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SIGNIFICANCE OF DIFFERENT TYPES OF INFORMATION IN LONG-RANGE FORECASTING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 5-14

[Article by Professor M. I. Yudin, Main Geophysical Observatory and Leningrad Hydrometeorological Institute, submitted for publication 22 August 1978]

Abstract: The author gives a critical analysis of the range of information drawn upon for the purpose of making long-range hydrometeorological forecasts, from the point of view of the theory of fundamental and conjugate equations of dynamics of the atmosphere and ocean developed by G. I. Marchuk. Some concepts are based on the results obtained by the use of the asymptotic methods of nonlinear mechanics used in atmospheric dynamics. The desire is expressed that large-scale indirect computations be made and that the archives be bolstered with data for use in hydrodynamic and physical-statistical long-range forecasting methods.

[Text] Until recently the problem of collecting the meteorological and hydrometeorological information necessary for predicting for a month and a season in advance was solved purely intuitively by each researcher. However, in the 1960's-1970's a number of researchers began to define the requirements on the information to be drawn upon for long-range forecasts, linking this to general considerations on the predictability of atmospheric processes and the regularities in the dynamics of the atmosphere-ocean-soil active layer system. Attention was given to a number of elements which earlier had not been regarded at all as characteristics of long-period processes (cloud cover, precipitation, boundary of the snow cover, etc.). Empirical and logical bases were defined for the need to employ new characteristics.

During these years another direction arose in research. It was based on variation of the initial conditions in the numerical forecasting problem. [60]. It was discovered that a change in the initial values of a number of meteorological elements exerts relatively little influence on the results of short-range numerical forecasting. This result means that such meteorological elements change rapidly, adapting to the "fundamental" initial conditions.

The conclusion was therefore drawn that in short-range, and especially in long-range forecasting, it is possible to not collect information on the initial values of a number of meteorological elements. The real conditions in this case are replaced by some standard conditions.

A new approach to the problem of the information necessary for hydrodynamic long-range weather forecasting was developed in the investigations of G. I. Marchuk [32, 33, 35, 57 and others]. The anomalies of meteorological elements are regarded as perturbations relative to the mean climatic values. For their determination it is possible to write a system of fundamental and conjugate equations for dynamics of the atmosphere and ocean. It is shown that solution of the conjugate problem determines the significance of different types of meteorological and hydrological information in dependence on the advance time of the forecast and the intervals for averaging the sought-for function in time and space.

The application of the theory of conjugate equations affords a possibility for a more rigorous validation of a considerable part of the conclusions concerning the information necessary for forecasts for a month and a season, earlier having only empirical confirmations. Another part of the conclusions is subject to refinement. In this light a restudy has been made of the problem of the makeup of the information which is used in predicting temperature and precipitation for the principal agricultural regions of the USSR by the physical-statistical method. Earlier this problem was analyzed in [38, 49, 51, and others]. In the examination of some of the disputable problems we will rely on the concept of the atmosphere-active layer of the ocean and land system as a multifrequency system in which rapid and slow movements in the first approximation can be separated [36, 55].

Information on the state of the upper layer of the ocean (water temperature, ice content). This source of information has long attracted the attention of researchers investigating the problems relating to large-scale interaction between the atmosphere and ocean. In particular, in the well-known studies of V. Yu. Vize [15, 16] a detailed study was made of the ice content of the Barents Sea as a predictor in the long-range forecasting of temperature and precipitation. The correlation established by Meinhardus [58] between the temperature of the Gulf Stream in November-January and air temperature in Central Europe in February-April was checked and re-evaluated several times. There were found to be considerable variations in the sample values of the correlation coefficient up to a change in sign of the correlation during individual periods. In a number of studies it was therefore concluded that data on water temperature in the ocean are of little practical importance for the purpose of making forecasts for a month and a season. A useful review of the discussion of this problem and clarification of a number of disputable points is contained in a book by T. V. Pokrovskaya [45].

The thought has been expressed that the state of the upper layer of the ocean is a result of atmospheric circulation conditions. On this basis it is postulated that models of the development of macroprocesses can be formulated independently of information on the ocean.

Sometimes one hears the contention that water temperature has little variability. The conclusion is therefore drawn that heat exchange between the ocean and the atmosphere is dependent to a higher degree on the air temperature anomalies than on water temperature anomalies. However, an analysis of data on the standard deviations of water temperature (σ_{T_w}) and air temperature (σ_{T_a}) in the North Atlantic [26, 27, 29] carried out during recent years does not confirm these statements. Comparison of the σ_{T_w} and σ_{T_a} values cited in these studies shows that these are comparable values. We carried out preliminary computations for checking the natural hypothesis that the ratio of the standard deviation of the mean water temperature during some time interval relative to this same air temperature characteristic increases with an increase in the averaging interval. (The sense of the hypothesis is that water temperature is more conservative than air temperature.) Some tendency to an increase in the considered ratio with a transition from monthly to seasonal means is actually detected. However, it is weaker than can be expected a priori. Evidently, the intensity of air transformation over the ocean is so great that the air temperature over the sea surface also acquires the property of conservatism. This problem requires further analysis.

A solid basis for use of data on temperatures of the upper layer of the ocean was the theory of fundamental and conjugate equations, mentioned above. The theory makes it possible to represent the air temperature anomaly during some time interval in the form of the sum of two terms, one of which characterizes the influence of initial disturbances in the atmosphere, whereas the other characterizes the influence of initial disturbances in the active layer of the ocean and land. It has been demonstrated that with an increase in the averaging interval the characteristic value of the first term decreases rapidly and the second becomes decisive. It is understandable that this conclusion does not relate only to the significance of water temperature in the ocean. In principle it can also serve as a basis for use of data on soil temperature and moisture content, ice content, times of disappearance of the snow cover in different regions, etc.

It would be of great interest to make a theoretical evaluation of the prognostic significance of the enumerated factors by means of solution of the fundamental and conjugate equations of the problem of disturbances of the thermal or precipitation regime. It should be noted that in principle the incorporation of data on ice content and on the dynamics of forming and disappearance of the snow cover and a number of factors important for monthly and seasonal forecasts do not require validation by means of computations using complex models of atmospheric circulation. An adequate basis is the conclusions drawn with the application of important simplifications, such as those obtained by M. I. Budyko [11, 12, 14, and others]

-- evaluations of the influence exerted by both the snow and ice cover on the thermal regime of the atmosphere. However, application of the theory of perturbations affords a possibility of localizing the expected effects in time and in space.

Information on the distribution of cloud cover. There are contradictory opinions on the problem of the significance of data on cloud cover for forecasting purposes. As is well known, the cloud cover field has long been considered small-scale (spotty). Moreover, an analysis of the relative significance of different initial data employed in numerical forecasting [28, 60] indicated that a change in initial data on the humidity field has relatively little influence on the forecasting results. On this basis V. M. Kadyshnikov in a numerical model of computation of steady precipitation adopted the initial condition for saturation of the atmosphere by water vapor in the entire space, and cloud cover and precipitation at subsequent moments in time are functions of the computed vertical velocities.

In [46] an attempt was made to refine the initial condition for the humidity field. Humidity was determined as a function of the observed values of nonconvective cloud cover and the computed vertical velocity values at the time used as the initial value. Using preliminary, still extremely limited data, such a formulation of the problem led to a satisfactory prediction of cloud cover for a time of 24 hours. With a more precise method for introducing data on initial cloud cover there is also some increase in the success of the forecast.

We feel that these results must be taken into account in solving the problem of rational methods for stipulating the initial humidity field for short-range forecasting purposes. However, for validation of the significance of data on cloud cover in long-range forecasting it is necessary to have demonstration of a different kind.

We can mention two bases for inclusion of cloud cover among the predictors:

-- the concept of a regulating role of cloud cover in processes of thermal interaction between the atmosphere and the active layer;

-- the concept of presence of a low-frequency global component in the cloud cover field.

Now we will examine these bases in somewhat greater detail.

Ideas concerning the important role of cloud cover as a regulator with a feedback in the processes of thermal interaction between the ocean and the atmosphere were expressed in 1963 by A. S. Monin [39]. A simple model for illustrating this role was formulated in [17]. It was demonstrated that variations of the type

warm sea
↓
development of convection, increase in cloud cover and cooling of the sea
↓
cold sea
↓
stable stratification, decrease in cloud cover and heating of the sea
(→ back to warm sea)

can have periods of about a month.

Further investigations of the role of cloud cover over the ocean in heat exchange processes are related to the theory of conjugate equations. In [34, 41-43] the influence of summer cloud cover anomalies over the North Atlantic on autumn and winter air temperature anomalies over Europe was examined from the theoretical point of view. There was also a statistical analysis of asynchronous correlations. The principal statistical conclusions of necessity are based on a time-limited series of measurement data on cloud cover made from a satellite, so that the investigation was far from completed. Nevertheless, the results confirm the considered influence is important.

Now we will consider what bases there are for asserting that there is a low-frequency global component in the cloud cover field. Here the reference is not to the thermal effect mechanism, which was mentioned above, but the dynamic mechanism determining long-persisting extensive regions of ascending movements, with which the formation and persistence of cloud cover are associated.

The first conclusions that in planetary movements, in contrast to strictly large-scale movements, the potential part of velocity is not very small in comparison with the solenoidal part, were drawn in [47, 56]. In particular, it is of interest to study a graph of the characteristic values of the horizontal divergence of velocity and its component terms, obtained in [47] by means of "scale analysis" of the terms in the equations of atmospheric dynamics. It follows from the graph that under mean conditions the considered ratio attains a minimum for a scale $L_1 \approx 800$ km and increases rapidly in the region of scales $L > L_1$. This conclusion gave hope for success in an attempt at empirical discrimination of the stable planetary component in the cloud cover field. It was surmised that its values can be a significant predictor in a long-range forecast. On a practical basis it was possible to collect long-term series of data on cloud cover in the Atlantic-European sector adequate for analysis. This material was processed by the method of expansion in empirical orthogonal components (EOC). The expansion coefficients were regarded as predictors. In [52] there was checking of the hypothesis of statistical significance of a set of asynchronous correlations relative to different groups of predictors. It was shown that the hypothesis of significance of data on cloud cover is satisfactorily confirmed on the basis of the considered material.

Further results were obtained in a cycle of studies [50, 54, 55] in formulating a hydrodynamic-statistical model of atmospheric circulation. The stream function and velocity potential are among the principal variables. Spectral transformations of the equations of atmospheric dynamics were carried out; these lead in the first approximation to the discrimination of a limited number of subsystems of ordinary differential equations. The characteristic frequencies and eigenvectors of the fundamental and conjugate equations [36] were computed in this same first approximation for a number of subsystems. The important conclusion was drawn that some planetary movements are characterized by very small characteristic frequencies (periods of several tens of days). It follows from the form of the eigenvectors that for zonal wave numbers n = 1 and n = 2 (first two harmonics) the contribution of the potential part of the vector is significant. This means that the planetary disturbances arising in the vertical velocity field, and accordingly, also in the cloud cover field, are not propagated rapidly from east to west (as follows from the Rossby theory), but are very slowly moving waves. The nonlinear interactions of waves exert a strong influence on the movements of waves and ridges from day to day. However, with considerable time averaging the total influence of these more or less irregular interactions lessens relative to the systematic movement of the waves.

We can therefore assert that the global cloud cover field is characterized by peculiarities which long retain their sign and therefore exert a significant influence on macroprocesses, whose prediction is the basic objective of monthly and seasonal forecasts. It is easy to see that both are basis for regarding cloud cover as a very important element in the system for long-range forecasting and supplement one another. The concept of a regulating role of cloud cover in heat exchange of the sea-atmosphere system rests on an analysis of forced oscillations of the system and the discrimination of the low-frequency component rests on an analysis of free oscillations in the atmosphere.

Now it is possible to understand why in [28, 60] it was not possible to detect a significant influence of the initial humidity (and cloud cover) field on the numerical forecasting result. The fact is that the variation of the initial data was a small-scale and accordingly a rapidly oscillating disturbance. In order to clarify the principal effect it was necessary to carry out variation of the planetary field component.

Information on the pressure field. First we note that in the light of the modern theory of predictability of individual synoptic processes there is no basis for considering all data on the pressure field as a source of useful information. In particular, at the present time it appears that the usefulness of the well-known similarity indices ρ_φ, ρ_λ for long-range forecasts requires careful validation. A shortcoming of these indices is that the basis for their determination is a comparison of the small-scale characteristics of fields at individual points.

Most authors of hydrodynamic, hydrodynamic-statistical, physical-statistical and synoptic methods of long-range forecasting limit the use of data on the pressure field to a few characteristics. For example, in the Ye. N. Blinova long-range forecasting theory [2-5, and others] the circulation index is of particular importance. The importance of the circulation index at the initial moment and computation of its changes is an important part of the routine method for predicting mean monthly air temperature anomalies for the northern hemisphere. The modern stage in development of the theory is related to the partial linearization method (discrimination of the main waves) developed by Ye. N. Blinova [6-8 and others]. As the initial data it is necessary to stipulate a relatively small number of coefficients for spherical functions.

In long-range forecasting methods based on a classification of meteorological processes and fields the number of characteristics used in forecasting is also reduced to a minimum. But the information used in the classification itself can be extremely extensive, as can be seen, for example, from the books [18, 19]. The same can be said about the complex physical-statistical method, in which the approach of expansion of the pressure field into series in empirical orthogonal functions is used for the purpose of discriminating the most large-scale and long-period processes [37, 48, 53, and others]. We note that with the substantial difference in the methods for processing information in the macrocirculation and physical-statistical methods the initial information still has much in common. This is attributable to the striving of researchers to somehow adapt all available information to use.

Now we will discuss conclusions from the G. I. Marchuk perturbation theory.

Among the approximate formulations of the long-range forecasting problem mentioned in [32] there is one which does not require the use of data on pressure and wind. It is assumed that the distribution of temperature in the active layer of water and land at the initial moment is everywhere known and the variations of the heat influx in the atmosphere were computed independently. An approximate solution of the forecasting problem with replacement of the values of the horizontal wind velocity component by the mean climatic values is obtained under these conditions. However, such a formulation of the problem is regarded only as intermediate. A more complete theory was based not only on information on the state of the atmosphere in the time interval $0 \leqslant t \leqslant T$, where the necessary information is restored by means of solution of the prognostic problem and the corresponding conjugate problem, but also precise information on the fields of meteorological elements in the time interval $-\infty < t < 0$, which should be obtained from observations.

The widespread use of integration limits for t to $t = -\infty$ in the formulas of the theory of perturbations is equivalent to the following: the initial values of the fields of meteorological elements (when $t = 0$), necessary for predicting weather using the formulas of perturbation theory are replaced by actual information on the state of the atmosphere at all the times preceding the zero moment ($-\infty < t < 0$) at the level of the ocean and continents. They must be known with the necessary accuracy ([32], pp 205-206).

It follows from this reference to the literature that information on the pressure field for the time $t < 0$ is necessary to that degree to which it will make it possible to supply the lacking data on the temperature of the upper layer of the ocean, continental temperature anomalies, heat influx in the atmosphere at the initial moment $t = 0$. Such an understanding of the significance of this information is fundamentally different from the synoptic approach to the long-range forecasting problem based on the classification and tracking of macroprocesses in the atmosphere as independent objects of investigation.

Now we will examine how to solve the problem of the significance of data on the pressure field in a hydrodynamic-statistical model. A solution can be obtained by separating the eigenvectors of the fundamental and conjugate equations into "slow" variables corresponding to small characteristic frequencies and "fast" variables corresponding to large frequencies. Then the approach of asymptotic methods of nonlinear mechanics is applied, making it possible to obtain an approximate solution for the averaged values of the slow variables, which is not dependent on the values of the "fast" variables. The overwhelming majority of eigenvectors relate to frequencies much greater than 2π/month.

This means that for the purpose of forecasting for a month or a season "almost all" the spectral components of the pressure field must be regarded as values whose initial phases exert no influence on the forecasting results. Such a conclusion fully corresponds to the concepts following from use of perturbation theory.

Table 1

Dependence of Characteristic Frequencies of Planetary Waves on Circulation Index

n	α/ω			
	0,05	0,04	0,03	0,02
1	0,005	0,015	0,025	0,035
2	0,008	0,028	0,048	0,068
3	0,003(3—B)	0,027	0,057	0,087
4	0,034(3—B)	0,006	0,046	0,086

[3 = W; B = E]

However, the presence of even a very small number of slow variables shows that from the initial data on the pressure field it is possible to draw some direct conclusions concerning the nature of development of atmospheric processes in the months immediately ahead. True, these conclusions to a considerable degree are conditional, since the characteristic frequencies of the slow variables are highly dependent on the future value of the circulation index. As a confirmation we cite Table 1 of the minimum characteristic frequencies characterizing planetary baroclinic waves with different values of the circulation index α/ω. The frequency values with $\alpha/\omega = 0$, cited in [36], serve as initial data. In cases when the designation (W-E) stands after the frequency, the waves are displaced from west to east. In the remaining cases the computations indicate an opposite movement of the waves.

Table 1 shows that allowance for the initial phase of the planetary waves is most important in the case of large values of the circulation index, that is, in the cold half of the year.

We note that if there is no spectral expansion of the fields in eigenvectors of the fundamental and conjugate problems, it is difficult to indicate an alternative method for isolating the information on the initial pressure field important for long-range forecasting. Therefore, it is promising to develop a variant of the theory of perturbations on the basis of a hydrodynamic-statistical model.

We do not have an opportunity of discussing the problem, very important for a hydrodynamic-statistical model, of describing the effects associated with "fast" variables. We only note that in the prepared variant of the model provision is made for a statistical description of those effects which are associated with stipulation of a small volume of data concerning the pressure (and thermal) field.

Indirect computations and archivizing of data. It can be expected that an approach based on perturbation theory leads to the establishing of a number of physically more significant predictors than those which long-range forecasters have at the present time. These predictors in essence will represent the substitutes for the lacking characteristics of the state of the active layer of water and land, and the total values of the heat and moisture fluxes. In addition, here it is necessary to include an extremely limited number of characteristics of the planetary pressure field.

In this connection it is very important to apply maximum efforts for obtaining empirical data on the global characteristics of heat and moisture exchange during individual months and seasons. Such a problem is real since the methods for indirect computations developed by Soviet and foreign researchers for indirect computations of the components of the heat and water balance, and parametric description of the state of the active layer, in principle can be used for large-scale computations. A description of a number of modern computation methods is contained, for example, in the books [13, 23-25, 40, 44, 59].

It can be shown that the preparation of archives of this sort over a long series of years is of basic interest for specialists developing physical-statistical forecasting methods, whereas specialists in the field of hydrodynamic methods for long-range forecasting are relatively little interested in such data. However, such an idea is erroneous. The development of hydrodynamic forecasting methods for intermediate and long periods shows that to a high degree they are dependent on the empirical data necessary for analysis of systematic errors in the model and its refinement. If it assumed, on the basis of the results published by G. P. Kurbatkin [30, 31, and others], that for the adjustment and correction of an intermediate-length forecast it is necessary to have archival data for approximately five years, the necessary length of the series for the purposes of forecasting for a month and season must not be less than 20-30 years.

Relying on an analysis of the stability of the correlations, which is regularly accomplished in the practice of forecasts making use of the complex physical-statistical method, it is necessary to deem preferable a series of 30-40 years. Thus, the requirements on information for the purposes of hydrodynamic or complex physical-statistical methods agree entirely satisfactorily. It appears that the preparation of the above-mentioned data will be of great importance for the development of a number of other methods having features in common in the approach to the initial information. This can be said, in particular, about the studies planned by G. V. Gruza on the application of the analogues method [20-22] to a monthly weather forecast and also on the methods of Ye. P. Borisenkov [9, 10], N. A. Bagrov [1], and others.

The great volume of work makes it desirable to combine the efforts of a number of groups, possibly in the form of a special international program (after ending of the primary processing of FGE data). It is desirable to discuss this problem in the Scientific Council on the "Weather Forecasting Problem" and in the Soviet Geophysical Committee.

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SIMPLE STATISTICAL MODEL OF MODERN CLIMATE

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Abstract: For an analysis of climatic processes with characteristic times of change of the order of tens of years the author has formulated a simple statistical model whose basic difference from the simple deterministic models used earlier by different researchers is allowance for weather fluctuations. The author has derived the fundamental equation for the model, in which only surface temperature, averaged for some region, is considered, on the assumption that this parameter is statistically independent of the other climatic parameters and modern climate has an isolated point of equilibrium. Two very simple variants of the model are investigated: Gaussian and power-law four-parameter.

[Text] Introduction. The problem of the possible influence exerted on the earth's climate by human activity is acquiring ever-increasing timeliness. A rather great number of hypotheses, validated to different degrees, concerning the physical mechanisms of such an influence, has now been advanced (for example, see [1, 2, 5]). However, despite the extremely broad front of investigations carried out in this direction, for the time being reliable experimental results have not been obtained; the rigorous assumptions used in the theoretical investigations for the time being give to the latter only the nature of frequently heuristic reasonings and propositions.

Evidently, when reference is to investigation of a possible anthropogenic change in modern climate, it is necessary, in particular, to study climatic processes with characteristic times of change of the order of tens of years. In the opinion of a rather large number of climatologists, precisely during such a time it is possible to expect, for example, a climatic effect from the influence exerted on the radiation balance of the earth-atmosphere system by the carbon dioxide entering into the atmosphere as a result of the combustion of coal and petroleum.

But during the indicated characteristic times a substantial influence on the change in some climatic characteristics will be exerted by their weather fluctuations. In this case we are dealing with a phenomenon which to some degree is similar to the influence of turbulence on the course of some atmospheric processes (for example, on cloud formation and evolution) or the influence of Brownian motion on the behavior of aerosol particles in the medium. Naturally, in an analysis of anthropogenic change of modern climate it is necessary somehow to take weather fluctuations into account. This article is devoted to the formulation of one of the possible models for taking them into account. We note that such an attempt was undertaken recently in [6]. We assume that we have been able to generalize somewhat and carry out further development of the ideas set forth in this study.

First of all, we will be more specific in what is meant by the terms "climatic change" and "weather fluctuations." We feel that it is necessary to do this here due to the fact that for the time being there are seemingly no definitions of these concepts which are generally accepted in climatic theory.

For the purpose of clarity we will have in mind the surface temperature T_{surf}, that is, the temperature of the air mass measured at different surface (or shipboard) meteorological stations or posts. Similarly it is possible to examine other so-called weather characteristics, such as the precipitation total, humidity, tenths of cloud cover, etc.

A time series of data on surface temperature, if the measurements have been made rather frequently, has an extremely irregular nature. If no attention is given to the diurnal variation, for short times the change in surface temperature at a stipulated point will be purely random and related, in particular, to the random movement of air masses in the atmosphere. We introduce the following notations

$$T_{\kappa}=\frac{1}{\tau_{\pi}}\int_{t}^{t+\tau_{\pi}}dt'\,T_{\pi}(t'),\quad T'\doteq T_{\pi}-T_{\kappa}, \tag{1}$$

[π = surf] where τ_{surf} is the characteristic correlation time $\dot{T}'$ (rate of change of fluctuations). [K = cli(matic)]

It seems to us that τ_{surf} is the most fitting and a completely natural parameter making it possible to separate the weather fluctuations of the value from its climatic change. In this case, for example, the weather characteristic T_{surf} becomes a purely climatic parameter when it is averaged in time τ_{surf}; the deviation of T_{surf} from T_{cli}, that is, T' becomes the weather fluctuation of surface temperature. The time τ_{surf} in order of magnitude can scarcely be more than a few months. It is evident that the climatic parameter T_{cli} is a random value, and this means that it makes sense to speak not of any values of this parameter at a stipulated moment in time, and about the distribution function $\varphi(T_{cli}, t)$ (reference is to the probability density function, normalized to unity). Therefore, henceforth under the term "climatic change in surface temperature" we will mean the evolution of the introduced distribution function $\varphi(T_{cli}, t)$.

We note that in the investigation of possible anthropogenic changes in climate the emphasis up to the present time has been devoted, as a rule, only to a study of the behavior of the first moment of this distribution function, that is, when reference was to surface temperature,

$$\langle T_{\kappa} \rangle = \int dT_{\kappa} T_{\kappa} \varphi(T_{\kappa}, t). \quad (2)$$

Frequently only intuitive considerations are presented with respect to the possible behavior of the variability of climatic parameters (climatology of second and higher moments). And indeed, it is not impossible that the vigorous development of industry at the present stage can begin to exert an influence (or has already influenced) not the climatic trends of different climatic characteristics, but specifically their variability, also playing an extremely significant role in our life.

Despite the rather rough description of the real processes, simple climatic models (Budyko, Sellers, Zat'sman, Adam and other models [5]) have an extremely high heuristic value. Therefore, it seemed desirable to us to formulate, proceeding on the basis of the simplest physical considerations, a similar model which would describe the evolution of the distribution function of the climatic parameters (in the considered case -- surface temperature) under the influence of the disturbing factors.

Principal physical assumptions. We feel that the simplest variant of a statistical model of climate can be formulated on the basis of a kinetic equation of the diffusion type for the φ distribution. However, for this it is necessary that the correlation time for the rate of change in weather fluctuations τ_{surf} could be considered negligible in comparison with the characteristic time of change in φ (we will denote it by τ_{cli}). The two characteristic times of change in φ closest to τ_{surf} are determined by the seasonal variation of temperature and the high-frequency variation of climate with a characteristic time of 2-4 years; the next characteristic time evidently has the order of several tens of years (warming beginning in the second half of the past century and ending in the 1940's of this century, for example). A rather detailed analysis of the state of investigations of the time structure of processes in the earth-atmosphere system is given in [4]. Thus, if it is necessary to examine the seasonal variation of φ as well, then, generally speaking, it is possible only with a definite strain to consider the condition $\tau_{surf} \ll \tau_{cli}$ to be satisfied. However, nevertheless even in this case in some first approximation it can be used, since there scarcely should be any effort to obtain more precise quantitative relationships in simple models.

In order to write a kinetic equation for only one random value T_{cli} it is necessary to satisfy the condition of its statistical nondependence on other random climatic parameters. It seems that it is scarcely possible to indicate situations when this condition would be satisfied completely for the earth's climate. Therefore, we will use it as a simplification necessary for consideration. If there were no others, then already due to this simplification all the subsequent description would be transformed into modeling.

We note that here reference is to possible T_{cli} values at a stipulated point. But for different points on the earth the T_{cli} distribution will knowingly be different, and in general, even in the simplest model it will be inadmissible to examine the evolution of φ at some point independently of its evolution at other points on the earth. However, it seems to us that it is possible to discriminate individual regions which in energy respects are more or less closed, so that it is possible to neglect the statistical dependence of the surface temperatures averaged for these refions in some first approximation. The choice of the extent of the region must be made on the basis of additional physicoclimatic data. Henceforth by T we will mean the surface temperature T_{surf} for which there was averaging for such a type of region.

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The considerations cited above make it possible to represent the rate of T change in the form of regular and fluctuating parts

$$\dot{T}=a(T,\ t),\quad \dot{T}'=F(T,\ t),\qquad (3)$$

where F is the delta-correlated random function with a mean equal to zero:

$$\bar{F}=0,\quad \overline{F(t)F(t+\tau)}=2D(T,\ t)\,\delta(\tau).\qquad (4)$$

Integrating (3) in the time interval (t, t+dt), we arrive at another form of this equation:

$$dT=a\,(T,\ t)\ dt+\sqrt{2\,D\,(T,\ t)}\ \xi\ \sqrt{dt},\qquad (5)$$

where ξ is a random value, with a normal distribution, with a mean equal to zero and a dispersion equal to unity: $\bar{\xi} = 0$, $\overline{\xi^2} = 1$.

In contrast to the ordinary differential equations, which for stipulated values of the function at the time t_0 determine its behavior at an arbitrary moment in time $t > t_0$, equation (5) makes it possible to compute not some T value, but its distribution at the moment in time $t > t_0$ on the basis of the stipulated distribution at the time t_0. Such a class of equation is usually called stochastic differential equations of the Ito type [3].

The procedure for solving equations of the type (5) is extremely complex and unwieldy. Therefore, usually there is transformation from these equations to the equivalent ordinary differential equations in partial derivatives for the distribution function φ -- kinetic equations. The derivation of the kinetic equations from (5) was obtained and validated by A. N. Kolmogorov and is cited in many monographs on the theory of random processes; therefore, here it makes no sense to discuss this in detail.

The kinetic equation following from (5) for describing the evolution of the distribution function φ with time has the form

$$\frac{\partial\varphi}{\partial t}+\frac{\partial}{\partial T}\,a\,(T,\ t)\,\varphi=\frac{\partial^2}{\partial T^2}\,D\,(T,\ t)\,\varphi.\qquad (6)$$

This is the ordinary equation of convective diffusion with the drift coefficient a and the diffusion coefficient D.

If D = 0, we arrive at a simple deterministic climatic model such as was mentioned in the introduction. Thus, a new element of the proposed climatic model is the inclusion of a diffusion term, which makes it possible to take into account the influence of weather fluctuations (to be sure, within the framework of the adopted assumptions and simplifications).

Gaussian variant of model. We will denote the climatic surface temperature, averaged over a period of about 100 years, by T_N, and the deviation of T from T_N by Ω. We will consider the point T_N to be an isolated stable point in modern climate, that is, a point to which, first of all, the temperature always returns after a small disturbance and in whose immediate neighborhood, second of all, there are no similar points. Mc .over, we will assume that other similar points of equilibrium of modern climate are at such great distances that their influence is not reflected in the evolution of the Ω deviations caused by either regular or random factors. Unfortunately, investigation of the factual material on the behavior of modern climate makes it possible to draw a conclusion only about the possibility of a hypothetical situation and does not make it possible to say anything about how close it is to reality, about how far the other points of equilibrium are from T_N.

The cited hypothesis makes it possible to expand the drift and diffusion coefficients in equation (6) into a Taylor series in some neighborhood of T_N:

$$a(T, t) = a(T_N, t) - \beta\Omega + \dots$$

$$D(T, t) = D(T_N, t) + \left.\frac{\partial D}{\partial T}\right|_{T=T_N} \Omega + \dots \quad (7)$$

The $a(T_N, t)$ value characterizes the factors leading to a regular change in Ω. In this connection it can be conveniently broken down into two parts

$$a(T_N, t) = A(t) + R,$$

where A(t) contains information on the mechanisms leading to a seasonal change in surface temperature and its variations with a period of 2-4 years if the latter actually exist and R gives information on the mechanisms exerting an influence on its change with a greater characteristic time. We can introduce into R information on the regular anthropogenic influence on surface temperature, for example, by virtue of an increase in the concentration of atmospheric CO_2, a change in albedo of the underlying surface, etc. If we substitute the cited two terms of the Taylor series for a(T,t) into (4) it immediately is clear that the β parameter characterizes the resistance of the climatic system relative to different regular or random disturbances and equal in order of magnitude to the inverse time of exponential relaxation of surface temperature to the T_N level after sudden cessation of exposure to the disturbing factor. The β parameter cannot be equal to zero since otherwise the dispersion of the random value Ω without influence of external regular factors would increase with time without limit. The stability of modern climate indicates that this does not occur. We note that similar considerations on the need for existence of a finite value for β are also given in [6]. Moreover, β cannot assume negative values, since the T_N point was determined as a point of stable equilibrium. The dependence of β on t can be neglected for the considered times, since its value must be determined by those same processes in the environment as the T_N value. To be sure, this assumption requires additional checking, but seems very probable to us. Moreover, in the climatic statistical model variants examined here allowance for a possible dependence of β on t leads to nothing new from the physical point of view.

First we will assume that D, that is, the intensity of the rate of change of weather fluctuations with time, is not dependent on Ω. One of the possible forms of the dependence of D on Ω will be examined in detail in the next section of this article.

Then the equation for φ assumes the following form:

$$\frac{\partial\varphi}{\partial t} + \frac{\partial}{\partial\Omega}(-\beta\Omega + A + R)\varphi = D\frac{\partial^2}{\partial\Omega^2}\varphi. \qquad (8)$$

This equation determines the simplest possible variant of the statistical model of climate.

For equation (8) we will examine the problem without initial conditions. We will seek a solution in the form

$$\ln\varphi = b_0 + b_1(\Omega - \langle\Omega\rangle)^2, \qquad (9)$$

where b_0, b_1 and $|\Omega|$ are some functions of t.

Substituting (9) into equation (8), we arrive at the following expressions for these functions:

$$b_0 = -\ln\sigma + C,\ b_1 = -\frac{1}{2}\sigma^{-2},$$
$$\frac{d\langle\Omega\rangle}{dt} = -\beta\langle\Omega\rangle + A + R, \qquad (10)$$
$$\frac{1}{2}\frac{d\sigma^2}{dt} = -\beta\sigma^2 + D.$$

Here C is some constant which must be determined from normalization conditions. It is easy to see that $C = -1/2 \ln 2\pi$.

Thus, solution of the problem without initial conditions for equation (8) has the form of a normal distribution

$$\varphi = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(\Omega-\langle\Omega\rangle)^2}{2\sigma^2}}, \qquad (11)$$

where the mean $\langle\Omega\rangle$ value and the dispersion σ^2 are solutions of the differential equations (10).

Therefore, the considered variant of the statistical model is naturally called "Gaussian."

We will denote the parameter characterizing the anthropogenic influence on climate by η. In the Gaussian variant of the model the evolution of dispersion with time, caused by the perturbing effect of η, can be accomplished only through a change in the parameters η and D. Assuming

η to be a small value, it can be assumed that

$$R \sim \eta, \quad \frac{\beta - \beta_0}{\beta_0} \sim \eta, \quad \frac{D - D_0}{D_0} \sim \eta,$$

where β_0 and D_0 are the values of the parameters β and D when $\eta = 0$.

Thus, the anthropogenic change in the mean surface temperature can be, in general, completely significant. However, the change in dispersion in this case can be fully ignored. This means that in the considered situation the appearance of a climatic trend still says nothing whatsoever about significant changes in the dispersion of surface temperature, about which some climatologists speak very categorically, assuming it to be possible, proceeding on the basis of close considerations. If the Gaussian variant of the model correctly reflects the real behavior of modern climate, the possible significant evolution of its variability under the influence of man's industrial activity must be investigated independently of an analysis of climatic trends by means of a search for the physical mechanisms of direct substantial disturbance of the β and D parameters. Insofar as we know, for the time being only a hypothesis is being formulated concerning the possible physical mechanisms of the anthropogenic influence on climatic trends. This problem is extremely interesting and therefore below we will examine a very simple model for evaluating the possible influence of climatic trends on the variability of climate (with postulation of existence of such a correlation).

Power-law four-parameter variant of model. Thus, according to the common, although, to be sure, not generally accepted opinion, the appearance of a climatic trend in the behavior of surface temperature should lead to an intensification of its variability. This assumption can be taken into account most simply, assuming

$$F(T, t) \approx F(T_*) + \beta'(T - T_*), \tag{12}$$

where β' is a delta-correlated random function with a mean equal to zero.

Strictly speaking, such a representation of the random function F is entirely legitimate since it is known that by virtue of the extremely complex intertwining of a great number of direct and inverse correlations in the climatic system there can be development of self-intensifying or (vice versa) self-sustaining extremal situations. But (12) includes the new parameter T_* characterizing the level with deviation from which there is an intensification of weather fluctuations of the rate of change in temperature and the entire problem involves specifically a determination of the T_* value. If it is assumed that $T_* = T_N + \langle \Omega \rangle$, we do not obtain a dependence of variability on trend. In this case the model is similar to the Gaussian variant, but the distribution form is different. If we simply assume $T_* = T_N$, then (12) will, in essence, in simplified mathematical form express the hypothesis of intensification of weather fluctuations with the appearance for any reason of a climatic trend in surface temperature. In general, T_N for this purpose can replace any other parameter not dependent on the parameters controlling the change in surface temperature for the time scales. Nothing changes from this, but $F(T_*)$ will be loaded with additional information, but we do not need an explicit form of this function in the future.

We note that there can be a somewhat different interpretation of expression (12). In actuality, if we compare this expression with the first expression in (7), it can be seen that the second term in (12) is an expression taking into account the weather fluctuations of resistivity in the climatic system.

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Substituting (12) into (4), we have

$$D(T, t) = D_0 + \alpha\Omega + \gamma\Omega^2,$$
$$2D_0\delta(\tau) = \overline{F(T_N)\,F(T_N)},\ \alpha\delta(\tau) = \overline{F(T_N)\,\beta'},\ 2\gamma\delta(\tau) = \overline{\beta'\beta'}, \tag{13}$$

where $\gamma \geqslant 0$, and α can assume an arbitrary sign, but without fail there must be satisfaction of the condition $D > 0$.

Using for a the expression (7), and for D the expression (13), we arrive at the following kinetic equation:

$$\frac{\partial\varphi}{\partial t} + \frac{\partial}{\partial\Omega}(-\beta\Omega + A + R)\,\varphi = \frac{\partial^2}{\partial\Omega^2}(D_0 + \alpha\Omega + \gamma\Omega^2)\,\varphi. \tag{14}$$

Multiplying this equation by Ω^n, where n = 0, 1,..., and integrating the result for Ω in the interval $(-\infty, +\infty)$, after simple transformations we arrive at the following recurrent expressions for the distribution moments φ:

$$\frac{1}{n}\frac{d}{dt}\langle\Omega^n\rangle = -[\beta - (n-1)\gamma]\langle\Omega^n\rangle + [A + R + (n-1)\alpha]\langle\Omega^{n-1}\rangle + (n-1)D_0\langle\Omega^{n-2}\rangle. \tag{15}$$

It can be seen from this expression that in order for there to be the first n moments of the function φ it is necessary to satisfy the condition $\beta/\gamma >$ n - 1. This is associated with the power-law behavior of solutions of the equations (14) in the case of large $|\Omega|$.

After simple transformations, from expressions (15) we find for the dispersion

$$\frac{1}{2}\frac{d}{dt}\sigma^2 = -(\beta - \gamma)\sigma^2 + D_0 + \alpha\langle\Omega\rangle + \gamma\langle\Omega\rangle^2. \tag{16}$$

It follows directly from this equation that the deviation of the mean surface temperature value in the considered model leads to a change in the dispersion. With sufficiently large $\langle\Omega\rangle$ values the dispersion will always be increased, whereas in the case of small $\langle\Omega\rangle$ it can also decrease if α is negative.

The parameters of the model can be determined by an analysis of the available factual material. For example, for their determination it is sufficient to find the first four moments for the time series of data. If this is done, using expression (16) it is easy to evaluate the change in dispersion for the predicted changes in surface temperature. To be sure, there is no assurance of the correctness of the expression, since for the time being it was derived using a completely unsubstantiated hypothesis.

Analysis of stationary solutions for a power-law parametric model. The coefficients γ, A and D_0 of the recurrent equations (15) are periodic functions of time with the period t_s, equal to a year (seasonal variation).

We note here that with a sufficient accuracy these coefficients can be represented in the form of a superpositioning of a finite number of harmonic oscillations with periods which are multiples of t_s. Therefore, averaging (15) for the time t_s and assuming for a simplification of the further analysis that R and the amplitudes of the coefficients γ, A and D_0 in expansions in harmonic oscillations are not dependent on time, in the problem without initial conditions for $\gamma_* < (n-1)^{-1}$ we obtain

$$<\Omega^n> = \frac{n-1}{1-(n-1)\gamma_*}\left[\left(\frac{\varepsilon}{n-1} + \alpha_*\right)<\Omega^{n-1}> + D_* <\Omega^{n-2}>\right]. \quad (17)$$

Here the asterisk denotes the mean annual values of the corresponding coefficients, divided by β ; $<\Omega^n>$ are the mean annual values of the distribution moments φ ; ε is the mean annual possible rate of change of surface temperature, divided by β (we recall that with the adopted assumption ε = const).

It is easy to see that we arrive at a similar type of recurrent equations also for the extremal mean monthly values of the distribution moments φ, but in this case γ_*, α_* and D_* will represent the mean monthly values of the corresponding coefficients, divided by β.

Expressions (17) cannot be used for computing moments whose numbers satisfy the condition $n \geq 1 + \gamma^{-1}$. With satisfaction of this condition there are no moments for the stationary problem. This is related to the power-law of behavior of the function φ when $|\Omega| \to \infty$ in the considered model. In actuality, with the same assumptions which were used in deriving (17), equation (14) is transformed to the form

$$(-\Omega + \varepsilon)\varphi = \frac{\partial}{\partial\Omega}(D_* + \alpha_*\Omega + \gamma_*\Omega^2)\varphi. \quad (18)$$

The asymptotic solution of this equation in the case of large $|\Omega|$ has the form

$$\varphi \sim |\Omega|^{-2-1/\gamma_*}, \ |\Omega| \to \infty, \quad (19)$$

We will assume that $\gamma_* < 1/3$. Then the first four distribution moments φ are known to exist. Assume that for some sufficiently great time interval t_* the parameter can be assumed equal to zero (unperturbed stationary problem). In this case from expressions (17), after simple transformations, for the mean value of the deviation of surface temperature from T_N, the dispersion σ^2, asymmetry $S = <(\Omega - <\Omega>)^3>/\sigma^3$ and excess $E = <(\Omega - <\Omega>)^4>/\sigma^4 - 3$ we find

$$<\Omega_N> = 0, \ \sigma_N^2 = \frac{D_*}{1-\gamma_*}, \ S_N = 2\frac{\alpha_*}{1-2\gamma_*}\sigma_N^{-1}, E_N = \frac{3}{1-3\gamma_*}\left[\frac{1}{2}S_N^2(1-2\gamma_*) + 2\gamma_*\right] \quad (20)$$

Here the subscript N was used in denoting the sought-for parameters when $\varepsilon = 0$ (that is, in essence, the norm).

Expressions (20) with factual data for σ_N, S_N and E_N make it possible to determine the necessary parameters for solution of stationary problems using a power-law four-parameter model. We have

$$\gamma_* = \frac{1}{3}\,\frac{E_N - 1.5\,S_N^2}{E_N - S_N^2 + 2},\quad D_* = (1 - \gamma_*)\,\sigma_N^2, \tag{21}$$

$$\alpha_* = \frac{1}{2}\,(1 - 2\,\gamma_*)\,\sigma_N S_N.$$

Formulas (21) can be considered working formulas for determining the parameters of the model using factual data. Below we will use them in evaluating γ_*, D_* and α_* for two different climatic regions.

It should be noted that a very interesting condition follows from the first expression in system (21); it relates asymmetry and excess, as is necessary in order that the results of the considered model not contradict what is known to be the actual behavior of the earth's climatic system. In actuality, by definition the parameter γ_* cannot be negative. And this means that necessarily there must be satisfaction of the condition

$$E_N \geqslant \frac{3}{2}\,S_N^2. \tag{22}$$

Otherwise the power-law four-parameter model is simply inapplicable. The value of the γ_* parameter is also limited upward, as was indicated above. However, this does not impose any additional limitation on the values of the existing distribution moments φ.

Our analysis makes it possible to draw some qualitative conclusions concerning the behavior of the stationary distribution profiles φ. It follows from condition (22), for example, that the stationary φ profiles must have sharper "peaks" than a normal distribution. Moreover, the sharpness of the peaks on these profiles will be the greater the greater their asymmetry. In accordance with (19), the "wings" of these profiles have a power-law form. The probabilities of "surges" of a random value beyond the level of several sigmas is substantially greater than for a normal distribution.

Now, within the framework of those assumptions for which the recurrent equations (17) were obtained, we will evaluate the influence of the climatic trend of surface temperature on its dispersion. After simple transformations we have

$$\sigma^2 = \sigma_N^2\left[1 + \frac{\alpha_*}{1-\gamma_*}\,\frac{\varepsilon_*}{\sigma_N} + \frac{\gamma_*}{1-\gamma_*}\,\varepsilon_*^2\right] \tag{23}$$

$$(\varepsilon_* = \langle\Omega\rangle/\sigma_N,\ \langle\Omega\rangle = \varepsilon).$$

It follows from these expressions that even in the considered model the influence of the climatic trend in surface temperature on the dispersion will be negligible if it is considerably less than the standard deviation

σ_N observed in a stationary climatic system. For asymmetry and excess we can arrive at these same conclusions in a similar way.

In order to obtain more detailed information on this problem we will turn to factual material. The negligibly small influence of the trends in dispersion, asymmetry and excess in the considered model, small in comparison with the standard deviation, makes it possible for determining the parameters γ_*, D_* and α_* to use instrumental measurements of surface temperature during the preceding years ($t_* \sim 100$ years). As was demonstrated above, our examination is suitable not only for mean annual surface temperatures, but also for the mean monthly temperatures of those months for which the temperature in its seasonal variation assumes an extremal value. The analysis was made for January -- the month of minimum temperatures and their maximum variability.

We will examine two different climatic regions: I (Africa + Eurasia, Northern Hemisphere; $1891 \leqslant t_* \leqslant 1976$), II (Arctic zone, 72.5-87.5°N $1881 \leqslant t_* \leqslant 1975$). It is extremely likely that both regions will satisfy the above-mentioned condition: the surface temperature averaged for these regions will be a statistically independent climatic parameter. We will not discuss this in detail, bearing in mind that we have only approximate data for the sought-for parameters. Using the data put at our disposal by G. V. Gruza, for the first region we have

$$\sigma_N^2 \approx 0{,}97, \quad S_N \approx 0{,}77, \quad E_N \approx 5{,}67.$$

In accordance with (21), for this region

$$\gamma_* \approx 0{,}22, \quad D_* \approx 0{,}76, \quad \alpha_* \approx 0{,}21.$$

Using the data put at our disposal by K. Ya. Vinnikov, for the second region

$$\sigma_N^2 \approx 5{,}20, \quad S_N \approx 0{,}37, \quad E_N \approx 0{,}23,$$

Thus,

$$\gamma_* \sim 0, \quad D_* \approx 5{,}20, \quad \alpha_* \approx 0{,}42.$$

In accordance with (23), for both regions we have, respectively

$$\begin{aligned} \sigma^2 (\mathrm{I}) &\approx 0{,}97 + 0{,}03\,\varepsilon + 0{,}28\,\varepsilon^2 \\ \sigma^2 (\mathrm{II}) &\approx 5{,}20 + 0{,}96\,\varepsilon. \end{aligned} \qquad (24)$$

It is interesting that for the second region the sign of change in dispersion is completely dependent on the sign of the appearing trend: with a decrease in temperature the dispersion always decreases and vice versa.

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EMPIRICAL MODEL OF MODERN CLIMATIC CHANGES

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[Article by Candidate of Physical and Mathematical Sciences K. Ya. Vinnikov and P. Ya. Groysman, State Hydrological Institute, submitted for publication 11 July 1978]

Abstract: On the basis of climatic data for the period of instrumental meteorological observations the authors have formulated a linear empirical-statistical model of the change in climate occurring in the northern hemisphere. The model is a system of empirical evaluations of the parameters characterizing the stochastic relationship of changes in the local characteristics of the thermal regime and atmospheric precipita- with a global climatic variable (mean annual air temperature at the surface in the northern hemisphere). The evaluations were made using the instrumental variable method.

[Text] At present it is usually assumed that changes in global climate can be regarded as the combination of determined changes, transpiring under the influence of factors external relative to the climatic system, and random changes which are a result of instability of the climatic system itself.

An analysis of empirical data shows that a significant part of the spatial-temporal variability of climatic parameters relates to the range of global climatic changes having the scale of spatial disturbances commensurable with the scale of a hemisphere and any period of temporal fluctuations exceeding 5-10 years [2, 3, 8]. The principal factors responsible for global climatic changes in the modern era are natural (associated with volcanic activity) variations of the aerosol layer in the stratosphere, leading to a change in the quantity of solar radiation reaching the earth's surface, and anthropogenic factors, the most important of which is an increase in the content of carbon dioxide in the atmosphere [5, 6, 13, 18, and others].

Computations using models of climatic theory show that although the physical mechanisms associated with a change in the aerosol layer of the stratosphere and the content of carbon dioxide in the atmosphere are essentially different, the highly important peculiarities of the global pattern of change in air temperature in the lower layer of the atmosphere corresponding to them have a similar character.

It can be postulated that the determined changes in global climatic parameters correspond to definite changes in the local characteristics of climate, which can be evaluated using empirical data for the period of instrumental observations.

We will call the set of statistical evaluations of the parameters describing the correlation between the changes in global climatic variables and changes in the local climatic characteristics in different seasons of the year "an empirical model of climatic changes."

It can be surmised that the use of paleoclimatic and other types of information on the climates of the preinstrumental period will make it possible to broaden the range of applicability of the empirical model of climatic changes beyond the limits of the scales and mechanisms of change in climate characteristic for the period of existence of the world network of meteorological stations.

We note that some aspects of formulation of the empirical model of climatic changes were examined in the studies of O. A. Drozdov [10, 11], Lamb [20], and others.

Selection of Climatic Variables

The modern theory of climate shows that a change in global climate in the first approximation can be characterized by one parameter -- the change in mean air temperature at the earth's surface [5]. Existing models give three fundamental solutions describing the changes in the global thermal regime with a change in the heat influx: the first of these corresponds to an absence of sea polar ice and continental glaciations, the second corresponds to a planet completely covered with snow and ice, whereas the third corresponds to the modern climatic situation -- presence of sea polar ice and major continental glaciations. It can be surmised that in the latter case as well for an approximate description of the state of global climate it is possible to use one parameter, since a change in the areas of the continental ice sheets of Greenland and Antarctica for time scales of the period of instrumental observations can be neglected, whereas the area of sea polar ice, as shown by data from recent investigations [12], reacts quite rapidly to changes in the global thermal regime.

The role of the principal climatic parameter -- the global climatic variable -- in this study is assigned to the mean annual air temperature at the earth's surface over the greater part of the northern hemisphere (17.5-87.5°N) [3].

As the local climatic variables it is natural to select characteristics limiting the economic activity of man. In different geographic regions this role is played by different elements, for the most part either air temperature of the lower layer of the atmosphere or atmospheric precipitation.

In this study as the local climatic characteristics we investigate the latitudinally averaged mean annual and mean seasonal air temperatures for the northern hemisphere, the annual and seasonal sums of atmospheric precipitation for the territory of the USSR and the seasonal sums of atmospheric precipitation, averaged for groups of stations located within the limits of some regions in the northern hemisphere.

Method for Evaluating Parameters of Model (Instrumental Variable Method)

Since in place of the true values of the global climatic variable x and the local climatic variables y_i ($i = 1, 2, \ldots, p$) we usually have only their estimates X and Y_i, obtained using data from network meteorological observations, the problem of formulating an empirical model of climatic changes is reduced to the problem of determining the parameters of the structural correlation between the random values y_i and x. (The structural or stochastic correlation is the functional relationship between random variables).

As a first approximation we postulate a linear structural model

$$\begin{cases} Y_i = \alpha_i x + \beta_i + \varepsilon_i, \quad i = 1, 2, \ldots, p; \\ X = x + \delta, \end{cases} \tag{1}$$

where α_i and β_i are parameters to be evaluated; X and δ is the unbiased evaluation and the random error of the variable x; Y_i is the unbiased evaluation of the variable y_i; $(\alpha_i x + \beta_i)$ is the contribution of changes in the variable x to the change in y_i; ε_i is a random value including both the error in evaluating the variable y_i, that is $(Y_i - y_i)$ and the y_i component not dependent on x; without diminishing universality, it can be assumed that $\overline{\varepsilon}_i = 0$ (the line at top denotes averaging in the statistical sense).

The fundamental impossibility of having precise values of the y_i and x variables does not make it possible, in evaluating the coefficients α_i, to use regression analysis.

Among the methods used in solving this problem the "instrumental variable method" is particularly effective; it was described in [17, 19]. This method ensures obtaining well-grounded evaluations of the α_i parameters in the presence of random measurement errors (evaluations on the basis of measurement data) for the x variable by means of use of additional information on the x-variable; for example, its measurements Z, carried out by a method not dependent on the main method.

Assume that we have a random Z value about which it is known that it does not correlate with ε_i and δ, but correlates significantly with x, that is

$$\begin{cases} \operatorname{cov}(Z, \varepsilon_i) = \operatorname{cov}(Z, \delta) = 0, \\ \operatorname{cov}(Z, x) \neq 0; \end{cases} \tag{2}$$

(the operator cov denotes the covariation of the variables in the parentheses). In this case a valid point evaluation of the values of the coefficients α_i is

$$\hat{\alpha}_i = \frac{\mathrm{cov}\,(Y_i,\ Z)}{\mathrm{cov}\,(X,\ Z)}. \tag{3}$$

The confidence interval for the parameter of the linear structural correlation α is dependent on the other parameter β, whose evaluations are not of independent interest.

In [9] it was demonstrated that the use of equations

$$\begin{cases} \mathrm{cov}\,(Y - \alpha X - \beta,\ Z) = \mathrm{cov}\,(\varepsilon - \alpha\delta,\ Z) = 0, \\ \overline{X} = \overline{x} = a, \\ \overline{Y} = \overline{y} = \alpha a + \beta \end{cases} \tag{4}$$

for the system of three parameters α, β and a, of which the last two are interfering, makes it possible, in a number of cases, to obtain a limited confidence region and thereby a finite confidence interval for α. In a case when the studied variables represent time series, it is necessary that their coherence be taken into account. The formulation of the problem, algorithm and an example of the confidence evaluation have been presented in greater detail in [9].

If the x, ε_1 and δ parameters can be considered uncorrelated with one another, then a ε_1 point evaluation can be used for obtaining an evaluation of the dispersion of errors. For this we can use the expressions cited in [19]

$$\sigma_\delta^2 = \sigma_X^2 - \mathrm{cov}\,(X,\ Y)/\alpha, \tag{5}$$

$$\sigma_\varepsilon^2 = \sigma_Y^2 - \alpha\,\mathrm{cov}\,(X,\ Y),$$

into which it is sufficient to substitute valid evaluations of α, the dispersions and covariations.

In a case when the climatic variables are represented by time series and their spectral expansion is admissible, it can be assumed that $\alpha = \alpha(\omega)$, that is, the correlation between the variables is dependent on the frequency of the perturbation ω. In this case it is easy to obtain

$$\hat{\alpha} = \frac{1}{\mathrm{cov}\,(X,\ Z)} \int_\Omega \alpha(\omega)\, R_{ZX}(\omega)\, d\omega, \tag{6}$$

where Ω is the frequency region, R_{XZ} is the cospectrum of the processes X and Z.

Accordingly, (3) gives an integral evaluation of the correlation of variables in the spectrum. The weighting function is proportional to the cospectrum of the global climatic and instrumental variables. Since it is difficult to check the hypothesis $\alpha = \alpha(\omega)$, in the use and selection of instrumental variables it is necessary to evaluate the filtering accomplished by them by an analysis of the spectral windows corresponding to them.

Selection of Instrumental Variables

The problem of selecting the instrumental variables applicable to the problem of formulating an empirical model of climatic change is reduced to the necessity of finding time series of such parameters as will be significantly correlated with changes in the global climatic variable and at the same time the processes characterized by these parameters in themselves will not affect the studied local climatic variables.

In this study as the instrumental variables we used series of the following climatic parameters:

Z_1 -- level of the Caspian Sea during 1882-1955 according to data from B. A. Apollov [1] and for 1882-1972 according to data from I. A. Shiklomanov [15] (in the latter case the data were corrected for the purpose of excluding the influence of human activity on the runoff of rivers in the basin of the Caspian Sea);

Z_2 -- ice content of the Barents Sea during the period 1900-1973 [16];

Z_3 -- air temperature of the extraequatorial part of the northern hemisphere (global climatic variable), taken with a two-year shift ahead (the use of Z_3 is possible only in the case of an absence of autocorrelation of the errors δ);

$Z_4 = bZ_1 + Z_3$ is a parameter representing a linear combination of the variables Z_1 and Z_3, correlated to the greatest degree with the global climatic variable.

The coefficients of correlation of data on the global climatic variable X and the instrumental variables Z_1, Z_2, Z_3 and Z_4 are equal to -0.75, -0.55, 0.65 and 0.90 respectively; all the cited evaluations are significant at the 95% level.

An analysis of conditions (2) shows that when formulating individual elements of the empirical model of climatic change it is not always possible to use all of the considered instrumental variables. For example, changes in the ice content of the Arctic basin, even relatively brief, exert a direct influence on the thermal regime of the atmosphere in the high latitudes and therefore the use of Z_2 in evaluating the correlation between air temperature in the high latitudes and mean temperature of the hemisphere is incorrect. Experience shows that using the evaluations obtained using several instrumental variables it is possible to detect cases of a direct influence of one of the instrumental variables on local climatic characteristics. In the absence of such an influence the different instrumental variables give noncontradictory evaluations.

Now we will examine the "spectral windows" corresponding to integral evaluations of the α_i parameters of the model, obtained using different instrumental variables.

We represent (6) approximately in the form

$$\hat{\alpha} = \sum_j P_j \alpha_j, \qquad (7)$$

where

$$P_j = \int_{\Omega_j} R_{\lambda Z}(\omega)\, d\omega / \mathrm{cov}(X, Z), \quad \bigcup_j \Omega_j = \Omega, \quad \sum_j P_j = 1.$$

In Table 1 for the instrumental variables Z_1, Z_2, Z_3 and Z_4 we have given the evaluations of the weighting factors P_j for the subregions Ω_j of the frequency region Ω limited on the one hand in connection with discreteness, and on the other hand, limited by the finite length of the analyzed time series.

Table 1

Evaluations of Weighting Functions in Frequency Region for Used Instrumental Variables

Период, годы 1	Z_1	Z_2	Z_3	Z_4
20—160	0,74	0,60	0,78	0,76
10—20	0,26	0,23	0,29	0,27
5—10	0,01	0,06	—0,02	—0,01
2—5	—0,01	0,11	—0,06	—0,02

KEY:

1. Period, years

The materials in Table 1 show that all the selected instrumental variables discriminate the correlation existing between the low-frequency (climatic) components of the processes with periods of fluctuations exceeding 10 years.

Empirical Model of Recent Changes in Zonal Air Temperature in Northern Hemisphere

Homogeneous series of mean monthly air temperature at the earth's surface for 1881-1975, averaged by circles of latitude 85, 80,...,20°N, were obtained in [3]. These materials were used for formulating an empirical model of recent changes in the zonal air temperature in the northern hemisphere.

The results of evaluation of the α parameters of the linear structural correlation of the mean annual temperature of the hemisphere (extraequatorial part) with the mean annual and seasonal temperature values at different latitudes are presented in Fig. 1 and in Table 2.

The α parameters in this case are dimensionless and show by how many times the changes in air temperature at a particular latitude and in the corresponding season differ from the changes in mean annual air surface temperature in the extraequatorial part of the northern hemisphere.

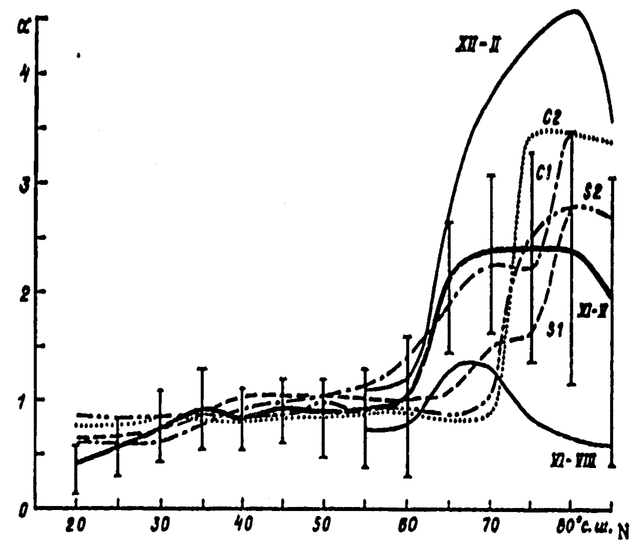

Fig. 1. Empirical model of change in air surface temperature in the northern hemisphere.

All the evaluations cited in Table 2 were obtained using the instrumental variable Z_4, ensuring the narrowest confidence intervals. The use of Z_1 and Z_3 leads to obtaining evaluations which are in good agreement. On the other hand, an attempt to use the instrumental variable Z_2 -- the ice content of the Barents Sea -- leads to an improbable exaggeration of evaluations of the α parameter for the region 75-85°N, in all probability, as already mentioned, as a result of nonsatisfaction of one of the conditions (2), and specifically, the conditions $\mathrm{cov}(Z, \varepsilon) = 0$.

Figure 1 graphically shows the evaluations obtained when using the instrumental variable Z_1 (Caspian Sea level) for the mean annual temperature (months from June through May), winter (December-February) and summer (June-August). For each of the evaluations $\hat{\alpha}$ in the model for the mean annual zonal air temperature the vertical lines in the figure give the 95% confidence intervals.

The materials in Table 2 and in Fig. 1 completely confirm the current qualitative ideas indicating that changes in the global thermal regime are manifested primarily in the high latitudes and especially in the cold season of the year.

The lines S1, S2, C1 and C2 in Fig. 1 give the theoretical evaluations of the α parameter for mean annual conditions, obtained using the results of numerical experiments with the aid of climatic theory models, specifically, the Manabe and Wetherald models of general circulation of the atmosphere [22, 25] -- 1 and the M. I. Budyko semiempirical model of the earth's thermal regime [5] -- 2. The symbol S denotes evaluations of the relative changes in zonal air temperature near the earth's surface obtained in numerical experiments with a change in the heat influx, simulated by a change in the solar content by 2% of its value. Accordingly, the symbol C denotes evaluations obtained in modeling of change in the heat influx caused by a doubling of the content of carbon dioxide in the atmosphere.

Table 2

Empirical Model of Change in Zonal Air Temperature of the Northern Hemisphere. Evaluations of α Parameters and 95% Confidence Intervals (Denoted (∧) and (∨))

		Широта, град 1													
		85	80	75	70	65	60	55	50	45	40	35	30	25	20
2 Зима	α	4,5	5,1	4,6	4,0	2,7	1,3	1,3	1,1	1,1	0,9	0,7	0,6	0,7	0,6
	∧	7,5	7,9	6,3	5,3	3,8	2,3	2,3	2,0	1,9	1,4	1,1	0,9	1,0	0,8
	∨	1,5	2,4	2,9	2,7	1,5	0,2	0,3	0,1	0,3	0,3	0,3	0,3	0,4	0,3
3 Весна	α	1,1	1,3	1,3	1,2	1,3	0,8	1,0	1,2	0,9	0,7	0,7	0,7	0,5	0,6
	∧	2,9	2,4	2,2	2,2	2,2	1,4	1,5	1,8	1,4	1,0	1,0	1,0	0,8	0,8
	∨	0,2	0,0	0,2	0,2	0,4	0,1	0,4	0,7	0,5	0,4	0,5	0,4	0,3	0,3
4 Лето	α	0,9	1,2	1,3	1,5	1,5	0,9	0,7	0,7	0,8	0,7	0,8	0,5	0,2	0,0
	∧	1,7	1,9	2,0	2,1	2,2	1,5	1,2	1,0	1,2	1,0	1,1	0,8	0,4	—
	∨	0,1	0,5	0,6	0,9	1,0	0,4	0,2	0,3	0,5	0,1	0,5	0,3	0,1	—
5 Осень	α	2,0	2,2	2,3	2,2	2,1	1,4	1,3	1,1	1,0	0,8	0,8	0,7	0,6	0,4
	∧	3,4	3,5	3,1	3,2	2,9	2,0	1,9	1,6	1,4	1,2	1,1	0,9	0,8	0,7
	∨	0,5	0,8	1,2	1,2	1,2	0,7	0,7	0,7	0,6	0,5	0,5	0,5	0,4	0,2
6 Год	α	2,1	2,5	2,4	2,3	1,9	1,1	1,1	1,0	1,0	0,8	0,8	0,6	0,5	0,4
	∧	3,5	3,7	3,2	2,9	2,4	1,6	1,4	1,4	1,3	1,0	1,0	0,9	0,7	0,6
	∨	0,8	1,2	1,6	1,7	1,4	0,6	0,7	0,7	0,7	0,6	0,6	0,5	0,3	0,2

KEY:
1. Latitude (degrees)
2. Winter
3. Spring
4. Summer
5. Autumn
6. Year

It can be seen that the evaluations obtained using climatic theory models do not contradict the empirical-statistical evaluations generalizing the climatic materials for the period of instrumental observations. This agreement is evidence of the relative reality of modern models of climatic theory. A comparison of the theoretical and empirical evaluations is possible only for average annual conditions, since for individual seasons of the year theoretical evaluations are lacking for the present.

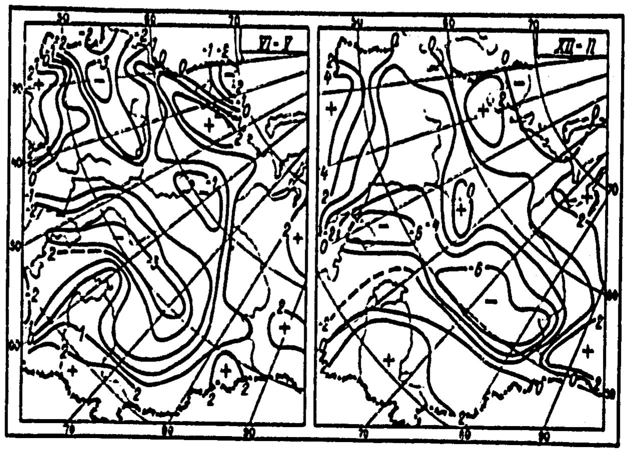

Fig. 2. Evaluations of correlation of changes in annual (June-May) and winter (December-February) sums of atmospheric precipitation with mean annual air temperature in northern hemisphere. Evaluations of the α parameter are expressed in percent of the norm with a change in temperature by 0.1°C.

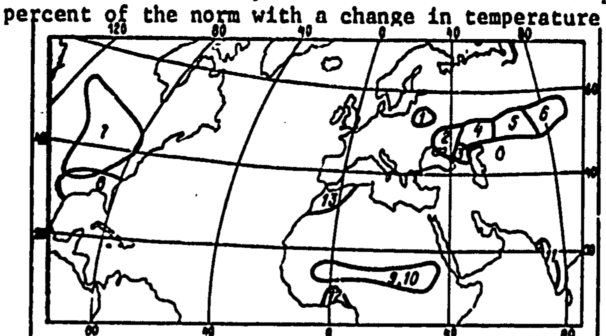

Fig. 3. Map of distribution and numbering of studied regions.

We note that time series of the evaluations ε_i for latitudinally averaged air temperature are uncorrelated series, that is, the changes in the global climatic variable in the first approximation exhaust the climatic components of change in air temperature of individual latitude zones.

Empirical Model of Modern Changes in Atmospheric Precipitation

A change in the thermal regime of the earth naturally should lead to changes in atmospheric circulation, and accordingly, to changes in the precipitation regime. For studying the influence of processes of global warming or cooling on the annual and seasonal sums of atmospheric precipitation we used archives of data containing time series of the monthly sums of precipitation for the period 1891-1970 (77) for 700 stations, of which 619 were situated in the territory of the USSR. The basis for this investigation was archives of the monthly sums of precipitation for the territory of the USSR prepared by the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center [14]. After partial computation, statistical checking, correction of obvious errors, supplementation and elimination of inhomogeneity of the series associated with changes in the methods for measuring precipitation [4], the data were plotted on a magnetic tape in the form of time series of the monthly sums of precipitation, reduced to the readings of a standard precipitation gage. On the basis of a study of the physiographic descriptions and histories of the meteorological stations it was possible to discriminate a subset of homogeneous observational records with which the further work was carried out. The data sources for foreign territories were [23, 26].

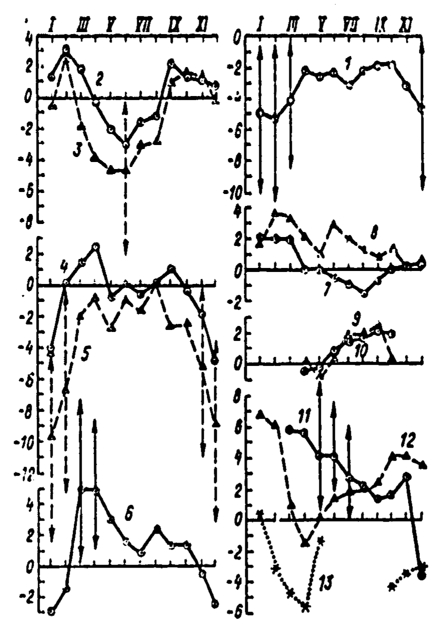

Fig. 4. Evaluations of correlation of seasonal (three-month) precipitation sums for regions shown in Fig. 3 with mean annual air temperature in northern hemisphere. Evaluations of the α parameter are expressed in percent of the norm with a change in temperature by 0.1°C. The vertical segments denote 95% confidence intervals.

Some results of evaluation of the α parameter of the linear structural correlation of precipitation with the mean annual air temperature of the northern hemisphere, showing by how many percent the three-month (or annual) precipitation sums vary from the norm with a change in hemisphere temperature by 0.1°C, are shown in Figures 2 and 4.

Figure 2 shows maps of the relative change in the annual (June-May) and winter (December-February) precipitation sums for a part of the territory of the USSR. In constructing the maps we used evaluations of the α parameter for individual stations. By virtue of the great intensity of the noise components in the precipitation series [4] the α evaluations are not statistically significant. Nevertheless, as shown by an analysis of the maps, in each season large zones are defined in the territory of the USSR containing evaluations of the same sign. For example, in winter and autumn an extensive region of decrease in precipitation (with a warming) occupies the center of the USSR from the Baltic region on the west to the Ob' on the east. A similar region of lesser intensity is shown on the map of evaluations for the annual sums of precipitation. In spring and autumn there are extensive regions of an increase in precipitation (with a warming), occupying Western Siberia and a considerable part of the northern half of the European USSR.

It is natural to assume that by averaging the data of precipitation gage observations at stations situated within the limits of climatically uniform geographical regions it is possible to ensure representativeness of the characteristics of the moistening regime in these regions, and using them, obtain reliable evaluations of the parameters of the model of correlation of precipitation with the mean temperature of the hemisphere. Such averaging was carried out for the territories of a number of agriculturally important regions in the northern hemisphere, six of which are situated in the territory of the USSR (see Fig. 3).

Figure 4 shows the results of evaluation of the α parameters, expressed in (% of the norm)/0.1°C, for the moving three-month (seasonal) precipitation sums. The evaluations are related to the middle months of the seasons. In those cases when the 95% confidence intervals of the evaluations α do not include the value $\alpha = 0$ these intervals are represented on the graphs by vertical segments.

The absence of confidence intervals means either an absence of a linear correlation between the climatic variables, an inadequacy of volume or unsatisfactory quality of the employed measurement data. All the evaluations shown in Fig. 2 and Fig. 4 were obtained using the instrumental variable Z_4. Other instrumental variables (except the variable Z_2 in the high latitudes, for the reason discussed above) give results not differing significantly from those cited.

Now we will examine the principal patterns of change in the mean quantity of precipitation during a warming, using the data in Fig. 4. (During a cooling, by virtue of linearity of the model, the effects have the opposite sign).

Region 1 (Poles'ye) -- during warming the precipitation decreases for all seasons of the year. A very significant decrease in precipitation occurs during the cold season of the year.

Regions 2 and 3 (Eastern Ukraine, Don, Northern Caucasus) -- with warming there was some increase in precipitation during the cold season of the year and a more significant decrease in the quantity of precipitation during the warm half-year.

Region 4 (southeastern part of the European USSR and northwestern part of Kazakhstan) -- an appreciable decrease in precipitation in winter and some increase in spring.

Region 5 (central part of Northern Kazakhstan) -- with a warming an insignificant decrease in the quantity of precipitation during the warm season and a marked decrease during the cold season.

Region 6 (northeastern Kazakhstan and the southern part of Western Siberia) -- some decrease in winter precipitation and an increase in precipitation with a warming in other seasons of the year, especially significant in the spring.

Generalizing the evaluations made for the grain zone of the USSR, it can be postulated that in the process of global warming there is an appreciable decrease in precipitation in the steppe and wooded steppe zones, and this is reflected in the effectiveness of agricultural production in these zones.

For individual foreign regions of the northern hemisphere it is possible to note the following regularities:

Region 7 (main grain region of the United States and Canada, 13 stations) -- the evaluations indicate that during warming there is a tendency to an increase in precipitation during the winter-spring period of the year and a decrease in precipitation in late summer and in autumn.

Region 8 (southern United States, 7 stations) -- a warming causes an increase in precipitation in all seasons.

Regions 9, 10, 12 (respectively, Sudan-Sahel zone, 11 stations; Sahel, 20 stations -- data supplied through the courtesy of H. Flohn; northern shores of the Gulf of Guinea, 4 stations). A warming causes an increase in precipitation during the period of the summer monsoon, especially during its second half (from June through September).

Region 11 (western shores of the Hindustan peninsula, 5 stations) -- an increase in precipitation during the summer monsoon, strongest at the beginning of the rainy season.

Region 13 (northwestern part of the African continent, 5 stations) -- with a warming some decrease in precipitation during the moist season of the year.

Thus, the presented evaluations show that precipitation in many regions of the hemisphere was sensitive to processes of global warming or cooling. Changes in precipitation in one and the same region can have a different sign in different seasons of the year. The scale of evaluations of the α parameters is from several percent to 10%/0.1°C. It is found that in individual seasons of the year in some regions up to 20% of the dispersion of the seasonal precipitation sums is associated with changes in mean hemisphere temperature.

In a number of studies the influence of the process of global cooling on precipitation has been investigated by means of an analysis of the difference in the mean quantity of precipitation during specific cold and warm intervals of years during the current century [20, 24 and others].

In contrast to this approach, using only a small part of the available information and highly dependent on the choice of the "periods," the estimates obtained by the method proposed in this study have a lesser selective variability.

Summary

The evaluations of the parameters for the linear empirical model of change in climate obtained using measurement data for the period of existence of the world network of meteorological stations are applicable for the range of change in mean air temperature in the extraequatorial part of the Northern Hemisphere, equal to approximately ±0.5°C. The authors of [6, 13, 18 and others] concluded that a global warming was developing in connection with the anthropogenic increase in the content of carbon dioxide in the atmosphere and a warming of about 0.5°C can be attained even before the ending of the 20th century. With such a substantial change in the earth's thermal regime the evaluations may already be inapplicable at the beginning of the coming century.

In generalizing data from meteorological observations over a relatively short period of time not exceeding a century, although we will attempt to obtain evaluations of the correlation between variables characterizing the general set, one must inevitably recognize the selectivity of the evaluations obtained. The selective variability evidently is what is responsible for the existence of some relatively small-scale peculiarities on the maps (Fig. 2) and on the graphs (Fig. 4).

In addition to the direct use of the empirical model of climatic change in formulating a forecast of impending climatic changes [7], the model can be used in checking the results of numerical experiments for evaluating the changes in local climate with modifications of global climate determined using climatic theory models. It must be remembered in this case that the conclusions drawn using models of general circulation of the atmosphere also have a stochastic character [21]. Therefore, the principles and methods for the processing of materials from numerical experiments and climatic information for the period of instrumental meteorological observations have much in common.

The further development of the empirical model of change in climate will be accomplished in the direction of incorporation of other climatic variables, refinement of evaluations of its parameters by use of more reliable empirical data, increase in the range of applicability of the model by means of departure from the linearity of correlations and use of information on climatic changes in the remote past.

In conclusion the authors express deep appreciation to M. I. Budyko and O. A. Drozdov for valuable comments, to G. V. Gruza, who had the kindness to make available data on atmospheric precipitation over the territory of the USSR, to I. I. Borzenkova for assistance in the work and participation in eliminating the nonuniformity in the precipitation series, and also to V. V. Kukushkina and O. L. Korogodskaya for assistance in implementing and finalizing the study.

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STUDY OF FORMATION OF THE TROPOSPHERIC TEMPERATURE FIELD BY THE CONJUGATE EQUATIONS METHOD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 37-42

[Article by D. B. Shteynbok, USSR Hydrometeorological Scientific Research Center, submitted for publication 16 May 1978]

Abstract: The approach suggested by Academician G. I. Marchuk, based on use of the conjugate equations of hydrothermodynamics, is used in a study of formation of the temperature regime in the troposphere in a baroclinic nonadiabatic model. The computed fields of the influence functions are compared with the corresponding fields of a barotropic model. The article gives some preliminary results of use of parameterization of heat sources on the basis of the cloud cover anomaly for the purposes of long-range prediction of the temperature anomaly within the framework of the conjugate equations method.

[Text] Academician G. I. Marchuk proposed a new approach based on use of the conjugate equations method [1]. In [3] a study was made of some practical aspects of use of this theory for analysis and prediction of mean air temperature over fixed regions. A very simple model was used for describing temperature changes in the troposphere. In particular, the contribution of vertical movements to formation of the temperature regime was not explicitly taken into account, but was considered one of the types of external heat sources and entered implicitly into the right-hand side of the heat inflow equation.

Two matters are examined in this study. First, a very simple baroclinic model of the atmosphere is proposed in which terms with vertical velocity are present. On the basis of the method described in [1, 3] a functional is constructed for evaluating the mean temperature for the stipulated region and the corresponding conjugate functions are investigated. Second, within the framework of the conjugate equations method, on the basis of the model in [3], an attempt is made to use the cloud cover anomaly as a nonadiabatic factor for computing the mean monthly temperature anomalies.

We will proceed from the following baroclinic nonadiabatic model on a spherical earth D in an isobaric system with the dimensionless vertical coordinate $\xi = p/1000$ (p is pressure, mb):

$$\left.\begin{aligned} &\frac{\partial \Omega_1}{\partial t} + L_1 \Omega_1 - \mu \nabla^2 \Omega_1 = 2\, l \tau \\ &\frac{\partial \Omega_2}{\partial t} + L_2 \Omega_2 - \mu \nabla^2 \Omega_2 = -2\, l \tau \\ &\frac{\partial T}{\partial t} + L_0 T - \mu \nabla^2 T - \sigma\tau = c_1 (T_{OK} - T) + c_2 (\tilde{T} - T) + \varepsilon \\ &\nabla^2 T = \frac{l}{R} (\Omega_1 - \Omega_2) \end{aligned}\right\} \qquad (1)$$

[OK = oc(ean)]

Here ∇ is the angular part of the Hamiltonian in spherical coordinates

$$L_i = \mathbf{V}_i \cdot \nabla, \; i \text{ is the number of the level, and}$$

$$\xi_i = \begin{cases} 0{,}25, & \text{if } i = 1, \\ 0{,}50, & \text{if } i = 0, \\ 0{,}75, & \text{if } i = 2; \end{cases}$$

$$\sigma = \frac{\gamma_a - \gamma}{g \bar{\rho}};$$

$\bar{\rho}$ is standard air density; l is the Coriolis parameter; R is the gas constant; μ is the coefficient of horizontal turbulent exchange; T_{OC} is ocean temperature; $c_1(\theta, \lambda)$ is the heat transfer coefficient, equal to zero over the continents; $\tilde{T}$ is the radiation temperature; c_2 is a parameter determining the rate of radiation heating (cooling); ε are the external heat inflows in the model; V_i, Ω_i is the horizontal wind and absolute vorticity at the i-th level; air temperature T and vertical velocity τ are related to the level ξ_0, that is, p = 500 mb.

The first two equations of model (1) represent the vorticity transport equations, written for the levels ξ_1 and ξ_2, in which the term with the ξ derivative is replaced by a finite-difference ratio. The last equation in system (1) was obtained by using the Laplacian for the equation of hydrostatics on the assumption of geostrophicity of motion. We will introduce a conjugate equation for model (1) (see [1]):

$$\left.\begin{aligned} &-\frac{\partial \Omega_1^*}{\partial t} + L_1^* \Omega_1^* - \mu \nabla^2 \Omega_1^* - \frac{l}{R} \tau^* = F_1^* \\ &-\frac{\partial \Omega_2^*}{\partial t} + L_2^* \Omega_2^* - \mu \nabla^2 \Omega_2^* + \frac{l}{R} \tau^* = F_2^* \\ &-\frac{\partial T^*}{\partial t} + L_0^* T^* - \mu \nabla^2 T^* + d T^* + \nabla^2 \tau^* = F_3^* \\ &2\, l (\Omega_2^* - \Omega_1^*) - \sigma T^* = F_4^* \end{aligned}\right\}, \qquad (2)$$

where

$$d(\theta, \lambda) = c_1(\theta, \lambda) + c_2.$$

We will set the initial conditions:

$$\Omega_1^* = 0, \quad \Omega_2^* = 0, \quad T^* = 0 \qquad \text{with} \quad t = t_0 + \Delta. \tag{3}$$

For computing the mean temperature $\overline{T}_{G,\Sigma}$ of the 500-mb isobaric surface over region G of the sphere D during the time period $\Sigma = [t_0, t_0 + \Delta]$ we assume

$$F_i(t, \theta, \lambda) = \begin{cases} 0, & i = 1, 2, 4; \\ \dfrac{\chi_G(\theta, \lambda)\, \chi_\Sigma(t)}{|G|\, \Delta}; & i = 3, \end{cases} \tag{4}$$

where $|G|$ is the area of the G region; χ_R is the so-called characteristic function or the indicator of the set R, that is

$$\chi_R(x) = \begin{cases} 1, & x \in R; \\ 0, & x \notin R. \end{cases}$$

Then the mean characteristic $\overline{T}_{G,\Sigma}$ of interest to us is determined from the expression

$$\overline{T}_{G,\Sigma} = \int_D (TT^* + \Omega_1\Omega_1^* + \Omega_2\Omega_2^*)_{t=t_0}\, d\omega + \\ + \int_{t_0}^{t_0+\Delta} \left[\int_{D_{OK}} c_1 T_{OK} T^*\, d\omega + \int_D (c_2 \widetilde{T} + \varepsilon)\, T^*\, d\omega \right] dt, \tag{5}$$

[OK = oc(ean)] where D_{OC} is the area occupied by the ocean.

The conjugate system (2) can be simplified. With the assumptions made in [4] we obtain

$$L_1^* = L_2^* = L_0^*. \tag{6}$$

On the basis of the method used in [3], under condition (6), the fields of conjugate functions were computed for a time of 60 days. We examined the case of monthly averagings, that is, $\Delta = 30$ days, and the region G was selected in the form of a spherical rectangle

$$G = \{(\theta, \lambda) : \theta_1 \leq \theta \leq \theta_2,\ \lambda_1 \leq \lambda \leq \lambda_2\},$$

bounded by the latitudes 47.5°-67.5°N and the longitudes 11.25°-78.75°E. In the numerical computations the discontinuous characteristic functions in formula (4) were replaced by smooth functions, similar to what was done in [3]. We also note that under the condition (6) the prognostic functional (5) assumes the form

$$\overline{T}_{G,\Sigma} = \int_D (T_{t_0} - b\nabla^2 T_{t_0})\, T_{t_0}^*\, d\omega + \\ + \int_{t_0}^{t_0+\Delta} \left[\int_{D_{OK}} c_1 T_{OK} T^*\, d\omega + \int_D (c_2 \widetilde{T} + \varepsilon)\, T^*\, d\omega \right] dt, \tag{7}$$

where $b = \frac{\sigma R}{4 l^2}$.

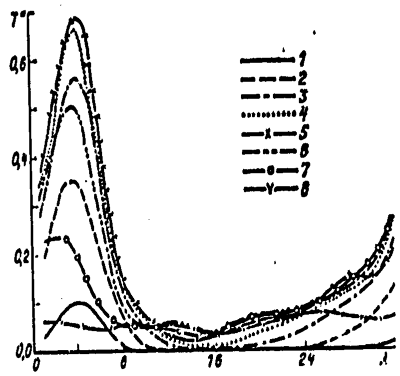

Fig. 1. Curves of the longitude dependence of conjugate temperature on latitude $\varphi = 57.5°$ for different moments in time. The numbering of the curves 1, 2,...,8 corresponds to 4, 8,...,32 days from the onset of integration. The numbers of the computation points in the model are plotted along the x-axis. The averaging region G takes in from the second to the eighth points respectively.

The nature of the temporal variability of the T^* function can be traced in Fig. 1. An analysis of the curves shown in this figure indicates that the main influence on the formation of mean temperature $\overline{T}_{G,\Sigma}$ is exerted during the predicted time period by processes over region G, despite the effect of advective transfer. This circumstance introduces additional information into the explanation of why T^*, computed for the period preceding the forecast, does not cause significant errors in computing $\overline{T}_{G,\Sigma}$. This is also the theoretical basis for the legitimacy of using as a predictor in some synoptic-statistical methods the states of circulation during the period preceding the predicted month.

The next item of interest is a direct comparison of the influence functions T^* of the baroclinic model (1) and the corresponding influence function computed without taking baroclinicity (vertical movements) into account. Figure 2 shows the field of the influence function T^* for model (1). It must be compared with Fig. 1a from [3]. The difference between these two maps is caused by the influence of vertical movements. A comparative analysis of the T^* fields shows that the contribution of vertical movements to the formation of the temperature regime G with monthly averaging is not significant.

Now we will cite some results of use of the cloud cover anomaly as a non-adiabatic factor for computing the mean monthly temperature of the lower troposphere. For this we will use the model from [3] with special parameterization of the heat sources

$$\frac{\partial T'}{\partial t} + \mathbf{V} \cdot \nabla T' - \mu \nabla^2 T' = \alpha S' + \beta. \tag{8}$$

Here T' is the mean temperature anomaly of the air layer between the 500 and 1000 mb surfaces; S' is the cloud cover anomaly; α and β are constants, which we will determine below.

Fig. 2. Normalized field of conjugate temperature of model (1) on 30th day from the onset of integration (maximum for the field is 0.146386 sec^{-1}).

On the right-hand side of equation (8) we parameterized the anomaly of heat inflow to the atmosphere using the cloud cover anomaly. The physical basis for such parameterization is set forth in [2].

The prognostic functional for equation (8) is written as follows:

$$\overline{T}'_{0,\Sigma} = k^* + \alpha q^* + \beta r^*, \tag{9}$$

where $k^* = \int\limits_D T'_{t_0} T^*_{t_0}\, d\omega,\; q^* = \int\limits_{t_0}^{t_0+\Delta} dt \int\limits_D S' T^* d\omega,\quad r^* = \int\limits_{t_0}^{t_0+\Delta} dt \int\limits_D T^* d\omega.$

It can be shown that in the case of solenoidality of motion ($\nabla \cdot \mathbf{V} = 0$) we have the expression

$$r^* = \frac{\Delta}{2}.$$

At our disposition we had archives of the daily cloud cover fields over the northern hemisphere during 1969-1973. Using these archives we computed the mean monthly five-year cloud cover norms and the deviations S' from these norms. Then for each of the ten months -- from March through December inclusive -- we computed the q^* values for this five-year period. The computations of the conjugate functions T^* were made for climatic wind values V. Such an approximation was made due to some stability of the T^* fields for computing the mean monthly temperature over large regions, established in [3]. The averaging time interval was a month and spatial averaging was carried out over region G. Table 1 gives the computed q^* values, mean monthly deviations from the temperature norm for the air layer between the isobaric surfaces 500 and 1000 mb. The temperature norms were also computed from this five-year series.

Table 1

Values $q^* \cdot 10^{-5}$ (Numerator) and Mean Monthly Deviations from Air Temperature Norm (°C), Averaged for Region G (Denominator)

Месяц 1	1969	1970	1971	1972	1973
2 Март	−0,02	1,62	−0,86	−1,49	0,75
3 Апрель	−1,02	−1,28	1,70	1,82	−1,22
4 Май	0,40	−2,24	−1,41	0,23	3,02
5 Июнь	−3,56	−0,37	2,95	−2,33	3,31
6 Июль	0,88	2,59	−0,71	−4,60	1,84
7 Август	−3,63	5,74	3,32	−3,57	−1,86
8 Сентябрь	−0,29 / 0,58	−0,16 / 0,80	−3,34 / 1,15	3,50 / −0,53	0,29 / −2,00
9 Октябрь	1,68 / −0,25	2,99 / 0,88	−1,45 / −0,44	−0,48 / 0,90	−2,74 / −1,09
10 Ноябрь	1,10 / 1,87	2,09 / −2,73	3,06 / 0,74	−6,25 / 0,84	— / −0,72
11 Декабрь	4,34 / 1,71	−3,65 / −1,48	3,64 / 0,83	−4,33 / 1,45	— / −2,51

KEY:

1. Month
2. March
3. April
4. May
5. June
6. July
7. August
8. September
9. October
10. November
11. December

Here we will mention only one conclusion from a comparative analysis of the data in Table 1. Specifically, the sign of the value

$$\bar{q}^* = \frac{1}{4}(q^*_V + q^*_{VI} + q^*_{VII} + q^*_{VIII})$$

for all the considered years, except 1971, when the deviation of the December temperature from the norm was insignificant, is opposite in sign to the December temperature anomaly. This result confirms the conclusions cited in [2] on the use of deviation of the cloud cover fields observed directly over the ocean from the norm as a predictor for predicting the temperature anomaly over Europe. It should be noted that the series of observations used in this study are insufficiently long for drawing final conclusions. It is proposed that a further investigation be carried out using a 10-year series of observations.

Orienting ourselves on the above-mentioned result of an analysis of numerical experiments and taking into account the contribution of the initial data k^*, from (9) we obtain the following simple formula for computing (predicting) the mean monthly temperature anomaly over region G:

$$\overline{T}'_{0,\tau} = \alpha \overline{q}^*{}_{\tau} + \beta r^*. \tag{10}$$

The coefficients α and β are found using the data in Table 1 by the least squares method. For example, for December we obtain

$$\alpha = -0{,}9 \cdot 10^{-5}, \quad \beta = -0{,}1 \cdot 10^{-6},$$

if the cloud cover anomaly is measured in tenths.

Despite external simplicity, formula (10) takes into account the hydrodynamics of atmospheric processes, since in computing the $\overline{q}^*$ and r^* values present in (10) we use the fields of the conjugate function T^* (influence function), which, in turn, is found from solution of the corresponding conjugate equation.

Thus, it has been shown that the conjugate equations method is a useful tool for the purposes of investigating formation of the temperature regime in the atmosphere. In the further development of this method it is proposed that extensive use be made of the formulated laws for developing hydrodynamic long-range forecasting models.

In conclusion the author expresses deep appreciation to V. P. Sadokov for constant attention to this work.

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COMPUTATION OF CHARACTERISTICS OF THE ATMOSPHERIC BOUNDARY LAYER USING DATA OBTAINED USING A METEOROLOGICAL MAST

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 43-49

[Article by Doctor of Physical and Mathematical Sciences N. L. Byzova and Candidate of Physical and Mathematical Sciences V. A. Shnaydman, Institute of Experimental Meteorology and Odessa Hydrometeorological Institute, submitted for publication 30 May 1978]

Abstract: The article describes a method for computing the characteristics of the atmospheric boundary layer using data from measurements on the meteorological mast at the Institute of Experimental Meteorology. The primary processing of punched tapes involves the forming of time series for temperature and the wind velocity components, their averaging. The characteristics of the boundary layer are determined on the basis of the Laykhtman-Zilitinkevich stationary model. A correction factor is determined for computing the velocity of the geostrophic wind on the basis of wind velocity at the level 300 m. The list of computed characteristics includes the wind and temperature profiles, the geostrophic friction coefficient, surface heat flow and a series of other parameters.

[Text] The solution of many practical problems requires a knowledge of the quantitative characteristics of the vertical structure of the lower layer of the atmosphere. Observations on the high mast at the Institute of Experimental Meteorology serve this purpose. The high mast at the IEM, the instrumentation of the measuring complex and the nature of the surrounding territory have been described in a series of publications [2, 6]. The height of the upper measurement level is about 300 m. The temperature and its differences are measured in the 300-m layer approximately each 25 m; the wind velocity and direction are measured each 25 m to 73 m and each 50 m higher up. Gradient measurements are made in the surface layer at a distance of 200 m on a small mast. The immediate neighborhood of the small mast is a meadow or sown area; according to measurements, the wind profiles there and the roughness do not change with a change in wind direction. At distances 500-3,000 m the underlying surface includes more complex elements: on the south -- a small forest area, on the southwest, southeast and east -- a built-up city area, on the north and northwest -- a meadow and field. The roughness, determined from wind measurements at the levels 25 m and above, is essentially dependent on the wind direction [9].

During the period from 1968 through 1974 the mast was used for about 300 daily series, during which the results of the measurements were automatically plotted on the punched tape by a "Minsk-22" electronic computer with a discreteness of 144 sec. Using these data a series of conclusions were drawn, a review of which can be found in [1]. In particular, they were used in determining the characteristics of the atmospheric boundary layer on the basis of similarity theory [12, 13]. In this paper we describe a method for determining the statistical characteristics of time series and the characteristics of the atmospheric boundary layer on the basis of the model described in [14, 15].

The first processing stage involved a representation of the data in the form of time series each with a duration of six hours with an initial discreteness. These series were formed in such a way that it was possible to consider separately the quasistationary segments of the diurnal variation (from 1000 to 1600 hours and from 2200 to 0400 hours) and transitional periods (from 0400 to 1000 hours and from 1600 to 2200 hours). In accordance with the structure of information on the punched tape [11], the following characteristics are printed out: the temperature values at heights 0.5, 8, 25, 169 and 301 m and the differences between the levels 0.5 and 1 m, 1 and 4 m, 4 and 8 m, 25 and 49 m, then at equal intervals (about 24.6 m) to the level 289 m, and between the levels 289 and 301 m; wind velocity values (m/sec) at heights 1, 2, 4, 8, 24, 49, 73, 121, 169, 217, 265, 301 m, and wind directions reckoned in degrees from north in a clockwise direction, at heights 8, 25, 49, 73, 121, 169, 217 and 265 m. These data can be used in computing the mean and fluctuating characteristics of the measured parameters with different averaging periods.

Further statistical processing was carried out using data from six-hour time series and provided for determination of the mean values, computation of the structural, correlation functions and spectral densities of temperature and the wind velocity components.

For determining stable means we selected an averaging period of one hour [8]. In this case it is easy to trace the principal characteristics of the diurnal variation as well.

The computed processing algorithm provided for the formation of time series of mean hourly values and the finding of the mean period value. The mean values are represented in the form of two tables. The first of these gives the mean period and mean hourly temperature values and the temperature differences in precise accordance with the table of initial time series. The second gives wind data. For averaging of the wind vector we found the values of its components in standard and local coordinate systems. In the first system the x-axis is directed along a circle of latitude from west to east, in the second -- in the direction of the surface wind vector; the y-axis is deflected to the left by 90°. The table gives the mean period values in a standard system, then six mean hourly values in this same system and six mean hourly values in a local system. Only the wind velocity modulus is given for the levels 0.5, 1, 4 and 301 m. A local coordinate system is more convenient for the assembly of data in the form of a physical-statistical set.

In order to characterize the measure of coherence and variability of meteorological elements in the lower 300-m layer, on the basis of initial series of temperature and wind velocity components we computed time correlation and structural functions, spectral densities and one-dimensional spectra. These computations were made both without filtering and with filtering of long-period trends [10] by means of a moving cosine filter with filtering of about one hour. Naturally, the statistical characteristics obtained from a short time series are only the initial information for further generalizations, in particular, averaging in a statistical set, for example, for time of day or by thermobaric situations.

For solution of a number of practical problems it is of interest to consider the quantitative parameters of turbulence in the atmospheric boundary layer. At present there are several approaches to their computation. The methods based on similarity theory were used in [12, 13]. The most physically sound approach is that relying on computation of the tensor of turbulent stresses, but the models formulated on this principle are still not ready for practical applications. For this purpose we can use boundary layer models in which the closing of the equations of motion is accomplished using different hypotheses concerning the turbulence scale (for example, see [17]), in particular, those in which the equation for the balance of turbulent energy is used [4, 5, 7]. An analysis of such theories demonstrated that the method proposed by D. L. Laykhtman and S. S. Zilitinkevich [7] and modified in [14, 15] is sufficiently sound and is easily put into practical use. These studies give a detailed description of the developed method; therefore, here we will discuss only its practical realization on the basis of data obtained using the high meteorological mast.

The essence of the computation algorithm, serving as a basis of the program for an electronic computer, is as follows. We will solve a closed system of equations for a stationary horizontally homogeneous planetary boundary layer which includes the equations of motion, the equations for the balance of kinetic energy, semiempirical expressions following from the generalized Karman hypothesis, the Kolmogorov hypothesis and the expression for the vertical gradient of potential temperature. The latter makes it possible to dispense with the heat influx equation and at the same time quite correctly describe the vertical profile of potential temperature using the controlling parameters: the turbulent heat flux near the underlying surface, dynamic velocity and the vertical gradient of temperature in the upper part of the boundary layer.

The program for calculating the vertical profiles of characteristics in the lower 300-m layer of the atmosphere consists of three principal blocks: computation of the determining external parameters, computation of dimensionless characteristics of the boundary layer, computation of the vertical profiles of the characteristics of the lower layer of the atmosphere, parameters of the dynamic and thermal interaction between the underlying surface and the atmosphere.

Now we will discuss the first and third blocks in greater detail. First we use the mean hourly profiles of meteorological elements to determine the external parameters: roughness, quantitative characteristics of stability of the layer and velocity of the geostrophic wind. The roughness z_0 is determined from the wind velocities at the levels 1, 2 and 4 m on the assumption of satisfaction of the logarithmic law within this layer. (Mesoscale roughness, which is dependent on wind direction [9], was not determined within the limits of this study and constitutes a problem for the future).

In order to determine the velocity of the geostrophic wind U, using the stipulated set of input parameters we determined the vertical wind profiles. These data made it possible to construct nomograms for determining U on the basis of wind velocity at one of the levels on the mast. The ratio of U to the wind velocity modulus at a height of 301 m for the latitude of Moscow with $\delta T_1 = 0.6°C$, $z_0 = 0.1$ m and different δT_2 is given in Fig. 1 (here δT_1 and δT_2 are the temperature differences used for quantitative characterization of stratification; for their determination, see below). Thus, we find all the input values necessary for solving the formulated problem.

In [16] the relationship between the velocity of the geostrophic wind and the the wind velocity at the 300-m level was obtained on the basis of generalized radiosonde data. A comparison of the two methods for determining U shows their good correspondence. In both cases with unstable and neutral stratification $v_{300}/U \leqslant 1$; with an increase in v_{300} this value decreases, attaining 0.8 when v_{300} = 20 m/sec; in the case of a stable stratification $1.3 > v_{300}/U \geqslant 0.9$. Since the dependence v_{300}/U on stratification is poorly expressed, the stability parameter for evaluating U can be estimated with a low accuracy. Figure 2 shows the correspondence of the U values computed from v_{300} by different methods.

In model [7] the dimensionless parameters are the Rossby number $Ro = U(fz_0)^{-1}$ and the two stability parameters -- internal $\mu = -\chi^2\lambda\Pi_0(fv^2)^{-1}$ and external $\nu = \lambda\chi^4(\gamma_a - \gamma_H)f^{-2}$. Here $\chi = 0.38$ is the Karman constant, $\lambda = g/T$

is the buoyancy parameter, $\Pi_0 = P_0/c_p\rho$ is the normalized turbulent heat flux near the underlying surface, $f = 2\omega\sin\varphi$ is the Coriolis parameter, v_* is dynamic velocity,

$$\gamma_H = -\left(\frac{\partial T}{\partial z}\right)_H$$

is the vertical temperature gradient near the upper boundary of the boundary layer, $\gamma_a = 0.98\cdot10^{-4}$ °C/cm is the dry adiabatic gradient.

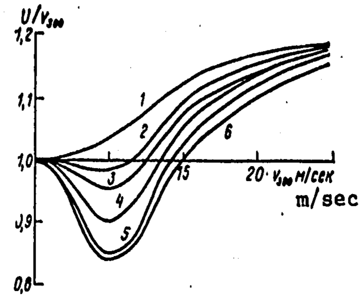

Fig. 1. Ratio of modulus of geostrophic wind to the wind velocity modulus at the 300-m level in dependence on v_{300} with $\delta T_1 = 0.6$°C and values δT_2 = 0.25 and 0.50; 0; -0.25; -0.5; -1.0: -1.5°C (1-6 respectively).

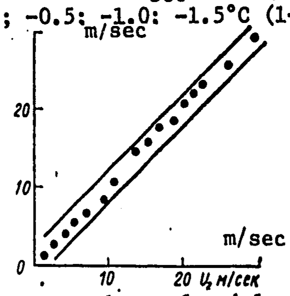

Fig. 2. Correspondence between values of modulus of geostrophic wind, computed from [16] (U_1) and from results in this study (U_2). Each dot represents the result of 5-7 determinations (averaged); the sloping lines represent the limits of deviations.

Integrating the adopted expression for the vertical gradient of potential temperature, with an accuracy to second-order values we obtain

$$\mu = -\frac{\varkappa^2\lambda\,(\gamma_a\,\delta z - \delta T_2)}{f\chi U}\left[\ln\frac{1-\frac{\delta z}{\bar z}}{1+\frac{\delta z}{\bar z}}\right]^{-1}. \quad (1)$$

Here δz is the thickness of the layer, $\bar z$ is the height determined at its middle, δT_2 is the temperature difference at its lower and upper boundaries, $\chi = v_*/\varkappa U$ is the geostrophic friction coefficient.

The initial μ value is determined for input into the block for computing the dimensionless characteristics. The χ value is considered to be dependent only on Ro and is described approximately by the expression

$$\chi = 0{,}027(10 - \lg \mathrm{Ro}). \qquad (2)$$

The resulting μ value is then refined. The dimensionless boundary layer parameters are also computed.

For evaluating the ν parameter we selected the δT_1 value -- the difference in temperatures at the levels 169 and 300 m. This choice was entirely satisfactory under all conditions other than strong instability, when for this it is necessary to have information on the temperature profile above 300 m.

For evaluating the μ parameter we used the temperature difference in the layer 49-25 m, in contrast to [12, 13], where the evaluation of the stability parameters was made using the temperature differences in the layer 1-8 m. Such a choice was made so as to decrease, to some degree, the influence of the thermal spottiness of the underlying surface and the associated variability of the temperature difference in the surface layer. The problems involved in comparison of the methods for determining the state of stability on the basis of the results of measurements on the high mast at the Institute of Experimental Meteorology are considered in [3]; there it was demonstrated under what conditions and within what limits it is possible to expect an agreement of the results when determining stability by different methods. Supplementing these comparisons, we note that in the case of a stable stratification the method described in this study reduces the μ values by a factor of 1.5-2 in comparison with their values cited in [3]; the considered values correlate well. In the case of unstable stratification the correlation is weaker and the degree of understatement amounts to an order of magnitude. An analysis indicated that this occurs because the adopted approximation of the profile of potential temperature in the case of instability requires a substantial refinement.

As a result of the work of the second block we obtain at the output: the geostrophic friction coefficient (χ), the angle of deviation of the actual wind from the geostrophic wind near the underlying surface (α), the vertical profiles of the components of tangential frictional stress and wind velocity in a coordinate system in which the x-axis is directed along the surface wind, the coefficient (K) and intensity of turbulence (b).

In the third block the dimensional parameters of the lower 300-m layer are computed and are fed out in the form of Table 1. This table gives: day, month, year, hour; initial data, dimensionless input parameters and interaction characteristics; profiles of the coefficient and intensity of turbulence, shearing stresses, modulus (V) and components (u and v) of wind velocity in a local system, vertical temperature gradient ($\partial T/\partial z$). The levels correspond to the heights of wind measurement on the meteorological mast, $\Pi_0 = P_0/c_p\rho$, $\tilde{\tau}_x = \tau_x/\rho$, $\tilde{\tau}_y = \tau_y/\rho$.

Table 1

Computed Parameters of Lower 300-m Layer (Example of Printout)

Date: 27 May 1971 1200 hours

Initial data:	$\delta T_1°$ C	$\delta T_2°$ C	U m/sec	z_0 m
	0.32	0.08	7.3	0.01

Dimensionless parameters	lg Ro		
	6.79	13	440

Characteristics of interaction	χ,	v_* m/sec,	α,	Π_0 °C·m/sec,	H m
	0.09	0.24	21	-0.020	342

Profiles

z м	K м²/сек 1	b м²/сек²	$\tilde{\tau}_x$ м²/сек²	$\tilde{\tau}_y$ м²/сек²	V м/сек 2	u м/сек	v м/сек	$\partial T/\partial z$ °C/100 м
8	0,7	0,235	0,055	—0,003	4,8	4,8	—0,0	1,79
25	1,7	0,182	0,050	—0,006	5,4	5,4	—0,1	—0,02
49	2,6	0,126	0,043	—0,010	5,8	5,8	—0,2	—0,38
73	2,8	0,083	0,036	—0,012	6,2	6,2	—0,3	—0,46
121	2,1	0,031	0,023	—0,014	6,7	6,7	—0,5	—0,43
169	1,3	0,010	0,012	—0,013	7,3	7,2	—1,0	—0,33
217	0,7	0,003	0,004	—0,010	7,7	7,6	—1,5	—0,21
265	0,3	0,001	—0,001	—0,005	8,0	7,7	—2,2	—0,08
301	0,1	0,001	—0,001	—0,002	7,9	7,4	—2,7	—0,02

KEY:
1. m²/sec
2. m/sec

These values were obtained for each hour for 37 days, corresponding to the series of observations. For convenience in analysis and classification we compiled tables of the diurnal variation of boundary layer characteristics, an example of which is Table 2 (in order to save space, the data are given each 3 hours). Here the subscripts "m" and "c" correspond to the actual (measured) and computed values.

Thus, we now have obtained extensive data on the characteristics of the atmospheric boundary layer, whose accumulation is continuing. This material will be used in formulating a physical-statistical model of the lower 300-m layer.

Table 2

Diurnal Variation of Boundary Layer Characteristics. 16 Oct 74, Series 54

	0	3	6	9	12	15	18	21 hours
δT_1 °C	0,08	0,34	0,06	1,06	1,29	1,23	0,97	0,58
δT_2 °C	0,05	0,17	0,14	0,26	0,32	0,28	0,04	0,08
U м/сек 1	12,7	11,0	10,6	7,2	7,5	3,2	0,4	4,2
v_{300}^{Φ} м/сек	12,7	9,4	8,6	6,5	6,5	3,3	0,3	4,1
v_{300}^{p} м/сек	11,4	10,6	10,3	6,9	7,2	3,2	—	—
z_0 м	0,30	0,11	0,17	0,21	0,12	0,11	0,10	0,33
lgRo	5,6	6,0	5,7	5,5	5,7	5,4	4,5	5,0
μ	7	3	4	−3	−7	−9	180	15
ν	550	450	560	110	4	18	150	320
χ	0,11	0,10	0,11	0,13	0,13	0,13	0,10	0,12
v_* м/сек	0,54	0,44	0,44	0,35	0,37	0,16	0,01	0,20
α_{Φ} град 2	61	38	37	34	11	12	37	64
α_p град	29	25	28	22	8	11	41	31
H_0 °C·м/сек	−51	−13	−20	9	25	6	−1,0	−15
K_{max} м²/сек	14	11	10	13	24	16	0,0	1,8
H_{max} м	121	121	121	169	301	265	—	49
H м	550	472	440	540	930	830	12	220

KEY:

1. m/sec
2. degrees

Subscripts: Φ = m(easured); p = c(omputed)

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USE OF DATA ON ATMOSPHERIC MOISTURE CONTENT FOR PREDICTING THE ALTITUDE OF THE LOWER BOUNDARY OF FRONTAL CLOUD COVER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 50-56

[Article by N. I. Sholokhova, USSR Hydrometeorological Scientific Research Institute, submitted for publication 19 June 1978]

Abstract: A study was made of moisture content conditions in a cold front zone, with which the appearance of low cloud cover in Western Georgia is associated. The author evaluates the evolution of different characteristics of total moisture content in a frontal zone during its movement toward the shores of Western Georgia. Linear equations are derived for discriminant functions for predicting the altitude of the lower cloud boundary, more or less 600 m, at Batumi airport for 12 hours in advance. An evaluation of success of the forecast on the basis of a dependent sample indicates the feasibility of using moisture content characteristics as the principal predictors.

[Text] One of the principal factors determining the intensity of cloud formation on a front is the moisture content of an air mass. In this paper we investigate moisture content conditions in a zone of cold fronts responsible for the appearance of low clouds in Western Georgia for the purpose of deriving prognostic dependences for the altitude of the lower boundary of cloud cover on moisture content characteristics.

The research material used were data on the hourly observations at the airports Sukhumi, Batumi, Kutaisi for 1970-1974, surface and high-level weather charts, and also radiosonde data for Batumi, Simferopol' and Ankara during this same period.

The research method was determined by the synoptic conditions for the appearance of low cloud cover in Western Georgia and the orographic characteristics of this region. The fact is that the mountain ranges bordering the territory of Western Georgia form an orographic funnel which is open to the west in the direction of the Black Sea. With intrusion of air masses from the west there is a convergence and forced rising of the air along the slopes of mountain ranges, which leads, under corresponding conditions, to an activation of the cloud formation process.

A synoptic analysis of cases of low cloud cover at the above-mentioned airports has shown that the cold fronts, whose passage in 73% of the cases causes the appearance of low clouds in this region, are associated either with cyclonic activity over the European USSR (western type), or with the arrival of cyclones developing on the Mediterranean branch of the polar front, in the direction of Transcaucasia or the southern European USSR (southern type).

An analysis of the direction and velocity of movement of the cold fronts made it possible to ascertain regions of the mean location of their sectors, determining weather conditions in Western Georgia 12 hours in advance relative to the time of appearance of low cloud cover along the shore. In the case of a westerly process this is the region of Crimea, whereas in the case of southerly processes, the south-southwestern part of the Black Sea or the northwestern part of Asia Minor. It was therefore assumed that the state of the atmosphere in a frontal zone with the mentioned advance time is characterized by the data from radiosonde observations at Simferopol' in the case of a westerly process, whereas in the case of a southerly process we examined values obtained by the interpolation of radiosonde data for Simferopol' and Ankara.

As the forecasting station we selected Batumi station, at which the greatest frequency of occurrence of clouds below 600 m is observed.

In order to obtain prognostic relationships we used the method of linear parametric discriminant analysis. An evaluation of the information content of the predictors was made using the Mahalanobis characteristic D^2. In the case of the two classes

$$D^2 = (M_1 - M_2)' S^{-1} (M_1 - M_2),$$

where M_1, M_2 are the mean values of the vector-predictor in the first and second classes, S^{-1} is the inverse generalized dispersion matrix.

The evaluation of the probability of a correct classification (success of the classification) for combinations of predictors was determined using a formula from [2]

$$P = \Phi(D/2), \qquad (1)$$

where

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{y^2}{2}} dy.$$

An analysis of the moisture content conditions in the frontal zone and a search for prognostic relationships between the characteristics of moisture content and the altitude of cloud cover was accomplished for the mentioned types of synoptic process separately. For each of them two groups of cases of cloud cover at Batumi were formed with respect to the altitude of the lower boundary: I -- below 600 m, II -- above 600 m. The total volume of the sample was 396 cases.

We used the integral (total) moisture content W^* for characterizing the moisture content of an air mass, together with the specific humidity at different levels and the total dew point spread at three isobaric surfaces (850, 700 and 500 mb):

$$W^* = \int_0^\infty a(z)\,dz \ (г/см^2), \qquad (2)$$

determined as the quantity of water vapor in the atmospheric layer ground-100 mb with a section 1 cm^2. Here a is absolute humidity (g/cm^3), z is the vertical coordinate.

Computations using expression (2) were carried out on an electronic computer using the Ye. P. Dombkovskaya program. This program ensures the output of another series of characteristics of atmospheric moisture content, to wit:

-- layer-to-layer water vapor content W_i^*, where i is the number of the layer (1 -- 0-1.5 km, 2 -- 1.5-3 km, 3 -- 3-5 km, 4 -- above 5 km);
-- relative total moisture content $W_{rel}^* = W^*/W_{max}^*$, where W_{max}^* is the moisture content of the column of the atmosphere saturated with water vapor at this same air temperature;
-- relative values of the layer-by-layer moisture content $W_{i\ rel}^* = W_i^*/W^*$.

Using data from radiosonde observations at Batumi at the time of cold front passage we examined the diagnostic relationship between the altitude of clouds with different moisture content characteristics. In general, the W^* values fell in the range 0.3-4.5 g/cm^2. For groups of cases with an altitude of the lower cloud cover boundary (LBCC) less than 600 m there is an increase in total moisture content, especially in the case of southerly processes, when the frequency of recurrence of W^* values is greater than 2.1 g/cm^2 for the first group of phenomena is 15% greater than for the second, and in the case of westerly processes this excess was 11%. There is also a substantial difference in the mean values, which for the two mentioned groups in the case of a westerly process are 2.09 and 1.76 g/cm^2 respectively, and in the case of a southerly process -- 2.23 and 1.94 g/cm^2.

The distribution of the total relative moisture content W_{rel}^* also agrees well with the considered gradations of cloud altitude. In more than 75% of the cases cloud cover with an altitude below 600 m is noted with values W_{rel}^* 80-100% and virtually not at all (frequency of recurrence 90% or more) with $W_{rel}^* < 70\%$). For a cloud cover altitude greater than 600 m the maximum of the frequency of recurrence W^*_{rel} (60-67%) is in the gradation 40-70% (Table 1).

Table 1

Frequency of Recurrence (%) W^*_{rel} at Batumi

Процесс [1]	НГО [2]	11—20	21—30	31—40	41—50	51—60	61—70	71—80	81—90	91—100
3 Западный	≤600	—	—	—	1	—	7	14	34	44
	>600	1	4	8	15	25	27	8	11	1
4 Южный	≤600	—	—	—	—	4	6	14	31	45
	>600	1	7	15	18	26	16	9	5	2

KEY:

1. Process
2. Lower cloud boundary
3. Westerly
4. Southerly

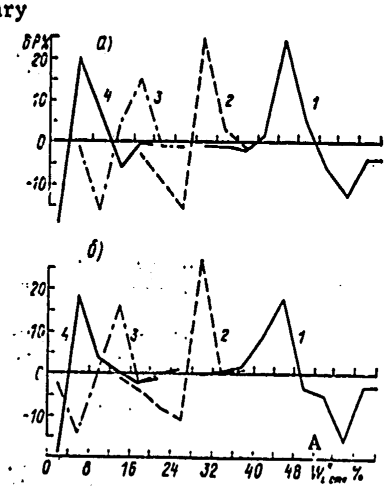

Fig. 1. Distribution of differences in frequency of recurrence $W^*_{i\ rel}$ for cloud altitudes above and below 600 m for southerly (a) and westerly (b) processes by layers: 1) 0-1.5 km, 2) 1.5-3 km; 3) 3-5 km, 4) above 5 km

KEY:

A) rel

At Batumi the lower cloud boundary with an altitude below 600 m in 75% of the cases, and a decrease in its altitude to 300 m or less in 87% of the cases is associated with the falling of precipitation. Therefore, the result is in agreement with the conclusion in [3] that there is a relationship between W^*_{rel} and zones of significant precipitation.

Table 2

Mean $W_{i\ rel}^{*}$ Values (%) in Southerly Process

НГО 1	Слои 2: 1	2	3	4
≤600	46,6	28,7	16,7	8,0
>600	49,6	26,8	15,6	8,0

KEY:
1. Lower cloud boundary
2. Layers

Table 3

Frequency of Recurrence (%) of δW^{*} and δW_{rel}^{*} Values With Cloud Altitude at Batumi More Than and Less Than 600 m

Характер изменения влажности 1	2 НГО<600 м: западный процесс 3			НГО>600 м: западный процесс 3		
		южный процесс 4			южный процесс 4	
	БС 5	БС 5	БА 6	БС 5	БС 5	БА 6
$\delta W^{*}>0$	83	86	61	70	72	47
<0	17	14	39	30	28	53
$\delta W_{отн}^{*}>0$	70	74	88	60	44	42
7 <0	30	26	12	40	56	58

KEY:
1. Nature of change in moisture content
2. Lower cloud boundary
3. Westerly process
4. Southerly process
5. Batumi-Simferopol'
6. Batumi-Ankara
7. rel

The correlation between the lower cloud boundary and the falling of precipitation noted above makes it possible to postulate a more intensive development of ordered movements during the passage of a cold front causing the appearance of clouds with an altitude below 600 m. A change in the intensity of vertical movements should be reflected in the layer-to-layer water vapor content in such a way that an intensification of ascending movements leads to an increase in moisture content in the upper layers of the atmosphere and its decrease in the lower layers [1].

Figure 1 shows the distribution of the differences between the frequency of recurrence (δ P) of the values of the layer-to-layer relative moisture content $W_{i\ rel}^{*}$ by gradations in the case of cloud altitudes below 600 m and above 600 m for four layers of the troposphere. Positive δP values correspond to an excess of the frequency of recurrence of $W^*_{i\ rel}$ values in the first class of events over the frequency of recurrence of those in the second; negative values correspond to the opposite case.

Table 4

Values of Mahalanobis Characteristic D^2

Процесс (1)	(1)	W^* (2)	$W^*_{3\ отн}$ (3 2)	W^*_3 (4)	T_{500} (5)	q_{500} (6)	T_{700} (7)	q_{700} (8)	$\sum_{850}^{500}(T-T_d)$ (9)
Западный (3)	$W^*_{отн}$ (2)	45,8	52,6	47,8	47,0	46,8	50,2	49,6	47,5
	2	—	18,1	16,3	40,9	10,0	56,8	16,0	37,1
	3	—	—	18,2	29,2	18,2	37,3	19,6	42,6
	4	—	—	—	48,4	11,0	64,7	12,6	40,1
	5	—	—	—	—	47,3	13,2	53,0	35,4
	6	—	—	—	—	—	59,5	12,6	37,8
	7	—	—	—	—	—	—	71,3	38,6
	8	—	—	—	—	—	—	—	42,4
Южный (4)	1	55,7	58,6	55,6	56,2	55,6	60,3	56,5	68,5
	2	—	16,4	11,6	71,9	8,6	85,5	13,2	72,5
	3	—	—	15,3	20,2	13,8	25,0	16,4	68,6
	4	—	—	—	61,7	11,8	72,1	12,9	71,2
	5	—	—	—	—	59,0	14,2	59,2	69,0
	6	—	—	—	—	—	63,4	13,2	69,4
	7	—	—	—	—	—	—	66,4	71,5
	8	—	—	—	—	—	—	—	70,7

KEY:

1. Process
2. rel
3. Westerly
4. Southerly

It follows from the figure that with an altitude of the lower cloud boundary less than 600 m (more intensive development of vertical movements) in the layer ground-1.5 km there is a decrease in moisture; in the above-lying layers of the atmosphere there is a characteristic increase. This phenomenon is expressed particularly clearly for the first and second layers, which is reflected in the mean vertical profiles $W^*_{i\ rel}$ (Table 2).

Taking into account the immediate nearness of mountain ranges to the Batumi airport it can be postulated that the moisture content field when the front passes over the shore experiences a definite evolution under the influence of additional vertical movements caused by orography. This problem is of particular interest due to the fact that the precipitation maximum for the entire territory of the USSR is noted in the Batumi region.

An evaluation of evolution of the moisture content field was made using an analysis of the differences between the values of the moisture content characteristics at Batumi and the corresponding values at Simferopol' and Ankara, taken for one and the same case of passage of a front with a 12-

hour interval. We considered the values $\delta W^*_{BS} = W^*_B - W^*_S$, $\delta W^*_{BA} = W^*_B - W^*_A$, as well as the similar differences for W^*_i, W^*_{rel}, $W^*_{i\ rel}$. The enumerated values can be regarded as the individual changes in moisture content characteristics in the frontal zone. [B = Batumi, S = Simferopol', A = Ankara]

It should be noted that the evolution of the moisture content field, computed by the adopted method, cannot be attributed entirely to the influence of orography in the coastal zone. A definite role in this respect is evidently played by transformation conditions along the trajectory of movement of the air mass.

Movement of a cold front, causing the appearance of cloud cover with an altitude below 600 m at Batumi airport, in the overwhelming majority of cases is accompanied by an increase in the total absolute and relative moisture content along the shores of Western Georgia (Table 3).

For cases with a cloud altitude more than 600 m the tendency to an increase in the W^* and W^*_{rel} values persists in the case of a westerly process. In the case of arrival of southerly cyclones in the direction Batumi-Simferopol' there is also a predominance of positive δW^* values, but the frequency of recurrence of cases of an increase in W^*_{rel} is reduced to 44%. In the Batumi-Ankara direction most frequently there are cases of a decrease in both the absolute and relative total moisture content.

An analysis of the change in the layer-to-layer water vapor content δW^*_i revealed that with both types of processes in the direction Batumi-Simferopol' an increase in W^* on the shore occurs as a result of an increase in the moisture content in all the considered layers of the atmosphere with a small predominance in the two lower layers. We note an increase in the frequency of recurrence of negative $\delta W^*_{i\ BA}$ values in the case of a southerly process in the layer ground-1.5 km, especially for the second group of cases, whereas in the second-fourth layers more commonly (about 70% of the cases) the moisture content was higher at Batumi. The location of Ankara at an elevation of 830 m above sea level possibly favors the formation of low stratiform clouds during the passage of a cold front, which leads to an increase in moisture content in the surface layer.

The relative layer-to-layer water vapor content remains virtually constant with movement of the front from Simferopol' to Batumi. Possibly the role of orographic vertical movements, favoring an increase in $W^*_{i\ rel}$ in the upper layers of the atmosphere, is compensated by a constant enrichment of the surface layer from the Black Sea surface with moisture. With respect to the Batumi-Ankara direction, the change in $W^*_{i\ rel}$ is in accordance with the distribution of the $\delta W^*_{i\ BA}$ differences considered above.

A preliminary analysis of the distribution of different moisture content characteristics in the frontal zone, ascertained 12 hours before, that is, at Simferopol' and Ankara, made it possible to discriminate seven parameters used as predictors for an alternative forecast of cloud cover altitude above and below 600 m at Batumi.

In addition to the moisture content values, we took the temperatures at levels 700 and 500 mb. The difference in the mean characteristics of moisture content at the mentioned points in the case of a southerly process serves as a basis for the averaging of these data for the purpose of obtaining a more complete description of the moisture content field in the frontal zone.

Table 4 gives the matrices of D^2 values (Mahalanobis characteristics) demonstrating the information content of dual combinations of parameters.

Table 4 shows that D^2 for all combinations with W^*_{rel} in the case of a westerly type, whereas in the case of a southerly type with

$$\sum_{850}^{500}(T-T_d)$$

have close, and on the average, the highest values for the corresponding matrix. This is evidence of the maximum information content of these predictors. The success of the P classification, determined using formula (1), for the best of the mentioned combinations in the case of a westerly process W^*_{rel}, W^*_{west}, was 69.1%; for the combination

$$\sum_{850}^{500}(T-T_d),\ W^*$$

(southerly process) P = 72.2%.

The information content for the absolute moisture content characteristics increases sharply when they are examined in combination with the temperature value at any level. The maximum D^2 values for a westerly process gives the combination q_{700}, T_{700} (P = 72.9%), whereas for a southerly process -- the combination W^*, T_{700} (P = 74.2%).

The use of a three-dimensional vector-predictor gives an increase in the probability of a correct separation: up to 74.2% for the combination W^*_{rel}, q_{700}, T_{700} (westerly type) and up to 76.5% for the combination

$$\sum_{850}^{500}(T-T_d),\ W^*,\ T_{700}$$

(southerly type). The discriminant functions, computed for the above-mentioned best combinations, have the form

$$L_1=-6{,}325+0{,}039\ W^*_{\text{отн}}-0{,}219\ T_{700}+0{,}963\ q_{700},$$

[OTH = rel] $$L_2=-4{,}055+2{,}346\ W^*-0{,}334\ T_{700}+0{,}107\sum_{850}^{500}(T-T_d).$$

An evaluation of the success of forecasting of cloud altitude below and above 600 m in a dependent sample is given in Table 5. The quality of the forecast was evaluated using the readings: Q -- total probable success of the forecast; Q_I, Q_{II} is the probability of success of forecast of the altitude of clouds below 600 m (class I) and above 600 m (class II) respectively; P_I, P_{II} is the warning of altitude of the phenomenon above and below 600 m.

The results of this investigation make it possible to conclude that it is possible to use the moisture content characteristics in combination with the temperature value in a frontal zone moving in the direction of Transcaucasia for predicting the lower cloud cover boundary on the shores of Western Georgia.

Table 5

Success of Forecast (%)

Дискриминантная функция[1]	Q	Q_I	Q_{II}	P_I	P_{II}
L_1	76,2	75,0	76,4	79,0	73,2
L_2	77,7	76,1	79,7	83,0	72,0

KEY:

1. Discriminant function

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UDC 551.(515.2+571.7)

TROPOSPHERIC MOISTURE CONTENT IN THE TYPHOON ZONE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 57-61

[Article by Candidate of Geographical Sciences N. I. Pavlov, Far Eastern Scientific Research Hydrometeorological Institute, submitted for publication 19 June 1978]

Abstract: This paper gives an analysis of the distribution of the total moisture content on the periphery of typhoons and also in the zone of their activity on the basis of materials from the expedition "Typhoon-75" and expeditionary voyages at the point 15°N, 135°E.

[Text] Water vapor is of exceptionally great importance in the production of energy and the development of atmospheric processes in the tropical zone. The vertical distribution of atmospheric moisture content is associated with the vertical movements and cloud formation processes. It was noted in [1, 6] that the maximum moisture content in a column of the atmosphere with a height of 10 km was noted in the region of the intratropical convergence zone (ICZ). The minimum moisture content was observed near the equator in the cloudless spaces between the ICZ of the northern and southern hemispheres. On the "Tropeks-74" expedition [2,4,5,7] a study was made of the distribution of water vapor content in different parts of the ICZ and also in the well-developed and "blurred" ICZ.

In this article, on the basis of materials from expeditionary observations at the point 15°N, 135°E, situated in the Philippine Sea during the period 1970-1973, and also on the basis of data from the "Typhoon-75" expedition, a study was made of the vertical structure of the humidity field, and also atmospheric moisture content.

All the computations of atmospheric moisture content for layers of the atmosphere with a thickness of 1 km, and also for the entire column of the atmosphere as a whole, were made using the formulas cited in [2].

The elasticity of saturated vapor F was determined from tables in which the input variable was air temperature. Then, using data on relative humidity and the elasticity of saturated vapor we computed the elasticity of water vapor f(h) using the formula

$$f(h) = \frac{u(h)F}{100}, \qquad (1)$$

where u(h) is the relative humidity of air measured at the level h.

The determined f(h) values were used for determining the absolute humidity a(h):

$$a(h) = \frac{216.7\, f(h)}{T}, \qquad (2)$$

where T is absolute air temperature.

The total moisture content for atmospheric layers with a thickness of 1 km was determined using the formulas

$$W_i = \int_{h_i}^{h_{i+1}} a(h)\, dh, \qquad (3)$$

where i = 0, 1, 2, 3,...,k is the number of the surface separating the layer of the atmosphere each 1 km.

The total moisture content in a column of the atmosphere with the height H was determined by summing the moisture content in elementary layers:

$$W = \sum_{i=1}^{k} W_i.$$

As indicated by computations, the moisture content in the troposphere (0-11 km) in the typhoon zone has a great variability (Fig. 1, 2). The greatest moisture content is noted in typhoons and in the ICZ. For example, on the distant periphery of typhoon Bess on 20 September 1971 the moisture content in the layer 0-11 km was 4.8 g/cm^2. With the entry of the scientific research weather ship (SRWS) "Priliv" (sixth voyage) into its southern part the moisture content in the mentioned layer increased by 26% and was 6.5 g/cm^2. A similar picture was also observed during sounding of the atmosphere on the periphery of typhoon Wilda on 9-10 August 1970 (third voyage of the SRWS "Priliv"). The maximum moisture content (7.22 g/cm^2) was observed at the point 18°12'N, 135°00'E on 8 October 1971 when the SRWS "Priliv" (sixth voyage) intersected the northeastern periphery of typhoon Faye (Fig. 2). The minimum moisture content is noted in the region of the subtropical zone of high pressure and also in weak anticyclones forming in the rear of typhoons. For example, during sounding of the atmosphere in the rear part of typhoon Tess at the point 19°30'N, 142°30'E on 7 September 1975 the moisture content was 2.37 g/cm^2. Such low moisture content values were caused by descending vertical movements on the northern periphery of the nucleus of high pressure arising in the rear part of typhoon Tess.

According to observational data from the SRWS at the point 15°N, 135°E the mean moisture content values during the period of observations in May-July 1973 were 4.90, 4.98 and 5.39 g/cm^2 respectively. It should be noted that according to the data in [7] in the ICZ of the Atlantic Ocean during the period of implementation of the "Tropeks-74" the mean moisture content in the layer 0-10 km during the observation period was 5.27 g/cm^2. Over the equator the moisture content is decreased to 3.5-3.9 g/cm^2. When the cloud bands crossed the equator the moisture content of the air masses increased by 25-30% and is 5.0-5.3 g/cm^2.

According to the data in [2], the mean moisture content over the equator at the meridian 23°30'W was 3.60-3.94 g/cm^2 and the maximum attained 5.2 g/cm^2. In the Indian Ocean the mean moisture content values over the equator at the meridian 60°E in May and June 1973, according to observational data from the "Monsoon-73" expedition, were 5.56 and 5.13 g/cm^2.

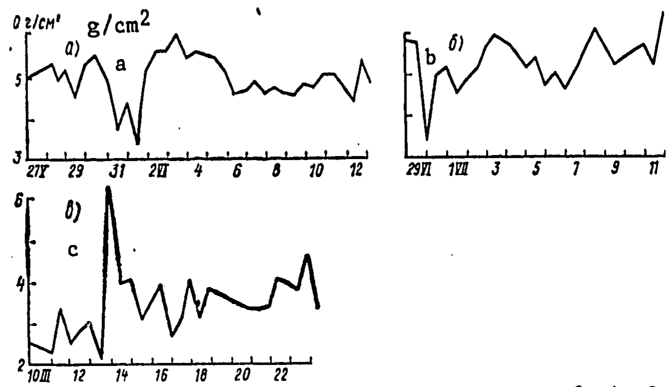

Fig. 1. Temporal variation of total moisture content of air Q in the layer 0-11 km at the point 15°N, 135°E. a) 26 May-14 June 1973, ninth voyage of the SRWS "Priboy"; b) 27 June-12 July 1973, ninth voyage of the SRWS "Priboy"; c) 9-24 March 1973, eighth voyage of the SRWS "Okean"

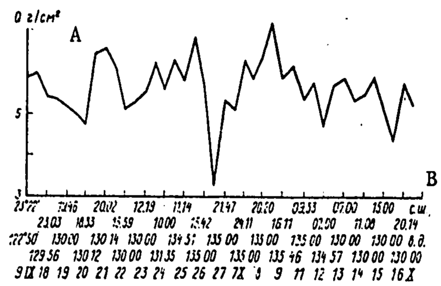

Fig. 2. Spatial-temporal variation of total atmospheric moisture content Q in layer 0-11 km in Philippine Sea during period 9 September-16 October 1971 on the sixth voyage of the SRWS "Priliv."

KEY:

A. Q, g/cm^2

B. N

The total moisture content in the layer 0-10 km to a high degree is dependent on the vertical structure of the atmosphere and primarily on the presence of Trade Wind inversions. The greatest quantity of water vapor is concentrated under the inversion in the lower kilometer layer, in which 30-40% of the total moisture content is concentrated.

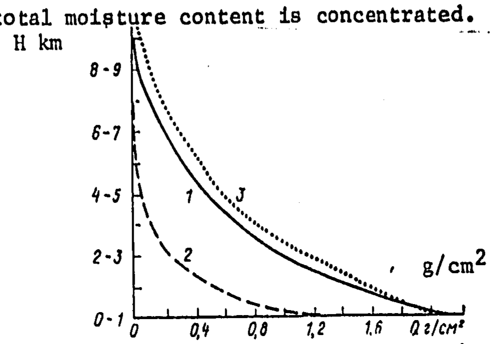

Fig. 3. Vertical profile of air moisture content Q in atmospheric layers with a thickness of 1 km. 1) southern part of typhoon Bess at distance of 250 km from center on 21 September 1971; 2) point 19°30'N, 142°30'E, 7 September 1975 0600 GMT; 3) point 18°12'N, 135°00'E, 8 October 1971, 0000 GMT.

With altitude the moisture content changes exponentially (Fig. 3). The specific moisture content profile is dependent on the vertical distribution of relative humidity and air temperature. The standard deviation of moisture content in the layer 0-11 km is 0.92 g/cm^2. For individual observation periods with a great diversity of synoptic situations it increases to 1.40 g/cm^2. If we examine the standard deviation of moisture content for layers a kilometer thick, its maximum values (0.24-0.29 g/cm^2) are noted in the layers 0-1 and 1-2 km.

It was found on the "Tropeks-72" expedition [4] that in the Trade Winds zone in the troposphere there are several inversion layers. Tropospheric stratification is easily traced in the air temperature and humidity fields. A further investigation of the structure of Trade Wind inversions was continued on the "Tropeks-74" expedition [5]. It was established that the characteristics of the blocking layers in the Eastern Atlantic have a broad dependence. With approach to the ICZ the inversion layers are destroyed or become poorly expressed.

Investigations of the vertical structure of the temperature and humidity fields on the basis of data from aerological observations at the point 15°N, 135°E for 1970-1973 and on the "Tayfun-75" expedition indicated that in the tropical zone of the northwestern part of the Pacific Ocean there are also several inversion layers (most frequently 1-2). The lower Trade Wind inversion is best expressed in the fields of meteorological elements. In this inversion there are vertical temperature gradients up to 1-1.5° per 100 m and vertical gradients of relative humidity up to 9-10% per 100 m.

Beneath the Trade Wind inversion the relative humidity attains 90-100%, but above it can sometimes decrease to 5-10%.

The maximum horizontal gradients of relative humidity, attaining 20% per 100 km, are observed at the boundary of the ICZ and on the periphery of typhoons.

The great variability of moisture content in the tropical zone is caused by a change in synoptic situations and interaction between the ocean and the atmosphere. Increasing distance of the ICZ and tropical cyclones causes a decrease in moisture content. Particularly great changes in moisture content are noted when there is a marked change in synoptic situations. For example, according to observations by the scientific weather ship "Priliv" (sixth voyage), the moisture content in the ICZ region (13.5°N, 135°E) on 26 September 1971 was 6.8 g/cm^2. With movement of the ship to the north along the meridian 135°E at 20°02'N the moisture content decreased sharply to 3.2 g/cm^2, which, as demonstrated by an analysis, is associated with the formation of a region of increased pressure in this region.

Appreciable fluctuations of moisture content were noted when carrying out a hydrological survey of the "trace" of typhoon Tess (7-8 September 1975) during the "Tayfun-75" expedition. As is well known, the cold temperature "trace" of the typhoons is caused by wind mixing of waters and the upwelling to the ocean surface of cold deep water masses. As a result of "feedback" mechanisms the hydrological "trace" of the typhoons exerts an active influence on the atmospheric boundary layer. For example, the "trace" of typhoon Tess, as a result of the mechanism of turbulent and radiant heat and moisture exchange caused the appearance of inversions in the layer 2-3 km. The thickness of the inversion layer was 500 m. This inversion, in contrast to the Trade Wind inversion, owed its origin to the hydrological "trace" of typhoon Tess. It developed in the westerly flows of the rear part of a typhoon.

In the "trace" of typhoon Tess the moisture content decreased in comparison with the background values by 10-20%.

The hydrological "trace" was situated to the right of the trajectory of typhoon Tess by approximately 8-100 km. Directly on the typhoon trajectory (at its rear) the moisture content was 0.5-0.8 g/cm^2 more than in the typhoon trace. The minimum moisture content values (2.4 g/cm^2) were noted on 7 September in the region of the voyage of the "Priboy" scientific research weather ship (20°N, 143°E) at a distance of 700 km to the right of the trajectory of movement of typhoon Tess. In this region there was an intensive inversion, above which the air was very dry (relative humidity 5-10%). A day later an anticyclone was formed in this region with a pressure at the center of 1010 mb and with a radius of 900 km.

Reduced moisture content values (2.5-4.0 g/cm^2) were also noted in a trough oriented to the southwest from typhoon Tess.

Sharp "bursts" of moisture content are noted with passage through a point of observations of wave disturbances in the ICZ. For example, on 13 March 1973, at a point 15°N, 135°E the moisture content had increased sharply to 6.42

g/cm^2 during the passage of a wave disturbance in the easterly flows. The mean moisture content during March 1973 at this observation point was 3.38 g/cm^2.

Conclusions

1. The maximum moisture content values (6.5–7.2 g/cm^2) are noted on the periphery of typhoons and in the ICZ. The minimum moisture content is observed in the centers of high pressure forming in the rear parts of typhoons.

2. The greatest quantity of water vapor is concentrated under the inversion in the lower kilometer layer, where 30–40% of the total moisture content is found.

3. The standard deviation of moisture content in the layer 0–11 km is 0.92 g/cm^2. The greatest standard deviations of moisture content (0.24–0.29 g/cm^2) are noted in the layers 0–1 and 1–2 km.

4. Marked "bursts" of moisture content are noted during the passage of wave disturbances in the ICZ through the observation point.

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TURBIDITY FACTOR AT MOSCOW FOR DIFFERENT WIND DIRECTIONS AND VELOCITIES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 62-66

[Article by Candidates of Geographical Sciences G. M. Abakumova and T. V. Yevnevich, Moscow State University, submitted for publication 26 April 1978]

Abstract: On the basis of long-term observations at the meteorological observatory at Moscow State University it was possible to establish a relationship between the turbidity factor and wind direction and velocity. During the course of the year the atmospheric turbidity maximum is noted in summer when there is a southerly direction of the wind, when the turbidity factor T_2 is 1.5 times greater than in winter; during all seasons of the year the greatest turbidity is observed during a calm and when there is a weak wind. With an increase in wind velocity to 6 m/sec or more T_2 decreases on the average by 20%. Also considered is the problem of the influence of atmospheric circulation on the optical regime of the air basin in the city.

[Text] Among the factors causing a change in atmospheric transparency in a city, one of great importance is the conditions for atmospheric circulation, with which is associated the entry of air masses with given optical properties into this region. At the same time, the prevailing direction of movement of air masses, coinciding on the average with the wind direction, to a considerable extent governs the distribution of atmospheric turbidity over the territory of the city. Therefore, it was of interest to use the results of long-term observations at the meteorological observatory at Moscow State University to investigate the relationship between the turbidity factor and wind direction and velocity.

The turbidity factor T_2 was computed from the hourly values of direct solar radiation (with the solar disk not covered by clouds) during the period from 1955 through 1974 [1, 2]. The wind direction and velocities during these same times were determined from the tapes of an anemorhumbograph or from the records in the KM-1 meteorological books (1965, 1972 and in part 1974). The values of the turbidity factor were grouped by wind velocity in the following way: calm, 1-2 m/sec, 3-4 m/sec, 5-6 m/sec, more than 6 m/sec. The registry of wind direction was for 16 directions, but for the sake of greater universality and statistical probability of the turbidity factor we converted from 16 directions to 8 directions, much as in the generally accepted method [3].

The total number of observations exceeded 8,000. With the maximum number of observations per year there were westerly wind directions (53%) and a velocity 3-4 m/sec (38%). The remaining wind directions are distributed almost evenly (8-10%) with respect to number of observations. With the minimum number of observations there were wind velocities greater than 6 m/sec (4%) and calm (7%).

The hourly data for the wind direction and velocity for the solar disk not covered by clouds were compared with data on the wind at the main meteorological times for all cloud cover conditions. The comparison indicated that there are no significant differences either for the year as a whole or by seasons. However, in the case of a clear sky there is some increase in the frequency of recurrence of westerly and northwesterly winds with a simultaneous significant decrease in the frequency of recurrence of southerly and southeasterly directions.

With respect to wind velocity, the greatest number of cases for the solar disk not covered by clouds falls in the range from 3 to 4 m/sec, which completely coincides with the climatological characteristic. Thus, it can be assumed that the turbidity factor, determined in observations with the solar disk not covered by clouds is a quite representative characteristic of the transparency of the air masses prevailing over the territory of Moscow.

Table 1

Mean Values of Turbidity Factor for Different Wind Velocity Levels

Сезон (1)	Скорость ветра, м/сек (2)				
	штиль (3)	1—2	3—4	5—6	>6
(4) Зима	3.58	3,13	2,97	2,78	2,62
(5) Весна	3,54	3,53	3,40	3,32	3,14
(6) Лето	3,82	3,86	3,77	3,41	3,29
(7) Осень	3,78	3,49	3,21	2,88	2.60
(8) Год	3.70	3,66	3,49	3,24	3,05

KEY:

1. Season
2. Wind velocity, m/sec
3. Calm
4. Winter
5. Spring
6. Summer
7. Autumn
8. Year

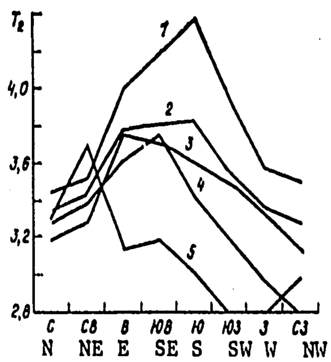

Fig. 1. Change in turbidity factor in dependence on wind direction. 1) summer; 2) year; 3) spring; 4) autumn; 5) winter

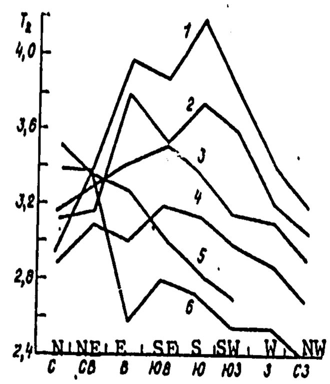

Fig. 2. Midday values of turbidity factor for different directions in Moscow (1, 3, 5) and outside city (2, 4, 6). 1, 2) summer; 3, 4) year; 5, 6) winter

The mean annual values of the turbidity factor vary from 3.26 in the case of a northwesterly wind direction to 3.81 in the case of a southeasterly wind, that is, by 17% (Fig. 1). The differences between the mean seasonal values of the turbidity factor are considerably greater, from 2.79 (in winter with westerly winds) to 4.37 (in summer with southerly winds), that is, by more than a factor of 1.5.

The atmosphere is most transparent for almost all wind directions in winter and only with northerly and northeasterly directions in spring and autumn. The minimum differences (8%) between the mean seasonal T_2 values are observed with winds of northerly directions; the maximum differences (45%) are observed in the case of southerly directions.

The influence of the city on the value of the turbidity factor in the Moscow State University region is observed during all seasons of the year other than summer. It is manifested in that T_2 in the case of a wind direction with an easterly component, that is, in the direction of the center of Moscow, is greater than in the case of a wind direction with a westerly component.

Wind velocity also exerts an extremely characteristic influence on atmospheric turbidity at Moscow. During all seasons of the year the greatest turbidity is observed during a calm and a weak wind (Table 1). With an increase in wind velocity by more than up to 6 m/sec the value of the turbidity factor decreases on the average by 20%; the greatest differences are observed in winter (37%) and autumn (45%). In spring and summer this difference does not exceed 16%. It is evident that the low wind velocity favors air stagnation and under the influence of local sources of contamination a singular "cap" of dry aerosol mist is formed over the city. Since the frequency of recurrence of weak winds (0-2 m/sec) averages more than 40%, their influence on air contamination in the city is extremely great.

Table 2

Turbidity Factor for Different Wind Directions and Velocities

Направление ветра 1	2 Скорость ветра, м/сек: 1—2, T_2	±σ	V%	n	3—4, T_2	±σ	V%	n
4 С	3,58	0,73	20	80	3,28	0,64	20	101
5 СВ	3,86	1,11	29	71	3,30	0,88	27	86
6 В	4,11	0,92	22	124	3,84	0,89	23	149
7 ЮВ	3.86	0,84	22	116	3,56	0,87	24	185
8 Ю	3.65	0,79	22	100	3,78	1,07	28	133
9 ЮЗ	3,58	1,06	30	265	3,36	0,84	25	185
10 З	3,48	0,93	27	216	3,30	0,81	25	184
11 СЗ	3,54	0,84	24	234	3.29	0.87	26	229

Направление ветра 1	2 Скорость ветра, м/сек: 5—6, T_2	±σ	V%	n	>6, T_2	±σ	V%	n	3 При всех скоростях ветра, T_2	±σ	V%	n
4 С	2,98	0,57	19	66	2,91	0,51	18	24	3,27	0,66	20	271
5 СВ	3,06	0,64	21	60	3,01	0,17	6	19	3,39	0,92	27	236
6 В	3,40	0,72	21	68	3.15	0,41	13	6	3,84	0,89	23	347
7 ЮВ	3,70	0,66	18	44	4,42	1,41	32	3	3,69	0,83	22	348
8 Ю	3,87	1,41	36	49	3,62	0,77	21	10	3,74	1,07	29	292
9 ЮЗ	3,28	0,89	27	60	3,06	0,73	14	32	3,44	0,97	28	542
10 З	3,07	0,69	22	99	2,87	0,88	31	30	3,31	0,84	25	529
11 СЗ	2,95	0,61	21	101	2,60	0,37	14	31	3,30	0,82	25	595

12 Примечание: n — число случаев.

KEY:

1. Wind direction
2. Wind velocity, m/sec
3. For all wind velocities
4. N
5. NE
6. E
7. SE
8. S
9. SW
10. W
11. NW
12. Note: n is the number of cases

A decrease in atmospheric turbidity with an increase in wind velocity is observed for all wind directions, except southerly and southeasterly, when there is transport of dust from the Caspian region and Central Asia.

For checking the reliability of our evaluations of the influence exerted on atmospheric turbidity by wind direction and velocity we also took a sample of the eight principal directions without taking the intermediate wind directions into account. Using the data from this sample we computed not only the mean values of the turbidity factor, but also the standard deviations (σ) and the variation coefficients (V%) (Table 2). The mean values of the turbidity factor obtained in this sample differ little from those which were found taking into account the intermediate wind directions (on the average not more than 3%).

Table 2 shows that the variation coefficient for the turbidity factor for different wind directions and velocities varies in most cases from 20 to 30%.

For the minimum (1-2 m/sec) and maximum (5-6 m/sec) wind velocities we found the difference in the turbidity factors and also the values of the reliability index for the determined differences (t). A comparison of t with its critical value, found from the Student's distribution for a stipulated confidence coefficient P = 0.95, indicated that only in the case of winds with a southerly component the differences between the T_2 values can be random [4].

The differences between the mean extremal values of the turbidity factor for different wind directions are statistically significant for all seasons of the year.

In order to evaluate the influence of wind direction and velocity on atmospheric turbidity under the conditions of a city and in its neighborhood we used simultaneous data for midday observations for 1955-1973 at the meteorological observatory at Moscow State University and the station imeni S. I. Nebol'sin, situated 40 km to the southwest of Moscow. Wind data were taken from observatory observations (Fig. 2).

Figure 2 shows that as an annual average the midday values of the turbidity factor are maximum at both stations in the case of a southeasterly wind direction. With a shifting of the wind from southerly to northerly directions the turbidity factor both in Moscow and outside the city decreases approximately identically (by 20%), that is, the influence of atmospheric circulation and the change in air masses in the city and outside the city is identical. However, in the case of a northeasterly wind direction a second T_2 maximum appears at the station imeni S. I. Nebol'sin; this is evidently caused by the inflow of air masses, considerably contaminated by urban aerosols.

An increase in turbidity is discovered in the case of a northeasterly wind direction and on the southwestern margins of Moscow (meteorological observatory of Moscow State University) during all seasons except summer. During summer there is no such increase in atmospheric turbidity when there are northeasterly winds since the influence of the city is overlapped by circulation factors. The maximum T_2 values are observed in summer when there are southerly flows bringing the most dust-laden air into the Moscow region.

The midday values of the turbidity factor for all wind directions in Moscow are greater than outside the city. As a yearly average the minimum differences between Moscow and the suburbs are observed in the case of southerly and southwesterly winds, whereas the maximum values (14%) are observed in the case of an easterly wind. There is also a decrease in the differences in the case of a northeasterly wind. It is traced during all seasons of the year, appearing most conspicuously in winter. During summer the greatest differences (10-12%) between the two stations are observed when there are southerly and southeasterly winds.

Fig. 3. Diurnal variation of turbidity factor. 1) 28 August 1965; 2) 29 July 1971.

For different wind velocities the differences between the city and the suburban region attain the highest level (20%) in the case of calm weather, when the influence of local sources of atmospheric contamination is manifested most strongly in Moscow. With an increase in wind velocity (more than 6 m/sec) the impurities contaminating the atmosphere are propagated over a great area and these differences are decreased by almost a factor of three.

The influence of atmospheric circulation on change in the turbidity factor can be traced on synoptic charts. A change in synoptic processes (deepening or blurring of cyclones and anticyclones, passage of fronts) and the accompanying change in air masses and change in wind direction and velocity are strongly reflected in the turbidity factor value and its diurnal variation.

In confirmation of this we will examine two examples of synoptic situations exerting a considerable influence on the diurnal variation of T_2 (Fig. 3).

On 28 August the minimum values of the turbidity factor were observed during the daytime and the maximum values were observed in the morning and evening. The amplitude between the extremal T_2 values was almost 50%. At this time over a period of three days Moscow was on the western margin of an extensive anticyclone whose center was situated in the Gor'kiy region. As a result, air from the southeast entered the central part of the European USSR, despite its low velocity. During the daytime hours, the wind velocity, under the influence of convection, somewhat increased, which led to an increase in atmospheric transparency. During the second half of the day, with attenuation of wind velocity, transparency decreased somewhat.

The diurnal variation of the turbidity factor on 29 July 1971 characterizes a different situation; on that day Moscow was situated in a region of increased pressure with its center in the Velikiye Luki region. On this day there was an intensive air flow from the north (4-6 m/sec). As a result, the T_2 value decreased by almost a factor of 2 from the morning to the evening hours.

The cited examples graphically show what an important influence different types of synoptic situations exert on the optical regime of the atmosphere in a particular place.

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UDC 551.464(261)

CONTAMINATION OF SURFACE WATERS OF THE CENTRAL REGION OF THE NORTH ATLANTIC BY THE ATMOSPHERIC FALLOUT OF STRONTIUM-90

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 67-72

[Article by Candidate of Physical and Mathematical Sciences K. P. Makhon'ko, Institute of Experimental Meteorology, submitted for publication 22 August 1978]

Abstract: In the Atlantic region 20-40°N, 20-60°W, in which in the first approximation it is possible to neglect advection, the author has computed the temporal variation of the mean annual concentrations of strontium-90 in a quasihomogeneous layer of the ocean for 1954-1976 on the basis of the quantity of atmospheric fallout of the isotope. Also examined is the relationship between the concentration of strontium-90 and the intensity of nuclear explosions and the influence of these explosions on the change in the fraction of the reserve of the isotope in the quasihomogeneous layer and on the dispersion of the concentrations of strontium-90 in the surface layer of the ocean.

[Text] The principal role in the global radioactive contamination of the seas and oceans is played by the atmospheric fallout of the products of nuclear explosions, which contaminate the surface water layer. Simultaneously with the precipitation of isotopes from the atmosphere onto the water surface there is a process of exchange of surface waters with the waters of the lower, deep layers, as a result of which the isotopes are transported into the deeper water layers. Under real conditions the process of advection of water masses is usually superposed on this picture [2, 4].

Now we will examine the contamination of the surface waters of the northern part of the Atlantic Ocean by the fallout of strontium-90 from the atmosphere. In order to avoid the influence of the advection of strontium-90 by sea currents, we will limit ourselves to the central region, where advection in the first approximation can be neglected.

As is well known, in the Atlantic the water masses move from east to west in the zone 10-20°N; then along the shores of America they are rapidly transported northward approximately to 40°N, and then move slowly eastward. Along the shores of Europe and North Africa the water flow moves to the south. The time for total circulation of water masses is 14-16 months. Thus, the exchange of water masses between the region approximately bounded by the ccoordinates 20-40°N and 20-60°W and adjacent regions is difficult and it can be neglected.

The strontium-90 falling from the atmosphere onto the water surface is relatively rapidly mixed in the quasihomogeneous layer of the ocean and from there enters the lower layers through the boundary from the thermocline. Here it is possible to see a certain similarity to the process of entry of the isotope from the stratospheric reservoir into the troposphere, which is described well by the law of first-order kinetics. This gives basis for using a similar approach in describing the process of vertical propagation of the isotope in the ocean.

A temporal change in the concentration of strontium-90 in the quasihomogeneous layer of the ocean dC/dt is ensured, on the one hand, by the flow of isotope from the atmosphere onto the water surface P(t) (strontium-90 in this case is mixed in a quasihomogeneous layer with the thickness h), and on the other hand, by a flow of isotope from this layer in depth -- ΛC and by radioactive decay -- λC:

$$\frac{dC}{dt} = \frac{P(t)}{h} - (\Lambda + \lambda)\, C. \quad (1)$$

The parameter Λ, characterizing the rate of elimination of the quasihomogeneous layer, with averaging for a year in the first approximation can be considered a constant value.

The solution of equation (1) has the form

$$C = e^{-\Lambda' t} \int_0^t \frac{1}{h} P(t)\, e^{\Lambda' t} dt + C_0 e^{-\Lambda' t}, \quad (2)$$

where $\Lambda' = \Lambda + \lambda$, C_0 is the strontium concentration in sea water with t = 0.

From (2) we find the value Λ.

Before the first thermonuclear explosions the radioactive fallout from the atmosphere was relatively small. Therefore, 1954, the year when the first nuclear explosion was set off, can be regarded as the beginning of reckoning and it can be assumed that $C_0 = 0$.

As is well known, the fallout of strontium-90 onto the sea surface occurs with the same intensity as on the surface of the land [8]; therefore, for computations we will use data in [5] on the fallout of strontium-90 in the latitude zone 20-40°N.

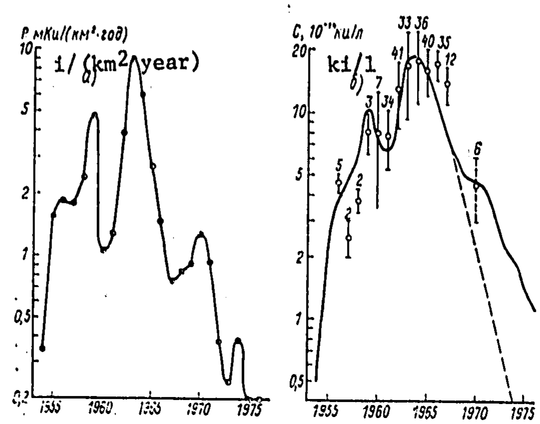

Fig. 1. Temporal change of fallout of strontium-90 from atmosphere in latitude zone 20-40°N (a) and its concentration in the quasihomogeneous layer of the ocean in the region 20-40°N, 20-60°W (b).

Figure 1 shows the temporal change P(t) -- values for the annual fallout of strontium-90 during 1954-1976.

The thickness h of the quasihomogeneous layer h in the considered region of the Atlantic Ocean can be evaluated on the basis of the character of the vertical profiles of water temperature [6]. During the year h varies in a wide range; the mean annual value is approximately 70 m.

The experimental data published by a number of authors on the concentration of strontium-90 in the surface waters of the Atlantic up to 1967 are presented in systematized form in [2]. Using data on the concentration of strontium-90 in the considered region and data on the intensity of fallout of this isotope from the atmosphere, using formula (2) by a numerical method we find the constant elimination of strontium-90 from the quasihomogeneous layer of the ocean λ. The results of computations by the least squares method give a value $\lambda' = 0.5$ year^{-1}, which corresponds to $\lambda = 0.485$ year^{-1} and a time of presence of strontium-90 in the quasihomogeneous layer $\tau = 1/\lambda = 2.1$ years.

The determined τ value agrees satisfactorily with the evaluation in [3] for the Atlantic Ocean $\tau = 3.5$ years, made on the assumption that the fallout of strontium-90 can be assumed constant during the period 1954-1961 (P = const) and with data in [7] for the abyssal part of the Pacific Ocean in the region of Bikini atoll τ = 2.6 years, obtained on the basis of measurements of the concentration of lead-210.

We will use the Λ values which we obtained for reconstructing the full chronology of contamination of the surface waters of the central region of the North Atlantic with strontium-90 of global origin after the onset of carrying out of thermonuclear explosions. The solid curve in Fig. 1b shows the change in the mean annual concentrations of strontium-90 in the quasihomogeneous layer, computed using formula (2) on the basis of data [5] on the atmospheric fallout of this isotope. In this same figure the dots represent measurement data for the concentration of strontium-90 in the surface waters of the considered region of the Atlantic which we took from [1, 2]. The numbers near the dots indicate the number of measurements included in the averaging; the short vertical lines designate the mean square scatter of data for individual measurements. Up to 1960 the number of measurements of the surface concentration of strontium-90 in the considered region was small and observations were not made in all seasons of the year. Therefore, the representativeness of the mean annual concentrations computed using these data is low. Nevertheless, the experimental points in general confirm the sharp increase in the concentrations of strontium-90 in 1954-1959, determined by computations. During the period 1961-1966 observations of the concentration of strontium-90 in the surface waters of the considered region were made virtually monthly. These data are most representative; the corresponding points coincide quite well with the computed curve. During the years which followed the number of observations and their regularity decreased sharply, but the few data available confirm the general shape of the concentration curve.

As follows from Fig. 1b, the concentration of strontium-90 of global origin in the surface waters of the considered region of the Atlantic after the onset of tests of thermonuclear weapons in 1954 increased by 1963-1964 by a factor of approximately 40. The signing of the Moscow agreement on the cessation of tests of nuclear weapons in 1963 led to a decrease in the contamination of surface waters in the years which followed as a result of a marked decrease in the atmospheric fallout of strontium-90 and natural processes of self-purification of ocean surface waters. By 1976 the global contamination of surface waters had attained the level of 1955 and continued to decrease.

A comparison of the curves in Fig. 1 makes it possible to note that the temporal variation of the surface concentration of strontium-90 for the most part duplicates the temporal variation of atmospheric fallout, but in a highly smoothed form. For example, the maxima of strontium-90 fallout were observed in the year following the next powerful series of nuclear explosions; accordingly, in this same year the maxima of the concentration of the isotope in sea water were observed. Between 1963 and 1967 there were no powerful injections of strontium-90 in the planetary atmosphere; as a result of natural processes of atmospheric self-purification the

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fallout of this isotope during this time decreased exponentially with a period of half-decrease of about 1 year. Beginning in 1967 countries not adhering to the Moscow agreement began to set off powerful thermonuclear explosions and therefore beginning in 1968 the stable decrease in radioactive fallout ceased and in some years even increased.

However, in the time interval free of powerful explosions from 1971 to 1973 the intensity of the fallout again decreased in conformity to this same law (see Fig. 1a).

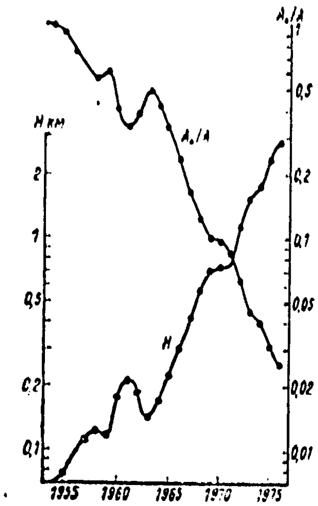

Fig. 2. Temporal change in reduced depth of penetration of strontium-90 into ocean (H) and fraction of reserve of isotope in quasihomogeneous layer of ocean (A_0/A) (region 20-40°N, 20-60°W).

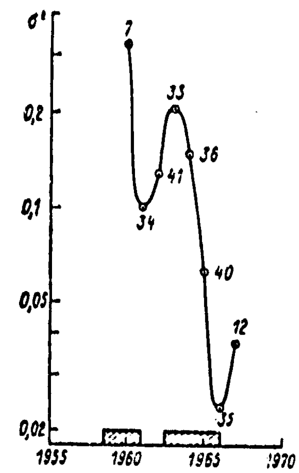

Fig. 3. Change in dispersion of mean annual concentrations of strontium-90 in surface layer of ocean (region 20-40°N, 20-50°W). The shading shows the periods during which there were no powerful nuclear explosions.

Now we will compute the concentration of strontium-90 in the quasihomogeneous layer of the considered region of the Atlantic on the assumption that after 1963 there were no powerful nuclear explosions and that fallout of the isotope from the atmosphere continued to decrease exponentially with the same exponent.

The results of these computations, using formula (2), are indicated by the dashed line in Fig. 1b. As can be seen in the figure, as a result of the continuing tests of nuclear weapons the concentration of strontium-90 in the surface waters by 1975 was 5-6 times greater than the value which could be expected if all the nuclear powers had adhered to the Moscow agreement.

It also follows from Fig. 1b that during the periods when there were no powerful nuclear explosions, the concentration of strontium-90 in the ocean also decreased exponentially, but with a different period of half-decrease, approximately in two years. In the year following a powerful injection of strontium-90 into the atmosphere, the fallout of the isotope from the atmosphere increased and accordingly the concentration of strontium-90 in sea water deviated from the exponent.

The noted regularities made it possible to establish an empirical correlation between the mean annual concentration of strontium-90 in sea water C_i in the i-th year and the intensity of nuclear explosions, which is proportional to the intensity of injection of strontium-90 into the atmosphere, W_{i-1} in the i - 1st year:

$$C_i = aC_{i-1} + bW_{i-1}, \quad \text{Ki/1}, \tag{3}$$

where C_{i-1} is the concentration of strontium-90 in the surface layer of sea water in the i - 1st year, a and b are empirical constants.

The intensity of nuclear explosions, corresponding to the yield of fission products of the nuclear fuel, as is well known, after 1962 was approximately proportional to the total intensity of explosions of the megaton rank; therefore, in formula (3) by W is understood the total intensity of the explosions and the data in [9] are used for the Northern Hemisphere. Then for the considered region of the Atlantic after 1963 the parameters in formula (3) assume the following values: $a = 0.75$, $b = 0.11 \cdot 10^{-14}$ Ki(1·Mt) with $1 \leq W \leq 3$ Mt. The mean discrepancy in computations based on formulas (2) and (3) is 5%, the maximum discrepancy is 16%.

The strontium-90 falling onto the ocean surface is relatively rapidly mixed in the quasihomogeneous layer and is gradually propagated in the layer of the main thermocline under the influence, for the most part, of vertical turbulent diffusion. As a result of seasonal variations of the lower boundary of the thermocline strontium-90 gradually penetrates into the deeper layers of the ocean, and reaching the bottom, is accumulated in the bottom deposits. The total reserve of strontium-90 in a vertical column of water with a unit base will evidently be equal to the time integral of atmospheric fallout of this isotope onto the water surface.

It is of interest to examine the temporal change in the ratio of the reserve of strontium-90 in the ocean A to its concentration in the surface layer C. The ratio $A/C = H$ has the dimensionality [L] and it can be interpreted arbitrarily as the depth of a column of water having the strontium-90 concentration C, which includes the entire quantity of the isotope falling onto the upper base of the column. We will call this parameter the reduced depth of penetration of the isotope into the ocean.

Figure 2 shows the change in the reduced depth H with time. There is a clearly expressed general tendency to a gradual increase in the reduced depth of penetration of strontium-90 into the ocean. A comparison of Fig. 2 and Fig. 1a makes it possible to note that the maxima of the curve of fallout of strontium-90 from the atmosphere correspond to the minimum values of the depth H or the case of a slowing of the rate of its increase. We note that if by the parameter A we mean the reserve of strontium-90 in a column of water without allowance for the quantity of isotope passing into the bottom deposits, then the reduced depth H cannot be greater than the depth of the ocean. However, if the A parameter includes the reserve of isotope in the bottom deposits, as time passes the reduced depth H can exceed the depth of the ocean; in this case the H parameter assumes an abstract sense.

Figure 2 also shows the temporal change in the fraction of the reserve of strontium-90 in the quasihomogeneous layer A_0 relative to its total reserve in the ocean A. The shape of this curve is the reverse of the shape of H(t); by 1975 only 3% of the strontium-90 was contained in the quasihomogeneous layer of the ocean.

We note in conclusion that all the preceding discussions related to the mean annual concentrations of strontium-90 in the quasihomogeneous layer of the ocean. In real measurements of concentrations of strontium-90 in the surface waters this sea water sample is taken only once and this makes it possible to determine only the instantaneous value of the concentration. In the course of the year the surface concentrations of strontium-90 must change as a result of the seasonal variation of radioactive fallout and also as a result of seasonal variation of thickness of the quasihomogeneous layer; the seasonal changes in the thermocline should also be reflected to some degree. In addition to the temporal changes, there should also be spatial variations in the field of concentrations of strontium-90 both by virtue of the "spotty" nature of the field of atmospheric fallout of this isotope and as a result of spatial inhomogeneities in the intensity of vertical exchange processes in the ocean.

All this forces us, for a correct determination of the mean annual concentrations of the isotope in the investigated region of the ocean, to carry out a great number of observations at different points throughout the year.

Figure 3 gives an idea concerning the really observed dispersions of the concentration of strontium-90 in the surface layer of the ocean. The figure shows the temporal change in the dispersion, computed using measurement data in the considered region of the Atlantic, cited in [2]. The numbers near the dots indicate the number of individual measurements used in computing the dispersion. In the lower part of the figure, by the shading, we have represented the periods of time during which there were no powerful nuclear explosions. Figure 3 shows that during these periods of time the dispersion decreased rapidly, but from the onset of the tests of nuclear weapons again began to increase, attaining 0.2-0.3 during individual years. This is indicative of the great nonuniformity of the field of concentrations of strontium-90 in the surface layer of the ocean during periods during which nuclear explosions are carried out.

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EVALUATION AND PREDICTION OF CHANGE IN WATER MINERALIZATION IN LARGE RIVERS OF THE EUROPEAN USSR WITH ALLOWANCE FOR THE INFLUENCE OF ECONOMIC ACTIVITY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 73-81

[Article by Ye. A. Leonov, State Hydrological Institute, submitted for publication 20 June 1978]

Abstract: the author gives an evaluation of the present-day increase in the mean annual mineralization of water in the large rivers of the European USSR. The article gives a prediction of the change in mineralization of river waters up to the year 2000, taking into account the influence of economic activity.

[Text] The rapid increase in industrial and agricultural production, increase in population and urbanization are leading to ever-increasing contamination of the atmosphere, fresh and oceanic waters, glaciers and the soil cover. The impact of man on the environment in the long run can lead to a disruption of the mechanisms of self-regulation of the biosphere, to irreversible effects. Therefore, the problem of protecting the environment against contamination, and especially the problem of maintaining and controlling (monitoring) the quality of water is one of the most important scientific-technical problems of our day.

Experience has shown that the anthropogenic salinization of waters of rivers, lakes and internal seas is fraught with serious economic and ecological consequences. At the present time, in different countries of the world, under the influence of man's economic activity the mineralization of water in individual rivers has increased by a factor of 2-3 in comparison with the natural level [4, 12, 13].

In order to monitor the quality of water, and also for determining the admissible anthropogenic load on the water medium there must be objective data on the present-day background characteristics of the hydrosphere, and especially, on one of its most important components -- mineralization. It is also of special interest to predict the expected changes in mineralization of river waters in the future, taking into account the planned water management measures and the development of the national economy of the country as a whole.

Investigations of the problem of the influence of economic activity on the quality of river waters began to develop particularly actively in the late 1960's and the early 1970's [2-9, 11]. Much attention has been devoted to the problem of the influence of industrial and domestic waste water on the quality of water [1-3, 7]. A strong influence of mine water on the change in mineralization of river water was noted [9]. Investigations were made to evaluate the salinization of river waters by drainage-basin runoff from irrigated fields [11]. A detailed study has been made of problems relating to the influence of reservoirs on the change in mineralization of river waters [5].

However, despite the diverse publications and special investigations, the problems relating to the influence of the entire complex of economic activity on the quality of water, and in particular, on the change in mineralization of river waters, have been studied inadequately. Most of the studies have a special, sometimes descriptive character.

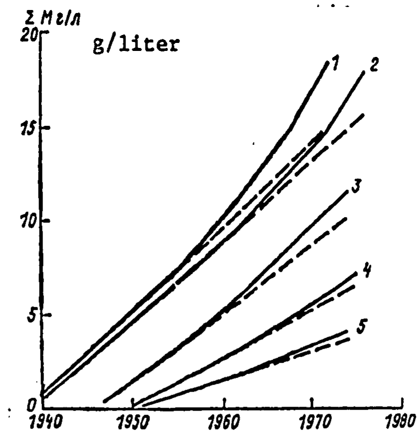

Fig. 1. Integral curves of the sums of mean annual mineralization of water. 1) Kura River -- Sal'yany, 2) Don River -- Razdorskaya station, 3) Terek River -- Kargalinskaya station, 4) Volga River -- Verkhne-Lebyazh'ye, 5) Zapadnaya Dvina River -- Daugavpils.

The scales and the intensity of the influence of economic activity on the mineralization of river waters is dependent on the extent of the drainage basin, the type and number of sources of salinization existing within the limits of the considered basins. It is obvious that the greater the extent of the fluvial drainage basin, the greater is the probability of an overall influence of different sources of salinization and types of economic activity on the change in mineralization of river waters.

It was demonstrated in [1, 2, 7] that the most concentrated waste water runoff is from enterprises of the chemical, coal and metallurgical industries. The mineralization of drainage-basin waters from irrigated fields is quite high. The greatest influence on the change in mineralization of river waters is exerted by: transfer of discharge, irrigation, urbanization, pumping out of mine water, application of fertilizers to agricultural fields, working of open pits and creation of reservoirs.

For a quantitative estimate of the change in the mean annual mineralization of water in large rivers of the European USSR under the influence of economic activity we used data from long-term (1936-1976) observations of runoff and mineralization of water published in the Hydrological Yearbooks. On the basis of data from network observations it is difficult to give a separate evaluation of the influence of different types of economic activity on the mineralization of river waters. Therefore, below we give integral evaluations of the change in the mean annual mineralization of water under the influence of the entire complex of economic activity factors.

A preliminary analysis of the chronological curves of the variation of mineralization of large rivers on the southern slope in the European USSR (Don, Kura, Ural and others) indicated that even visually it is possible to trace the temporal trend, expressed in a systematic growth in the mineralization of river waters. The mineralization of water began to increase particularly sharply in the the mid-1950's-1960's. A quantitative evaluation of the change in the mineralization of river waters was made using the integral curves method. As an example, Fig. 1 shows the integral curves for the mean annual mineralization of water in the Kura, Don, Terek, Volga and Zapadnaya Dvina Rivers.

An analysis of the integral curves of the mean annual mineralization of water on the large rivers of the European USSR made it possible to discriminate periods with a hydrochemical regime which is natural and a regime which has been disrupted by economic activity. A quantitative characterization of the change in the mean annual mineralization of water in the large rivers of the European USSR during periods with different levels of development of economic activity in the drainage basins is given in Table 1, from which it can be seen that the mineralization of water has increased to the greatest degree in the Kura and Don.

On the Kura River at Sal'yany, as an average for 1958-1972, the increase in the mean annual mineralization of water was 0.21 g/liter or by 47% over the natural level (Table 1). The increase in water mineralization for the most part was caused by the development of irrigated agriculture. In the basin of the Kura River in 1975 the area of the irrigated lands attained 1,670,000 hectares. With such a great area of irrigation and the high salinization of the soils of the Kura-Araksinskaya Lowland the runoff of highly mineralized drainage-basin waters was very significant. For example, the total volume of the annual runoff of only the two largest collectors (Glavnyy Shirvanskiy collector and the Mugano-Sal'yanskiy channel)

Table 1

Characteristics of Mean Annual Mineralization of Water in Large Rivers of the European USSR During Periods With Different Levels of Economic Activity in Basins

1 Река—пункт	2 Площадь водосбора, км²	3 Норма стока, м³/сек	4 Период наблюдения за минерализацией	5 Средняя годовая минерализация воды, г/л	6 Среднее приращение минерализации, г/л	Средняя годовая минерализация, г/л 7: 8 наименьшая	9 наибольшая	10 Коэффициент вариации
11 *Реки южного склона*								
13 Волга — с. Верхне-Лебяжье	1 360 000	8050	1951—1959 / 1960—1975	0,250 / 0,290	0,040	0,230	0,360	0,07
14 Дон — ст-ца Раздорская	378 000	885	1936—1963 / 1964—1976	0,430 / 0,590	0,160	0,30	0,78	0,18
15 Днепр — г. Киев	328 000	1362	1947—1966 / 1967—1973	0,210 / 0,230	0,020	0,18	0,27	0,10
16 Терек — ст-ца Каргалинская	37 400	277	1947—1957 / 1958—1974	0,382 / 0,432	0,050	0,33	0,49	0,12
17 Кубань — х. Зайцево Колено		189	1951—1960 / 1966—1974	0,260 / 0,340	0,080	0,22	0,38	0,09
18 Кура — г. Сальяны	188 000	550	1939—1957 / 1958—1972	0,444 / 0,661	0,217	0,329	1,00	0,31
19 Урал — г. Оренбург 19	82 300	136	1949—1964 / 1965—1974	0,402 / 0,450	0,048	0,250	0,552	0,16
12 *Реки северного и северо-западного склона*								
20 Печора — Усть-Цильма	248 000	3520	1948—1974	0,060	0,00	0,051	0,072	0,10
21 Сев. Двина — г. Усть Пинега	350 000	694	1950—1971	0,160	0,00	0,133	0,214	0,14
22 Нева — пгт. Ново-Саратовская	281 000	2530	1949—1968 / 1969—1976	0,053 / 0,064	0,011	0,049	0,074	0,04
23 Зап. Двина — г. Даугавпилс	64 600	403	1951—1962 / 1963—1974	0,161 / 0,138	0,027	0,122	0,230	0,14
24 Луга — г. Кингисепп	12 700	92,7	1947—1962 / 1963—1975	0,162 / 0,194	0,032	0,127	0,203	0,12

KEY:

1. River - station
2. Basin area, km^2
3. Runoff norm, m^3/sec
4. Period of observation of mineralization
5. Mean annual mineralization of water, g/liter
6. Mean mineralization increment, g/liter
7. Mean annual mineralization, g/liter
8. Minimum
9. Maximum
10. Variation coefficient
11. Rivers of southern slope
12. Rivers of northern and northwestern slope
13. Volga -- Verkhne-Lebyazh'ye
14. Don -- Razdorskaya station
15. Dnepr -- Kiev
16. Terek -- Kargalinskaya station
17. Kuban' -- Zaytsevo Koleno
18. Kura -- Sal'yany
19. Ural -- Orenburg
20. Pechora -- Ust'-Tsil'ma
21. Sev. Dvina -- Ust' Pinega
22. Neva -- Novo-Saratovskaya
23. Zap. Dvina -- Daugavpils
24. Luga -- Kingisepp

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during recent years was 1.5-1.8 km^3. This is 10% of the annual runoff norm for the Kura River at Sal'yany, and in years with little water -- up to 15-30%. The present-day mineralization of drainage waters of these collectors on the average is 10-14 g/liter, but during the initial period of work in 1954 it was 28-36 g/liter. The runoff of these collectors enters directly into the Caspian Sea, bypassing the river network. If these waters were discharged into the Kura River, the mineralization of the rivers would be several times greater than at the present time. Only due to the separate scheme for the diversion of drainage waters during irrigation the mineralization of Kura waters is relatively low.

In the Don River at Razdorskaya station the increase in water mineralization during the last 13 years (1964-1976) was 0.16 g/liter or by 37% over the natural level. The intensity of increase in mineralization of river waters was 0.0123 g/liter per year. The salinization of river waters was caused for the most part by technogenic factors, especially in the basin of the Severskiy Donets, where there was a great inflow of highly mineralized mine waters of the Donbass and the industrial runoff of numerous enterprises of the coal, metallurgical, chemical industries. The irrigation of arid lands along the lower Don plays a secondary role in salinization of river waters because the mineralization of drainage-basin waters on the average ranges around 2-5 g/liter, whereas the total volume of runoff

KEY FOR TABLE 2

A. River -- station
B. Area of basin, km^2
C. Initial year
D. Trend line formula
1. Volga -- Verkhne-Lebyazh'ye
2. Don -- Razdorskaya station
3. Dnepr -- Kiev
4. Terek -- Kargalinskaya station
5. Kuban' -- Zaytsevo Koleno
6. Kura -- Sal'yany
7. Ural--- Orenburg
E. t is the sequence number for the computation year; for the initial year t = 1

KEY FOR TABLE 3

1. River -- station
2. Observed
3. Predicted
4. Volga -- Verkhne-Lebyazh'ye
5. Don -- Razdorskaya station
6. Dnepr -- Kiev
7. Terek -- Kargalinskaya station
8. Kuban' -- Zaytsevo Koleno
9. Kura -- Sal'yany
10. Ural -- Orenburg
11. Note: The figures in the parentheses are the approximate water mineralization values. The confidence interval for the prediction was determined with the probability level 0.9 (linear trend).

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of the collector waters of irrigation systems of the lower Don in 1975 with an irrigated area of about 235,000 hectares was 0.75 km^3. Relative to the river annual runoff norm the volume of these waters is only 2.6%.

On the Terek River (Kargalinskaya station) as an average for the period 1958-1974 the increase in the mean annual mineralization of river waters was 0.050 g/liter or 13% above the natural level. This intensity of increase in the mean annual mineralization of water during these years was 0.0030 g/liter annually. The small increase in water mineralization is attributable to the fact that the greater part of the irrigated lands (150,000 hectares) is situated in the delta of the Terek River, that is, below the measuring post at Kargalinskaya station. A considerable part of the lands irrigated by the waters of the Terek are situated outside the limits of the basin, whereas the remainder (about 200,000 hectares) is situated in the middle and upper course of the river, in regions of old irrigation, where there is an almost steady hydrochemical regime of collector and river waters.

On the Kuban' River below Krasnodar, during the last 10 years the mean annual mineralization of river waters in the delta distributaries (Zaytsevo Koleno settlement station) increased by 0.080 g/liter or by 31% over the natural level (Table 1). The relatively low increment of mineralization of river waters in the delta of the Kuban' River, despite broad development of rice cultivation (irrigated area in 1975 under rice rotation was 153,000 hectares), was caused by a relatively low salinization of the soils by smooth and quite prolonged periods of rice cultivation. The first rice system in the delta of the Kuban' delta was created in 1932-1936. In addition, by virtue of the separate scheme for water diversion the drainage waters from the largest Petrovsko-Anastasiyevskaya and Kubanskaya rice systems were discharged directly into the estuaries of the Sea of Azov, bypassing the river network. The influence of the irrigation systems on the mineralization of river waters situated above Krasnodar was extremely small because the total areas in irrigation constitute only about 30,000 hectares. The present-day influence of industrial-communal runoff on the mineralization of Kuban' water is small due to the relatively small volume. By 1980-1985 the volume of these waters can be doubled, which will result in an increase in the mineralization of river waters.

On the Volga River at Verkhne-Lebyazh'ye, as an average for the period 1960-1975, the mean annual mineralization of Volga waters increased by 0.040 g/liter or by 16% over the natural level (Table 1). The intensity of increase in the mean annual mineralization of water in this case was 0.0025 g/liter. The increase in water mineralization for the most part was caused by the entry of salts into the river with industrial-communal waste water, mine water and the wash of fertilizers from agricultural fields. The influence of drainage waters from the irrigation systems of Saratovskaya, Kuybyshevskaya and Volgogradskaya Oblasts on the increase in mineralization of Volga waters at the Verkhne-Lebyazh'ye station is extremely insignificant, since in 1975 in the coastal zone Volga waters were used for irrigating only 400,000 hectares of lands, whereas the drainage waters from these lands in part were discharged into closed depressions and did not reach the rivers.

On the Ural River at Orenburg during recent years (1965-1974) the mineralization of river waters increased by 0.048 g/liter or by 12% over the natural level; the intensity of increase in mineralization of river waters was 0.0050 g/liter per year. As in the Volga, the increase in mineralization of the Ural river waters was caused for the most part by the discharge of industrial-communal waste waters into the river.

In the rivers of the northwestern European USSR the intensity of salinization of river waters in comparison with the rivers on the southern slope of the country is lower. For example, in the Zapadnaya Dvina River at Daugavpils it was 0.0025 g/liter per year, in the Neva River at Novosaratovskaya station -- 0.0014 g/liter per year. During the most recent years there has also been a slow increase in the mineralization of waters in the Neman, Narva, Luga, Onega and others.

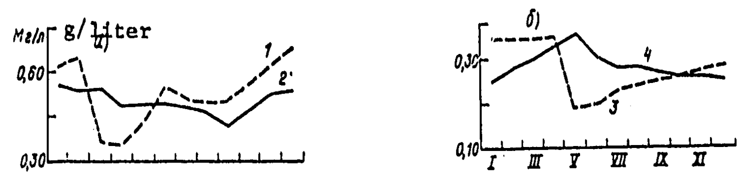

Fig. 2. Intraannual variation of mineralization of waters. 1, 3) under natural conditions; 2, 4) under conditions of regulated runoff and intensive economic activity in drainage basin.

In the long-term variation of the mean annual mineralization of river waters of the Pechora, Severnaya Dvina, Mezen' and some other rivers in the northern European USSR it was not possible to detect the influence of economic activity on an increase in the mineralization of river waters.

The different duration of the periods of natural and impaired hydrological and hydrochemical regimes of different rivers in the European USSR is attributable to the nonuniform development of industry and agriculture both in area and in time.

In connection with the presently adopted technology for the purification of waste waters industrial strongly mineralized waste waters are usually accumulated in settling tanks and dealkinization tanks and are discharged into rivers during the period of spring high water. As a result, even in large rivers the intraannual variation of the mineralization of water has experienced changes under conditions of economic activity. The creation of large reservoirs has led not only to a redistribution of runoff within the year, but also to an evening-out of the annual variation of the mineralization of water. As an example, Figure 2 shows graphs of the course of mineralization of water in the Don River at Razdorskaya station (a) and in the Volga River at Verkhne-Lebyazh'ye (b) under natural conditions and under conditions modified by economic activity. Figure 2 shows that the intraannual course of mineralization of river waters under the influence of a complex of economic activity factors has radically changed. The onset of the time of minimum mineralization of Don waters has been displaced from March to September; the amplitude of the variation decreased. On the Volga there has also been a radical change in the times of occurrence of the phases of increased and reduced mineralization of water.

A prediction of the mean annual mineralization of the waters in the large rivers of the European USSR for 10-15 years was made by the statistical forecasting method [9]. The possibility of using this method was governed by the availability of sufficiently long series of observations of runoff and mineralization. In addition, by virtue of the great inertia of the processes of anthropogenic salinization of river waters in large river basins the use of methods of statistical forecasting for a period of 10-15 years is quite reliable since during the course of such a period the economic systems, experiencing changes, still do not completely lose "inertia." The water-mineral balance method was not used for predicting the mean annual mineralization of water since considering the great number (usually more than 1,000) of different anthropogenic sources of salinization situated within the limits of one major river basin its use is extremely difficult.

A statistical forecasting of mean annual mineralization of water was accomplished using data from network observations made over a period of many years. We selected a representative series, using which we selected an approximating function in the form of the mean annual water mineralization trend line equation (Table 2). The computed values of the mean annual mineralization of water for 1980 and 1985, determined using these trend line equations, are given in Table 3. In this same table, for comparative purposes, we have given the observed values of the mean annual mineralization of water during the preceding years.

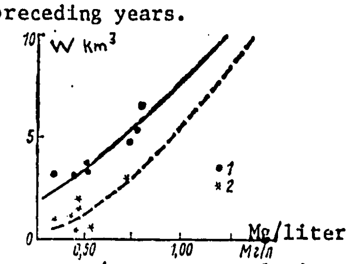

Fig. 3. Correlation between the mean annual mineralization of water and total nonreturn water consumption for communal and industrial needs and irrigation for the Kura River at Sal'yany (1) and the Don River at Razdorskaya station (2) determined from averaged data for 1940, 1950, 1955, 1960, 1965, 1970 and 1975.

An analysis of Table 3 shows that up to the year 2000 for all the major rivers on the southern slope of the European USSR there will be a further increase in the mean annual mineralization of river waters. In 1985, in comparison with 1975, it is expected that there will be an increase in the mean annual mineralization of water in the Don River at Razdorskaya station by 0.240 g/liter or by 33%, for the Kura River at Sal'yany by 0.200 g/liter or by 24%. In the other rivers the increase in mineralization of river waters is expected to be less significant (Table 3).

A prediction of the change in the mean annual mineralization of river waters in the year 2000 was made in two variants. Using the first variant, the computations were made under the condition that the mean intensity of increase in the mean annual mineralization of water in individual rivers will remain constant to the end of the century. Using the second variant, we took into

Table 2

Equation for Trend Lines for Mean Annual Mineralization of Water (g/liter) for Major Rivers in the European USSR

Река — пункт A	Площадь водосбора, $км^2$ B	Исходный год C	Формула линии тренда D
1. Волга — с. Верхне-Лебяжье	1 360 000	1959	$M=0{,}29+0{,}0030\ (t-9)$
2. Дон — ст-ца Раздорская	378 000	1964	$M=0{,}59+0{,}0252\ (t-7)$
3. Днепр — г. Киев	328 000	1965	$M=0{,}24+0{,}0079\ (t-6)$
4. Терек — ст-ца Каргалинская	37 400	1957	$M=0{,}42+0{,}0077\ (t-6)$
5. Кубань — х. Зайцево Колено	—	1966	$M=0{,}33+0{,}00483\ (t-5)$
6. Кура — г. Сальяны	178 000	1956	$M=0{,}64+0{,}0194\ (t-9)$
7. Урал — г. Оренбург	82 300	1962	$M=0{,}43+0{,}0041\ (t-7)$

E Примечание. t — порядковый номер расчетного года; для исходного года $t=1$.

Table 3

Mean Annual Mineralization of Water (g/liter) of Major Rivers in European USSR

Река — пункт 1	2 Наблюденная					3 Прогноз		
	1940	1950	1960	1970	1975	1980	1985	2000
4 Волга — с. Верхне-Лебяжье	—	0,250	0,308	0,268	0,360	0,33±0,04	0,34±0,05	0,43—0,51
5 Дон — ст-ца Раздорская	0,463	0,550	0,432	0,473	0,728	0,84±0,14	0,97±0,16	1,04—1,40
6 Днепр — г. Киев	—	0,216	0,219	0,189	(0,280)	0,32±0,08	0,36±0,10	0,38
7 Терек — ст-ца Каргалинская	—	0,330	0,376	(0,410)	0,449	0,55±0,11	0,58±0,12	0,60—0,75
8 Кубань — х. Зайцево Колено	—	0,250	0,290	0,363	0,383	0,38±0,07	0,40±0,09	0,50—0,60
9 Кура — г. Сальяны	0,430	0,340	0,510	0,770	(0,700)	0,95±0,25	1,05±0,28	1,15—1,35
10 Урал — г. Оренбург	—	0,445	0,360	0,396	0,563	0,48±0,18	0,50±0,21	0,58—0,65

11 Примечание: В скобках даны приближенные значения минерализации воды. Доверительный интервал прогноза определен при уровне вероятности 0,9 (линейный тренд).

account the influence of the increasing rates of nonreturn water consumption in industry, communal management and irrigated agriculture on the increase in the mineralization of river waters. Experience has demonstrated that the correlation between the mean annual mineralization of river waters and the total nonreturn water consumption for economic needs is quite close for individual rivers. As an example, in Fig. 3 we show such a correlation for the Don and Kura Rivers. When using this correlation for predicting the mean annual mineralization of water data on the total nonreturn water consumption for river basins for the period up to the year 2000 were taken in accordance with the studies of the State Hydrological Institute. The nonreturn losses were taken into account only for industrial-communal needs and irrigation. In both variants of the forecast it was assumed that up to the year 2000 there will be no redirecting of the runoff of northern rivers onto the southern slope of the country and apparatus for the demineralization of waste water will be used only in individual cases and their operation will not exert an appreciable influence on a decrease in the mineralization of river waters.

According to the first variant of the forecast (Table 3), by the year 2000 the mean annual mineralization of water in the major rivers of the southern slope of the European USSR will increase in comparison with 1975: on the Volga River at Verkhne-Lebyazh'ye -- by 0.07 g/liter and will attain 0.43 g/liter; on the Don River at Razdorskaya station -- by 0.31 g/liter and will attain 1.04 g/liter, on the Terek River at Kargalinskaya station -- by 0.15 g/liter and will be equal to 0.60 g/liter, on the Kuban' River at Zaytsevo Koleno -- by 0.22 g/liter and will increase to 0.60 g/liter, on the Kura River at Sal'yany -- by 0.45 g/liter and will attain 1.15 g/liter.

According to the second variant of the forecast, the anticipated values for the mean annual mineralization of river waters for these same points by the year 2000 are found to be somewhat greater than according to the first variant, as follows: for the Volga River -- 0.51 g/liter, for the Don River -- 1.40 g/liter, for the Terek River -- 0.75 g/liter, for the Kura River -- 1.35 g/liter. Taking into account the approximate nature of the forecast, the resulting difference in the values of the mean annual mineralization of water, obtained by the two independent methods, can be considered satisfactory.

It is impossible to give a forecast for the year 2000 for the mean annual mineralization of water in the major rivers of the northern European USSR (Pechora, Severnaya Dvina, Mezen', Onega, and others) using data from network observations because tests of time series of the mean annual mineralization of water in these rivers to ascertain a trend did not reveal any significant, directed change in the mineralization of water with time. This is attributable to the insignificant present-day development of industry and cities in the basins of the mentioned rivers. However, taking into account the planned measures for developing the productive forces of the northern regions of the European USSR up to the year 2000 it can be expected that in the major rivers of this region by the end of this century we will begin to see an insignificant increase in the mineralization of river waters, similar to the present-day increase in the rivers of the northwestern European USSR (Neva, Luga, Zapadnaya Dvina -- see Table 1).

An analysis of the already occurring and a prediction of the anticipated changes in the mean annual mineralization of waters in the major rivers of the European USSR made it possible to draw the following conclusions:

1. In connection with the vigorous growth of industrial production, urbanization and use of chemicals in agriculture, the mean annual mineralization of water in the major rivers in the southern European USSR increased at the most downstream stations (Volga -- 16%, Don -- 49%, Dnepr -- 10%, Terek -- 13%, Kuban' -- 31%, Kura -- 47%, Ural -- 12%).

2. In the rivers of the northwestern European USSR an increase in the mineralization of waters under the influence of anthropogenic sources of salinization began later and with a lesser intensity than on the rivers of the southern slope, to wit: for the Neva -- 19%, for the Zapadnaya Dvina -- 6%, for the Luga -- 20%. In the Pechora, Severnaya Dvina, Mezen' and other rivers with the present-day level of development of economic activity in the basins of these rivers it was not possible to detect any appreciable changes in the mineralization of waters. At the same time, there is a definite tendency to an increase in the mineralization of river waters, noted from the beginning of the 1970's on the Neman, Narva, Onega and other rivers.

3. According to the forecast, by the year 1985 one can expect the following increase in the mean annual mineralization of water in comparison with 1975: Don -- by 33%, Dnepr -- by 15%, Terek -- by 30%, Kuban' -- by 32%, Kura -- by 24%. In the rivers of the northwestern European USSR the increase will be in the range 2-15%. By the year 2000 the mean annual mineralization of river waters will attain: Volga -- 0.43 g/liter, Don -- 1.04 g/liter, Dnepr -- 0.34 g/liter, Terek -- 0.60 g/liter, Kuban' -- 0.50 g/liter, Kura -- 1.15 g/liter.

4. The anticipated increase in the mineralization of river waters by the year 2000 will be caused by an increase in the washing of fertilizers from agricultural fields (whose production doubles each 8-10 years), an increase in the discharge of industrial-communal waste water by a factor of 2.5-3 in comparison with 1975, a considerable development of mining work, an increase in the quantity of combusted mineral fuel and other types of economic activity intensifying the migration of mineral salts in the biosphere.

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UDC 556.537

COMPUTATION OF VOLUMES OF WIND TRANSPORT OF SEDIMENTS IN CHANNEL FORMATIONS IN THE NADYM RIVER

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 82-85

[Article by Candidate of Geographical Sciences A. A. Levashov and O. N. Baryshnikova, Leningrad Hydrometeorological Institute, submitted for publication 19 June 1978]

Abstract: The authors propose a method for determining the magnitude and direction of reformations of morphological sand formations (not fixed by vegetation) under the influence of the wind.

[Text] A number of investigations [1, 3, 4, 6] have been devoted to the wind movement of solid material in channel formations and on floodplains [1, 3, 4, 6]. For example, N. I. Makkaveyev noted [3] that coastal shoals exposed when there are low water horizons, as a result of the looseness of the alluvium making them up and the lack of vegetation on them, are usually subject to a strong deflation which begins as soon as the upper layer of sediment dries out.

However, one cannot find information in the literature on a quantitative evaluation of the size of the transported solid material, especially in Siberian rivers. At the same time, this evaluation has become necessary in connection with the intensive exploitation of rivers and the dredging which has been carried out. The piles of sand created in the construction of navigable channels are commensurable with the dimensions of mesoforms and are also deflated.

The authors observed this process in different channel formations of the Nadym River over a period of years. In particular, on the surfaces of spits and mid-channel islands exposed after a dropoff of levels there were found to be sand ridges with a height from 5 to 20 cm, which after approximately two weeks disappeared and the surface of channel formations was leveled.

In 1976 studies were organized for a quantitative estimate of the transport of sand on a spit, mid-channel island and dump created by a suction dredge. For this purpose, flush with the surface of the sand formation we installed

Table 1

Observational Data on Sand Discharges and Wind Velocity

Дата измерений 1	Продолжительность измерений, ч 2	Средняя скорость ветра, м/сек 3	Осредненный вес песка по двум ловушкам, г 4	P, г/(см·ч) 5	Объемный вес песка, г/см³ 6
21 июля 7	16,4	3,4	828,2	6,02	2,0
22	2,5	2,6	90,1	5,03	2,1
26	12,0	2,2	287,0	3,29	2,2
28	8,5	3,8	810,3	13,20	2,6
30	8,2	1,6	282,0	3,48	2,8
31	2,2	1,8	66,7	4,13	1,8
31	3,75	1,5	46,0	1,68	1,8
1 августа 8	5,5	3,9	128,0	5,51	1,9
4	6,9	2,5	61,0	1,28	2,0
11	1,0	3,7	59,0	8,10	2,4
12	1,5	4,5	113,0	10,30	2,6
12	1,0	4,8	121,5	16,70	1,9
12	1,4	4,2	80,0	9,20	1,9
13	2,0	4,2	278,0	19,00	2,0
13	2,0	4,1	215,0	14,90	2,0
13	3,25	2,6	14[illegible],5	6,20	1,8
15	2,0	5,4	452,5	30,90	1,9
15	1,0	6,0	479,0	65,50	2,0
15	1,0	6,7	725,0	99,50	2,3
15	1,0	7,5	975,0	133,0	2,3
15	0,5	8,1	591,0	163,0	2,4
				9 Среднее	2,13

KEY:

1. Measurement date
2. Duration of measurements, hours
3. Mean wind\velocity, m/sec
4. Averaged weight of sand, using two traps, g
5. P, g/(cm•hour)
6. Volumetric weight of sand, g/cm^3
7. July
8. August
9. Mean

traps in the form of glass jars with a diameter of the opening 7.3 cm and a height of 10 cm in such a way that the sand particles entrained by the wind did not ecounter any obstacles and appearing over the opening, fell into the trap. The time for placement of the traps was determined using a stopwatch. After a sufficient quantity of sediment was accumulated, the stopwatch was stopped and the contents were weighed. As a check, the traps were placed in pairs at a distance of 2-3 m from one another. At the same time, an anemometer was used in measuring wind direction and velocity in the immediate neighborhood of the traps (2 m) at a height of 0.2 and 2.0 m from the surface of the mid-channel island. Using averaged measurement data, we computed the sand discharges per unit width of the channel formation P, obtained by dividing the weight of the contents of the trap by the width of its opening and the measurement time (Table 1). Using the values of mean wind velocity v and the discharge of sediments P, obtained during the measurements, we formed the dependence P = f(v). Figure 1 shows that the beginning of movement of particles of rather uniform sand with a mean grain size 0.3 mm, determined on the basis of a large number of measurements, began with a wind velocity of 1.5 m/sec.

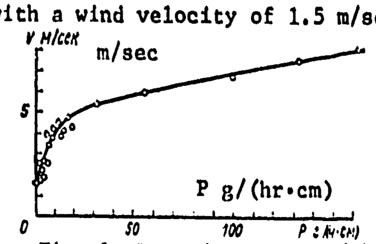

Fig. 1. Dependence P = f(v).

Table 2

Data on Total Transport of Sand on Mid-Channel Island in 1976, kg/m

Месяц 1	С 2	Ю 3	СВ 4	ЮЗ 5	СЗ 6	ЮВ 7	В 8	З 9	Сумма 10
VI	238	8,8	90,2	26,2	345,2	52,8	14,5	5,9	782
VII	213	15,7	256,2	25,3	100,5	55,5	35,4	5,6	707,2
VIII	66	111,7	112,7	15,4	373,9	12,5	11,5	35,0	738,3
IX	272,7	82,3	109,5	116,2	126,2	130,1	5,1	19,7	961,8
X	22,3	38,1	9,0	41,6	25,5	0,5	25,8	7,8	170,6
11 Сумма	812	256,6	577,6	225	971,3	251	92,3	73	3258
	13 С—Ю		14 СВ—ЮЗ		15 СЗ—ЮВ		16 В—З		
12 Разность, кг/м	555		352		720		19		

KEY:

1. Month
2. N
3. S
4. NE
5. SW
6. NW
7. SE
8. E
9. W
10. Sum
11. Sum
12. Difference, kg/m
13. N-S
14. NE-SW
15. NW-SE
16. E-W

The scatter of points corresponding to data from field observations in the lower part of the graph can be attributed to a change in the moisture content of sand, condensing air moisture at nighttime and measurement errors. The dependence P = f(v) was obtained for dry sand with a volumetric weight

2.13 g/cm^3 (Table 1) because during the 1976 observation period there was no rain. As was established by observations in 1977 on the Pur River, after rains, due to a marked increase in the moisture content of the sand, the dependence $P = f(v)$ is impaired. Therefore, the lower envelope of the field of points, taking into account their scatter due to the inaccuracy in measurements, must correspond to the movement of dry sand.

In order to generalize the dependence and to be able to use data from network observations of the wind direction and velocity we carried out parallel measurements on a mid-channel island and in a meteorological area situated 10 km from the mid-channel island. Using these data we computed the coefficient (equal to 0.86) for computing the wind velocity over a mid-channel island using data obtained from vane observations and observations in the meteorological area.

In order to estimate the quantity of sand transported by the wind from the surface of mid-channel islands and spits we used observational data obtained on the Nadym River during arid 1976. The mean extent of the mid-channel island [2] was 0.03 km^2. Using wind velocity observations made eight times a day at Nadym meteorological station during the snow-free period from 25 May through 6 October, taking into account a conversion factor of 0.86 and the curve in Fig. 1, we determined the direction and intensity of the wind transport of sand per unit width of the mid-channel island (Table 2).

Computing the difference in transport in mutually opposite directions (Table 2) and constructing the resultant vector, we determine that during the investigated period there was a transport of sand from northwest to southeast. Quantitatively this predominance was expressed at 1,300 kg/meter.

Multiplying this value by the presentation width of the mid-channel island, 175 m [2], we find that during the snowless period a total of 227.5 tons is transported through its section, which corresponds to a sand volume of 106.8 m^3. Dividing the determined volume by the height of the bank ($h = 0.75$ m) (according to field measurement data) which is formed as a result of the piling up of sand from the mid-channel island and by its mean width 175 m, we obtain the averaged value of the displacement path of sand in the predominant direction of transport $L = 0.81$ m.

Thus, all the computations were made for one year with use of information on the duration of the snowless period. The results of the computations corresponded closely to field data. The length of the displacement path of sand, obtained on the basis of several measurements in different places of predominant transport, varied from 0.5 to 1.0 m. The measurements were made on a mid-channel island (Fig. 2) formed in 1976 from a spit adjacent to the downstream end of an island (115 km from the mouth of the Nadym River). The high water of 1976 created a shallow channel (130 m from the place of joining to the island), which was not futher developed due to the frozen core in the mass of the spit. As a result of the dropoff of the high water the channel almost disappeared and was a natural trap for the sand which was transported from the mid-channel island, which was accumulated on its slope in the form of a bank. The height and length of the bank of sand adjacent to the mid-channel island, differing from it in having a lesser density and purity of the transported sand, was determined by measurements. The mid-channel island was situated in the middle of the river and was exposed to winds of all directions.

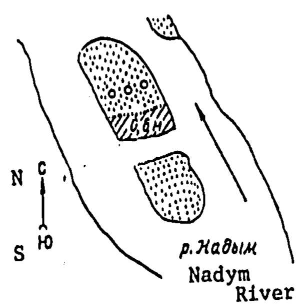

Fig. 2. Diagram of sector of observations of wind transport of sand on mid-channel island in Nadym River. The shading represents the piling up of sand transported by the wind in the dried-up channel (width of bank 0.8 m); the circles represent the sites for placement of traps and anemometers.

In those places where the channel was not dried up the sand was transported directly in the flow. On large spits (length about 1 km and width 300 m) the sand was transported toward the shores, accumulating in brush growths along the banks. Singular ridges or longitudinal embankments were formed in these places.

The drift of sand into the isolated embayments shoreward of the spits gradually narrows the width of such embayments. Thus, the sand transported into the river, natural deepenings and brush growths evidently cannot again be transported in the opposite direction, except for the part of the sand which has not firmly settled before a stable change in wind direction. Accordingly, the surface of the formations created by the high water after its dropoff is leveled and reworked as a result of exposure to the wind. This can result in a disruption of the relief structure of sandy morphological formations. Mid-channel islands can increase in width and grow in length from the upstream part of the island due to the transport of sand here by the wind. However, as correctly noted by I. V. Popov [4], this is a secondary phenomenon, although it is capable in a number of cases of disrupting considerably the structure of relief of sandy morphological formations, but rarely can radically modify it. They cannot be regarded as key factors under all conditions.

The vertical relief of the investigated mid-channel island is 0.009 m, which at first glance does not agree with field observations because two weeks after the high water and the drying-out of the sand the sawtoothlike ridged surface of the central part of the spits and mid-channel islands with a ridge height up to 20 cm on them is leveled. Evidently, their surfaces are not "worked" uniformly as was assumed in computations (vertical relief), but to a considerably lesser degree on the periphery. As indicated by the computations made and their comparison with field data, the magnitude and direction of the reformations can be estimated by the method proposed above. In such cases it is necessary to use data on the wind measured at meteorological posts situated not more than 100 km from the investigated sector, as is recommended in [5]. It must also be emphasized that the proposed method can be applied only to channel formations not held in place by vegetation and open to the wind.

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UDC 551.524:631

COMPUTATION OF HEAT SUPPLY FOR THE DEVELOPMENT OF SOME AGRICULTURAL CROPS DURING SPRING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 86-92

[Article by Professor Yu. I. Chirkov and L. G. Larin, Moscow Agricultural Academy imeni K. A. Timiryazev, submitted for publication 9 August 1978]

Abstract: The authors compare two methods for evaluating the heat supply of plants: that commonly employed -- on the basis of mean daily temperatures, and that proposed by the authors themselves, in which the diurnal temperature variation is taken into account.

[Text] The more complete use of climatic resources in agricultural production favors an increase in the productivity of agricultural crops. Under the conditions prevailing in the Nonchernozem zone, where the heat resources are limited, their effective use is most important, especially during the spring period, characterized by considerable temperature variations.

At the present time, in heat supply computations, extensive use is made of the sums of active and effective air temperatures, reckoned from some limit corresponding to the biological minimum of growth. Calculations of these sums are made using the mean diurnal air temperatures, which, especially in spring, give only an approximate idea concerning the actual distribution of heat, both in the upper soil layers at the depth of seed embedment during the sowing-sprouting period and in the surface air layer after the appearance of sprouts. In such an approach no allowance is made for the extremely productive (in biological respects) daytime hours in the diurnal temperature variation when the upper soil layer is greatly heated and the seeds, with adequate moistening, use this heat for germination. With emergence at the soil surface and the development of the above-ground part of the plant the computations of heat supply on the basis of mean diurnal air temperature also do not reflect the real consumption of heat by plants.

How can one take into account the influence of the diurnal temperature variation when calculating the sums of heat received by plants in the course of their growth and development? An extensive literature has been devoted to the formulation of quantitative characteristics for evaluating the heat necessary for the growth and development of plants. We worked on solution of these problems in the example of germinating corn seeds.

The need of corn for heat during the sowing-sprouting period is determined by the lower temperature limit at which development begins and the total quantity of heat necessary for the appearance of sprouts. The lower temperature limit at which corn seeds germinate, according to data published by Wallace and Bressman, is +4.5°C. Some authors (F. I. Lishchenko, A. A. Shigolev) use 6°C as the minimum germination temperature. Other scientists (N. N. Kuleshov, V. N. Stepanov, I. S. Shatilov) assume that the temperature minimum for germination falls in the range 8-10°C. V. N. Stepanov indicates that it is necessary to distinguish the minimum initial temperature for the germination of seeds from the biological minimum temperature for the formation and appearance of sprouts, which is 2-3°C higher.

In the artificial climate laboratory at the Moscow Agricultural Academy in 1956 the sprouting of corn seeds of 47 varieties at 7°C indicated that the seeds do not begin to sprout at this temperature (Z. I. Kaloshina). In the experiments of Yu. I. Chirkova the germination of corn seeds occurred at a temperature above 8°C. According to I. V. Kozhukhov, S. S. Andreyenko, F. M. Kuperman, the temperature must be not less than 10-12°C for germination.

Thus, the lower limit for the germination of corn seeds, according to data from many authors, falls in the range 4.5-12°C.

Data on the total quantity of heat necessary for the sowing-sprouting period are cited by a number of researchers. As the heat supply criterion we take the air or soil temperature sums.

The field experiments of R. D. Veselovzorova, carried out over an eight-year period at 18 state seed selection sectors in Odesskaya Oblast, indicated that the dependence of the duration of the sowing-sprouting period for corn is expressed considerably more precisely for the sums of effective temperatures, that is, the temperatures not reckoned from 0°C, as in calculations of the sums of positive temperatures, but from some biological "zero," below which the development of plants does not occur. The correlation between the mean rate of plant development and the mean air temperature for this interval was determined by this author using the A. A. Skvortsov method:

$$\frac{1}{n} = \frac{T-B}{A}, \tag{1}$$

where 1/n is the mean rate of plant development, that is, the part of the development period "covered" by the plant in one day; T is the mean air temperature during the period; B is the lower limit of germination of corn seeds; A is the sum of effective mean diurnal air temperatures required for passage through the analyzed periods of plant development.

As the lower limit of temperature necessary for germination R. D. Veselovzorova used a temperature of 6.2°C. The sum of effective temperatures A above this limit was 122°C.

According to A. A. Shigolev, this sum is 93°C, with a lower germination limit 6°C. N. N. Kuleshov obtained for formula (1), using data from Ukrainian seed selection stations, B = 7.5°C; A = 95°C. According to Yu. I. Chirkov, formula (1) assumes the form

$$\frac{1}{n} = \frac{T-8}{83}. \tag{2}$$

As can be seen from the cited brief review of the literature on this problem, different authors select different heat supply criteria and there is no unanimous opinion on this subject.

In order to study the reaction of germinating corn seeds to soil heating of different intensity we carried out an experiment in artificial climate chambers. We compared two methods for evaluating the heat supply of corn seeds during the sowing-sprouting period: 1) using mean diurnal temperatures, 2) with diurnal variation taken into account. In the experiments we used corn seeds of the hybrid Dneprovskiy 247 MV. Germination took place in quartz sand with a depth of embedding of 3 cm. The temperature in the climatic chambers was stipulated with a periodicity of 12 hours, that is, for a half-day a temperature of 4°C was maintained in the chambers (relatively neutral in biological respects); the next half-day there was a biologically active temperature, ranging from 6 to 20°C each 2°C, and beginning from 20 to 30°C, each 5°C. For example, in one of the experimental variants the temperature in the chamber over a 12-hour period was kept equal to 4°C, in the next 12 hours it was 18°C, and this cyclic regime was stipulated up to the appearance of sprouts. Similarly a change in temperatures was carried out in other variants of the experiment as well.

In addition, we studied the influence of a low temperature (4°C) of different duration on germinating corn seeds. For this purpose we carried out experiments in which the duration of exposure to a temperature of 4°C was maintained for 24, 48, 120 and 240 hours, with temperature "bursts" of 25°C with a duration of 12 hours. These experiments were also carried out until sprouts had appeared.

A temperature of 4°C for the investigated hybrid was below the biological minimum for germination. The execution of experiments in the chamber was carried out with a chamber temperature of 4°C. The first "burst" of active temperature was imparted after 17 hours and thereafter a cyclic regime was maintained until sprouts had appeared.

During the period when the experiment was carried out in order to avoid dessication an air humidity of about 90% was maintained during all temperature regimes in the chamber.

Table 1

Sums of Positive Temperatures by Phases of Development of Corn Plants in Dependence on Temperature Amplitude

Режим температуры, °C 1	Периодичность смены режимов, ч 2	3 Суммы положительных температур (°C) от посева до					
		начала наклевывания 4	60% наклевывания 5	начала прорастания 6	40% прорастания 7	начала появления всходов 8	60% всходов 9
4+6	12	154	—	—	—	—	—
4+8	12	66	128	120	—	—	—
4+10*	12	90	118	123	236	—	—
4+12	12	52	76	92	107	280	350
4+14	12	51	60	77	86	215	250
4+16*	12	44	59	66	80	174	210
4+18	12	41	52	62	80	146	171
4+20*	12	30	48	52	60	130	150
4+25	12	22	34	47	50	99	112
4+30	12	18	45	48	50	95	106
4+25	4°C—24 25°C—12	30	45	60	60	120	150
4+25	4°C—48 25°C—12	32	52	52	71	147	175
4+25*	4°C—120 25°C—12	45	70	62	108	347	—
4+25	4°C—240 25°C—12	45	111	104	129	—	—

10 * Средняя сумма по результатам двух опытов.

KEY:

1. Temperature regime, °C
2. Periodicity of change in regimes, hours
3. Sums of positive temperatures (°C) from sowing to...
4. Onset of appearance of sprouts
5. 60% of beginning of appearance of sprouts
6. Onset of germination
7. 40% of germination
8. Onset of appearance of sprouts
9. 60% sprouts
10. Mean sum from results of two experiments

In the course of the experiment systematic observations were made of the condition of the seeds. We noted the passage of the plants through the corresponding development phases. As the onset of appearance of sprouts we used an outward extension of the primary root 1-2 mm; as the onset of germination we used a length of the shoot 1-2 mm; as the onset of appearance of the sprouts -- a plumule up to 5 mm.

Using graph paper we calculated the sums of mean diurnal temperatures by phases of development of corn plants for all experimental variants (Table 1).

In addition, we computed the sums of effective temperatures for the phases of development from the lower limit of 6°C in all variants of the experiment for the periods: 1) sowing -- onset of sprouting; 2) sowing -- 60% sprouting. The computations were made using mean diurnal temperatures (Table 2).

Table 2 shows that the level of sums of effective temperatures from sowing to the appearance of 60% of the sprouts in the variants of the conducted experiment in general was lower than according to the data published by A. A. Shigolev, who carried out an experiment for the germination of corn seeds, also in a chamber. This can probably be attributed to methodological differences in formulating the experiments.

With a temperature regime of 4-6°C with a period of alternation of temperature of 12 hours the seeds showed signs of development in 31 days but germination was not noted in this regime, that is, it can be said that a temperature of 4-6°C is the lower limit for the onset of sprouting of seeds of corn of the investigated hybrid. The sums of positive temperatures from sowing to the appearance of sprouting in this variant were 154°C (Table 1).

Table 2

Sums of Effective Temperatures Above 6°C During Periods: Sowing - Onset of Sprouting (1); Sowing - 60% Sprouting (2)

Период (1)	Температурный режим, °C (2)										Средняя (4)	По Шиголеву (5)
	4÷12	4÷14	4÷16*	4÷18	4÷20*	4÷25	4÷30	4÷25 24 ч 12 ч (3)	4÷25 48 ч 12 ч	4÷25 120 ч 12 ч		
(1)	64	64	63	65	58	52	58	48	55	83	61	
(2)	86	76	82	77	80	58	69	68	64	—	73	93

KEY: 6 * Расчет производился по результатам двух опытов.

1. Period
2. Temperature regime, °C
3. hours
4. Mean
5. According to Shigolev
6. Computations made using results of two experiments

In the regime 4-8°C the seeds began to develop in 12 days; the sums of positive temperatures by this time were 66°C. On the 21st day the seeds began to germinate, at this time having been exposed to a sum of positive temperatures of 120°C. With this temperature regime there were no independent sprouts. After the seeds had been in the artificial climate chambers with this temperature regime in the course of 50 days the chamber temperature was set at 25°C in order to set the percentage of death of seeds under the influence of prolonged low temperatures. It was equal to about 50%.

In a regime 4-10°C there were also no independent sprouts; germination was noted on the 33d day of the experiment (there were 32 temperature "bursts" of 10°C). The percentage of death of seeds was determined as in the preceding case and was also equal to about 50%.

In the temperature regime 4-12° the first independent sprouts were noted on the 35th day of the experiment. The positive temperature sum in this case was 280°C, whereas the sum of effective temperatures above 6°C was 63°C (Table 3). As was already mentioned, according to data in the literature the lower limit of germination of corn seeds is in the temperature range from 4.5°C to 12°C; for the forming and appearances of sprouts, as pointed out by V. N. Stepanov, this limit is 2-3°C higher. In this variant of the experiment the mean diurnal germination temperature was about 8°C and sprouts were obtained (more than 50% at the end of the experiment on the 45th day). It can therefore be concluded that the mean diurnal soil temperature, and especially the mean diurnal air temperature, used in computing the sums of active and effective temperatures, the principal indices of heat supply of plants, cannot serve as the sole criterion of heat supply of corn seeds during germination. The duration of the sowing-sprouting period is influenced considerably by the amplitudes of daily heatings of the soil and they must be taken into account in computing the heat supply of sown crops.

In the opinion of some researchers (V. N. Stepanov, A. I. Korovin, Z. A. Mishchenko), the mean temperatures for a day, ten-day period and a month inadequately characterize the thermal regime in which the seeds are actually present at the depth of embedment, especially under the conditions of a continental climate during the spring period. The experiments of N. N. Tret'yakov (1955-1957), as pointed out by V. N. Stepanov, demonstrated that the duration of the sowing-sprouting period is determined not only by the mean daily temperatures, but also by the level of the maximum temperature. In the experiments of N. N. Tret'yakov, with an identical mean daily temperature of 10.8°C and 10.5°C the duration of the sowing-sprouting period differed by seven days because the maximum temperatures observed during the period of carrying out the two experiments differed by 4°C in the course of a 24-hour period.

The studies of V. P. Dmitrenko also emphasize the idea of a physiological nonequivalence of temperatures of different levels for plant development. He points out that the development rate is determined by the temperature level; each specific temperature value exerts only its characteristic influence on the growth and development of plants.

It is therefore evident that the mean diurnal temperature, and accordingly, also the sums of active and effective temperatures, computed on their basis, are not objective heat supply indices for plants.

Probably the method for calculating the area between the curve of the diurnal variation of soil temperature at the depth of seed embedment and the abscissa corresponding to the lower limit of germination for a particular corn variety (hybrid) more fully takes into account the real temperature conditions to which the seeds in the soil are exposed. The sum of these areas gives the sum of effective temperatures during the time during which this temperature was observed from sowing to the corresponding development phase.

Table 3 gives the results of computations of the sums of effective temperatures above 8°C during the sowing - onset of sprouting period by the usual method (method 2), that is, on the basis of the mean diurnal temperature values, and on the basis of method 1, that is, taking into account what has been said above.

Table 3

Sums of Effective Temperatures Above 8°C During Sowing - Onset of Sprouting Period, Computed Using Methods 1 and 2

1 Способ	2 Температурный режим, °C									
	4+12 3по 12 ч hours	4+14 по 12 ч	4+16* по 12 ч	4+18 по 12 ч	4+20* по 12 ч	4+25 по 12 ч	4+25 24 ч 12 ч	4+25 48 ч 12 ч	4+25* 120 ч 12 ч	4+30 по 12 ч
1	63	66	63	63	58	56	58	58	82	60
2	—	17	32	38	39	43	38	39	60	49

4 * Средняя сумма по результатам двух опытов.

KEY:

1. Method
2. Temperature regime, °C
3. each
4. Average sum based on results of two experiments

Method 1. The computations were made from graph paper by integration of the area between the temperature variation curve and the abscissa 8°C by the trapezia method, which is highly accurate in comparison with the triangles method. Then the total sum of temperatures above 8°C during the entire time during which it was observed was reduced to the sum of the mean diurnal effective temperatures.

Method 2. The computations were made by the usual method of summing of the mean diurnal temperatures, reckoned from the lower limit 8°C.

Table 3 shows that the temperature sums, computed by method 1, fall in the range 56-66°C, that is, the scatter is small, although the temperature amplitudes vary in a wide range from a regime 4-12°C to a regime 4-30°C, except for the experimental variant in which a temperature "burst" of 25°C with a duration of 12 hours was imparted each 120 hours, that is, after five days, during which the temperature in the chamber was maintained at 4°C. This prolonged low temperature considerably slowed down the appearance of sprouts, and the sum of effective temperatures relative to the other variants was higher. Computations by the usual method (method 2) gave a considerable scatter of the sums of effective temperatures from 17°C in a regime 4-14°C to 49°C in a regime 4-30°C.

In variants of the experiment in which the duration of exposure to a low temperature of 4°C was fixed at 24, 48, 120 and 240 hours with temperature "bursts" of 25°C with a duration of 12 hours, the following fact was observed: 40% of the germination in the experiments with intervals of 12, 24 and 48 hours between temperature "bursts" was observed after four "bursts," and in experiments with an interval of 120 and 240 hours -- after three "bursts." Evidently this can be attributed to the fact that after a temperature "burst" of 25°C, already at the temperature of the conditional "biological zero," biochemical processes still continue for some time in the seeds, and in experiments with greater intervals between temperature "bursts" the inertia of these processes is used to a full degree.

The computation of heat resources by method 1 for a broad network of stations is unrealistic due to its complexity. However, on the basis of Table 3 it is possible to determine the corrections Δ to the sums of effective temperatures above 8°C, computed by the usual method for corn during the sowing - onset of sprouting period in dependence on the level of diurnal temperatures t_d, which are represented below:

t_d °C	12	14	16	18	20	25
Δ °C	63	49	31	25	19	13

Computations of the heat supply, taking into account the diurnal heatings of the soil, make it possible to change substantially the point of view concerning the optimum times of sowing of corn in the Nonchernozem zone, which are usually considered 20-25 May, that is, when the soil temperature in the layer 0-10 cm is stably higher than 10°C. No use is made of the heat resources received during considerable heatings at the end of April and during the first half of May, which occur in this zone in most years.

Similar computations were made for the new valuable fodder crop "safflower rhubarb," differing sharply from corn with respect to heat requirements. According to data available in the literature (P. P. Vavilov, A. A. Kondrat'yev), the lower limit of development for the new fodder crop is a temperature of 4-5°C. However, the experiments which we carried out in 1977-1978 indicated that the aftergrowing of this crop occurs almost immediately after disappearance of the snow cover. An analysis of the diurnal variation of air temperature and temperature at the soil surface indicated that during the daytime hours the air and soil temperature exceeds by several degrees the mentioned limit, with mean diurnal temperatures close to 0°C or even negative.

Conclusions. 1. In an agrometeorological evaluation of the state of plants during the spring period it is necessary to take into account the daytime heatings of the soil, since plants use this for their growth and development. 2. The method of integration of the areas between the curve of diurnal variation of temperature in the soil or air (depending on the plant development phase) and the abscissa corresponding to the lower limit of the temperature necessary for passage through a particular development phase can be used in computations of the heat supply of different crops. This method more fully takes into account the real physical conditions under which a plant lives and develops than the summation of the mean diurnal temperatures. 3. Refinement of the heat requirements of plants during spring is important for validating the most rational times of sowing heat-loving plants in the Nonchernozem zone, which will favor an increase in their productivity.

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INFLUENCE OF THE BETA EFFECT IN THE FRICTION FIELD ON VERTICAL MOVEMENTS IN A CYCLONE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 93-96

[Article by V. I. Ponomarev, Main Geophysical Observatory, submitted for publication 30 May 1978]

Abstract: A study was made of the influence of change in the Coriolis parameter on the field of vertical velocity caused by friction in the planetary boundary layer of the atmosphere. The paper gives the results of computations of friction vertical velocity in the region of the upper boundary of the planetary boundary layer with a stipulated cyclonic pressure field. The discovery of peculiarities in the appearance of the β-effect in the field of frictional currents gives basis for assuming that it can exert a significant influence on formation of the warm sector of a cyclone and its fronts.

[Text] It is known from theoretical studies in meteorology that a change in the Coriolis parameter ($l = 2\omega \sin\varphi$) with latitude (φ) exerts an influence on atmospheric processes arbitrarily called the β-effect

$$\left(\beta - \frac{1}{a}\frac{\partial l}{\partial \varphi}\right).$$

In evaluations of the β-effect in the vorticity equation or in the vertical velocity equation it is found that its relative contribution increases with an increase in the horizontal scale of motion L (see [5]). In the field of mesoscale movements ($L < 500$-600 km) the β-effect is small, but in movements of a planetary scale it is one of the principal factors governing the evolution of vorticity and velocity divergence.

Much attention has been devoted to the influence of change in the Coriolis parameter with latitude on dynamic processes in the free atmosphere, including on vertical velocity. However, the influence of the β-effect on vertical movements in the frictional field at the earth's surface has remained virtually unstudied, although frictional vertical movements themselves have been analyzed (see [3]). As demonstrated in [3], the influence of frictional vertical velocities on vertical velocities above the planetary boundary layer is represented by positive influence functions, sufficiently large that the influence of friction in the lower troposphere is considered significant.

In the first stage it is desirable to examine the appearance of the β-effect specifically in the field of vertical movements caused by friction, not going beyond the framework of the stationary theory of the planetary boundary layer set forth in [1]. In addition, in this study we will limit ourselves to computation of frictional vertical velocities and analysis of the β-effect in a large-scale axially symmetric cyclone, assuming the wind at the upper boundary of the planetary boundary layer to be stipulated.

The expression for frictional vertical velocity at the upper boundary of the planetary boundary layer, as is well known, has the following form (see [3, 4]):

$$w_E = \frac{1}{\rho} \operatorname{rot}_z \frac{\vec{\tau}^0}{l} = \frac{1}{\rho l} \operatorname{rot}_z \vec{\tau}^0 + \frac{\tau_x^0 \beta}{\rho l^2}, \quad (1)$$

where $l = 2\omega \sin \varphi$ is the Coriolis parameter, $\beta = \partial l / \partial y$ is the Rossby parameter, ρ is air density, $\vec{\tau}^0$, τ_x^0 are the vector of frictional shearing stress at the earth's surface and its component along the x-axis, directed to the east.

The y-axis is directed to the north, the z-axis is directed vertically upward.

The frictional stress components are usually expressed through the wind velocity at the upper boundary of the planetary boundary layer in accordance with the following formulas:

$$\tau_y^0 = \rho \varkappa^2 \chi^2 G \,(u \sin \alpha + v \cos \alpha),$$
$$\tau_x^0 = \rho \varkappa^2 \chi^2 G \,(u \cos \alpha - v \sin \alpha), \quad (2)$$

where u, v and G are the wind components and velocity modulus at the upper boundary of the planetary boundary layer, which are external parameters, $\varkappa$ is the Karman constant, χ is the geostrophic component of friction, α is the angle of wind rotation in the planetary boundary layer (or the angle between the vectors $\vec{G}$ and $\vec{\tau}^0$).

The χ and α parameters are functions of the Rossby number ($Ro = G/l z_0$, z_0 is the roughness parameter) and the stratification parameter (μ_0). In the computations we used the functions $\chi(Ro, \mu_0)$ and $\alpha(Ro, \mu_0)$ cited in [1] for fixed conditions of unstable stratification ($\mu_0 = -50$) in order to take convection into account parametrically.

Table 1 gives estimates of the characteristic values of the terms on the right-hand side of formula (2) and their ratios dependent on latitude and horizontal scale of movement L. The characteristic value of the modulus of frictional stress at the earth's surface is assumed to be 1 dyne/cm^2, which corresponds to a mean wind velocity $G \approx 7$ m/sec (with $\mu_0 = -50$, $\chi = 0.13$, $\alpha = 35°$). For convenience the first term on the right-hand side of formula (1), dependent on the vorticity of frictional stress, is denoted by w_r, whereas the second term, caused only by the β-effect, is denoted by w_β. It can be seen from the estimates that the relative contribution to the frictional velocity of the term w_β is great in the low latitudes and is important in the middle latitudes when $L > 500$ km, that is, in large-scale movements.

Table 1

Evaluations of β-Effect in Field of Frictional Vertical Movements for Different Latitude Zones and Horizontal Scales of Movement (w_β and w_r in cm/sec)(Computed Values w_β, w_r, w_r/w_β Have Been Rounded Off With Accuracy to 0.1).

$\varphi°$	w_β	L=500 км		L=2000 км		L=4000 км	
		w_r	$\frac{w_r}{w_\beta}$	w_r	$\frac{w_r}{w_\beta}$	w_r	$\frac{w_r}{w_\beta}$
20	0,7	3,1	4,6	0,8	1,1	0,4	0,5
30	0,3	2,1	7,4	0,5	1,8	0,3	0,9
40	0,2	1,6	11,0	0,4	2,6	0,2	1,3
50	0,1	1,4	15,0	0,3	3,8	0,2	1,9
60	0,05	1,2	22,0	0,3	5,0	0,1	2,5

At the same time, the latitudinal distribution of w_β corresponds to the distribution of frictional vertical velocity in the idealized case of a constant zonal wind: $v = 0$, $\chi = \text{const}$, $\alpha = \text{const}$.

$$w_E = w_\beta = \frac{3\varkappa^2 \chi^2}{l^2} |u| u \cos \alpha.$$

Thus, in the westerly zonal flow ($u > 0$) the "frictional β-effect" generates ascending frictional movements, whereas in the easterly flow descending movements are generated.

Now we will examine frictional vertical movements in an axially symmetric cyclone, assuming that the wind at the upper boundary of the planetary boundary layer is geostrophic. Pressure is assumed to be only a function of radius ($p = f(r)$), by virtue of which expression (1), with (2) taken into account, in polar coordinates (r, γ) assumes the following form:

$$w_E = \frac{\varkappa^3 \chi^2 \cos \alpha}{\rho^2 l^3 r} \left| \frac{\partial p}{\partial r} \right| \frac{\partial p}{\partial r} \left[1 - 2r \frac{\partial^2 p}{\partial r^2} \Big/ \frac{\partial p}{\partial r} - 3r \frac{\beta}{l} (\sin \gamma + \cos \gamma \operatorname{tg} \alpha) \right], \tag{3}$$

$$w_r \sim \left(1 - 2r\frac{\partial^2 p}{\partial r^2} \Big/ \frac{\partial p}{\partial r}\right); \quad w_\beta \sim -3r\frac{\beta}{l}(\sin\gamma + \cos\gamma \operatorname{tg}\alpha).$$

Figure 1 shows the w_β and w_E fields, computed everywhere using formulas (3), with the exception of the neighborhood of the central point with constant

$$\frac{\partial p}{\partial r}\left(\frac{\partial p}{\partial r} = 1.8 \cdot 10^{-2} \text{ mb/km},\right.$$

$$G \approx 10 \text{ m/sec}).$$

The point $r = 0$ is situated at latitude 50°, that is, in the zone of most intensive cyclogenesis. Since the pressure field is stipulated, each fixed value of the r coordinate can be considered the radius of a cyclone with a definite horizontal scale $L = 2r$.

We will enumerate the principal conclusions following from formula (3) and the results of computations of the fields w_r, w_β and w_E for the noted particular case.

1. Since the cofactor in formula (3), outside the parentheses, is inversely proportional to l^3, by virtue of this alone, a change in the Coriolis parameter leads to a considerable asymmetry of the field of frictional vertical movements relative to the zonal axis of the cyclone (x-axis). As shown in Fig. 1, the frictional velocities attain maximum values in the southern part of the cyclone.

2. In addition, extremely interesting peculiarities of manifestation of the β-effect in a cyclone are attributable to the fact that w_β changes sign in dependence on the γ coordinate. When $-\alpha < \gamma < \pi - \alpha$, that is, approximately in the northern part of the cyclone, $w_\beta < 0$ and the β-effect lessens the ascending frictional movements, whereas with $\pi - \alpha < \gamma < 2\pi - \alpha$, that is, approximately in the southern part of the cyclone, on the other hand, intensifies them ($w_\beta > 0$). As a result, the asymmetry relative to the zonal axis of the cyclone in the w_β field, for example, represented in Fig. 1a, is substantially greater than in the w_r field. At the same time, the w_β field has some asymmetry relative to the meridional axis of the cyclone (y-axis), dependent in this case only on the angle of rotation of the wind in the planetary boundary layer (α).

3. With an increase in the horizontal scales of the cyclone or with movement of a large-scale cyclone to the south the asymmetry of the w_E field relative to the zonal axis (x-axis) increases. The w_E gradients in this case very significantly increase in the southern sector of the cyclone.

It is easy to confirm that the qualitative nature of the "frictional β_0-effect" in the cyclone is not dependent on the method for computing τ_x^0, τ_y^0, and also is retained in more general cases, when

$$\partial^2 p / \partial r^2 \neq 0, \quad \chi \neq \text{const}, \alpha \neq \text{const}.$$

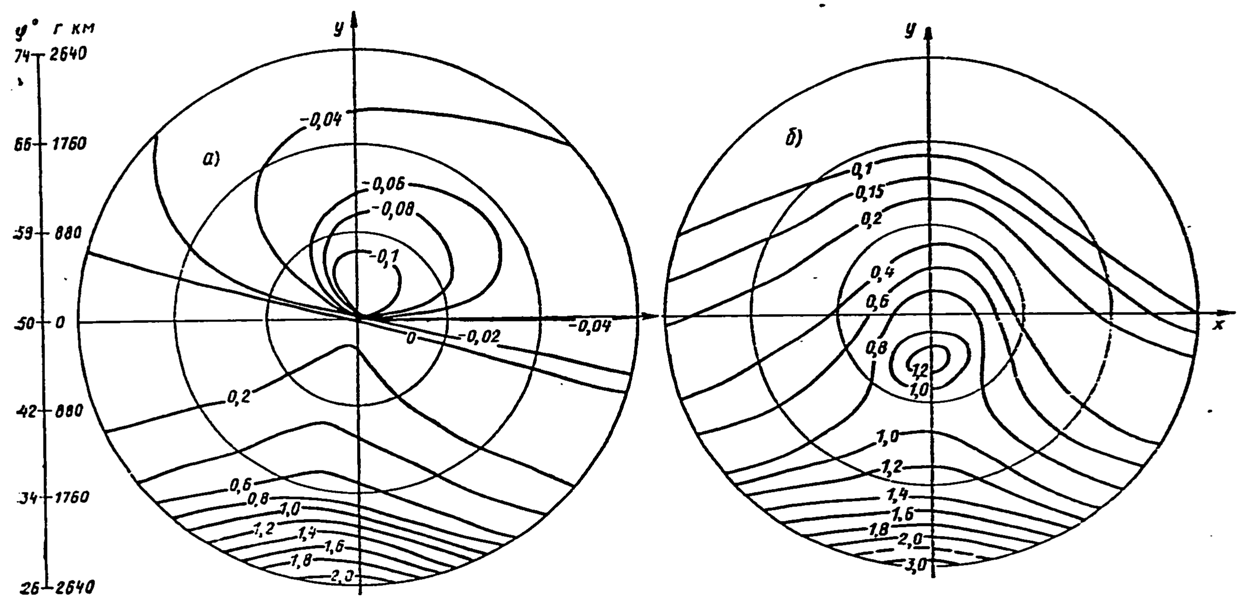

Fig. 1. Fields w_β cm/sec (a) and w_E cm/sec (b) with stipulated cyclonic pressure field:

$$\left(\frac{\partial p}{\partial \gamma} = 0, \ \frac{\partial p}{\partial r} - 1.8 \cdot 10^{-2} \ \text{mb/km},\right.$$

that is, $G \approx 10$ m/sec).

Thus, the β-effect always creates a maximum of frictional ascending movements in the southern part of an axially symmetric cyclone, usually occupying its warm sector. At the same time, as is well known, in the warm air mass of a cyclone there is a maximum cloud cover, which gives precipitation within the limits of the warm sector at the earth, in front of the warm and behind the cold front. Thus, the condensation process, accompanied by the release of latent heat, the same as the frictional currents, attains a maximum intensity in the southern part of a cyclone, occupied by the warm sector and fronts.

It is obvious that such a coincidence of the regions of maximum values of the ascending frictional movements, cloud cover and air temperature is not random. As demonstrated in [2], the vertical velocities below the condensation level (w_0) exert a substantial influence on the intensity of condensation in cumulus clouds (in [2] the w_0 values were stipulated a priori). The process of large-scale condensation also is subject to the influence of vertical movements caused by dynamic factors. The functions for the influence of frictional vertical velocities on the vertical velocities in the lower troposphere are positive (see [3]). Therefore, the above-mentioned circumstances give basis for assuming that the formation and evolution of fronts and the warm sector of a cyclone to a considerable degree are governed by the "frictional β-effect" against a background of condensation processes and mesoscale cloud convection. An indirect argument in support of the noted assumption is the fact that the typhoons moving in the temperate latitudes, with an increase in their spatial scales, frequently acquire a warm sector and fronts.

A checking of this hypothesis on the formation of a warm sector of a cyclone is possible within the framework of a nonadiabatic model of the atmosphere in which the fronts are interpreted as regions of large temperature gradients. First, there must be a high resolution in the model, making it possible to decrease the influence of horizontal diffusion. Second, particular attention must be devoted to parameterization of the boundary layer, convectional processes and condensation.

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MODEL APPARATUS FOR SIMULATING ATMOSPHERIC CONDITIONS

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[Article by Candidate of Physical and Mathematical Sciences M. B. Fridzon, Central Aerological Observatory, submitted for publication 22 March 1978]

Abstract: The article describes the operating principle, design and also the principal technical and metrological specifications of the automated "Oblako" apparatus, being a complex simulator of atmospheric conditions. The apparatus has been certified by the USSR Gosstandart as a second-class model measuring apparatus. The principal metrological specifications of the apparatus are as follows. Working range of temperatures from -50 to 30°C, pressure from 10 to 1100 mb, relative humidity 1-95%. The accuracy in stabilizing temperature is 0.1°C, pressure 2.5 mb, relative humidity 1% (in the temperature range 0-30°C), 3% (in the temperature range -20-0°C) and 5% (in the temperature range -50- -20°C).

[Text] At the present time an increase in the reliability of hydrometeorological, and especially aerological information, is impossible without laboratory apparatus making it possible to create and maintain with a high accuracy in its working volume, atmospheric conditions with respect to temperature, humidity and pressure. Such apparatus makes it possible to investigate the metrological characteristics of existing hydrometeorological instruments and to develop new sensors, instruments and observation methods.

Until recently in the scientific research and routine practice of the Hydrometeorological Service there has been no apparatus making it possible to simulate atmospheric conditions in the range of temperature, humidity and pressure necessary for meteorology and aerology. During 1973-1977 specialists of the Central Aerological Observatory, jointly with the Ivanovo Power Institute, undertook the development and investigation of the "Oblako" universal moist air generator, in essence being a complex highly accurate simulator of atmospheric conditions. Some preliminary results of the development work have been published in [1, 5, 6]. In this article we generalize data relating to the development and investigation of this generator.

The "Oblako" generator has the following technical and metrological specifications. Working range of temperatures from -50 to 30°C. Working range of pressures from 10 to 1100 mb. Relative humidity range from 1 to 95%. Accuracy in stabilizing temperature 0.1°C, pressure 0.0025 kg/cm^2, relative humidity 1% (in the temperature range 0-30°C), 3% (in the temperature range -20-0°C) and 5% (in the temperature range -50 - -20°C). The nonuniformity of the temperature field in the volume of the working chamber is not worse than ±0.1°C; the nonuniformity of the field of relative humidity is ±1%. The velocity of the air flow in the working volume of the generator is 0.2-1.0 m/sec. The nonuniformity of the air flow velocity in the horizontal section is ±5%. The volume of the working chamber is 12 liters. Generator control is automated.

These specifications show that the apparatus makes it possible to simulate the conditions for operation of radiosondes and many surface meteorological instruments.

Traditional means and methods are used for creating a definite temperature and pressure in the working chamber of the generator. The stipulated humidity is created by means of varying the temperature and pressure of presaturated air (so-called combined method of two temperatures and two pressures [5]). The essence of the method is as follows. If a definite air volume is brought to a state of saturation at the temperature t_{sat} and the pressure p_{sat} (elasticity of water vapor over a plane water surface $E(t_{sat})$) and then its temperature and pressure are changed to the values t and p, then the relative air humidity in this volume is expressed as follows

$$U = K \frac{E(t_H)}{E(t)} \frac{p}{p_H}, \quad (1)$$

[H = sat] where E(t) is the elasticity of water vapor saturation at a temperature t,

$$K = \begin{cases} 1 \text{ when } t_{sat} \geqslant 0\ °C \\ \dfrac{E_{ice}(t_{sat})}{E(t_{sat})} \quad \text{when } t_{sat} < 0°C \end{cases}$$

$E_{ice}(t_{sat})$ is the elasticity of water vapor saturation over ice at the temperature t_{sat}.

Figure 1 shows an integrated structural and circuit diagram for the air preparation unit and the system for automatic regulation of the generator. Atmospheric air by means of the air compressor 1 is fed through the purification system (filter F) to the input of the unit for preliminary preparation of the air. This unit includes the dessicator 2, humidifier 3 and mixing chamber 4. In this unit the air drying process takes place using silica gel, which fills the internal volume of the dessicator. Moistening is accomplished by the bubbling of air through a layer of heated water in the humidifier. By changing the ratio of the flows of dry and moist air by means of the three-pass cock RK and also by setting a definite temperature in the mixing chamber 4, it is possible to set the desired air temperature and humidity roughly, but rather close to the stipulated level. The mixing chamber, in addition to its direct purpose, is used for the preliminary cooling and drying of the air when working in the field of negative temperatures. From the mixing chamber 4 the air is fed into the saturation chamber 5, where an equilibrium humidity over a water or ice surface is attained at the temperature t_{sat} and pressure p_{sat}.

Then this air is fed through the pressure reducer 6 into the working chamber 7 in which there is stabilization of the temperature t and pressure p corresponding to the stipulated regime. A vacuum pump VN (type VN 2MG) is installed at the output from the working chamber; this creates a rarefaction in the working chamber. The mixing, saturation and working chambers are seamless chrome-plated steel cylinders with a height of 400 mm and a diameter of 240 mm. Each of these chambers is installed in a special thermostat bath filled with ethyl alcohol, serving as an intermediate coolant. The evaporators of the cooling apparatus, the heaters of the heat stabilizing system and the cooling (heating) coils are installed in the baths. FGK-07 cooling plants are used as the source of cold. These plants make it possible to create a temperature to -30°C in the chambers. Dry ice, whose sublimation temperature is about -80°C, is strewn in the temperature baths in order to obtain lower temperatures. The temperature is measured in the working chamber and in the saturation chamber by using model platinum resistance thermometers 8 and 9 (type TSPN-1) and d-c bridges of the type R 329, class 0.05. Pressure is measured using model manometers (type MO) and vacuum gauges (type VO) 10 and 11. Maximum error in measuring temperature 0.1°C, pressure -- 0.0025 kg/cm^2.

Thus, by setting a definite temperature and pressure in the saturation chamber, and also a definite temperature and pressure in the working chamber, it is possible to obtain in the working chamber air with a stipulated pressure, temperature and relative humidity.

The automatic regulation system (ARS) provides for automatic regulation of water temperature in the humidifier (moistener), air temperature in the mixing chamber, saturation chamber and mixing chamber. The ARS for temperature in the saturation chamber, standardized with the similar ARS for the working chamber, constitute a complex system with an intermediate pulse passing through the high-speed load - coolant temperature channel. The coolant temperature is determined by the resistance thermometer 1TS, operating in combination with a regulating 1LR logometer. The coolant temperature regulator is a three-position device with a no-response zone. The 1LR regulator controls operation of the cooling plant K_1. The main signal on air temperature in the saturation chamber is fed from the 1TP thermocouple to the automatic regulating potentiometer 1PSR, which controls operation of the heater 1N. The technical control system, in addition to the described measuring and regulating systems, provides for monitoring air pressure beyond the compressor 12, in the dessicator 13, in the humidifier 14 and in the mixing chamber 15, and also controls the temperature in the humidifier 16 and in the mixing chamber 17. Remote control of the power supply is accomplished using the magnetic starters PM and the switching relays RP, controlled by the buttons KP, KS and KU. The signaling tubes (LS) signal that the power supply and heating systems are "on."

With respect to design, the apparatus consists of two units -- the operating unit and the control unit. The operating unit includes the air preparation system, mixing, saturation and working chambers, thermostat baths, cooling components. In order to shorten the length of the air channel lines and the lines connecting with the cooling apparatus we selected a three-section organization of the main units and assemblies with placement of the equipment at two levels -- at the upper level, the air channel, at the lower level -- the cooling and vacuum compression apparatus. The control unit is used in monitoring the measuring, control, automatic control and signaling systems.

Special operating charts are computed for facilitating the practical work with the apparatus. Using these operating charts, for a stipulated temperature in the working chamber t and a stipulated relative humidity we determine either the necessary temperature in the saturation chamber t_{sat} with a constant ratio of pressures p/p_{sat} or this ratio with a selected temperature value t_{sat}. Whereas the temperature regime change requires a quite long time, when the pressure is changed the new regime is established almost instantaneously. This makes it possible to carry out investigations not only of the static, but also the dynamic characteristics of the instruments, especially the hygrometers.

It can be seen from what has been said above that the temperature and pressure in the working chamber of the apparatus are measured with a high accuracy by means of model instruments. Setting and determination of humidity are by computation. Therefore, it is necessary to discuss the errors in determining humidity by the considered method. The maximum error in determining humidity ΔU consists of three components:

$$\Delta U = \Delta U_1 + \Delta U_2 + \Delta U_3, \qquad (2)$$

where ΔU_1 is the error caused by the deviation of the properties of the vapor-air mixture from the laws for an ideal gas; ΔU_2 is the error in the indirect method for determining relative humidity from temperature and pressure measurements; ΔU_3 is the error in reproducing relative humidity, caused by design of the apparatus.

The theoretical computations based on the data in [7] have shown [5] that the ΔU_1 value for the temperature range -50-30°C is negligible. This error becomes appreciable only at temperatures below -70°C.

Table 1

Results of Experimental Checking of Accuracy in Determining Relative Humidity in Working Chamber of "Oblako" Moisture Generator

$p_н$ мб 1 2	p мб	$t_н$ °C	t °C	$E(t_н)$ мб 3	$E(t)$ мб	$U_{рас}$ % 4	$U_К$ % 5	$U_В$ % 6	$U_Б$ ппм 8	$U_Б$ %	$U_{рас}-U_К$ 9	$R_К^{max}$ 10	$U_{рас}-U_В$ 11	$R_В^{max}$	$U_{рас}-U_Б$ 12	$R_Б^{max}$
1093,8	1035,9	19,2	18,8	22,16	21,73	96,4	96,5	96,6	—	—	—0,1	1,5	—0,2	2,5	—	—
1079,1	961,4	18,1	19,0	21,15	21,96	86	85,0	84,0	—	—	1,0	1,5	2,0	2,5	—	—
1579,4	956,5	16,9	18,9	19,25	21,83	53,2	52,0	55,0	—	—	1,2	1,5	—1,8	2,5	—	—
1692,2	941,8	16,0	18,7	18,17	21,55	47	48,0	46,0	—	—	—1,0	1,5	1,0	2,5	—	—
2172,1	932,0	0,3	18,5	6,24	21,29	11	12,0	12,0	—	—	—1,0	1,5	—1,0	2,5	—	—
2825,3	951,6	0,5	18,9	6,33	21,83	9,8	10,0	11,0	—	—	—0,2	1,5	—1,2	2,5	—	—
2992,0	936,9	—12,3	19,0	2,11	21,96	3	4,0	5,0	—	—	—1,0	1,5	—2,0	2,5	—	—
3080,3	946,7	—13,9	18,7	1,83	21,55	2,6	3,0	4,5	—	—	—0,4	1,5	—1,9	2,5	—	—
1059,5	1010,4	—22,0	—21,5	0,85	1,101	73,8	—	—	790	74,2	—	—	—	—	0,4	5
1226,2	1030,0	—24,0	—21,7	0,699	1,082	54,4	—	—	610	55,7	—	—	—	—	—1,3	5
1824,7	1030,0	—27,3	—22,0	0,501	1,014	27,5	—	—	200	24,8	—	—	—	—	2,7	5
2766,4	1010,4	—37,0	—21,6	0,179	1,091	6	—	—	69	6,3	—	—	—	—	—0,3	5
1471,5	981,0	—48,5	—32,0	0,0754	0,420	9	—	—	375	8,7	—	—	—	—	0,3	5
1077,4	1004,1	—49,2	—33,7	0,0696	0,357	13	—	—	255	13,5	—	—	—	—	—0,5	5
1821,2	1555,3	—58,1	—49,3	0,0241	0,0688	19	—	—	41	19,8	—	—	—	—	—0,8	5

Notes: U_K, U_V and U_B are the relative humidity values determined using the "Kvarts," "Volna" and "Baykal-3" hygrometers respectively; R_K^{max}, R_V^{max} and R_B^{max} are the statistical sums of errors in computations and measurement of relative humidity by the "Kvarts," "Volna" and "Baykal-3" instruments respectively.

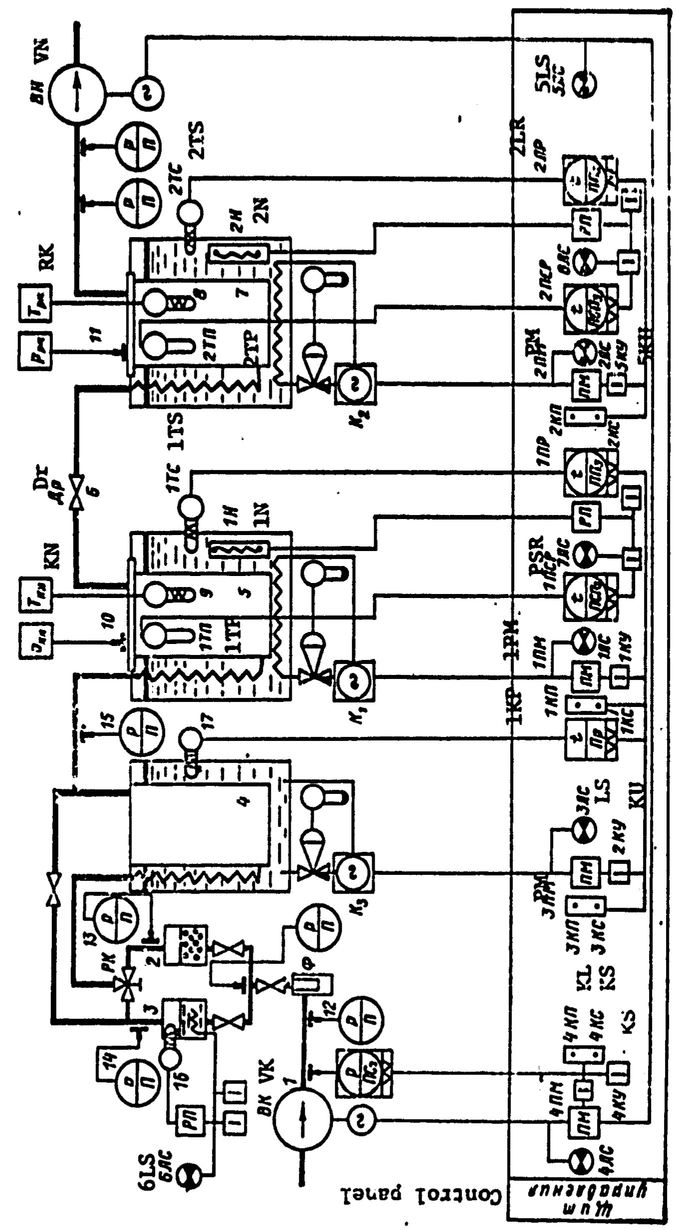

Fig. 1. Integrated structural and circuit diagram for air preparation system and system for automatic control of "Oblako" general-purpose moist air generator.

KEY FOR TABLE 1

1. p_{sat}
2. mb
3. t_{sat}
4. U_{comp}
5. U_K ("Kvarts")
6. U_V ("Volga")
7. U_B ("Baykal")
8. Unidentified
9. $U_{comp}-U_K$
10. $U_{comp}-U_V$
11. $U_{comp}-U_B$
12. R_B^{max}

ANNOTATIONS ON FIGURE 1

KP, KS, Ku -- buttons
PM -- magnetic starter
LS -- signaling tube
RP -- switching relay
F -- filter
TS -- resistance thermometer
VN -- vacuum pump
RK -- three-pass cock
MO -- model manometer
VO -- vacuum meter
LR -- regulating logometer

The absolute error in the indirect method for determining relative humidity ΔU_2 is determined by the expression

$$\Delta U_2 = \pm U \sqrt{N_t \Delta t^2 + \frac{N_p}{p_н^2} \Delta p^2}, \quad (3)$$

[N = sat] where Δt and Δp are the absolute errors in measuring temperature and pressure respectively,

$$N_t = \frac{1}{E^2(t_н)} \left[\frac{\partial E(t_н)}{\partial t_н}\right]^2 + \frac{1}{E^2(t)} \left[\frac{\partial E(t)}{\partial t}\right]^2,$$

$$N_p = 1 + \frac{p_н}{p}.$$

The coefficient N_t increases with an increase in relative humidity and a temperature decrease in the working chamber. The N_p coefficient increases with a pressure decrease in the working chamber. Thus, the error ΔU_2 is determined by the values of the absolute errors in measuring temperature and pressure and increases with an increase in relative humidity and a decrease in temperature and pressure in the working chamber.

The results of computations made using formula (3) indicated that in order to set humidity with an error of about 1% it is necessary to measure temperature with an error $\Delta t \leqslant \pm 0.1$°C and pressure with an error $\Delta p \leqslant \pm 0.005$ kg/cm^2, which was accomplished during development of the apparatus.

The error ΔU_3, consisting of the influence of such factors as the sorption and desorption of moisture in the channel, nonuniformity of the temperature and velocity fields, etc., can be determined only experimentally. However, in developing the apparatus we took into account and reduced to a minimum virtually all the factors which could lead to an appreciable ΔU_3 value. Thus, for a theoretical estimate it can be assumed that $\Delta U = \Delta U_2$.

An experimental determination of the correctness of humidity computations in the working chamber of the generator was made using a number of control hygrometers (due to the lack of standard instruments). As the control instruments we used:

a) in the temperature range from 10 to 30°C -- the "Kvarts" hygrometer developed by the All-Union Scientific Research Institute of Metrology imeni D. I. Mendeleyev, accuracy ±1% [2];
b) in the temperature range from 5 to 30°C -- the "Volna" hygrometer, developed by AF OKBA, accuracy ±2% [3];
c) in the temperature range below -15°C -- the "Baykal-3" coulometric hygrometer, also developed by AF OKBA, accuracy in the used range ±4%.

Since the errors in the control instruments are comparable to the errors in computing relative humidity, when carrying out the experiments we proceeded on the principle that the discrepancies between the computed and measured humidity values should not exceed the statistical sum R of the computation and measurement errors, that is

$$U_{\text{рас}} - U_{\text{из}} \leqslant \sqrt{(\Delta U_{\text{рас}})^2 + (\Delta U_{\text{из}})^2} = R, \qquad (4)$$

[PAC = comp; ИЗ = meas] where U_{comp}, ΔU_{comp} are the computed value and the error in computing relative humidity (computed using formula (3)), U_{meas}, ΔU_{meas} are the readings and the certificate error for the measuring instrument.

The experimental results are given in Table 1, which shows that in all the investigated regimes the results of experimental determination of humidity do not contradict the computed values.

The described apparatus is used for investigating temperature and humidity sensors for network and promising radiosondes, including film, electrolytic and aluminum oxide sensors. The apparatus was employed in investigating a dew point hygrometer developed by the Institute of Experimental Meteorology, ceramic humidity sensors developed at the Scientific Research Insitute of Hydrometeorological Instrument Making, TsVGMO semiconductor hygrometers, heated lithium chloride hygrometers of the Kiev Institute of Automation and a number of other instruments.

We note in conclusion that with respect to temperature, pressure and humidity ranges, and also with respect to accuracy characteristics, the apparatus has no equals. In December 1977 the apparatus underwent State Metrological

Certification and was classified as a second-class model apparatus. Technical specifications are now being drawn up for the manufacture of a consignment of this apparatus.

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OZONE AND GLOBAL CONTAMINATION OF THE ATMOSPHERE

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[Article by Doctor of Physical and Mathematical Sciences I. L. Karol', Main Geophysical Observatory, submitted for publication 13 March 1978]

Abstract: This is a discussion of processes of photochemical formation and destruction of ozone in the atmosphere, the system of compounds of hydrogen, nitrogen, chlorine and bromine chemically bound with catalysts, destroying ozone, natural and anthropogenic sources of these compounds, and evaluations of the anticipated increase in the intensity of anthropogenic sources in the coming decades. The article describes the principal types of quantitative models of transport and photochemical transformations of ozone and the gases in the atmosphere bound to it. Also given are model evaluations of changes in ozone content. The possibility of their detection by existing ozonometric systems is considered.

[Text] Since the early 1970's the effect of atmospheric contamination on stratospheric ozone has been receiving great attention from researchers and the public. At the beginning of the decade the main purpose of the investigations in this field was an evaluation of the possible degree of destruction of ozone by nitrogen oxides ejected by the jet engines of supersonic transport aircraft (SSTs), with the anticipated increase in the number of their flights in the present and coming decades. In the United States, Great Britain and France special commissions were formed for investigating a broad range of problems related to these phenomena -- from study of the natural undisturbed stratosphere to determination of the possible biological and also economic and social consequences of the impact of SST's on the composition of the stratosphere and corresponding changes in global climate. The results of these investigations were published in 1975-1976 in the form of a series of monographs (for example, see [7, 17, 18, 21]; reviews of the results were presented in [1, 2]).

In 1974 work began on investigating the effect exerted on stratospheric ozone by atomic chlorine Cl and its oxide ClO, forming in the stratosphere during the photodissociation by UV radiation (UVR) of hydrocarbons containing halogens (in particular, freon-11 $CFCl_3$ and freon-12 CF_2Cl_2). A number of groups of researchers is now occupied with this problem; a review of their results is given in [6, 22, 25].

During recent years specialists have located new global sources both for the ozone-destroying nitrogen oxides in the atmosphere and also for freons -- surface sources with a maximum intensity in the middle latitudes of the northern hemisphere with the greatest concentration of industry and population. The nature of the effect of impurities from these sources on stratospheric ozone can be different from the effect of aircraft effluent.

In this brief review of the problem we will enumerate natural and anthropogenic increments and losses of different groups of ozone-destroying gases in the atmosphere. We give the characteristics of classes of mathematical models as the fundamental method in modern investigations of the effect of atmospheric contaminants on ozone and compare the computed estimates of the anticipated decrease in stratospheric ozone with the possibilities of its instrumental detection.

Models of Photochemical Transformations of Stratospheric Ozone

Instead of the four or five reactions between atomic and molecular oxygen and ozone (Chapman reactions) by which the photochemical formation and destruction of ozone were explained only 10 years ago, we now know of hundreds of reactions among tens of compounds of hydrogen, nitrogen, carbon and halogens. The principal models of cycles of photochemical destruction of ozone in the stratosphere are represented in Fig. 1. The catalytic destruction of ozone is of the greatest importance:
-- nitrogen oxides with the transition $NO \rightleftarrows NO_2$;
-- oxygen and its oxides with the transition $H \rightleftarrows OH \rightleftarrows HO_2$;
-- chlorine and bromine and their oxides with the transitions $Cl \rightleftarrows ClO$, $Br \rightleftarrows BrO$.

In these cycles the gases indicated in the lower lines enter from the troposphere and are the sources of catalyst gases, whereas the upper lines indicate gases passive to ozone, transported partially into the troposphere. Thus, these cycles are not closed in the stratosphere, in contrast to the Chapman cycle. According to rather rough estimates, the relative contribution of these cycles to the total photochemical destruction of ozone in the stratosphere is 60-70% for nitrogen oxides and approximately 10% for each of the remaining cycles, including the Chapman cycle [25, 28]. All these gases reacting with ozone also react intensively with one another, forming a complex system of photochemical bonds. The indicated evaluations of the contribution of different groups of catalysts to the destruction of ozone were obtained with present-day, still extremely incomplete concepts concerning the natural content of the gases of these groups in the stratosphere and on the rates of reactions and photodissociations for many of the compounds entering into them.

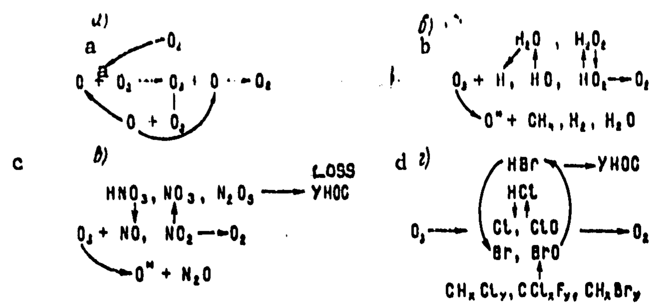

Fig. 1. Diagrams of cycles of small gas impurities photochemically interacting with ozone in the stratosphere ($O^* = O(^1D)$ -- an atom of oxygen in an excited state). a) Chapman cycle (upper stratosphere), b) HO_x cycle (lower and upper stratosphere), c) NO_x cycle (lower stratosphere), d) ClO_x, BrO_x cycles (for the most part the upper stratosphere).

The model of transfer and photochemical transformations of atmospheric gases active relative to ozone during recent years has been constantly refined and has become more complex. For example, in 1976 it was indicated in [18] that in the lower stratosphere ClO and NO_2, combining, form chloronitrosyl $ClONO_2$, passive to ozone. This compound in the upper stratosphere by UVR is again decomposed into ClO and NO_2. Accordingly, the zone of catalytic destruction of ozone moves upward and there is a change in the vertical profile of its density (O_3) (up to 30%, according to preliminary estimates). A decrease in O_3 in the upper stratosphere increases the UVR reaching the lower stratosphere and accordingly, the intensity of formation of O and O_3 there. Also, recently sources [12, 27] gave a system of reactions in which ozone is formed during the oxidation of methane in accordance with the scheme

$$CH_4+4O_2+3h\nu_1+h\nu_2 \rightarrow H_2O+CO_2+H_2+3O_3$$

with the participation of nitrogen oxides and photons $h\nu_1$ and $h\nu_2$ by UVR with a wavelength less than 400 nm. According to this scheme, ozone can be formed more effectively in the upper stratosphere and in the troposphere. Outside the layer its maximum content is in the stratosphere. Thus, a considerable part of the tropospheric ozone distant from the cities and industrial centers -- its anthropogenic sources -- cannot have a stratospheric origin. This puts in doubt the global estimates of the rate of ozone transfer from the stratosphere on the basis of global measurements of its content in surface air and estimates of its destruction over different forms of underlying surface [23].

It must be emphasized that many photochemical transformations have not been observed in the real atmosphere and even under laboratory conditions. The parameters of a number of chemical reactions and photodissociations have not been measured, nor has there been measurement of their dependence on external conditions; there has only been an evaluation on the basis of indirect findings [14, 20].

Sources of Gases Chemical Active Relative to Ozone

During recent years great attention has been devoted to anthropogenic sources of gases active relative to ozone and many of them have now been studied considerably better than natural sources of these gases.

a) Products of combustion of engines of aircraft and space rockets. The combustion products (nitrogen oxides) ejected by the engines of high-altitude (supersonic) transport aircraft were the first sources attracting extensive public attention to the problem of the anthropogenic effect on stratospheric ozone. In a number of investigations prognostic estimates have been made of the increase in the total effluent of combustion products from world transport aviation during the coming decades [8, 21].

Table 1 gives a comparison of estimates of the total quantity of combusted fuel and the effluent of NO_2 in the coming decade. There is no substantial difference among the estimates published in different sources; only the value for SSTs in 1985 given in [21] deviates in a greater direction. During the entire predicted period the volume of NO_2 effluent from supersonic transport aircraft is a small fraction, 6-17%, of the volume of effluent from subsonic transport aircraft.

We have already mentioned the possibility of ozone formation during the oxidation of methane with the participation of NO in the troposphere from the effluent of subsonic aviation. Such a possibility still has been but poorly investigated, especially in laboratory measurements, and at the present time cannot be considered firmly established.

The combustion products of engines of space rockets contain chlorine compounds in a quantity of about 100 tons HCl per launching [35], which with one launching per week gives 5 kilotons (thousands of tons of HCl per year -- a quantity insignificant in comparison with the present-day annual receipts of chlorine in the stratosphere from freons and other halogen-substituted hydrocarbons (hundreds of thousands of tons) (see below).

b) Nuclear explosions. In a number of studies (see [10]) the authors have made rather rough estimates of the number of NO molecules forming in the fireball of a nuclear explosion in the limits $(0.2\text{-}1.0)\cdot 10^{32}$ per megaton of the TNT equivalent of shot energy. The tests of nuclear weapons in 1961-1962 should give rise to 0.3-1.5 megatons of NO_2 -- approximately 10 times more than the anticipated annual effluent from SST's in 1985, indicated in Table 1. However, approximately 5% of the computed global decrease in the total ozone content X in the stratosphere of the northern hemisphere could not be detected with statistical reliability on the basis of measurements in the network of ground stations against the background of a great natural variability of X, in particular, its quasi-two-year variations. It was also impossible to trace reliably, by continuous measurements by the "Nimbus IV" satellite, the effect exerted on ozone by the French thermonuclear test explosion of 30 May 1970 in the Pacific Ocean [13].

Table 1

Estimates of the Total Quantity of Combusted Fuel (QCF) and NO_2 Effluent of Engines of Subsonic Transport Aircraft and Supersonic Transport Aircraft on the Basis of Estimates from Different Sources

Тип самолета 1	Источник 2	3 КСТ Мт/год 1975	1980	1985	4 NO_2 кт/год 1975	1980	1985
5 СТС	[21][a]	0,1	1,34—1,6	6,7	1,8	24 - 29	120
	[8][a]	0	0,86—0,99	2,54—3,39	0	13 - 15	39 - 52
6 ДТС	[21][a]	20[б]	36—50	74	196[б]	330 - 460	690
	[8][a]	45,5	61—69	81,0—107,3	425	600—670	670—880

7 Примечание: а — указаны нижняя и верхняя границы оценок; б — указаны оценки для 1974 г.

KEY:

1. Type of aircraft
2. Source
3. QCF Megatons/year
4. NO_2 kilotons/year
5. Supersonic transports
6. Subsonic transports
7. Note: a) the lower and upper limits of the estimates are given; b) estimates for 1974 are given

Table 2

Estimates of the Total Annual Atmospheric Effluent (kilotons) of Halogen-Substituted Hydrocarbons

Примесь 1	Источник 2	1972	1973	1974	1975	1976	Примечание 3
$CFCl_3$ (F-11)	[22]	261	302	341	340	320[a]	Годовой прирост 14% 5
CF_2Cl_2 (F-12)	[22]	349	382	423	413	370[a]	Годовой прирост 9,6% 5
CCl_4	[24]	78	90	—	—	--	В 1955—65 гг. 50—60 кт 6
CH_3Cl	[16]	4 около 100—200					1/3 антропогенного происхождения 7

8 а — оценки по данным о производстве в 1975 г. и при предположении, что годовой выброс составляет около 90% продукта, произведенного в предыдущем году, как было в среднем до 1975 г.

KEY:

1. Impurity
2. Source
3. Remarks
4. About
5. Annual increment...
6. In...kilotons
7. 1/3 of anthropogenic origin
8. a) estimates based on data on 1975 production and on the assumption that the annual effluent is about 90% of the product produced in the preceding year, as it was on the average prior to 1975

This is probably a result of the poor knowledge of processes of formation and destruction of ozone and nitrogen oxides in the process of an atmospheric nuclear explosion.

c) Nitrogen fertilizers and fuel combustion. The principal source of NO and NO_2 -- nitrous oxide N_2O -- also enters into the atmosphere during the decomposition of agricultural nitrogen fertilizers in the soil. An intensive study of this process has now begun and the first estimates of the fraction of total nitrogen bound in the fertilizers, entering into the atmosphere in the form N_2O, and the rates of this process have been published [15, 29, 34]. With a strong increase in production and the use of fertilizers in agriculture throughout the world (increase by a factor of 20-30 during the last 25 years and an anticipated increase by a factor of 5 during the next 25 years with the production of 40 megatons of bound nitrogen in 1974 [15, 34]) the fraction of anthropogenic N_2O in the atmosphere is increasing and will become comparable with its natural content. It must be taken into account that the total quantity of nitrogen naturally bound in nature, primarily by soil bacteria, is estimated at approximately 200 megatons/year [15, 34].

However, the characteristics of the rate of decomposition (denitrification) of nitrogen fertilizers in the soil and plants have still been poorly studied; the fraction of bound nitrogen transformed into N_2O is estimated at 5-10%, whereas estimates of the mean denitrification time, according to different authors, vary from tens to thousands of years [15, 29, 34].

A considerable fraction (about 20 megatons in 1974) of the atmospheric nitrogen is associated with the combustion of fuel with an annual 4-6% increment and individual measurements have indicated the presence of N_2O in the plumes escaping from chimneys [34].

Thus, the anthropogenic fraction of the source of N_2O in the atmosphere is evidently increasing, but for the time being we are unclear about its magnitude in comparison with the natural sources of N_2O in the atmosphere, which have been studied appreciably less well than anthropogenic sources.

Thus, it still has not been established whether the ocean as a whole is a "giver" or "taker" of N_2O and estimates of the mean time of its presence in the atmosphere vary from several years to several tens and hundreds of years, depending on the author [29, 31].

Under such circumstances it is particularly necessary to carry out constant monitoring of the concentration of N_2O in the atmosphere and it has already begun or is being planned in some countries. Attempts at determining the change in the mean global content of N_2O by a comparison of data from modern measurements and measurements approximately 10 years old for the time being have yielded no reliable result due to the low accuracy of the latter [34].

d) Halogen-substituted hydrocarbons. These gases (the best known of which are freon-11 ($CFCl_3$) and freon-12 (CF_2Cl_2) as sources of ozone-destroying catalysts Cl and ClO (and also Br and BrO) have been extensively investigated in the stratosphere and have been extensively discussed in the press during recent years. Among the approximately 20 compounds from surface sources, in addition to the freons, carbon textrachloride CCl_4 and methyl bromide and chloride CH_3Cl and CH_3Br, whose natural sources have been poorly studied, enter the stratosphere in appreciable quantities and form the mentioned catalysts.

Estimates of the annual escape of these gases into the atmosphere during recent years are cited in Table 2 on the basis of data which are the most complete from a series of publications [22, 24, 25]. Here it must be noted that the cited data relate to anthropogenic effluent in the atmosphere in the western countries, in Japan, and especially in the United States. The discharge of freon-11 and freon-12 in the socialist countries is small and according to different sources does not exceed several percent of the values indicated in Table 2 [22]. The mean time between the production of freons and their escape into the atmosphere is different, depending on their use, but its mean weighted value for the fractions discharged into the atmosphere was close to one year [22]. During the period from 1960 through 1973 the mean increase in the production of freon-11 and freon-12 and its escape into the atmosphere was approximately 14 and 10% annually respectively and only in 1974 production, and in 1975 -- escape, remained at the level of the preceding year. According to oral communications of American specialists, the production and escape of freons decreased still more in the United States in 1976.

Since 1960 10-20% of the annual production of CCl_4 in the world has escaped into the atmosphere and during the years 1955-1965 its annual discharge into the atmosphere was almost constant at the level 50-60 kilotons, whereas during 1972-1973 it increased to 80-90 kilotons with the annual production being 0.9-1.0 megaton. The agreement of global measured CCl_4 concentrations during 1971-1974 with their estimates made on the basis of the cited data on its discharge into the atmosphere is indicative of the almost completely anthropogenic source of atmospheric CCl_4 [24]. An analysis of the losses of CCl_4 from the atmosphere in [24] leads to the conclusion that for like freons, the principal reason for the loss of CCl_4 is its photodissociation in the stratosphere and the mean time of its presence in the atmosphere is 25-70 years, as for freon-11.

Thus, this gas, sending into the stratosphere more chlorine atoms than freon-11, and at the same rate, and according to [24], produced in greater volumes than freons, can constitute an equal threat for stratospheric ozone.

It therefore follows that it is extremely difficult and scarcely feasible to predict the future levels of anthropogenic discharges of halogen-substituted hydrocarbons into the atmosphere.

The magnitude of the annual escape of CH_3Cl and the anthropogenic part of it are estimated extremely roughly and its contribution to the stratospheric reservoir of chlorine and its compounds (like the contribution of other halogen-substituted hydrocarbons) is small in comparison with the contribution of freons and CCl_4.

The natural sources of gases active relative to ozone were already mentioned above in relation to the anthropogenic sources and the difference between them for some gases is arbitrary. For example, the principal natural source of bound nitrogen is the root bacteria of legumes, a considerable percentage of which are cultivated by man. The poor knowledge of the natural levels of gas content in different parts of the geosphere does not make it possible to determine the anthropogenic sources.

a) Nitrogen compounds. In addition to the already mentioned sources, a considerable contribution to the stratospheric reservoir of nitrogen oxides is from fluxes of charged particles (primarily protons) of cosmic or solar origin. The most important source is cosmic particles and particles of solar "proton flares." Estimates of the intensity of formation of NO molecules by these sources were made in [19, 33] and their overall characteristics are given in Table 3 for some of the largest solar "proton flares."

Table 3

Total Number of NO Molecules in a Vertical Column of the Stratosphere to the North of 60°N Formed by Charged Particles [19]

Cosmic particles during solar activity period 10^{15} cm^{-2}/year		Solar proton flares 10^{15} cm^{-2}/event		
maximum	minimum	Nov 60	Sep 66	Aug 72
1.2	1.8	2.0	0.6	6.0

This table shows that the total annual intensity of these sources is comparable, but major solar flares occur rarely, not every year, and evidently do not exert a significant influence on the mean distribution of ozone content. The constantly operative "cosmic" source of NO molecules has the same order of magnitude of total intensity as their principal "natural" source -- the reaction

$$N_2O + O^* \begin{cases} 2\,NO \\ N_2 + O_2 \end{cases}$$

only the maximum vertical distribution of its intensity is situated lower -- in the layer 10-15 km versus 25-35 km respectively. This "cosmic" source is taken into account in most model computations.

b) Compounds containing chlorine. In addition to the above-mentioned natural sources, for the most part HCl, there are volcanic eruptions (primarily powerful) and sea salt particles, decomposing in the atmosphere. The latter are a powerful source of chlorine in the troposphere, but only a small fraction (and it is unknown precisely what fraction) enters into the stratosphere, passing through the layer of washing out of aerosols by clouds and precipitation. According to estimates in [11, 16], volcanoes eject into the stratosphere an average of 10-30 kilotons of HCl per year and about 5 kilotons are supplied by sea particles. These values are more than an order of magnitude less than the intensity of the above-mentioned chlorine sources in the stratosphere and failure to take them into account should have no appreciable effect on global estimates.

Numerical Models of Global Transfer and Photochemistry of Ozone in the Stratosphere

We now know of several tens of such models used for obtaining estimates of the anthropogenic effect on stratospheric ozone [3-5, 9, 12, 14, 20, 32]. They are all based on solution of systems of integro-differential equations and can be divided into the following three groups:

1) Three-dimensional models of stratospheric dynamics, describing in detail all the "meteorological" processes, including the transfer of ozone and impurities, and also taking into account the inverse influence of change in ozone content on the radiation, temperature and movements field. Such models are extremely complex and unwieldy and have been employed only in the United States at several centers with the most powerful electronic computers, taking into account only the simplest models of photochemical reactions in the Chapman cycles and nitrogen oxides [9, 32]. The great expenditures of computer time for powerful electronic computers do not make it possible to carry out the necessary number of numerical experiments for investigating the influence of the many factors taken into account on the transfer and photochemistry of ozone and therefore the broad possibilities of such models remain unrealized.

2) One-dimensional models with a detailed description of the entire system of photochemical cycles. In these models, for tens of impurities, up to a hundred or more photodissociations and reactions are taken into account. The atmospheric transfer of all these impurities is "parameterized" by vertical macroturbulent diffusion with the coefficient K_z variable in height but usually constant with time. Such models are least time-consuming and most numerous (a review of these is given in [14, 20]); most of the estimates of the anthropogenic effect were obtained using them.

The excessively great "roughness" of such modeling of atmospheric transfer is obvious. Allowance for the seasonal change in K_z in a one-dimensional model of transfer of freons indicated considerable seasonal variations in their concentration in the middle and upper stratosphere, exerting an influence on the content of Cl and ClO [4]. The inverse correlation between changes in ozone with temperature (determining the rate of chemical reactions) and transfer in the stratosphere is not considered in such models. Such models in general are ill-suited for describing the effect of impurities on ozone, since the global transfer of the latter in the stratosphere is directed not so much downward as from the upper stratosphere of the tropics into the lower stratosphere of the polar zones, that is, is essentially two-dimensional. However, one-dimensional models can be used for solving "inverse" problems in computing the distributions of the content of impurities from surface sources with a stipulated ozone distribution [5, 20].

3) Two-dimensional models occupy an intermediate position. In these models there is discrimination of ordered and macroturbulent transfer with an intensity changing with latitude, altitude and season and there is a more detailed photochemical scheme (usually a full description of the Chapman cycles, hydrogen and nitrogen). However, in most of these models the distribution of transfer parameters is considered stipulated (mean climatic values) and no allowance is made for the inverse correlation between ozone change and temperature and stratospheric movements [3, 14, 27]. Nevertheless, at the present time for modern computers the development of such models is most promising for approximate and prognostic computations.

According to recent refined estimates, computed using a two-dimensional model with full photochemistry [27], the total ozone content X in the northern temperate latitudes varies by approximately -0.5% from a volume of 220 kilotons of NO_2 per year at the level 18 km and by +0.5% from the volume of about 2 megatons of NO_2 per year at the level 11 km (2-5 and 3-4 times greater than the anticipated ejection of NO_2 by SST and subsonic aircraft engines in 1985 respectively according to the estimates in Table 1). In the mentioned model there is allowance for the formation of ozone in the upper troposphere described above for the case of oxidation of methane with the participation of nitrogen oxides (combustion products of engines of subsonic aircraft). Thus, the effect of subsonic and supersonic aircraft on ozone seemingly is compensated one by the other.

Computations of the effect of total ozone on the basis of one-dimensional models [4, 22, 25, 28, 36] show that due to the freons-11 and -12 present in the atmosphere in 1975 X decreased by approximately 1% and another 1-2% from CCl_4 and other hydrocarbons containing halogens. There was a somewhat greater (up to 10%) decrease in ozone density in the layer near the level 30 km.

Thus, present-day global anthropogenic effects on stratospheric ozone can lead only to small changes in its content which, first of all, are determined extremely inexactly because in magnitude they do not exceed the errors in the model computations themselves, and secondly, are not detectable using existing means for observation of ozone (see below). This virtually eliminates the possibility of checking the models and also model parameters and results obtained using observational data.

The only known case of such checking was a comparison of computations using the above-mentioned two-dimensional model [27] of the effect of a powerful solar proton flare in August 1972 (see Table 3) with materials from satellite measurements (on "Nimbus IV") of the mean zonal ozone content above the level 4 mb (37 km) on the basis of reflected UVR. In the zone to the north of 75°N this content decreased sharply (by approximately 20%) after the flare, which is only 30% greater than the computed value with a maximum at the level about 2 mb (43 km); however, an appreciable model decrease in ozone in the layer above 4 mb extends to 30-40°N, which was not confirmed by the mentioned measurements [26]. The decrease in total ozone X to the north of 75°N in this case was about 1.3% and was not detected by the network of ground ozonometric stations [26].

All the mathematical models of ozone and small atmospheric impurities published and enumerated here must be called simulations. Their authors endeavor to take into account most fully all the factors exerting an influence on the object of investigation and to obtain results closest to observations. The constant development of stratospheric photochemistry, the discovery of more and more impurities which exert an effect, will make obsolete the old models and make it impossible to obtain estimates with them; it will necessitate the reworking of these models, etc.

At the same time it is necessary to evaluate the error in model results arising both from the errors in the values of the parameters and from errors in the approximate computations used in the model. This model error determines the lower limit of the "signal" level, the effect on the modeled process, the effect of which can be computed with a stipulated reliability.

Such an effect is usually determined by a comparison (subtraction) of the results of "perturbed" and "control" variants of computations, which evidently leads to a great error, especially in the case of small perturbations. Here it is desirable to apply the small perturbations method to the model directly, using a system of equations which is conjugate to the model system for computing the perturbed values of the functionals by the method formulated by G. I. Marchuk [7].

It is also necessary to formulate nonsimulating models and investigate them. These describe the principal correlations and interactions of processes in which ozone and other small impurities in the stratosphere participate. These models are more abstract, but they make it possible to study the main character of the interaction of these impurities with one another and with the meteorological characteristics. They should give an answer to the question: how stable is stratospheric ozone to random variations of the content of impurities destroying it, transfers, photochemical parameters.

In order to formulate such models it is promising to use the methods of modern systems analysis and the qualitative theory of nonlinear stochastic equations.

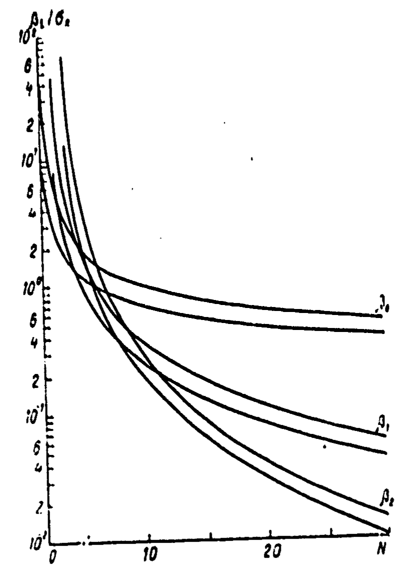

Fig. 2. Dependence of number N of independent observations necessary for determining with a probability P = 0.95 (lower curve of pair) and P = 0.99 the mean value $\bar{x} = \beta_0$ of the random value x with the standard deviation σ_x, its linear β_1 and quadratic β_2 trends by the least squares method [30].

Possibilities of Reliable Detection of Trend in Ozone Content. Summary

We have already mentioned unsuccessful attempts at observations of natural and anthropogenic effects on stratospheric ozone from a satellite or in a network of ground stations. The importance of the latter is especially great since their observations make it possible to form climatological time series and find the characteristics of the variability of the total ozone content.

Figure 2 shows curves of the dependence of the number N of independent observations of the x value necessary for determining, by the least squares method, the ratios to it σ_x: for the mean value $\bar{x} = \beta_0$, linear β_1 and quadratic β_2 trends with the probabilities P = 0.95 and 0.99 from [30]. In particular, it follows from these graphs that for discriminating the linear trend β_1 of the mean annual total ozone X (with P = 0.95) of 10% in 10 years with $\sigma_x/\bar{X}$ = 2-3% characteristic for the temperate northern latitudes (such a positive trend was observed in this zone in 1961-1970 [30]) there must be 10-12 years of measurements at a single station. The use for this purpose of data from a network of stations in a limited region with an approximately uniform trend hinders the correlation of these data. In some cases such a difficulty can be overcome when there is a simple nature of this correlation, but there will not be a substantial decrease in the number of necessary equivalently independent observations. It follows from these simple calculations that the existing networks of surface stations measuring total ozone cannot with a high reliability discriminate in a zone with a width of several tens of degrees in latitude any mean annual trend of several percent in the course of several (2-3) years. For the time being it is unclear whether the results of satellite measurements of ozone can be used for this purpose: the estimates of their accuracy are inadequate, the necessary series of such observations have not yet been accumulated, and their statistical characteristics have not been determined.

Special investigations must be made of the bases of a system for the monitoring of stratospheric ozone for obtaining the possibility of rapid and reliable detection of the anthropogenic effect on ozone.

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OZONOMETRIC NETWORK IN THE USSR

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 111-116

[Article by Doctor of Technical Sciences G. P. Gushchin, Main Geophysical Observatory, submitted for publication 18 July 1978]

Abstract: The article gives a brief history of creation of the USSR ozonometric network. At present this network consists of 45 stations. The author describes an integral method and the M-83 instrument developed at the Main Geophysical Observatory for measuring the total ozone content (TOC) in the network of stations. Also given are the results of eight interdepartmental and international comparisons of different ozonometric instruments. The discrepancy in the readings of the modernized M-83 instrument from the readings of the international ozonometric standard for the mean daily TOC values does not exceed 2.6%.

[Text] At the Interdepartmental Conference on Atmospheric Ozone held at the Main Geophysical Observatory during the period 4-5 April 1957 [3] the Main Geophysical Observatory was assigned the responsibility of creating a network of ozonometric stations in the territory of the USSR for participating in the work of the IGY. This assignment for creating an ozonometric network was carried out despite a number of difficulties related to the absence at that time of tested methodological procedures, perfected ozonometric instruments and trained personnel.

An important role in creating the ozonometric network was played by the reference (control) ozonometric station of the Main Geophysical Observatory at Voyeykovo, opened in 1956 [4]. The Dobson No 9 ozone spectrophotometer was used at this station; all the network ozonometric instruments of the USSR were tied in to that instrument.

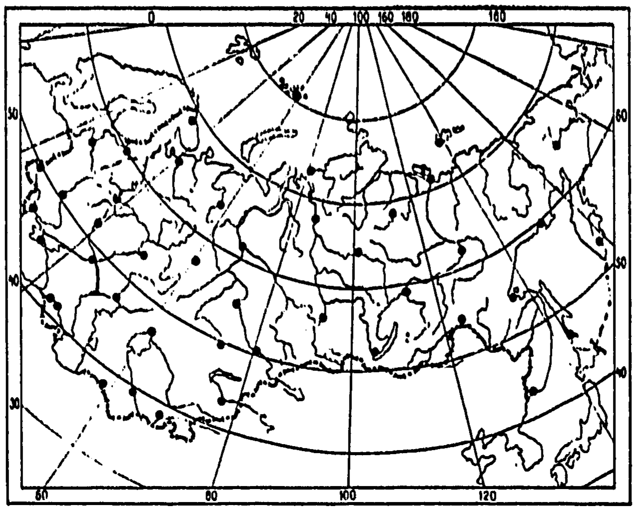

Fig. 1. Ozonometric network of USSR.

During the IGY period (1957-1959) 11 ozonometric stations operated in the territory of the USSR, in 1963 there were 23 such stations [4], in 1967 -- 37 stations [8], and since 1970 there have been 45 ozonometric stations (Fig. 1). These stations are rather uniformly distributed over the territory of the USSR: 17 stations in the European part, 27 stations in the Asiatic part and one station in Antarctica.

At the present time the USSR ozonometric network includes 42% of the stations in the world ozonometric network, consisting of 106 operating stations for measuring the total ozone content (TOC) [23]. It should be noted that during recent years abroad there has been a decrease in the number of operating ozonometric stations, whereas in the USSR this number has not changed.

Observations of the total content of atmospheric ozone at USSR stations are carried out in accordance with a unified program which is identical for all stations with M-83 instruments [4, 13]. In 1970 new systematic instructions were published for carrying out and processing TOC observations [12]. They took into account the experience in making ozone observations in the network of stations and the method used for these observations was improved.

Beginning in 1971 in the USSR ozonometric network a modernized M-83 instrument came into use [10]. This made possible a considerable improvement in the quality of observations of TOC and a reduction in the error of collected data. The principal difference between the modernized M-83 instrument and the old M-83 instrument is the use of new glass light filters, which made it possible to shift the spectral response curves for the instrument in the region of the two light filters into the short-wave spectral region and bring these curves closer together. In 1972 all the M-83 instruments, operated in the ozonometric network, were modernized and tied in to the Dobson No 108 spectrophotometer, which since 1969 was used as the Soviet standard. In turn, the Dobson No 108 spectrophotometer was tied in to the world ozonometric standard -- the Dobson No 83 spectrophotometer located in the United States. The tie-in of this network instrument M-83 to the Soviet standard instrument has been accomplished since 1957 regularly once in two years at the scientific-experimental bases of the Main Geophysical Observatory in the neighborhood of Leningrad and in the Feodosiya region.

Table 1

Results of Official Comparisons of Different Ozonometric Instruments

	Пункт сравнений 1	Период сравнений 2	Номера сравниваемых приборов 3: с/ф Добсона 4	Номера сравниваемых приборов 3: М-83	Наибольшее отклонение (по абсолютной величине) среднедневных данных ОСО η, % 5	Источник 6
7	Ленинград	2—7 VI 1959 г.	9	2	8,5	[11]
8	Ташкент	13—19 XII 1963 г.	71 71	10 11	17,3 20,9	[6]
9	Шиофок (Венгрия)	12—15 V [illegible] г.	84	60	10,5	[7]
10	Ленинград	24 V—9 VI 1969 г.	108 108	24 61 модерниз. 14	14,5 3,8	[1]
11	Бельск (Польша)	26 VI—3 VII 1974 г.	83	58 модерниз.	2,6	[20, 21]
12	Мауна-Лоа (США)	6—25 X 1976 г.	63	121 модерниз.	5,3	15 Протокол сравнений, подписанный в СССР и США
13	Боулдер (США)	28 X—1 II 1976 г.	82	121 модерниз.	3,9	
13	Боулдер (США)	2 и 20 VIII 1977 г.	83	121 модерниз.	2,5	16 Материалы сравнений, переданные ГГО В. Комхиром

KEY:

1. Comparison point
2. Comparison period
3. Number of compared ed instruments
4. Dobson spectrophotometer
5. Maximum deviation (using absolute value) of mean daily data for TOC η, %
6. Source
7. Leningrad
8. Tashkent
9. Shiofok, Hungary
10. Leningrad
11. Belsk, Poland
12. Mauna Loa (USA)
13. Boulder (USA)
14. modernized
15. Comparison document signed in USSR and US
16. Comparison data sent to Main Geophysical Observatory by V. Komkhir

Table 2

Results of Comparisons of Instrument M-83 No 58 (USSR) and Dobson Ozone Spectrophotometer No 83 (United States), the International Standard, at Belsk (Poland) 1974

Высота Солнца, *град* 1	Общее содержание озона, 10^{-3} *см* 2		η %	Высота Солнца, *град* 1	Общее содержание озона, 10^{-3} *см* 2		η %
	с/ф Добсона 3 № 83 (США)	М-83 4 № 58 (СССР)			с/ф Добсона № 83 (США)	М-83 № 58 (СССР)	
5 28 июня							
29,5	381	381	0	28,0	382	375	−1,8
29,1	382	367	−3,9	28,0	382	365	−4,5
				7 Среднее	382	372	−2,6
6 29 июня							
50,0	374	402	7,5	46,6	372	368	−1,1
50,0	374	370	−1,1	42,4	374	378	1,1
48,9	368	371	0,8	39,1	379	380	0,3
48,0	377	364	−3,4	38,3	379	380	0,3
48,0	377	375	−0,5	36,8	378	382	1,1
47,4	375	372	−0,8	36,2	375	381	1,6
				7 Среднее	375	377	0,5

KEY:

1. Solar altitude, degrees
2. Total ozone content, 10^{-3} cm
3. Dobson spectrophotometer No 83 (USA)
4. M-83 No 58 (USSR)
5. 28 June
6. 29 June
7. Mean

For measuring TOC in the ozonometric network of the USSR use is made of an integral method developed in 1958 [4, 5] for ozonometric instruments with light filters discriminating rather broad spectral bands. This method made it possible to measure the TOC with simpler and less expensive instruments with light filters [12]. As is well known, the Dobson quasimonochromatic method [4, 15] is not suitable for instruments with broad transmission bands as a result of the Forbes effect [4]. The integral method [4, 12] is free of this shortcoming, since it takes into account the mentioned effect, manifested in a change in the position of the spectral maximum of the effective response of a broad-band instrument with a change in solar altitude or TOC. A comparative analysis of the integral and quasimonochromatic methods for measuring TOC, carried out during recent years, made it possible to draw a number of conclusions. The advantage of the employed integral method is that when it is used it is not necessary to compute the effective wavelengths (or

Table 3

Results of Comparisons of Instrument M-83 No 121 (USSR) and Dobson Ozone Spectrophotometer No 83 (United States), the International Standard, at Boulder (USA) in 1977

Высота Солнца, град (1)	Общее содержание озона, 10^{-3} см (2): с/ф Добсона № 83 (США) (3)	Общее содержание озона, 10^{-3} см (2): М-83 № 121 (СССР) (4)	η %	Высота Солнца, град (1)	Общее содержание озона, 10^{-3} см (2): с/ф Добсона № 83 (США) (3)	Общее содержание озона, 10^{-3} см (2): М-83 № 121 (СССР) (4)	η %
(5) 2 августа							
33,5	313	315	0,6	51,5	306	294	—3,9
35,4	312	318	1,9	60,7	304	290	—4,6
37,0	311	304	—2,2	61,2	304	297	—2,3
38,7	310	298	—3,9	62,1	304	292	—3,9
49,0	307	297	—3,3	63,1	304	294	—3,3
				(7) Среднее	308	300	—2,5
(6) 20 августа							
16,7	300	303	1,0	28,8	307	293	—4,6
17,5	301	325	8,0	30,5	307	302	—1,6
18,3	302	312	3,3	36,5	306	303	—1,0
19,8	303	314	3,6	45,8	304	297	—2,3
20,5	304	325	6,9	47,6	304	289	—4,9
21,3	304	316	3,9	50,1	303	288	—4,9
22,9	305	300	—1,6	53,6	302	284	—6,0
23,6	306	311	1,6	54,9	302	287	—5,0
24,4	306	309	1,0	58,5	301	290	—3,6
26,3	306	285	—6,9	61,2	300	288	—4,0
				(7) Среднее	304	301	—0,86

KEY:

1. Solar altitude, degrees
2. Total ozone content, 10^{-3} cm
3. Dobson spectrophotometer No 83 (USA)
4. M-83 No 121 (USSR)
5. 2 August
6. 20 August
7. Mean

the effective values of the ozone absorption and Rayleigh scattering indices), discriminated by light filters, as is done, for example, in [22]. The effective wavelengths (or the effective values of the mentioned indices) are themselves dependent on the ozone content and their use considerably complicates TOC computations. In addition, with use of the integral method for measuring TOC use is made of a rather broad spectral part of the ozone absorption band, which reduces the errors associated in the quasimonochromatic method with the instability of wavelengths passing through the instrument slits. These errors in the quasimonochromatic method increase as a result of extremely significant jumps on the ozone absorption curve. It must be expected also that with use of the integral method for measuring TOC there is an increase in the errors associated with variations in stratospheric temperature.

However, the most important advantage of the integral method in comparison with the quasimonochromatic method is that when it is used there is no longer a need for determining the exoatmospheric spectral constants of the instrument, which always causes difficulties when the quasimonochromatic method is employed. In the integral method use is made of the spectral curve of the density of energy illumination caused by solar radiation outside the atmosphere, measured using aircraft, rocket or satellite instrumentation [14].

At the same time it should be noted that some light filters used in the M-83 instrument (UFS-2 and ZhS-20) are subject to solarization and as a result are inadequately stable. Therefore, in the M-83 instrument regular use is made of a control device which monitors constancy of transmission of the light filters and the light filters are changed each two years without fail.

The most valuable information on the quality of operation of different instruments for measuring TOC was obtained as a result of their direct comparisons. During the last 20 years specially created interdepartmental or international commissions, with participation of representatives of the Main Geophysical Observatory, have carried out eight official comparisons of different ozonometric instruments (including Dobson spectrophotometers and M-83 ozonometers). The results of these comparisons are given in Table 1. This same table gives the deviations η of mean daily (to be more precise, during the comparison period during the course of the day) TOC data for the two compared instruments: the Dobson spectrophotometer and the M-83 ozonometer.

The η value was determined using the formula

$$\eta = \frac{\Omega_{M\text{-}83} - \Omega_{c.\,Д}}{\Omega_{c.\,Д}} \cdot 100, \qquad (1)$$

[c. Д = Dobson spectrophotometer] where Ω_{M-83} is the mean daily TOC according to the M-83 instrument, Ω_{DS} is the mean daily value according to the Dobson spectrophotometer.

Table 1 is based only on synchronous TOC values measured by both instruments with a time difference not exceeding 2 minutes. The TOC values according to the Dobson spectrophotometer, entering into Table 1, were determined only for the standard pair of wavelengths AD (except for the Dobson spectrophotometer No 9, where pair C was used); the corrections obtained as a result of the comparisons were not introduced into the data for the two instruments.

As a comparison, we give Table 4, which gives the results of comparisons of data obtained using different Dobson spectrophotometers at international comparisons at Belsk [20, 21]. The corrections obtained as a result of the comparisons have not been introduced into the data in Table 4.

The following conclusions can be drawn from Tables 1 and 4:

1) The greatest deviations of the mean daily TOC values, measured with the nonmodernized M-83 instrument, from the mean daily TOC values according to different Dobson spectrophotometers, attain 20.9%.

Table 4

Results of Comparisons of Different Dobson Spectrophotometers at Belsk in Period 26 June-3 July 1974 (AD Pair, Direct Sunlight). The Dobson No 83 Spectrophotometer (United States) Was Used as the International Ozonometric Standard

Numbers of Dobson spectrophotometers and countries participating in comparisons	Maximum Deviation of Mean Daily TOC values from Values Using Standard (in Absolute Value) for Comparison Period η, %
No 41, Great Britain	3.3
No 64, GDR	4.7
No 77, Canada	3.7
No 84, Polish People's Republic	7.5
No 96, APE	1.4
No 101, Switzerland	3.3
No 108, USSR	4.6
No 110, Hungarian People's Republic	6.4
No 112, India	2.8

2) The maximum deviations of the mean daily TOC values, measured with different Dobson spectrophotometers, do not exceed 5.3%.

3) The greatest deviations in the mean daily TOC values, measured with different Dobson spectrophotometers, from the corresponding values using the international standard, vary in the range 1.4-7.5%.

4) The maximum deviations of the mean daily TOC values measured with the modernized M-83 instrument from the corresponding values according to the international standard vary in the range 0.5-2.6%.

It follows from the second and fourth conclusions that the relative error in the mean daily TOC values, measured by the modernized M-83 instrument in direct sunlight, does not exceed 5%. It must be remembered that all international publications [23] give only the mean daily TOC.

Tables 2 and 3 are given for judging the errors in one-time TOC values obtained using the modernized M-83 instrument.

In the preparation of Tables 2 and 3 we used all synchronous TOC values obtained during international comparisons using M-83 modernized instruments and using the international ozonometric standard.

It follows from Tables 2 and 3 that for the modernized M-83 instrument there is no appreciable dependence of TOC data on solar altitude. The relative error in one-time TOC values, obtained using the M-83 instrument, does not exceed 8%, whereas the relative error in the mean daily TOC values does not exceed 2.6% (it is assumed that the error in the international ozonometric standard is equal to zero).

In addition to the official comparisons of ozonometric instruments there have been several unofficial comparisons, in particular, at Sofia in 1966-1967 [17], at Belsk in 1969-1970 [19], at Budapest in 1969-1970 [18]. It should be noted that in all the unofficial comparisons of ozonometric instruments use was made of the old unmodernized M-83 instruments which were removed from use in the USSR ozonometric network in 1972. The results of the unofficial comparisons of ozonometric instruments are close to those which were obtained in the USSR in a comparison of the unmodernized instruments [6, 7, 11].

In addition to the carrying out of regular TOC network measurements in the USSR, on the initiative of and with the participation of the Main Geophysical Observatory, during the last 20 years there have been periodic TOC observations from aircraft and ships [2, 4, 16]. TOC observations from aircraft made it possible to investigate the fine spatial structure of the TOC field, to establish the presence of a close correlation between the TOC field and the atmospheric pressure fields at the 300- and 200-mb surfaces, and in particular, to detect the phenomenon of deformation of the field of atmospheric ozone in the jet stream zone [8, 13]. In addition, the ozonometric apparatus carried aboard an aircraft was usually used for checking the readings of surface ozonometric stations.

Many years of TOC observations from Soviet scientific research vessels in the Pacific, Atlantic and Indian Oceans [2] have made it possible to ascertain the patterns of horizontal distribution of TOC over ocean areas: latitudinal variation, correlation with the pressure field, and in particular, with the ICZ. It should be noted that as a result of the carrying out of ozonometric observations from Soviet scientific research ships it has become possible to obtain surface data on atmospheric ozone over ocean areas. Such observations are not being carried out abroad due to the lack of appropriate instrumentation.

As a result of a generalization of Soviet and world observational data on TOC it was possible to plot monthly maps of the horizontal TOC distribution in the northern hemisphere [9]. It was thereby possible to clarify more precisely the position of the East Siberian TOC maximum, since the maps were plotted using all Soviet TOC observations, including data for stations not included in the international exchange program. The mean maps of TOC distribution in the northern hemisphere are now being refined on the basis of use of data obtained using the modernized M-83 instrument.

Long series of TOC data obtained using the modernized M-83 instrument will become reference data by means of which it will be possible to evaluate the possible anthropogenic influence on the ozone layer.

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TWENTIETH ANNIVERSARY OF DISCOVERY OF THE POLE OF RELATIVE INACCESSIBILITY IN ANTARCTICA

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 117-118

[Article by Candidate of Physical and Mathematical Sciences Yu. N. Avsyuk]

[Text] On 13 December 1958 a sledge-tractor train of the Third Soviet Antarctic Expedition reached the Pole of Relative Inaccessibility in Antarctica. The outfitting of the station began: the booths of the meteorological area were placed not far from the living hut, a radio tower was erected and several tractors began the rolling of a landing strip. A bust of Vladimir Il'ich Lenin was placed on the hut roof.

The opening of the Pole of Inaccessibility station was marked by the raising of the State flag. All the participants on the trek, 17 persons, lined up in the meteorological area and the chief of the expedition, Ye. I. Tolstikov, raised the flag of our Motherland.

A solemn and joyous moment had arrived: the most lengthy (at that time) scientific trek had been made through unexplored Antarctica and the region most remote from the shoreline had been reached. One of the most difficult of the obligations of Soviet science during the geophysical year had been carried out. All the efforts on preparation and the difficulties of the trek were justified -- the goal had been achieved: the Pole of Relative Inaccessibility of Antarctica had been discovered by Soviet people.

With the elapsing of a definite time the earlier seemingly fragmented episodes could be viewed as a series of interrelated events directed to a single goal. The trek to the Pole of Relative Inaccessibility was an undertaking of the entire Antarctic expedition. The success of such a major scientific undertaking was ensured by the experience of the preceding expeditions, the careful and multisided preparation of equipment, scientific apparatus and personnel.

This was a scientific trek with a broad complex of geophysical investigations. The reaching of the most remote point was not an end in itself. The objective was the carrying out of scientific observations along a route most representative for all of Eastern Antarctica. Continuous scientific observations were made from the shore to the very center of Antarctica. Preparations for the trek were made continuously by each subdivision of the expedition, beginning with the moment of landing on the continent.

During the first autumn trek of the tractors not only was Sovetskaya station established, but tractors with broadened treads were also tested. An optimum variant for loading of the sledges was selected and a method for gravimetric observations was checked out.

During the last days of the Antarctic autumn there was testing and improvement of seismic apparatus in a test polygon in the neighborhood of Pionerskaya station. This brief, but very difficult trek enabled the seismology specialists to check out their instruments and equipment for thermophysical and ultrasonic measurements in boreholes, to understand the peculiarities of excitation and reception of a signal in the ice and firn layers and in the course of the winter to reconstruct and adapt part of the apparatus to these conditions.

During the reconnaissance flights there was testing of a method for aerological leveling -- the sole operational method for determining elevations along the route followed by the scientific sledge-tractor train. The idea of the method was that an aircraft in flight maintains some fixed isobaric surface and the altimeter readings are used in determining the elevation of the surface relative to the flight level.

By the beginning of winter the scientific and transport personnel of the expedition clearly understood the problems facing them and had time to take them into account in the spring trek.

Winter was spent in preparation of equipment and instrumentation. A train of tractors and "Pingvin" cross-country vehicles departed from Mirnyy early in spring. The train had to deliver fuel to Pionerskaya and Komsomol'skaya stations and support the work of seismologists between these stations. When some of the tractors which had delivered fuel to Pionerskaya had returned to Mirnyy the main sledge-transport train moved out to the Pole of Relative Inaccessibility. Meteorological, seismic, gravimetric, magnetometric and thermophysical measurements were made along the entire route. These observations were used in constructing a section of the glacier cover along the route of the train. A graph of the change of the gravitational anomaly and the Z-component of the magnetic field was constructed.

The discovery of underice mountain structures (Gamburtsev, Golitsyn Mountains, Shmidt Plain) occurred and are now shown in the ATLAS OF ANTARCTICA. It was established on the basis of gravity anomalies that the weight of the glacier lying on the continent caused a redistribution of subcrustal material so that at the present time the continent is in isostatic equilibrium. Borehole measurements of temperature and ultrasonic observations made it possible to detect the zone of the lowest temperatures within the continent, and also to establish the fine structure of the firn snow stratum. The snow, quietly accumulating over the millenia, produced a loud noise from settling beneath the heavy tractors, without any apparent phenomena at the surface.

On this trek all the participants exhibited high qualities of willpower. The route of the trek passed through areas of severe natural conditions; at times the tractors passed through a blizzard with a visibility not greater than one meter and got stuck in snow which was as loose as sand. But the train overcame all these sectors and moved on and on as a unified column. The schedule of movement provided for stopping for scientific observations, at the same time that fueling and preventive maintenance of the tractors was carried out. The high professional level of the drivers made it possible to carry out repair work in the shortest time possible, so that the schedule of movement corresponded to the plan. To be sure, all these operations were made with a great output of effort: the bitter cold and high mountain conditions had a strong effect on the overall feeling of well-being of the people. Some participants on the trek, due to their health, had to remain at Sovetskaya station and then returned to Mirnyy by aircraft.

The success of the trek with the conquest of the Pole of Relative Inaccessibility can be explained, somewhat rephrasing the words of F. Nansen, who stated: "the necessary people were at the necessary place, both in making preparations for and in implementing the trek."

Twenty years have passed and interest in study of Antarctica has not lessened. In Antarctica (especially in its deep regions) important investigations can be carried out which affect the earth as a whole. The stratified snow and firn contain information on the history of climate over the course of tens of thousands of years. A recognition of the periodicity of climate in the past is very important for solving the problems in general climatology. It would be of great importance to formulate astronomical observations of the position of the axis of rotation in the southern hemisphere. In contrast to the northern hemisphere such systematic observations have not yet been made here.

The value of the scientific undertaking is to become apparent with time. And now, after 20 years have passed and the scientific results are known to the entire world, the trek and the discovery of the Pole of Relative Inaccessibility can rightfully occupy their place among the outstanding geographical discoveries of the 20th century.

REVIEW OF MONOGRAPH BY F. M. KUPERMAN AND V. A. MOISEYCHIK: VYPREVANIYE OZIMYKH KUL'TUR (DAMPING OF WINTER CROPS), LENINGRAD, GIDROMETEOIZDAT, 1977, 168 PAGES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 p 119

[Article by Professor A. I. Korovin and Candidate of Agricultural Sciences V. A. Korneyev]

[Text] The damping of winter crops in the Nonchernozem zone of our country is an important national economic problem. Damping does not always lead to such an impressive destruction of sown areas as destructive freezing, but it always causes a decrease in the yield of winter crops, an incomplete grain harvest. In individual years, however, it leads to the death and resowing of winter crops.

It is gratifying that the book was written by two outstanding specialists in their fields: the biologist-morphophysiologist F. M. Kuperman and an agrometeorologist specializing on the wintering of winter crops, V. A. Moiseychik. The joining together of the experience and knowledge of a biologist and agrometeorologist made possible the most complete, thorough and exhaustive description of the present status of investigations of damping.

The book has no traditional exposition of history of the problem. It gives a very brief review of the most important experimental investigations of the processes of growth and development of plants during the autumn-winter-spring period as factors involved in the formation of winter hardiness of winter crops and the processes responsible for their damping. Only the most important material is presented, and this has reduced the volume of the book and has made possible a clearer and better presentation of the present state of the problem.

The most important part of the book is an examination of the dependence of damping processes on current and impending agrometeorological conditions, the patterns of their seasonal change, and the diagnosis of damping from changes in the apical cone. The authors feel that it is precisely changes in the apical cone which can serve as an integral direct indicator of the state of plants, the degree of their damping.

Something which is new in the book is a critical generalization of everything which has been done in recent years for investigating the processes of growth and development of plants during the autumn-winter-spring period, playing an important role in forming resistance to damping -- this being an important component of winter resistance. Another new aspect is that all the problems related to plant damping are examined from the point of view of their relavence for predicting damage and destruction of sown areas from damping and for validating already existing and newly developed methods for contending with damping, with its negative effect on yields. The systematic exposition of the known regularities in the development and dynamics of damping processes and their biological and agrometeorological essence yields rich material for thought, gives basis for improving already known and developing new methods and procedures for contending with the damping of winter crops and its negative effects.

The authors cite interesting data on quantitative evaluation of the agrometeorological conditions for wintering and the state of winter crops in regions with a thick snow cover, on the influence of agrometeorological conditions on the gross yield of grain and the area of winter crops perishing due to damping, and on the probability of damping of winter crops in different regions of the USSR.

A special place is devoted to sections which set forth the methods for preparing long-range forecasts of the damping of winter crops and methods for contending with damping.

In our opinion, the book does an excellent job of introducing biological elements into agrometeorology.

While welcoming the appearance of a book on damping, one must nevertheless reproach the authors for leaving unused the most recent studies on chemical methods for contending with damping and the use of fungicides and Tur preparations.

In addition, in their monograph the authors have passed over investigations in the field of physiological damping carried out at the Institute of Plant Physiology (Moscow) under the direction of Professor A. S. Kruzhilin and others.

The publication of this book by F. M. Kuperman and V. A. Moiseychik on the damping of winter crops is an important and timely, from the point of view of its contribution to science, aid in efforts directed to increasing agricultural production in the Nonchernozem zone of the RSFSR.

REVIEW OF MONOGRAPH BY G. T. GUTIYEV AND A. S. MOSIYASH: KLIMAT I MOROZO-STOYKOST' SUBTROPICHESKIKH RASTENIY (CLIMATE AND FROST RESISTANCE OF SUBTROPICAL PLANTS), LENINGRAD, GIDROMETEOIZDAT, 1977, 280 PAGES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 119-120

[Article by Doctor of Geographical Sciences I. A. Gol'tsberg]

[Text] The Soviet subtropics constitutes a region of highly intensive agriculture characterized by a very great diversity of species and varieties of cultivated crops. But a number of widely cultivated and new crops are here at the northern boundary of their range (tea, citrus fruits, olives, etc.). This makes necessary a precise determination of the climatic parameters limiting their range.

This book by G. T. Gutiyev and A. S. Mosiyash is devoted to a detailed study of this problem of very great importance and is divided into two parts. The first examines the climate of the subtropics of the USSR; the second is devoted to a study of the frost-resistance of subtropical plants. The most detailed description is given for the climate of the moist subtropics of the Caucasus -- the Black Sea coast, Alazanskaya and Talyshskaya Oblasts, affording extensive possibilities for the development of subtropical crops. There is an original presentation of this description by individual landscape zones defined by the authors (foothills, hills near the sea and individual hill complexes and isolated hills distant from the sea), making it possible to make clear some mesoclimatic characteristics of considerable importance for the range of subtropical crops.

The climatic description is given on the basis of observations made at individual meteorological stations, but taking into account their sites in the relief and using the known microclimatic patterns of distribution of minimum air temperatures (frost resistance). The monograph gives much numerical data characterizing the temporal and spatial distribution of temperature, precipitation and winds.

No cartographic representation of the studied climatic elements is presented. There are only diagrams of some mountain profiles and ecological regions, the distribution of individual crops by elevations, these poorly supplementing the text.

There is a less detailed description of the dry subtropics along the southern shores of the Crimea, Eastern Transcaucasia and Central Asia. The authors correctly emphasize the broad possibilities for the development here of more frost-resistant and drought-resistant subtropical crops.

Each section in the text in the first part of the book ends with brief conclusions giving an evaluation of the prospects for the development of subtropical agriculture by regions. A separate chapter is devoted to the peculiarities of the microclimate of the moist subtropics. It emphasizes the enormous importance of taking microclimate into account in the distribution of crops and the necessity for compiling microclimatic maps for individual farms.

The second part of the book contains extensive and very valuable new material on the frost-resistance of the principal subtropical crops under field conditions, obtained over a period of many years of development of subtropical agriculture. Frost-resistance is determined taking into account the variety and age of the plants and their condition. The great range of frost-resistance of these plants in dependence on these factors is demonstrated. The phenology of development of subtropical crops is given. The conclusions give clear recommendations on the makeup of varieties in the regions of development of both already cultivated (tea, citrus fruits, olives, etc.) and relatively new crops (pineapples, avocado, etc.).

The extensive bibliography presents studies from the end of the last century to recent years.

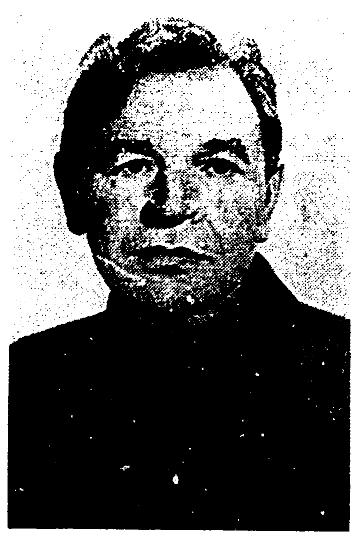
The book is well published, illustrated with figures and photographs of plants, is easily read and is necessary for a broad range of specialists engaged in developing the agriculture of the Soviet subtropics.

SIXTIETH BIRTHDAY OF VLADIMIR NIKOLAYEVICH PARSHIN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 p 121

[Article by the Board of the USSR State Committee on Hydrometeorology and Environmental Monitoring]

[Text] Professor Vladimir Nikolayevich Parshin, Doctor of Geographical Sciences, marked his 60th birthday and the 35th year of his scientific activity on 16 January 1979. He is Deputy Director of the USSR Hydrometeorological Center.



V. N. Parshin belongs to the generation of hydrometeorologists who began their practical activity on the fronts of the Great Fatherland War. For his successful accomplishment of the tasks of his assignment he was awarded the Red Star and many medals.

The scientific activity of V. N. Parshin began in 1945 at the Central Institute of Forecasts, now the USSR Hydrometeorological Center, within whose walls he manifested his distinct talents as a researcher, a scientific organizer, as well as his practical work on routine support of the national economy of the country with hydrological forecasts and information. His services in this field were recognized by a high government award -- the Order of the Red Banner of Labor.

Vladimir Nikolayevich is one of the leading scientists in the Soviet Union in the field of general hydrology and hydrological forecasts. He is widely known for his fundamental investigations of the water balance of the zone of inadequate moistening and creation of the physical principles of methods for predicting the runoff of rivers in this zone. The forecasting methods which he developed made possible a considerable improvement in hydrological support of the national economy of Kazakhstan and the southeastern European territory of the USSR. They are used extensively in routine practice.

Studies by V. N. Parshin on the problem of predicting the runoff of mountain rivers are of great interest. He developed physical-statistical principles for the methods of these forecasts and proposed a method for long-range predictions of runoff of the most important rivers in the Turkmen SSR, which over a period of years has been effectively used in the hydrological servicing of irrigated agriculture in this republic.

The investigations of V. N. Parshin made a significant contribution to study o. the formation and distribution of snow cover in the European territory of the USSR as the main factor in spring runoff. In a series of studies on this problem he provided a theoretical basis for the rational distribution and optimizing of the network of stations carrying out snow-measuring surveys.

For the first time in world practice V. N. Parshin used analytical methods for the objective analysis of the fields of meteorological elements for a study of the field of spring runoff. The method which he developed on this basis for predicting the inflow of water into the reservoir of the Tsimlyanskaya Hydroelectric Power Station on the basis of the runoff of small rivers in the Don basin already for many years has served as a reliable basis for the servicing of this highly important hydroelectric power complex.

V. N. Parshin has published a total of 45 studies. His scientific studies represent a major contribution to hydrology. They have led to the creation of new scientific directions and to a high degree favor the rational use of the water resources of the country. The most important results of the work were incorporated in manuals for the hydrological forecasting service and in textbooks for colleges.

The extensive scientific work of V. N. Parshin is combined with extensive practical activity in supporting the national economy of the country with all types of hydrometeorological forecasts. Along these lines he has done much work in the practical use in the national economy of the latest attainments of hydrometeorological science.

The great scientific, administrative and public work of V. N. Parshin does not prevent him from remaining a sensitive and responsive person, profoundly interested in the personal lives of each worker at the institute.

In congratulating Vladimir Nikolayevich on his remarkable anniversary, we are sure that he, with his characteristic energy, purposefulness and love of his work will make a significant contribution to hydrometeorological science, and especially to the further development and improvement of hydrometeorological forecasts.

AWARD OF A. A. FRIDMAN PRIZE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 p 122

[Article by personnel of the USSR Order of Lenin Hydrometeorological Scientific Research Center]

[Text] By a decree of the Presidium USSR Academy of Sciences dated 28 September 1978 the A. A. Fridman Prize for 1978 in the amount of 2,000 rubles was awarded to Corresponding Member USSR Academy of Sciences Yekaterina Nikitichna Blinova for a series of studies in the field "Dynamics of Atmospheric Movements on a Planetary Scale. Hydrodynamic Long-Range Weather Forecasting and Climate Theory."

All the activity of Ye. N. Blinova, taking place in the institutes of the USSR Academy of Sciences and at the USSR Hydrometeorological Service, has been devoted to solution of one of the most important and complex problems in meteorology -- long-range weather forecasting. In 1943 she published the fundamental work "Hydrodynamic Theory of Pressure and Temperature Waves and Centers of Action in the Atmosphere," in which the classical theorem of hydromechanics of eddies was applied to the planetary dynamics of the atmosphere and served as a basis for the first theory of hydrodynamic long-range forecasting. Her doctoral dissertation (1946) was devoted to the hydrodynamic theory of climate and here Ye. N. Blinova demonstrated how theoretically, in the office, it is possible to reproduce the observed nonzonal distribution of meteorological elements in the atmosphere.

These two studies provided the momentum for intensive development of the hydrodynamic theory of climate and long-range forecasting and exerted a great influence on the forming of the Soviet scientific school in this field.

The basis for the mentioned investigations was the spectral approach to solution of the problem, which during the last 25 years has been applied by Ye. N. Blinova and a number of other scientists in the Soviet Union to many linear problems in long-range hydrodynamic forecasting and the theory of climate with an exponential broadening of the range of predicted parameters and a refinement of the physical aspects of the models.

Characteristics of Yekaterina Nikitichna are exceptional clarity of formulation of the problem and thoroughness of the work carried out, the aspiration to put the results in numbers, to put results to practical use. This has been manifested in the fact that under her direction in the USSR for the first time work was initiated on the preparation of several kinds of routine hydrodynamic long-range forecasting, including a hemispherical forecast of mean monthly anomalies of temperature and precipitation, the method for which is based on the idea of a "steady regime."

The further investigations of Ye. N. Blinova were directed to a changeover from linear to nonlinear regimes with the use of the full equations of hydrothermodynamics with retention of the spectral method. It could be demonstrated that in a number of important special cases the change to nonlinear prognostic equations in place of linearized equations leads to stable solutions with the same initial values of the parameters for which in the linear problem there was a dynamic instability present. Relying on analytical solutions obtained for such special cases, Yekaterina Nikitichna during later years formulated a method for long-range forecasting with the discrimination of the "main oscillations" and proposed an effective numerical algorithm for solution of the problem based on the writing of spectral equations by the Bubnov-Galerkin method. The method for discriminating the "main waves" in this case was used in a model in which an allowance is made not only for the solenoidal part of wind velocity, but also the potential part; included are the heat influxes due to turbulent heat conductivity, radiation and evaporation and motion over a real underlying surface, with continents and oceans being taken into account.

An important characteristic of the methods for long-range forecasting developed by Ye. N Blinova within the framework of nonlinear theory is that the changes in meteorological elements, important for weather formation, are found in this case here simultaneously with the climatic background.

An original approach to study of large-scale atmospheric processes and solution of the long-range forecasting problem was formulated by Ye. N. Blinova by use of "correlation moments" -- the statistical characteristics of these movements, for the first time introduced by the Soviet meteorologists A. A. Fridman and L. V. Keller.

Yekaterina Nikitichna is the author of more than 60 scientific studies published in Soviet and foreign publications. Her ideas exerted a significant influence on the development of a number of Soviet researchers. Ye. N. Blinova is devoting much attention to studies under the GARP program, being a member of the Soviet committee on this program and chairman of its subgroup on numerical experimentation.

In congratulating Yekaterina Nikitichna Blinova on receipt of the A. A. Fridman Prize, we wish her good health and further creative successes in solving one of the most difficult problems of our day, which she has made her life purpose: the development of methods for long-range hydrodynamic weather forecasting.

AT THE USSR STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 p 123

[Article by V. N. Zakharov]

[Text] In November 1978 the Presidium of the Scientific and Technical Council examined a plan for scientific-research and experimental-design work for the State Committee on Hydrometeorology and Environmental Monitoring for 1979.

There was an examination of the subject matter in the fields of development of methods for predicting meteorological, hydrological and heliogeophysical phenomena and climate; study of the influence of economic activity on the environment for the purpose of preserving nature and rational use of natural resources; development of methods for computing hydrometeorological characteristics, regime-reference and specialized aids; artificial modification of meteorological processes; technical development and improvement of systems for obtaining, collecting, processing and transmission of data on the environment, etc.

The directors of the corresponding scientific institutes or the scientific directors of the section presented brief communications on each section of the plan.

As a result of the discussion the Presidium of the Scientific and Technical Council approved, with the comments taken into account, the plan for scientific research and experimental design work for 1979. After correction it was certified by the Chairman of the State Committee on Hydrometeorology and Environmental Monitoring Corresponding Member USSR Academy of Sciences Yu. A. Izrael' and in December 1978 was disseminated.

As in past years, a considerable part of the plan consists of investigations in the field of development of methods for hydrometeorological forecasts, and in turn, weather forecasts.

A major place in the plan is devoted to subject matter investigated in accordance with the programs approved by the State Committee on Science and Technology. A number of themes are being studied within the framework of international scientific and technical cooperation.

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 123-126

[Article by L. F. Yermakova, Yu. G. Slatinskiy, Doctor of Physical and Mathematical Sciences V. I. Shlyakhov, Candidate of Geographical Sciences N. A. Zaytseva, V. K. Vasil'yev and M. N. Mytarev]

[Text] During the period 27-29 June 1978, at the Sevastopol' Division of the State Oceanographic Institute, there was a conference where the participants examined the results of network hydrochemical laboratories of the Sea of Azov-Black Sea basin. Reports and communications on the operation of the sea network for the collection of information on the state of waters in the basin and the prospects for the development of investigations in the coming years were presented by A. A. Shekhovtsov (State Committee on Hydrometeorology), N. A. Rodionov (State Oceanographic Institute), Yu. S. Osipov, A. I. Ryabinin, L. F. Yermakova, S. A. Nazarenko, Ye. V. Grel' (Sevastopol' Division State Oceanographic Institute), F. G. Stepanyuk (Ukrainian Hydrometeorological Observatory), V. F. Bayev (Rostov Hydrometeorological Observatory), N. G. Davitaya (Batumi Hydrometeorological Observatory).

It was noted at the conference that the subdivisions of the State Committee on Hydrometeorology have done much work on creating a well-organized system for the monitoring of state of the environment. In particular, during 1975-1977 an experiment was organized in the Sea of Azov for checking out methods for monitoring the state of the waters over the entire surface of the sea, including the deltas of the Don and Kuban' Rivers, by means of carrying out patrols twice a month during the course of the entire navigation season. At 36 reference stations there was a regular taking of samples from the surface and from the bottom for determining the principal ingredients of the chemical composition. The results of the experiment indicated the possibility of a technical realization of the ideas embodied in the plan for creating a unified nationwide system for monitoring the qualitative state of the environment. Therefore, the subdivisions of the State Committee on Hydrometeorology have now been assigned the task of organizing the systematic monitoring of the state of waters over the entire water area of the basin. For this purpose the entire network of reference stations was divided into several categories. Each category has its own discreteness of observations. At most of the stations in the coastal zone plans call for carrying out observations at least once a month.

The conferees noted the great amount of work carried out by the Sevastopol' Division of the State Oceanographic Institute for improving the activity of network hydrochemical laboratories. In particular, it was noted that since 1977 there has been a centralized supply of all hydrochemical laboratories in the basin with standard chemical reagents for some analyses. At the Sevastopol' Division of the State Oceanographic Institute specialists are developing a referee test method for the quantitative monitoring of the quality of all hydrochemical observations in the network. Each year inspections are made of laboratories and there is training for the making of new analyses. Regularly, twice a year, conclusions are drawn concerning operation of the network.

The conferees noted the necessity for accelerating the development of remote methods for monitoring the state of the medium, in particular, making broader use of aerial surveys, radar methods and satellite information.

In the adopted resolution the conferees formulated a series of the leading problems in further development of hydrochemical investigations for monitoring the state of waters in the basin. It was recommended, in particular, that there be an examination of the problem of the possibility of concentrating the implementation of the most precise forms of analysis for the entire Sea of Azov-Black Sea basin in one base laboratory. The Sevastopol' Division of the State Oceanographic Institute was assigned for systematic correction of the scheme for the distribution of reference stations for the purpose of obtaining the most representative data. It was also decided to carry out an analysis of the inspection records of the hydrochemical laboratories during recent years for the purpose of evaluating the effectiveness of the measures adopted for realizing the recommendations.

L. F. Yermakova and Yu. G. Slatinskiy

The Tenth All-Union Conference on Actinometry was held at Ryl'sk in Kurskaya Oblast during the period 31 July-4 August 1978. The conference was organized and carried out by the Central Aerological Observatory in collaboration with the Radiation Commission of the Section on Meteorology and Atmospheric Physics of the Interdepartmental Geophysical Committee of the Presidium USSR Academy of Sciences.

The purpose of the conference was the accomplishment of an exchange of scientific information between different scientific research institutes of the State Committee on Hydrometeorology of the USSR Academy of Sciences and other departments on problems relating to the development of methods for measuring different kinds of radiation, the radiation energy of the atmosphere, use of radiation in hydrodynamic models of atmospheric circulation, etc.

Four sections operated at the conference:

1. Instruments and methods for measuring radiation in the atmosphere.
2. Results of actinometric observations at the earth's surface.
3. Radiation, cloud cover and aerosol in the atmosphere.
4. Allowance for radiation in atmospheric models. Atmospheric radiation energy.

Sixty-four reports were presented and discussed.

It was noted that during the period which has elapsed from the preceding Ninth All-Union Conference on Actinometry and Atmospheric Optics a great number of new experiments has been carried out, new interesting results have been obtained in the field of radiation energy and radiation climatology, and new instruments have been developed for measuring different types of radiation. Using ground, shipboard and aircraft radiation measurements it was possible to obtain extensive materials which are finding use in studies in the numerical modeling of general circulation of the atmosphere and in developing methods for long-range weather forecasting.

There has been development of practical investigations of the radiation regime, the results of which are being applied in the national economy (in the planning and construction of cities, the development of forests, in resort science, etc.). Radiation measurements are necessary in the service for preserving and monitoring the environment.

Within the framework of the GARP program complex experiments have been carried out for investigating the energy balance of the atmosphere and its interaction with the underlying surface (KENEKS [Complex Energy Experiment], ATEP [GATE], POLEKS [Polar Experiment] and others). In the Soviet Union, at the Main Geophysical Observatory, an International Data Center has been established for the GATE radiation subprogram; it is successfully completing its work on the collection, validation and dissemination of GATE data.

There has been considerable development of investigations directed to clarification of the role of radiation factors in the formation of climate. A study was made of the UV radiation regime in the territory of the Soviet Union and over the earth.

The past decades in the physics of the atmosphere and dynamic meteorology have been marked by great attention to studies of general circulation of the atmosphere and climate and an examination of specific forms of heat exchange. Important studies have been made in numerical modeling of the transport of radiation in the cloudy atmosphere.

There has been broadening of work on investigation of atmospheric aerosol, the results of which are of practical importance for investigating atmospheric contamination and the influence of human activity on the environment.

During the period preceding the conference in Ryl'sk there were comparisons of actinometric instruments for measuring short- and long-wave radiation. Involved in the comparisons were the pyrheliometers of the Main Geophysical Observatory, Moscow State University, Karaganda State University, and also the surface, aircraft and radiosonde radiometers of the Central Aerological Observatory. The preliminary results of these comparisons were reported at the conference.

There has been a considerable lag in work in the field of satellite actinometry, as a result of which there is an almost complete lack of data on outgoing radiation of the earth-atmosphere system, on the solar constant regime, etc.

In investigations of atmospheric energy particular importance is being given to the problems involved in experimental determination of the spectral composition and intensity of solar and atmospheric radiation. At the same time, the available technical base is inadequate for a satisfactory solution of this problem. Therefore, it is particularly timely to deal with the problems involved in the development, designing and improving of instruments and systems for observing the radiation parameters of the atmosphere and circumterrestrial space with special emphasis on satellite global observations.

The conference noted that the considerable successes in the development of actinometry are inadequate for solving new and important problems in the development of modern science, in particular, for improving numerical weather forecasting models, solution of the climate problem, for studying the anthropogenic factors involved in changes in the gas and aerosol composition of the atmosphere.

Therefore, in the next few years the main objective is the carrying out of a global meteorological experiment, with subsequent processing, analysis and adoption of the results.

Doctor of Physical and Mathematical Sciences V. I. Shlyakhov and Candidate of Geographical Sciences N. A. Zaytseva

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APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000100050054-6

The first session of the Joint Working Committee of the IOC/WMO on the "OGSOS" program was held in Paris during the period 14-27 September 1978 in the UNESCO building.

Before the beginning of the session, on 14-15 September, there was a meeting of the organizing committee on the holding of a seminar-conference on the system for data processing and servicing for the "OGSOS" program (Moscow, April 1979).

Those present at the meeting of the organizing committee summarized the results of the preparatory work done by the secretariats of the IOC and WMO and the organizing committee during the elapsed period (March-September 1978). It was noted that the plan developed at the first session of the organizing committee (Hamburg, March 1978) for carrying out the seminar-conference in 1979 had been implemented. The latter made it possible: to determine the attitude of the countries toward the carrying out of the seminar-conference, to receive summaries of reports, to formulate a specific plan for carrying out the seminar-conference (select reports, break them down by subject matter, to designate coordinators for the subjects, to prepare a schedule for the seminar and a working plan for the conference).

The first session of the Joint IOC/WMO Working Committee on "OGSOS" began its work on 18 September 1978. It was attended by 35 representatives from 17 countries -- members of the IOC and WMO. In addition, the session was attended by representatives of six international organizations (15 persons). In the course of eight days the session participants discussed a broad range of problems covering all aspects of implementation and development of the "OGSOS" program.

The reports of the secretariats of the IOC and WMO and the chairman of the working committee of directors of the teams of experts emphasized that the "OGSOS" program is being carried out successfully. The number of daily BATI/TESAK observations during the last four years has increased by a factor of 2.5 and the number of on-shore radio stations receiving BATI/TESAK summaries has increased to 124, which, for the most part, enables ships to transmit observational data on a routine basis. The experimental "OGSOS" program on the problem of contamination of the sea by petroleum is close to completion.

In their addresses the representatives of international organizations (UNEP, KOST-43, SCOR, CMM, NKS) noted the importance of the "OGSOS" program and unanimously expressed for it support and coordinated efforts.

In the course of the discussion of agenda items and the exchange of views, the session participants formulated specific recommendations and resolutions directed to eliminating existing shortcomings and further development of the "OGSOS" program. These recommendations include:

-- improvement of the transmission of BATI/TESAK summaries through WMO communication channels;
-- broadening of the number of countries participating in the "OGSOS" program;
-- maintenance and additional assignment of radio frequencies for the transmission of oceanographic data;
-- transformation of the "OGSOS" experimental project on the problem of contamination of the sea by petroleum into a permanent project;

-- transmission of data from drifting buoys (during the GATE period) on a routine basis;
-- broadening of the range of "OGSOS" information yield for a more complete satisfaction of the needs of marine activity and support of scientific projects;
-- creation of groups of experts for solving the specific scientific and operational tasks of "OGSOS," carrying out their functions on an interim basis.

The session participants discussed the proposal of West German specialists on the regionalization of the "OGSOS" program. The Soviet delegation expressed the opinion that such an approach to implementation of the "OGSOS" program is unacceptable because the basic concept of the "OGSOS" program is its global scale. Accordingly, the "OGSOS" program must remain global and be carried out on the basis of national and regional contributions, as well as the contributions of other international scientific programs (Flemish Cape, GATE, El Nino, KOST-43, and others).

V. P. Vasil'yev

A regular working session on the theme "Standards-Reference Aids for Computing Climatic Parameters for Construction Planning," carried out jointly by the meteorological services and the hydrometeorological services of the Socialist countries, was held at the Main Geophysical Observatory during the period 18-22 September 1978. The coordinator of this work is the State Committee on Hydrometeorology.

The conference was attended by representatives from Hungary, East Germany, Bulgaria, Poland and the USSR.

The preparation of "Standards-Reference Aids for Computing Climatic Parameters for Construction Planning" is necessary due to the differences in the current norms and methods for computing climatic parameters in the socialist countries.

The purpose of the working conference was a discussion of the status of implementation of the project, reviews of existing methods for computing the climatic parameters of glaze, snow and wind loads, the climatic parameters of precipitation, soil freezing and complex temperature-moisture parameters necessary for evaluating the atmospheric corrosion of construction materials, and also a discussion of proposals on their standardization. Another task of the conference was a refinement of the program for further work on the subject.

During the course of conference work the members of the delegations heard and discussed communications from the hydrometeorological and meteorological services on scientific research studies carried out in accordance with the subject program.

Information on methods for computing the climatic parameters of glaze loads on suspended wires was prepared by A. G. Zakharov and M. N. Mytarev (USSR). After a discussion of the communications on this problem the conferees expressed the opinion that the presently existing differences in them are completely admissible. The conference recommended completion of work on more precise determination of the coefficients for scaling the parameters of glaze loads on wires of different diameters and different heights of suspension and also from a vertical rod on the wires of a glaze frame. In addition, it was deemed necessary to continue the work carried out by the State Committee on Hydrometeorology for developing methods for computing glaze loads on high structures.

All the delegates told about the methods employed in their countries for calculating the climatic parameters of snow loads.

A resolution was adopted asking the CzSSR Hydrometeorological Service to carry out a comparative evaluation of snow loads for the purpose of selecting an optimum computation variant. On the proposal of the Soviet delegation, it was also recommended that there be a clarification of the availability in the socialist countries of data which can be used in computing brief snow loads arising as a result of heavy snowfalls and wet snow, and insofar as possible, carry out such computations.

Information on this subject was presented by V. I. Lipovskaya (USSR).

In the discussion of work done for clarifying the possibility of developing a standard method for computing wind loads it was noted that a major contribution has been made by the agency responsible for this part of the research program -- the Meteorological Service of the GDR, which has carried out a comparison of the existing methods. The information was presented by H. Gochmann (GDR). It was pointed out that in working on this problem it is necessary to take into account the differences in the instruments used for measuring wind velocity in different countries and the diversity of needs of the national economy.

The conference recommended refinement of the scaling factors for maximum velocities, averaged for different time intervals; it was recommended that the wind velocity for 10 minutes be used as the basic averaging interval. It was also recommended that work be continued for determining corrections to wind velocity head, taking into account the influence of the elevation and nature of relief in mountain regions.

Information on this subject was presented by M. M. Borisenko (USSR).

With respect to the problem of computations of the wind loads on high structures, a detailed communication on existing computation methods was presented by M. M. Borisenko. In the course of the discussion it was acknowledged that for the time being there is still inadequate information for computing wind loads in cities, under conditions of mountainous relief and a nonuniform underlying surface. On the proposal of the Soviet delegation the conference recommended that further investigations be carried out in the socialist countries for creating a more detailed differentiation of the climatic parameters of a wind load on high structures, devoting attention at the same time to the influence of the underlying surface and relief. The State Committee on Hydrometeorology will generalize these data.

The Meteorological Service of the Hungarian People's Republic was responsible for carrying out work in the field "Methods for Computing Complex Temperature-Humidity Parameters for the Evaluation of Atmospheric Corrosion." Information on the work done was presented by Ya. Salma and E. Tatarne-Sabo (Hungarian People's Republic). A detailed communication on the work carried out on this problem in the Soviet Union was presented by N. V. Kobyshev.

The discussion revealed that the responsible countries assigned this task have materials for computing the temperature-humidity complex. It was deemed desirable that the conference recommend for computations a method developed in the USSR. The recommendations noted the need for a standardization of computation methods for determining the probabilities and continuous duration of different combinations of air temperature and humidity and expressed a request of the Meteorological Service of the Hungarian People's Republic to the State Committee on Hydrometeorology, using as a basis the method developed in the Soviet Union, that recommendations be drawn up for computing the climatic parameters of temperature-humidity complexes.

The conference heard information on computations of the climatic parameters of atmospheric precipitation. The Hydrometeorological Service of the Polish People's Republic is the agency responsible for implementation of this work. The conferees listened with great interest to a characterization of precipitation proposed by H. Lorencz (Poland). It was recommended that there be processing of data on the intensity of precipitation, that the gradations of precipitation adopted in the hydrometeorological and meteorological services of the socialist countries be published, and a study be made of methods for the processing of data on precipitation used by the Hydrometeorological Service of the Polish People's Republic and the State Committee on Hydrometeorology. The recommendations also expressed the request to the RGKNIR that a study be made of the problem of standardizing the terminology on this problem.

Ts. A. Shver told about the work carried out in the USSR on this problem.

A review of methods for computing the climatic parameters of soil freezing was presented by A. K. Shkadova (USSR).

3 OF 3

After being familiarized with the work carried out on this problem, the conference concluded that the work must be continued and the State Committee on Hydrometeorology was asked to generalize the available experience for the purpose of developing a standardized computation method.

The conferees refined the program for work on subject No 21 of the RGKNIR for 1978-1980. It was noted that the program adopted at the first working cconference in 1976-1977 has been fully implemented.

COMPARISON OF DOBSON SPECTROPHOTOMETERS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 126-127

[Article by Yu. Ye. Kazakov]

[Text] In accordance with the plans for Soviet-American cooperation in the field of preservation of the environment, within the framework of the working group on the problem "Influence of Changes in the Environment on Climate," comparisons of the calibration curves of the Soviet regional standard ozonometer (Dobson spectrophotometer No 108) and the world standard (Dobson spectrophotometer No 83), kept at the NOAA Atmospheric Research Laboratory, were carried out in September 1978 at Boulder, Colorado.

These bilateral comparisons supplemented the international comparisons of Dobson spectrophotometers carried out at Boulder in July-August 1972.

The Dobson spectrophotometer No 108 was taken to Boulder by Soviet specialists of the Main Geophysical Observatory V. A. Kovalev and S. A. Sokolenko. On the American side the participants were in a group of specialists from the NOAA Atmospheric Research Laboratory headed by the director of the project on geographical monitoring of climatic changes (GMCC) at NOAA, K. J. Jenson.

The preliminary tests carried out immediately after the arrival of the instrument indicated that the calibration of the Soviet spectrophotometer, carried out four years before during the international comparisons in Poland (Belsk), had virtually not changed. The comparison of the Soviet instrument No 108 with the world standard spectrophotometer, Dobson No 83, indicated a good coincidence of the calibration curves -- data on the total content of ozone, measured at a pair of atmospheric wavelengths, agree on the average within the limits 0.6% for observations carried out in the range of air masses 1.3-3.2; the greatest discrepancy in the data on total ozone content was observed in the range of air masses 1.5-2.0 and was 1%.

At the same time, there has been a modernization of the Soviet instrument, including a replacement of the power units and amplifier, constructed using tube circuits, by similar units with microcircuits. The adjustment and calibration of the optical part of the instrument was also carried out. the wedge was calibrated and new values of the tables were determined for setting the required wavelengths. After modernization and adjustment of the optical systems the discrepancies in the results of measurement of the total ozone content by spectrophotometers Nos 108 and 83 with a pair (AD) of the mentioned wavelengths averaged 0.1% with a maximum value 0.6% (for air masses 1.15-1.5). A still better agreement was observed for wavelengths A, C, D and the wavelength pair CD, and also for air masses greater than 3.2.

In the report on the results of intercalibration of the Dobson spectrophotometer No 108 (USSR) and No 83 (United States) it is indicated that instrument No 108 "to a high degree corresponds to its use as a secondary standard."

During presence in Boulder the Soviet and American scientists discussed the results of work with the Soviet filter ozonometer M-83 No 121, carried out at Boulder during the past year. These results indicated that during observations directly in the sun and with a clear zenith the results of the measurements carried out with the M-83 instrument with air masses in the range 1.15-3.2 agree with data for the world standard -- the Dobson No 83 spectrophotometer -- in the error range ±3%. However, a substantial difference was noted in the case of observations carried out when there were clouds in the zenith. It can be postulated that such observations require either the introduction of empirical corrections or the use of different functional curves K_z for the cloudy and clear zenith. The detected effect can be associated with the elevation of the station relative to sea level and can be extremely significant for the elevation of Boulder -- 1,600 m above sea level.

During their stay in Boulder Soviet scientists had the opportunity to visit individual sections of the NOAA Atmospheric Research Laboratory and also the field observatory of the wave propagation laboratory, where there were useful discussions of programs for measuring ozone, CO_2, aerosol components and radiation. It appears that the cooperation of Soviet and American scientists will favor further improvement in methods for measuring the atmospheric components and increasing the reliability of the results both in the USSR and United States, as well as in the global network of stations for measuring ozone.

Yu. Ye. Kazakov

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 3, Mar 79 pp 127-128

[Article by B. I. Silkin]

[Text] As reported in the GARP NEWSLETTER, May 1978, No 35, pp 1-5, the World Meteorological Organization, in carrying out the First Global Experiment of GARP, the MONEX experiment for studying monsoons and the West African monsoonal experiment WAMEX, has had to contend with the fact that most of the ships participating in these international measures do not have equipment making it possible to carry out sounding of the high layers of the atmosphere.

As a result of the measures adopted in 1978 an international voluntary fund was created, making it possible to remedy this important gap in the observation system. The special set of equipment with which the ships are supplied is given the name "Navaid Sounding System First Global Experiment GARP."

The instruments of this system, carried by pilot balloons, during ascent into the high layers of the atmosphere, receive signals from the world "Omega" navigation system and relay them to shipboard receiving stations. Wind direction and velocity are determined from changes in the position of a pilot balloon relative to the coordinates established by the "Omega" network.

There are two variants of the "Navaid" electronic system. The first of these ("module A") is a relatively simple receiving-transmitting apparatus whose servicing can be learned in two weeks. It is placed in an air conditioned room and has the capability of registering meteorological conditions under a routine program. The outfit also includes equipment for filling a balloon with gas and for launching and also a source of electric power.

"Module B" includes, in addition to the components listed above, instruments for the primary processing of meteorological data in real time. They require a stable power source and skilled personnel for servicing. Provision is also made for the possibility of connecting a small computer to this system for more thorough routine processing of the collected data.

During the period of the First Global Experiment GARP system "A" is being used on 26 ships carrying out observation of tropical winds; two vessels equipped with the more complex "B" system are participating in the "MONEX" program.

The program provides for vertical profiling of temperature, pressure, humidity and wind velocity from the sea surface to a level of more than 70 mb twice a day. These observations, as a rule, are carried out at local midday and midnight. Upon return to port the magnetic tape with these data is sent to the primary processing center, located in Finland, from whence for final analysis the materials are sent to the second-level center established in Sweden at the Meteorological and Hydrological Institute at Norrkoping.

It is assumed that more than 5,000 magazines with recorded meteorological data will be received at the Finnish center during the period of the First Global Experiment.

The testing of this entire system was carried out in August 1977 in the waters of the Atlantic between Miami (Florida) and the Barbados, and also from November 1977 through January 1978 in Helsinki (Finland). It yielded results completely satisfying the participants in the experiments. It was established that the "Navaid" system is as effective as existing radar systems for registry of wind in the high layers of the atmosphere. The only shortcoming is that the "Omega" navigation system, which must be established in Australia during the period of the First Global Experiment GARP, has not yet become operative and without it the accuracy in determining winds is reduced. Therefore, in the region between 80 and 140°E to the south of the equator, as well as in the waters adjacent to Madagascar, the data will be somewhat less reliable.

The funds for creating the "Navaid" system were received from UN agencies charged with implementing the program for studying the environment, and also from Saudi Arabia, United States, Finland and India.

The ships on which this system is being installed for their participation in the observation of tropical winds have been supplied by Australia, Brazil, Chinese People's Republic, India, Indonesia, Italy, German Democratic Republic, Ivory Coast, Mexico, Peru, Philippines, USSR and the United States.

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