimum interpolation and the mean square of the additional error. It is easy to demonstrate this rule for a general case of optimum interpolation of a function of many arguments.

The principal error $\bar{\delta}_0^2$ is the minimum possible error in optimum interpolation with given characteristics of the element f and also with a given frequency and accuracy of its measurements. Precisely this error is determined using the formula proposed by L. S. Gandin [2]. In the most common case, when it is assumed that the measurement errors and the deviations $\overset{0}{f}$ from the mean are stationary in the interval T between successive measurements, and in addition, there is assumed to be a noncorrelation of the errors in measurements with one another and with the deviations $\overset{0}{f}$, the

Gandin formula can be written in the form

$$\varepsilon_0(\tau) = \frac{\overline{\delta_0^2(\tau)}}{D_f^{и}} = 1 - a_1^{и}(\tau)\, r_f^{и}(\tau) - a_2^{и}(\tau)\, r_f^{и}(T-\tau), \tag{4}$$

where $\varepsilon_0(\tau)$ is the measure of the principal error in optimum interpolation; D_f is the dispersion of the element f; T is the time interval between successive measurements; the superscript "true" denotes the true statistical characteristics of the element f, and also the coefficients computed on the basis of these characteristics.

With these same assumptions concerning the interpolated process an evaluation of the mean square of the additional error can be found by squaring and averaging the difference between the $\hat{f}(\tau)$ value, represented by (1), and the optimum value $\hat{f}^{true}(\tau)$, also obtained using formula (1), but with use of the true statistical characteristics

$$\varepsilon_д(\tau) = \frac{\overline{\delta_д^2(\tau)}}{D_f^{и}} = (1 + \eta_f^{и})\,[\Delta a_1^2(\tau) + \Delta a_2^2(\tau)] + 2\,\Delta a_1(\tau)\,\Delta a_2(\tau)\, r_f^{и}(T) + \frac{(\Delta \bar{f})^2}{D_f^{и}}\,[1 - a_1(\tau) - a_2(\tau)]^2. \tag{5}$$

[И = true; Д = add]

Here $\eta_f = \sigma^2_{meas\ f}/D_f^{true}$ is the measure of error in measuring the element f; $\Delta \bar{f} = \bar{f} - \bar{f}^{true}$ is the error in the mean value (assumed to be constant in the T interval); $\Delta a_1(\tau) = a_1(\tau) - a_1^{true}(\tau)$ and $\Delta a_2(\tau) = a_2(\tau) - a_2^{true}(\tau)$ are the errors of the interpolation coefficients $a_1(\tau)$ and $a_2(\tau)$.

The cited expressions (3), (4) and (5) give basis for computing the error in optimum interpolation. However, their use is possible only in those cases when in addition to the employed inaccurate statistical characteristics of the element f to be interpolated its true statistical characteristics are available. Since in actual practice the true statistical characteristics are usually unknown, formulas (3), (4) and (5) can serve indirectly for computing maximum optimum interpolation error (taking into account the predetermined maximum errors in the statistical characteristics), or for modeling the influence of specific errors of statistical characteristics (including systematic errors). The sequence of computations using these formulas is as follows: by subtracting from the inexact statistical characteristics the errors present in them we obtain the true statistical characteristics; from them we determine the true coefficients $a_1^{true}(\tau)$ and $a_2^{true}(\tau)$, and also the measure of the principal interpolation error $\varepsilon_0(\tau)$; then, using the inexact statistical characteristics we compute the inexact coefficients $a_1(\tau)$ and $a_2(\tau)$; we compute the errors of these coefficients $\Delta a_1(\tau)$ and $\Delta a_2(\tau)$; finally, using formula (5) we find the additional interpolation error $\varepsilon_{add}(\tau)$, and using formula (3) -- the total error $\varepsilon(\tau) = \overline{\delta^2(\tau)}/D_f^{true}$.

In evaluating the errors in optimum interpolation it would be more convenient to use formulas which do not include any specific errors in statistical characteristics, but the probabilistic parameters of these errors, for example, the standard deviations. However, in a general case such formulas are extremely unwieldy and unsuitable for use and therefore below, as a simplification, they are derived only for the middle of the interval T between adjacent measurements, where the accuracy of interpolation is lowest.

As is well known, at the point τ = 05T, with the earlier adopted assumptions concerning the stationarity of processes in the T interval and on the noncorrelation of the measurement errors with one another and with the $\overset{0}{f}$ value, the following equalities exist:

for the interpolation coefficients

$$a_1(0{,}5\,T) = a_2(0{,}5\,T) = a = \frac{r_f(0{,}5\,T)}{1+\eta_f+r_f(T)}; \tag{6}$$

for the errors of interpolation coefficients

[И = true]
$$\Delta a_1(0{,}5T) = \Delta a_2(0{,}5T) = \Delta a = a - a^{и}. \tag{7}$$

Examining the errors in statistical characteristics as random values with zero mathematical expectations and substituting formulas (6) and (7) into (5) and then formula (5) into (3), by means of averaging the left- and right-hand sides of the resulting expression it is possible to derive an approximate formula for the mathematical expectation of the measure of error in optimum interpolation in the middle of the time interval

$$\overline{\varepsilon(0{,}5\,T)} = \overline{\varepsilon_0(0{,}5\,T)} + 2\,ar_f(0{,}5\,T)\,\sigma^2_{0a} + (1-2\,a)^2\,S_{\bar f}. \tag{8}$$

Here $\overline{\delta_{0a}}$ is the relative mean square error in interpolation of the coefficient a; $S_{\bar f} = \overline{(\Delta \bar f)^2}/D_f^{true}$ is the measure of error of the mean value $\bar f$.

The error of the interpolation coefficient a is determined with the accuracy of of the autocorrelation function $r_f(\tau)$ and the measure of the error in measurements η_f. In this connection we note that the accuracy of the autocorrelation function can be characterized by different methods. It is assumed below that the true autocorrelation function of the f(t) process is approximated satisfactorily by an attenuating exponential function

[И = true]
$$r_f^{и}(\tau) = e^{-\frac{\tau}{\theta^{и}}}, \tag{9}$$

therefore, the unreliability of the employed autocorrelation function $r_f(\tau)$ is expressed only in the deviation of the θ parameter from the true parameter θ^{true}. With such an assumption the relative mean square error of the interpolation coefficient a by means of expansion into a Taylor series can be represented in the following way:

$$\begin{aligned}\sigma^2_{0a} &\approx \frac{\theta^2}{a^2}\left(\frac{\partial a}{\partial \theta}\right)^2\sigma^2_{0\theta} + \frac{\eta_f^2}{a^2}\left(\frac{\partial a}{\partial \eta_f}\right)^2\sigma^2_{0\eta} + \\ &+ 2\left(\frac{\theta}{a}\frac{\partial a}{\partial \theta}\sigma_{0\theta}\right)\left(\frac{\eta_f}{a}\frac{\partial a}{\partial \eta_f}\sigma_{0\eta}\right)r_{\theta,\eta} = \\ &= \left(\frac{1-2\,ar_f(0{,}5\,T)}{2\nu}\right)^2\sigma^2_{0\theta} + \left(\frac{a\eta_f}{r_f(0{,}5\,T)}\right)^2\sigma^2_{0\eta} + \\ &+ 2\left(\frac{1-2\,ar_f(0{,}5\,T)}{2\nu}\sigma_{0\theta}\right)\left(-\frac{a\eta_f}{r_f(0{,}5\,T)}\sigma_{0\eta}\right)r_{\theta,\eta}.\end{aligned} \tag{10}$$

Table 1

Coefficients K_θ, K_η and $K_{\bar{f}}$ Reflecting the Influence of Errors of Statistical Characteristics on Error in Optimum Interpolation in Middle of Time Interval

Measure of measurement error η_f	Coefficients	Discreteness parameter $\nu=\Theta/T$					
		0,5	1	2	3	4	5
0,01	K_θ	$3,7\cdot10^{-1}$	$1,7\cdot10^{-1}$	$5,5\cdot10^{-2}$	$2,6\cdot10^{-2}$	$1,5\cdot10^{-2}$	$9,9\cdot10^{-3}$
	K_η	$-4,2\cdot10^{-3}$	$-5,3\cdot10^{-3}$	$-5,4\cdot10^{-3}$	$-5,3\cdot10^{-3}$	$-5,2\cdot10^{-3}$	$-5,2\cdot10^{-3}$
	$K_{\bar{f}}$	$3,6\cdot10^{-1}$	$1,2\cdot10^{-1}$	$3,6\cdot10^{-2}$	$1,9\cdot10^{-2}$	$1,3\cdot10^{-2}$	$1,0\cdot10^{-2}$
0,1	K_θ	$3,6\cdot10^{-1}$	$1,7\cdot10^{-1}$	$6,1\cdot10^{-2}$	$3,1\cdot10^{-2}$	$1,9\cdot10^{-2}$	$1,4\cdot10^{-2}$
	K_η	$-3,7\cdot10^{-2}$	$-4,8\cdot10^{-2}$	$-4,9\cdot10^{-2}$	$-4,9\cdot10^{-2}$	$-4,9\cdot10^{-2}$	$-4,8\cdot10^{-2}$
	$K_{\bar{f}}$	$4,0\cdot10^{-1}$	$1,7\cdot10^{-1}$	$8,7\cdot10^{-2}$	$6,8\cdot10^{-2}$	$6,1\cdot10^{-2}$	$5,7\cdot10^{-2}$
0,5	K_θ	$3,4\cdot10^{-1}$	$1,9\cdot10^{-1}$	$8,1\cdot10^{-2}$	$4,7\cdot10^{-2}$	$3,3\cdot10^{-2}$	$2,4\cdot10^{-2}$
	K_η	$-1,2\cdot10^{-1}$	$-1,7\cdot10^{-1}$	$-1,8\cdot10^{-1}$	$-1,8\cdot10^{-1}$	$-1,8\cdot10^{-1}$	$-1,8\cdot10^{-1}$
	$K_{\bar{f}}$	$5,5\cdot10^{-1}$	$3,5\cdot10^{-1}$	$2,6\cdot10^{-1}$	$2,4\cdot10^{-1}$	$2,3\cdot10^{-1}$	$2,2\cdot10^{-1}$

Table 2

Measure of Error of Linear and Optimum Interpolation at Different Points in the Time Interval T Between Successive Measurements

Characteristics of error	Type of interpolation	Characteristics of error	τ/T — time, fractions of interval				
			1	0,9	0,75	0,6	0,5
			0	0,1	0,25	0,4	0,5
Favorable	Optimum	Principal, ε_0	0,082	0,114	0,149	0,167	0,171
$\nu^н = 4$		Additional due to inaccuracy θ and η_q	0,0079	0,0075	0,0072	0,0072	0,0072
$\eta_q^н = 0,1$		Additional due to inaccuracy $\bar{q}$	0,0061	0,0067	0,0073	0,0078	0,0079
		Total additional, ε_{lin}	0,0140	0,0142	0,0145	0,0150	0,0151
$\bar{q}^н = 0,6\sigma_q^н$		Actual, ε	0,096	0,128	0,164	0,182	0,186
	Linear	Actual, ε_{lin}	0,100	0,127	0,156	0,171	0,174
Unfavorable	Optimum	Principal, ε_0	0,277	0,393	0,512	0,572	0,584
$\nu^н = 1$		Additional due to inaccuracy θ and η_q	0,0092	0,0112	0,0200	0,0235	0,0244
$\eta_q^н = 0,4$		Additional due to inaccuracy $\bar{q}$	0,0061	0,0067	0,0073	0,0078	0,0079
		Total additional, ε_{add}	0,0153	0,0179	0,0273	0,0313	0,0323
$\bar{q}^н = -0,6\sigma_q^н$		Actual, ε	0,292	0,411	0,539	0,603	0,616
		Actual, ε_{lin}	0,400	0,504	0,609	0,661	0,671
Mean $\nu = 2,5$	Optimum	Computed from intermediate statistical characteristics, ε_{op}^{int}	0,180	0,224	0,273	0,297	0,302
$\eta_q = 0,25$ $\bar{q} = 0$	Linear	Computed from intermediate statistical characteristics, ε_{lin}^{int}	0,250	0,277	0,305	0,320	0,323

[н = true]

Here $\nu = \theta/T$ is the discreteness parameter; $\sigma_{0\theta}$ is the relative mean square error of the parameter θ of the autocorrelation function $r_f(\tau)$; $\sigma_{0\eta}$ is the same for the measure of error in measurement η_f.

As a result of the nonlinearity of the dependence $a(\theta)$ formula (10) is correct only with $\sigma_{0\theta} \leqslant$ 20–30%.

Finally, substituting formula (10) into (8), we have the mathematical expectation of the measure of the mean square error in interpolation in the middle of the time interval

$$\overline{\varepsilon(0{,}5\,T)} \approx \overline{\varepsilon_0(0{,}5\,T)} + K_\theta^2 \sigma_{0\theta}^2 + K_\eta^2 \sigma_{0\eta}^2 + 2(K_\theta \sigma_{0\theta})(K_\eta \sigma_{0\eta})\, r_{\theta,\eta} + K_{\bar{f}}^2 S_{\bar{f}}. \quad (11)$$

Here the coefficients

$$K_\theta = \sqrt{2\,a r_f(0{,}5\,T)}\,[1 - 2\,a r_f(0{,}5\,T)]/2\,\nu, \quad (12)$$

$$K_\eta = -\sqrt{2\,a r_f(0{,}5\,T)}\,a\,\eta_f, \quad (13)$$

$$K_{\bar{f}} = 1 - 2\,a. \quad (14)$$

Table 1 gives the coefficients K_θ, K_η and $K_{\bar{f}}$ with different values of the parameters ν and η_f. Table 1 shows that in rare measurements optimum interpolation in the middle of the time interval is most sensitive to errors in determining the autocorrelation function and the mean value of the element f. In the case of frequent measurements there is an increase in the influence of inaccuracy of the measure of error in measurements η_f.

Now we will examine a numerical example of the use of the expressions derived by the author.

Methods based on optimum and linear interpolation of the dimensionless corrections q to the discharges curves, developed by I. F. Karasev [3, 4], are extremely promising in the automation of computations of the runoff of rivers with an unstable correlation between the water level and discharge. An investigation and comparison of the accuracy of these methods made by I. F. Karasev in [3] using formula (4) indicated that the optimum interpolation of corrections in all cases is more precise than linear interpolation, especially in the case of relatively rare and inexact measurements of water discharge.

In connection with the nonstationary character of the corrections and the difficulty in creating large-volume samples the question arises: is the Karasev conclusion confirmed if a similar comparison is made not on the basis of the Gandin evaluation (4), but on the basis of the proposed formulas (3), (5) and (11)-(14), taking into account the inaccuracy of the statistical characteristics used in optimum interpolation?

In the search for an answer to the formulated question we use data for the Amu Dar'ya River cited in [4]. Relying on these data, we will assume that for low-water periods in different years the statistical characteristics of the corrections q vary from $\nu^{true} = 1$; $\eta^{true}_q = 0.4$ and $\bar{q}^{true} = 0.6\sigma^{true}_q$ in the years most unfavorable for interpolation (that is, years with the minimum relative frequency and accuracy of observations) to $\nu^{true} = 4$; $\eta^{true}_q = 0.1$ and $\bar{q}^{true} = -0.6\sigma^{true}_q$ in the most favorable years (with the maximum frequency and accuracy of observations). Here σ^{true}_q is the standard deviation of the correction q for a particular year. We will assume further that in computations of water runoff the changes in the statistical characteristics of the corrections from year to year are not taken into account and in optimum interpolation of the corrections use is always made of one and the same intermediate statistical characteristics $\nu = 2.5$; $\eta_q = 0.25$ and $\bar{q} = 0$, which correspond to the frequency and accuracy of measurements averaged for a long-term period.

Taking into account the assumptions made, Table 2 gives a comparison of the accuracy in optimum and linear interpolation of corrections in favorable and unfavorable years. The measure of the actual error in optimum interpolation $\varepsilon(\tau)$ was computed using formulas (3), (4) and (5), and the measure of the actual error in linear interpolation -- using the formula

$$\varepsilon_{л}(\tau) = 1 + (1 + \eta^{и}_{q}) \left(1 - 2\frac{\tau}{T} + 2\frac{\tau^2}{T^2}\right) - 2\frac{\tau}{T} r^{и}_{q}(T-\tau) - 2\left(1 - \frac{\tau}{T}\right) r^{и}_{q}(\tau) + 2\frac{\tau}{T}\left(1 - \frac{\tau}{T}\right) r^{и}_{q}(T). \quad (15)$$

[И = true]

For greater clarity Table 2 also gives the commonly employed measures of error of optimum ε^{err}_{op} and linear ε^{err}_{lin} interpolation, computed using formulas (4) and (15) respectively on the basis of intermediate statistical characteristics. In precisely such a way computations were used earlier [2-4] in evaluating and comparing the accuracy of interpolation. However, it is evident that such a method is entirely suitable only in those years when the true statistical characteristics coincide with the intermediate characteristics, that is, in years average with respect to the frequency and accuracy of observations.

It can be seen from Table 2 that in a favorable year, when the intervals between successive measurements, and also the errors in measurements are relatively small, the actual error in both optimum and linear interpolation is less than the errors in interpolation in an average year, which were computed on the basis of intermediate statistical characteristics. Thus, relative accuracy and frequency of measurements exert a decisive influence on the error of both linear and optimum interpolation. However, as a result of the use of intermediate statistical characteristics in optimum interpolation the actual interpolation error ε in favorable and unfavorable years is greater than the error ε_0 which would be present if the true statistical characteristics for a particular year were used. Precisely for this reason in a favorable year optimum interpolation was even less precise than linear interpolation.

In a more complete comparison of optimum and linear interpolation it makes sense to evaluate the accuracy of these methods as an average for a long-term period. For this purpose we will assume that the mathematical expectation of the parameters ν^{true}, η^{true}_q and $\bar{q}^{true}$ coincide with the intermediate values adopted in interpolation: $\nu = 2.5$; $\eta_q = 0.25$ and $\bar{q} = 0$, whereas the true values of the parameters in favorable and unfavorable years correspond to deviations $\pm 2\sigma$ from the mathematical expectation. Then $\sigma_{0\theta} = \sigma_{0\eta} = \sqrt{S_{\bar{q}}} = 0.3$. In addition, we arbitrarily assume that $r_{\theta\eta} = -1$. These data are adequate, using formula (11), for computing the errors in optimum interpolation in the middle of the time interval, averaged for a long-term period. The coefficients entering into expression (11) and computed using formulas (12)-(14) are as follows: $K_\theta = 5 \cdot 10^{-2}$; $K_\eta = -11 \cdot 10^{-2}$ and $K_{\bar{q}} = 15 \cdot 10^{-2}$. Hence, taking into account the approximate equality $\varepsilon_0(\nu^{true}, \eta_q^{true}) \approx \varepsilon_0(\nu, \eta_q)$ we have

$$\overline{\varepsilon(0{,}5T)} \approx 0{,}302 + (3+12+11+22) \cdot 10^{-4} \approx 0{,}307. \quad (16)$$

With these same initial data the error in linear interpolation is

$$\overline{\varepsilon_л(0{,}5T)} \approx 0{,}323. \quad (17)$$

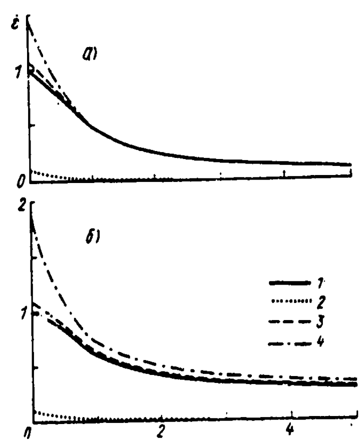

Fig. 1. Comparison of accuracy in optimum and linear interpolation in middle of interval between successive measurements. a) $\eta_f = 0.01$; b) $\eta_f = 0.5$. 1) measure of principal error in optimum interpolation $\overline{\varepsilon}_0$; 2) measure of additional error in optimum interpolation $\overline{\varepsilon}_{add}$; 3) measure of total error in optimum interpolation $\overline{\varepsilon}$; 4) measure of error in linear interpolation $\overline{\varepsilon}_{lin}$.

Thus, despite the fact that in individual years linear interpolation can be even more precise than optimum interpolation, nevertheless in general over a long-term period it is optimum interpolation which has the advantage.

In order to check the degree of universality of this conclusion, in accordance with I. F. Karasev we will make a comparison of the error in optimum and linear interpolation in the middle of the time interval with different ν and η_f parameters, averaged over a long-term period. The results of computations using formulas (11) and (15) with $\sigma_{0\theta} = \sigma_{0\eta} = \sqrt{S_{\bar{f}}} = 0.3$ and a correlation coefficient $r_{\theta,\eta} = -1$ are shown in Fig. 1 in the form of curves of the functions $\overline{\varepsilon}(\nu)$.

This figure shows that the measure of additional error in optimum interpolation $\bar{\varepsilon}_{add}$ caused by the inaccuracy in statistical characteristics increases with a deterioration in the conditions for interpolation and in our example is up to 10% of the measure of the principal interpolation error $\bar{\varepsilon}_0$. However, at the same time there is an increase in the difference between the errors of linear and optimum interpolation. Therefore, the advantage of optimum interpolation over linear interpolation is nevertheless retained.

Summary

The formulas proposed in the article make it possible to compute the error in optimum interpolation with inexact statistical characteristics of the hydrological element to be interpolated. Using formulas (3), (4) and (5) it is possible to evaluate the influence of different specific errors of statistical characteristics (in particular, limiting and systematic errors), and using formula (11) -- the influence of random errors.

An analysis of the errors in optimum interpolation (in the example of interpolation of corrections to the discharges curve) makes it possible to draw the following conclusions:

a) The accuracy in optimum interpolation of any element to a far greater degree is dependent on the error and the frequency of its measurements than on the reliability of the statistical characteristics used in the interpolation;
b) in connection with the weak influence of the errors in statistical characteristics on the error in optimum interpolation it can be assumed that in periods in different years which are uniform in phase in the computations of river runoff it is admissible to use the very same statistical characteristics of the corrections to the discharges curve averaged over a long-term period;
c) the advantage of optimum interpolation over linear interpolation decreases with a decrease in the accuracy of the statistical characteristics used. However, with relative mean square errors of the statistical characteristics less than 30% the error in optimum interpolation in general is less than the error in linear interpolation, especially in the case of very rare and inexact measurements. Roughly speaking, optimum interpolation loses its advantage over linear interpolation only with relative mean square errors in the statistical characteristics of more than 50-60%.

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INFLUENCE OF SOLID PARTICLES ON THE KINEMATICS OF THE TRANSPORTING FLUID FLOW

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 86-91

[Article by N. N. Grishin, candidate of physical and mathematical sciences, Institute of Water Problems, manuscript received 29 May 80]

[Text]

Abstract: It is shown that suspended and entrained sediments exert a different influence on the kinematics of the transporting medium. This is attributable to the difference in the mechanism of vertical movement of particles: the movement of suspended sediments is caused by the turbulence of the flow transporting them, whereas for bottom sediments turbulence is not a decisive factor. A scheme is proposed for the transformation of the energy in the bottom region of a turbulent flow carrying a saltation load. According to this scheme, some of the energy of the averaged flow of fluid can be transformed into the energy of turbulent pulsations of its velocity by means of the mechanism of saltation transport of sediments. Experimental results confirm this concept.

The kinematic structure of a sediment-carrying water flow differs from the structure of a flow of pure water flowing under similar conditions. In this article it is shown that the influence of suspended and entrained sediments on the kinematics of the flow transporting them frequently is opposite, which is associated with the difference in the mechanisms for the vertical transport of particles.

Fine sediments rise from the bottom and are maintained in a suspended state due to the effect of the vertical component of the instantaneous values of the velocity of the fluid, which evidently was pointed out for the first time at the beginning of the century by Glushkov [9]. Some fraction of the energy of the vertical fluctuations of fluid velocity is expended in the performance of work against gravity on suspended particles. Accordingly, in a general case there should be a partial extinction of turbulence in a suspension-carrying flow.

In the detachment of larger entrained sediments and their lifting from the bottom a significant role is played by the collision of particles moving along the bottom with projections of bottom roughness and with one another [11]. In these collisions the horizontal velocity of the sediments is partially transformed into vertical velocity. Accordingly, in the rising of saltating particles from the bottom the energy of the vertical velocity fluctuations of the fluid may or may not be expended. Moreover, inertial saltating sediments, moving in a vertical direction in the fluid volumes surrounding them, can favor a production of turbulence in the flow carrying the sediments. We will examine in greater detail the effect first of suspended and then entrained sediments on the kinematics of the medium transporting them.

Suspended sediments. The effect of suspended sediments on the profile of the time-averaged longitudinal velocity of the suspension-carrying flow, since the time of Vanoni [32], who was the first to discover this phenomenon, is usually determined experimentally and unambiguously: there is a decrease in the values of the Karman parameter $\varkappa_0$ in comparison with its value $\varkappa$ for a flow of pure water. In this case the velocity profile remains logarithmic [22, 29, 30, 33]:

$$\overline{V}_X(z) = \frac{V_*}{\varkappa_0} \ln \frac{V_* z}{\nu} + C, \tag{1}$$

where $\overline{V}_X$ (z) is the averaged longitudinal velocity of the fluid at the distance z from the bottom; V_* is dynamic velocity; ν is the kinematic viscosity of the fluid; C is a constant.

A theoretical explanation of the decrease in the Karman parameter for a suspension-carrying flow and a quantitative evaluation of this phenomenon was given by Barenblatt [1, 2]. The volume concentration of particles in the mentioned studies was assumed to be quite small, which made it possible to neglect their interaction. In the transport of sediments in a limiting saturation regime, that is, when the flow is freely exchanged with particles from the bottom, the value $\varkappa_0 = \varkappa\omega$, where $\omega = W/\varkappa V_*$, by definition of the considered process, is less than unity, whereas W^* is the steady rate of free precipitation of particles.

Empirical expressions for $\varkappa_0$, containing the dependence of this parameter on the volume concentration of particles, are cited, for example, in [10, 33]. The experimental checking of such expressions is difficult because in constructing a logarithmic dependence in the form (1) the value of the Karman parameter to a considerable degree is dependent on the choice of the zero reading z = 0 [10], which different authors interpret differently.

Velikanov [7, 8] proposed that that the expenditure of fluid flow energy on the maintenance of particles in a suspended state be taken into account. In the so-called gravitational theory of the movement of suspended sediments which he developed it was assumed that on the suspension of particles there is expenditure of some part of the energy of the averaged movement of the carrying fluid, in turn caused by the energy of the earth's gravitational field.

Certain aspects of gravitational theory, including its fundamental energy expression, caused vigorous scientific discussion [14] and attracted the attention of scientists in different fields of specialization to the discussed problem. In the opinion of Fidman [24], the great importance of the study by Velikanov was that it gave encouragement for subsequent study of the problem and served, in essence, as a point of departure for formulating more perfect theoretical schemes.

Kolmogorov [17] demonstrated that in the gravitational theory the role of the work of suspension in the energy balance of a sediment-carrying flow was incorrectly determined because the particles are kept in a suspended state due to the energy of turbulent pulsations, not the averaged movement of the fluid. In the scheme of the principal transformations of energy in a turbulent flow carrying suspended particles proposed by the author of [17] during the performance of the work of suspension a part of the energy of macroscale velocity pulsations of a fluid is transformed into gravitational energy.

Kolmogorov's ideas concerning the balance of fluctuation energy of a flow of a homogeneous incompressible fluid [16] in the already mentioned studies of Barenblatt [1, 2] served as a basis for analysis of the movement of a plane turbulent suspension-carrying flow. It was found that the movement of a two-phase medium is essentially dependent on the dimensionless combination

$$\mathrm{Ko} = g\left(\frac{\rho_0}{\rho} - 1\right)\frac{dS}{dz}\left(\frac{d\overline{V}_X}{dz}\right)^2, \quad (2)$$

later called the Kolmogorov number (here S and $\overline{V}_X$ are the mean values of the volume concentration of particles and the longitudinal component of flow velocity at a given point). In particular, a decrease in the fluctuation velocity of the suspension-carrying flow of fluid is expressed by the dependence

$$V_0 = V(1 - \mathrm{Ko})^{1/4}, \quad (3)$$

where V_0 and V are the mean square values of pulsations in the velocity of the fluid, carrying the suspension and without particles respectively. The dynamic effect of the suspended particles on the flow even in the case of their extremely small volume concentrations is important "due to the enormous influence of gravity" [3].

The attenuation of turbulent pulsations of velocity of the medium in flows of fluid or gas with the introduction of small solid particles in them is indicated by the results of numerous investigations, such as [4, 13, 15, 25, 26, 32], but from time to time the opposite assertions are encountered [29, 30].

Dement'yev and Pechenkin [12] investigated the laws of movement of suspension-carrying flows with different concentrations up to total saturation using a method based on the optical homogeneity of particles and the fluid transporting them [21]. According to the results, the intensity of turbulence begins to decrease appreciably with a volume concentration of the suspension S close to 0.1. Later data obtained by Pechenkin indicate high S values at which the pulsations of the fluid phase decrease [22]. In the experiments of Bagnold [27] with particles close in density to the fluid transporting them there was also found to be a decrease in the intensity of turbulence with a considerable volume concentration of particles ($S \simeq 0.3$) and its total extinction with $S \simeq 0.35$.

The presence of suspended particles in the flow distorts the spectrum of turbulent pulsations of fluid [4, 6], causes a decrease in the turbulence scale [5, 6, 15] and exerts an influence on the movement of entrained sediments. It was established experimentally that in the presence of a suspension the transport of entrained sediments can both increase and decrease [31]. It is evident that this problem requires further study.

Entrained sediments. In a theoretical study of the movement of entrained sediments the quite rigorous methods of the mechanics of a continuous medium and hydrodynamics are inapplicable with low Reynolds numbers, although they are employed successfully for describing suspension-carrying flows. This is evidently the reason why investigations of the mechanics of bottom particles are not so numerous as studies of suspended particles. In particular, only in individual studies has there been an investigation of the influence of bottom sediments on the kinematics of the flow transporting them. However, some conclusions nevertheless can be drawn on this subject because the results of investigation of this phenomenon are usually noncontradictory. For example, they indicate an increase in the intensity of turbulence in a flow of fluid transporting particles in the bottom region in comparison with a flow without particles.

Concepts were expressed that the movement of entrained sediments creates an effect similar to the effect of an additional bottom roughness [18, 20, 28], which, as is well known [23], favors the formation of turbulence in the flow. According to Owen [20], the vertical dimension of this additional roughness is equal to the mean height of jumps of saltating sediments.

On the other hand, the formation of turbulence of the flow transporting the bottom sediments can be explained on the basis of the mechanism of detachment of saltating particles from the bottom, in which the main role is played by the collision of particles with projections of bottom roughness [11]. For this we will examine a scheme of the principal energy transformations (Fig. 1), similar to the Kolmogorov scheme for a suspension-carrying medium, proposed for the case of a bottom layer of flow and the saltation movement of sediments occurring in it.

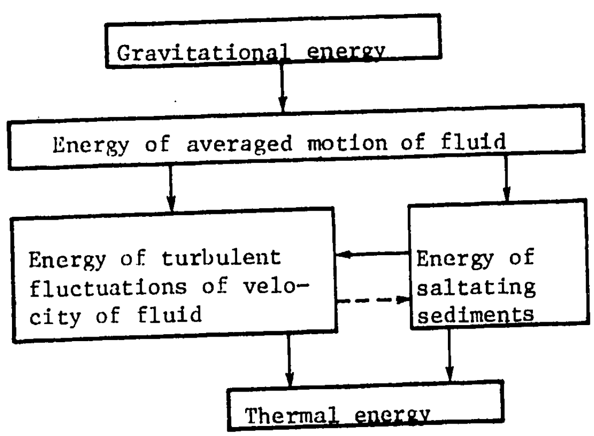

Fig. 1. Block diagram of principal energy transformations in bottom region of turbulent flow transporting saltation load.

Gravitational energy generates the energy of averaged flow of a fluid, which, first of all is transformed into the energy of turbulent pulsations of flow velocity and second, is expended on the transport of entrained sediments in a horizontal direction. In collisions with projections of bottom roughness and detachment of

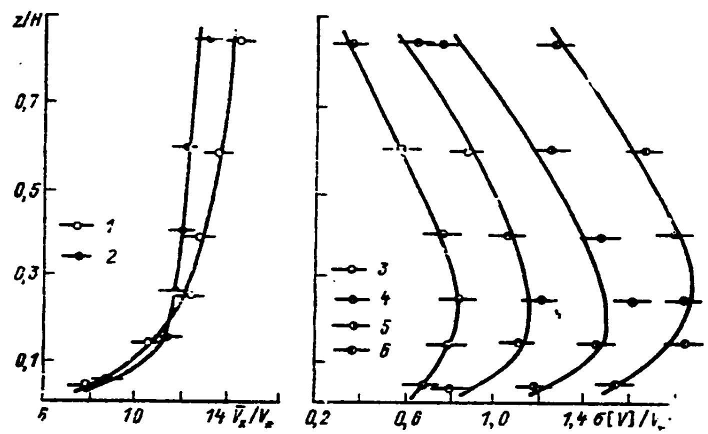

Fig. 2. Influence of saltating particles on kinematics of fluid flow transporting them. 1, 3, 5) flow without particles; 2, 4, 6) flow with particles; 1, 2) mean velocity of fluid; 3, 4) vertical and 5, 6) horizontal pulsations of velocity of fluid.

particles from the bottom their longitudinal velocity is partially transformed into vertical velocity. The saltating particles rising from the bottom are entrained upward together with the surrounding fluid.

In this case the kinetic energy of the particles is transformed into their potential energy and also into the energy of turbulent pulsations of the velocity of a fluid and thermal energy. Similarly on the descending branches of the trajectories the saltating particles impart a negative vertical velocity to the fluid surrounding them. In this case a fraction of the potential energy of a heavy particle situated at some distance from the bottom is transformed into the energy of turbulent pulsations.

The intensive vertical movement of saltating sediments amidst fluid layers having extremely differing longitudinal velocities in the bottom region favors entrainment and horizontal fluctuations of fluid velocity.

The authors of [19] discovered some increase in the intensity of turbulence of a water flow transporting grains of gravel (mean size $D = 0.005 \pm 0.002$ m) even with an insignificant volume concentration of sediments — about 0.01. In these experiments the depth of flow H varied from 0.068 to 0.106 m, the dynamic velocity varied from 0.10 to 0.13 m/sec, the values of the Reynolds numbers varied from $0.7-1.5 \cdot 10^5$ and the Froude number was in the range 1.9-2.8.

For a more graphic demonstration of the considerations expressed concerning the influence of saltating sediments on the kinematics of a sediment-carrying flow we processed an experiment obtained from the film archives of the Department of Physics of the Sea and Waters of the Land of the Physics Faculty at Moscow State University. In this experiment a study was made of the saltation of extremely large ($D = 0.043$ m) individual particles having an irregular configuration and a density of $1.45 \cdot 10^3$ kg/m^3. The parameters of the experiment were: $H = 0.094$ m; $V_* = 0.13$ m/sec; $Re = 1.3 \cdot 10^5$; $Fr = 2.4$. More than half of the saltating particles rose higher than the level $z/H = 0.5$, and some of them touched the free surface of the flow.

The data from the motion picture survey were used in determining the averaged and pulsating kinematic characteristics of flows of pure water and sediment-carrying flows (Fig. 2). The figure shows that in the second case in addition to some change in the curve of averaged longitudinal velocity there was an obvious increase in the values of both vertical and longitudinal pulsations of fluid velocity (on the average by 46 and 31% respectively). The confidence intervals of the experimental data correspond to a confidence coefficient of 0.95. We note that in a flow with entrained particles the value of the Karman parameter increased by approximately 40%, and did not decrease, as is observed in the presence of a suspension.

Thus, there is some basis for assuming that the influence of suspended and entrained (saltating) sediments on the kinematics of the flow transporting them is not identical, but instead opposite. This can be attributed to the difference in the mechanism of vertical movement of particles: the movement of the suspended sediments is attributable to the turbulence of the flow transporting them, whereas for entrained sediments turbulence is not a decisive factor.

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DYNAMIC-STATISTICAL METHODS FOR PREDICTING THE YIELD OF AGRICULTURAL CROPS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 92-102

[Article by A. N. Polevoy, candidate of geographical sciences, All-Union Scientific Research Institute of Agricultural Meteorology, manuscript received 17 Jun 80]

[Text]

Abstract: Methods are proposed for predicting the yield of agricultural crops which combine the use of statistical methods for prediction on the basis of one time series and methods for evaluating agrometeorological growth conditions based on dynamic productivity models. A combined method is described for developing prediction procedures on this basis which are applicable to specific regions.

The task of predicting the yield of agricultural crops involves great difficulties due to the need for taking into account a whole series of complex biological laws of formation of the yield of cultivated plants in its solution. The complexity of development of such an approach makes it necessary to carry out extensive research work and to proceed along different paths to its solution -- from a description of the external aspects of the processes involved in yield formation and a search for statistical relationships indirectly taking into account effects whose nature is not entirely known to an explanation of their internal laws, for this purpose employing the materials and methods of sciences related to agrometeorology.

The principal theoretical concepts of agrometeorological prediction of the productivity of agricultural crops and grasses were formulated by R. E. David, V. M. Obukhov, N. A. Zubarev, S. A. Verigo, L. A. Razumova, Ye. A. Tsuberbiller, Ye. S. Ulanova, M. S. Kulik, A. V. Protserov, K. V. Kirillicheva, Yu. I. Chirkov, A. P. Fedoseyev, V. A. Moiseychik, and others. All subsequent investigations in this field of agricultural meteorology were made on the scientific basis which they created and new approaches were developed for solution of this problem.

In the development of methods for agrometeorological predictions the time series for the yield of agricultural crops (y_t) can be regarded as the sum of two terms: the determined component and random deviations from it:

$$y_t = f(t) + \varepsilon_t, \qquad (1)$$

where f(t) is some nonrandom function of time (trend), ε_t is the random component of the time series.

The crop yield trend is dependent on the introduction and application of the attainments of science and technology into practice, the increase in the expenditure of technical resources, an improvement in the organization of labor and the application of fertilizers, change in the species structure of sown areas and land improvement. It is a result of a gradual improvement in the sophistication of crop cultivation against the background of the average level of soil-climatic conditions. Deviations of crop yield from the developing trend are determined primarily by the agrometeorological conditions of the growing season of specific years.

Thus, a prediction of crop yield can be made taking into account both components of the time series: the trend -- by means of extrapolation using any of the prediction methods based on one time series and deviations from the trend -- using methods for the evaluation of the agrometeorological conditions for crop growth. The sum of the two predictions obtained in this way gives a general overall prediction of crop yield. The methodology of dynamic-statistical prediction of the yield of agricultural crops [6, 7] rests, on the one hand, on the use of methods for prediction based on one time series, employed extensively in the prediction of economic phenomena, and on the other hand -- on methods for evaluating the agrometeorological conditions for yield formation using dynamic productivity models [5-7, 12].

The carrying out of investigations for the choice of the most acceptable approach to extrapolation of the trend in crop yield [3, 4] and the development of methods for determining the parameters of dynamic models of yield formation on the basis of standard agrometeorological information [8] created the prerequisites for a changeover to a qualitatively new stage in the development of dynamic-statistical prediction of the productivity of agricultural crops. It can be formulated briefly as the creation of methods for prediction on the basis of dynamic-statistical yield prediction methods applicable to different regions of the country.

In dynamic models of formation of the yield of agricultural crops there is a combination of both general theoretical concepts concerning the process of formation of the yield of a specific crop and stable quantitative characteristics -- the parameters of the models. Two groups stand out among the parameters of dynamic productivity models. The first includes characteristics typical of a particular type of crop and their numerical values can be considered independent of habitat conditions. The numerical values of these parameters are determined in the stage of development of the dynamic model and the method for predicting the yield of a specific agricultural crop. The second group includes characteristics typical for a crop whose numerical values vary in dependence on the climatic conditions for crop cultivation. The problem of developing methods for prediction of the yield of agricultural crops applicable to a specific soil-climatic zone or an individual part of it essentially involves a determination of the numerical values of parameters of the second group and evaluation of their geographical variability on the basis of standard agrometeorological information.

For predicting the yield (y_{pred}) use is made of the expression

$$y_{pred} = y_{t+1}c, \qquad (2)$$

in which y_{t+1} is the crop yield trend during the predicted year; c is the evaluation of the degree of difference between the agrometeorological conditions for formation of the crop yield prevailing on the date of preparation of the prediction from the long-term values, against whose background the crop yield trend is formed.

Now we will examine methods for computing the components of equation (2), as well as the development of methods for yield prediction applicable to specific soil-climatic zones.

Prediction of Yield Trend by the Harmonic Weights Method

In methods of prediction based on one time series an assumption is made concerning the type of trend; its form and parameters are determined as a result of choice (according to some statistical criteria) of the best function from among the available criteria. In comparison with these methods the harmonic weights method [14, 16] has the advantage that such assumptions need not be made.

As some approximation $\hat{f}(t)$ of the true trend f(t) use is made of a broken curve smoothing a stipulated number of points of the time series y_t. The changing position of individual segments of the broken curve, representing the trend, describes the continuous changes in the studied process, that is, its individual phases.

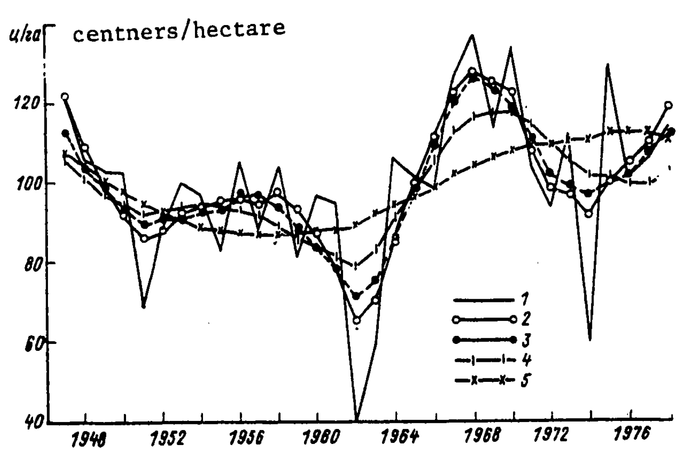

Fig. 1. Smoothing of time series of potato yields in Kaluzhskaya Oblast. 1) actual potato yield, 2) yield trend with k = 5, 3) with k = 7, 4) with k = 10, 5) with k = 16.

In order to determine the individual phases of movement of the moving trend we find a number $k < n$ and using the least squares method find the equations for the linear segments:

$$y_i(t) = a_i + b_i t, \quad (i = 1, 2, \ldots, n - k + 1), \tag{3}$$

here for i = 1 t = 1, 2,...,k;
for i = 2 t = 2, 3,...,..., k + 1;
for i = n - k + 1, t = n - k + 1, n - k + 2,..., n.

We will determine the value of each function $y_i(t)$ at the points:

$$t = i + h - 1, \quad (h = 1, 2, \ldots, k).$$

Among these values we select those for which t = i and by $y_i(t)$ we denote the values of the functions $y_i(t)$ for t = i.

Assume that such values will be g_i. The means can be determined using the expression

$$\overline{y_j}(t) = \frac{1}{g_i} \sum_{l=1}^{g_i} y_l(t), \quad (j = 1, 2, \ldots, g_i). \tag{4}$$

The nature of the trend line connecting the mean values $\overline{y}_i(t)$ will be dependent on the choice of the number k -- the smoothing interval. As demonstrated in Fig. 1, with small values of this parameter the crop yield trend also includes variations of crop yield under the influence of the weather conditions prevailing in specific years. And only with rather high values (10 or more years) will the crop yield trend be free of short-period fluctuations.

A checking of hypotheses concerning choice of the form of trend and also on the stationarity of the random component of the time series of yields indicated that for most agricultural crops the smoothing interval k in the limits 14-16 years ensures a proper exclusion of the crop yield trend from the time series of yields.

In order to extrapolate the crop yield trend we determine the increments ω_{t+1} of the function f(t) as

$$\omega_{t+1} = f(t+1) - f(t) = \overline{y}_{t+1} - \overline{y}_t \tag{5}$$

and compute the mean of the increments

$$\overline{\overline{\omega}} = \sum_{t=1}^{n-1} c^n_{t+1} \omega_{t+1}, \tag{6}$$

where c^n_{t+1} are coefficients satisfying the following conditions:

$$c^n_{t+1} > 0, \quad (t = 1, 2, \ldots, n - 1), \tag{7}$$

$$\sum_{t=1}^{n-1} c^n_{t+1} = 1. \tag{8}$$

The harmonic weights are determined using the formula

$$c^n_{t+1} = \frac{m_{t+1}}{n-1}. \tag{9}$$

Expression (6) makes it possible to assign greater weights to later observations. If the earliest observations have the weight

$$m_2 = \frac{1}{n-1}, \tag{10}$$

the weight of the information m_3, relating to the next moment in time, will be determined as

$$m_3 = m_2 + \frac{1}{n-2}. \tag{11}$$

Thus, a series of weights is determined using the equation

$$m_{t+1} = m_t + \frac{1}{n-t}, \quad (t=2, 3, \ldots, n-1) \tag{12}$$

with an initial value expressed by equation (10).

The predicted value of the time series is determined using the formula

$$y_{t+1} = y_t + \bar{\omega}. \tag{13}$$

Evaluation of Agrometeorological Conditions of Formation of the Yield of Agricultural Crops

The task of agrometeorological diagnosis essentially involves a determination of the degree of difference in the variation of the indices of photosynthetic activity of sown crops under the influence of the agrometeorological conditions of the evaluated period from their mean long-term variation caused by the corresponding agrometeorological regime against whose background the crop yield trend is formed.

The change in the volume of the yield (its deviation from the trend) under very definite agrometeorological conditions during the course of the evaluated time interval, different from the mean long-term conditions, is determined by the change in all the most important indices of photosynthetic activity, which is caused by the influence of these agrometeorological conditions.

The basis for the quantitative evaluation of the agrometeorological conditions for the growth of agricultural crops, which in the evaluation of a prolonged growing season is also an evaluation of the possible deviation of the crop yield from its trend, is the expression [7]

$$c = \frac{\hat{y}}{\bar{y}}, \tag{14}$$

where c is the evaluation of the agrometeorological conditions for formation of the yield during the course of the considered growing season; $\hat{y}$ is the yield, computed using a dynamic model on the basis of data characterizing the conditions of the period to be evaluated; $\bar{y}$ is the yield, computed using a dynamic model on the basis of the mean long-term agrometeorological data.

The change in the indices of photosynthetic activity of sown crops under the influence of very definite agrometeorological conditions of the period to be evaluated is in a mutually unambiguous correspondence with the change in crop yield.

A quantitative evaluation of agrometeorological conditions essentially involves computation of the yield taking into account the indices characterizing the agrometeorological conditions of the period to be evaluated and the yield computed against the background of climatic conditions. This evaluation characterizes the magnitude of the crop yield deviation under the influence of weather conditions in a specific year from its trend forming against the background of climatic conditions.

In making the evaluations we carried out computations on the basis of applied dynamic models of formation of the yield of agricultural crops. These models, intended for agrometeorological computations, describe the processes of photosynthesis, respiration and growth and accordingly contain three biological "blocks": photosynthesis, respiration and growth, and also a block for the transformation of initial agrometeorological information -- agrometeorological.

Photosynthesis block. The photosynthesis of leaves can be represented by the formula [18]

$$\Phi_0^j = \frac{kbI^j}{k + bI^j}, \qquad (15)$$

where Φ_0 is the intensity of photosynthesis under the optimum prevailing conditions of heat and moisture supply and real illumination conditions, mg $CO_2/(dm^2\cdot$hour); k is the intensity of photosynthesis in the case of light saturation and a normal CO_2 concentration, mg $CO_2/(dm^2\cdot$hour); b is the initial slope of the photosynthesis light curve, mg $CO_2/(dm^{-2}\cdot hour^{-1})(cal^{-1}\cdot cm^2\cdot min^{-1})$; I is the intensity of photosynthetically active radiation (PAR) within the sown crop, cal/$(cm^2\cdot$min), f is the number of the step in the computation period.

In ontogenesis the photosynthetic activity of a leaf is determined by its age and the intensity of the water-heat regime.

In computations of photosynthesis in ontogenesis under real environmental conditions different from the biologically optimum we use the expression

[Φ = ph]

$$\Phi_{\text{ф}}^j = \Phi_0^j \alpha_{\Phi}^j \psi_{\Phi}^j \gamma_{\Phi}^j, \qquad (16)$$

where $\Phi_{\text{ф}}$ is the intensity of photosynthesis under real environmental conditions, mg $CO_2/(dm^2\cdot$hour); α_{ph} is the ontogenetic photosynthesis curve; ψ_{ph}, γ_{ph} are functions of the effect of environmental factors (air temperature averaged for the light time of day and soil moisture content), constituting single-peak curves.

The functions α_{ph}, ψ_{ph} and γ_{ph} entering into expression (16) were normalized and vary from 0 to 1.

The total photosynthesis of the sown crop during the light time of day can be computed using the formula

$$\Phi^j = 1\Phi_{\text{ф}}^j L^j \tau_{\text{д}}^j, \qquad (17)$$

[д = day]

where Φ is the daytime photosynthesis of the sown crop per unit area, $g/(m^2 \cdot day)$; $\mathcal{E}$ = 0.68 is the coefficient of efficiency of photosynthesis; L is the area of the leaf surface, m^2/m^2; τ_{day} is the length of day, hours.

Respiration block. In contrast to the photosynthesis process, all plant organs have a capacity for respiratory gas exchange.

Expenditures on respiration are subdivided [13, 15, 17] into respiration associated with the maintenance of the structural organization of the tissues and respiration associated with the movement of substances, photosynthesis and the creation of new structural units:

$$R^j = \alpha^j_R (c_1 M^j + c_2 \Phi^j), \tag{18}$$

where R are the expenditures on respiration, g/m^2; α_R is the ontogenetic respiration curve; c_1 is a coefficient characterizing the expenditures on the maintenance of structure; M is the dry biomass of the sown crop, g/m^2; c_2 is a coefficient characterizing the expenditures associated with the movement of substances, photosynthesis and the creation of new structural units.

Growth block. The increment of biomass of the sown crop is determined by the difference between the total photosynthesis of the sown crop and the expenditures on respiration

$$\Delta M = \Phi^j - R^j. \tag{19}$$

In describing the growth of individual plant organs we will use the growth equations proposed in [9] but in a modified form [1]

$$\begin{cases} m_i^{j+1} = m_i^j + (\beta_i^j \Delta M^j - \vartheta_i^j m_i^j) \\ m_p^{j+1} = m_p^j + \left(\beta_p^j \Delta M^j + \sum_i^{l,\,s,\,r} \vartheta_i^j m_i^j \right), \end{cases} \tag{20}$$

where m_i is the total dry biomass of individual $i \in \ell$, s, r (ℓ is the leaf, s is the stem, r is the root, p are the reproductive organs) organs, g/m^2; β_i is the function of redistribution of "fresh" assimilates; ϑ_i is the function of redistribution of "old" assimilates.

The growth of the area of leaves of the sown crop is determined with a positive increment of the biomass of leaves using the formula [1, 13]

$$L^{j+1} = L^j + \Delta m_l \frac{1}{z}, \tag{21}$$

where z is the specific surface density of the leaves, g/m^2.

With a negative increment of the biomass of leaves for describing the growth of their assimilating surface we use an expression in the form [8]

$$L^{j+1} = L^j - \Delta m_l \frac{1}{z} \frac{1}{k_c}, \tag{22}$$

where $k_c = 0.3$ is a parameter characterizing the critical value of the decrease in the living biomass of leaves at which its dying-off begins.

Agrometeorological block. The PAR absorbed by the sown crop is computed using the formula [10]

$$I^j = \frac{I_0^j}{1 + cL^j}, \tag{23}$$

where I_0 is the intensity of PAR at the upper boundary of the sown crop, cal/(cm^2·min); c = 0.5 is an empirical constant.

The flux of PAR at the upper boundary of the sowed crop is determined using the formula

[Д = day] $$I_0^j = \frac{0.5\,Q}{60\,\tau_д}, \tag{24}$$

where Q is the total solar radiation, cal/(cm^2·day).

The total solar radiation is computed using the Sivkov formula [11]

$$Q^j = 12{,}66\,(S^j)^{1.31} + 315\,(\sin h_n^j)^{2.1}, \tag{25}$$

where S is the duration of sunshine, hours; h_n is midday solar altitude.

The mean air temperature during the light time of day [2] is computed using formulas in the form

$$T_{day} = a_1\,T_{max} + a_0, \tag{26}$$

where T_{day} and T_{max} are the mean daytime and maximum air temperatures; a_0, a_1 are empirical coefficients.

Table 1

Mean Relative Error (%) in Computing Area of Leaf Surfaces and Biomass of the Reproductive Organs

Crop	Leaf area	Biomass of reproductive organs
Winter rye	15	18
Winter wheat	14	18
Spring wheat	20	23
Spring barley	19	25
Oats	22	27
Potatoes	18	21

The parameters of the models described above were determined applicable to the conditions prevailing in the Nonchernozem zone of the European USSR for the following crops: winter rye, winter wheat, spring wheat, spring barley, oats and potatoes. The error in computations with the model for the area of the assimilating surface is 14-22%, for the dry biomass of the reproductive organs -- 18-27% (see Table 1).

Development of Methods for Predicting Yield Applicable to Specific Soil-Climatic Zones

The methods for predicting yield of any crop applicable to a specific territory are being developed on the basis of the dynamic-statistical method for predicting the yield of this crop, a component part of which is a dynamic model for the formation of crop yield.

The development of this method essentially involves a determination, applicable to the conditions of a specific territory, of the numerical values of those parameters of the model which vary in dependence on the climatic conditions for cultivation of the crop.

As already mentioned, the parameters of the model of yield formation can be divided into two groups.

The first group of parameters includes:
-- the parameters k and b of the photosynthesis light curve;
-- the functions for the influence of air temperature ψ_{ph} and soil moisture content γ_{ph} on the intensity of photosynthesis;
-- the coefficient of expenditures on the maintenance of structures c_1 and the coefficients of expenditures on constructive respiration c_2.

The numerical values of these parameters were assumed to be independent of habitat conditions.

The second group includes the parameters:
-- ontogenetic photosynthesis curves α_{ph};
-- ontogenetic respiration curves α_R;
-- functions for the period of vegetative growth β_i;
-- functions for the period of reproductive growth δ_i.

Computations of these functions are made applicable to the specific territory on the basis of standard agrometeorological information published in the reference manuals AGROKLIMATICHESKIYE RESURSY OBLASTI (Oblast Agroclimatic Resources). For this purpose it is necessary to determine the air temperature sums (effective above 5°C for winter and early spring grain crops, active above 7°C for potatoes) during the principal growing seasons:
-- renewal of growing (sprouting) - leaf tube formation $\sum t_1$;
-- renewal of growing (sprouting) - earing (tasseling, budding) $\sum t_2$;
-- renewal of growing (sprouting) - blossoming $\sum t_3$;
-- renewal of growing (sprouting) - gold ripeness (wilting of top) $\sum t_4$.

The ontogenetic photosynthesis (α_{ph}) and respiration (α_R) curves are described by an expression in the form

$$\alpha^j = e^{\frac{-a\,(\Sigma t^j - \Sigma t_{max})^2}{10}}, \qquad (27)$$

in which the α parameter is found using the expression

$$a = \frac{-100 \ln \alpha^{\circ}}{\Sigma t_{max}}, \tag{28}$$

where $\sum t^j$ is the sum of effective (active) temperatures accumulating from the beginning of the growing season in the j-th step; $\sum t_{max}$ is the sum of temperatures characterizing the time of onset of the maximum of the intensity of photosynthesis or respiration, equal to $1/4 \sum t_4$; α° is the value of the ontogenetic curve at the point $\sum t^{\circ} = 0$, assumed equal to 0.5.

In accordance with [9], the functions for the period of vegetative growth are determined as

$$\beta_i = \frac{\Delta m_i}{\sum\limits_{i}^{l,\,s,\,r,\,p} \Delta m_i} \tag{29}$$

and show the fraction of the total increment of the entire plant accounted for by the i-th organ.

The functions for the period of reproductive growth were written [1, 9] as

$$\vartheta_i = \frac{\Delta m_i}{m_i}; \; i \in l, s, r. \tag{30}$$

They show the outflow (redistribution) of the assimilates from each vegetative organ after completion of its growth into reproductive organs.

The computations for the functions of the period of vegetative and reproductive growth in practical models of yield formation involve the following.

The dynamics of the biomass of plant organs in relative units can be represented in the form of a family of curves whose inflection points $\sum t_i^2$, $i \in l$, s, r, p were related to the sums of effective temperatures, equal to half the entire sum necessary for completing the growth of each organ. The sum $\sum t_p$, reduced to the x-axis in Fig. 2, represents the sum of temperatures from which the growth of reproductive organs begins.
Describing each of these curves by the equation for a logistical curve, differentiating this equation and multiplying by the coefficient c_i, characterizing the fraction of the organ in the total biomass with maturing, we obtain the following expression [8] for determining the functions of the period of vegetative growth

$$\beta_i = \frac{\Delta\theta_i}{\sum\limits_{i}^{l,\,s,\,r,\,p} \Delta\theta_i}, \tag{31}$$

in which

$$\Delta\Theta_i^j = \frac{4{,}6052 \cdot 10^{\frac{2(\Sigma t_i^2 - \Sigma t^j)}{\Sigma t_i^2}}}{\Sigma t_i^2 \left(1 + 10^{\frac{2(\Sigma t_i^2 - \Sigma t_j)}{\Sigma t_i^2}}\right)^2} c_i; \quad i \in l, s, r, p, \tag{32}$$

where $\sum t_i^2$ is the sum of effective temperatures, equal to half the sum of the temperatures necessary for completing the growth of each of the organs; c_i is the coefficient of the ratio of different organs in the plant during maturing.

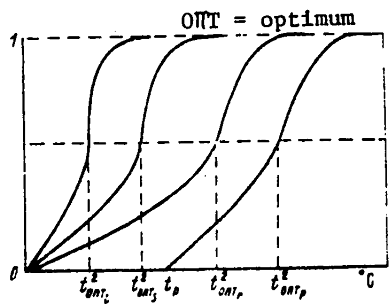

Fig. 2. Dynamics of accumulation of biomass of individual plant organs. In the figure

$$\sum t_l^2, \sum t_s^2, \sum t_r^2, \sum t_p^2$$

are the sums of the effective temperatures, equal to half the sum necessary for completion of the growth of organs: l -- leaves, s -- stems, r -- roots, p -- ears; $\sum t_p$ -- beginning of growth of ear.

The redistribution of "old" assimilates from leaves, stems and roots into the reproductive organs begins from the moment of completion of growth of each of these organs. The growth functions for the period of reproductive growth ϑ_i for each vegetative organ are found from the expression [8]

$$\vartheta_i^l = \frac{0,3 \sum t^l}{(2 \sum t_p^2 - \sum t_p) - 2 \sum t_i^2}; \quad i \in l, s, r. \qquad (33)$$

The position of the functions of the period of vegetative and reproductive growth, describing the redistribution of the "fresh" and "old" assimilates among the plant organs, is determined by the temperature sums necessary for completing the growth of leaves, stems, roots, the beginning of growth of ears, tubers, the onset of gold ripeness (wilting of tops).

The time of appearance and completion of growth of each organ is related to the corresponding phase of plant development. Then the sum of temperatures determining the position of the growth function of any organ, that is, the sum $\sum t_i^2$ of expressions (32), (33), will be equal for leaves to $\sum t_l^2$ -- $1/2 \sum t_2$, for stems -- to $\sum t_s^2 - 1/2 \sum t_3$, for roots -- to $\sum t_r^2 - 1/2 \sum t_3$.

It is necessary to determine the sum of temperatures $\sum t_p$ with which growth of the reproductive organ begins. For grain crops this sum is determined as

$$\Sigma t_p = \frac{\Sigma t_1 + \Sigma t_2}{2}. \qquad (34)$$

For potatoes $\sum t_p$ is equal to $\sum t_2$.

The position of the growth function of an ear (tuber) is determined by the sum of temperatures $\sum t_p^2$, which is found using the following expression:

$$\Sigma t_p^2 = \frac{\Sigma t_1 - \Sigma t_p}{2} + \Sigma t_p. \qquad (35)$$

Thus, the determination of the numerical values of the parameters of the models is based on the use of air temperature sums for the main periods of growing of cultivated plants.

In order to develop a forecasting method there must be appropriate processing of data from agrometeorological observations for the purpose of obtaining these cardinal sums. The temperature sum during the main growing periods reflect the climatic conditions for cultivation of a crop in a specific area, and accordingly, the parameters of the forecasting method will reflect the peculiarities of this specific territory.

Thus, there is a fundamental possibility, on the basis of dynamic-statistical methods for forecasting crop yields, to develop forecasting methods applicable to different regions of the country. The first application of this possibility was carried out in [6] applicable to the conditions prevailing in the Baltic area and in Belorussia.

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UDC 551.506.24

ORGANIZATION OF COMPUTERIZED DATA ARCHIVES FROM ANALYSES OF METEOROLOGICAL FIELDS OBTAINED UNDER THE FGGE PROGRAM

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 103-107

[Article by S. L. Belousov, candidate of physical and mathematical sciences, and A. M. Gofen, USSR Hydrometeorological Scientific Research Center, manuscript received 18 Aug 80]

[Text]

Abstract: Fundamental information is given on the content and structure of level-III data sets for the First Global Experiment (FGGE), constituting the results of objective analyses of meteorological fields at grid points. Taking into account the peculiarities of structure of these data, and on the basis of experience in work with them programming techniques are proposed for access to this material and procedures are described for their use for numerical experiments on an electronic computer. Information is given on one specific realization of the proposed processing procedures as employed at the USSR Hydrometeorological Center on a CYBER-172 electronic computer and information and recommendations are given for its realization using other electronic computers.

Introduction. FGGE Level-III Data

It is well known that there is a need for sufficiently complete and reliable data on the state of the atmosphere both for meteorological investigations and for computing numerical forecasts on a routine, operational basis. The collection of an adequate volume of reliable data for these purposes (like an evaluation of the really required volume of data) was always one of the unsolved problems in applied and theoretical meteorology. In order to obtain data in a volume exceeding that which is accessible every day under operational conditions, international and regional observation projects have been repeatedly organized, as well as experiments and other programs. Among the earlier implemented observational experiments of this type we can mention, in particular, the programs of the International Geophysical Year (IGY) (1957-1959), the Year of the Quiet Sun (1964-1965), and also measures carried out within the framework of implementation of the GARP program: the Basic Data Set Project [2], Atlantic Tropical Experiment (GATE, 1974) of GARP, and others.

The most significant experiment of this type was the First Global Experiment (FGGE) of GARP. It differs in the following two ways from most of the preceding global experiments, whose principal purpose was the collection and accumulation of data:
-- the observations were made on a global scale over the course of a sufficiently long period of time (about two years) with the use not only of the usual observational techniques, but also a series of new observation systems specially created for these purposes;
-- a program for observations, transmission and accumulation of data which was part of a more general program, also making provision for their processing, in which the end product is both checked masses of observational data and masses of objective analyses of meteorological fields, computed on the basis of these data (level-II and level-III data respectively); these and other data were registered on magnetic tapes in accordance with a standard agreed upon internationally.

Without presenting all the details concerning the program for the processing of FGGE data, we will mention only some characteristics of level-III data sets following from the above-mentioned features of the experiment and significant for purposes of this article.

Computations of analyses both on the basis of data which are available on a routine basis and also using more complete data were carried out by world meteorological centers (three centers, level-IIIa data) and research institutes which have especially assumed these obligations (two processing centers, level IIIb data) respectively. A special standard was adopted for the registry of level-III data on magnetic tapes. This ensured a possibility for the international exchange of these data sets prepared by different processing centers (see [3]). The adopted standard provides for a widely developed system for the identification of the fields of meteorological elements corresponding to both the present-day and possible future needs of users.

Within the framework of this standard there was adoption of unformated registry (on magnetic tape) of the values at grid points in a packed form with the choice of a suitable scale and reading level in accordance with the real range of numbers of the considered field of analysis; this results in saving of space on the magnetic tape. After carrying out transformations, taking the selected scale and reading level into account, each element of the data mass is represented by a 16-digit whole number occupying two eight-bit bytes. The selected scale and the reading level are included among the significant field data and are incorporated in the heading ("mark") of the mass of packed numbers (see below).

On each coil of magnetic tape (being one "volume" in a full data set), in addition to blocks with packed values of meteorological elements at the grid points there are special blocks (files) with a description of the data containing both coded indicators and textual commentaries. Each tape begins with a text block (file), intended for adjustment of the read-out heads of the electronic computer magnetic tape storage unit.

Each block with data at the grid points contains an analysis of one meteorological element at one level for one observation time. It begins with a "mark" (identifier of the data field) with a length of 384 bits, followed by the 16-digit values of the parameters at the grid points. One or more blocks with data form a file with data. The blocks for describing the data, together with the marks within the blocks with data, form a convenient system for the identification of level-III data masses.

The total volume of level-III data on magnetic tapes at any one processing center can attain 100 or more coils (approximately 2000 megabytes). For example, the level-IIIa data at the World Meteorological Center in Washington cover the period from 1 January 1978 through 31 December 1979 (a total of 104 weeks); one coil of magnetic tape holds data from analyses for one week. (The data volumes at other centers can be different.)

Such a great volume and diversity of available data, together with the already noted peculiarities of their format, and also the real needs and existing possibilities for the use of data in various research programs predetermine the choice of the means of access to level-III data. These means must satisfy at least the following two requirements:
-- there must be assurance of an arbitrary and quite economical access to all the required elements of the data mass -- the fields of analysis necessary for different types of experiments;
-- arbitrary access must be accomplished by means of "keys" formed on the basis of stipulation (in accordance with the user's practical program) of parameters having graphic mnemonics and corresponding to the standard identification adopted for level-III data.

With these two requirements taken into account, the procedures for work with level-III data described below were formulated and applied.

Procedures and Organization of Work With Level-III Data

The proposed technology is described from a computer-independent point of view. It does not require a high speed of the processor or a great volume of the operational memory which is above and beyond that characteristic of average third-generation electronic computers in their minimum configuration. It is necessary to have magnetic recorders reading out a standard magnetic tape with a width of 0.5 inch, magnetic disks and in the mathematical support, presence of direct types of access to disk files. The volume of the accessible memory on the disks will exert a substantial influence on the nature of work with the archives, and specifically on the number of different entries accessible to the user in a particular problem. This number is determined, in particular, by the number of entries (blocks) adopted in the used data set, which in turn is determined by the number of points in the grid in the field of analyses. For example, in the analyses available at the United States National Meteorological Center (Washington) one record contains 10,780 bytes. For other producers of level-III data the extent of the record can be different [2].

The proposed technology provides for the implementation of the following stages in the work:

1. The user familiarizes himself with the catalogue listing the contents of the entire set of magnetic tapes (volumes) and selects those which contain the necessary fields of meteorological elements.

In a general case it is proposed that the information required for the researcher be registered on many coils, although with respect to volume it may not be great -- not more than 1-3 complete coils (1 coil$\approx$20 megabytes), so that it can be placed on direct-access carriers -- on magnetic disks.

2. In the next stage, from the information contained on the selected coils of magnetic tape, the necessary fields of meteorological elements must be extracted and a file with indexed-sequential or indexed organization is generated. For this the user prepares an order expressing the conditions which the selected fields must satisfy, and only they. Special programs introduce the order and by means of a one-time readout of all the selected tapes create the sought-for file on the disk. In accordance with the adopted standard [3], the identification of the fields is based on a standard mark occupying the first 384 bits, with which each record with data begins. The keys of the entries in the file should consist of the main components of the mark, such as:

Q -- type of parameter (1 -- altitude, 8 -- pressure, 16 -- temperature, 48 and 49 -- wind velocity components, etc.);

S1 -- type of surface at which the parameter was determined (8 -- isobaric surface, 128 -- mean sea level, 129 -- ground surface, 130 -- tropopause level);

C1, E1, where $C1*10^{E1}$ is the pressure value at the isobaric surfaces in the form of a normalized number; CD and CM are the sequence numbers for the day and month respectively (for climatological data);

K -- the conventional number of the grid for a particular processing center at the point for which the values of the meteorological elements are represented;

JJ, MM, YY, GG -- year, month, day and hour to which the sought-for analysis is related.

(In addition to the mentioned specifications the standard mark includes a number of other characteristics of the data mass necessary for use of the access programs, in particular, the selected scale and reading level with packing of the field.)

3. The user now has the possibility for arbitrary access to the file entries. In order to read any entry from its program he consults a special subprogram with a flexible system for the stipulation of parameters determining, by means of the mark components, the key to the required entry. The consultation of this subprogram must be allowed with any number of parameters, but those most used must be determined implicitly, by convention, or be retained from the preceding consultation. The stipulation of the parameters must be as flexible as possible and be allowed in the form of whole Hollerite constants (or simply variables of a whole type) "Q = 1", "JJ = 79", "MM = 1", "S1 = 130" or mnemonic values, such as "H", "TRO", denoting "Q = 1", "S1 = 130" and so forth respectively. In the absence of mark components in the consultation there is a readout of the next entry in the file in sequence (the sequential concept, for example, corresponds to an increase in the keys).

In the course of the work it is proposed that use be made of subprograms for accomplishing "unpacking" and reduction of data to the form of real numbers, interpolation from a geographic grid into a stereographic grid, and digit-by-digit access to the memory. The presented computer-independent description of procedures for working with level-III data is embodied in the BANKLIB packet written in expanded FORTRAN for a CYBER-172 electronic computer (A. M. Gofen is the author of the algorithm and packet of programs).

Some Peculiarities of Application of the Packet

The packet consists of 15 programs in expanded FORTRAN and three procedures in the language of the controlling components of the operational system for the CYBER-172 electronic computer. The volume of the two principal programs is about two pages of initial text in FORTRAN, and the volume of all the others is about half a page.

The peculiarities in implementation of the BANKLIB packet follow from the technical peculiarities of the CYBER-172 electronic computer and the level of its mathematical support. Some inconvenience, namely that the length of a word in the computer memory (60 digits) is not a multiple of eight (the length of the byte adopted for the representation of numbers), is easily overcome using programs for the readout/registry of an arbitrary sequence of digits and is compensated by a substantial broadening of standard FORTRAN, by means of which the packet programs are written. The packet provides for an indexed-sequential organization of a file on a disk. The key is determined as the first 192 digits of the mark (of a total of 384). The "through" sequence number of the observation, computed from JJ, MM, YY and GG, is registered in the digits from 161 through 192, and the pressure value at the isobaric surface is reduced to a nonnormalized form (El = 0). The capacity of only one packet of disks for this electronic computer is 10^6 memory words, which makes it possible to create constant or temporary files with a volume up to five complete coils of magnetic tape (with a registry density of 800 bytes/inch, adopted as the FGGE standard).

Summary

The BANKLIB packet was tested on magnetic tapes with level-III data registered in conformity to the FGGE standard and arriving from different sources. In particular, using this packet much work was carried out with DST-6 data (DATA SYSTEM TEST, 1976) and the fields of climatic norms ("fixed fields") obtained at the United States National Meteorological Center by way of preparation for the FGGE and kindly made available to the USSR Hydrometeorological Center, and also directly with FGGE level-III data from this same source. These and other data masses contain the fields of analyses of geopotential, temperature and wind velocity components at 12 standard levels (to the level 50 gPa), the relative humidity fields at six levels, the pressure field at sea level, fields of pressure and temperature at the level of the tropopause, air temperature field at the earth's surface and some other parameters (a total of 120-122 fields for each of the two principal observation times 0000 and 1200 hours). All the fields were stipulated in a geographic grid with an interval of 2.5° in latitude and longitude for the northern and southern hemispheres.

Work with these data in a number of the experiments carried out confirmed the effectiveness of their use in research programs. It therefore seems desirable to create a packet similar to BANKLIB for computers of the YeS type. In creating new archives with level-III data it also seems desirable to adhere to the FGGE format adopted for the storage of data on a magnetic tape.

It must be remembered that when working with a YeS computer, in which the standard mathematical support provides for access to eight-digit bytes and any sequences of such bytes, the difficulties associated with the above-mentioned noncorrespondence between the CYBER computer digital grids and the FGGE standard disappear.

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UDC 535.361.1:551.575

VISIBILITY OF LIGHT SIGNALS IN A CRYSTALLINE FOG

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 108-109

[Article by L. N. Pavlova, candidate of physical and mathematical sciences, Institute of Experimental Meteorology, manuscript received 17 Jun 80]

[Text]

Abstract: In the single-scattering approximation the author has computed the illumination of the observer's eye by radiation scattered by droplets and crystals in a beam of a He-Ne laser. It is shown that the range of detection of a light beam in the directions of angles $2° \leqslant \theta < 45°$ to its axis in crystalline fogs is less than in droplet clouds with the same range of visibility. Expressions are given for estimating the change in range of detection of a beacon in a crystalline fog.

Recently sources of laser radiation in the visible wavelength range have come into use in optical signaling and navigation systems. The purpose of these systems is the creation of extended light guides for the spatial orientation of aircraft or ships under foggy conditions or in the presence of a low cloud cover [1]. In order to compute the required power of the light source it is necessary to know the laws of propagation of directed radiation through a turbid atmosphere. A light beam, propagating in the atmosphere, is scattered by aerosols and can be seen in directions not coinciding with the direction of its propagation. The scattered light creates some illumination E on the observer's retina. If this illumination exceeds the threshold illumination of the eye, the observer will see a light guide. The magnitude of the illumination E is dependent both on the parameters of the light source and the geometry of observation, as well as on the optical characteristics of the aerosol: attenuation index and coefficient of directed light scattering [4].

Knowing these and others, it is possible, using an expression for E from [4], to compute illumination at the observation point (in the single scattering approximation). For example, in [2] data are given on the range of detection of the radiation of a He-Ne laser by an observer situated at a distance of 10 m from the light beam under the conditions prevailing in a droplet fog.

However, in the cold season of the year clouds and fogs frequently contain ice crystals. The scattering function of mixed and crystalline clouds in almost the entire range of scattering angles differs from the scattering function for droplet clouds [7]. Accordingly, the range of detection of light guides under the conditions prevailing in a crystalline cloud cover must be different than when they are observed in a droplet fog.

E W/cm^2

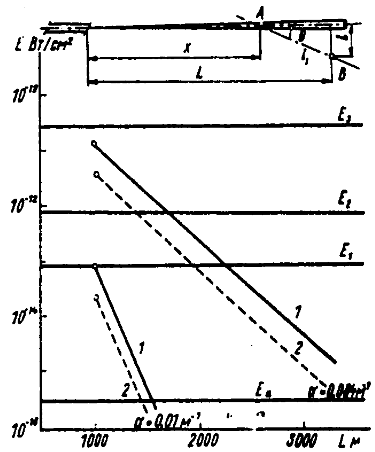

Fig. 1. Diagram of observation of a light beam by an observer from the point B and illumination of the eye with θ = 2° and different L.

Figure 1 shows the results of computations of the illumination created in the observer's pupil when he is situated at the point B by the light of a He-Ne laser with a power of 100 mW under the conditions observed in a droplet (1) and a crystalline (2) fog with two values of the attenuation coefficient: 0.01 and 0.004 m^{-1}. The parameters of the eye are: diameter of pupil 0.5 cm, angular resolution 1° [6]. In the computations we used the values of the normalized scattering function of cloud model C.1 [5] and the experimental value for crystals [7] for θ = 2°. The small circles correspond to those L values less than which with l = 35 m the angle θ = 2° is not realized. The lines parallel to the x-axis correspond to the threshold values of illumination of the eye for red light when the light guide is observed against the background of snow at nighttime during moonlight E_1, in twilight hours E_2 and during daytime E_3. These values were taken from [3], but were scaled to energy units using the expression 1 lux = $1.6 \cdot 10^{-7}$ W/cm^2 [6]. The absolute light threshold $E_a = 3 \cdot 10^{-16}$ W/cm^2. The abscissa of the points of intersection E_a, $E_{1,2,3}$ and the lines 1 and 2 determines the range L of detection of a beacon from the point B in droplet and crystalline fogs. For example, at midday against a background of snow a beacon is not visible from the point B in all cases when $\alpha \geqslant 0.004$ m^{-1}, that is, in a dense haze and fogs. With $\alpha \geqslant 0.01$ m^{-1} the beacon is not visible even on a moonlit night.

With an identical observation geometry and identical attenuation indices α the difference in the range of detection of the light beacon in droplet and crystalline fogs is

[KP = cr; K = drop]

$$\Delta L(\theta) = \frac{1}{\alpha} \ln \frac{f_{\text{кр}}(\theta)}{f_{\text{к}}(\theta)}, \quad (1)$$

where $f_{cr}(\theta)$ and $f_{drop}(\theta)$ are the values of the normalized scattering function for crystals and droplets. The sign on $\Delta L(\theta)$ is determined by the sign on $\ln f_{cr}(\theta)/f_{drop}(\theta)$. The table gives $f_{cr}(\theta)$ values and the ratio $f_{cr}(\theta)/f_{drop}(\theta)$ for a series of θ angles (using the data in [5, 7]), which can be used in an evaluation of $\Delta L(\theta)$. Similar to (1), $\Delta L(\theta)$ is determined with a change in illumination E_{thr}, source intensity, etc. For example, with an increase in source power by a factor of 10^4 the range of beacon detection increases by $\Delta L \simeq 2300$ m with $\alpha = 0.004$ m^{-1} and by $\Delta L \simeq 920$ m with $\alpha = 0.01$ m^{-1}.

Thus, in the case of a crystalline fog the range of detection of a beacon in the directions 2-45° decreases, but in the directions 55-90° increases in comparison with a droplet fog of the same optical density. For an angle $\theta = 2°$ ΔL is about 312 m with $\alpha = 0.004$ m^{-1} and about 125 m with $\alpha = 0.01$ m^{-1}.

However, usually with the crystallization of a fog there is a decrease in α from α_{drop} to $\alpha_{cr} < \alpha_{drop}$. Therefore, for example, with artificial modification of a fog after crystallization the range $L(\theta)$ in the direction $\theta = 2$-$45°$ may not change or may even increase if

[K = drop; KP = cr]

$$K^{\frac{\alpha_K}{\alpha_{KP}}-1} \left[f_{KP}(\theta)\,\alpha_{KP}\right]^{\frac{\alpha_K}{\alpha_{KP}}} > \alpha_K f_K(\theta), \qquad (2)$$

where K is a constant for a particular beacon, which is dependent on its parameters and the observation conditions.

	θ°											
	2	5	10	15	25	35	45	55	65	75	85	90
$f_{cr}(\theta)/f_{drop}(\theta)$	0,25	0,5	0,3	0,2	0,6	0,52	0,95	1,2	1,7	2,6	4,0	6,0
$f_{cr}(\theta)$	10,3	1,12	0,232	0,138	0,145	0,067	0,063	0,040	0,027	0,021	0,017	0,015

$$K = \frac{P_0}{S(x)} \frac{V(\theta)\sin^2\theta}{E_{пор}\, l^2}, \qquad (3)$$

[пор = th]

where P_0 is source power, W; S(x) is the beam cross section at the distance x from the source; $V(\theta)$ is the volume illuminated by the beam and visible to the observer from the point B; E_{thr} is threshold illumination of the eye.

It should be noted that computations of E were made in the single scattering approximation. At distances $(x + l_1) \geqslant 1000$ m even with $\alpha = 0.004$ m^{-1} the optical thickness of the medium is $\tau \geqslant 4$. Accordingly, precise expressions for E must take into account the contribution of multiple scattering, which, on the one hand increases the illumination of the volume $V(\theta)$ and E, and on the other hand, increases the brightness of the background against which the light beam is observed. The contribution of multiple scattering is important for large angles θ and therefore, for computing E with $\theta > 2°$ it is necessary to know the field of multiple scattering in crystalline media.

The author expresses sincere appreciation to O. A. Volkovitskiy for formulating the problem and attention to the work.

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MEASUREMENTS OF THE OZONE CONCENTRATION IN THE TROPOSPHERE

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[Article by S. Zh. Toktomyshev, candidate of physical and mathematical sciences, and L. K. Tolbayev, Frunze Polytechnic Institute, manuscript received 23 Jul 80]

[Text]

Abstract: The article gives the results of measurements of the ozone concentration in the troposphere using silvered-film sensors. The collected data indicate that the proposed method makes it possible to determine the fine structure of the vertical profile of ozone in the troposphere.

Earlier communications [1, 3] described methods for measuring the concentration of oxygen atoms [O] and ozone molecules [O_3] in the upper layers of the atmosphere based on the use of thin silvered films. This article gives the results of measurements of the ozone concentration in the troposphere obtained in balloon experiments.

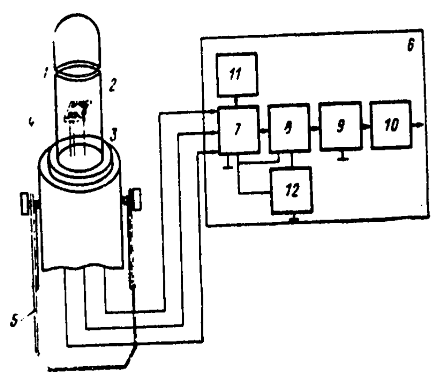

Fig. 1. General diagram of unit for measuring ozone.

The capacity of thin silver films to change their resistance with oxidation is used in measuring O_3.

When carrying out field experiments with sensors in the troposphere and stratosphere a new unit was developed for this purpose; its general diagram is shown in Fig. 1.

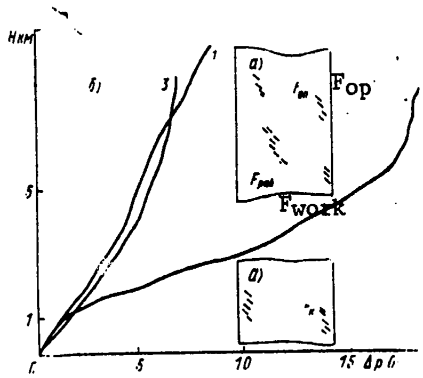

Fig. 2. Change in resistance of sensors during balloon experiments.

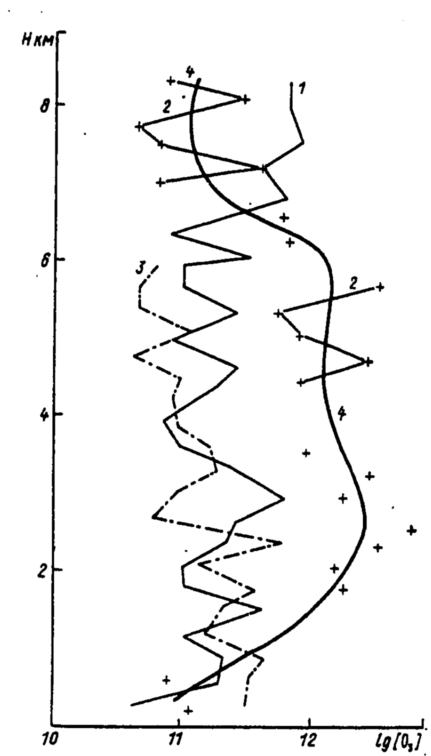

Fig. 3. Vertical distribution of ozone concentration in troposphere.

The ozone cell 1 is a glass ampule within which there is a silvered sensor 2 with a temperature compensator 3. In contrast to the sensor described in [1], the sensor and temperature compensator were on a common backing and the vacuum spraying occurred in a single action. The temperature compensator was introduced for compensating the temperature drift of the resistance Q of the sensor and constitutes a silvered film (of the same rating as the sensor), covered by a dielectric material safeguarding it against the action of O_3. The ampule 4 is opened on the ground prior to launching or by means of a mechanical firing pin 5 triggered by a sylphon-type pressure sensor at the necessary altitude. The ozone cell is attached to the body of the RKZ-5 radiosonde (6) in such a way that the sensor with the temperature compensator are in the open atmosphere under identical temperature conditions.

The sensor and the temperature compensator are cut in through opposite arms of the measuring bridge 7 and the signal of a change in sensor Q is read as the difference in potentials of the bridge diagonal.

The potential difference of the measuring bridge diagonal is fed to a differential scaling amplifier 8. The amplified signal from the amplifier output is fed to a matching unit 9 which makes it possible to connect the described unit in place of the standard sensors (temperature, humidity, etc.) of the RKZ-5 radiosonde to the input of the RKZ-5 radio block (10).

The signal emitted by the RKZ-5 in field experiments is received by a ground "Meteorit" station which on a tape prints out information on the change ρ of the sensor. In order to make allowance for the error introduced by "0" drift of the entire measurement channel a zero potential difference is periodically fed to the inputs of a differential scaling amplifier by means of the commutator 11. The information on the "0" drift of the measurement channel is also printed out on the tape; 12 are the current sources.

Figure 2a shows a sample of the record of information on the "Meteorit" tape obtained in the course of a field experiment with the sensor. Here F_{work} is the line of change in sensor resistance and "0" drift of the measurement channel; F_{op} is the line of "0" drift of the measurement channel; F_{cal} is the line of preflight calibration.

It was established in laboratory experiments that the resistance of the silvered film of the sensor, whose thickness is less than the length of the free path of the charge carriers, increases appreciably with its entry into a medium containing ozone. For the fabricated films the change ρ of the sensor begins with an ozone concentration $\sim 10^8$ particles/cm^3. The rate of increase in sensor resistance $d\rho/dt$ is functionally dependent on the ozone concentration. N_2, O_2, H_2, N, H, Ar, CO_2, propane, butane and laboratory air under normal conditions do not change ρ of the sensor. The influence of NO, N_2O, NO_2, H_2O, CL_2, CCL_4 and HNO_3 at concentrations corresponding to their atmospheric content on the sensor is insignificant and $d\rho/dt$ is virtually equal to zero.

Figure 2b shows the curve of change ρ of sensors on the basis of data from field experiments carried out (in the plan of joint investigations of Frunze Polytechnic Institute and the Institute of Experimental Meteorology) at the meteorological station in Frunze. Curves: 1--2 March 1980, 1130 hours; 2--23 March 1980, 1440 hours; 3--30 March 1980, 2057 hours (LT).

In processing data from balloon experiments use was made of the results of laboratory experiments. The calibration dependence of $d\rho/dt$ on $[O_3]$ for the sensors was determined in the laboratory for the pressure range from 700 to 1 mm Hg, an ozone concentration from 10^8 to 10^{15} particles/cm^3 and a gas temperature from +25° to -65°C.

The ozone concentration is computed using the formula

$$\left(\frac{d\rho}{dt}\right)_H = A\,[O_3]^B\, e^{-E/RT}, \qquad (1)$$

where E is the activation energy of heterogeneous processes leading to a change ρ of the sensors, R is the universal gas constant, A and B are constants dependent on the technology for fabrication of the sensors. Then

$$\left(\frac{d\rho}{dt}\right)_H$$

for different altitudes is taken from Fig. 2.

Figure 3 gives the results of processing data from balloon experiments. Curves: 1--2 March 1980, 1130 hours; 2--23 March 1980, 1440 hours; 3--30 March 1980, 2057 hours (LT). The solid line (curve 4) represents the averaged $[O_3]$ profile according to the data represented by curve 2 in Fig. 2b.

The vertical profiles of ozone distribution in the troposphere were close to the data in [2] which were obtained in aircraft observations in 1960-1961 with the use of the chemical method. A peculiarity of these, and also our data, is that there is a complex layered character of the vertical distribution of $[O_3]$ in the troposphere.

The fine structure in the vertical distribution of $[O_3]$ is evidently associated with geophysical peculiarities of the troposphere [4].

The error in determining the ozone concentration by this method can be evaluated in the following way. By varying (1), we have

$$\frac{\delta [O_3]}{[O_3]} = \frac{1}{B}\left[\frac{\delta\left(\frac{d\rho}{dt}\right)_H}{\left(\frac{d\rho}{dt}\right)_H} + \frac{\delta E}{RT} - E\frac{\delta T}{RT^2} - \ln[O_3]\,\delta B - \frac{\delta A}{A}\right]. \quad (2)$$

The errors in determining A, B, E are dependent on the accuracy in laboratory calibration of the sensors, that is, on the errors in ascertaining the electric characteristics of the sensor, on the concentration of O_3 particles, etc. Control experiments for checking these parameters give the error in determining the sensor constants $\delta A/A < 3\%$, $\delta B/B = 1\%$, $\delta E/E < 4\%$ for the calibration conditions.

Preflight surface calibration and allowance for the error introduced by the "0" drift of the entire measurement channel directly in the course of the flight experiment with the sensors made it possible to evaluate the error in determining

$$\frac{\delta\left(\frac{d\rho}{dt}\right)_H}{\left(\frac{d\rho}{dt}\right)_H}$$

It was about 7-8%. The error in determining atmospheric temperature by the standard method was $\delta T/T \leqslant 2\%$. All this leads to an error in determining the ozone concentration $\delta[O_3]/[O_3] \approx 15\%$ for the parameters corresponding to this experiment $[O_3] \sim 10^{11}$-10^{12} particles/cm^3.

In conclusion the authors express appreciation to Yu. A. Bragin, B. U. Utirov, Ye. G. Vdovenko and A. V. Kovalev for discussion of the results and A. I. Krutikov and K. T. Tabaldiyev for assistance in carrying out the balloon experiments.

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UDC 551.509.58:796.092.1(470.311)

METEOROLOGICAL SUPPORT FOR THE TWENTY-SECOND OLYMPIC GAMES IN MOSCOW BY THE USSR HYDROMETEOROLOGICAL CENTER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 113-118

[Article by A. I. Snitkovskiy, candidate of geographical sciences, and A. D. Chistyakov, candidate of physical and mathematical sciences, USSR Hydrometeorological Scientific Research Center, manuscript received 4 Sep 80]

[Text]

Abstract: The article examines the experience of meteorological support of the Twenty-Second Olympic Games in Moscow by the USSR Hydrometeorological Center and it is proposed that the positive aspects of this support be used in the future in the operational synoptic practice of weather forecast preparation.

The carrying out of the Twenty-Second Olympic Games in Moscow in 1980 was an outstanding event of our time. The Twenty-Second Olympic Games were held on a high technical and sports level. The success of the Games was favored to a significant degree by the favorable weather which prevailed in Moscow during the period from 19 July through 3 August 1980. Nevertheless, during the two weeks allocated to the holding of the Games Moscow experienced virtually all types of weather: cold air intrusion, transport of hot air in from the southwest, stagnation of a cold anticyclone, and at the very end of the Games -- the movement of wave disturbances toward Moscow from the southwest. However, weather forecasts for Moscow in general were successful. Particular mention should be made of the forecast for the opening day of the Games -- 19 July 1980, when under complex synoptic circumstances, with a strong west-east transport of air masses, it was possible to make a precise prediction of the onset of rainfall late in the evening of 19 July and the opening of the Games occurred during exceptionally favorable weather.

Organizational Aspects

The USSR Hydrometeorological Center began preparations for the Twenty-Second Olympics in 1978. After studying the experience in meteorological support of the Twentieth and Twenty-First Olympics in Munich and Montreal and emphasizing the positive aspects of this support, the USSR Hydrometeorological Center proceeded to the development of forms of meteorological bulletins, the volume and content of weather forecasts and weather information. On 22 November 1979 the Executive Bureau of the Organizing Committee of "Olympics-80" awarded the USSR Hydrometeorological Center the honorary title "Official Hydrometeorologist of the Twenty-Second Olympic Games." The meteorological services at the preceding Olympic Games did not have such a title. The organizing committee gave the USSR Hydrometeorological Center the right to disseminate their product -- weather forecasts -- by the means of mass information, in the publicity announcements of the Olympics, and also to use the official emblem of the Games in combination with the awarded title in meteorological weather bulletins for Olympic events. During the Games the USSR Hydrometeorological Center used this right and widely transmitted weather forecasts via Central Television and All-Union Radio.

In turn the USSR Hydrometeorological Center obligated itself, without remuneration, to prepare meteorological bulletins with weather forecasts for the next 24 hours and the next two days and provide them to the organizing committee and each three hours relay information on the actual weather for Olympic events and six-hour forecasts for Moscow, and also warnings concerning weather phenomena unfavorable for the holding of the Games.

When the USSR Hydrometeorological Center proceeded to the working out of formats of weather bulletins for Olympic events we had at our disposal bulletins for the Twenty-First Olympics in Montreal. A positive merit of these bulletins was that they contained probabilistic forecasts of precipitation and cloud cover. At the same time, the bulletins lacked a weather map, which in our opinion considerably detracted from their value. Using the experience of cooperation with the newspaper IZVESTIYA, it was decided that the Olympic bulletin should contain a prognostic weather map with the anticipated nature of the pressure field and the position of atmospheric fronts, maximum air temperatures and weather phenomena. We also understood that the formulations of weather forecasts and their content should be comprehensible to all, and at the same time should reflect the nature and complexity of the anticipated synoptic situation. Accordingly, in the content of meteorological bulletins and in the texts of weather forecasts for radio and television we frequently used probabilistic forecasts of precipitation and cloud cover, and when it was possible, indicated the time in hours of the beginning and end of the rain. It was later found that these innovations were successful.

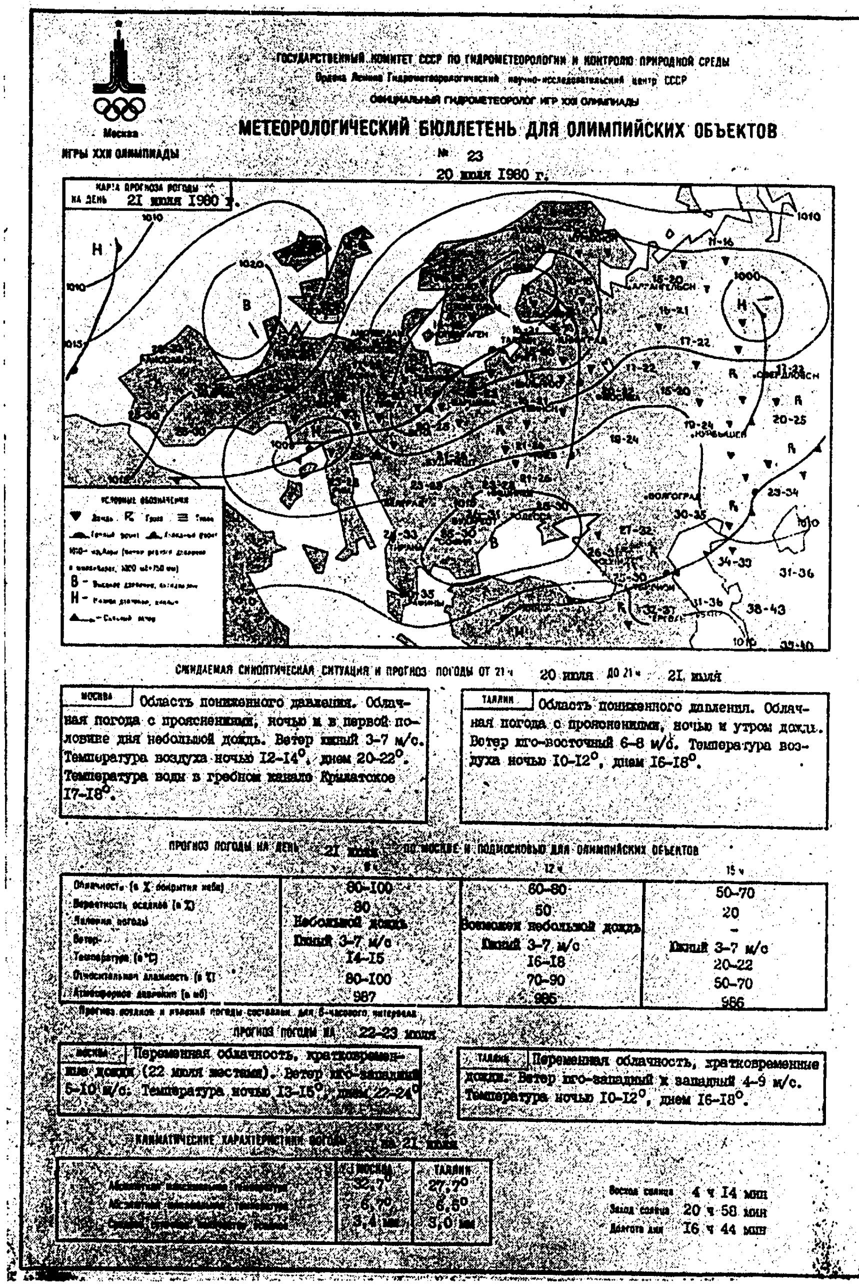
Bearing in mind that the Operations Staff of the organizing committee planned its actions twice a day -- early in the morning and late in the evening -- it was decided that each day two types of meteorological bulletins for Olympic events would be prepared: morning and daytime. The morning bulletin was prepared for 0800 hours and the daytime bulletin for 1500 hours. In the morning bulletin weather information was communicated in a text, and in the daytime bulletin, not only a text, but also a weather forecast map for the territory of Europe for the next 24 hours. Taking into account the requirements of the organizing committee, the bulletins were bilateral and published in two languages: Russian and English (Fig. 1).

It must be noted that the publication of the bulletins required great clarity and smoothness in the work of many sections of the USSR Hydrometeorological Service: short-range weather forecasts, 10-day weather forecasts, information for administrative agencies, foreign communications, editing, preparation and printing of products and bureaucratic. An operations staff was established at the USSR Hydrometeorological Center for coordination of interaction among the sections for supplying meteorological information to the Olympic Games, at whose conferences there was a working solution of all the necessary operational matters arising in the course of servicing the Games. The work of each section was recorded in the minutes and at a rigorously allocated time the sections carried out the tasks assigned to them. For the filling out of the corresponding sections of the bulletin with one form of information or another each section prepared special working forms, which considerably accelerated the preparation of the bulletin.

Meteorological bulletins for Olympic events were printed on good glossy paper in four colors: green, red, yellow and blue. They looked beautiful and made an excellent impression. The daily printing of the morning and daytime bulletins during the period of the Games was 500 copies. During the time of the Twenty-Second Olympic Games more than 25,000 meteorological bulletins were issued for Olympic events. The "Olympics-80" organizing committee dispatched meteorological bulletins to 21 sports centers, to the main press center and the administrative offices of the organizing committee. Weather bulletin boards, where bulletins were regularly hung, were organized in the Krylatskoye sports complex, in rooms where sports teams were being prepared.

Taking into account the importance of the weather information during the period of the Twenty-Second Olympic Games, a schedule was prepared for the dissemination of weather forecasts through the Olympic cities by the USSR Hydrometeorological Center via All-Union Radio and Central Television. For this purpose the State Committee on Hydrometeorology arranged for the transmission by the Leningrad, Kiev, Minsk and Tallin Weather Bureaus of weather forecasts for their cities to the USSR Hydrometeorological Center three times each day. In turn, the USSR Hydrometeorological Center transmitted weather forecasts via Moscow to the address of the enumerated bureaus. This schedule was adhered to undeviatingly during the course of the Games, which made possible the operational transmission of weather forecasts by radio and television, but forecasts for Tallin and the Gulf of Tallin were published in the bulletins. Weather forecasts for the Olympic cities were transmitted by radio in accordance with three programs 11 times a day, including in the program "Moscow World Service" in the English language, by television in the program "Vremya" and in "Novostyakh" five times a day. In order to accelerate the receipt of information with weather forecasts at the Olympic cities by radio and television and for exchange of information among the weather bureaus all the telegrams were sent with the prefix: "For the Olympics." In this connection we should note the enormous amount of work done by the Main Radiometeorological Center for the transmission, dissemination of meteorological information and its exchange during the period that the Games were held.

The delivery of meteorological bulletins to the sports competition centers was accomplished by a special courier. The remaining types of information -- six-hour forecasts for Moscow, storm warnings concerning unfavorable weather phenomena and a review of the actual weather were transmitted by the USSR Hydrometeorological Center to the organizing committee, Krylatskoye, by radio and television, by teletype and via a specially established Olympics telephone network.



ГОСУДАРСТВЕННЫЙ КОМИТЕТ СССР ПО ГИДРОМЕТЕОРОЛОГИИ И КОНТРОЛЮ ПРИРОДНОЙ СРЕДЫ

ОФИЦИАЛЬНЫЙ ГИДРОМЕТЕОРОЛОГ ИГР XXII ОЛИМПИАДЫ

Москва

ИГРЫ XXII ОЛИМПИАДЫ

МЕТЕОРОЛОГИЧЕСКИЙ БЮЛЛЕТЕНЬ ДЛЯ ОЛИМПИЙСКИХ ОБЪЕКТОВ

№ 23

20 июля 1980 г.

КАРТА ПРОГНОЗА ПОГОДЫ НА ДЕНЬ 21 июля 1980 г.

ОЖИДАЕМАЯ СИНОПТИЧЕСКАЯ СИТУАЦИЯ И ПРОГНОЗ ПОГОДЫ ОТ 21 ч 20 июля ДО 21 ч 21 июля

МОСКВА. Область пониженного давления. Облачная погода с прояснениями, ночью и в первой половине дня небольшой дождь. Ветер южный 3-7 м/с. Температура воздуха ночью 12-14°, днем 20-22°. Температура воды в гребном канале Крылатское 17-18°.

ТАЛЛИН. Область пониженного давления. Облачная погода с прояснениями, ночью и утром дожди. Ветер юго-восточный 6-8 м/с. Температура воздуха ночью 10-12°, днем 16-18°.

ПРОГНОЗ ПОГОДЫ НА ДЕНЬ 21 июля ПО МОСКВЕ И ПОДМОСКОВЬЮ ДЛЯ ОЛИМПИЙСКИХ ОБЪЕКТОВ

	9 ч	12 ч	15 ч
Облачность (в % покрытия неба)	80-100	60-80	50-70
Вероятность осадков (в %)	80	50	20
Явления погоды	Небольшой дождь	Возможен небольшой дождь	-
Ветер	Южный 3-7 м/с	Южный 3-7 м/с	Южный 3-7 м/с
Температура (в °C)	14-15	16-18	20-22
Относительная влажность (в %)	80-100	70-90	50-70
Атмосферное давление (в мб)	987	985	986

Прогноз осадков и явлений погоды составлен для 6-часового интервала

ПРОГНОЗ ПОГОДЫ НА 22-23 июля

МОСКВА. Переменная облачность, кратковременные дожди (22 июля местами). Ветер юго-западный 5-10 м/с. Температура ночью 13-15°, днем 22-24°.

ТАЛЛИН. Переменная облачность, кратковременные дожди. Ветер юго-западный и западный 4-9 м/с. Температура ночью 10-12°, днем 16-18°.

КЛИМАТИЧЕСКИЕ ХАРАКТЕРИСТИКИ ПОГОДЫ НА 21 июля

	МОСКВА	ТАЛЛИН
Абсолютная максимальная температура	32,7°	27,7°
Абсолютная минимальная температура	6,7°	6,5°
Средний суточный максимум осадков	3,4 мм	3,0 мм

Восход солнца 4 ч 14 мин

Заход солнца 20 ч 58 мин

Долгота дня 16 ч 44 мин

Fig. 1. Daytime meteorological bulletin for Olympic events.

Methodological Aspects

The designation of the USSR Hydrometeorological Center as the "official hydrometeorologist" of the Twenty-Second Olympic Games and the acceptance by the USSR Hydrometeorological Center of the obligation for supplying the operations staff of the Olympics with data on actual and anticipated weather in the neighborhood of Olympic events in Moscow meant that it was necessary to have much additional hydrometeorological information, make use of new methods for predicting convective weather phenomena and substantially restructure the organization of operational work of a number of sections at the USSR Hydrometeorological Center.

In order to implement these tasks, on the instructions of the State Committee on Hydrometeorology the Central High-Altitude Hydrometeorological Observatory, in addition to the network of meteorological stations and posts existing in Moscow, also opened a hydrometeorological station at Krylatskoye, a meteorological post at Mytishchi, and called upon the existing meteorological stations to relay information to the USSR Hydrometeorological Center each three hours, and from Krylatskoye station and Mytishchi post -- each hour. In addition, all the meteorological stations and posts were to relay warnings immediately to the USSR Hydrometeorological Center concerning the beginning and end of rain and weather phenomena unfavorable for the holding of the Games.

Thus, the existing and newly opened meteorological stations and posts provided data on actual weather to all Olympic events held in the open air (Fig. 2).

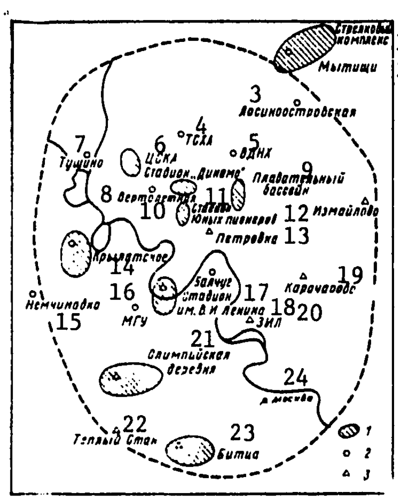


Fig. 2. Sketch map of location of Olympic events and meteorological stations in Moscow. 1) Olympic sites; 2) meteorological stations; 3) meteorological posts.

KEY:
1) Shooting range
2) Mytishchi
3) Losinoostrovskaya
4) Agricultural Academy (TSKhA)
5) All-Union Exhibition of Achievements in the National Economy
6) TsSKA
7) Tushino
8) Dynamo Stadium
9) Swimming complex
10) Heliport
11) Southern Pioneers Stadium
12) Izmaylovo
13) Petrovka
14) Krylatskoye
15) Nemchinovka
16) Moscow State University
17) Balchug
18) V. I. Lenin Stadium
19) Karacharovo
20) ZIL (factory)
21) Olympic village
22) Teplyy Stan
23) Bittsa
24) Moscow River

On the basis of data from the Balchug and Moscow State University meteorological stations it was possible to judge the weather at the V. I. Lenin Central Stadium at Luzhniki; weather data from the meteorological station situated in the neighborhood of the air station on Leningradskiy Avenue were indicative for the "Dynamo" stadium, the TsSKA sports complex and the Southern Pioneers Stadium; data from the Krylatskoye meteorological station were indicative for the special shooting events stadium at Krylatskoye; data from the meteorological post at Mytishchi were indicative for the target range at Mytishchi; and the data for the meteorological post at Teplyy Stan -- for the horsemanship complex at Bittsa.

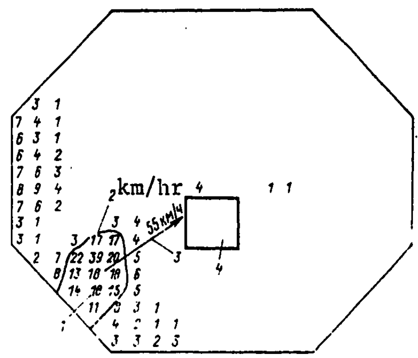


Fig. 3. Radar map of quantity of falling precipitation at Dolgoprudnyy, 2000-2100 hours on 19 July 1980. 1) quantity of precipitation in tenths of a millimeter (1.8 mm) for area of 10 x 10 km; 2) isohyet for 1 mm; 3) direction and velocity of movement of rain zone; 4) territory of Moscow, area about 900 km^2.

Information from these meteorological stations and posts were used in preparing weather reviews for the Olympic events, which each three hours, together with the six-hour forecasts, were relayed to the Olympics operations staff.

The Central Aerological Observatory carried out an exceptional amount of work on the organization of three radar stations for measuring the quantity of falling precipitation at Dolgoprudnyy, Kaluga and Ryazan'. These radar stations during the period of the Games operated around-the-clock, and from 0600 to 2100 hours each hour relayed to the USSR Hydrometeorological Center the quantity of falling precipitation for an area of 10 x 10 km in a radius of 100 km. They also reported the total quantity of falling precipitation in the course of 3 and 12 hours over an area of 10 x 10 km and for regions where meteorological stations and posts are located in Moscow over an area of 3.3 x 3.3 km (Fig. 3). By successively comparing the hourly data on precipitation it was possible to see directly the appearance of new zones of rain, a change in their intensity, and also to determine their direction and rate of movement.

After comparing data on the actual quantity of precipitation for the stations and posts of Moscow with radar data (area 3.3 x 3.3 km) the preliminary conclusion can be drawn that the agreement of surface and radar data with respect to the falling of rain attains 90%, whereas with respect to quantity the correlation coefficient is 0.65-0.70.

Information from the radar stations at Dolgoprudnyy, Kaluga and Ryazan' was extremely useful, especially in its joint use with data from meteorological stations and posts and the radar of the USSR Hydrometeorological Center, determining the position of foci of convective phenomena. The radar information was used extensively in preparing six-hour weather forecasts and warnings concerning unfavorable weather phenomena.

Particularly important were the weather forecasts for the current day and for 24 hours because they were used directly by the operations staff of the Olympics for the planning of their operations. In preparing a weather forecast for the next day it was first necessary to predict cloud cover, wind, temperature, relative humidity and atmospheric pressure for a definite hour (0900, 1200 and 1500 hours) and weather phenomena and precipitation for six-hour time intervals (0900-1500, 1200-1800 and 1500-2100 hours). Cloud cover was predicted in percent of sky coverage, atmospheric pressure was predicted in millibars at the level of the station, relative humidity was predicted in percent, and most importantly, precipitation was predicted in percent of the probability that rain would fall. In the morning Olympic bulletin these elements were predicted for three-hour periods (0900-1200, 1200-1500, 1500-1800 and 1800-2100 hours).

In the preparation of forecasts of these meteorological elements use was made of synoptic and computation methods, and also a hydrodynamic model for the prediction of precipitation.

The prediction of precipitation in probabilistic form was prepared by a group of specialists consisting of 6-8 persons having definite experience in preparing such forecasts.

The weather forecasting map for the territory of Europe for the next day, published in the daytime Olympic bulletin, was prepared on the basis of a synoptic prognostic surface pressure field and fronts chart, numerical pressure and geopotential charts and prognostic charts of the United States National Meteorological Center and the British Meteorological Service. Predictions of maximum temperatures and weather phenomena were computed by the synoptic method. It should be noted that the Olympics organizing committee, judges and sportsmen displayed great interest in the weather forecasting map.

The weather forecasts for six hours, the current day and the next day for the Twenty-Second Olympics were prepared by specially designated weathermen who made up a duty shift. In case of necessity these weathermen introduced corrections into the prognostic charts, constructed air particle trajectories and made all additional computations for predicting the parameters of convection and precipitation and their detailed determination by periods. They also analyzed observational data for the meteorological stations of Moscow, data on the quantity of falling precipitation measured by the radar stations in Dolgoprudnyy, Kaluga and Ryazan' and monitored the development and movement of the foci of convective phenomena on the basis of radar and satellite data: weather reviews were prepared for Olympic events and six-hour weather forecasts were issued, as well as warnings concerning unfavorable weather phenomena.

Weather forecasts for Moscow for the next two days were prepared by the synoptic method with the use of charts of the geopotential field in the middle troposphere and the surface pressure field and the position of atmospheric fronts for 24 hours, which proved to be quite successful. These forecasts were also prepared by specially assigned weathermen.

The meteorological bulletins, in addition to weather forecasts, gave a prediction of water temperature for the current day and the days immediately to follow in the Krylatskoye sport rowing canal. For this purpose for the Twenty-Second Olympic Games the USSR Hydrometeorological Center developed a special method for predicting water temperature at Krylatskoye. In this method use was made of long series of observations at adjacent hydrological stations.

The weather in general favored the holding of the Olympic Games, but the atmospheric processes during the course of the 16 days of the Games were quite complex. On 10 of the 16 days there was rain at Moscow; in seven cases it either did not affect Olympic events or it was very light and did not interfere with the holding of the Games. The rains of 22, 26 July and 2 August were more intense. During the day on 22 July the rain was brief and did not make it difficult to hold the competitions, but the heavy rain passed after 2000 hours; on 26 July and 2 August the rain was of brief duration. All the rains were called for in the daily and morning weather forecasts.

To be sure, there were also failures. An example was the forecasts for 24 and 25 July. On these days there was a forecast for showers, thunderstorms and hail. On 24 July the rain passed only in the northern part of Moscow (All-Union Exhibition of Achievements in the National Economy, Agricultural Academy and Tushino) and was light (up to 0.7 mm); on 25 July no more than 1.2 mm of precipitation fell. These rains did not hinder the holding of the Games. The forecasts for 24 and 25 July require additional analysis because it is difficult to answer the question as why with a very high dew point at the ground surface and a high instability in the atmosphere convection developed weakly.

During the period of the Twenty-Second Olympic Games the USSR Hydrometeorological Center made extensive use of probabilistic formulations of weather forecasts. On the day of opening of the Games a forecast was issued in the following formulation: "...During the daytime rain is improbable, rain is possible in the evening." And in actuality a light rain passed only through Tushino at 1920 hours and strong rains began at 2110, 2120 hours and later. On 2 August the following was given in the diurnal forecast: "After 1500 hours, rain"... And in actuality heavy rains began at 1500 hours or later.

Conclusions

The USSR Hydrometeorological Center completely carried out its obligations as the "official hydrometeorologist" of the Twenty-Second Olympic Games. The weather forecasts prepared by the USSR Hydrometeorological Center in general were good and the most successful forecasts were those for the opening and closing days of the Games and for 2 August.

The successful meteorological support of the Twenty-Second Olympic Games was favored by:
-- the great amount of preparatory work carried out within the USSR Hydrometeorological Center;
-- the development of the forms and content of meteorological bulletins, formulation of texts of forecasts in probabilistic form, introduction of new types of radar information into operational practice;
-- close interaction with the Olympics organizing committee, the Central Aerological Observatory, the High-Altitude Hydrometeorological Observatory, with the Leningrad, Kiev, Minsk and Tallin weather bureaus, the Main Radiometeorological Center, Central Television and All-Union Radio;
-- organization of a network of radar stations around Moscow for measuring the quantity of falling precipitation and new meteorological stations and posts in Moscow;
-- the positive experience acquired during the time of servicing of the USSR Spartakiada of the People in 1979 and during the period of two general training sessions in late May and mid-June 1980.

In order to enhance the quality of servicing of national economic organizations and the population with weather forecasts and weather information, using the experience of supporting the Twenty-Second Olympic Games, it is proposed that:
-- in the daily hydrometeorological bulletins the map of actual weather be replaced by a weather forecast map for the next day;
-- in the formulation of short-range weather forecasts, on radio, television and in the press probabilistic precipitation forecasts be given, making extensive use of the time (in hours) of the beginning and end of precipitation;
-- in the texts of weather forecasts a qualitative characterization of the trend in change of atmospheric pressure be added;
-- the radar network for the measurement of the quantity of falling precipitation be expanded.

ACTIVITY OF THE INTERNATIONAL DATA CENTER ON ATMOSPHERIC ELECTRICITY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 119-120

[Article by V. P. Kolokolov, doctor of geographical sciences, Main Geophysical Observatory, manuscript received 20 Jun 80]

[Text]

Abstract: The results of activity of the International Data Center on Atmospheric Electricity during the 15 years of its operation are summarized.

The implementation of the programs of the International Geophysical Year (IGY) and the period of International Geophysical Cooperation (IGC), and later the International Year of the Quiet Sun (IQSY), had the objective of combining the efforts of the scientists of the entire world for solution of many problems in the different geophysical sciences, including problems related to atmospheric electricity.

The principal problem in the study of atmospheric electricity is the origin of the earth's electric field and the related problems of the origin of global and local variations of this field. These can be solved only by means of measurements in the world network of stations. Scientific investigations can be effective only in the case of international cooperation in this field, since it is necessary to study them in different parts of the earth's surface simultaneously. It goes without saying that it is desirable that this study be carried out under jointly formulated and coordinated programs by unified methods and instruments yielding reliable, comparable results. It is also important that they be studied over the broadest possible expanses, preferably over the earth's surface.

The fourth session of the IGY special committee, held in September 1956 in Barcelona, recommended to the countries that they carry out systematic measurements of the electric field and air conductivity, and also the vertical electric current.

Investigations of atmospheric electricity under international programs for the first time were made during the IGY period during 1957-1958, and then during the IQSY period during 1964-1965. These investigations were an example of international cooperation in the field of study of atmospheric electricity. It is evident that for the effective solution of the formulated problems in the field of atmospheric electricity it is necessary that the measurement data be available to a broad range of scientific workers concerned with atmospheric electricity. It was easiest to do this by the organization of an International (World) Data Center on Atmospheric Electricity which could collect these data from the world network and publish them in easily accessible form.

In the early 1960's an agreement was attained between the WMO Secretariat and the USSR Hydrometeorological Service on the organization of an international data center in Leningrad, at the Main Geophysical Observatory. With the organization of the center the first question to arise was the matter of standardizing measurement units, observation methods and methods for the processing of data on atmospheric electricity. The lack of standardization made difficult the use of observational data.

Standardized observation methods, methods for data processing, measurement units and forms of tables for the principal elements of atmospheric electricity were proposed by the Main Geophysical Observatory for the implementation of work under a unified program. In addition, unified measurement units met the requirements of convenience in the processing of observational data, were simple and graphic, with a guaranteed measurement accuracy, meeting the requirements of theoretical investigations and the needs of practical use. After some discussion the proposals of the Main Geophysical Observatory were adopted.

The international data center was organized in 1965 in Leningrad and began its work. A decision was made to publish materials on atmospheric electricity obtained in the world network since 1964. Now for 15 years these data have been systematically published in the form of monthly summaries of surface observations and sporadically in the form of individual small volumes of measurements in the free atmosphere.

The following surface observation data are published:

-- potential gradient (strength) of the electric field in the atmosphere -- mean hourly, daily and monthly values;
-- positive conductivity, negative conductivity of the air -- mean hourly, daily and monthly values;
-- vertical electric current in the atmosphere -- mean hourly, daily and monthly values.

The publications of materials on atmospheric electricity obtained as a result of sounding of the free atmosphere include high-altitude data, primarily on measurement of the electric field, and sometimes conductivity and the vertical electric current.

In investigations of atmospheric electricity carried out under the international program there were 17 participating countries and measurements of the elements of atmospheric electricity at the surface, in the free atmosphere and over the ocean areas were made at more than 50 stations.

However, these investigations at the stations have not always been carried out simultaneously. Frequently at different stations they have been carried out at different times and the series of observations have varied from 1 to 15 years.

But many stations, especially those located in the territory of the Soviet Union, have carried out observations (and have transmitted the materials of these observations to the data center) during the entire 15 years and are continuing these observations at the present time. In the USSR such stations include Leningrad (Voyeykovo), Sverdlovsk (Vysokaya Dubrava), Irkutsk, Dusheti, Tashkent, and abroad -- Uccle and Durbas (Belgium), Lerwick, Eskdalemgor (Scotland) and Kew (England).

Over a period of 15 years (with short interruptions) such observations have also been made at the stations Kiev, Odessa, Lisbon. Since it was initially assumed that the activity of the international data center at Leningrad would be limited to the period of the quiet sun (IQSY), that is, the period 1964-1965, some of the stations in a number of countries were organized precisely for this period. After 1965 they ceased to exist or no longer sent their data to the WDC. These stations include Bombay, Tizna (India), Kaklona, Memashbetsu (Japan), Socorro, University Park (United States), Potsdam (East Germany), Aachen (West Germany).

Some stations continued to make observations after the IQSY period had ended. For example, at Montreal (Canada) observations were made up to 1973, at Budapest (Hungary) -- up to 1969, at Murmansk (USSR) -- up to 1970, at Bol'shaya Yelan' (USSR) -- up to 1969, at Venice (Italy) -- up to 1969, and at Auckland (New Zealand) -- up to 1969.

At some stations in a number of countries observations were organized after the IQSY had already ended. For example, observational data obtained at the Polish station at Swider were published for the first time for 1966, then there was a gap, but since 1970 the data have been published regularly; the data for the Portuguese station Porto were first published after 1970, for Yuzhno-Sakhalinsk station after 1969, and for Borispol' and Kirov stations, after 1974. Among the foreign stations which lagged in the publication of data were Sakushima (Japan), since 1974, Macerata (Italy) -- since 1976, Athens (Greece) -- since 1971. At some stations brief observations were made for one-two years also after the IQSY (Toronto, Canada; Nivot Ridge (United States).

In the monthly summaries "Results of Surface Observations of Atmospheric Electricity (World Network) (REZUL'TATY NAZEMNYKH NABLYUDENIY ZA ATMOSFERNYM ELEKTRICHESTVOM (MIROVAYA SET')) certain data are also published on measurements of the electric field over the surfaces of the oceans collected aboard expeditionary ships of West Germany (1965, 1968, 1969) and the USSR (1974), as well as data on the number of small and large ions (Greece, Portugal).

Twelve to fifteen issues of the REZUL'TATY NAZEMNYKH NABLYUDENIY ZA ATMOSFERNYM ELEKTRICHESTVOM (MIROVAYA SET') have been published annually. Several volumes of observational data have been published on the elements of atmospheric electricity, primarily on the strength of the electric field at different altitudes obtained by the launching of radiosondes in the following countries: Japan (Sapporo -- for 10 years; Tateno -- for 10 years; Kagoshima -- for 10 years; Khatsiyodzima -- for 10 years; Siuva -- for 4 years); India -- for 2 years; West Germany -- for 2 years; on the expeditionary ship "Meteor" -- for 2 years; Belgium (in Antarctica, at Roi Baudouin station) -- for 1 year; Sweden -- for 1 year.

In the USSR the electric field in the free atmosphere has been measured by means of sounding aircraft primarily in the IGY period in 1964 (Leningrad, Kiev, Tashkent). Later sporadic observations in the USSR were made in the Arctic (1968), at Adler (1970), at Palanga (1970) and at Leningrad (1970).

The numerous examples of use of the data published by the WDC by both Soviet and foreign scientists are evidence that the 15 years of activity of this center have facilitated the further development of the science of atmospheric electricity.

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FIFTIETH ANNIVERSARY OF THE MAIN AVIATION METEOROLOGICAL CENTER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 121-124

[Article by A. V. Brodskiy, head of the Main Aviation Meteorological Center]

[Text]

Abstract: The author outlines the stages in creation and development of the Main Aviation Meteorological Center from 1931 to the present time and its role in the meteorological support of civil aviation.

The Order of the Red Banner of Labor Main Aviation Meteorological Center (MAMC) marked its glorious 50th anniversary on 24 January 1981.

The MAMC is the leading operational and methodological institute of the State Committee on Hydrometeorology and Environmental Monitoring for the meteorological support of domestic and international airlines.

All the activity of the MAMC is associated with the development of civil aviation in the Soviet Union.

In 1931 the warning bureau of the Central Weather Bureau was established and this must be regarded as the beginning of meteorological servicing of civil aviation. In 1935 the warning bureau was transformed into a specialized agency for the servicing of civil aviation -- the Aviation Meteorological Bureau (AMB).

In the 1930's the organization of meteorological support of rapidly developing Soviet aviation experienced considerable difficulties due to inadequate work experience, unreliable communication for obtaining meteorological data and an inadequate quantity of meteorological data, especially high-altitude data. All this made exceedingly difficult the normal meteorological support of flights of the first transport aircraft of the types U-2, R-5, K-5, PS-9 and others.

The basis for the scientific research work on the themes "Meteorological Conditions for the Icing of Aircraft" and "Conditions for Flights in Frontal Zones" were the materials collected at the AMB by I. G. Pchelko and V. M. Kurganskaya. These studies were a valuable contribution to the method for the servicing of aircraft flights and were used for many years. S. M. Prostyakov and I. G. Pchelko, weathermen at the AMB, were the first to develop the terminology for aviation forecasts and advisories and also the procedures for the preparation of storm warnings.

By 1937 there had been a considerable increase in the number of domestic and international routes. There were already more than 30 and about 100 aircraft takeoffs per day took place along them, including nighttime flights along the Moscow-Leningrad route.

The Central Civil Aviation Meteorological Station (CCAMS) was organized in 1938 on the basis of the AMB.

Soon new Soviet passenger aircraft, such as the PS-38, PS-40, PS-41, PS-89 and others appeared in our civil aviation. They had more perfect equipment and flew at greater altitudes. This required the development of new forms of meteorological servicing.

The pressure pattern chart method developed by this time at the Central Institute of Forecasts (N. L. Taborovskiy and Kh. P. Pogosyan) was successfully introduced into the practical work of the CCAMS. On its basis a method was developed at the CCAMS in close collaboration with the Scientific Research Insitute of the Civil Air Fleet for creating a method for making wind forecasts along routes at altitudes having great practical importance for determining the optimum flight regimes.

The experience of the CCAMS in preparing wind forecasts aloft was generalized in an article by Ye. I. Gogolevaya and V. D. Panchenko in OPYT OBSLUZIVANIYA VYSOTNYKH SKOROSTNYKH SAMOLETOV PROGNOZAMI VETRA NA VYSOTAKH (Experience in Servicing High-Altitude High-Speed Aircraft With Wind Forecasts Aloft), published as a separate brochure in 1940.

In accordance with the increasing requirements there was improvement and strengthening of the organizational structure of the CCAMS. The further development of high-altitude flights led to the necessity for creating methodological and aerological groups in 1940-1941 in the CCAMS.

In March 1942 the CCAMS was put directly under the Main Administration of the Hydrometeorological Service, which had a favorable effect on the development of all its activity.

During the period of the Great Fatherland War 1941-1945 the work of the CCAMS was completely subordinate to the tasks of the Moscow Special-Purpose Aviation Group, military-transport aviation of the Civil Air Fleet and the People's Commissariat of the Aviation Industry operating at several airdromes (Moscow, Vnukovo, Myachkovo, Kazan', Kuybyshev, etc.). The CCAMS accumulated much experience in the meteorological support of flights in the enemy rear in the territory which was poorly covered by meteorological data.

Despite a number of difficulties, specialists of the CCAMS even during the time of the war continued to improve the method for the meteorological support of aircraft flights.

A method for preparing graphic weather forecasts was developed in 1942 and came into use in the entire network of air weather stations of the Civil Air Fleet.

New types of aircraft (Il-12, Li-2, Il-14) were put into operation during the war years. This made it necessary for the CCAMS to deal with a number of new problems in predicting the upper boundary of cloud cover, the intensity of icing, turbulence and other meteorological weather elements.

After ending of the Great Fatherland War, in November 1945, the CCAMS was moved to the central Moscow airport Vnukovo and combined with the aviation meteorological station operating there earlier and an operations group with the work load of a first-order aviation meteorological station remained at the M. V. Frunze airport. At the same time a new structure of the CCAMS was approved. It made provision for a synoptic section with operations and aerological groups, a group for methodological and scientific-research work, a communications section, an aircraft weather reconnaissance laboratory and other services. For the purpose of studying meteorological flight conditions in echelons and operational use of these data the CCAMS for the first time in the Soviet Union began aircraft weather reconnaissance.

In addition to weather reconnaissance along routes the CCAMS carried out vertical and horizontal weather reconnaissance in the airport zone in a radius up to 100 km, which made it possible to detect dangerous weather phenomena (icing, turbulence, thunderstorm activity and others) and use these data in control of aircraft flights. The mass collection of weather data from scheduled airliners in flight was organized. The CCAMS daily received up to 300 reports on "on-board weather." These data were plotted on special cards and were taken into account in the preparation of aviation route forecasts.

The introduction of jet and turbojet aircraft, as well as further improvement in civil aviation in the years 1950-1960, imposed new requirements on the aviation meteorological service, and especially on the organization of instrumental meteorological observations, improvement in the forms and methods of prediction. It was precisely in these years that the CCAMS began to receive new meteorological instruments for testing and introduction.

There was a considerable improvement in the collection and dissemination of meteorological information after the CCAMS in 1956 received the necessary wire communication channels. Subsequently a system of direct aviation communications (DACS) was organized by late 1959 for the reception and transmission of data on the actual weather and weather forecasts for domestic airports. In 1957 the CCAMS converted to the centralized reception of facsimile weather maps.

The introduction of new meteorological instruments into routine work, the improvement in the collection and dissemination of meteorological information by means of the DACS system -- a new type of communication for facsimile transmission and reception, the use of aircraft reconnaissance, and also "on-board" weather, enabled the CCAMS to increase the quality of forecasts and storm warnings. The introduction (in 1959) of computation methods for predicting weather phenomena dangerous for aviation favored a further improvement in the quality of the meteorological servicing of the flights.

On 31 August 1959 the CCAMS was reorganized into the Moscow Main Aviation Meteorological Center (MMAMC) with affiliates at the Sheremet'yevo airport and at the Main Administration of the Civil Air Fleet.

The decade 1960-1970 in the work of the MMAMC was characterized by fundamental changes in the method for the meteorological support of aviation, its further centralization and outfitting with new electronic and radar apparatus and modern communication facilities.

Beginning in 1961 specialists at the Vnukovo and Sheremet'yevo airports proceeded to the meteorological support of flights with aviation prognostic weather charts (AKP-1) of special weather phenomena and 300- and 400-mb high-altitude charts, since the graphic representation of weather conditions is unquestionably more effective and corresponds to the international rules for meteorological support.

The aviation prognostic charts prepared at the MMAMC later were transmitted by radio facsimile and wire communication systems to the aviation meteorological stations at airports in the European USSR, Europe and Western Siberia, that is, came into use by all aviation prognostic agencies located over a considerable distance. In 1965 specialists at the MMAMC began to prepare aviation prognostic charts at a larger scale intended for the meteorological support of flights on local air routes within the limits of the European USSR which were transmitted through facsimile communication lines for further use at the aviation meteorological stations. The new method of centralized meteorological support by means of facsimile communication lines proved to be extremely useful and is still being used. There was improvement in the organization of implementation of meteorological observations which were shifted from the meteorological sites to the aprons located near the runways, as a result of which the weather observations became more representative and the accuracy and quality became higher due to the use of meteorological instruments.

In 1964 a meteorological radar was installed and put into operation at the MMAMC at Vnukovo. It was used for detecting cumulonimbus clouds, the foci of thunderstorms, as well as measurements of the altitude of the upper cloud boundary. Radar data came into successful use in the preparation of aviation forecasts, in advisories to aircraft crews and flight controllers.

Aircraft weather reconnaissance and artificial modification of low supercooled clouds and fogs came into use in the practical operations at the MMAMC.

The aircraft sounding group at the Central Aerological Observatory, working since 1950 at Vnukovo, in April 1961 was put under the MMAMC. In 1963 it proceeded to regular work on the scattering of low clouds and fogs using surface apparatus. During seven years of work (1963-1970) about 150 missions were flown for the scattering of low clouds and fogs at Moscow airports; during this time surface apparatus was employed in 69 cases. For the most part with proper computations the scattering was effective and made possible the takeoff and landing of a large number of aircraft without delay.

Further technical improvement made it possible to use data on meteorological conditions obtained from meteorological artificial earth satellites. Satellite meteorological charts are most useful in supporting superdistant flights made with aircraft of the Il-62 and Tu-114 types.

The organizational structure of the MMAMC was improved. There was a further centralization of the meteorological support of flights in the Moscow air zone. In March 1963 the aviation meteorological stations Domodedovo, Bykovo, Myachkovo, Tushino and others became affiliates of the MMAMC. The MMAMC considerably expanded its sphere of activity after being assigned supervision over a number of aviation meteorological stations near Moscow which had earlier been subordinate to the administrations of the Hydrometeorological Service of the central oblasts.

The principal type of work of the MMAMC became the meteorological support of flights of passenger and cargo aircraft in the civil aviation fleet along international and domestic air routes at the major Moscow airports Vnukovo, Sheremet'yevo, Domodedovo and Bykovo. The support of flights of special aviation (aerial photographic surveys, aviation chemical work, etc.) has been carried out directly by the Myachko affiliate since 1942.

The Tushino affiliate, founded in 1936, is the center of meteorological support of flights of subdivisions of DOSAAF (All-Union Voluntary Society for the Promotion of the Army, Aviation and Navy), including the USSR Central Aeroclub imeni Chkalov.

Thus, the MMAMC became a center of meteorological support of all possible types of aircraft and helicopters at airports in the Moscow air zone.

The activity of the MMAMC was highly appreciated by the country: in February 1971 the MMAMC, on the basis of the results of implementation of the tasks of the Eighth Five-Year Plan, was awarded the Order of the Red Banner of Labor.

The 1970's were characterized by a further increase in the effectiveness of meteorological servicing of civil aviation. A new task was assigned to the MMAMC: meteorological support of experimental and later regular flights of supersonic passenger aircraft of the Tu-144 type.

New high-speed aircraft (Tu-134, Tu-154, Il-62) were put into operation during this period. Superdistant air routes (Moscow-Tokio, the new route Moscow-Havana, Moscow-Petropavlovsk-Kamchatskiy and others) were established, imposing special requirements on the meteorological support of flights.

During this period the MMAMC prepared and disseminated 200-mb aviation prognostic charts for the servicing of superlong-range flights and collated its aviation prognostic charts for special weather phenomena and high-level aviation prognostic charts for Khabarovsk, Novosibirsk, Tashkent, Orly, Frankfurt-am-Main and others.

Flights of Tu-144 supersonic transport aircraft began in December 1975. The unusualness of the flight conditions for the Tu-144 and its technical characteristics necessitated new forms of meteorological support.

MMAMC specialists were the first who developed a method and forms of organization of meteorological support of flights of supersonic civil aircraft. They organized the reception of data, preparation, analysis and use of pressure pattern charts (100 and 70 mb) and construction of prognostic charts for the crews of Tu-144 aircraft. The basis of the support method was set forth in an article entitled "The Meteorological Support of Supersonic Passenger Aircraft" in the METODICHESKOYE PIS'MO MGAMTs (MMAMC Methodological Letter), No 8. Such letters are issued constantly: in 17 years a total of 17 methodological letters were published containing the studies of specialists of the MMAMC of the USSR Hydrometeorological Center dealing with new problems in the meteorological support of flights of modern high-speed transport aircraft, supersonic transport aircraft, different aspects of a new automated system for control of air traffic at the Moscow center Vnukovo, problems involved in the servicing of international civil aviation in accordance with the rules of the WMO/ICAO, making of aviation meteorological observations on the basis of a new meteorological remote apparatus for supporting flights of ICAO categories I and II and other timely problems.

The MMAMC methodological letters have contained refined methods for predicting weather phenomena dangerous for aviation for the airports of the Moscow air zone, the results of testing of new methods for predicting weather elements, recommendations on allowance for local peculiarities in the prediction of thunderstorm activity, fogs, low cloud cover, glaze, icing in clouds and precipitation, on the use of data from meteorological artificial earth satellites, meteorological radars, high-altitude meteorological complexes in the preparation of aviation weather forecasts.

The MMAMC has improved a forecasting method by the introduction of new methods for predicting weather phenomena dangerous for aviation.

For example, the following were tested and introduced: a method for predicting zones of moderate and strong turbulence in the clear sky, methods for predicting a radiation fog, and also minimum visibility in a fog, prediction of an advective fog one hour in advance, prediction of thunderstorms, hail and icing.

In accordance with the WMO/ICAO rules the preparation of aviation prognostic charts for special weather phenomena was organized, as well as 300- and 200-mb aviation prognostic charts for facsimile transmission through the New Delhi channel. Aviation prognostic charts in the English language are used at Sheremet'yevo and Vnukovo for the servicing of international flights.

At Vnukovo, Domodedovo and Sheremet'yevo airports the meteorological observations for the most part are automated. A new stage in automation of meteorological observations began in 1976, this ensuring the landing of aircraft as a minimum in conformity to ICAO category II.

The MMAMC has occupied a leading place in preparations for and providing meteorological support of flights with participants in and guests of the 1980 Olympics.

Looking backward, it is necessary to recall with appreciation those who dedicated great strength and energy, capabilities and knowledge to the creation and development of the MMAMC. In the past the directors of the Aviation Center were S. M. Prostyakov (up to 1935), K. A. Skobtsev (1935-1936), V. D. Nekrasov and K. N. Makhayev (1937-1938), A. A. Baturin (1939-1945), M. S. Razgon (1945-1946), P. A. Sokolov (1946), V. M. Vasil'yev (1946-1949).

Such scientists as doctors of sciences I. G. Pchelko and I. V. Koshelenko, candidates of sciences V. M. Kurganskaya, Ye. I. Gogoleva, Ye. S. Iznoskova and others began their work at the Moscow Main Aviation Meteorological Center.

REVIEW OF MONOGRAPH BY I. A. SHIKLOMANOV: ANTROPOGENNYYE IZMENENIYA VODNOSTI REK (ANTHROPOGENIC CHANGES IN THE WATER VOLUME IN RIVERS), LENINGRAD, GIDROMETEOIZDAT, 1979, 300 PAGES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 125-126

[Review by S. I. Kharchenko, doctor of technical sciences, and K. V. Tsytsenko, candidate of geographical sciences]

[Text] In the modern epoch, when man's economic activity has acquired truly global scales, the influence of anthropogenic factors has begun to be reflected in many components of the environment, especially in water resources.

In particular, this is conspicuous in the semiarid and arid regions, where an increase in the extent of irrigated agriculture, the construction of industrial facilities, cities, etc., has led to the formation of extremely strained water balances and has revealed a deficit of water resources.

In this connection a problem has arisen which is exceptionally important from the scientific and practical points of view: evaluation of anthropogenic changes which have already occurred in the runoff of rivers, and what is equally important, obtaining a scientifically sound prediction of the anticipated change in river runoff in the future, proceeding on the basis of the projected plans for development of the national economy.

Naturally, the solution of such a problem required the formulation of corresponding methodological procedures and methods for a quantitative evaluation of the effect of economic activity on the water volume of rivers.

The reviewed monograph by I. A. Shiklomanov, representing the most fundamental experience in the generalization of numerous investigations made in our country, is devoted to these problems. The author has collected an enormous amount of material, has compared the results obtained and has theoretically validated the method and evaluated the change in runoff for many rivers of the earth and especially the Soviet Union. The results are of great importance for water management planning of runoff use.

In the introductory chapters of the book I. A. Shiklomanov examines the extent of study of the problem of the influence of economic activity on the runoff of rivers and a method for its quantitative evaluation. The author convincingly and graphically reveals the entire complexity and diversity of the processes exerting an influence on the runoff of rivers with different forms of economic activity.

While noting the debatable character of some aspects of the problem, I. A. Shiklomanov validates further approaches in study of still unsolved problems.

The author defines three groups of methods: water balance method, analysis of long-term variations of runoff and the active experiment method. In examining the advantages and shortcomings of the analyzed methods, the author defines the limits and possibilities of their application, using as a point of departure the availability of initial data, physiographic characteristics of the investigated territories, etc. He expresses the thought that with the present-day level of available information in order to obtain reliable results it is necessary to make joint use of the water balance method and the method of analysis of runoff series.

Still another important point must be emphasized to which the author of the monograph returns repeatedly in his book. He warns about the inadmissibility of identifying unreturned water consumption with changes in river runoff.

A considerable place in the book is devoted to an examination of the problems related to anthropogenic changes in the runoff of lowland rivers and the development of methodological principles for the differentiated evaluation of individual types of economic activity (channel regulation, agromelioration measures, etc.). As a result of the computations which were made it was found that in the basins of the Volga, Dnepr and Don approximately to 1940 the effect of anthropogenic factors on the runoff of these rivers was unimportant. On the other hand, in the 1970's the influence of reservoirs and ponds became most conspicuous: on the Volga $\approx$ 75% of the total decrease in annual runoff was caused by runoff losses in the Volga-Kama cascade of reservoirs.

It is interesting that in the long run in the Volga basin irrigated agriculture will take first place in accounting for unreturned losses -- 52% of the total expenditures of runoff (the role of irrigation in the present stage is relatively small), whereas the influence of reservoirs in the overall structure of unreturned water consumption will be reduced to 20%.

In examining the problem of a reduction in the level of the Caspian Sea, I. A. Shiklomanov notes that its dropoff up to 1940 was attributable to the influence of climatic factors; at the present time the level regime of the Caspian is entirely determined by the influence of economic activity.

The author gives a hydrological validation of a long-range scheme for control of the water balance and the level regime of the Caspian Sea and the Sea of Azov, taking into account the shifting of part of the runoff of the northern rivers. In his opinion, these problems must be solved simultaneously, taking into account the asynchronous nature of variations in the runoff of rivers in the mentioned basins.

With respect to changes in the runoff of mountain rivers, on the basis of an analysis of long-term variations in runoff in the zone of formation and computations of the water balance in the region of its use it was possible to establish periods when economic activity, as a result of the influence of compensatory factors (decrease in nonproductive evaporation due to the annihilation of moisture-loving vegetation, construction of a collector-drainage network, etc.), exerted no substantial influence on the volume of water carried by rivers.

With the exhaustion of the compensatory possibilities in the basins the influence of anthropogenic factors began to be manifested more clearly. This was manifested most graphically in the basins of the Amu-Dar'ya, Syr-Darya, Kuban', Terek and others.

The final chapters of the book are devoted to an evaluation of the change in the volume of water carried by the rivers of the USSR and the earth as a whole under the influence of economic activity. In the territory of our country in the next few years (especially during periods with a low water volume) the deficit of water resources will show up in the southern regions of the USSR; in the northern and eastern regions of the country the runoff of rivers will remain virtually unchanged.

At the present time, for the purpose of a timely liquidation of the disproportion arising in the distribution of water resources, investigations are being made of the problem of shifting of some of the runoff of Siberian rivers to the southern slope of our country. Since this problem in scientific and technical respects is still far from solution, in the work, in our opinion, increased attention should be given to the scientific validation of measures directed to the economical and rational use of available water resources.

In investigating the change in water resources of the earth under the influence of anthropogenic factors, I. A. Shiklomanov relies on numerous sources in the Soviet and foreign literature. Despite the well-known approximate character of certain initial data, he was able to give a rough evaluation of the effect of economic activity on the water resources of individual countries, continents and the earth as a whole.

With a mean annual runoff of the rivers on our planet estimated at 46,800 km^3/year the unreturnable losses for economic needs already by 1970 were 1,600 km^3/year. It was postulated that by the year 2000 their volume will increase by approximately double. In the author's opinion, in the future one should not anticipate significant changes in runoff over large areas, but in exploited regions with inadequately ensured runoff even at the present time there can be considerable changes in the water volumes in rivers.

It should be understood that this monograph is not without shortcomings, attributable to the complexity of the examined questions, the lack of necessary initial data, etc. Nevertheless, it contains validated recommendations for evaluating and predicting a decrease in the runoff of large rivers. The reviewed book will unquestionably be a valuable contribution to modern hydrology and will serve as a reference manual in water management planning and the use of water resources.

SEVENTIETH BIRTHDAY OF ISAY GRIGOR'YEVICH GUTERMAN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 pp 127-128

[Article by a group of colleagues]

[Text] Professor Isay Grigor'yevich Guterman, doctor of geographical sciences, marked his 70th birthday on 18 February 1981. He heads the Aeroclimatology Laboratory of the Moscow Division of the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center.

Isay Grigor'yevich began his work activity at the Pochep Meteorological Station (Bryanskaya Oblast) as an observer at the meteorological station. During 1929-1935 he worked as an aerologist at polar stations and worked in a number of arctic expeditions. He was a winterer at the geophysical observatory on Franz Josef Land, the most northerly of that time, which was headed by I. D. Papinin. The observatory operated under the program of the Second International Polar Year.

In the polar diaries of Ye. K. Fedorov the following lines were devoted to him: "Isay Guterman could always be found in the laboratory adjusting radiosondes. Isay very, very carefully checked and adjusted each individual instrument, making it ready for launching... The launching of a radiosonde was an event for us. In calm weather this was a beautiful spectacle. Wavering slightly, the long train of air spheres rose upward. Isay attached the instrument to the end of the line, fastened an antenna line on it and carefully released it. The entire wavering structure rose skyward, rising to altitudes which for that time were regarded as enormous, 10-15 km, for penetrating into the mysterious stratosphere."

I. G. Guterman for the first time organized the systematic launching of radiosondes under polar night conditions. An analysis and generalization of radiosonde data became the basis for his candidate's dissertation, which Isay Grigor'yevich successfully defended after his completion of graduate training at the Moscow Hydrometeorological Institute and three years serving on the fronts in the Great Fatherland War.

During 1944-1954 Isay Grigor'yevich headed the observations section at the Central Aerological Observatory, studying the lower stratosphere, improving and introducing new means for making aerological investigations.

Isay Grigor'yevich has already been working for a quarter-century at the Moscow Division of the All-Union Scientific Research Institute of Hydrometeorological Information, dedicating himself of study of the climate of the free atmosphere and the boundary layer, primarily the circulation regime over the territory of the USSR and on a global scale. In part the results of these investigations were published in his monograph RASPREDELENIYE VETRA NAD SEVERNYM POLUSHARIYEM (Wind Distribution Over the Northern Hemisphere), which was defended in 1964 as a doctoral dissertation.

Guterman is the author and editor of more than a hundred scientific articles, monographs and reference aids devoted to different aspects of aerological observations, methods for processing them and the spatial-temporal structure of individual meteorological elements. He is one of the pioneers of automated processing of the results of observations at the USSR State Committee on Hydrometeorology. The first and second variants of the standard atmosphere for wind were developed under his direction and he participated in the compilation and publication of the first USSR Aeroclimatic Yearbook. During the last decade he devoted much strength and energy to the creation of a new USSR Aeroclimatic Yearbook. This work falls in the sphere of international cooperation of the socialist countries. The first stage in studies for a reference manual on the free atmosphere was completed with the publication of 12 volumes.

Isay Grigor'yevich devotes much attention to young people, endowing them with a love for the profession, the know-how for organizing work, dedication to achieve goals which have been set, and imparting his vital energy to them. His demanding attitude toward his colleagues is well known, but he is still more demanding on himself. Those young scientists who have worked with him or who are working under his direction say with pride and respect that they have passed through the "Guterman School."

Isay Grigor'yevich meets his birthday full of creative forces and scientific ideas.

We wish him good health and new creative successes.

AT THE USSR STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 p 128

[Article by V. N. Zakharov]

[Text] For the purpose of improving the coordination of work in the field of the hydrology of the land and agrometeorology scientific councils have been created in the system of the State Committee on Hydrometeorology and Environmental Monitoring on the problems of hydrology and agrometeorology.

The director of the State Hydrological Institute, A. A. Sokolov, doctor of geographical sciences, was named chairman of the Scientific Council on Hydrology; the deputy director of the State Hydrological Institute, I. A. Shiklomanov, doctor of geographical sciences, was designated deputy chairman; the scientific secretary of the State Hydrological Institute, G. P. Levchenko, candidate of technical sciences, was appointed scientific secretary.

The director of the All-Union Scientific Research Institute of Agricultural Meteorology, I. G. Gringof, candidate of biological sciences, was named chairman of the Scientific Council on Agrometeo-ology; a senior scientific specialist at the USSR Hydrometeorological Center, V. A. Moiseychik, doctor of geographical sciences, and the deputy director of the All-Union Scientific Research Institute of Agricultural Meteorology, Yu. A. Khvalenskiy, candidate of physical and mathematical sciences, were appointed deputy chairmen; the scientific secretary of the All-Union Scientific Research Institute of Agricultural Meteorology, D. V. Kozinets, candidate of geographical sciences, was designated scientific secretary.

The makeup of the scientific councils includes representatives of the central headquarters of the State Committee on Hydrometeorology, its central and regional scientific research institutes, scientists and specialists of other ministries and departments.

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NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 81 p 128

[Article by B. I. Silkin]

[Text] As reported in NEW SCIENTIST, Vol 87, No 1219, p 856, 1980, the "GOES-D" satellite was launched in Florida in September 1980. It becomes part of the series of geostationary artificial earth satellites for investigation of large-scale meteorological phenomena by the personnel of NOAA in the United States. Like other geostationary satellites, it will be constantly situated over one and the same point on the earth's surface.

The mission of this satellite included the collection of meteorological data relative to the territory of the United States, and also a large region of the Atlantic Ocean adjoining this territory, where tropical storms (hurricanes) are usually generated. For this purpose the satellite carried a new instrument intended for scanning radiometry of the atmosphere in the visible part of the IR spectrum.

Like earlier similar instruments, it gives a two-dimensional image of cloud cover with a half-hour interval. But in contrast to them it also has additional filters which make it possible to collect data on temperature and humidity at different altitudes in the atmosphere.

Such information is especially important for specialists investigating the conditions for the generation of a storm, for which a special vertical structure of the clouds is characteristic. As a result, the new satellite will be observing one major sector of the earth's surface and specialists will be able to monitor the development of a storm and the vertical structure of cloud cover associated with it.

Data from the satellite will be sent to the Goddard Spaceflight Center (NASA, Greenbelt, Maryland) and to the University of Wisconsin, where they will be processed and analyzed for use in improving meteorological forecasting.

The satellite, in addition to transmitting to earth "raw" meteorological data on the generation and development of the next hurricane, will be used in relaying the primary meteorological information processed under surface conditions to the network