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22 April 1980

USSR Report

METEOROLOGY AND HYDROLOGY

No. 2, February 1980

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Translation of the Russian-language monthly journal METEOROLOGIYA I GIDROLOGIYA published in Moscow by Gidrometeoizdat.

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DECREE OF THE CPSU CENTRAL COMMITTEE AND USSR COUNCIL OF MINISTERS ON AWARDING OF USSR STATE PRIZES FOR 1979 IN THE FIELD OF SCIENCE AND TECHNOLOGY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 4-5

[Unsigned decree]

[Text] The CPSU Central Committee and the USSR Council of Ministers, after examining the proposals of the Committee on the Lenin and State Prizes USSR in the Field of Science and Technology of the USSR Council of Ministers, decrees the awarding of the USSR State Prizes for 1979:

II. In the Field of Technology

2. To Petr Vasil'yevich Babkin, Doctor of Geological and Mineralogical Sciences,

to Igor' Mikhaylovich Nazarov, Candidate of Technical Sciences, Deputy Director of the Institute of Applied Geophysics,

to Lidiya Ivanovna Boltneva, Candidate of Physical and Mathematical Sciences, senior scientific specialist, worker at this same institute,

to Vladimir Aleksandrovich Ionov, Candidate of Physical and Mathematical Sciences, senior scientific specialist, worker at this same institute,

to Shepa Davidovich Fridman, Candidate of Technical Sciences, deputy division head, worker at this same institute,

to Aleksandr Vladimirovich Matveyev, Candidate of Technical Sciences, Deputy Director of the All-Union Scientific Research Institute of Exploratory Geophysics,

to Vyacheslav Borisovich Stepanov, chief engineer, worker at this same institute,


L. I. Boltneva


A. V. Dmitriyev


V. A. Ionov


I. M. Nazarov


M. V. Nikiforov


Sh. D. Fridman

to Vadim Valentinovich Filimonov, Candidate of Technical Sciences, division head, worker at this same institute,

to Pavel Nikolayevich Fogt, division head, worker at this same institute,

to Mikhail Vladimirovich, Candidate of Physical and Mathematical Sciences, laboratory head at the All-Union Scientific Research Institute of Agricultural Meteorology,

to Emiliya Yakovlevich Ostrovskiy, Doctor of Technical Sciences, senior scientific specialist at the All-Union Scientific Research Institute of Mineral Raw Material,

to Aleksey Viktorovich Dmitriyev, physical engineer,

for theoretical and experimental development and introduction into the national economy of a gamma-spectrometric method for remote sensing of the environment, search for and detection of deposits of nonferrous, rare and noble metals.

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STATISTICAL PREDICTION OF RADIATION AND RADIATION-ADVECTIVE FOGS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 6-13

[Article by Candidate of Physical and Mathematical Sciences P. K. Dushkin, Moscow, submitted for publication 17 May 1979]

Abstract: The author has developed a method for statistical alternative prediction of radiation and radiation-advective fogs on the basis of standard meteorological measurements at a single point. Empirical graphs of discriminant functions were constructed for use in prediction. None of the computations require the use of an electronic computer. The direct use of long-term observations at some station is a prerequisite for taking regional peculiarities into account. The method was checked by the author using data from long-term observations at a number of stations in Moskovskaya Oblast, containing more than 1,000 cases favorable for fog prediction. On the average, the sum of errors of the first and second kinds does not exceed 0.40.

[Text] A great number of investigations have been devoted to the physical and synoptic conditions for fog formation. The list of publications on the problems involved in fog prediction has lengthened [2]. However, if we evaluate the purely practical side of solution of the problem, here we do not note any significant progress.

However strange it may seem, neither the investigations of the prediction methods nor the systematic studies carried out in the Hydrometeorological Service for evaluating the success in predicting fogs make possible a sufficiently true determination of the attained level. This is attributable to the fact that in the evaluation of predictions it is customary to use the general guaranteed probability test, representing the ratio of the number of predictions which have proven correct to the total number of forecasts. The application of this evaluation has already been subjected to criticism in [1]. We recall that the general guaranteed probability is dependent not only on the effectiveness of the method, but also on climatic characteristics. The general guaranteed probability in essence is an evaluation of the probability of a correct forecast. For example, applicable to fogs it can be represented in the form

$$U=1-[\alpha p(\overline{\Phi})+\beta p(\Phi)],$$

where U is the general guaranteed probability, $\alpha = p(\Phi_f/\overline{\Phi})$ and $\beta = p(\overline{\Phi}_f/\Phi)$ are errors of the first and second kinds; the symbols Φ and $\overline{\Phi}$ are used in denoting a fog and its absence respectively and Φ_f and $\overline{\Phi}_f$ are forecasts of these events.

In accordance with the definition of general guaranteed probability cited above, it is unthinkable to use it for a comparative evaluation of the success of forecasts in different climatic zones.

A necessary and adequate condition for fog formation in the most general form can be represented in the form of the relationship $T \leqslant T_d$, in which T, T_d are air temperature and dew point respectively, measured in the psychrometric booth. The use of this condition for predicting a fog is possible if there is parallel prediction of T and T_d.

In different form the condition for fog formation is represented by the expression

$$\delta T > \delta T_н,$$

[H = i] where δ T is the drop in air temperature,

$$\delta T_н = T_0 - T_{dт} + \delta T^*,$$

[H = i; T = f(og)] T_0 is air temperature in the initial period; $T_{d\ f}$ is the dew point at the time of fog formation, δT^* is some additional air cooling, necessary for appearance of the corresponding liquid-water content.

Since the time of fog formation is not known in advance, in place of $T_{d\ f}$ it is customary to use the minimum T value. In addition, the δT^* value in some methods is not taken into account at all [2].

Computations of T and T_d involve solution of equations describing heat exchange in the atmospheric boundary layer with additional conditions (initial and boundary). In order to determine the requirements on initial meteorological data necessary for a definite fog prediction the author carried out an experiment for modeling the processes of heat and moisture exchange using an electronic computer. Use was made of the actual surface gradient measurements of meteorological elements and data on temperature distribution in the soil. The temperature and humidity forecasts are for not more than 12 hours in advance. The profile of the turbulence coefficient was determined in accordance with the B. I. Izvekov-L. T. Matveyev model [3].

A numerical experiment indicated that the mean absolute errors in predicting T and T_d were 1.0 and 2.6° respectively. Whereas forecasts of temperature with the above-mentioned errors must be regarded as successful, a similar conclusion cannot be drawn with respect to precomputation of humidity. In actuality, the relative error in computing dew point, determined as the ratio of the error to the variability of T_d, was equal to approximately 100%. This is attributable to the following factors: inaccurate representation of the initial humidity profile (vertical measurements are made at only two points), the absence of any information on soil moisture content, which precluded the setting of a suitable boundary condition at the ground level. It is necessary to note the considerable value of the temperature difference in the layer 0-2 m, as well as the admissibility of approximation of the initial temperature distribution in evening at heights more than 2 m by an isothermic profile.

The numerical experiment not only confirmed the necessity for gradient measurements in the surface sublayer and in the soil, but also made it possible to validate the accuracy in measuring a number of meteorological elements and the error in computing some characteristics and parameters. For example, measurements of T and T_d must be made with errors not greater than 0.1°C, whereas the errors in computing the turbulence coefficient and the parameters characterizing soil heat conductivity must not exceed 15%.

The prediction of the time of fog formation, strictly speaking, requires a parallel sufficiently precise computation of T and T_d, which is impossible when the information given above is not available.

In the MANUAL ON SHORT-RANGE FORECASTING [4] the algorithm for predicting fog is formulated in the form of the expression

$$T_{fog} \geqslant T_{min},$$

where T_{min} is the minimum air temperature at the level of the psychrometric booth, T_{fog} is the temperature of fog formation, determined by the expression $T_{fog} = T_d - \delta T_d$, in which T_d is dew-point temperature at the observation time, close to sunset, δT_d is the dew-point decrease in the period from the initial time to the time of fog formation.

The success of fog formation using the algorithm $T_{fog} \geqslant T_{min}$ is dependent on the accuracy in predicting T_{fog} and T_{min}.

As indicated by our computations, the prediction of T_{fog} by the method recommended in [4] is accomplished with a mean square error 2.4°C, that is, with a relative error close to 100%. This checking was carried out using a 15-year series of observations at Moscow.

In accordance with [4], a prediction of T_{min} must be made with an accuracy to 0.5°C. However, the status of prediction of minimum air temperature by no means looks favorable. Therefore, the above-mentioned requirement on the accuracy in predicting T_{min} at the present time is clearly too high; it cannot be met using any method due to the lack of the necessary meteorological information, enumerated above.

Graphs constructed on the basis of a sufficiently perfect physicomathematical model are recommended in [4] for predicting T_{min}; this model was developed by M. Ye. Berlyand. It takes into account all the principal factors determining the processes of heat and moisture exchange in the atmospheric boundary layer. However, a changeover to the practical realization of the model by constructing the mentioned graphs was not possible without a loss of accuracy caused by an inadequacy of initial data. As a result, the turbulence parameters, for example, are not determined by gradient measurements, but on the basis of wind velocity at the height of the vane and the temperature distribution in the soil is not taken into account directly. In addition, a forecast using these graphs is possible only in the absence of a snow cover. The latter restriction is extremely important because in most cases fogs are formed at negative temperatures. For example, according to our evaluations, at Moscow at the Central Helicopter Station (CHS) during the period 1947-1971 62% of the radiation and radiation-advective fogs developed at negative temperatures.

It follows from everything stated above that the main obstacle on the path of creation of adequately effective methods for predicting fogs is the lack of the necessary meteorological information. These difficulties forced us to develop a method for a statistical alternative forecast of radiation and radiation-advective fogs. We will take into account the interests and possibilities of meteorological offices not having electronic computers. In other words, the method should be simple and its application must not involve great expenditures of labor.

We will formulate the problem along the lines of discriminant analysis. Assume that there are two classes of phenomena Φ and $\overline{\Phi}$. Measurement of the pre-determined vector-predictor X was accomplished. We introduce the pair of discriminant functions $D_{\Phi}(X)$ and $D_{\overline{\Phi}}(X)$ having the following property. If X belongs to Φ, then $D_{\Phi}(X) \geqslant D_{\overline{\Phi}}(X)$. For an alternative forecast it is convenient to use one discriminant function

$$D(X) = D_{\Phi}(X) - D_{\overline{\Phi}}(X).$$

In accordance with the definition, if $D(X) \geqslant 0$, the observation is assigned to the class Φ, when $D(X) < 0$ -- to class $\overline{\Phi}$.

As customary in a mesoforecast, the synoptic background will be considered known. This means, in particular, that at the evening observation time it is first necessary to establish whether the synoptic situation is favorable for fog formation. If it is favorable, on the basis of the available forecast we next obtain the mean cloud coverage in tenths, regardless of the number of levels, vertical development and other characteristics, during the period from 1800 to 0600 hours. This average cloud coverage must be expressed by two alternative gradations: $N < 5/10$ or $N \geqslant 5/10$. Thus, the requirements on the background forecast are not burdensome. In other words, the prognostic model is stable to errors in the forecasting of cloud cover. A rough allowance for cloud cover in the form of two gradations of total cloud coverage was introduced because the 16-year series of observations used is too short to make use of a more detailed classification.

The second component of the vector-predictor, the duration of night, is taken into account approximately and indirectly, combining the observations of each month in different years into one sample. However, due to the inadequate volume of observations it was necessary to create the series by combining data from different months. For example, first we formed the following groups: No 1 (March, April, September), No 2 (November, December, January) and No 3 (October, February). But in the concluding stage in the work the latter two groups had to be combined. In order to validate the above-mentioned combinations of observational data we also made use of empirical distribution functions for dew-point spread at 1800 hours, computed for different months separately for situations with fog and its absence.

As indicated by our investigations, the two other components of the vector-predictor are the dew-point spread at 1800 hours Δ_{18} and the mean wind velocity from 1800 to 0600 hours $\overline{V}$.

We computed the mean values Δ_{18}, $\overline{V}$, when fog developed or was absent, for evaluating X as a predictor.

From the Δ_{18} distribution (group No 1, $N \leqslant 10/10$) we obtained evaluations of the conditional probabilities $p(\Delta_{18}/\Phi \leqslant 6°C) = 0.80$ and $p(\Delta_{18}/\overline{\Phi} \leqslant 9°C) = 0.80$. Similarly for the mean wind $p(\overline{V}/\Phi \leqslant 2$ m/sec$) = 0.80$ and $p(\overline{V}/\overline{\Phi} \leqslant 3$ m/sec$) = 0.80$. In the comparison of the latter evaluations it must be remembered that in both samples (Φ and $\overline{\Phi}$) a weak wind was considered a favorable synoptic background.

Now we proceed to choice of the method for computing the discriminant functions. First we will evaluate the practical possibilities of the Bayes formulas, frequently employed in the statistical solutions method. The solution for prediction of fog formation will have the following form:

$$\frac{p(X/\Phi)}{p(X/\overline{\Phi})} > \frac{p(\overline{\Phi})\, C(\Phi_{\Pi}/\overline{\Phi})}{p(\Phi)\, C(\overline{\Phi}_{\Pi}/\Phi)}, \quad (1)$$

[Π = f(orecast)] where $C(\Phi_f/\overline{\Phi})$ and $C(\overline{\Phi}_f/\Phi)$ are some functions determining the losses associated with unsuccessful forecasts.

Computations can be made using formula (1) if we know the loss functions and available observational data make it possible to compute the conditional probabilities $p(X/\Phi)$ and $p(X/\Phi)$. In most cases computations of the loss functions involve greater, and sometimes insuperable difficulties. With respect to determination of evaluations of the conditional probabilities entering into (1), it requires very long series of observations. This is attributable to two circumstances: the statistical dependence of components of the vector-predictor and the relatively rare frequency of recurrence of fogs. For example, we note that the hypothesis of nondependence of the Δ_{18} and $\bar{V}$ values, which we checked using data from a series of observations extending over many years (1947-1971), in general was not confirmed for Moscow.

In order to avoid unsound assumptions, like the nondependence of Δ_{18} and $\bar{V}$ or their normal distribution, for solution of the formulated problem we turned to a graphic method for determining the discriminant functions. For this purpose each sample (Φ and $\bar{\Phi}$), depending on the number of the group to which they belong (No 1 and No 2), and the N values are divided into four parts, for each of which we construct a graph.

On the horizontal axis we plot the mean velocity $\bar{V}$ m/sec, and on the vertical axis -- the dew-point spread Δ_{18}. Using different notations for the situations Φ and $\bar{\Phi}$, on the graph we plot the points corresponding to X ($\bar{V}$, Δ_{18}). We draw a demarcation line between the different points, separating the Φ and $\bar{\Phi}$ regions in such a way that the $Q = 1 - \alpha - \beta$ value is maximum. On a practical basis the choice of an optimum variant is made after 1-3 samples, for each of which the Q evaluation is computed. In essence, the demarcation line is the curve for the discriminant function $\Delta^*_{18}(\bar{V})$.

If the dew-point spread and the mean wind velocity are known at 1800 hours, on the plane of the $\bar{V}$, Δ_{18} graph they are represented by the point $\bar{V}_i$, $\Delta_{18\ j}$, depending on whose position relative to the curve $\Delta^*_{18}(\bar{V})$ it is possible to formulate the following decision rule. If the value

$$d = \Delta^*_{18}(\bar{V}_i) - \Delta_{18,j}(\bar{V}_i) \geq 0,$$

a fog is predicted; otherwise its absence is predicted. In the latter formula the d value is the distance along the y-axis between the point ($\bar{V}_i$, Δ^*_{18}), situated on the $\Delta^*_{18}(V)$ curve and the point (V_i, $\Delta_{18\ j}$), whose coordinates were obtained from observational data. In other words, the entire closed region, together with its boundaries, formed by the $\Delta^*_{18}(\bar{V})$ curve and cut off by its segments on the coordinate axes, is interpreted as a fog zone and all the points outside this region correspond to its absence.

In order to construct the $\Delta^*_{18}(\bar{V})$ graphs we used an observation series (CHS, 1947-1961, Moscow). Diagnostic evaluations of the model are given in Table 1. Checking on the basis of independent observational data at this same station (1962-1971) made it possible to obtain the following evaluations: $\alpha = 0.20$, $\beta = 0.14$, $Q = 0.66$.

The developed method involves introduction of the $\overline{V}$ value, which in the tests was computed diagnostically, but in a general case it must be replaced by predicted velocity, which increases the error in predicting fogs. We note that a prediction of $\overline{V}$ on the basis of the initial wind velocity value at 1800 hours was unsuccessful. We had no possibility for using wind measurements at earlier times, for example, for the prediction of $\overline{V}$, since the appropriate data were not available. We will evaluate the possibilities of computing $\overline{V}$ on the basis of later observations. It is of interest, for example, to examine a linear model of forecasting of the mean wind

$$\overline{V}_п = 0{,}77\,\overline{V}_3 - 0{,}09, \qquad (2)$$

[π= f(orecast)] where

$$V_3 = \frac{V_{18} + V_{20} + V_{22}}{3}.$$

We note that the correlation coefficient between $\overline{V}$ and $\overline{V}_3$ is equal to 0.90 and the mean square error in computing $\overline{V}_f$ using formula (2) is 0.67 m/sec.

The second variant of the forecasting model was obtained on the basis of Δ_{18} and $\overline{V}_3$. Diagnostic evaluations of the models (Δ_{18}, $\overline{V}_f$) and (Δ_{18}, $\overline{V}_3$) are given in Table 2, from which it can be seen that the variant with $\overline{V}_3$ is more effective. Its testing on the basis of independent data was completed with the following evaluations: α = 0.17, β = 0.22/Q = 0.61/.

Table 1

Diagnostic Evaluations. Model (Δ_{18}, $\overline{V}$). Teaching Sample 1947-1961, Moscow, CHS

Группа выборки 1	N, баллы 2	α	β	Q
X, XI, XII, I, II	<5	0,29	0,07	0,64
	>5	0,25	0,08	0,67
IX, III, IV	<5	0,14	0,21	0,65
	>5	0,10	0,15	0,75

KEY:
1. Sample group
2. N, tenths

Table 2

Diagnostic Evaluation. Group No 1 N<5/10, 1947-1961

Модель 1	α	β	Q
(Δ_{18}, $\overline{V}_п$)	0,21	0,39	0,40
(Δ_{18}, $\overline{V}_3$)	0,20	0,15	0,65

KEY:
1. Model
2. π = f(orecast)

In conclusion we will examine a final variant of the forecasting method. A distinguishing characteristic of the $\overline{V}_3$ value is that the significance of the velocities V_{18}, V_{20}, V_{22} determining it as predictors increases with increasing distance from the initial observation time at 1800 hours. In order to take this peculiarity into account and smooth the high-frequency velocity fluctuations, we introduce smoothing in the form $\hat{V}_{22} = aV_{22} + abV_{20} + b^2V_{18}$, where $a + b = 1$, $a > b$. A numerical experiment made it possible to select a suitable value $a = 0.8$.

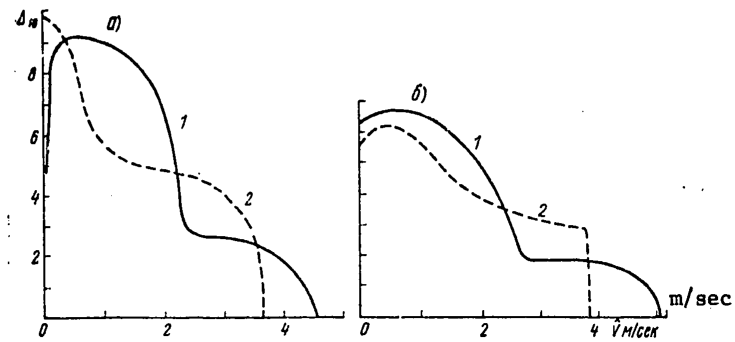

Fig. 1. Graph for predicting fogs in March, April, September (August) (a) and in October, November, December, January and February (b). 1) $N \geqslant 5/10$, 2) $N < 5/10$.

Table 3

Diagnostic Evaluations. Model (Δ_{18}, $\hat{V}_{22}$), 1947-1961 CHS

Группа выборки 1	N, баллы 2	α	β	Q
IX, III, IV	<5	0,17	0,16	0,67
	>5	0,20	0,10	0,70
X, XI, XII, I, II	<5	0,20	0,11	0,69
	>5	0,21	0,13	0,66

KEY:
1. Sample group
2. N, tenths

Table 4

Evaluations of Diagnosis and Prediction on Basis of Independent Observations 1962-1971 CHS

Операция 1	α	β	Q	$\rho(\Phi/\Phi_п)$ 2	$R(\Phi/\Phi_п)$ 2	U	U_0
3 Диагноз	0,19	0,13	0,68	0,74	0,90	0,83	0,53
4 Прогноз	0,20	0,14	0,66	0,67	0,92	0,82	0,53

KEY:
1. Operation
2. Π = f(orecast)
3. Diagnosis
4. Forecast

The figure shows curves for discriminant functions constructed on the basis of the (Δ_{18}, $\hat{V}_{22}$) model. It is interesting that attempts to use Δ_{20} or Δ_{22} instead of Δ_{18} were unsuccessful. The diagnostic evaluations of the (Δ_{18}, $\hat{V}_{22}$) model are presented in Table 3. Their comparison with the results obtained earlier (Table 1) indicate a successful choice of the predictor $\hat{V}_{22}$.

Table 5

Evaluations of Forecasts at Airports and for the Entire Moscow Airport Complex in a Series of Observations 1965-1970

Оценки 1	Внуково 2	Домодедово 3	Шереметьево 4	Быково 5	Аэроузел 6
α	0,16	0,23	0,22	0,26	0,21
β	0,23	0,16	0,17	0,20	0,19
Q	0,61	0,61	0,61	0,54	0,60
U	0,82	0,79	0,80	0,76	0,80
U_0	0,67	0,57	0,52	0,52	0,56
$p(\Phi/\Phi_п)$ 7	0,60	0,53	0,64	0,60	0,60
$p(\bar{\Phi}/\bar{\Phi}_п)$	0,93	0,94	0,91	0,88	0,92

KEY:

1. Evaluations
2. Vnukovo
3. Domodedovo
4. Sheremet'yevo
5. Bykovo
6. Airport complex
7. π = f(orecast)

The data in Table 4 give some idea concerning the evaluations obtained when testing the Δ_{18}, $\hat{V}_{22}$ model on the basis of independent observational data. The table includes additional evaluations: U -- general guaranteed probability, U_0 -- guaranteed probability of a random forecast, and also evaluations of the probabilities $p(\Phi/\Phi_f)$ and $p(\overline{\Phi}/\overline{\Phi}_f)$, introduced for the first time by N. A. Bagrov [1]. They determine the soundness of categorical formulations of prediction of a fog and its absence.

It is of interest to study the possibilities of using the developed graphs for predicting fogs in different regions of the country. A solution of this problem involves processing of long-term meteorological observations at many stations. We have already taken the initial step in this direction: we carried out checking of effectiveness using data from a 6-year series of observations at the airports Vnukovo, Domodedovo, Sheremet'yevo, Bykovo, represented in the form of coded telegrams.

Now we will evaluate the quality of the meteorological observations at the mentioned airports (1965-1970). In contrast to the observations at the CHS (1947-1961), where the humidity measurements were made with a psychrometer at positive temperatures and with a hair hygrometer in the case of negative temperatures, the data for the Moscow airports contain information on humidity measured year-round using a hair hygrometer. Thus, the humidity measurements at airports were made for the most part with large errors. An obvious shortcoming of the analyzed data is also the rounding-off of air temperatures and dew point to whole degrees, accomplished during the coding of meteorological observations.

The results of checking of the forecasting method on the basis of the model are presented in Table 5. Their comparison with the data in Table 4 shows that at airports there is some worsening in the quality of forecasts (a decrease in Q on the average by 6%), which is a result of the above-mentioned errors in observational data. To be sure, it is not impossible that a decrease in the quality of forecasts is to some degree a result of the manifestation of local conditions, about which we know nothing. For example, the decrease in Q by 12% at Bykovo is evidently caused by the influence of some local conditions.

Despite some worsening in the evaluations of the forecasts, the main conclusion drawn from tests of the method is that the developed graphs can be employed successfully, at least in the Moscow region. We emphasize that the fog forecasts made by the method propc: .d in this study are characterized on the average by the evaluation Q = 0.60. As a comparison we recall that for the prediction of thunderstorms by different methods this evaluation falls in the range 0.23-0.35 [1].

With respect to the possibilities of using the proposed graphs in other regions of the country, this problem can be solved only after corresponding tests. The following conclusions are possible.

1. The graphs can be used in the particular region in unmodified form.

2. It is necessary to take into account regional characteristics within the framework of the recommended predictors, but the graphs must be reconstructed, using local meteorological observations for this purpose. The archival data used for this purpose, depending on the frequency of recurrence of fogs in the particular region, must usually incorporate a 10-15-year series of observations. In some regions with a relatively great frequency of recurrence of fogs the volume of archival data used in constructing the graphs can be limited to a 5-year series of hourly observations.

3. Necessary allowance for local peculiarities must be made by making use of additional components of the vector-predictor.

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UDC 551.551.8

THE BOUNDARY CONDITION IN PROBLEMS OF ATMOSPHERIC DIFFUSION OF AN ADMIXTURE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 14-20

[Article by Doctor of Physical and Mathematical Sciences N. L. Byzova, I. A. Krotova and G. A. Natanzon, Institute of Experimental Meteorology, submitted for publication 23 February 1979]

Abstract: In the joint solution of the problem of dynamics and diffusion it is desirable to formulate boundary conditions for the admixture at the dynamic roughness level, rather than having a common boundary for all equations in the system. The parameter in the boundary condition for the concentration of admixture characterizing its entrapment can be obtained by scaling the experimental values of the rate of dry precipitation to the level $z = z_0$. The article gives a review of the experimental values of the rate of dry precipitation. The authors analyze the results of numerical solution of the diffusion equation with a boundary condition of the mixed type. A region of values of the rate of dry precipitation, transitional from a total reflection regime to a total absorption regime, which corresponds to the real range of measured values, is detected.

[Text] A more precise determination of the boundary condition at the underlying surface in problems of the diffusion of an admixture in the atmosphere is of considerable interest in those cases when the contamination of the soil by the effluent of industrial enterprises is investigated because even limited fallout of contaminating matter from the atmosphere over a prolonged period can lead to appreciable concentrations on its surface. Within the framework of the semiempirical theory this boundary condition, introduced independently in [9] and [13], has the following form:

$$P = K \frac{\partial q}{\partial z} + wq = vq. \qquad (1)$$

The equation for computing vertical diffusion of an admixture from a long-acting source is written in the form:

$$U \frac{\partial q}{\partial x} - w \frac{\partial q}{\partial z} = \frac{\partial}{\partial z} K \frac{\partial q}{\partial z}. \quad (2)$$

Here P is the flux of admixture onto the underlying surface, K is the coefficient of vertical turbulent diffusion, U is wind velocity, q is the concentration of admixture, w is the rate of gravitational precipitation of admixture particles in the calm air, v is a characteristic having the dimensionality of velocity.

For the purpose of a clearer understanding of the physical sense of condition (1) we will examine a case when near the underlying surface horizontal transfer can be neglected and the vertical flux can be considered approximately constant with altitude. This can occur, in particular, at an adequate distance from it. Limiting ourselves to the case of a weightless admixture (w = 0), assuming

$$K = \varkappa u_* z, \quad (3)$$

where u_* is dynamic velocity, from (2) in this approximation we have

$$q(x, z) = \frac{P(x)}{\varkappa u_*} \ln \frac{z}{z_g} = \frac{P(x)}{V(z)}. \quad (4)$$

Here ln z_g is an integration constant, for the time being not determined, and the value

$$V(z) = \frac{\varkappa u_*}{\ln (z/z_g)} \quad (5)$$

can be considered as not dependent on x.

The experiments show that the vertical flux of admixture near the earth in actuality is proportional to the surface concentration. The V(z) parameter, which is usually called the "rate of dry precipitation," is dependent both on the properties of the admixture and the underlying surface and on meteorological conditions [20]. Usually the rate of dry precipitation is determined from the measured concentration and the flux of admixture at some altitude (in the atmosphere -- about 1 m above the underlying surface). In principle, at this altitude it would also be possible to stipulate boundary condition (1), but in a number of cases it is desirable to relate it to some universal height, for example, to the roughness level z_0, where a boundary condition is also set for wind velocity. Then, using (1)-(5), we obtain a correlation between z_g v and V(z)

$$V(z_0) = v = \frac{V(z)}{1 - \frac{V(z)}{\varkappa u_*} \ln (z/z_0)}, \quad (6)$$

$$z_g = z_0 \exp\left(-\frac{\varkappa u_*}{v}\right). \quad (7)$$

We note that under the total reflection condition ($v = 0$) we have $z_g = 0$, whereas with complete absorption ($v \rightarrow \infty$) the z_g value tends to z_0, which also determines the range of its possible values.

We must emphasize again that in the problem of diffusion of an admixture the formulation of the boundary condition (1) with $z = z_0$ is no more than a convenient mathematical procedure ensuring a single boundary for problems of diffusion and dynamics. The $q(z_0)$ value figuring in (1) does not coincide with the real concentration at the level z_0 because expression (3) is not applicable in the immediate neighborhood of the underlying surface. In particular, one must not identify $q(z_0)$ with the mean concentration at the earth's surface q_s, which within the framework of the considered formulation does not enter into the problem at all. In this respect this approach differs from [7, 12], where the concept of near-wall resistance and diffusion roughness is introduced for different scalars, taking into account the difference between the concentrations at the level z and at the underlying surface.

Naturally, the z_g values determined using (4)-(7) coincide with those introduced in [12], but with $q_s = 0$. However, expressions (1)-(7) can be employed, using only experimental data on the flux and concentration at some level z within the effective limits of the logarithmic law. Using the V(z) value it is easy to determine the boundary condition parameter v. The relationship between V(z) with different z for $w \neq 0$ is given in [14], and between V(z) and v -- in [4].

Taking into account everything said above, we note that study [18] in our opinion is methodologically incorrect. Its authors, introducing a laminar sublayer and determining the concentration jump using the empirical formula for temperature, attempted to correct the v values determined in [4] on the basis of experimental data in the atmosphere. The negative values of this parameter obtained in [18] are attributed not to the "inaccuracy in experimental data," but to the inadmissibility of such use of them. The authors of [11] allowed the opposite error, specifically, they attempted to find a coefficient characterizing the entrapment of the admixture in the laminar sublayer, correcting measurement data for the concentration and fluxes only in the turbulent layer.

Now we will discuss in greater detail the problems involved in precipitation of an aerosol admixture onto the underlying surface. It follows from general considerations that for very heavy particles the flux is determined entirely by the rate of gravitational settling ($v = w$). This is also confirmed by experimental data [2]. For a weightless admixture ($w = 0$) it is desirable to assume $v = bu_*$, where b is a dimensionless coefficient, which, speaking in general, can also be dependent on u_*. In a general case the v value is determined as some function of w and u_*. As noted in the review [19], the precipitation of particles is determined for the most part by the properties of the flow near the wall; in this case a very important role is played by turbulent fluctuations, which penetrate into the laminar sublayer. Therefore, for describing the precipitation of particles it is necessary to have a more detailed knowledge of the near-wall region than for computing the transport of momentum. In the case of very small particles it is necessary to take Brownian diffusion into account, and in the case of larger particles -- their inertia. The influence of wall roughness is extremely great, although it is known poorly; both the z_0 values and the form of the elements are important.

The principal results of the theoretical studies used in [19] relate to smooth walls and the experiments were carried out in wind tunnels. The authors of [19] for a smooth wall recommend the expression

$$b = \frac{v}{u_*} = AS_*^2, \tag{8}$$

where for spherical particles

$$S_* = 0{,}05 \left(\frac{u_* d}{\nu}\right)^2 \frac{\sigma}{\rho}, \tag{9}$$

(d is particle diameter, σ and ρ are the densities of matter in particles and air density, ν is the kinematic viscosity of the air). Expressions (8)-(9) can be used with $z_0 u_*/\nu < 0.13$, $0.3 < S_* < 8$. In the atmosphere the first of these conditions is satisfied only for such surfaces as ice, snow and calm water when there is a weak wind. The numerical coefficient A in different theoretical evaluations varies from $1.7 \cdot 10^{-4}$ to $6.7 \cdot 10^{-4}$; in experiments it was found that $4.7 \cdot 10^{-4}$.

There are almost no such recommendations in the literature for rough surfaces. For example, the model of precipitation of particles onto the rough walls of pipes formulated in [11] is not generalized directly for an atmospheric flow around a surface since it is suitable only for intermediate Reynolds numbers. The model computations of the v value cited in [11] reveal the presence of a minimum in the region of a diameter of particles of about several micrometers and its gradual smoothing with an increase in roughness, its considerable dependence on roughness -- an increase with an increase in z_0 for all sizes of particles, most conspicuous in the range of their radii from 10^{-1} to $5\,\mu$m. The attempt at constructing a model for the precipitation of particles in the vegetation layer in the case of a real atmosphere [6] cannot be considered completed.

The results of experimental determination of the V(z) and v values under different conditions for particles of different sizes with different chemical properties can be found in [2, 14, 20], and for gases and aerosols under natural conditions also in [15-17, 21]. All the experimental data exhibit a great scatter, associated both with the fundamental difficulties in measuring the sought-for values and with uncontrollable factors, of which there are a particularly great number in natural experiments. As follows from [2, 4], for many surfaces which do not very greatly intercept particles, v exceeds the measured V(z) values by not more than 30-40%.

For strongly intercepting surfaces, such as moist grass, fabric, artificial grass, the v value can exceed V(z) by an order of magnitude or more. In a number of cases, with finite V(z) values it becomes virtually infinitely large; in other words, these surfaces completely absorb the tiny particles falling on them.

The most complete experimental results of determination of V(z), both under field conditions and in a wind tunnel, are given in [14]. The dependence of the V(z) value obtained here, virtually coinciding in this case with v, on particle size d shows that in the range of diameters greater than 10μm with sufficient accuracy it can be assumed that $v = bu_* + w$; b is virtually not dependent on d and u_*. With a decrease in d to 1μm the b value decreases by more than an order of magnitude; in the region $d \approx 1$ μm there is a minimum, after which with a further decrease in particle diameter b increases as a result of Brownian diffusion (the dependence qualitatively coincides with [11]).

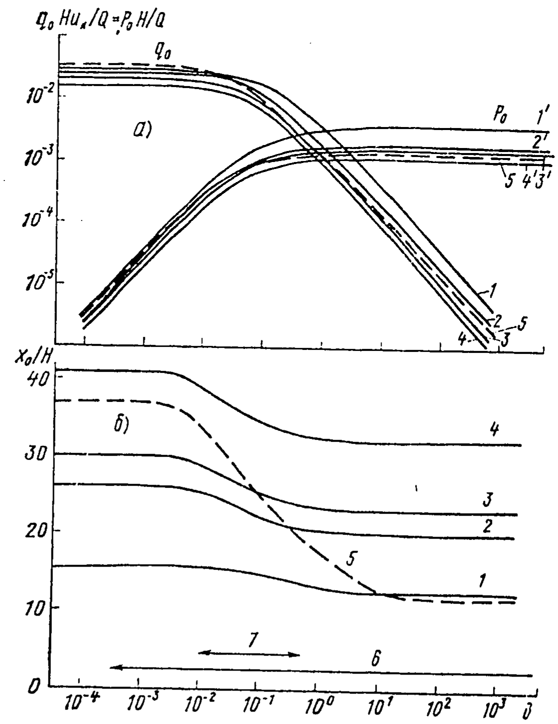

Fig. 1. Dimensionless maximum concentrations and flux of admixture (a) and distance of the concentration maximum to projection of the source (b) in dependence on $b = v/u_*$. 1-4) under condition (3), H/z_0 = 100, 500, 1000, 5000 respectively, 5) with U and K not dependent on z; 6) total range of experimental values b; 7) same for grass

We will note the general properties of the V(z), v and b parameters which make it possible to be oriented in the ranges of their values cited in [2, 4, 14-17, 20, 21]. In the case of a horizontally uniform surface they are not dependent on the distance to the source. Under ordinary conditions the b value can be considered nondependent on wind velocity, so that v in actuality is linearly related to u_*; but when there is a considerable wind and a dry surface there is a tendency to a decrease in b with an increase in u_*, evidently in connection with the process of deflation of particles from surface elements. In this process particles less than 20 μm in diameter lie within the viscous sublayer and are deflated to a lesser degree. All other conditions being equal, the v and V(z) values are always greater for chemically active particles than for inactive particles, for a surface covered by vegetation, than for a bare surface, for a moist surface than for a dry surface, with an unstable stratification than with a stable stratification. For all the investigated surfaces $v \geqslant w$, although it is possible to visualize a very smooth surface near which the heavy particles are accumulated, but are not entrapped by it (see [22]).

In general, the minimum V(z) values, according to data in the literature, are 0.02-0.03 cm/sec for particles with a diameter less than 1-2 μm and 0.1-0.2 m/sec for particles with a diameter more than 2 μm (under conditions of a weak wind, stability, slightly and moderately entrapping surface). The maximum V(z) values with $w \leqslant 2$ cm/sec are 30-36 cm/sec (artificial grass, moist canvas). For natural grass and soil in nature we give the V(z) values from 0.2 to 8 cm/sec, in dependence on z_0, u and stability. The ratio of the V(z) values for moist and dry surfaces is 1.1-2.8. The range of the value $B(z) = [V(z) - w]/u_*$ is somewhat narrower. For natural dry grass and particles greater than 5 μm in diameter it is, for example, from 0.01 to 0.08. The minimum v and b values coincide with the minimum V(z) and B(z) values, but in the direction of maximum values the range of v and b values widens virtually without limit.

The influence of dry precipitation on the field of concentration of an admixture in the atmosphere in the case of its modeling by the boundary condition (1) is examined in [3, 8, 10, 22]. For this use is made of solutions of equation (2) with a linear source of the intensity Q at the level H. Source [3] analyzes the expression for the concentration and flux obtained in [10] with the parameters K and U not dependent on z. It was shown that in the case $v = 0$, $w \neq 0$ the concentration at the earth's surface with $x \to \infty$ tends to some constant value, which is associated with the accumulation of particles precipitating from the atmosphere near a completely reflecting discontinuity. However small v may be, the admixture is expelled from the atmosphere and such accumulation does not occur. Sources [8, 22] give the results of numerical solution of equation (2) with a logarithmic wind profile and with stipulation of K in accordance with (3); the boundary condition is set at the level $z = z_0$. The cases $v = 0$ and $v = w$ are considered in [22]. It was found that with $H > 0$ and $v = 0$ particles are accumulated near the boundary, but only under the condition $w > \varkappa u_*$. With some combinations of parameters the surface concentration increases monotonically with an increase in x, completely not having a maximum.

Source [8] gives some special results of computations with w = 0 and variation of the v parameter in a broad range. Using these, and also a number of additional results of computations, we will examine the dependence of the characteristics of the field of concentration of the admixture near the underlying surface on the boundary condition parameter v. Figure 1 gives the values of the normalized maximum (subscript 0) concentrations and the coordinates of the concentration maximum as a function of $b = v/u_*$ and H/z_0. Here we have also plotted the full range of experimentally determined values b and the range of values of this parameter for natural grass. As might be expected, in the case of small b the concentrations, and in the case of great b -- the flux are virtually not dependent on b. The mentioned limiting cases correspond to substantially different patterns of formation of the maximum surface concentration and the maximum flux. With an increase in entrapment the maximum of the surface concentration is displaced toward the source.

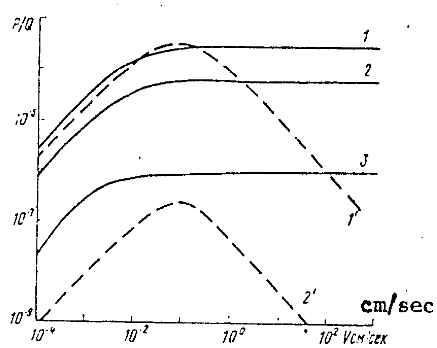

Fig. 2. Vertical flux of matter onto underlying surface in dependence on v at different distances. 1) 300 m; 2) 1000 m and 3) 10 000 m; 1' and 2' -- same as 1 and 2 for a model with constant U and K.

We note that the right-hand sides of the curves ($b > 5$), in contrast to the left-hand sides, being constructed in nonnormalized coordinates, merge for different u_*. The similar dependences for a model of diffusion with a wind velocity and turbulent diffusion coefficient (here b = vH/K) constant with height, plotted in Fig. 1, show that qualitatively the dependence of P_0, q_0 and x_0 on b remains the same with changeover to another model. However, x_0 with constant K and U, is dependent on b more strongly, which in this case is associated with the absence of a layer poorly conducting the admixture.

It is of interest to study the behavior of the concentration, and in particular, the flux of the admixture onto the underlying surface far from the source. With $v = 0$ it is absent, but however small v may be, it is greater than zero, and accordingly there can be an accumulation of admixture matter on the soil. Figure 2 gives the results of numerical computation of the value $P = vq$ with $z = z_0$, $H/z_0 = 100$, $u_* = $ ~.2 m/sec and different x values in dependence on the v value. It is interesting that at any distance the flux behaves the same as at the point with the maximum value: in the case of small v it increases linearly with an increase in v, whereas with large v it tends to a constant value and ceases to be dependent on v. This is attributable to the fact that with small v precipitation onto the surface is limited specifically by this parameter, whereas in the case of large v -- by that limiting conductivity which can be ensured by a surface layer with small values of the coefficient of turbulent diffusion. As indicated by Fig. 2, in a case when K and U are stipulated as not dependent on z, with small v the dependence of the P parameter on it is the same, although with a change in x the drop-off occurs considerably more rapidly. However, in the case of large v the flux at near distances is not limited and therefore at great distances ($x \gg x_0$) it decreases with an increase in v as 1/v. In this sense the result in [5], relating to the role of entrapment of an admixture by the underlying surface at great distances, obtained when using a model with a turbulent diffusion coefficient not dependent on z, is possibly in need of correction.

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PREDICTION OF AIR CONTAMINATION OVER THE APSHERON PENINSULA

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[Article by Candidate of Physical and Mathematical Sciences A. A. Gorchiyev and R. M. Rafiyev, Institute of Space Investigations of Natural Resources Academy of Sciences Azerbaydzhan Academy of Sciences, submitted for publication 11 June 1979]

Abstract: The author proposes a method for the short-range forecasting of the mean concentration of SO_2 and NO_2 by means of the method of expansion of variables in natural orthogonal functions. In contrast to other studies, here it is proposed that use be made of the coefficients of expansion of the fields of concentration of SO_2 and NO_2, wind velocity and the vertical temperature profile as predictors. The probability of success of such a prediction for SO_2 and NO_2 is 58.2% and 60.4% respectively.

[Text] At the present time a short-range forecast of air contamination for several days in advance is of practical interest. Interest in short-range forecasting can be attributed to the fact that in many cities and industrial centers the discharge of harmful substances into the atmosphere and their concentration in the air are very high. However, it is not always possible to move large sources of air contamination far beyond the limits of a city. The need therefore arises of lessening the discharge into the atmosphere during periods of time when unfavorable meteorological conditions arise and a high level of air contamination can be created in residential areas as well. The prediction of contamination of the air basin on the basis of data on meteorological conditions makes possible the timely adoption of measures for the purpose of preventing negative consequences, or at least, limitation of their scales. For example, in the case of prediction of a dangerous concentration, exceeding the sanitary-hygienic norms, it is possible to shift to the use of a different kind of fuel (from mazut to gas, etc.) or temporarily shut down functioning apparatus.

The problem of the influence of meteorological conditions on the concentration of harmful admixtures in the atmosphere has been examined both in theoretical investigations [3, 4] and in studies of analysis of actual observational data [2, 7].

The authors of this article have devoted their main attention to the dependence between weather conditions and air contamination in general over a major city, Baku. For this purpose we use the first coefficients of expansion in natural orthogonal functions (NOF) of the fields of concentrations of SO_2 and NO_2, as was first done in [5].

Taking into account the meteorological characteristics of the Apsheron Peninsula, as predictors we included individual meteorological elements which in the majority of cases are characteristic for a stable state of the atmosphere in the presence of temperature inversions. It follows from [6] that the Apsheron Peninsula is characterized by high frequencies of recurrence of temperature inversions, which in the lower kilometer layer of the atmosphere constitute almost 75% per year. It is also important to take the nature of the wind regime into account. The mean annual wind velocity here, according to long-term data, is 6.3 m/sec, whereas the number of days with a wind velocity greater than 15 m/sec averages 67 per year.

For the analysis and prediction of the degree of air contamination as the initial information we used five-year data for the summer season (1971-1975) on the concentration of harmful admixtures (SO_2 and NO_2) at 17 observation points in Baku and also air temperature data from aerological stations at ten standard levels (0.03; 0.20; 0.33; 0.50; 0.63; 0.75; 0.93; 1.00; 1.50 and 2.00 km) over the Apsheron Peninsula and wind velocity data for nine stations situated around Baku (Astara, Baku, Mashtagi, Neftechala, Neftyanyye Kamni, Artem Island, Zhiloy Island, Svinoy Island and Sumgait).

In contrast to [5], in predicting air contamination we did not use the meteorological elements themselves, but their coefficients of expansion in NOF, vertical temperature profiles and wind velocity fields.

It must be noted that the rate of convergence of the expansion for temperature is considerably greater than for the SO_2 and NO_2 concentrations. Thus, in the mentioned season the first term of the SO_2 concentration expansion describes 55-63%, the first two terms -- 65-70% of the total variability, and NO_2 -- 37-40% and 53-55% respectively. For the vertical temperature profile the first term of the expansion describes 92% and the first two terms -- 97% of the total variability. The first eigenvector usually well describes the main vertical variation of temperature deviations from the mean profile, which corresponds to a definite character of the interlevel correlation between the temperature variations at the ground and its variations at higher-lying levels. The second vector describes the variation of the additional correction to the temperature variations caused by the influence of the underlying surface.

Table 1

Correlation Coefficient R_i Between $\bar{q}$ and Coefficients of Expansion in NOF

	a_1	a_2	a_3	a_1^T	a_2^T	a_1^V	a_2^V	R^2
$\bar{q}_{SO_2}$	0,96	0,11	0,05	—0,17	—0,03	—0,19	0,03	1,00
$\bar{q}_{NO_2}$	0,98	0,06	0,04	—0,11	—0,01	—0,19	0,02	1,00

For wind velocity the first term of the expansion describes 59%, and the first two terms -- 75% of the total dispersion; the first EOF characterizes the principal characteristics of the spatial behavior of the wind velocity field, its simultaneous changes in general over the Apsheron Peninsula.

The question as to how many coefficients of the expansion of each specific field must be included in the forecast is extremely important because with the dropping of a part of the NOF there is a decrease in the accuracy of representation of the initial fields. In selecting the number of NOF, from the set of which the archives of proposed predictors is formed (that is, the test predictors), it is necessary to be guided first and foremost by the spatial scale of the considered fields; in each specific case for this purpose we analyzed the form of the isolines of the NOF and the behavior of the differences of the eigenvalues corresponding to them [8]. For the purpose of predicting the mean concentration of SO_2 and NO_2 for the first and second halves of the day for two days in advance in the set of test-predictors we included the three coefficients of expansion of the concentration fields α_1, α_2, α_3, and also the coefficients of expansion of the temperature fields α_1^T, α_2^T and wind velocity α_1^V, α_2^V in NOF.

The test-predictors (α_1, α_2, α_3), (α_1^T, α_2^T) and (α_1^V, α_2^V), representing the coefficients of expansion of different elements, can be related to one another and are not orthogonal. The latter circumstance required the use of orthogonalization of predictors. A new orthogonal system of predictors was obtained by the maximum projections method [1]. In subsequent stages of prediction the test-predictors were subjected to further analysis and rejection of unsuccessful predictors. For this purpose we computed the correlation coefficients R_i between the SO_2 and NO_2 concentrations and the i-th expansion coefficients. The results of the computations are given in Table 1, where $R^2 = \sum_i R_i^2$ is the square of the multiple correlation coefficient.

In accordance with the table we carried out a so-called "revision" of all the predictors. As a result, the predictors α_3, α_2^T and α_2^V were discarded. Thus, for predicting the mean concentration of SO_2 and NO_2 for the city as a whole as the predictors we include two coefficients of expansion in NOF -- one coefficient each for expansion of the vertical temperature profile and the wind velocity field. The first group of predictors (α_1, α_2) takes into account the influence of inertial factors, the second (α_1^T) and third (α_1^V) groups in turn take into account the conditions for vertical and horizontal diffusion of harmful admixtures. In combination these parameters determine the state of local and general circulation processes, on which, for the most part, is dependent the distribution of harmful admixtures in the atmosphere. The principal contribution to the general level of atmospheric contamination is from α_1 and in part α_1^T and α_1^V. The correlation between the mean concentration of SO_2 and NO_2, atmospheric stratification (α_1^T) and wind velocity (α_1^V) is negative (0.17; -0.11 and -0.19; -0.19).

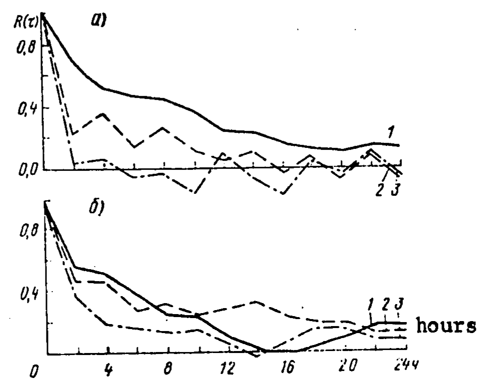

Fig. 1. Autocorrelation functions of first (1), second (2) and third (3) coefficients of expansion of the fields of concentration of SO_2 (a) and NO_2 (b).

It is known that the first coefficient of expansion of the concentration of harmful admixtures (α_1) characterizes the level of general contamination of the atmosphere in a city and is more closely related to the meteorological situation [5]. The scheme makes use of the α_1 values obtained using data from measurements made two days prior to the time for which the forecast is made. The degree of coherence of the series of concentrations was evaluated using correlation functions computed using the formula

$$R(\tau)=\frac{\frac{1}{N-\tau}\sum_{i=1}^{N-\tau}a_i a_{i+\tau}-\overline{a_1}\,\overline{a_2}}{\left[\left(\frac{1}{N-\tau}\sum_{i=1}^{N-\tau}a_i^2-\overline{a}_1^2\right)\left(\frac{1}{N-\tau}\sum_{i=1}^{N-\tau}a_{i+\tau}^2-\overline{a}_2^2\right)\right]^{1/2}}, \quad (1)$$

where $\bar{\alpha}_1$ and $\bar{\alpha}_2$ are the mean values of the first $N-\tau$ and last $N-\tau$ terms in the series respectively; τ is the lag (time shift), $\tau = 2, 4, 6, \ldots$ days. These correlation functions describe large-scale meteorological disturbances.

Figure 1 shows the time correlation function of the parameters α_1, α_2 and α_3 during the mentioned period of the summer season for sulfur gas and NO_2, computed on a "BESM-6" electronic computer. It follows from an analysis of variation of the functions $R\alpha_1(\tau)$, $R\alpha_2(\tau)$ and $R\alpha_3(\tau)$ for SO_2 and NO_2 that the most prolonged correlations are obtained for the first expansion coefficient; for the subsequent coefficients, as a rule, the time correlation radius decreases. Figure 1a shows that in the city for α_1 of sulfur gas a high correlation $R\alpha_1(\tau) \geqslant 0.5$ is retained to the interval $\tau = 6$ days, and for NO_2 -- to $\tau = 4$ days (Fig. 1b). Such a variation of $R\alpha_1(\tau)$ is evidently attributable to the presence of a stable "contamination cap" over the city. After two days the correlation coefficient for SO_2 and NO_2 is 0.67 and 0.54 respectively. On the basis of these investigations it can be assumed that this information on the state of the air basin over a city is adequate for the prediction of atmospheric contamination.

The initial data for the element to be predicted for the forecasting station were the deviations of the mean concentration from the sample mean separately for each of 17 observation points. The problem involved a determination of the predicted values Δq_{ij} for two days in advance (anomalies of the mean concentration for the i-th day for point j) with the use of four orthogonal expansion coefficients. For this purpose we used the multiple regression method. The anticipated value $\Delta q_{j,\, i+2}$ for two days in advance in this case was determined using the regression coefficient

$$\Delta q_{j,\, i+2} = b_j \alpha_{1\,i}^T + c_j \alpha_{1\,i}^V + \sum_{n=1}^{2} a_{nj} \alpha_{ni}. \qquad (2)$$

The weighting coefficients a_{nj}, b_j and c_j were computed by the least squares method, that is, in such a way as to satisfy the condition

$$\sum_{i=1}^{M} \left[\Delta q_{j,\, i+2} - \left(b_j \alpha_{1\,i}^T + c_j \alpha_{1\,i}^V + \sum_{n=1}^{2} a_{nj} \alpha_{ni} \right) \right] = \min. \qquad (3)$$

The finding of the coefficients a_{nj}, b_j and c_j is considerably simplified if we take into account the property of the orthogonality of the expansion coefficients.

$$\sum_i \alpha_{ki} \cdot \alpha_{li} = 0; \quad k \neq l, \qquad (4)$$

where α_{ki} and α_{li} correspond to α_{nj}, α_{1i}^T and α_{1i}^V.

Differentiating equation (3) for a_{nj}, b_j and c_j and equating it to zero, we obtain a system of normal equations which is solved relative to the weighting coefficients. As a result of condition (4) the coefficients

a_{nj}, b_j and c_j are found from the expressions

$$a_{nj} = \frac{1}{\sum_i a_{ni}^2} \sum_i \Delta q_{j,\, i+2}\, a_{ni};\ n = 1,\ 2$$

$$b_j = \frac{1}{\sum_i (a_{1i}^T)^2} \sum_i \Delta q_{j,\, i+2}\, a_{1i}^T; \qquad (5)$$

$$c_j = \frac{1}{\sum_i (a_{1i}^V)^2} \sum_i \Delta q_{j,\, i+2}\, a_{1i}^V.$$

In order to check the possibilities of the resulting forecasting schemes we constructed a series of maps on the basis of a priori material. An evaluation of the success of the forecast of the mean concentration for the city in the first and second halves of the day was made separately for the three groups. For sulfur gas: low (0.00-0.15), increased (0.16-0.29) and high ($\geqslant$0.30), and for NO_2 the corresponding figures were: low (0.00-0.040), increased (0.041-0.084) and high ($\geqslant$0.085). The results of this checking are given in Table 2, from which it follows that according to a priori data the total probable success for SO_2 is 58.2%, and for NO_2 -- 60.4%.

Table 2

Probable Success of Forecasts Using A Priori Material, in %

Примесь 1	Прогнозируемая группа 2	Количество прогнозов 3: испытанных 4	Количество прогнозов 3: оправданных 5	Оправдываемость 6
SO_2	Пониженная 7	3	2	66,7
	Повышенная 8	76	43	56,6
	Высокая 9	12	8	66,7
	Общее 10	91	53	58,2
NO_2	Пониженная	3	2	66,7
	Повышенная	75	44	58,7
	Высокая	13	9	69,2
	Общее	91	55	60,4

KEY:

1. Admixture
2. Predicted group
3. Number of forecasts
4. Tested
5. Successful
6. Success (%)
7. Low
8. Increased
9. High
10. Total

In order to take sanitizing and prophylactic measures the "high" category is of the greatest interest. The probable success of this group for SO_2 is 66.7%, and for NO_2 -- 69.2%.

If one also takes into account the number of forecasts not falling into the predicted group, but close to it, the probable success for SO_2 is increased to 81.8% and for NO_2 to 86.5%. The probable success of the forecasts was evaluated using the index

$$Q = \frac{n_+ + 0,5\,n_{0,5}}{N},$$

where n_+ is the number of cases in which the actual and predicted values of the concentration fell in one group, $n_{0.5}$ is the number of cases in which the predicted and actual concentrations fell into adjacent groups, N is the number of tests.

In conclusion it must be noted that the considered schemes are now being used in routine work.

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INFLUENCE OF DIRECTION OF TRANSPORT OF AIR MASSES ON THE CONTENT OF ORGANIC MICROADMIXTURES IN PRECIPITATION

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 27-31

[Article by L. A. Volokitina and V. S. Shuklin, Institute of Experimental Meteorology, submitted for publication 24 April 1979]

Abstract: The authors determined the concentrations of organic carbon in a number of precipitation samples. The influence of the direction of transport of air masses on the content of oranic microadmixtures in precipitation in the central part of the European USSR is examined.

[Text] In order to understand the physicochemical processes transpiring in the atmosphere it is necessary to know the chemical composition of aerosols. One of the principal ways in which aerosol reaches the earth's surface is precipitation, with which more than 50% of all aerosol matter falls out [2] and the chemical composition of whose admixtures, accordingly, characterizes the aerosol in a particular air mass. Inorganic admixtures in precipitation have been investigated relatively extensively [10]. It has been established that their concentration is in the limits 1-100 mg/liter. Organic admixtures in precipitation have been determined sporadically [7, 9], which is due to the diversity of the admixture types and the complexity of the chemical methods for analysis of organic compounds. However, organic admixtures constitute a considerable fraction of the total contamination of precipitation. The concentrations of organic substances in precipitation are close to those in the surface waters of the land [9]. Therefore, the data characterizing organic admixtures in precipitation are also of interest in a study of problems in geochemistry and hydrochemistry (chemical weathering processes, balance of organic substances for water bodies, formation of chemical compcsition of surface waters).

It should be noted that for an anthropogenic aerosol it is possible to expect a relatively great quantity of organic substances since man uses mostly organic substances as food products, raw material and fuel.

This makes it possible to hope that an investigation of the relationship between the contamination of precipitation by organic admixtures and the transport of air masses will help to evaluate, on a regional scale, the influence of different sources of anthropogenic contaminations. For this purpose in this study we have determined the concentration of organic admixtures in precipitation, taking into account the direction of transport of air masses to the point where precipitation samples are taken.

The water in precipitation contains a number of organic compounds: hydrocarbons, alcohols, ethers, acids, etc., most of which have a photoluminescent capacity.

However, at room temperature (T 300 K) the luminescence spectra of these compounds overlap, which make virtually impossible the photoluminescent determination of individual compounds in such a mixture. In this case with a constancy of the component makeup of admixtures it is possible to determine the total quantity of organic admixtures in solution.

Investigation of the photoluminescent characteristics of precipitation water has shown that the luminescence spectra of precipitation of different aggregate state (water and snow) differ little from one another and change insignificantly from season to season [6], which confirms data on the relatively constant (from the point of view of the content of the principal groups of organic compounds) composition of the organic component of atmospheric aerosol [11]. This, in turn, makes it possible to use the intensity of luminescence for determining the total concentration of organic admixtures in precipitation. For this purpose in this study we have found the relationship between the level of luminescence of precipitation and the concentration of organic carbon in it, the fraction of which in precipitation water accounts for approximately half of all the organic matter [7].

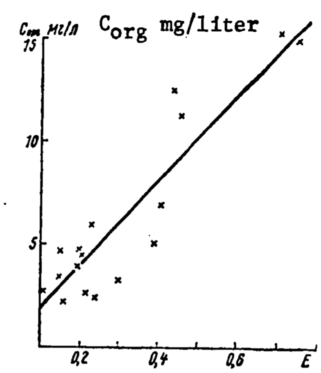

Fig. 1. Dependence of concentration of organic carbon in precipitation water on its luminescence level.

Table 1

Concentration of Organic Admixtures C_{org} in Precipitation and Meteorological Parameters on Days of Collection of Samples at Obninsk in 1976

Дата 1	Вид осадков 2	$C_{орг}$ мг/л 3	Преобладающий ветер (H=300 м) 4	Направление переноса на высоте 1,5 км 5	Районы выноса воздушной массы 6	Форма облаков 7
27 I	снег 8	8.0	ЮЮВ 11	западное 12	Северное море 20	St
29 I	то же 9	6.4	Ю	западное	Северное море	Frnb, As
30 I	»	8,0	ЮЗ	южное 13	Средиземное море 21	St
2 II	»	8,0	ЮЮЗ	северо-восточное 14	север Западной Сибири 22	St
2 III	»	14,0	ЮЗ	—	—	As
4 III	»	28,0	ЮЮЗ	южное 13	Черное море 23	Cb
5 III	»	12,8	ЮЮЗ	восточное 15	Западная Сибирь 24	Frnb, Ns
17 III	дождь 10	21,6	Ю	южное 13	Черное море	Sc, Cb
5 IV	снег 8	3,2	ЗЮЗ	северо-западное 16	Северная Атлантика 25	Sc
13 V	дождь 10	22,4	В	южное 13	Черное море	Cb, Sc
18 V	то же 9	4,8	ЮЗ	западное 12	Северное море	Cu
19 V	»	3,2	СЗ	северное 17	Скандинавия	Cb
3 VI	»	4,0	З	южное 13	Черное море	Cu
7 VI	»	3,6	Ю	западное	Северное море	Cu, Ac
16 VI	»	4,0	ВСВ	западное	Северное море	Cu, Ac
17 VI	»	5,2	СВ	западное	Северное море	Cu
4 VIII	»	8,0	ЮЮВ	—	—	As, Cu
6 VIII	»	3,6	ЮВ	западное 12	Северное море	Cb, Cu
5 X	»	6,8	ССЗ	южное 13	Средиземное море	Sc
12 X	снег 8	3,6	ЮЗ	северное 17	Ледовитый океан 26	As, Frnb
1 XI	дождь	12,8	ССЗ	западное	Балтийское море 27	Sc, Frnb
30 XI	то же	12,0	ССЗ 18	юго-западное	Западная Европа 28	Sc, Cb
9 XII	снег	11,2	СВ 19	юго-восточное	Малая Азия 29	Cb
13 XII	то же	8,0	ЗЮЗ	южное	Средиземное море	Ac(Cu)
14 XII	»	4,0	ЗЮЗ	южное	Средиземное море	Ac(Cu)
17 XII	»	10,0	ЗЮЗ	южное	Средиземное море	Sc, Ac
18 XII	»	17,2	ЗСЗ	южное 13	Средиземное море	Cb, Ac
20 XII	»	24,0	ЮЗ	юго-восточное 13	Малая Азия 29	Cb, St

KEY:

1. Date
2. Type of precipitation
3. C_{org}, mg/liter
4. Prevailing wind
5. Transport direction at 1.5 km
6. Regions of air mass emergence
7. Form of precipitation
8. Snow
9. Same
10. Rain
11. Abbreviations (see next page)
12. Westerly
13. Southerly
14. Northeasterly
15. Easterly
16. Northwesterly
17. Northerly
18. Southwesterly
19. Southeasterly
20. North Sea
21. Mediterranean Sea
22. Northwestern Siberia
23. Black Sea
24. Western Siberia
25. North Atlantic
26. Arctic Ocean
27. Baltic Sea
28. Western Europe
29. Asia Minor

ABBREVIATIONS IN TABLE

SSE = ЮЮВ	ENE = ВСВ
S = Ю	NE = СВ
SW = ЮЗ	SSE = ЮЮВ
SSW = ЮЮЗ	SE = ЮВ
WSW = ЗЮЗ	WSW = ЗЮЗ
E = В	NNW = ССЗ
NW = СЗ	NE = СВ
W = З	WNW = ЗСЗ

According to measurements of 1976, the amplitude of the fluctuations of concentrations of organic admixtures in the collected precipitation is 3-30 mg/liter. Proceeding on the basis of the idea that during the movement of air masses over great distances there is an accumulation of aerosols in clouds, including organic admixtures, it was natural to assume that the difference in the concentration of organic admixtures in precipitation collected at a given point was caused, as in cases of transport of inorganic admixtures [1, 5], by a change in the direction of arrival of air masses (advection) at a particular point.

Before determining the dependence of the concentrations of admixtures in precipitation on the direction of distant transport (advection), we checked their dependence on wind direction at the measurement point. All cases of measurements, in dependence on the prevailing wind direction, were divided into four groups corresponding to the principal directions of the compass.

For each group of days with a particular wind direction we computed the mean concentration of organic admixtures in precipitation. We did not discover significant differences in the concentration of organic admixtures in the water when there were winds of different directions. It can therefore be concluded that the concentration of admixtures has little dependence on local sources. In order to detect the dependence of the concentration of admixtures on the origin of air masses we carried out a comparison of the concentrations of admixtures in dependence on the region from which the air mass arrived. The region of air mass origin was determined on the basis of the 2- or 3-day trajectories from the sampling point, constructed graphically by the known method [3]. AT_{850} diagnostic pressure pattern charts for 0300 and 1500 hours were used. The true air particle trajectories are more complex than those constructed from the pressure pattern charts since each air particle is also displaced vertically, which is caused by vertical movements of different origin. The trajectories constructed by the graphic method and taking into account only horizontal movements are the averaged trajectories of many air particles.

Table 2

Mean Concentrations of Organic Admixtures C_{org} mg/liter in Precipitation for Different Directions of Transport of Air Masses at an Altitude 1.5 km

Parameters	Group of air mass transport toward Obninsk				
	Northerly	Westerly	Southerly	Southerly	
				subgroup I	subgroup II
$\bar{C}_{org}$	3.3±0.2	6.0±2.9	13.5±7.8	6.8±2.2	19.5±4.9
C_{max}	3.6	12.8	28.0	--	--
C_{min}	3.2	3.6	4.0	--	--
n	3	8	13	6	7

Note: The table gives the standard deviation from the mean value; n is the number of cases.

The method for collecting samples involved the following: liquid precipitation was collected using a glass funnel into a beaker, whereas solid precipitation in the form of snow was collected after its falling onto the underlying surface. The photoluminescence of samples of water in precipitation was excited by the radiation of a nitrogen laser with a wavelength $\lambda = 337.1$ nm. The luminescence spectrum was measured using a DMR-4 monochromator and a FEU-51 photomultiplier. The spectral width of the slit in the region of the maximum of luminescence intensity ($\lambda = 380$-390 nm) was $\Delta\lambda = 6.3$-6.4 nm. The photoluminescent measurements method was described in detail in [6]. The concentration of organic carbon in precipitation water was determined from the permanganate oxidability of this water [8].

The figure shows the dependence of the luminescence level of individual precipitation samples on their concentration of organic carbon. In this case the error in measuring luminescence intensity did not exceed 10-20% [6]; the uncertainty with respect to the concentration of organic carbon was determined by the uncertainty in the correlation between permanganate oxidability and the concentration of organic carbon and was a value of about 30% [8]. On the assumption of a linear correlation between the luminescence level and the concentration of organic impurities in the water we used the least squares method in obtaining a direct regression, described by the equation $C_{org} = -0.2 + 20.8\ E$ [mg/liter]. The linear correlation coefficient was 0.91; the dispersion for the slope of the regression line was 2.2. The existence of such a correlation made it possible to determine the concentration of organic carbon (by the photoluminescent method) in small samples (volume 3-5 ml) of precipitation water, whereas such a determination by chemical methods requires water samples with a volume not less than 50-100 ml. It should be noted that the concentration of organic carbon in the samples which we investigated $C_{org} \approx 3$-30 mg/liter does not contradict the data characteristic for the precipitation in a number of regions in the USSR (Georgia, Arkhangel'skaya, Novosibirskaya, Omskaya, Rostovskaya, Yaroslavskaya Oblasts, Khabarovskiy Kray) and Sweden [7-9].

An investigation of organic impurities in precipitation was carried out at Obninsk in the neighborhood of the high meteorological mast (HMM) in different time intervals during the light time of day. Both in the city itself and in the immediate neighborhood there were no large industrial enterprises and therefore there were no large local sources of contamination.

The results of measurements of the organic component in precipitation water are presented in Table 1. The table also gives some meteorological parameters characterizing the conditions for the falling of precipitation; the wind direction at the 300-m level and the form of the clouds from which the precipitation fell (the information was selected from hourly measurements on the HMM); the direction of transport in the troposphere at the 1.5-km level, determined from AT_{850} pressure pattern charts, was determined twice a day at the USSR Hydrometeorological Center.

The accuracy in constructing trajectories from pressure pattern charts was evaluated in [4]. In the temperate latitudes of Eurasia, at levels close to the standard isobaric surfaces, the error attains considerable values. The trajectory error in cases of construction from pressure pattern charts increases with an increase in wind velocity and the duration of transport. In our case for construction of 2- or 3-day trajectories from the AT_{850} charts the error at the end of the trajectory is about 200 km. All the cases of measurements of the concentrations of organic impurities were grouped in dependence on the direction of air mass arrival. For each of these groups we computed the mean concentrations of organic admixtures in the collected precipitation. The results are presented in Table 2. It follows from the data in Table 2 that in the samples of precipitation falling on days when the arrival of air masses occurred from the south and southwest (Atlantic Ocean, Mediterranean and Black Seas) the mean level of organic admixtures in the precipitation was: C_{org} = 13.5 (7.8) mg/liter (the standard deviation is given in parentheses). For the group of samples of precipitation falling on days with the westerly transport of air masses the mean level of the concentration of organic admixtures was: C_{org} = 6.0 (2.9) mg/liter, and for the group of samples of precipitation falling on days of arrival of air masses from the north, C_{org} = 3.3 (0.2) mg/liter. We should note the considerable value of the deviation from the mean level of concentrations in the group of days with southerly transport. In order to find an explanation for such a scatter of the concentrations of admixtures within this group, an attempt was made to take into account the differences in the vertical thickness of cloud cover observed at the hours of collection of precipitation. All the cases of observations in this group were broken down into two subgroups: the first subgroup included days with a cloud cover for the most part of St and Sc forms (vertical extent up to 2-3 km); the second subgroup included days when there was a predominance of cloud cover situated at an altitude of 4-5 km Ns-As, and Cb (vertical thickness 9-10 km). The cloud systems from the second subgroup were usually frontal and were caused by extensive zones of ascending movements of moist air along atmospheric fronts in cyclones and troughs. The mean concentration of organic admixtures in precipitation was computed for subgroups I and II (Table 2). Without discussing the possible mechanism, we point out that the precipitation falling on days with southerly advection from well-developed cloud systems Ns-As and Cb contains maximum concentrations of organic matter for the entire period.

It follows from everything set forth above that the arrival of an air mass from the south, southwest and southeast is associated with an increase in organic admixtures in precipitation. The mentioned increase is particularly conspicuous on days when precipitation falls from cloud systems of the Ns-As and Cb types. The data were obtained using a small amount of experimental data. Nevertheless, they are evidence of the possibility of determining the region from which the air mass arrives in the central part of the European USSR on the basis of the concentration of organic admixtures in precipitation.

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OBJECTIVE ANALYSIS OF THE TROPOPAUSE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 32-39

[Article by Candidate of Physical and Mathematical Sciences V. A. Gordin and Ye. A. Loktionova, USSR Hydrometeorological Scientific Research Center, submitted for publication 5 June 1979]

Abstract: Applying the spline approximation method and using data on geopotential, the authors determine the characteristics of the tropopause, agreeing with the actually observed values. A variational smoothing method is proposed for using data on the tropopause surface as initial data in prognostic models. This makes it possible to obtain a single-sheet surface close to isentropic.

[Text] #1. Introduction. A method for constructing the vertical temperature profile from geopotential values at ten standard isobaric surfaces by means of a spline approximation was proposed in [3]. The good accuracy of the method made it possible, on the basis of this temperature profile, to construct an algorithm for determining the level of the tropopause in accordance with the WMO criterion. An exposition of this algorithm is the main content of this paper.

An alternative to the mentioned algorithm would be "direct" objective analysis of data on the tropopause, in which these data, contained in aerological telegrams, are interpolated by some method at the grid points of intersection. Realization of this method involves the following difficulties:

1) At the present time there is no program for the checking of data on the tropopoause. However, for such checking it is possible to employ our algorithm, resting on checked geopotential data.

2) The great spatial variability of the tropopause field. The absence of data on the correlation function of the tropopause field. Difficulties associated with the possibility of existence of a different number of

tropopauses at adjacent stations.

3) The mismatch between the temperature profile obtained as a result of objective analysis at a given point in a grid and obtained as a result of independent objective analysis of the tropopause level. In our algorithm these difficulties are absent.

In formulating the algorithm we took into account two types of possible data output: 1) the actual tropopause, which is computed at points in the objective analysis grid or at stations; 2) a "stylized" tropopause, intended for use in a numerical prognostic model in a σ-system of coordinates for setting of a boundary condition [8, 10].

In the first case the only quality criterion is the closeness of the determined characteristics of the tropopause (p and T) to the characteristics of the tropopause contained in aerological telegrams (group with the distinguishing digits 88).

In the second case the final quality criterion is the quality of the forecast according to a particular model, and intermediate criteria of the type of smoothness of the tropopause field (mandatorily single-sheet) allow different interpretations.

#2. Definition of Tropopause

According to the WMO definition [6].

a) The first tropopause is defined as the very lowest level at which the vertical temperature gradient is decreased to 2°C/km or less, under the condition that the mean vertical gradient between this level and all higher levels in the limits 2 km does not exceed 2° C/km;

b) If above the first tropopause the mean gradient between any level and all higher levels in the limits 1 km exceeds 3° C/km, then a "second tropopause" is defined using the same criterion as indicated in (a); this tropopause can be either within or above a layer with a thickness of 1 km.

The tropopause level lying below 500 mb is taken only in a case when:
1) there is no tropopause above this level,
2) the mean vertical temperature gradient in any layer with a thickness less than 1 km does not exceed 3°C/km above this level,
3) the maximum altitude of rising of a radiosonde is not below 200 mb.

Point (a), defining the tropopause level z_1, is formalized in the following way:

$$z_1 = \min_{p(z) \leqslant 500 \text{ mb}} z; \ \{\text{for any } \tilde{z} \text{ such that } z + 2 \text{ km} \geqslant \tilde{z} > z, \ -(T(\tilde{z}) - T(z)) \leqslant 2^\circ\text{C/км} \cdot (\tilde{z} - z)\}. \quad (1)$$

If T(z) is a smooth function (and this is true in our case), then it is easy to demonstrate that

$$-\frac{dT}{dz}(z_1) = 2^\circ \text{C/км}. \quad (2)$$

Condition (2), it goes without saying, is inadequate for the satisfaction of (1), but makes it possible to find so-called "probable tropopauses" at which by definition there is satisfaction of equation (2), and then check condition (1) for them.

In conditions (1) and (2) it is possible to proceed to the $\xi = -Rg^{-1}\ln p$ coordinate: $\xi_1 = \min_{\xi > \xi(500)} \xi$: for any $\tilde{\xi}$ such that $H(\xi) + 2$ km $\geqslant H(\tilde{\xi}) \geqslant H(\xi)$,

$$-(T(\tilde{\xi}) - T(\xi)) \leqslant 2^\circ \text{C/км} \, (H(\tilde{\xi}) - H(\xi))\}. \quad (1')$$

Similarly there is formalization of point (b) in the definition of tropopause levels.

#3. Description of Algorithm for Finding Probable Tropopauses

We will assume

$$P(\xi) = \frac{dT}{d\xi} + LT,$$

where L = 2°C/km/ This is a spline of the order 2 and defect 2. For finding its roots it would be adequate to solve (2) for each of the layers between the standard levels, within the limits of each of which $P(\xi)$ is a second-degree polynomial. But it may be found that the roots of this polynomial fall outside the mentioned interval, and accordingly, in seeking them we in vain extracted the square roots; the operation is relatively time-consuming with respect to computer time. Therefore, in seeking the roots the first step is to check the presence of roots in this interval.

Assume that a, b are the ends of the interval. If $P(a)P(b) < 0$, there is one root in the interval, if not, then 0 or 2. In the second case, if $P'(a)P'(b) \leqslant 0$, then there are no roots in this interval, and if not, then we compute the discriminant $D = P'(a)^2 - 2P(a)P''(a)$. If $D < 0$, there are no roots (since the case $D = 0$ is not a general situation, in this program this condition is replaced by $D \leqslant 0$), whereas if $D > 0$, there can be the four cases illustrated in the figure. Cases (a) and (c) are distinguished by the condition $P'(a)P(a) < 0$. We note that checking of the condition $P'(a)P'(b) \geqslant 0$ could be excluded without sacrifice for completeness of examination of variants, but since this condition is frequently realized, and in this case subsequent checkings are excluded, we deemed it desirable to leave it. If there are roots in the [a, b] interval and P changes sign in it from negative to positive with a decrease in ξ, such a root is called the probable tropopause and is determined using the formula

$$\xi_{1,2} = [P''(a)]^{-1}[-P'(a) \pm D^{1/2}].$$

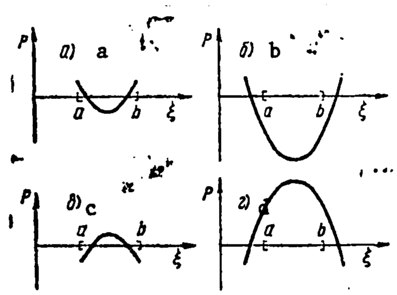

Fig. 1. Possible curves of quadratic spline $P(\xi)$ in one of smoothness segments [a, b] under conditions $P(a)P(b) > 0$, $P'(a)P'(b) < 0$, $D > 0$. Cases a and c, in which there are roots $P(\xi)$ in the segment [a, b] are characterized by the condition $P(a)P'(a) < 0$.

#4. Description of Algorithm for Finding First Tropopause

Assume that ξ_1 is the probable tropopause. We will assume that

$$P_1(\xi) = -T(\xi) + T(\xi_1) - L[H(\xi) - H(\xi_1)] = \int_{\xi_1}^{\xi} P(\xi)\,d\xi.$$

ξ_1 is the first tropopause if $P_1(\xi) < 0$ when $\xi \in (\xi_1, \xi_2)$, where ξ_2 is determined implicitly from the equation $H(\xi_2) - H(\xi_1) = 2$ km using the pressure gradient formula (on the assumption that the temperature in this interval is constant and coincides with the temperature $T(\tilde{\xi}_1)$ at the standard level $\tilde{\xi}_1$ upward closest to ξ_1:

$$\xi_2 = \tilde{\xi}_1 + [T(\tilde{\xi}_1)]^{-1}[H(\xi_1) + 2\ \text{км} - H(\tilde{\xi}_1)].$$

This formula can be regarded as approximate, and computing $H(\xi_2) - H(\xi_1) - 2$ km, still another iteration can be made using the pressure gradient formula, but elementary estimates show that the necessary accuracy is attained at once.

ξ_1 is the first tropopause if $P_1(\xi)$ does not have roots in the semi-interval (ξ_1, ξ_2). We recall that $P_1(\xi)$ is a cubic spline with the defect 2. This condition is checked in the following way. If $[\text{sign}\, P_1(\xi_1 + 0)]P_1(\xi_2) < 0$, there are an odd number of roots in the semi-interval, and accordingly is non-zero. (Here sign $P_1(\xi_1 + 0) =$ sign $P''_1(\xi_1)$, since $P_1(\xi_1) = P'_1(\xi_1) = 0$). Otherwise we will seek the roots $P(\xi) = P'_1(\xi)$ in the semi-interval (ξ_1, ξ_2). If there are none, then $P_1(\xi)$ in this semi-interval is a monotonic function and does not change sign. If in (ξ_1, ξ_2) there are the roots $P(\xi)$ (we will denote them ξ^j), we check the condition for all j $P_1(\xi_1)P_1(\xi^j) \geqslant 0$.

According to the Weierstrass theorem, it is satisfied if and only if there are no roots for the continuous function $P_1(\xi)$ in the semi-interval (ξ_1, ξ_2). In this case the condition (1') is satisfied.

#5. Description of Algorithm for Finding Next Tropopauses

Assume that the first tropopause ξ_1 has been found and aloft there are probable tropopauses ξ_i. According to point (b) #2, in order for a second tropopause to exist it is necessary that there be a "blocking layer," that is, the existence of such ξ_0 that

$$\xi_0 = \min_{\xi > \xi_1} \xi: \text{ (for any } \tilde{\xi} \text{ such that} \quad -[T(\tilde{\xi}) - T(\xi)] > L_1[H(\tilde{\xi}) - H(\xi)]\}, \quad (3)$$

where $L_1 = 3°C/km$.

As in #2, it therefore follows that $-\frac{dT}{d\xi}(\xi_0) = L_1 T$

and the "probable blocking layers" are found similarly as in #3 with a replacement of L by L_1 and with the condition that the polynomial

$$Q(\xi) = \frac{dT}{d\xi} + L_1 T$$

must change sign in the root from positive to negative. The least of the probable ξ_0 satisfying condition (3), which is checked in the same way as in #4, marks the beginning of the "blocking layer." The procedure #4, etc., is applied to the probable tropopauses situated above ξ_0.

Thus, it is possible to obtain as many tropopauses as desired, but for real profiles we did not obtain more than three.

Table 1

Results of Comparison of Data on the Lower Tropopause Obtained Using Data on Geopotential and Contained in Aerological Telegrams

	2/XI-1977	9/XI-1977
Number of stations	346	400
Mean absolute error p, mb	17.4	19.3
Mean square error p, mb	28.4	30.6
Mean absolute error T, °C	2.14	2.09
Mean square error T, °C	3.44	2.86

Using the determined ξ_1 we compute the characteristics of the tropopause: $p(\xi_1)$; $H(\xi_1)$; $T(\xi_1)$.

The determined characteristics of the lower tropopause (p, T) were compared with data on the lower tropopause communicated in aerological telegrams. The results of a comparison for two observation times (see Table 1) seems to us to be satisfactory.

Comment 1. A similar method can be used in determining convectively unstable layers (it is only necessary to change the constant L). Then it is also possible to determine the integral characteristics of these layers.

Comment 2. Since our method for computing tropopause parameters was based on use of checked geopotential data [1], the parameters obtained using the described algorithm can be used for checking information on the tropopause, so that then this information can be drawn upon for refining our algorithm.

#7. "Stylized" Tropopause

The behavior of the tropopause with the course of time can be described approximately by the equation of motion for a material surface [4]; in an adiabatic approximation an isentropic surface moves as a material surface. This suggests that at the "stylized" tropopause the potential temperature (θ) must change slightly (in [9] it is assumed that it must not change at all, except for a jump in the subtropical regions).

For the purpose of finding the surface which is close with all x, y to one of the tropopauses $\xi_i(x, y)$ and close to isentropic, we will minimize the functional

$$I[\xi(x, y)] = \frac{1}{2}\int_a^b\int_c^d [\mathrm{grad}_{x,y}\,\theta(\xi(x, y), x, y)]^2 + \alpha[\min_i(\xi(x, y) - \xi_i(x, y))]^2\,dx\,dy,$$

where $\alpha > 0$, $\{\xi_i\}$ are the tropopauses found by the method in #3-5.

The corresponding Euler equation [5] is

$$-\frac{\partial\theta}{\partial\xi}\left[\frac{D^2\theta}{Dx^2} + \frac{D^2\theta}{Dy^2}\right] + \alpha G(\xi) = 0, \tag{4}$$

where

$$a)\ \frac{D}{Dx} = \frac{\partial\xi}{\partial x}\frac{\partial}{\partial\xi} + \frac{\partial}{\partial x};\qquad б)\ G(\xi) = \xi - \tilde{\xi}(\xi);$$

c) $\tilde{\xi}(\xi)$ is that of the ξ_i values at which is attained $\min|\xi - \xi_i|$ with some ξ, being elliptical only in the case when $\partial\theta/\partial\xi \neq 0$.[1] In the objective analysis fields this condition can be violated as a result of neutral stratification. In this case we used the convective adaptation procedure described in [7] and provided to us through the courtesy of the author.

This procedure replaces the profile of temperature T by stable $\tilde{T}$, without changing the geopotential profile. Thus, the equation of statics ceases to be satisfied.

As demonstrated in [3], the equation of statics in a case when H is a cubic spline can be written in the form $\langle T\rangle = C\langle H\rangle$, where $\langle T\rangle$ and $\langle H\rangle$ are 10-vectors of the temperature and geopotential values at standard surfaces, C is a matrix of the order 10, rank C = 9. Assuming the H_{1000} value to be invariant in the case of convective adaptation and knowing the $<\tilde{T}>$ vector, by the least squares method we obtain a 9-vector $<\tilde{H}>$. The 10-vector $<\tilde{T}> = C \ll \tilde{H}>$, H_{1000} constructed using the 10-vector $\ll \tilde{H}>$, $H_{1000}>$ is extremely close to $<T>$ and therefore is convectively stable.

After application of this procedure equation (4) becomes elliptical. As a boundary condition we used the Neumann condition, which is obtained from the variational problem as the transversality condition [5]. The Liebman method was used for solution of (4) [2, 4].

We recall the fundamental formulas of the method:

when $1 < i, j < N$

$$\Delta\theta^{\nu}_{i,j} = h^{-2}[\theta(\xi^{\nu}(i+1,j), i+1, j) + \theta(\xi^{\nu+1}(i-1,j), i-1, j) + \theta(\xi^{\nu}(i,j+1), i, j+1) + \theta(\xi^{\nu+1}(i,j-1), i, j-1) - 4\theta(\xi^{\nu}(i,j), i, j)],$$

$$R^{\nu}_{i,j} = \beta\left(\frac{\partial\theta^{\nu}_{i,j}}{\partial\xi}\right)^{T}\left\{-\frac{\partial\theta^{\nu}_{i,j}}{\partial\xi}\Delta\theta^{\nu}_{i,j} + \alpha G(\xi^{\nu}(i,j))\right\},$$

$$\xi^{\nu+1}(i,j) = \xi^{\nu}(i,j) + R^{\nu}(i,j);$$

when $i = 1$, $1 < j < N$

$$\xi^{\nu}(1,j) = \xi^{\nu}(2,j) + 2h^{-1}[\theta(\xi^{\nu}(2,j), 2, j) - \theta(\xi^{\nu}(1,j), 1, j)] \times \left[\frac{\partial\theta^{\nu}_{1,j}}{\partial\xi} + \frac{\partial\theta^{\nu}_{2,j}}{\partial\xi}\right]^{-1}$$

and similarly when $i = N$ and when $j = 1, N$.

The θ function and its derivative of ξ are computed using the formulas:

$$\theta(\xi) = 1000^{\frac{1-\varkappa}{\varkappa}} T(\xi)\exp l\xi,$$

where $l = g(\varkappa - 1)R^{-1}\varkappa^{-1}$,

$$\partial\theta/\partial\xi = \theta[T^{-1}\partial T/\partial\xi + l].$$

The process is considered finalized if n iterations are carried out or if the inequalities

$$|R^{\nu}(i,j)| < \varepsilon, \quad 1 \leq i, \ j \leq N.$$

are satisfied.

The β and γ parameters were selected empirically from considerations of the most rapid convergence of the iteration process. Here $\gamma_{opt} = 0$, $\beta_{opt} = -0.015$. It was not possible to establish optimum α because the result of stylization, according to a subjective evaluation, had a slight dependence on it and the number of prognostic examples was highly limited.

In the D. Ya. Pressman prognostic model [8] there are two groups of reference levels -- tropospheric and stratospheric, for each of which a coordinate system was introduced. Among the initial data for this model it is necessary to stipulate the surface separating these two layers, which is naturally identified with the tropopause. The solution of the elliptical problem (4) in our experiments also determined the altitude of this surface. Additional physical boundary conditions are not set at this surface and thus a change in the tropopause surface, used as part of the initial data for the model, leads only to a change in the coordinate system. Nevertheless, these changes had an appreciable effect on the results of a two-day forecast using the particular model.

Allowance for difference between the tropopause and the surface p = const could a priori lead to phenomena of the "burst" type, much as sometimes occurs when the prognostic model is supplemented by a "block" for taking orography into account. In our case this did not occur.

Table 2

Relative Forecasting Error Using D. Ya. Pressman Model in Dependence on Variant of Stipulation of Initial Position of Tropopause (Prediction from 9 to 11 March 1978)

	Уровень; число точек, по которым производилась оценка 1	2 Вариант		
		p=200 мб 3	процедура конвективного приспособления не использовалась; n=7 4	процедура конвективного приспособления использовалась; n=15 5
6	Давление на земле; 870 точек	1,07	0,93	0,94
7	500 мб; 870 точек	0,70	0,72	1,01
7	300 мб; 870 точек	0,65	0,68	0,97
8	p тропопаузы; 24 точки	1,01	0,84	0,84

KEY:

1. Level; number of points from which evaluation was made
2. Variant
3. ... mb
4. Convective adaptation procedure not used
5. Convective adaptation procedure used
6. Pressure at surface; 870 points
7. ... mb, 870 points
8. p of tropopause; 24 points

We computed three variants of the forecast from 1200 hours on 9 March to 1200 hours on 11 March 1978, differing only with respect to the initial position of the tropopause. The initial geopotential data were obtained using operational objective analysis at the USSR Hydrometeorological Center [1]; wind was computed from the geostrophic relationships. The forecast region was a grid of 39 x 40 points with an interval h = 300 km; the center of the region was at a distance of 150 km from the north pole.

The results of the forecast were compared with synoptic charts. The evaluations of the relative error are given in Table 2.

We should note the obvious inadequacy (only one forecast) of the represented statistics. This was associated with the great time required for computations for this model with a BESM-6 electronic computer and the absence of evaluation programs; the evaluations were made without a computer. Nevertheless, on the basis of the results we can draw the following conclusions.

1. Inclusion of the tropopause leads to appreciable changes in the results of the forecast and and does not lead to "explosion" of the model.

2. The convective adaptation procedure, guaranteeing ellipticity of the problem (4), is not always mandatory; in our example in variant 2 the iteration process converged even without use of this procedure.

3. Evidently, it is not only possible but desirable to create a prognostic model which includes the tropopause as the reference level at which the boundary condition is set or other information is introduced on the fields of meteorological elements. A final "fitting" of the parameters of the objective analysis procedure, described above, should be made for the specific model. It goes without saying that this fitting should be accomplished in a series of forecasts, and not in a single forecast.

The principal result of this investigation is a method for computing the tropopause field using data on geopotential, employing an electronic computer. This method can be used for different purposes in an operational regime with existing electronic computers.

This investigation was made in the Division of Operational Numerical Forecasts USSR Hydrometeorological Center, to whose specialists the authors express appreciation for constant assistance and support.

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CHECKING OF THE APPLICABILITY OF BALANCE EQUATIONS ON THE BASIS OF EMPIRICAL DATA

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[Article by A. M. Babaliyev, Candidate of Physical and Mathematical Sciences V. V. Kostyukov and T. N. Kochergina, West Siberian Regional Scientific Research Hydrometeorological Institute, submitted for publication 10 May 1979]

Abstract: The authors examine the problem of the applicability of two balance equations on the basis of empirical data. The influence of different methods for objective analysis of the wind on the accuracy of geopotential computations is investigated.

[Text] It is customary to assume that the more general expressions for atmospheric dynamics better reflect reality than do simplified expressions. This seems almost obvious from the physical point of view. However, when working with actual data it is necessary to remember the following. First, at the present time the spatial-temporal resolution of measuring systems is low relative to some differential characteristics. For example, the relative error in real fields of even the first derivative of geopotential is not less than 25%, whereas for its Laplacian and wind vorticity it exceeds 60% [4, 6, 11, 12]. Second, in the fuller expressions there are usually nonlinear terms having an increased sensitivity to errors of different origin (measurement, interpolation, approximation and rounding-off errors) in comparison with the linear terms.

Accordingly, in some cases it is found that a change from simple to theoretically more precise equations in practical work results in a worsening rather than an improvement in the results of the computations. Therefore, it is necessary to clarify the actual effectiveness of each approximation of interest to us, particularly on the basis of empirical data.

The objective of this study was a checking of real data on the applicability of the linear (1) and nonlinear (2) balance equations relating the fields of the components of the horizontal wind and geopotential

$$\Delta H = l\,(v_x - u_y), \qquad (1)$$

$$\Delta H = l\,(v_x - u_y) - (u_x^2 + 2\,v_x u_y + v_y^2 + \beta u). \qquad (2)$$

Here Δ is a two-dimensional Laplace operator; the Coriolis l and Rossby β parameters were considered constant; the subscripts indicate the differentiation operation.

The checking of the applicability of each of these approximations was accomplished, for the most part, in the following way. First measurement data on geopotential and wind at the stations were used in obtaining their values at the points of intersection in a regular grid (H^0, u^0, v^0), that is, an objective analysis was made. The field of geopotential H^0, as being more precise, was taken as a standard. Then, using the results of an analysis of the wind components u^0, v^0, employing equations (1) and (2), we calculated the geopotential H, which was compared with the standard H^0 value. The approximation, leading to a lesser value of the standard deviation (σ_H) of the computed geopotential from the actual value, is considered more precise.

$$\sigma_H = \sqrt{\frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}(H - H^0)_{ij}^2}\,. \qquad (3)$$

As an additional evaluation of the accuracy in applying the equations we also used the relative mean square nonclosures (η_1, η_2), which characterize the sensitivity of the corresponding operators to the errors in the initial fields

$$\eta_1 = \sqrt{\frac{\Sigma\Sigma\,[\Delta H^0 - l\,\Omega^0]_{ij}^2}{\Sigma\Sigma\,[\Delta H^0]_{ij}^2}},$$

$$\eta_2 = \sqrt{\frac{\Sigma\Sigma\,[\Delta H^0 - l\,\Omega^0 + (u_x^0)^2 + 2\,v_x^0 u_y^0 + (v_y^0)^2 + \beta u^0]_{ij}^2}{\Sigma\Sigma\,[\Delta H^0]_{ij}^2}}, \qquad (4)$$

where $\Omega^0 = v_x^0 - u_y^0$. As a simplification in writing the expressions the subscripts on the summation symbols have been omitted.

Equations (1), (2) for H are equations of the Poisson type. Written in finite differences (with a second order of approximation), they were solved by the successive upper relaxation method [10].

Such experiments have been carried out before [2]. However, evidently due to the low capabilities of the computers of those years they were carried out only for five continuous dates in one month at the 700-mb surface and were limited with respect to the range of studied problems. The applicability of the approximations was checked only on the basis of the standard deviations and the wind and geopotential fields were constructed manually by the weather analyst. In addition, in regions poorly supplied with information, instead of the actual wind the geostrophic wind was taken, which should lead to an artificial understatement of the discrepancies between the computed and actual fields.

Table 1

Standard Deviations of Actual Geopotential from Computed Geopotential (σ_1, σ_2) and Relative Mean Square Nonclosures in Applying the Balance Equations (η_1, η_2) (700-mb Surface, November 1976; Geopotential and Wind Data are Operational)

	Дата Date							
	1	2	3	4	5	6	7	8
σ_1 дам dam	2,5	3,3	2,4	2,0	1,8	3,7	3,0	2,1
σ_2 дам	2,3	3,0	2,7	2,9	2,7	11,0	6,0	2,7
η_1	0,86	0,92	0,84	0,85	0,89	1,23	1,07	0,95
η_2	0,87	0,93	0,83	0,86	0,90	1,38	1,07	0,96

Note: Here and in the other tables the subscript 1 designates a linear balance equation and 2 designates a nonlinear balance equation.

Accordingly, it was of interest to carry out broader numerical experiments for constructing the fields making use of modern methods in objective analysis.

The direct basis of our investigations was the results which were obtained during tests using routine material with algorithms for the assimilation of initial fields in a weather forecast [9]. With respect to the tests, the computations of geopotential from equations (1), (2) were auxiliary, at a definite stage serving the function of checking of data. The results were somewhat unexpected. They are given in Table 1. It can be seen that on only two dates of the eight the computation of geopotential using the nonlinear equation gave lesser deviations than when the linear equation was used. Moreover, on two other dates the standard deviations (σ_1, σ_2) were extremely significant. With respect to the relative nonclosure, in seven cases it was greater for the nonlinear equation.

It was surmised that this effect was caused by the peculiarities of the operational information, which, as is well known, due to severe restrictions on the time of collection, checking and correction of data has a higher level of errors than the archival data. Therefore, it was decided to make the experiments using archival data. For this purpose we randomly selected 16 dates in different seasons relating to 1964-1971.

First it was of interest to clarify the sensitivity of the equations to the magnitude and type of errors. For this purpose we constructed two groups of fields, one of which precisely satisfied equation (1), whereas the other precisely satisfied equation (2). They were obtained at first by substituting the wind components into the right-hand sides of the corresponding equations and computing the geopotential. Then onto the fields of each group the errors, having a normal distribution, with a zero norm and a stipulated dispersion (σ^0), are superposed. We used independent and correlated errors (employing a linear law with a correlation radius equal to four grid intervals).

The necessity for constructing this type of fields was dictated by the circumstance that the specific situation in principle can be described best by either one or the other equation. And in order to check the reaction of the equation in pure form it is necessary, first of all, to have standard data, precisely satisfying it, and second, data distorted in a definite way, simulating possible and real cases.

The distorted fields of each group were substituted into the corresponding equations. The relative mean square nonclosures were used here as a measure of the accuracy in satisfying the equations.

The results are given in Table 2. This table shows that even insignificant independent errors (0.5 dam, 0.5 m/sec) result in a substantial distortion of the balance equations (by 70% or more).

Table 2

Dependence of Relative Mean Square Nonclosures in Satisfying Linear (η_1) and Nonlinear (η_2) Balance Equations on (σ^0) Value and Type of Error

σ^0 дам, м/сек 1	Ошибки независимые 2		Ошибки коррелированные 3	
	η_1	η_2	η_1	η_2
0,5	0,70	0,76	0,18	0,42
1	0,90	0,91	0,31	0,49
2	0,98	0,99	0,57	0,65
3	0,99	1,00	0,69	0,77
4	1,00	1,01	0.80	0,85

KEY:
1. dam, m/sec
2. Independent errors
3. Correlated errors

In the case of correlated errors the applicability of the equations is appreciably better. It should be noted that in the fields obtained by means of objective analysis it is precisely correlated errors which are present.

It can be concluded from a comparison of the η_1 and η_2 values that the nonlinear equation reacts more strongly to errors, especially in the case of dependent errors. However, these differences decrease with an increase in errors.

A comparison of Tables 1 and 2 also makes it possible to evaluate the mean square error characteristic for real fields. It can be seen that the values of the relative nonclosures in them are close when $\sigma^0 = 4$ (dam, m/sec).

Table 3

Standard Deviations of Actual Geopotential from Geopotential Computed Using Linear (σ_1) and Nonlinear (σ_2) Balance Equations With Use of the Wind Components Obtained by Different Objective Analysis Methods (at 500-mb Surface)

Дата 1	Оценка 2	3 Метод анализа ОИС 4	ОИВ 5	ВАИ 6	ВС 7
8 I 1971	σ_1	3,9	3,9	3,3	3,9
	σ_2	8,2	5,8	4,5	4,1
10 II 1971	σ_1	6,2	6,2	5,5	5,2
	σ_2	7,0	8,7	5,6	5,2
27 III 1965	σ_1	4,9	5,4	4,8	4,0
	σ_2	4,7	5,7	4,4	3,7
4 IV 1965	σ_1	4,2	4,4	4,7	5,0
	σ_2	3,6	4,1	3,8	4,5
30 X 1965	σ_1	6,0	6,6	6,8	5,8
	σ_2	5,0	4,7	4,2	3,8

KEY:
1. Date
2. Evaluation
3. Analysis method
4. OIS
5. OIV
6. WAI
7. WM

The next series of experiments was carried out with real data on both wind and geopotential. It was proposed that a study be made of the influence exerted on the computation of geopotential by different methods for analysis of the wind.

We used four methods: optimum interpolation in scalar (OIS) and vector (OIV) forms, weighted anisotropic interpolation (WAI) and the weighted mean (WM) method [3, 4, 8]. The standard geopotential field was constructed by the WAI method, which for it gives virtually the same results as optimum interpolation [1].

The accuracy of the analysis was evaluated using the mean square nonclosures of the comparison σ_v^0, σ_H^0

$$\sigma_v^0 = \sqrt{\frac{1}{m}\sum_{k=1}^{m} [(\tilde{u}_k - u_k^\circ)^2 + (\tilde{v}_k - v_k^\circ)^2]}, \qquad (5)$$

$$\sigma_H^0 = \sqrt{\frac{1}{m}\sum_{k=1}^{m}(\tilde{H} - H^*)^2} . \qquad (5)$$

Here u_k^*, v_k^*, H_k^* are the measured, and $\tilde{u}_k$, $\tilde{v}_k$, $\tilde{H}_k$ are the integrated values at the stations; m is the number of stations participating in the analysis, varied on different dates from 180 to 250.

Now we will proceed to a description of the results. Table 3 gives examples of the standard deviations (σ_1, σ_2) of the actual geopotential from the computed geopotential for specific dates in order to illustrate the encountered case of different effectiveness of use of equations (1), (2).

Table 4

Values of Parameters Averaged for 16 Dates and Related to Applicability of the Balance Equations (500-mb Surface)

Оценка 1	Метод анализа 2			
	ОИС 3	ОИВ 4	ВАИ 5	ВС 6
σ_1 дам 7	5,8	7,1	5,4	5,6
σ_2 дам	6,5	8,1	5,0	5,4
ν, %	31	19	56	62
η_1	0,99	1,05	0,86	0,89
η_2	1,03	1,08	0,87	0,90
σ_v^0 м/сек 8	10,0	9,7	10,1	14,3
σ_H^0 дам	3,7	—	3,8	5,3
λ	0,29	0,30	0,23	0,20

Note. σ_1, σ_2 are the standard deviations of computed geopotential from the actual geopotential; ν is the number of cases of a high effectiveness of use of the nonlinear equation; η_1, η_2 are the relative mean square nonclosures in satisfying the equations; λ is the nonlinearity parameter; σ_v^0, σ_H^0 are the mean square nonclosures in comparison of the modulus of the wind vector and geopotential respectively.

KEY:

1. Evaluation
2. Analysis method
3. OIS
4. OIV
5. WAI
6. WM
7. dam
8. m/sec

Table 4 gives the results averaged for all 16 dates. The following are given: σ_1, σ_2 -- mean square nonclosures in satisfying the equations; ν is the number of cases (in percent), when the nonlinear equation ensured better results; η_1, η_2 are the relative mean square nonclosures, making it possible to judge the sensitivity of the equations to errors in the fields of meteorological elements; λ is the nonlinearity parameter, reflecting the contribution to the full balance equation (2) from its nonlinear part, to wit

$$\lambda = \sqrt{\frac{\Sigma\Sigma\,[u_x^2 + 2\,v_x u_y + v_y^2]_{ij}^2}{\Sigma\Sigma\,[\Delta H]_{ij}^2}}; \tag{6}$$

σ_V^0, σ_H^0 are the mean square nonclosures in comparison of the wind vector modulus and geopotential respectively, characterizing the accuracy in their restoration by a definite analytical method.

An analysis of the data in the table leads to the following conclusions.

1. Calculation of geopotential using wind data on the basis of the nonlinear balance equation by no means always ensures better results than when using the linear equation.

2. A definite role is played by choice of the wind analysis method. A gain from the use of equation (2) with respect to both the standard deviation and with respect to the number of cases of a high effectiveness occurs when using methods which are more approximate (relative to the accuracy in restoration, that is, σ_V^0). This is attributable to the fact that in less precise analytical methods smoother fields are obtained [3, 7], and therefore the finite-difference approximation of the differential expressions on the right-hand sides of equations (1), (2) becomes better.

3. In the nonlinear equation the sensitivity to errors (η_1, η_2) is higher than in the linear equation. In more precise analytical methods the difference between the relative nonclosures is considerably greater.

4. The contribution to the balance equation from its nonlinear part (λ) is dependent on the analysis method. The nonlinearity is manifested to a greater degree if optimum interpolation is used.

On the basis of these conclusions the recommendation can be made that in choosing the analytical method it is necessary to take into account the specific final objective of its use.

Here it must be emphasized, in particular, that the results in these experiments have, it goes without saying, a limited character due to the specific nature of the equations, and also the methods and conditions for their realization. By the latter is meant the network of meteorological stations at the current moment, the finite-difference interval, the accuracy of approximation, etc.

Some of these computations were repeated, but with an increased accuracy of the approximation (fourth order) of all the differential operators of the equations (1) and (2). The results are given in Table 5.

Table 5

Values of Standard Deviations of Computed Geopotential from Actual Values (σ_1, σ_2) and Number of Cases of Greater Effectiveness of Applying Nonlinear Equation (ν) in Case of Use of an Increased Accuracy (Fourth Order) of Approximation of Derivatives. (Values are Averaged for 16 Dates; 500-mb Surface)

Оценка 1	2 Метод анализа			
	ОИС 3	ОИВ 4	ВАИ 5	ВС 6
σ_1 *дам* 7	4,6	4,7	4,2	4,3
σ_2 *дам*	9,6	8,9	9,1	8,6
ν %	0	0	12	6

KEY:

1. Evaluation
2. Analytical method
3. OIS
4. OIV
5. WAI
6. WM
7. dam

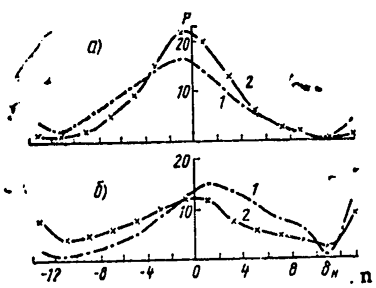

Fig. 1. Distribution of deviations of geopotential by gradations. a) linear equation, b) nonlinear. 1) second order of approximation, 2) fourth order

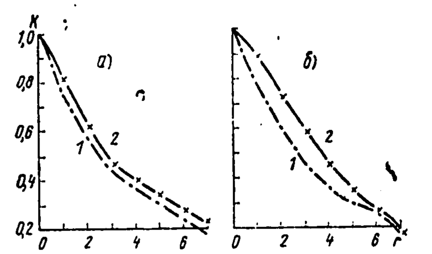

Fig. 2. Correlation function of fields of deviation of geopotential K. r -- distance in the grid interval units, equal to 300 km. For annotations see Fig. 1.

These show that in the overwhelming number of cases the linear equation ensured considerably lesser standard deviations of computed geopotential from the actual value than the nonlinear equation. The influence of the choice of the analytical method in this case is weaked when using an increased order of approximation. For example, whereas the maximum difference in the standard deviations of different methods for the linear equation in Table 4 was 1.7 dam, now (Table 5) it has become 0.5 dam; for the nonlinear equation this difference was 3.1 dam, but now is 1 dam.

It is also interesting to note that whereas in the linear equation an increase in the order of the approximation led to a substantial increase in the accuracy of computing geopotential (the standard deviations decrease by approximately 25%), in the linear equation, on the other hand, the deviations increase appreciably (by approximately 50%).

The noted effects are evidently a manifestation of the small-scale structure of the fields of errors. The fact is that the nonlinear terms on the right-hand side of equation (2), enriching the spectrum of perturbations, gives rise to still lower harmonics down to the subgrid scale. An increase in the order of approximation of the derivatives, improving the description of the true fields, simultaneously aggravates the influence of the field of errors on the final result.

Figure 1 gives the distributions of deviations of geopotential by gradations in cases of linear (a) and nonlinear (b) balance equations for the two approximation methods, for economy of space averaged for all analytical methods. It can be seen that the deviations for the most part fall in the range from -6 to +6 decameters. We also note that with shifting from equation (1) to equation (2) the tops of the distributions are displaced in the direction of positive values and the number of maximum deviations increases.

In Fig. 2 we show the correlation functions of geopotential deviations averaged by both dates and analytical methods. These show that the fields of deviations correlate strongly and therefore the use of linear filters for refining the geopotential computations using equations (1), (2) will be ineffective [5].

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SOME METHODS FOR PARAMETERIZATION OF SUBGRID PROCESSES

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[Article by Candidate of Physical and Mathematical Sciences Ye. Ye. Kalenkovich, N. V. Novikova and I. V. Cholakh, West Siberian Regional Scientific Research Hydrometeorological Institute, submitted for publication 1 June 1979]

Abstract: For a model in the full equations of hydrothermodynamics the authors examine three methods for the parameterization of turbulent terms horizontally: a linear mechanism with a constant coefficient and two nonlinear mechanisms. The first of these is close to the form proposed by Smagorinskiy, with a turbulence coefficient dependent on deformation, whereas the other turbulence coefficient is dependent on "plane" divergence. The latter method gives the best results. The coefficient factors are optimized on the basis of the results of the forecast. They are dependent on the vertical coordinate. The introduction of surface friction makes it possible to decrease the number of parameters to be optimized.

[Text] The problem of a short-range forecasting for the northern hemisphere in an isobaric coordinate system in a stereographic projection in an adiabatic approximation was described in [2]. The system of prognostic equations is approximated in time using schemes of the Crank-Nicholson type and is solved on the basis of the splitting method [4]. As indicated by experiments using real data, the model has a systematic error leading to an understating of geopotential values in cyclones and an exaggeration in anticyclones. In addition, despite the absolute stability of the scheme, small-scale oscillations appear. In order to eliminate these shortcomings we tested some methods for stipulating the turbulent terms in horizontal variables, which are added to the equation of motion and heat influx equation. At the lower boundary we use a determination of the analogue of the vertical component of velocity in p-coordinates, which is transformed into an equation for the prediction of lower-level geopotential [3]. In this equation, similar to [3], we stipulate an expression for the friction component of velocity vertically w_{fr}. In addition, we will assume that the operator obtained in this process coincides in form with the operators of horizontal turbulence in the equation of motion and in the heat influx equation. We will neglect the dependence of the cartographic factor on horizontal coordinates in the turbulent terms.

The purpose of this study was an experimental checking of the influence of different methods for the parameterization of horizontal turbulence and also optimization of the parameters. For saving computer time the main experiments were carried out using a model with a coarse grid: the time interval was two hours and the horizontal interval was 600 km.

1. Constant Turbulence Coefficient

The turbulent terms are written in the form $F_\varphi = \mu \Delta \varphi$, where μ is the turbulence coefficient,

$$\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}.$$

The following problem was formulated for determining μ: how is it necessary to smooth the prognostic fields using a nine-point smoothing operator (horizontally) in order to minimize the mean square error in predicting geopotential? This problem leads to a cubic equation relative to the smoothing parameter α, determining the weight of the central point. As is well known [7], the use of a smoothing operator can be regarded as a difference scheme for solving an equation of the parabolic type $\varphi_t = \mu \Delta \varphi$. Then, knowing α, it is possible to determine the μ value approximately. In all the experiments the equation for α had one real root from which the mean value $\mu \approx 5_{10}5$ m^2/sec was obtained. Without question, such a single smoothing, and this applicable only to the geopotential fields, is not equivalent to the introduction of turbulent terms into nonlinear equations, but the determined μ value can be regarded as a quite good approximation to the optimum value for the particular model, since the described method is related to a specific difference scheme and the methods of its solution.

2. Nonlinear Turbulence Coefficient, Dependent on Deformation

In [6] a nonlinear form was proposed for writing turbulent terms in which the effect of the turbulence mechanism is dependent on total deformation. In this study we investigated a form of the turbulent terms similar to [6] but somewhat simplified, to wit:

$$F_\varphi = \frac{\partial}{\partial x}\left(K \frac{\partial \varphi}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial \varphi}{\partial y}\right). \quad (1)$$

Here φ are the horizontal components of velocity u, v is the temperature or geopotential of the 1000-mb surface, h is the horizontal interval of the difference grid,

$$K = \frac{k_0^2}{2} h^2 D, \quad k_0 = 0{,}4, \tag{2}$$

In addition, F_φ was multiplied by some constant k which was varied for the purpose of finding its optimum values.

3. Nonlinear Turbulence Coefficient Dependent on Divergence

As indicated by experiments,, such functions as the vertical component of the wind velocity vector and horizontal divergence react most sensitively to the appearance of instability and an increase in the amplitude of the lesser harmonics. In [1] these characteristics of the difference solutions were used in selecting the parameters for combining schemes of a different order of approximation. In this paper we propose a method for writing the turbulent terms in a form similar to (1)-(2), but with

$$D = (D_T^2 + D_S^2)^{1/2}, \; D_T = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}, \; D_S = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}. \tag{3}$$

In this way we pursue the objective of a local limitation on the rate of increase in gravitational waves. The coefficient on the divergence modulus was selected taking into account that divergence usually is an order of magnitude less than deformation. As in the preceding case, we varied the additional factor k.

Now we will examine the results of experiments using real data. As a criterion for selecting the optimum values of the sought-for parameters we used the standard deviation σ of the daily forecast of the geopotential fields for the standard levels 1000, 850, 700, 500, 300 and 200 mb for the territory of the West Siberian region (4800 x 7200 km^2).

Table 1

Values of the k Parameter Minimizing the Standard Deviation of Prediction of the Geopotential Fields

	Уровень Level					
	1	2	3	4	5	6
df	9,2	7,2	6,4	1,6	1,6	3,2
dv	5,6	4,2	3,8	1,6	1,6	2,4

The process of seeking the optimum k values was broken down into several stages. In the first stage the k constant for all levels and equations were varied for the purpose of obtaining k values minimizing σ for each separate standard level.

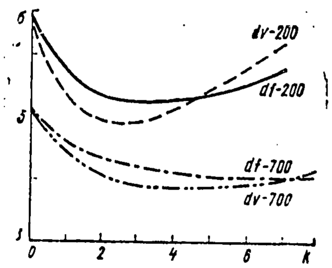

Fig. 1. Dependence σ(k) for the levels 200 and 700 mb for schemes df and dv.

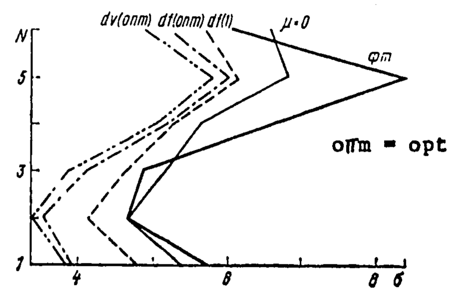

Fig. 2. Standard deviations of geopotential forecast. ϕm -- inertial forecast; μ = 0 -- adiabatic variant; df (1) -- in point 2 k = 1; df (opt) -- stipulation of turbulent terms in accordance with point 2 with optimum k values from Table 1; dv (opt) -- same for point 3

Table 1 gives the results of computations. The levels were numbered from below (1000 mb -- 1st, etc.); the forms of representation of the turbulent terms, in accordance with points 2, 3, are denoted by df and dv respectively.

High k values were obtained at the lower levels. This can be attributed to the fact that in the model surface friction was not taken into account. If the surface friction effect is parameterized, as is usually done, in the form $a^2\vec{V}$, it can be seen that the turbulence and friction operators are dissipative; it therefore follows that they have a formally similar mechanism of the effect to the predicted fields. Thus, the absence of friction in the model can, in some sense, be compensated by an increase in the horizontal turbulence coefficient. The small increase in k at the upper level is probably associated with the artificial limitation on the altitude of the atmosphere in the model of the free surface. The scatter of coefficients in the dv scheme is less than in the df scheme. It can be postulated that the dv scheme reacts "more operatively" to an increase in the amplitude of gravitational waves.

Figure 1 shows the dependence of σ(in dam) on k for the levels 200 and 700 mb according to the dv and df schemes. The principal peculiarity of all the curves is their smooth behavior in the neighborhood of the minima. The behavior of the curves at the other levels is similar. This makes it possible to hope that with a change in the positioning and number of levels, and also in experiments with other initial data the errors in determining the k values do not lead to significant changes in σ.

Figure 2 gives the standard deviations of a forecast for different model variants; N is the number of the level. The ϕm curve is the mean square actual trend, that is, the error in the inertial forecast. The symbol μ = 0 is used to denote errors in a forecast without turbulent terms. It can be seen that only at the levels 1000, 500 and 300 mb the relative errors are less than unity. The df curve (1) characterizes the quality of a forecast in the initial form (2), that is, with k = 1 in point 2. Already such a method for taking turbulence into account gives a considerable decrease in errors. Computations with a constant turbulence coefficient $\mu = 5_{10}5$ m^2/sec (point 1) give deviations from the last curve only in the third places.

A still greater decrease in errors in forecasting the geopotential field can be obtained by using the "optimizing" k values for the df and dv schemes in accordance with Table 1.

Figure 2 shows that the best results were obtained using the dv scheme. Accordingly, further experiments were carried out specifically with this scheme.

Up to this time the optimization was carried out separately for each level. A number of problems arise when proceeding to a full model. First, all the estimates were made for the six above-mentioned standard levels. At the same time, the positioning and number of computation levels cannot coincide with the standard levels. In particular, in our model we employed a grid which was uniform vertically. The initial data, by means of cubic splines, are interpolated to the computation levels and the results of the forecast are interpolated back to the standard levels for evaluating forecast quality. Therefore, the values of the k coefficients found by optimization for individual levels were also interpolated to the corresponding computation levels.

Another problem is the choice of a forecast quality criterion. We used different types of evaluations, computed using the procedure described in [5]: $\mathcal{E}$, r, ρ -- the relative error, correlation coefficient and guaranteed probability with respect to sign for the geopotential trends, and also the evaluations for the "wind" sl -- the quotient of the mean (in absolute value) errors and the maximum of the predicted and actual trends of the wind field and c -- the relative error. In actuality, in place of wind velocity in the last two evaluations we use the components of the geopotential gradient in horizontal coordinates.

Thus, the use of a complex of evaluations makes it possible to make a comparison of the norms of different functional spaces in difference analogues.

In addition, in a multilevel model it is not entirely clear how to select the total quality criterion (test). As indicated by the experiments, an improvement in the evaluations at some levels is frequently accompanied by a worsening at the others. If an integral evaluation is taken, for example, using the trapezia formula, evaluations at the lower and upper levels will be assigned low weights. Therefore, taking into account the relatively poor vertical resolution, we took a mean evaluation for all levels with equal weights.

The results of the first computation with variable k, according to Table 1, were very close to the results of level-by-level optimization. Then we attempted to obtain the optimum values by the "coordinate descent" method. As a result of three computation cycles at the lower levels the evaluations were improved by several percent, but at the same time deteriorated at the upper levels, so that the total quality criterion (test) was changed for all types of evaluations by a fraction of a percent.

Table 2

Evaluations of Forecasts With Adiabatic Model and With Allowance for Friction and Turbulence

		Уровень Level					
		1	2	3	4	5	6
$k = C_D = 0$	ε	86	100	107	91	84	107
	r	53	57	59	65	71	69
	s 1	64	56	51	40	41	40
	c	95	72	60	40	39	35
$k \equiv 2$	ε	67	75	86	81	70	86
	r	71	71	67	66	74	72
$C_D = 2.4_{10}{-3}$	s 1	57	50	43	40	40	33
	c	65	49	43	38	36	28

Then on the right-hand sides of the equations of motion at the first level we added the terms

$$\vec{F}_D = -\frac{g\rho}{\Delta p} C_D |\vec{v}| \vec{v},$$

describing the influence of surface friction. Here g is the acceleration of free falling, ρ is standard density, Δp = 50 mb, C_D is the surface friction coefficient. Taking into account the results of the preceding experiments, we optimized only two parameters: C_D and k_1. We obtained the values C_D = $0.6_{10}{-3}$ and k_1 = 6.8. The C_D values here are somewhat less than those which are usually used in other models. As we have already mentioned above, this is evidently associated with the compensating effect of the horizontal turbulence mechanism.

New parameters inevitably appear with the adding of additional physical factors. It is extremely difficult to carry out optimization for such a multiparameter model. Accordingly, in the subsequent group of experiments we introduced a k value which is constant vertically and carried out optimization using only two parameters: k and C_D. It was found that a change in the quality criterion occurs by a fraction of a percent. The optimum k value can be assumed equal to two. A decrease in the horizontal turbulence coefficient leads to more realistic values of the friction coefficient: the optimum values $C_D = 2.4_{10}{-3}$.

Table 3

Improvement in Evaluations in Comparison With Adiabatic Model for Different Resolution in Time and Horizontally

Уровень Level	Шаги Intervals 2ʰ/600 км		1ʰ/600 км		1ʰ/300 км		0.5ʰ/300 км	
	ε	r	ε	r	ε	r	ε	r
1	25	25	21	22	11	7	12	12
2	26	17	18	12	6	4	14	7
3	30	13	15	8	6	2	12	4
4	14	5	9	2	2	0	5	1
5	9	4	6	1	1	0	1	0
6	2	6	13	2	4	0	3	0

Table 2 gives results showing the effectiveness of optimization. The upper part of the table gives the results when using an adiabatic model; the lower part gives the results with allowance for friction and turbulence. All the evaluations were multiplied by 100.

The coefficients obtained above were used in carrying out experiments for increasing resolution. Naturally, the carrying out of optimization for models with better resolution and with a greater quantity of initial data requires considerable expenditures of computer time. Accordingly, the purpose of the experiments was checking the effectiveness of introducing friction and horizontal turbulence. Table 3 shows the improvement in the relative errors and correlation coefficients (in %) in comparison with an adiabatic model. It gives the mean values for three daily forecasts. The upper line gives the relationship of the time intervals to the horizontal. Vertically the resolution was not changed. As before, the evaluations were computed for standard levels.

The lesser influence of the mentioned mechanisms with an improvement in resolution is attributable to the fact that the values of the parameters cease to be optimum, and in addition, there is an increase in the accuracy of the forecasts using a model without friction and horizontal turbulence. But nevertheless, especially at the lower levels, the contribution of these terms remains significant.

Attempts to change the relationship of the coefficients of turbulent viscosity and thermal conductivity did not result in any improvement in the results of the forecast.

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UDC 551.553.8

HURRICANES OF MIDDLE-LATITUDE SEAS AND THEIR CONSEQUENCES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 54-61

[Article by Candidate of Geographical Sciences L. N. Ikonnikova, State Oceanographic Institute, submitted for publication 31 May 1979]

Abstract: The author gives generalized results of a joint analysis of the fields of pressure topography, synoptic situations and thermal regime of sea water for particularly dangerous hurricanes in the extratropical latitudes associated with the formation of secondary cyclones over a local thermal depression. The article gives information on dangerous hydrological phenomena and different types of waves accompanying them.

[Text] The necessity for studying the conditions for the formation of especially severe storms is attributable to the fact that the different dangerous phenomena arising during their passage cause serious destruction on seacoasts and in many cases lead to the loss not only of ships, but also human lives. An example of this was the storm "Capella," assigned that name from the name of the ship which was lost with a crew of 11 on 3 January 1976 in the North Sea [6, 9, 10]. Storms whose reputation persists for centuries occur in extratropical seas. The exceptional nature of such hurricanes is indicated by the placenames assigned them (such as the Balaklava storm of 1854) or the name of an entire country (the Dutch storm of hurricane force of 1953).

In this article we will examine the conditions for the appearance of exceptionally severe storms observed on the seas of the middle latitudes in the northern hemisphere during the last 10-15 years (5-6 January 1966, 3 December 1967 and 28-29 January 1968 on the Black Sea, 28-29 October 1969 on the Sea of Azov, 18-19 October 1967, 2 November 1969 and 28-29 September 1975 on the Baltic Sea, 11-13 November 1972 and 1-3 January 1976 on the North Sea, 10-11 December 1977 on the sea between England and Ireland, 10-12 September 1969 on the Sea of Okhotsk, 9-12 December 1974 on the Bering Sea and 21-24 July 1973 over the Canadian Arctic). Among the series of severe storms we selected storm data, first of all, because many of them have been recognized as the strongest storms of hurricane force in the 20th century and second, because some of them caused destruction along coasts comparable to the effects caused by tropical hurricanes, and third, because they were caused by very infrequent and at the same time, similar synoptic situations [1-3, 6, 13].

The conditions for the development of exceptionally severe storms must be studied taking into account the origin of the cyclone, the stage of its development, the velocity and direction of its movement, and also taking into account the position and nature of movement of adjacent anticyclones and the conditions for heat exchange between the sea and the atmosphere. All these factors were taken into account in an analysis of the synoptic situations of the above-mentioned storms. An analysis of these storms shows that they all occurred under one and the same characteristic synoptic conditions. Specifically, in all cases these were the two-center depressions, illustrated in Fig. 1, with a secondary cyclone moving over the sea, which, passing over an anomalously warm water surface (that is, over a local thermal depression at sea), acquired some characteristics of a tropical cyclone [2, 8].

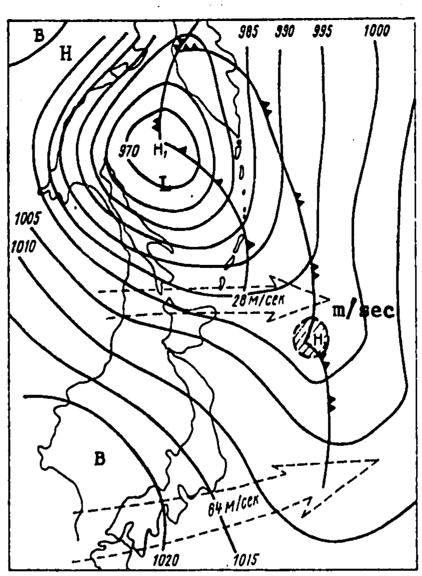

Fig. 1. Synoptic situation for the northwestern part of the Pacific Ocean (H_1 -- central cyclone, H_2 -- secondary cyclone). The arrows indicate the extreme positions of jet stream axes in the particular region of the Pacific Ocean.

According to [4], secondary cyclones are formed on the southerly and less frequently on the southwesterly or southeasterly periphery of a central cyclone, in turn, for whose formation there must be a warm anticyclone in the southeast and a cold trailing anticyclone in the northwest. However, Khromov feels that a central cyclone alone is inadequate for causing a monsoon; it is the result of a joining of several occluded disturbances.

Khromov postulates that a secondary cyclone is either a "younger" cyclone of this same series as the main cyclone or a cyclonic disturbance at the point of occlusion of a central cyclone. With respect to external criteria, the development of a secondary cyclone is tied in closely to the process of serial cyclogenesis, but these processes cannot be mixed because they result in phenomena which are essentially different in nature. In particular, in a secondary cyclone the disturbing influence, in contrast to an ordinary serial cyclone, is concentrated over a small area and is not spread over an enormous space.

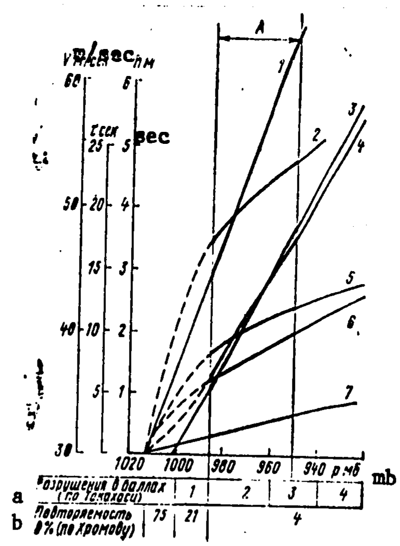

Fig. 2. Dependence of elements of different types of waves (wind velocity) on pressure at center of cyclone of the Ferrel type (secondary thermal cyclone). 1) mean height of wind wave; 2) period of swell ("uneri") wave; 3) wind velocity; 4) height of storm surge; 5) mean period of wind wave; 6) height of swell ("uneri") wave; 7) height of pressure wave at center of cyclone. A) zone in which secondary thermal cyclone of extratropical latitudes is effective. (a) destruction in units (from Takahasi); b) frequency of recurrence in % (from Khromov)

Table 1

Set of Numerical Conditions ("Criteria") Necessary for the Development of Winds of Hurricane Force Arising on Extratropical Seas Causing Catastrophic Phenomena on Coasts

Давление в центре вторичного циклона, мб 1	Температура воды у поверхности моря, °C 2	Разность температур воды и воздуха, °C 3	Положительная аномалия температуры воды, °C 4	Скорость движения вторичного циклона, км/ч 5	Скорость ветра у поверхности земли, м/сек 6	Опасная стадия жизни циклона 7	Подверженный воздействию циклона участок побережья 8	Разрушения в баллах по Такахаси 9
<985	>8	>2	>0,5	40—80	>25	Стадия зрелости 13	Параллельный траектории смещения циклона 15	1—3
Повторяемость таких циклонов по Хромову составляет 4% 10	Вода должна быть прогрева до глубин 60 м 11			В Северо-западной части Тихого океана 100 км/ч 12		Момент перехода к стадии распада 14		По пятизначной шкале разрушений [2] 16

FIRST LINE: Secondary cyclone moving over local thermal depression at sea
SECOND LINE: Notes

KEY:

1. Pressure at center of secondary cyclone, mb
2. Water temperature at sea surface, °C
3. Temperature difference, water-air, °C
4. Duration of water temperature anomaly, °C
5. Rate of movement of secondary cyclone, km/hour
6. Wind velocity at earth's surface, m/sec
7. Dangerous stage in life of cyclone
8. Coastal sector exposed to cyclone
9. Destruction in units (from Takahasi)
10. The frequency of recurrence of such cyclones according to Khromov is 4%
11. Water must be heated to depths of 60 m
12. In NW Pacific Ocean 100 km/hour
13. Maturity stage
14. Time of transition to decay stage
15. Parallel to trajectory of cyclone path
16. According to 5-unit destruction scale [2]

In the initial stage of development the secondary cyclone is less deep than the main cyclone. But together with the central cyclone it forms a single extensive and high two-center depression in which the cyclones rotate counterclockwise around a common center of gravity situated near the center of the main cyclone. On the southern periphery of the two-center depression, as a result of superposing of the gradients of the main cyclone on the gradients of the secondary cyclone there will be development of strong winds which are stable in velocity and direction, with a southerly or westerly component. It is clear that this effect is absent in serial cyclogenesis.

P. Raetjen assumes that two types of cyclones of a different nature can develop over seas: dynamic (extratropical cyclone of the Hann type) and thermal (tropical cyclone of the Ferrel type). Extratropical cyclones receive additional energy from the jet stream at the boundary between the troposphere and tropopause. Therefore, extratropical cyclones are called dynamic, in contrast to thermal cyclones, which receive additional energy over warm seas as a result of moist instability. The vertical structure of such cyclones is shown in Fig. 2 [8]. According to [8], an important prerequisite for the formation of a thermal cyclone of the Ferrel type and its moist-labile storms is the condition in which the water temperature in the sea is 2°C higher than for the surface air. This condition usually always exists over the extratropical seas in the transitional and cold seasons of the year, during these periods therefore forming favorable conditions for the appearance of dangerous storms.

Thus, a study of sources in the literature, together with an analysis of the surface and high pressure topography fields and with allowance for the hydrological state of sea waters, enabled us to combine known, but unrelated facts and on the basis of such an approach establish combinations of numerical conditions, with the coincidence of which a storm of hurricane force, developing over the warm waters of seas in the middle latitudes, becomes a calamity (Table 1). These conditions must be regarded as the critical conditions under which a secondary cyclone over an underlying sea surface becomes thermal with all the consequences which follow. On the other hand, an analysis of the synoptic situations for all especially dangerous storms indicated that for them to develop there should exist a definite high and surface pressure system characterized by the presence in the northeast of a deep very slowly moving central cyclone, on whose southern periphery, in a trough, there is formation and movement of a secondary thermal cyclone, with mandatory existence of two anticyclones: one warm in the southeast and the other cold in the northwest. In the absence of one of these elements in the synoptic situation the secondary center disappears before the wind velocity attains a catastrophic value and causes disaster. An analysis of the defined synoptic situations and thermal regime of sea waters for all cases of especially dangerous storms indicated that these conditions contain the principal necessary factors, similar to those which in the tropics lead to development of a tropical hurricane [2, 5, 7, 8, 11, 12].

Table 2

Relationship Between the Velocity of Cyclone Movement (v_1) and Velocity of Steering Current (v_2)

	Море 1	Район 2	Дата 3	Скорость движения циклона, м/сек 4	Скорость ведущего потока, м/сек 5	v_1/v_2	Примечания 6
7	Черное	Евпатория—Балаклава 15	5—6 I 1966 г.	14	12—16	1,17—0,88	Сдвиг ветра по направлению в слое до 500 *мб* был везде менее 10°. 27
8	Балтийское	Калининград—Ленинград 16	18—19 X 1967 г.	20	24	0,83	
7	Черное	Кобулети—Батуми 17	2—3 XII 1967 г.	16	16	1,00	
7	Черное	Новороссийск—м. Пицунда 18	28—29 I 1968 г.	15	16	0,94	
9	Азовское	Темрюкский район 19	28—29 X 1969 г.	12,5	12	1,05	
8	Балтийское	Рижский залив 20	2 XI 1969 г.	19	24	0,80	
10	Охотское	Охотский район 21	10—12 XI 1969 г.	15	16	0,94	
11	Северное	Гамбург 22	11—12 XI 1972 г.	20	20	1,00	
12	Берингово	Северо-Западное побережье Аляски 23	9—10 XI 1974 г.	14	16	0,88	
8	Балтийское	Ленинград	28—29 IX 1975 г.	20	24	0,83	
13	Северное	Гамбург 24	1—3 I 1976 г.	20	24	0,83	
14	Тихий океан	Типовое барическое поле 25	Повторяемость 0,8%	26 25—28	28	0,9—1,0	

KEY:

1. Sea
2. Region
3. Date
4. Velocity of cyclone movement, m/sec
5. Velocity of steering current, m/sec
6. Notes
7. Black Sea
8. Baltic Sea

Key to Table 2 (Continued)

9. Sea of Azov
10. Sea of Okhotsk
11. North Sea
12. Bering Sea
13. North Sea
14. Pacific Ocean
15. Yevpatoriya-Balaklava
16. Kaliningrad-Leningrad
17. Kobuleti-Batumi
18. Novorossiysk-Cape Pitsunda
19. Temryukskiy region
20. Gulf of Riga
21. Okhotsk region
22. Hamburg
23. NW coast of Alaska
24. Leningrad
25. Standard pressure field
26. Wind shear in the layer to 500 mb was in direction everywhere less than 10°

One of such factors is a trough in the steering current zone. All secondary cyclones, causing catastrophic phenomena along coasts, developed on the southern periphery of powerful central cyclones near the axis of jet streams (Fig. 1), as a result of which a communication channel developed in the upper atmosphere with a region of steering transport (westerly), ensuring the effective carrying off of the heat released during the intensification of convection in the zone of a developing low. The trough, which in the initial stage enabled a secondary center to develop into a two-layer cyclone, then imparted to it a translational movement in the direction of the steering current (in some cases with a small displacement to the left of it) with a velocity 0.8-1.2 the velocity of the steering current (Table 2). In all the storm situations which we examined the central cyclone and its trough with the secondary cyclone were encircled by several isobars, of which the inner isobar, outlining both centers, nowhere exceeded 1000 mb (frequently it also had lesser values), whereas the outer isobar was everywhere 1010 mb or more (sometimes by 2.5-3 mb). In addition, in the troughs there were always sharp changes in air temperature, the falling of which at times attained 10°C or more in 12 hours. During these periods the water temperature in the sea in many cases was 5°C, and at times 10°C or more higher than the air temperature.

A second factor necessary for the development of a hurricane in all cases was anomalously warm sea water. The prestorm and storm periods of all the hurricanes which we studied were characterized in all cases by positive water temperature anomalies. In the overwhelming majority of cases they were 1-3°C, but the water temperature anomalies were especially high (up to 7°C or more) in the Baltic and North Seas during the period and after the great drought in Western Europe, which began in May 1975 and ended in September 1976. A result of this drought was the development of the storm "Capella" in the North Sea, which, in the opinion of many researchers, was comparable only with the "Great Storm" of 26-27 November 1703, the greatest in the history of the British Isles, when 8,000 persons perished [6, 9, 10].

The thermal conditions in middle-latitude seas have substantially lesser absolute water and air temperatures than in the tropics, but considerably greater contrasts between them, as a result of which the flow of thermal energy of the seas in the extratropical latitudes into the atmosphere in several cases is greater than the thermal energy released by the ocean in the tropics [2, 7, 8].

In the initial stage of development of a two-layer depression (with a thermal cyclone of the Ferrel type at the sea surface) the thermodynamic factor plays a small role, but it becomes a powerful stimulator of cyclogenesis as soon as it is within the limits of the trough on the southern periphery of a central cyclone of dynamic origin. Under such conditions the warm and moist air filling the local thermal depression rushes toward the center of the secondary cyclone or axis of the trough and rises upward. Under favorable circumstances — the presence of a communication channel with a steering current in the upper atmosphere -- the thrust exceeds the air inflow and then the local, unmoving cyclonic disturbance, associated with the warm underlying sea surface, becomes increasingly stronger and is transformed into a storm of hurricane force, after which it, together with the secondary cyclone, begins to move in the direction of the steering current. In other words, in this case a favorable condition is created in which due to the ascending movement there is transformation of great quantities of thermal energy into kinetic energy. The thermodynamic factor plays a considerable role in the formation of a dangerous synoptic situation in the seas of the USSR and the North Sea, especially during the autumn period when the sea most intensively releases heat to the atmosphere.

The thermal energy imparted by the sea to the atmosphere can be computed using a formula taken from [5]. When using the formula derived for oceanic conditions for seas in the middle latitudes we replace $t_w \geqslant 26°C$ by t_{cr} and by t_{cr} we will understand the mean monthly long-term water temperature, exceeding by 2°C the mean monthly long-term air temperature over the sea. Then this formula is written in the following form:

$$E = \int_{z_0}^{z_H} P_w C_w (t_w - t_{\text{кр}})\, dz. \tag{1}$$

where P_w is the volume of sea water, C_w is the specific heat capacity of water, t_w is water temperature in the prestorm (or storm) period.

Before particularly severe storms, which we analyzed, there was always anomalously warm weather for the particular month, as a result of which the water temperature was also above the norm and virtually did not vary during the synoptic period of the preceding (and current) storm. This circumstance makes it possible to select t_w for the observation times closest to the storm period for water temperature from the surface z_0 to the depths z_H at which $t_w = t_{cr}$.

The next necessary factor making hurricanes dangerous is the Coriolis force, whose contribution to the kinetic energy budget, due to eddy transformation processes, as researchers assume, may be not only larger, but in individual cases also dominant [5, 8, 11, 12].

In the long run, over an enormous sea expanse a complex two-center and two-layer cyclonic system is formed which receives additional energy from two completely different sources: due to the jet stream in the upper atmosphere and due to the thermal energy of the sea at the underlying surface.

Researchers studying North Sea storms assume that a theoretical description of a two-layer cyclone in the extratropical latitudes (with a cyclone of the Hann type above and a cyclone of the Ferrel type at the sea surface) can be obtained from the eddy theory of Exner cyclones, which, in their opinion, with sufficient fullness explains this aerological phenomenon and which, they feel, has for long years been relegated to obscurity without justification [8].

The two-center and two-layer cyclones discovered in middle-latitude seas constitute an exceedingly dangerous synoptic situation. They are sources of not less than five or six systems of dangerous type of waves. The graph (Fig. 2) gives the dependence of the height of different types of waves on the intensity of a cyclone of the Ferrel type [2, 14].

At the rear of a two-center depression there is an extensive region with hurricane wind velocities, a contribution to whose formation is made by both central and secondary thermal cyclones. The presence of common isobars, outlining both cyclones, gives rise to winds which are stable in direction, which blow over enormous areas (in the sea from shore to shore) in a direction close to the direction of the steering current. Accordingly, in the presence of a particular synoptic situation, first enormous wind waves arise whose elements attain the maximum possible values. Figure 2 (curves 1 and 2) show that very high wind waves are formed whose mean height can attain 7 m, with a period of 12 sec or more. Such high wind waves usually arise to the right of the direction of movement of the secondary thermal cyclone and most frequently can be observed over ocean areas adjacent to the eastern and northern sea shores. Then, in a zone of maximum wind velocities, waves arise which have high propagation velocities. This type of wave is called "uneri" waves by Japanese scientists. Propagating from the zone of their generation and outrunning the cyclone, they attain the distant shores long before the storm. They are propagated most intensively in the direction of cyclone movement and especially its right "wing." Reaching the places where the sea depth becomes much less than the wave length, they are deformed, forming an exceedingly strong surf. In Fig. 2 the height and period of the "uneri" wave for the zone of influence of the secondary thermal cyclone are shown by the sixth and second curves respectively. The figure shows that these waves can attain more than one meter in height and in period -- more than 17 sec.

The drift effect of the wind also leads to the appearance of a third type of waves -- waves associated with surges. In making a quantitative estimate of the catastrophic inundations caused by the drift effect of the wind use is made of the tidal equations (shallow water theory), as well as the equation for an unsteady current with initial and boundary conditions, known as the St. Venant equation. According to these computations, made for cases of passage of secondary thermal cyclones, level surges on the seas can attain 1-4 m (Fig. 2, curve 4).

The fourth type of waves is a pressure wave arising at the center of a secondary thermal cyclone due to sharp changes in atmospheric pressure -- its dropoff, and then, after passage of the center of the cyclone, its increase (pressure change by 1 mb results in a level change by 1 cm). Due to movement of the cyclone with a great velocity the rising of sea level is replaced by its decrease very rapidly, which under conditions of relatively small horizontal dimensions of the cyclone leads to formation of a wave of the Cauchy-Poisson type -- a meteorological tsunami.

The sea shelves, in the presence of such a source of waves, in some cases are occupied by waves of definite frequencies, dependent on the width of the shelf, whereas in other cases transform them. In the first case the waves can attain great dimensions as a result of resonance effects, and in the second case -- due to the redistribution of wave energy in the water layer when the waves enter into the shallow-water area.

Both these effects can result in an increase in the heights of waves to dangerous sizes and only losses of wave energy due to friction of the fluid against the bottom impede their unlimited increase.

For the purpose of determining waves of resonance origin the shelf is regarded as a resonance channel with one solid and one liquid wall, which intercepts waves from the open sea. In those cases when the wave velocity coincides with the velocity of movement of the cyclone (close to it) there is an increase in the level as a result of resonance [2].

Thus, on the basis of a joint analysis of synoptic situations, pressure topography field and thermal state of the underlying surface of sea water in the case of particularly severe storms, causing catastrophic phenomena, it was possible to detect some characteristics of secondary cyclones as vortices of the "typhoon" type. It was found that such vortices, having definite laws of movement, are capable of generating different types of waves, frequency and amplitude, on the shelves of seas. The characteristics of these waves are determined by the morphometric characteristics of shelf areas. Without question, a deep and many-sided investigation in this field would be of considerable scientific and practical importance and therefore we hope that this article will draw attention of forecasters, meteorologists and oceanologists to this problem.

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UDC 551.46.01(261)

SOME FEATURES OF WATER CIRCULATION IN THE NORTH ATLANTIC

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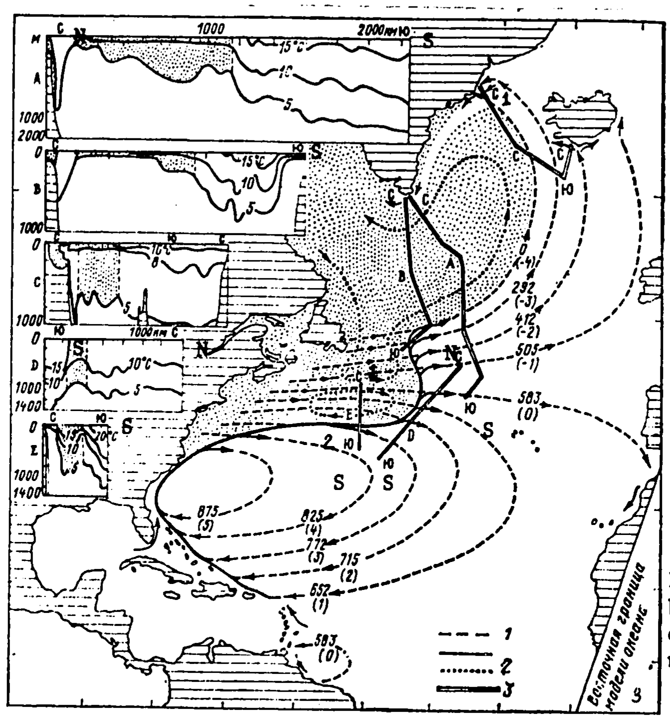
[Article by Candidate of Physical and Mathematical Sciences A. A. Kutalo, State Oceanographic Institute, submitted for publication 17 May 1979]

Abstract: On the basis of the results of hydrodynamic modeling of structure of anticyclonic circulation of waters in the Gulf Stream system and the position of the polar front the author has concluded that wind shearing stress plays a decisive role in forming the circulation of waters in the North Atlantic. The article examines the problems involved in the nonlinear evolution of mesoscale circulation disturbances of the baroclinic layer of the ocean, which are in geostrophic balance. Expressions are derived for relating the initial parameters of the disturbance with its lifetime and distance covered before destruction begins.

[Text] One of the problems in the general circulation of waters both in the world ocean as a whole and in the North Atlantic in particular is a determination of the relative contribution of wind shearing stresses and nonuniform heating to its formation. The main difficulty in such a determination is the lack of reliable, sufficiently valid data from instrumental observations of circulation parameters. For example, the models of circulation in the North Atlantic published by Sverdrup [14], Iselin [11], Stommel [13], Worthington [17] and Bulatov [1] have many substantial differences, but the features common for these models do not have satisfactory explanations for the factors causing them.

The results of hydrodynamic calculations and analyses of this problem for the purpose of determining cause-and-effect relationships also do not give an unambiguous interpretation of the observed characteristics of circulation and structure of ocean waters. In this study we will examine some factors indicating a wind nature of circulation of waters in the North Atlantic. The most important of these include a determination of details of circulation in the Sargasso Sea and the position of the polar front. We will also examine some problems involved in evolution of mesoscale disturbances (200-500 km) of the baroclinic layer in the ocean.



Eastern boundary of ocean model

Fig. 1. Model of water circulation in the North Atlantic. 1) isolines of thickness of the upper layer L m and function $m = a/2(h^2 - h_0^2)$, 2) hypothetical compensatory currents, 3) hydrological sections, A, B, C (VIII-IX 1958) [15], D (IV 1964), E (XI 1956) [17].

KEY:

1. С = N
2. Ю = S
3. Eastern boundary of ocean model

In the hydrodynamic modeling of the anticyclonic circulation of waters in the North Atlantic, its flows directed to the south are uniformly distributed over the entire extent from the eastern shore to the western boundary current of the Gulf Stream [12, 18]. According to observational data, such a uniformity of the southerly flows in the open ocean is not noted. For the most part the southerly flows in the circulation are concentrated in the central part of the ocean between 50 and 40°W. For example, according to [17], the closing of the anticyclonic circulation of waters in the Gulf Stream system virtually completely occurs within the limits of the Sargasso Sea. Such a peculiarity is also confirmed by the sharper westward deepening of the main thermocline at the indicated longitudes.

We will carry out an analysis of the formulated problems in the following hydrodynamic model of a two-layer ocean:

1. The water density in the upper and lower layers is constant. The upper layer models the influence of thermal factors only through the characteristic scales of thickness (about 600 m) and stratification ($\delta = 1.5 \times 10^{-3}$ g/cm^3), selected on the basis of observational data.

2. The redistribution of waters of the upper layer over the ocean surface occurs only under the influence of wind shearing stresses.

3. There is no exchange of momentum and mass between the layers.

4. The currents in the lower layer can be neglected when determining circulation in the upper layer.

5. Movements satisfy the conditions of hydrostatics and geostrophic balance.

With such assumptions outside the boundary coastal regions, adhering to [3], the problem can be reduced to solution of an equation for the thickness of the upper layer h:

$$h_t - abhh_\lambda = b\left(\frac{\tau^\lambda}{\cos\varphi} - \tau^\lambda_\varphi \sin\varphi + \tau^\varphi_\lambda \operatorname{tg}\varphi\right), \qquad (1)$$

where t is time, λ, φ are longitude and latitude in the adopted spherical coordinate system,

$$a = \frac{\delta g}{\rho R}; \quad b = \frac{1}{2\omega R \sin^2\varphi},$$

ω is the angular velocity of the earth's rotation, R is the earth's radius, g is the acceleration of free falling, ρ, $\rho - \delta$ is water density in the lower and upper layers respectively, τ^λ, τ^φ are the zonal and meridional components of the vector of wind shearing stresses.

The subscripts denote differentiation.

In equation (1) the dependence on φ is parametric; this makes it easy to proceed to the new variable $\tilde{\lambda} = \lambda + f(\varphi)$. The form $f(\varphi)$ is determined from the condition of modeling of the eastern shore of the North Atlantic by a slant line in accordance with Fig. 1.

The wind stresses $\vec{\tau}$ are selected in such a way as to model climatically stable circulatory systems in the atmosphere caused by the Icelandic Low and the Azores High, and also their winter intensification and summer weakening. On the other hand, the form of $\vec{\tau}$ must ensure obtaining an analytical solution of equation (1). Taking such requirements into account, we select

$$\tau^{\lambda} = \bar{\tau}^{\lambda}(1 + \mu \sin qt); \quad \bar{\tau}^{\lambda} = -\tau_0 (\cos 3{,}5\,\varphi - 0{,}75 \cos 8\,\varphi); \qquad (2)$$

$$\tau^{\varphi} = \bar{\tau}^{\lambda}_{\varphi} F(\bar{\lambda})(1 + \mu \sin qt); \quad F = F_0 (\bar{\lambda}_0 - \bar{\lambda}) \exp [k (\bar{\lambda}_0 - \bar{\lambda})^2]. \qquad (3)$$

The distribution of zonal stresses τ^{λ} with $\mu = 0$ is given in Fig. 2a. The small circles represent observational data [18]. The form of the meridional stresses τ^{φ} was selected in such a way as to intensify the anticyclonic and cyclonic vorticity of the assumed purely zonal stresses (2) and thereby more realistically model the wind systems of the Azores High and the Icelandic Low. The coordinates of the centers of these circulatory systems in the atmosphere, in accordance with (2)-(3) with the assumed slope of the eastern shore (Fig. 1) and with $\bar{\lambda}_0 = 34.5°$ (about 0.6 rad), will be $\varphi = 31°$, $\lambda = 42°$, $\varphi = 65°$, $\lambda = 22°$ respectively.

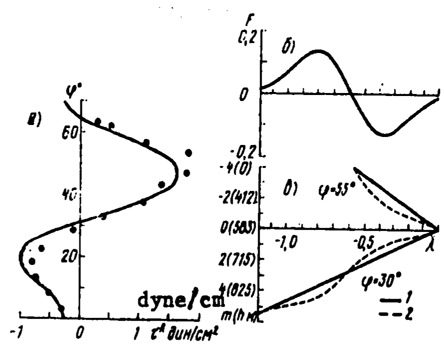


Fig. 2. a) Distribution of zonal wind stresses with latitude (a), curve of function $F(\bar{\lambda})$ (b) and curve of function $m(\bar{\lambda})$ (c). 1) case of a purely zonal wind ($\tau^{\varphi} = 0$), 2) with allowance for the meridional component ($\tau^{\varphi} \neq 0$).

We will assume $k = 10$ and $F_0 = 1$. The highest values of the zonal stresses are 1.7 dyne/cm^2, and for meridional stresses -- 0.7 dyne/cm^2. The curve of the dependence of F on $\bar{\lambda}$ is shown in Fig. 2b.

The amplitude of the annual variation of stresses ($q = 2\pi/1$ year) is determined by the coefficient μ; following [3], we select $\mu = 0.65$.

The zonal U and the meridional V transport of water in the upper layer is expressed through h in the following way:

$$U = \frac{1}{2\omega \sin\varphi}[ahh_\varphi + \tau^\varphi]; \quad V = \frac{1}{2\omega \sin\varphi}\left[\frac{ahh_\lambda}{\cos\varphi} - \tau^\lambda\right]. \tag{4}$$

In (4) τ^φ and τ^λ determine purely drift transport in the Ekman friction layer; the remaining part of the flows in the upper layer is governed by the topography h and is determined by the slopes h_λ, h_φ.

1. Stationary solution. In this case equation (1) has the form

$$hh_\lambda = \frac{1}{a}\left(\tau^\lambda_\varphi \sin\varphi - \frac{\tau^\lambda}{\cos\varphi} - \tau^\varphi_\lambda \operatorname{tg}\varphi\right). \tag{5}$$

In the case of small angles of deviation of the eastern shore from a meridional direction (in Fig. 1, about 15°) and the condition of nonflowthrough on the shore, the solution of (5) has the form

$$h = h_0^2 - \frac{2}{a}\left\{\left(\frac{\tau^\lambda}{\cos\varphi} - \tau^\lambda_\varphi \sin\varphi\right)\bar{\lambda} + \tau^\lambda_\varphi [F - F(0)] \operatorname{tg}\varphi\right\}. \tag{6}$$

This solution in the form of a scheme of distribution of the value m = $a/2(h^2 - h_0^2)$ is represented in Fig. 1 by dashed lines. The values are given in parentheses under the figures for depth of the discontinuity between the layers. According to (4), the m value characterizes the magnitude of water transport in a baroclinic layer between the eastern shore, where for all practical purposes h = h_0, and the reading point h.

We will note two important characteristics of the solution of (6). One is related to the redistribution of flow within circulations due to the influence of the meridional components of wind stresses ($\tau \neq 0$) and the second is related to emergence of the discontinuity between the layers to the surface in the region of a cyclonic circulation (m = -4; h = 0). This line of emergence can be regarded as the polar front. Additional allowance for wind vorticity through the introduction of meridional components leads to a concentration of flows. In a cyclonic circulation it occurs in the direction of the polar front, and in an anticyclonic circulation -- in the central part of the ocean (35-50°W).

Figure 2c shows the distributions of m along φ= 30 and 55°, illustrating such redistributions of flows with allowance for τ^φ-- the dashed lines -- and in the case of a purely zonal wind (τ^φ= 0) -- solid lines. Water transport in the noted regions almost doubled in comparison with the purely zonal wind (τ^φ= 0) with a constant general transport in the circulations.

The solution obtained (6) is correct only outside the westerly boundary regions. The problem arises of closing the represented model of circulation in the open part of the ocean. In its solution we will assume that all the currents necessary for such closing have a compensatory nature. An example of the general circulation model constructed in such a way is shown in Fig. 1. In its construction we took into account the phenomenon of detachment of the Gulf Stream from the shore at the latitude of Cape Hatteras and the results of modeling of this phenomenon in a two-layer approximation, relating the detachment and the location of the current to the line of emergence of the discontinuity between the layers at the surface and the volume of the current discharge [3, 4].

According to computations, in the anticyclonic circulation the transport of waters to the south at latitude 30° is about 50 sverdrup. This determines the similar discharge of the westerly compensatory current. In a cyclonic circulation such a closing by a compensatory current is evidently impossible. First of all, this is associated with the position and configuration of the line of emergence of the discontinuity between the layers at the surface. According to Fig. 1, this line (the polar front) begins at Newfoundland and runs to Greenland at a latitude 66°. Thus, the compensatory boundary current of this cyclonic circulation must bend around Greenland from the south, pass along the shores of Davis Strait and Labrador in the direction of Newfoundland. The currents must be in the limits of the upper (baroclinic) layer. Such a scheme evidently cannot be realized due to processes of intensive cooling of the upper warm waters in the high latitudes and the plunging of these waters to great depths. In this case the flow of upper-layer waters to the north in a cyclonic circulation can be regarded as the source of the deep waters. According to computations, it is about 20 sverdrup. Compensation of the circulation, however, evidently occurs through deep flows of waters to the south, their rising and transformation into upper-layer waters in the low latitudes (for example, in upwelling zones along the shores of Africa) and through an additional transport to the north in the anticyclonic circulation of the Gulf Stream system. The Canaries Current and the rising of deep waters in upwelling zones can be regarded as sources of the Northern Trades. Such a model agrees with that proposed by Stommel [13]. As a result, discharge of the Gulf Stream as a compensatory boundary current will be determined by the intensity of both the anticyclonic circulation of waters in the low latitudes and cyclonic circulation in the high latitudes. This, according to computations, gives a Gulf Stream discharge of about 70 sverdrup, which corresponds to available estimates.

In regions of emergence of deep waters at the surface the circulation is represented schematically, in accordance with the vorticity of the wind fields over them. The reality of this model of circulation of North Atlantic waters is confirmed by the hydrological sections shown in Fig. 1 (inset) [15, 17]. The shaded regions on the sections and in the scheme correspond to regions with an upper (baroclinic) layer which wedges out. The computed data agree well with the observed peculiarities of water structure. We note two factors in the correspondence of computed and observed data important in solving the problem of contribution of the wind and heating to the formation of circulation: 1) localization of the anticyclonic circulation in the western part of the ocean; 2) correspondence between the positions of the line of emergence of the discontinuity between the layers at the surface ($h = 0$) according to the scheme and the polar front according to the hydrological sections. The correspondence of these two important circulation details and the fact that the scheme in Fig. 1 is governed only by the structure of the wind stresses fields indicate that the wind plays a dominant role in forming water circulation in the North Atlantic.

Nonstationary solution. We will write equation (1) in the form

$$h_t - abhh_{\bar{\lambda}} = bw(1 + \mu \sin qt), \qquad (7)$$

where

$$w = \frac{\bar{\tau}^\lambda}{\cos\varphi} + \bar{\tau}^\lambda_\varphi (F_{\bar{\lambda}} \operatorname{tg}\varphi - \sin\varphi)$$

corresponds to the vertical velocity component at the lower boundary of the Ekman friction layer.

The integral basis of equation (7) will be as follows

$$h - \int bw(1+\mu \sin qt)\,dt = c_1; \quad \bar{\lambda} + ab\left[c_1 t + \iint bw(1+\mu \sin qt)\,dt\,dt\right] = c_2. \qquad (8)$$

The solution (7) is implicitly determined using (8) from the relationship $\Phi(c_1, c_2) = 0$, whose specific form is found from the boundary or initial conditions. We will examine some important corollaries following from (8). Assume $w = 0$, then

$$h = c_1; \qquad (9)$$
$$\bar{\lambda} + abht = c_2.$$

The second integral expression (9) shows that any disturbance in the thickness of the baroclinic layer is propagated in a west-north direction with a phase velocity increasing toward the equator and proportional to h:

$$c = \frac{\delta g h \cos\varphi}{2\omega_\oplus R \sin^2\varphi}\ [\text{см/сек}]. \quad [\text{cm/sec}] \qquad (10)$$

We find that the initial disturbances, oriented in a meridional direction, with westward advance will be curved. This is attributable to the fact that sectors of the disturbance situated closer to the equator will be displaced westward with a greater velocity than in the high latitudes. Thus, with a characteristic thickness of the baroclinic layer of 600 m the zonal velocities at latitudes 10, 20, 30, 40° will be 32, 8, 3.5, 1.8 and 1.1 cm/sec. Thus, during a year a disturbance at latitude 10° is displaced 10,000 km to the west, whereas at 40° latitude -- by only 350 km.

The second important corollary is associated with the fact that the phase velocity is proportional to the thickness h of the baroclinic layer. As a result, the initial form of the disturbance will change with advance in the direction of the phase velocity. Sectors of the disturbance with greater h values will outstrip sectors with lesser h. This peculiarity will be manifested in an intensification of disturbances which are in geostrophic balance, directed in a northeasterly direction of the currents. A similar result in a more complex hydrodynamic formulation of the problem was obtained in [8, 10].

The dependence of phase velocity on h will also lead to a change in slope of the vertical axis of the disturbance. An intensification of the slope will be in the direction opposite the direction of the phase velocity because the deeper sectors of the disturbance will outstrip those situated above. Such a peculiarity was noted in an analysis of an eddy disturbance on the basis of data from instrumental observations in a hydrophysical polygon in the Tropical Atlantic [2].

As a result of the considered peculiarities in the evolution of disturbances, depending on the initial parameters, the disturbances, not reaching the western shores, will be destroyed due to disruption of hydrostatic stability (overturning).

Now we will examine this problem in greater detail. Assume that an initially axially symmetric disturbance is in geostrophic balance and has the following characteristic dimensions: radius r and deviation $\pm\Delta h$ from the undisturbed thickness of the upper layer h. A positive Δh value corresponds to an anticyclonic eddy disturbance, whereas a negative value corresponds to a cyclonic eddy disturbance. The phase velocities of propagation of the "bases" of the disturbances ($h = h_0$) and their "tops" ($h = h_0 \pm\Delta h$) will be in accordance with (10):

$$c_0 = \frac{\gamma g h_0 \cos\varphi}{2\omega_0 R \sin^2\varphi}, \quad c_B = c_0\left(1 \pm \frac{\Delta h}{h_0}\right). \tag{11}$$

The condition of hydrostatic stability of disturbances requires that after the time interval Δt the "top" of the disturbance will not emerge from the neighborhood of its "base." This will be satisfied under the condition

$$|c_0 - c_B|\Delta t < r, \tag{12}$$

[B = top]

Introducing the distance L into (12) in place of Δt, the distance covered by the disturbance before the beginning of destruction, and taking (11) into account, we will have the following relationship:

$$L \leqslant r\frac{h_0}{\Delta h}. \tag{13}$$

It can be seen that L is not dependent on latitude and is determined only by the initial parameters of the disturbance. This means that the disturbances will begin to be destroyed in that sector which moves with the greater phase velocity, that is, situated in the lower latitudes. In this case the destruction front will rise along the disturbance in a poleward direction, as the disturbance at the corresponding latitude attains the critical value

$$L_K = r\frac{h_0}{\Delta h}.$$

Such a peculiarity of the dynamics of destruction of a disturbance is confirmed by the results in [8].

In a general case the discrimination of a solution from (8) is extremely difficult due to the nonlinearity of the initial equation (7). Its linearized solutions were obtained in a two-layer approximation in [3, 16] and with a self-similar density distribution with depth, in [5, 7, 9].

According to these sources, the seasonal variation of wind stresses and heat fluxes gives rise to waves with an annual period in the ocean; these propagate with a phase velocity corresponding to that cited in (10). These waves can give rise to circulatory disturbances exceeding the mean climatic circulation and thereby to a stable mesoscale intermittence of ocean waters [5, 6]. In combination with the described peculiarities of nonlinear evol on of disturbances such waves of seasonal origin can be the basis the observed mesoscale variability of hydrological fields in the ocean.

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UDC 551.(460.18+507.362)

COMPARISON OF SATELLITE AND SHIPBOARD DATA ON TEMPERATURE MEASUREMENTS OF THE WATER SURFACE IN THE EQUATORIAL ATLANTIC

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 70-73

[Article by Candidate of Geographical Sciences A. D. Kirichek and A. F. Lyashenko, State Oceanographic Institute, submitted for publication 17 May 1979]

Abstract: This paper gives a comparison of the results of satellite and shipboard measurements of temperature of the water surface in the Equatorial Atlantic with a spatial resolution of 30 miles and a time discreteness of 1 day. It is shown that satellite measurements of temperature exceed the data from shipboard observations by 0.41°C, whereas the standard deviation attains 0.61°C. It is postulated that there is a possible dependence of the results of satellite measurements of surface temperature on the observation region.

[Text] The appearance of remote research methods in oceanology (aircraft, artificial earth satellites) is making it possible to obtain qualitatively new information on the spatial and temporal variability of such an important hydrophysical characteristic as temperature of the ocean surface.

Despite considerable difficulties both in obtaining such data and in interpretation of the results [1, 2], interesting data are available on the peculiarities of distribution of the temperature of the water surface in the Tropical Atlantic during the international experiment "Tropeks-71" [6]. The problem of comparison of satellite and shipboard data at the present time has been poorly investigated, although the importance of its solution is entirely obvious. For example, in [2] there was a comparison of observational data obtained for the most part from commercial ships and satellite data. This comparison indicated that the mean discrepancy between them for all the oceans on one of the days in March 1975 (11 March) is -0.43°C and the standard deviation is 2.00°C.

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In this study an attempt was made at such a comparison of data from the ships "Akademik Kurchatov," "Passat" and "Ayselin" during the time of carrying out the "Tropeks-74" experiment with source [6] data, the latter reference containing the results of satellite and shipboard measurements of temperature of the water surface in the Tropical Atlantic with a spatial resolution of 30 miles and a time discreteness of one day. The mentioned vessels were situated along the equator: "Passat" at 10°W, "Akademik Kurchatov" at 23°30'W, "Ayselin" at 28°30'W. It should be noted that this zone was selected due to the circumstance that during the entire observation period, according to satellite data [4], the zone was free of cloud cover. This made it possible to neglect its influence on the accuracy in measurements of temperature of the ocean surface. Since the satellite measurements characterized the mean daily data, the results of the thermobathygraphic observations on the ships "Passat" and "Akademik Kurchatov," carried out 8 times a day, were also averaged. In comparing the results of observations we used data from Soviet ships in all three phases of the experiment, whereas the "Ayselin" measurements were used only in the second phase (Fig. 1). The figure shows that the mean scatter of data does not exceed ±0.5°C. However, there are some peculiarities of the interrelationship between satellite and shipboard data in dependence on the absolute temperature values in individual regions.

It was noted earlier that the scientific research ship "Passat" was situated at 10°W. This region is the zone of most intensive upwelling with temperatures of 21.5-24.0°C. Here satellite data surpass shipboard temperature measurements on the average by 0.63°C (see Table). The temperature of the water surface in the work region of the "Akademik Kurchatov," situated 800 miles to the west of the "Passat," was somewhat higher -- 24.5-26.5°C.

Table 1

Comparison of Shipboard and Satellite Observations During "Tropeks-74" Experiment

Судно 1	Западная долгота 2	Число наблюдений 3	Среднее расхождение, *град* 4	Дисперсия, (*град*)^2 5	Среднеквадрат. откл., *град* 6
«Пассат» "Passat"	10°00′	59	0,63	0,40	0,63
«Академик Курчатов» "Kurchatov"	23 30	49	0,32	0,20	0,44
«Айселин» "Iselin"	28 30	28	0,29	0,56	0,75
Среднее Average	—	—	0,41	0,39	0,61

KEY:

1. Ship
2. W
3. No of observations
4. Mean discrepancy, °
5. Dispersion, (°)^2
6. Standard deviation, °

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000200070043-5

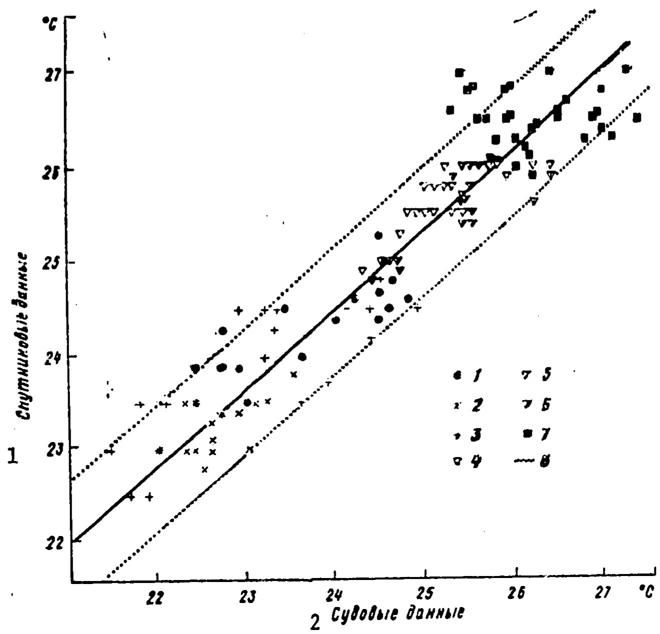

Fig. 1. Comparison of satellite and shipboard measurements of water surface temperature in Equatorial Atlantic. "Passat": 1) phase 1 (27 June - 16 July), 2) phase II (28 July - 15 August), 3) phase III (30 August - 18 September); "Akademik Kurchatov": 4) phase I, 5) phase II, 6) phase III; "Ayselin": 7) phase II, 8) ±0.5°C.

KEY:
1. Satellite data
2. Shipboard data

It was found in a comparison of satellite and shipboard temperature measurements that the discrepancy between them is somewhat less -- 0.32°C. In addition, it is characteristic that the dispersion of temperature fluctuations according to measurements on the "Akademik Kurchatov" is half as great as for the "Passat" measurements. A comparison of shipboard data for the "Ayselin," situated 300 miles to the west of the "Akademik Kurchatov," and satellite observations shows that the discrepancy between them on the average did not exceed 0.29°C, although the standard deviation was maximum -- 0.75°C.

On the whole, as can be seen from the table, satellite temperature measurements exceed the data from shipboard observations by 0.41°C and the standard deviation attains 0.61°C.

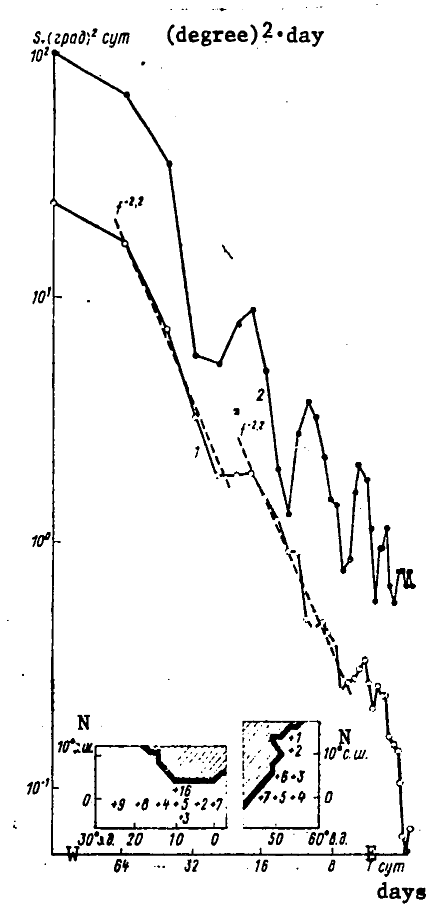

Fig. 2. Generalized spectra of fluctuations of water surface temperature in Equatorial Atlantic (1) and in zone of Somali Current (2).

It should be noted that a similar result was obtained in [2] for the northern part of the tropical zones of the Western Atlantic and Eastern Pacific Ocean, where the temperature measurements from satellites exceeded the shipboard measurements on the average by 0.76°C.

The collected data suggest a possible dependence of satellite measurements of surface temperature on the region of observations. In actuality, according to the results obtained in source [6], the spatial resolution of satellite measurements is about 30 miles at the nadir. At the same time, an analysis of the spatial-temporal variability of the water surface temperature along the equator indicated that the horizontal dimensions of the inhomogeneities in the region where the "Passat" was situated were minimum in comparison with other regions and were 30-50 miles, whereas their characteristic "lifetime" was from 2 to 4 days [5]. It can therefore be postulated that in this case the satellite IR radiometer could not "note" the mentioned inhomogeneities and, accordingly, there were exaggerated surface temperature values. Such a conclusion must be considered preliminary, since it is in need of checking on the basis of massive observational data.

Thus, despite some discrepancies with shipboard observations, data on water surface temperature obtained from a satellite are quite reliable and afford a possibility for investigating the spectral structure of fluctuations of the temperature field in the synoptic range of frequencies. For this purpose we selected two regions: Equatorial Atlantic and coastal zone of the Somali Current (eastern Indian Ocean). In the first mentioned region we selected nine points from which we read the daily surface temperature values (100 days), in the second -- 7 points (Fig. 2, insert). Then for each case we computed the time spectra of surface temperature fluctuations. The individual spectra indicated the presence of spectral density peaks approximately at one and the same frequencies, which made it possible to combine them by regions and obtain generalized spectra (Fig. 2). The number of degrees of freedom of the generalized spectra, evaluated taking into account the partial coherence of the records entering into the set [3], on the average was about 20. Figure 2 shows that the level of the spectral density in the region of the Somali Current is approximately five times greater than the corresponding level in the Equatorial Atlantic. In general, this result is easy to explain because the region of the Somali Current is characterized by intensive coastal upwelling and considerable horizontal gradients of the surface temperature field. We also note that both spectra are nonmonotonically decreasing with a frequency approximately as "$f^{-2.2}$."

At the same time, in the Somali Current a considerable part of the energy of the fluctuations was concentrated in the neighborhood of the three frequency intervals corresponding to periods 20, 10 and 6 days. In the Equatorial Atlantic, although such clearly expressed energy peaks were not observed, one could see a plateau at approximately these same periods, even manifested in the averaged spectra.

Thus, the definite similarity of the spectra obtained both in the open ocean (Equatorial Atlantic) and its coastal regions (eastern part of the Indian Ocean) in the synoptic frequency interval makes it possible to postulate a wave nature of fluctuations of the surface temperature field in the considered zones.

In conclusion it must be noted that measurements of water surface temperature from satellites, as follows from this communication, are an effective method for investigating its spatial-temporal variability.

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ACCURACY IN COMPUTING THE MONTHLY WATER BALANCE OF THE ARAL SEA

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[Article by V. N. Bortnik, State Oceanographic Institute, submitted for publication 11 May 1979]

Abstract: The author has estimated the errors in computing the monthly and annual water balances of the Aral Sea and their individual components. It is shown that these errors have a clearly expressed annual variation. The mean absolute errors in computing the monthly sea water balances attain 4.9 cm and the corresponding annual values attain 10.0 cm of a water layer. The maximum contribution to the errors in computing the water balances of the sea are from errors in computing evaporation.

[Text] In connection with routine computations of monthly and annual water balances of the Aral Sea, which are carried out at the State Oceanographic Institute within the framework of the USSR State Water Inventory, and also at the request of national economic organizations, an extremely timely question is that of the accuracy of computing these balances and their individual components. A knowledge of the error in computing water balances makes it possible to evaluate the reliability of the results and affords a possibility for comparing different computation schemes. In addition, it is possible to trace which components or individual hydrometeorological elements exert the greatest influence on computation errors, which is a necessary stage in increasing the accuracy of their measurements and computation and further improvement in the computation schemes.

This study is a continuation of the investigations carried out at the State Oceanographic Institute for evaluating the accuracy in computing the water balances of the internal seas of the USSR [19] and its principal objective is an evaluation of the accuracy in computing the monthly water balances of the Aral Sea.

The water balance equation for the Aral Sea, which is a water body without any outflow, can be represented approximately in the form

[б = bal; p = r]
$$\frac{V_р}{S} + P - E = \Delta H_б, \quad (1)$$

where V_r [$V_p = V_r$] is the total runoff of rivers, P is the precipitation falling on the sea surface S, E is evaporation from the sea surface, ΔH_{bal} is the sea level increment, computed using the water balance equation.

The equation shows that computation of the water balance components using this scheme is accomplished in linear units (centimeters of a water layer). The error in computing the sea water balance can be estimated approximately from its nonclosure (Δh), which is determined as follows

$$\Delta h = \Delta H_б - \Delta H_Ф, \quad (2)$$

[б = bal; Ф = act]

where ΔH_{act} is the actual sea level increment during the computation period. It can be seen from (2) that the mathematical expectation of Δh is equal to zero.

A detailed scheme for computing the monthly water balances in the sea was given in [4]. Therefore, here we will limit ourselves only to the most concise information necessary for estimating the computation error. Since most of the hydrometeorological elements used in computing the water balance components, and these components themselves, have a clearly expressed annual variation, the estimate of the errors in computing the water balances was accomplished separately for each month of the year. The estimate of the accuracy in hydrometeorological observations was carried out in accordance with [13]. Taking into account that the distances between hydrometeorological stations in the Aral Sea are actually much greater than the optimum (50-60 km), in all cases in evaluating the errors of areal interpolation we used their upper values.

Since the distribution of random errors in measurements of hydrometeorological elements as a rule conforms to a normal distribution law [13], the mean absolute measurement error was identified with the mean square error (standard deviation) σ, the limiting error -- with 3σ.

The limiting absolute errors in computations were determined by differentiation of the computation equations and subsequent replacement of the differentials by finite differences. For correlation of the measurement errors and computations we used the hypothesis of an equality of the limiting absolute errors in computations and measurements [6, 7, 17, 19]. However, in the study we made no estimate of the accuracy of some hypotheses embodied in the computation scheme.

The mean monthly components of the water balance of the Aral Sea were computed by the author for 1961-1977 -- a period of its marked decrease in level. The errors cited in the table characterize the approximate errors in one-time specific measurements and computations, whereas the long-term mean monthly values of the water balance components in this case serve only for an evaluation of these errors. However, the error in computing the long-term values of the water balance components will be approximately $\sqrt{n}$ times less, where n is the number of averaging years. As the fundamental errors in the study we examined the mean absolute (ε) and relative (ε%) errors; the corresponding limiting errors are equal to triple the means.

Level and morphometry. The mean absolute error in computing the mean monthly level at an individual point in a nontidal sea in the case of observations four times a day is 1-2 cm [13]. This is in good agreement with the data published by G. S. Ivanov and V. I. Kondrat'yeva [8]; they demonstrated that for most hydrometeorological stations the mean monthly level with a guaranteed probability of 95%, which for all practical purposes corresponds to 2σ, is determined with an accuracy to ±2 cm. The mean error in interpolation of the level between Aral Sea stations can be assumed equal to 7 cm. Then the mean absolute error in computing the mean monthly sea levelon the basis of data for six stations will be 2.9 cm. The mean monthly sea level increment is determined using the difference in levels on the first day of the computation and succeeding months. The level on the first day of the month in turn is computed approximately as the half-sum of successive mean monthly levels. Proceeding on the basis of this computation scheme, the mean error in determining the mean monthly increment in sea level was estimated at 2.9 cm. The table shows that the mean computation error is comparable with the actual mean monthly values of these increments and in some cases also exceeds them. The mean error in computing the annual level increment, determined as the sum of the monthly increments, is 10.0 cm. However, the annual sea level increment can be determined from the difference in levels on 1 January of the computation and subsequent years, similar to the monthly increments. In this case the mean error in computing the annual level increments will be equal to the error in computing the monthly increments (in the table in parentheses).

The mean error in computing the mean monthly sea area is determined by the mean technical error in measuring the area of the Aral Sea and the mean error in computing area on the basis of the mean monthly level. The first, according to the data of R. V. Nikolayeva [14], is ±137 km^2; the second, within the limits of the readings 53-47 m (abs.) was estimated by us as 58 km^2. Thus, the mean absolute and relative errors in determining sea level under the conditions mentioned above are 195 km^2 and 0.3% respectively. We have 56 km^2 and 0.1% respectively for the mean annual values. It should be noted that the accuracy in computations of the mean annual sea area as the mean of the mean monthly values is approximately three times greater than the accuracy in its determination from the mean annual sea level. Accordingly, insofar as possible, the first method must be used in practical work.

Monthly and Annual Values of Water Balance Components for the Aral

		I	II	III	IV	V	VI	VII
V_{comp}	V_p	2,2	2,0	1,9	2,9	5,4	7,1	8,3
	ε	0,2	0,1	0,1	0,2	0,4	0,5	0,6
	ε%	7,0	7,0	7,0	7,0	7,5	7,5	7,5
	P	1,0	0,8	1,4	1,7	0,6	0,7	0,6
	ε	0,1	0,1	0,1	0,2	0,1	0,1	0,1
	ε%	10,2	10,2	10,2	12,2	12,2	12,2	12,2
	E	2,0	1,0	1,7	4,2	9,8	14,4	16,6
	ε	0,9	0,6	0,8	1,6	2,7	3,9	4,5
	ε%	46,1	55,5	45,2	38,5	27,7	27,3	26,8
H_{bal}	$\Delta H_б$	1,2	1,8	1,6	0,4	—3,8	—6,6	—7,7
	ε	0,9	0,6	0,8	1,6	2,7	3,9	4,5
H_{act}	$\Delta H_ф$	—1,6	0,2	3,0	3,8	2,5	0,1	—4,0
	ε	2,9	2,9	2,9	2,9	2,9	2,9	2,9
	Δh	2,8	1,6	—1,4	—3,4	—6,3	—6,7	—3,7
	ε	3,0	3,0	3,0	3,3	4,5	4,9	5,4

River runoff. The error in computing mean monthly water discharges at the most downstream stations at Temirbay (Amudar'ya) and Kazalinsk (Syrdar'ya) were computed using the State Hydrological Institute method [10-12]. Here use was made of data from direct measurements of water discharges at the mentioned stations for 1965-1973. Data for recent years (1974-1977) were not employed because these years were characterized by highly unusual low water: the runoff of the Amudar'ya into the sea did not exceed 7-10 km^3 and in individual periods during these years it ceased as a result of blockage of the channel by dams, whereas in the mentioned years there was virtually no runoff of the Syrdar'ya which reached the sea.

The mean relative error in measuring the mean monthly discharges at Kazalinsk changes insignificantly during the course of the year, which is associated with the virtually complete regulation of Syrdar'ya runoff. Accordingly, we assumed it to be identical for all months of the year and equal to 6.5%. For Temirbay station the mean relative error in calculating mean monthly discharges was estimated by us for the high-water period (May-October) at 7.4%, for low water -- 6.7%. Taking into account that during the period 1961-1977 the ratio of inflow of the waters of the Syrdar'ya and Amudar'ya into the sea was approximately 1:3, the accuracy of computation of the total mean monthly river runoff for the low-water period is 6.7%, for high water -- 7.2%. The accuracy in calculating river runoff in linear units, taking into account the mean relative error in determining sea area, will be 7.0 and 7.5% respectively for the low- and high-water periods. As indicated in the table, the mean absolute error in calculating river runoff is low and even for the high-water months does not exceed 0.5-0.6 cm. For the annual values the mean errors are 1.2 cm and 2.3% respectively.

Table 1

Sea and Mean Errors in Their Calculation (in cm of a Water Layer)

VIII	IX	X	XI	XII	Год Year
7,1 0,5 7,5	6,1 0,5 7,5	4,4 0,3 7,5	3,2 0,2 7,0	2,4 0,2 7,0	53,0 1,2 2,3
0,4 0,0 12,2	0,7 0,1 12,2	1,3 0,2 12,2	1,3 0,1 10,2	1,1 0,1 10,2	11,6 0,4 3,4
17,9 4,9 27,3	14,6 3,9 26,8	9,6 2,7 27,7	5,0 1,6 32,6	3,8 1,4 36,8	100,6 9,9 9,8
—10,4 4,9	—7,8 3,9	—3,9 2,7	—0,5 1,6	—0,3 1,4	—36,0 10,0
—9,3 2,9	—11,2 2,9	—9,6 2,9	—6,4 2,9	—3,4 2,9	—35,9 10,0 (2,9)
—1,1 5,7	3,4 4,9	5,7 4,0	5,9 3,3	3,1 3,2	—0,1 14,2 (10,4)

Precipitation. The accuracy in measuring precipitation at an individual point is determined as the random error in direct measurement of the quantity of precipitation in a precipitation-gaging instrument and the errors in calculating the corrections for wetting of the instrument, inadequate allowance for the wind and evaporation. These corrections are introduced in order to eliminate systematic errors in precipitation-gaging instruments [18].

The mean relative error in measuring the quantity of precipitation collected in a precipitation-gaging instrument, according to [13], for the mean daily values is 5% for liquid precipitation and 13% for solid precipitation. These same values with some approximation can also be adopted for the mean monthly values. The random error in the corrections enumerated above does not exceed the values of the corrections themselves. For example, the accuracy in determining the wind correction, which is the largest of the corrections, for most regions of our country, including for the Aral Sea region, for liquid precipitation is 25-40% and for solid precipitation is 20-25% of the value of the correction itself [2, 3]. In accordance with [15-16], the period from November through March can be used as the period with solid precipitation in the Aral Sea region. Taking into account that the total correction for the hydrometeorological stations of the Aral Sea for the summer months does not exceed 20-24%, and in the winter months -- 36-39% of the mean monthly precipitation sums [1], the mean relative error in computing the mean monthly sums of liquid precipitation at an individual point can be estimated at 15%, and solid precipitation -- at 23%.

The mean error in interpolating the mean monthly precipitation sums between stations is also dependent on the type of precipitation and for liquid precipitation is 30% and for solid precipitation -- 25% [13].

The mean precipitation for the sea is determined by averaging the data for six stations [4]; therefore the mean relative error in computing liquid precipitation as a whole for the sea is 12.2%, solid precipitation -- 10.2%. Converting to the absolute values, we obtain the mean absolute errors in computing precipitation for each month (see table). Due to the insignificant quantity of precipitation falling over the waters of the Aral Sea, their absolute determination errors are also small and for the mean monthly values do not exceed 0.2 cm. For the annual values the mean absolute error attains 0.4 cm, and the relative error -- 3.4%.

Evaporation. In computing evaporation from the sea surface on the basis of data from shore and island stations we use the semiempirical formula derived by N. P. Goptarev [5], which takes into account the influence of the temperature stratification of air masses on the rate of evaporation. In the computations of the monthly evaporation values it has the form

$$E = \frac{327.5\,(e_s - e_2)\,U_z}{(\ln^* 2 - \ln^* z_0)^2}, \tag{3}$$

where e_s is maximum water vapor elasticity (mb) at the water temperature of the sea (or ice) surface; e_2 is the elasticity of water vapor (mb) in the atmosphere at a height of 2 m -- the standard height of observations of temperature and humidity at the hydrometeorological stations; U_z is wind speed (m/sec) at the height z (m), z_0 is the roughness parameter (for the Aral Sea assumed equal to $6 \cdot 10^{-4}$ m), $\ln^*$ is the factorial algorithm

$$\ln^* z = \ln z + \alpha z + \frac{(\alpha z)^2}{2 \cdot 2!} + \ldots + \frac{(\alpha z)^n}{n \cdot n!}, \tag{4}$$

where α is a parameter taking into account the influence of temperature stratification in the lower layer of the atmosphere on the evaporation rate.

E is measured in millimeters.

For practical use of (3) the dependence K = f(ri), where

$$K = \frac{327.5}{(\ln^* 2 - \ln^* z_0)^2} \quad \text{and} \quad \mathrm{ri} = \frac{t_w - t_a}{2}$$

is the analogue of the Richardson number, t_w is water temperature, t_a is air temperature, was tabulated. A peculiarity of the mentioned dependence is that the maximum variability K is noted for ri values close to zero and with $\mathrm{ri} \leqslant -0.014$ and $\mathrm{ri} > 0.100$ K = const. A determination of the errors in computing evaporation was carried out proceeding on the basis of the accuracy in measurement and interpolation of the hydrometeorological elements used in the computations [13]. Taking into account the mentioned complexity of the dependence K = f(ri), the limiting relative error in computing K was found to be 5%. By means of reduction of equation (3) to logarithmic form and differentiation, the limiting relative error in computing evaporation at a single point was determined; it varies from 31% for the summer months to 48% for the winter months. In this way it was possible to determine the limiting relative error in extrapolating the mean monthly evaporation values in the direction of the open sea. This error for one station attains 62% for the summer months and 124% for the winter months. Computations indicated that the maximum contribution (up to 80%) to the error in computing evaporation is from errors in determining the mean wind velocity. Proceeding to the absolute values and taking into account that evaporation from the sea surface is determined by the weighted averaging of data from five hydrometeorological stations, we find that the mean absolute errors in computing evaporation vary in the course of the year in the range 0.6-4.9 cm, whereas the relative errors vary in the range 27-55% (see table). As a result of the clearly expressed annual variation of evaporation there is an inverse relationship between the absolute and relative errors -- the maximum relative errors for the winter months correspond to the minimum absolute errors. For the summer months, however, with minimum relative errors the absolute errors are maximum. In the case of the annual values the mean absolute error attains 9.9 cm, and the mean relative error -- 9.8%.

The mean absolute errors in determining the monthly level increments, computed from the water balance equation (1), are almost completely determined by the error in computing evaporation; however, the contribution of the absolute errors in computing river runoff and precipitation is insignificant (see table). For the mean monthly values the mean absolute errors vary from 0.6 to 4.9 cm and are comparable with the values of the various increments themselves, whereas the mean absolute error of the annual values attains 10.0 cm.

The mean absolute errors in determining the nonclosures of the monthly water balances attain 3.0-5.7 cm, and the annual values -- 14.2 cm. However, if the mean error in determining the annual actual level increment is assumed to be 2.9 cm, the mean absolute error in the annual nonclosure value can be estimated at 10.4 cm (in the table in parentheses). Thus, the small absolute values of the nonclosure of monthly and annual water balances of the sea in general are not evidence of a high accuracy in computing these balances since the mean absolute errors in computing the nonclosure are comparable with their absolute values, and for some months exceed them.

Summary

1. The errors in computing the monthly water balances of the Aral Sea and their individual components have a clearly expressed annual variation. The mean absolute errors in computing the monthly values of river runoff attain 0.5-0.6, precipitation 0.2 and evaporation 4.5-4.9 cm of a water

layer. Thus, the greatest contribution to the errors in computing monthly water balances are from errors in computing evaporation.

2. The mean errors in determining the monthly balance level increments are comparable with the values of the increments themselves and vary in the range 0.6-4.9 cm, for the annual values attaining 10.0 cm.

3. The large absolute errors in computing the nonclosure of monthly and annual water balances of the sea, attaining 3.0-5.7 and 10.4 cm respectively, do not make it possible to use them for evaluating the accuracy in computing these balances.

4. An increase in the accuracy of computing the monthly and annual water balances of the Aral Sea is possible, in particular, by improving the method for calculating evaporation and increasing the accuracy in determining mean wind velocity.

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USE OF THE RESIDUAL METHOD OF STATISTICAL ANALYSIS FOR THE INVESTIGATION OF HYDROMETEOROLOGICAL PROCESSES

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[Article by Professor A. R. Konstantinov and N. M. Khimin, Leningrad Hydrometeorological Institute, submitted for publication 8 May 1979]

Abstract: The article briefly discusses the results of use of the residual method by means of manual construction of two-parameter graphic regressions. The algorithm for the residual method in analytical form is presented in greater detail. The authors present the results of a numerical experiment for checking the proposed algorithm. There is a discussion of the results of application of the method in the analysis of the correlations between the norms of runoff of high water and hydrometeorological factors and the characteristics of the drainage basin.

[Text] Local correlations of investigated processes with individual factors, frequently used in hydrometeorology, cannot always satisfy the multisided practical needs of hydrometeorological, hydraulic and hydromelioration computations. However, the formulation of a sufficiently rigorous theoretical model of the phenomenon, making it possible to comprehend the entire diversity of relationships and interrelationships characteristic of this process, for the time being is difficult due to the poor study of the processes. Accordingly, in many cases researchers must endeavor to formulate empirical models which give the quantitative characteristics of the principal aspects of the investigated process and which are ensured with the necessary information.

The choice of the method for analysis of the relationship between the investigated process and the determining factors must be based, in particular, on allowance for the peculiarities of the hydrometeorological information. This peculiarity is related to the multifactor nature of the studied phenomenon, the absence of a reliable quantitative characteristic of many factors, smallness, interrelationship and nonuniformity of the initial data.

Statistical series of hydrometeorological observations (especially hydrological and agrometeorological), carried out using a unified method, in many cases are extremely limited and the items of the sample themselves have a high coherence, as a result of which the number of equivalent-independent items in the sample is greatly reduced. Accordingly, investigators of hydrometeorological processes frequently must deal with small samples. In such cases preference must be given to statistical analysis methods automatically taking into account the coherence of the terms in the sample and allowing simultaneous use of additional a priori information on the regularities of the investigated process or phenomenon and also the specific information obtained in other investigations made earlier. These conditions are met by the residual analysis method (or the residual deviations method) with the use of graphic regressions [2, 10, 12 and others].

The principal merit of the residual method is the possibility of analysis of any form of correlation between the phenomenon and the determining factors, including the nonlinear correlations, extremely common in hydrometeorological processes. In our country this method is used in the studies of the hydrometeorologists of the Ukrainian Scientific Research Hydrometeorological Institute, Institute of Experimental Meteorology and State Hydrological Institute [3-7, and others]. During recent years it is also finding application in economic investigations [8, 9]. Foreign investigations in the field of statistics [2, 10, 12, 14 and others] in general give a positive evaluation of the possibilities of the residual method, experience in its use has been accumulated and an evaluation of its accuracy is given.

Until now this method most frequently has been applied by means of forming of two-parameter regressions manually [3, 4, 6]. The method proved to be highly effective; the closeness of the established correlations was higher than in analysis by other methods. The two-parameter base of the correlation made possible the most complete allowance for the effect of interrelationship of the determining factors. The principles for maximizing the closeness of the geometrical construction of families of curves of parametric correlations and their analytical expression were formulated [7] and nevertheless the greatest objections from opponents of the residual deviations method are due to the apparent subjectivity of manual construction of graphic regressions. It is apparent and not real because by means of checking the closeness of the correlation between the measured values of the analyzed factor and those taken from the isolines (by means of interpolation) there is a possibility of maximizing this correlation, which makes it possible to reduce to a minimum and virtually exclude the subjectivity in constructing the considered graphic regressions. For complete objectivity in this article we propose an algorithm for applying the residual deviations method in analytical form.

We will assume that the values of the variable y of some natural process can be predicted using the values of the variables x_1, x_2,..., using a model in the form

$$\{x_{j,i};\ \eta_i^s\};\ j=1,2,\ldots,k;\ i=1,2,\ldots,N;\ s=0,1,\ldots \qquad (1)$$

It is necessary to find this dependence, proceeding on the basis of experimental data, such as $x_{j,i}$ -- the values of the j-th variable in the i-th measurement ($j = 1, 2,\ldots,k$; $i = 1, 2,\ldots,N$) and Y_i -- the values of the variable y, distorted by the random errors z_i. Therefore, the final form of the model is as follows:

$$Y_i = y_i + z_i = F_0 + \sum_{j=1}^{k} F_j(x_{j,i}) + z_i. \qquad (2)$$

A determination of the functions $F_j(x)$ is a problem in regression analysis. In the traditional multiple linear regression method the functions $\alpha_j \varphi_j$ are used as F_j, where φ_j are prestipulated functions, and the α_j coefficients are determined by the least squares method. The residual deviations method makes it possible to evaluate the F_j functions in the model (2) without prestipulating their specific form.

Since in the above-mentioned studies the idea of the method is set forth in considerable detail, we will here not dwell on its description, but will instead proceed to the algorithm for its analytical realization.

Now we will examine the double series

$$y = F_0 + F_1(x_1) + F_2(x_2) + \ldots + F_k(x_k). \qquad (3)$$

Here the superscript s denotes the number of the next step in the residual deviations method, whereas the η_i^s values are the values of the deviations from the regression lines, which are determined recurrently from the η_i^{s-1} values. Then $\eta_i^0 = Y_i - F_0$ and F_0 is an evaluation of the mean value of the random value $\{Y_i\}$.

In a general case the elements of the series $\{x_{1,i}\}$, $\{x_{2,i}\},\ldots,\{x_{k,i}\}$ are arranged randomly and can contain equal elements with different i values. We will rearrange the terms in all these series in such a way that in the newly formed series

$$\{\xi_{j,i}\},\quad i=1,2,\ldots,M_j\ (M_j \leq N) \qquad (4)$$

the elements $\xi_{j,i}$ are arranged in a strictly increasing order with respect to the subscript i.

$$\xi_{j,1} < \xi_{j,2} < \ldots < \xi_{j,M_j}.$$

The symbol "<" on the right-hand side of (4) corresponds to a case when there are equal elements in the $\{x_{j,i}\}$ samples: otherwise the symbol " = " is used.

Assume that $n_{j,i}$ is the multiplicity of the element $\xi_{j,i}$, that is, a number showing by how many times the series $\{x_{j,i}\}$ contains an element equal to $\xi_{j,i}$ from (4). It is evident that

$$\sum_{l=1}^{M_j} n_{j,l} = N.$$

The series $\{\tilde{\eta}_i^s\}$ is used in accordance with the series (4), whose elements are computed using the expression

$$\tilde{\eta}_i^s = \frac{1}{n_{j,l}} \sum_{l_{j,l}}^{n_{j,l}} \eta_{i_j}^s, \tag{5}$$

where the summation is for those l_j which correspond to the elements $x_{j,i}$ from (3), equal to $\xi_{j,i}$ from (4). In other words, $\tilde{\eta}_i^s$ represent the mean arithmetical values η_i^s corresponding to the equal elements $x_{j,i}$ in series (3).

For the series $\{\tilde{\eta}_i^s\}$ we will compute the serial correlation coefficient R_j^s using the formula

$$R_j^s = \frac{\sum_{i=2}^{N} \tilde{\eta}_i^s \tilde{\eta}_{i-1}^s}{\sum_{i=1}^{N} (\tilde{\eta}_i^s)^2}. \tag{6}$$

Computing this coefficient for all j, we obtain a series of R_j^s values, from which we select the maximum; we will denote the number j corresponding to it by J. It is known [11] that the criterion (6) can serve as a measure of the closeness of the statistical correlation of an arbitrary form between two random values. The greater it is, the closer is the correlation. In the limit when the relationship between the variables is functional and the distance between adjacent points tends to zero this coefficient tends to 1.

For the series $\{\xi_{J,i}, \tilde{\eta}_i^s\}$, using the method presented in [15], we construct the trend $f_J^s(x_j)$, and for all $j \neq J$ we assume $f_j = 0$. Then, in accordance with the general idea of the residual deviations method, we determine the new vector η_i^{s+1} as the difference between the η_i^s values and the values of the trend f_J^s at the points $x_{j,i}$.

$$\eta_{i_i}^{s+1} = \eta_i^s - f^s(x_{J,i}) \tag{7}$$

and substitute it in the place of the vector η_i^s in (3). Then all the process described above is repeated from the beginning. And so we will proceed until for all j = 1, 2,...,k the serial correlation coefficient (6) will not satisfy the condition

$$R_j^s < \frac{u_q}{\sqrt{N}}, \tag{8}$$

where q is the stipulated significance level and $\tilde{u}_q$ is found from the table of the normal distribution law. The corresponding s value is denoted s_0. The condition (8) means that for all j = 1, 2,...,k the series $\tilde{\eta}_i^{s_0}$ with the probability 1 - q can be considered realizations of a purely random process [1], that is, the random value $\{\eta_i^{s_0}\}$ does not correlate with any

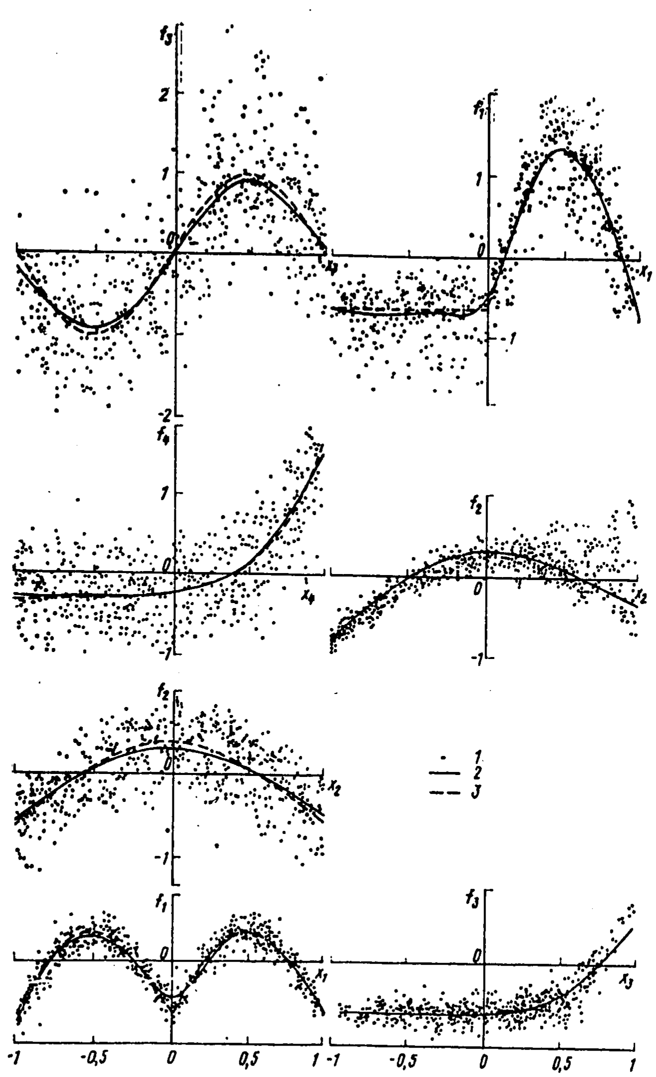

Fig. 1. Example of computation of regression lines by the residual deviations method. Left column -- uncorrelated variables, right column -- correlated. 1) field of scattering of residual differences, 2) curves of approximation splines, 3) theoretical curves.

of the variables $\{x_{j,i}\}$ and is an analogue of the random value z_i in model (2).

Now it is possible to write a formula for the evaluation $\tilde{F}_j$ of the F_j functions in (1) and thereby close the algorithm used in the residual deviations method

$$\tilde{F}_j(x_j) = \sum_{s=0}^{s_0-1} f_j^s(x_j). \tag{9}$$

As already noted, the residual deviations method is an effective statistical analysis method not only in a case when the variables $x_1, x_2, \ldots,$ are independent, but also in a case when there is a correlation between some of these variables. However, it appears that $\tilde{F}_j$, computed using formula (7), have a different sense than F_j in model (1) (that is, in the case of correlated variables); $\tilde{F}_j(x)$ in this case are not evaluations of the functions $F_j(x)$.

Due to the importance of the latter circumstance we will discuss it in somewhat greater detail, illustrating it with an example. Assume that (1) describes the correlation between the variable y and the two variables x_1 and x_2; as a simplification we assume $F_0 = 0$. Assume that x_1 and x_2 are functionally related, $x_2 = \varphi(x_1)$. Then model (2) will have the form

$$Y_i = F_1(x_{1,i}) + F_2(\varphi(x_{1,i})) + z_i. \tag{10}$$

In this case the residual deviations method must give the following:

$$\tilde{F}_1(x_1) \approx F_1(x_1) + F_2(\varphi(x_1)); \ \tilde{F}_2(x_2) = 0. \tag{11}$$

It does not follow from (11) that y is not dependent on x_2 -- this dependence can be very strong, but with $x_2 = \varphi(x_1)$ we actually are dealing with a function of one variable

$$Y = F(x_1) = F_1(x_1) + F_2(\varphi(x_1)), \tag{12}$$

whose evaluation on the basis of the sample values Y_i, $x_{1,i}$, $x_{2,i}$ is a function of $\tilde{F}_1(x_1)$.

If there is a correlation between x_2 and x_1, it is impossible to write an expression of the type (11) indirectly, but it is clear that the residual deviations method will give $\tilde{F}_1(x_1)$ and $\tilde{F}_2(x_2)$ functions, which assume intermediate values between the values which they would have in the case of a functional relationship between x_2 and x_1 and in the case of their nondependence.

The conclusions drawn in the example of a two-parameter model can also be applied to the case of a great number of variables.

In accordance with the method set forth above, a program was developed for computations on a BESM-6 computer, feeding out the analytical results in the form of graphic constructions simultaneously with analytical equations for the curves for these correlations. The program provides for a step-by-step allowance for and exclusion of the influence of the determining factors (predictors) in accordance with the ranking by closeness of their correlation with the predictant.

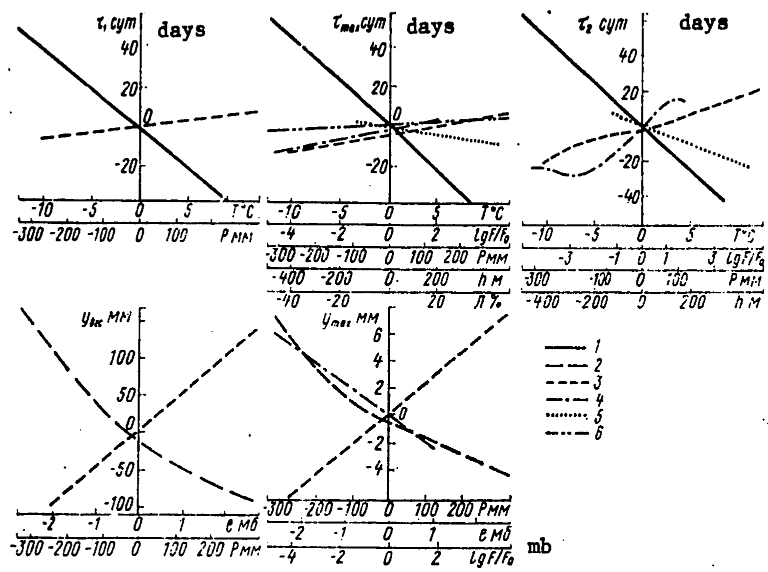

Fig. 2. Dependence of date of beginning τ_1, maximum τ_{max} and end τ_2 of high water, and also total Y_{spr} and maximum Y_{max} spring layer of runoff on mean annual temperature values T°C (1) and humidity e (2) of air, precipitation sums P (3), area F (F_0 = 1 km^2) (4), height h (5) and forest cover π (6) of watershed. All data are given in deviations from mean values: $\bar{\tau}_1$ = 10 IV; $\bar{\tau}_{max}$ = 27 IV; $\bar{\tau}_2$ = 1 VII: $\bar{Y}_{spr}$ = 124.8 mm; $\bar{Y}_{max}$ = 8.3 mm; $\bar{T}$ = 1.28°C; $\bar{e}$ = 6.81 mb; $\bar{P}$ = 647.9 mm; $\overline{\lg F/F_0}$ = 3.52; $\bar{h}$ = 181.6 m; $\bar{\pi}$ = 50.4%.

For checking the quality of performance of the algorithm described above we carried out a series of numerical experiments for computing the $\hat{F}_j$ functions for models in which F_j were known in advance. A comparison of computed $\tilde{F}_j$ and actual F_j revealed a high quality of this method. We will illustrate this by one of the examples.

A model corresponding to (2) was stipulated in the form

$$Y_i = |\sin(\pi x_{1,i})| + \cos\left(\frac{\pi}{2} x_{2,i}\right) + \sin(\pi x_{3,i}) + \frac{e^{3x_{4,i}}}{10} + \frac{z_i}{10}, \qquad (13)$$

where $\{z_i\}$ is a normally distributed random value with a zero mean value and a dispersion equal to 1. We examined cases of both uncorrelated variables $\{x_{j,i}\}$ and cases with interseries correlation.

In the first case the variables x_j were independent and were stipulated in the form of random values uniformly distributed in the segment [-1, 1]. In the left column of Fig. 1 we show curves of the functions $F_j(x_j)$ and $\widetilde{F}_j(x_j)$. The arrangement from top to bottom corresponds to a decrease in the value of the criterion (6) for the corresponding parameter. The correlation ratio r, computed using formula [13],

$$r = \sqrt{1 - \left(\frac{\sigma_z}{\sigma_y}\right)^2},$$

was equal to 0.992. Here σ_y^2 and σ_z^2 are sample evaluations of dispersions of the random values $\{Y_i\}$

$$\{Y_i\} \quad \text{and} \quad \left\{Y_i - \sum_{j=1}^{4} \widetilde{F}_j(x_{j,i})\right\}. \qquad F = 1.658.$$

In the second case the variables $x_{1,i}$ and $x_{2,i}$ were stipulated, as before, with a uniform distribution in the segment [-1, 1], whereas the other two were determined in the following way: $x_{3,i} = x_{1,i}$, which corresponds to a functional relationship between x_1 and x_3; $x_{4,i} = (2\,x_{2,i} + \xi_i)$, which corresponds to the correlation between x_2 and x_4 with the correlation coefficient 0.895 ($\{\xi_i\}$ is a random value distributed uniformly in the segment [-1, 1] and not correlated with any of the values $\{x_{j,i}\}$, f = 1, 2, 3). In the right column of Figure 1 we have given the computed functions $F_j(x_j)$. The correlation ratio of the determined correlation was equal to 0.986.

As an example of the practical use of this program, the authors, in collaboration with L. A. Dosycheva, carried out a statistical analysis of the correlations of the norms of spring high water for 210 drainage basins in the territory of the USSR with the determining factors: mean long-term annual precipitation P, in mm, temperature, T °C, and humidity e, mb, area F, km^2, wooded area λ, % and elevation h of the watershed, m. As the parameters of the high water hydrograph we selected the dates of the beginning τ_1, maximum τ_{max} and end τ_2 of the high water, total runoff Y_{spr}, mm and the maximum daily runoff Y_{max}, mm/day (Fig. 2).

An analysis of the graphic dependences (Fig. 2) shows, as might be expected, that the spring high water begins and ends earlier with an increase in the mean annual air temperature, but with an increase in the annual quantity of precipitation all the times of high water are displaced to later times. In addition to climatic factors, the dates of the maximum and end of the high-water period are influenced by the area and mean elevation of the drainage basin above sea level. With an increase in the area the duration of the high water becomes greater and the dates τ_{max} and τ_2 occur later. With an increase in the drainage basin above sea level, indirectly related to the mean slope, the duration of the high water decreases and the dates τ_{max} and τ_2 set in earlier. The date of the maximum discharge is dependent on the extent to which the basin is forested: the greater the degree to which the basis is forested, the later does the maximum occur.

The total layer of high-water runoff is dependent on the mean annual air humidity and the annual quantity of precipitation: the runoff layer decreases with an increase in humidity and increases with an increase in precipitation. A decrease in runoff with an increase in humidity is caused by the close correlation between the norms of mean annual humidity and air temperature, observed in nature. The same as the total layer, the maximum daily runoff layer is in direct proportional dependence on the annual quantity of precipitation and is inversely proportional to air humidity. The maximum daily runoff layer is influenced by the area of the drainage basin: with an increase in area the runoff layer decreases.

The closeness of the correlation between the measured parameters and their values taken from the constructed curves, characterized by the values of the correlation coefficient or the correlation ratio (for nonlinear correlations) varies from 0.193 to 0.993 with a high significance level. Naturally, the correlations with the first factors taken into account are maximum. They gradually decrease when establishing a correlation with subsequent factors.

As might be expected, the closeness of the sought-for correlation of characteristics of high water with the determining factors increases with an increase in the number of factors taken into account from 0.933 to 0.948 for τ_1; from 0.895 to 0.934 for τ_{max}; from 0.783 to 0.901 for τ_2; from 0.411 to 0.638 for Y max and from 0.633 to 0.875 for Y_{spr}. For all the high-water characteristics, except, to be sure, Y_{max}, the determined correlations can be used in actual practice in constructing hydrographs for poorly studied drainage basins. In order to obtain more precise correlations for Y_{max} it is necessary to use additional information on the nature of spring (whether it is fast and steady), precipitation during the high-water period, etc.

Such analyses have also been made successfully for many other hydrometeorological phenomena. The described statistical analysis method can be applied in computations and in other fields of the national economy.

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CALCULATION OF LENGTH OF SAND RIDGES IN OPEN FLOWS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 89-96

[Article by Candidate of Technical Sciences B. F. Snishchenko, State Hydrological Institute, submitted for publication 11 July 1979]

Abstract: On the basis of the hypothesis of proportionality of the length of sand ridges to the interval between large-scale channel eddies, the author has derived a computation formula for determining the length of microforms in rivers and canals and under laboratory conditions. The formula was derived using extensive field and experimental data from the author's own observations and also data from other authors.

[Text] Microforms are small sand ridges which occur widely, not expressing the overall morphological structure of the channel, but creating its macroroughness and constituting the principal form of transport of bottom sediments [11]. The most widely accepted classification is the division of ridges into three types: ripples, dunes or ridges proper and antidunes. The object of this investigation is large microforms which occur on a large scale -- dunes, which henceforth will be called ridges or microforms. Horizontally the configuration of these ridges is characterized by a great diversity and until now it has not been possible to relate it reliably to the determining factors. Accordingly, in this article we will not further divide this class of ridges into subtypes.

The formation of sand ridges is associated with the periodic effect of turbulent fluctuations on the bottom. This idea, for the first time expressed by M. A. Velikanov [1], is fundamental in this study. There are also other opinions with respect to the reasons for the formation of periodic bottom structures, determining local bottom deformations. K. V. Grishanin for the first time confirmed Velikanov's idea, using an analytical approach, that the mechanism leading to the formation of ridges is structural eddies of the turbulent flow [3]. The initial lengths of the sand ridges of 1-3 flow depths approximately correspond to the dimensions of large turbulent disturbances. N. A. Mikhaylova [14] and N. S. Sharashkina [21] demonstrated this in the laboratory. Under field conditions, the author's measurements indicated that the length of the newly forming ridges on the leveled river bottom was also 2-4 flow depths [15].

It has been experimentally demonstrated that there are structural kinematic elements in the flow: eddies having dimensions close to depth of the flow [2, 7, 12, 13, 18]. In a natural flow with a ridged bottom it was possible to determine periods of large-scale velocity fluctuation associated with the largest turbulent eddies and fluctuations of a lesser period corresponding to small eddies [12, 18].

A. B. Klaven and Z. D. Kopaliani, on the basis of experiments in the channel laboratory of the State Hydrological Institute, established some properties of kinematic structural elements of channel turbulence [7, 8, 9]. In particular, it was found that large-scale flow elements, whose height is equal to the depth, consist of eddies of a lesser size. The longitudinal dimension of the largest structural eddy formations is on the average 6.5 times the flow depth in the case of a flat bottom and decreases with an increase in granular roughness. The eddies are displaced in the direction of the averaged flow current and with movement from left to right rotate clockwise. The structural elements of the flow in the case of a ridged bottom were not investigated in the experiments in [9]. However, it follows indirectly from the results of two experiments close in conditions, with ridges and an even bottom, that the longitudinal dimensions of large-scale eddies correspond to the length of the ridges.

Field observations show [18] that flow around the ridges is accompanied by periodic surges to the surface of water masses having a high energy. Since the periodic surges occur in the region of the troughs, there is basis for assuming that the rear part of the eddy, having the maximum energy of ascending fluid flows, is adapted to this ridge element at the time of the surge. The presence of surges over the troughs of adjacent ridges indicates that within the limits of the ridge one large-scale eddy periodically appears and diffuses, and its length corresponds to the length of the ridge.

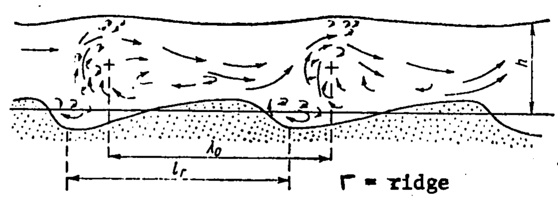

Fig. 1. Basic diagram of interaction between large channel eddies and microforms. λ_0 -- eddy interval; l_{ridge} -- length of microform (ridges).

It therefore can be assumed that large-scale elements of turbulence are localized in the case of a ridged bottom profile. The formation of ripples on the body of the ridge, evidently, must be associated with the effect exerted on the bottom by small bottom eddies entering into the makeup of the large-scale formation.

Figure 1 shows the proposed scheme for the interaction of large-scale eddies with ridges of a steady profile in the longitudinal flow plane. A structural diagram of the eddy was prepared on the basis of modern experimental data [10, 20]. The mean distance between adjacent large eddies in the channel flow, the eddy train interval λ_0, can be determined using the K. V. Grishanin formula [4]

$$\lambda_0 = \frac{1}{\text{const}} \frac{C}{\sqrt{g}} h, \qquad (1)$$

where h is the flow depth; C is the Chezy formula; g is the gravitational constant.

In 1979 Grishanin [5] transformed formula (1) to the form

$$\lambda_0 = h \sqrt[3]{\frac{C^2}{g}}, \qquad (2)$$

which we will also use for establishing a correlation between the eddy interval and the ridge length. Formulas (1) and (2) were obtained by the methods of the theory of dimensionalities, proceeding on the assumption of a proportionality of the λ_0 interval to the flow depth and its inverse dependence on the rate of energy dissipation. The greater the rate of dissipation, the denser is the spacing of large eddies along the length of the flow.

Proceeding on the basis of the adopted hypothesis of a proportionality of the length of the ridges to the eddy interval in the channel flow, we will establish a correlation between them, using dependence (2) and experimental information on the lengths of the microforms:

$$l_r = f(\lambda_0) = f\left(h \sqrt[3]{\frac{C^2}{g}}\right). \qquad (3)$$

As the initial data we used materials specially collected by the author of the observations and information from published studies. A bibliography and the method for measuring ridges under field conditions are given in [17, 19]. The C coefficient was computed primarily on the basis of the measured slopes and current velocities. Data for the Vychegda and Volga Rivers (points 9 and 10 in Fig. 2) were processed taking into account formula (6), derived for conditions close to those for the mentioned rivers.

In order to establish the universality of the origin of ridges under different scale conditions of interaction between the liquid and solid phases we drew upon data from experiments and full-scale observations in flumes, in rivers and canals of different size.

The experimental points on the graph $l_{ridge} = f(\lambda_0)$ (see Fig. 2) fell, with some scatter, along a single straight line, thereby confirming the hypothesis of a correspondence between the lengths of the ridges and the interval of the large-scale channel eddies. The correlation coefficient between the right and left parts of formula (5) is 0.87 and the percentage standard deviation is 84%.

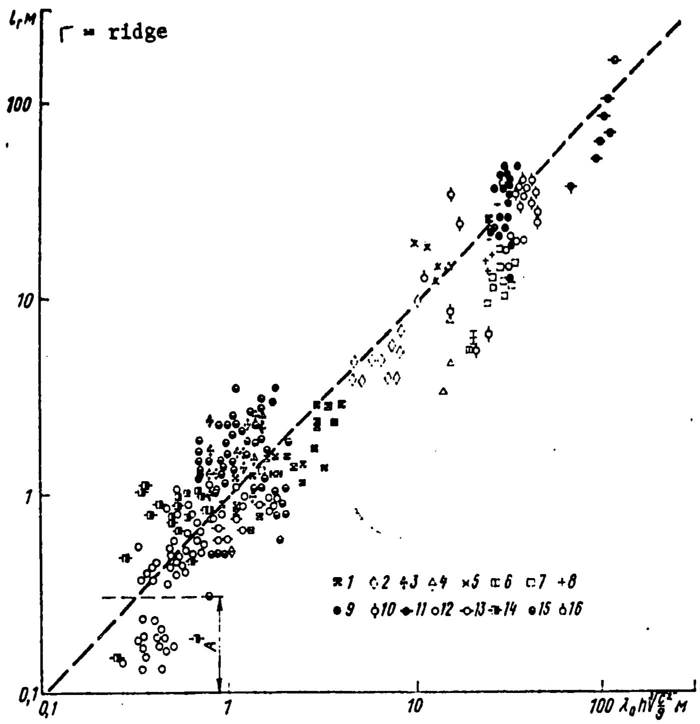

Fig. 2. Correlation between length of ridge l_{ridge} and eddy interval λ_0 under field and laboratory conditions. A) region of ripples. Field data: 1) Hiya River and Japanese canals (Sinohara and Tsubaki); 2) Polomet' River (Korchokha); 3) Polomet' River; 4) Severnaya Dvina River; 5) Oka River; 6) Don River; 7) Karakumskiy Canal; 8) Volga River; 9) Volga River; 10) Vychegda River; 11) Danube River; 16) Luga River (Sinshchenko, State Hydrological Institute). Laboratory data: 12) Pushkarev; 13) Kopaliani; 14) Znamenskaya; 15) Hay, Simons and Richardson.

The existing scatter of experimental data about the correlation line is an ordinary phenomenon when reference is to empirical graphs of the dependence of the dimensions of ridges on the flow parameters. The scatter is attributable to a number of factors and requires special investigation. We can only briefly discuss some of them.

In laboratory experiments for creating a ridge-formation process similar to that in nature it is necessary to take into account too great a number of factors, including the physicomechanical and hydrodynamic properties of the ground and flow, the morphological characteristics of the flow, ridge formation time, etc. They are not identical in the experiments of different authors and therefore with one and the same values of the usually measured mean parameters of the flow (depth, velocity, diameter of particles) the dimensions of the ridges are different, with a definite random error.

Such errors also arise as a result of the use of different samples by experimenters in the processing of field and laboratory data. The imperfection of measuring instruments and methods for measuring ridges and flow parameters also gives rise to errors.

Under field conditions the most significant systematic errors can arise for two reasons:

-- due to the measurement, at low water, of relict ridges formed by the high water and having dimensions not corresponding to the low-water flow hydraulics;
-- due to failure to take into account the three-dimensionality of the ridges when processing bathygrams of longitudinal measurements. The latter circumstance leads to an underestimate of ridge dimensions by 20-50%, which is reflected in deviation of the points from the straight line in the upper part of the graph (Fig. 2).

The underestimate occurs due to the fact that the length of the ridges, measured at the line of the maximum reading of a three-dimensional ridge, does not coincide with the length determined from the longitudinal lines intersecting the crest at the sites of lower readings. On the river bottom the three-dimensional ridges were distributed randomly; therefore, the maximum readings of their crests, giving some idea concerning the true height and length of the ridge, are not situated along a single longitudinal line. On the bathygram of longitudinal measurements, made by an echo sounder along the three-dimensional ridges, different sectors of these microforms will be noted, and accordingly, different heights and lengths of ridges, differing from the true maximum values of these parameters. The averaging of the determined values along different longitudinal lines, first of all does not lead to identical results [18], and second, understates the true dimensions of the ridges.

Taking into account what has been said, a straight line can be drawn on the graph at an angle of 45°, which is evidence of existence of the correlation

$$\ell_{\text{ridge}} \approx \lambda_0 \qquad (4)$$

in a broad range of investigated conditions.

The equation for the straight line has the form

$$\ell_{ridge} = h\sqrt{\frac{C^2}{g}}. \qquad (5)$$

The presence of the coefficient C in formula (5) is an important circumstance, taking into account the inverse relationship between hydraulic resistance and the mean distance between large eddies.

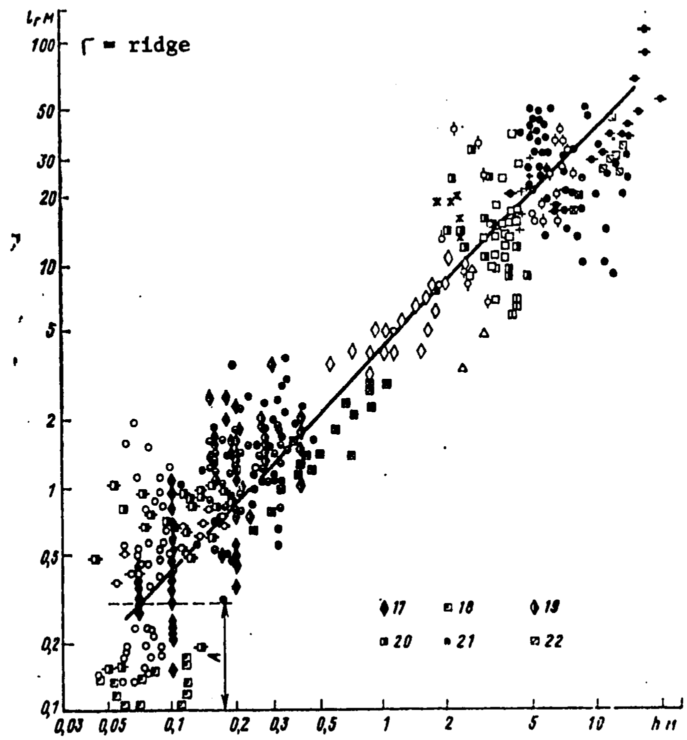

Fig. 3. Dependence of length of ridge ℓ_{ridge} on flow depth h according to field and laboratory measurements. A) region of ripples. Field data: 20) Selenga River (State Hydrological Institute); 21) Volga River (Gidroproyekt, State Hydrological Institute); 22) Irtysh River (State Hydrological Institute). Laboratory data: 17) Gonkarov and Lapshin; 18) Irtysh River (State Hydrological Institute); 19) Zheznyakov and Debol'skiy. The remaining symbolization is the same as in Fig. 2.

Direct observations of ridges confirm this correlation. Measurements by the author of [16] on a number of rivers in the European USSR with a fine-sand bottom led to a formula for the coefficient of hydraulic resistance in dependence on ridge steepness h_{ridge}/ℓ_{ridge}

$$\lambda = 0{,}23\,\frac{h_r}{l_r} + 0{,}0075. \qquad (6)$$

[r = ridge]

The free term in this formula takes granular roughness into account. The dependence (6) was obtained for a state of dynamic equilibrium of the bottom.

Using formula (6) and the expression $\lambda/2 = g/C^2$, we can transform formula (2) to the form

$$\lambda_0 = h\sqrt{\frac{1}{0{,}11\,\frac{h_r}{l_r} + 0{,}0037}}. \qquad (7)$$

[r = ridge]

Hence it follows directly that the distance between the eddies decreases with an increase in ridge steepness, that is, with an increase in channel macroroughness.

Accordingly, in the case of a ridged bottom dependence (5) reflects the self-regulability of the moving "flow-channel" system: increasing the bottom macroroughness of the channel, the flow more intensively expends its energy due to an increase in the number of eddies per unit length (steep ridges are shorter than gently sloping ones).

A dependence close in structure to (5) and giving good agreement with field data was derived in 1974 by A. V. Karaushev [6]:

$$l_r = 0{,}44\,h\sqrt{\frac{0{,}7\,C^2 + 6\,C}{g}}. \qquad (8)$$

It follows from the graph $\ell_{ridge} = f(\lambda_0)$ (see Fig. 2) that the equality $\ell_{ridge} \approx \lambda_0$ is observed in rivers, canals and flumes under field and laboratory conditions. However, at the lower part of the graph it is possible to discriminate a group of points not adhering to a direct proportionality between ℓ_{ridge} and λ_0. This region is occupied by laboratory-produced small ridges which can be classified as ripples and in whose formation the most important role is played by other factors -- small bottom eddies, etc.

Evidently, the region of ripples must be clearly detected on a graph of an extremely simple form $\ell_{ridge} = f(h)$. The correspondence of the length of large-scale formations to the flow depth makes it possible to postulate the presence of a high correlation between ℓ_{ridge} and h.

In order to construct the graph $\ell_{ridge} = f(h)$ (see Fig. 3) we used about 500 experimental points obtained in a broad range of characteristics of the flow and channel [17, 19]. The correlation is approximated by the dependence

$$l_\Gamma = 4{,}2h. \qquad (9)$$

The correlation coefficient between l_{ridge} and h was 0.85. The percentage standard deviation was 92%.

Klaven and Kopaliani, on the basis of initial data of lesser volume [9], obtained an expression similar to (9) with a close proportionality factor

$$l_\Gamma = 5h.$$

[Γ = ridge]

The straight line $l_{ridge} = 4.2$ h is real for depths greater than 10-12 cm.

The regions of points in Figures 2 and 3, not approximated by the dependences (5) and (9), must be regarded as a class of ripples and the seeking of other relationships is required for their description.

Computation of the length of ridges is of great importance in channel process theory and practical hydraulic construction. The evaluation of energy losses of the flow in the case of a ridged bottom of the channel, construction of theoretical schemes of genesis of microforms, development of dependences for evaluating the discharge of sediments and computation of channel deformations require a knowledge of the functional type of the parameter l_{ridge}. It is fitting to recommend formula (5) for the indicated purposes.

In engineering computations of channel deformations methods taking into account the structural form of sediment transport are coming into increasingly broader use. In addition to the height of the ridges and their rate of movement, for practical work it is also necessary to know the length of the ridges.

Calculations of the period of advance of ridges across an engineering structure on the bottom of a river -- scattering the discharge of waste waters, the heads of water intakes, underwater excavation, etc., none of these can be reckoned without a knowledge of the length of microforms together with the rate of their movement. The proper setting of distances between structures along a river in the laying out of systems for the discharge of waste water, for water diversion, and water intakes, systems for dissipating energy, etc., also requires calculation of the length of microforms. In many cases in the computation formulas for other ridge parameters the ridge length enters as an argument and in such cases this characteristic must be computed correctly.

In practical computations it is recommended that formula (5) for rivers, canals and laboratory conditions be employed. This requires the availability of information on the depth and mean velocity of the flow and on slope of the water surface. The numerous dependences for the Chezy velocity factor C which are available, in the case of their use, can also require a knowledge of other characteristics of the flow and channel.

As the first rough approximation in the early stages of planning it is admissible to make calculations of the length of microforms using dependence (9). In order to determine the parameter l_{ridge} more precisely it is necessary that the research program include corresponding observations of flow and channel parameters.

In organizing network channel observations at hydrometeorological observatories it is necessary to set the length of the segment of detailed observations correctly, as well as the time interval between longitudinal depth measurements with an echo sounder.

Preliminary calculations of the length of ridges using formulas (9) or (5) make it possible to stay free of error in fixing the extent of the longitudinal line along which it is necessary to plot the number of ridges necessary for statistical processing -- not less than 30. The time interval t must be less than the period τ of movement of the ridges. The formula for the rate of movement of ridges c_{ridge} [19], derived on the basis of extensive laboratory and field data, makes it possible to obtain the computed period as

$$\tau = \frac{l_\Gamma}{c_\Gamma}.$$

[Γ = ridge]

Further investigations in the study of microforms should involve a joint analysis of macroturbulence and the parameters of ridges under laboratory, and especially under field conditions.

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INVENTORY OF AGROCLIMATIC RESOURCES IN THE SPECIALIZATION OF AGRICULTURAL PRODUCTION IN THE UKRAINE

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Abstract: The authors present generalized information on the agroclimatic resources of the Ukraine and phenomena in its territory which are dangerous for agriculture. The article gives the optimum values of photosynthetically active radiation, the sums of temperature and precipitation for the principal agricultural crops during the growing cycle. The data presented here can be used in an agroclimatic validation of specialization of agricultural production. The needs of agricultural science and production for agroclimatic information are examined in this connection.

[Text] As is well known, crop yield is the end result of the influence of numerous factors in the life of plants. Among these, agroclimatic resources are of great importance. These characterize the supply of plants with solar radiation, heat and moisture. The necessity for their more complete and proper inventory is now increasing substantially in connection with the intensification, specialization and concentration of agricultural production on the basis of interfarm cooperation and agroindustrial integration.

The climatic zones of the Ukraine differ from one another with respect to the level of supply of the principal factors for the life of plants. The relationship to them of each type of agricultural crops is determined by the needs of plants. Accordingly, in solving problems involved in the validation and planning of agricultural production it is necessary to take into account the correspondence between the needs of agricultural crops and the availability of agroclimatic resources in the territory.

Tables 1 and 2 give data on the agroclimatic resources of the territory of the Ukrainian SSR in the form of the sums of photosynthetically active radiation $\sum$ PAR, the sums of active temperatures $\sum T$, the precipitation sums $\sum R$ during the growing season and data on the need of the principal agricultural crops for these resources [1, 4].

A comparison of the data in these tables makes it possible to determine what factors are limiting in each zone of the UkrSSR and for what crops. However, a comparison of the needs of some agricultural crops with the availability of climatic resources in its territory does not always confirm this.

Now we will examine this point in individual examples. The opinion has been established in the literature [10] that solar radiation is not a limiting factor and the supply of the territory with PAR (receipts during the growing season, limited by a temperature +5°C) is greater than the needs by winter wheat (receipts of PAR during the growing cycle of this crop). Accordingly, in all zones of the UkrSSR the energy resources are adequate for its cultivation, and in addition, there is a definite reserve for the cultivation of afterharvested crops. For sugarbeets the energy resources as an average for the republic are also adequate, but in the northern zones they are much less than the need or are equal to it. Therefore, here it is very important to sow beets at the optimum time. A delay with the sowing leads to an underharvest and creates stressed conditions during its harvesting. The energy conditions of the UkrSSR on the average meet the need of early maturing corn over the entire territory. Medium-late varieties and hybrids cannot really be cultivated for grain. Similar conclusions can also be drawn using the sums of active temperatures, which correlate closely with the sums of PAR.

The supply of the territory of the Ukraine with moisture decreases toward the south and southeast, which is due to a decrease in the quantity of precipitation and an increase in evaporability in this direction. This can be seen on the accompanying schematic map for a change in annual temperature coefficients from 2.0 to 0.7.

The agroclimatic conditions in the UkrSSR can be compared with the yield of gross production from plant cultivation per 1 hectare of agricultural lands in rubles. The map shows that for the most part they are in agreement. The maximum productivity of plant cultivation is in regions where the annual temperature coefficient is in the range 1.0-1.3. The minimum gross yield of production from crop cultivation is noted in regions with inadequate moistening.

The climate of the Ukraine in general is favorable for the cultivation of agricultural crops. However, it is characterized by a great variability and the presence of a number of unfavorable weather phenomena. These include drought, dry searing winds, dust storms, showers, hail, frost, severe cold, ice crusts, etc. Information on these phenomena are given for different zones of the UkrSSR in Table 3, prepared on the basis of studies [1, 3, 9 and others].

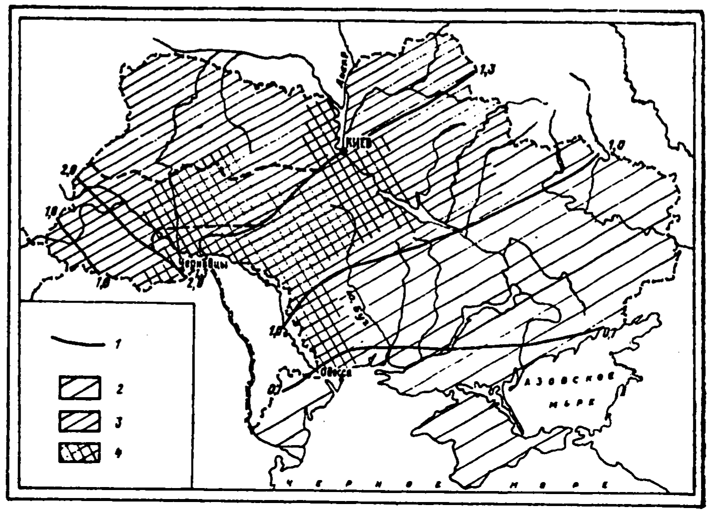

Fig. 1. Agroclimatic zones of the UkrSSR (1 - annual temperature coefficient) and yield of gross production from plant cultivation per 1 hectare of agricultural lands [2) 128-166 rubles, 3) 167-227 rubles, 4) 228-262 rubles] (from [1, 2]).

The enumerated phenomena inflict a considerable loss on agriculture. Under conditions of intensification of agricultural production there must be proper allowance for the principal factors in relation to its peculiarities and the more complete use of information on the unfavorable weather phenomena.

The most important peculiarity of agricultural production in general and each of its branches is an uncertainty as to the outcome, which is expressed in the circumstance that the final result from carrying out any measure is difficult to foresee with an accuracy adequate for practical purposes. This peculiarity is governed by the great duration of the process of obtaining production, the dependence of the productivity of agricultural crops in any stage of development and all links in the technological process on climatic and weather conditions, and also the great variability of climate and weather.

Agrometeorological science has created and continues to develop a number of methods for obtaining special information by means of which the uncertainty of the outcome is substantially reduced. These include methods for evaluating and predicting the agrometeorological conditions for carrying out field work, cultivation and wintering of agricultural crops, predictions of the heat supply during the growing season, onset of the principal phases of development, prediction of crop yield and reference literature.

Table 1

Agroclimatic Resources of the Territory of the UkrSSR

	Зона 1	Σ ФАР за вегетационный период, ограниченный $T>5°$ C, 10^9 ккал/га 2	Σ ФАР за вегетационный период, ограниченный $T>10°$ C, 10^9 ккал/га 3	Σ $T>10°$ C	Σ R за апрель—октябрь, мм 4	W в слое почвы 0—100 см под озимой пшеницей в фазу возобновление вегетации, мм 5	ГТК 6
7	Полесье	3,7—4,0	3,2—3,5	2350—2500	500—400	150—200	1,3—2,0
8	Лесостепь	4,0—4,3	3,5—3,7	2500—2800	400—325	150—200	1,0—1,3
9	Степь северная	4,3—4,6	3,7—4,0	2800—3200	325—250	125—150	0,7—1,0
10	Степь южная	4,6—5,1	4,0—4,6	3200—3400	250—200	100—125	0,7
11	Предкарпатье	4,0	3,5	2400	500	—	—
12	Закарпатье	4,7	4,0	3000	450	—	—
13	Предгорье Крыма	5,1	4,5	3300	200	125—150	1,0—0,7
14	Южный берег Крыма	5,3	4,7	3800	225	—	—

KEY:
1. Zone
2. Σ PAR during growing season, limited to T> 5°C, 10^9 Cal/hectare
3. Σ PAR during growing season, limited to T> 10°C, 10^9 Cal/hectare
4. Σ R during April-October, mm
5. W in soil layer 0-100 cm planted in winter wheat in phase of renewal of vegetation, mm
6. Annual temperature coefficient
7. Poles'ye
8. Wooded steppe
9. Northern steppe
10. Southern steppe
11. Ciscarpathia
12. Transcarpathia
13. Crimean foothills
14. Southern shores of Crimea

Table 2

Need of Agricultural Crops for Agroclimatic Resources During the Growing Cycle in the Ukraine

	Культура 1	Средняя продолжительность, *дни* 2	Сумма ФАР, 10^9 *ккал/га* 3	Сумма положительных температур [2], °C 4	Сумма осадков [3], *мм* 5
6	Озимая пшеница	315	2,9	2870	650
7	Яровой ячмень	100	2,2	1470	285
8	Овес	100	2,5	1470	290
9	Кукуруза				
10	раннеспелая	130—140	3,0	2030—2180[3]	220—310
11	среднеспелая	135—145	3,2	2200—2310[3]	280—350
12	позднеспелая	—	3,3	—	400
13	Просо	100	2,2	1765	300
14	Горох	90	2,1	1250	320
15	Сахарная свекла	150	3,7	2340	530
16	Подсолнечник	135	2,9	2430	250

KEY:
1. Crop
2. Mean duration, days
3. Sum of PAR, 10^9 Cal/hectare
4. Sum of positive temperatures, °C
5. Precipitation sum, mm
6. Winter wheat
7. Spring barley
8. Oats
9. Corn
10. Early maturing
11. Middle maturing
12. Late maturing
13. Millet
14. Peas
15. Sugar beets
16. Sunflower

Notes: 1) By "growing cycle" is meant the period from sowing to maturing of a particular crop; 2) sum of positive temperatures during period with $T \geqslant 10°C$; 3) precipitation sum ensuring obtaining 90-95% of the maximum yield

Other peculiarities of agricultural production, such as crop diversification, operation of many factors and seasonality are also closely related to the variability of climatic conditions. Their presence complicates the control of production of agricultural crops and zonality in the distribution of climatic factors makes necessary the specialization and concentration of agricultural production.

Using agroclimatic indices it is possible to solve a variety of fundamental problems in the agroclimatic validation of agricultural production in the form of agroclimatic regionalization. Among such indices we can mention the radiation and light [5], thermal [10], moistening [10] and bioclimatic [11] indices.

The increasing requirements on agricultural production increased the requirements on agroclimatic regionalization as well. For example, factors which are of great importance for solving problems in the intensification of agriculture are the agroclimatic validation of meliorative measures, systems for working the soil, fertilizing systems, especially under conditions of irrigated agriculture, etc.

The specialization of agricultural production brings to the forefront the problem of agroclimatic validation of the structure of sown areas. Its objective is the most complete and effective use of the peculiarities of climate for obtaining the maximum production. One of the most important problems in specialization is the agroclimatic validation of species regionalization of individual crops.

For example, the entire territory of the Ukraine is relatively favorable for the cultivation of winter wheat, but the climatic peculiarities of the steppe and wooded steppe zones and the Poles'ye in the republic introduce a need for corrections in the productivity of this crop.

The soils in the steppe zone have an adequate quantity of nutrients, the territory is supplied with heat, but here there is a shortage of precipitation, resulting in frequent droughts. The deficit of water consumption by winter wheat here is 140-180 mm during the growing season. Therefore, in the steppe part of the Ukraine there is a predominance of drought-resistant varieties: Bezostaya-1, Avrora, Kavkaz, Odesskaya-51 and others. In the wooded steppe zone the soils are in need of application of a large dose of fertilizers, more than in the steppe zone; here the climatic conditions are favorable for the cultivation of bushy varieties of the Mironovskaya selection.

The problems involved in the specialization of agricultural production to a fuller degree require solutions of problems in the agroclimatic validation of the times and methods for carrying out agricultural investigations on working of the soil, care for sown areas, application of fertilizers, etc. A lack of knowledge or an incorrect use of climatic resources of any area can reduce the effect of specialization.

The rational concentration of agricultural production is possible when there is a clear-cut answer to the question of the quality or productivity of climate in any particular locality. This is particularly important at the present time when the process of socialization of production in agriculture and industry is progressing at all levels and in different forms.

Characteristics of Phenomena in the Ukraine

	1 Зона	2 Вероятность засух за теплый период (IV—XI), %	3 Число дней с суховеями (IV—X)	4 Наибольшее число дней с пыльной бурей в год	5 Вероятность (% лет) минимальной температуры почвы —14°C и ниже на глубине залегания узла кущения (3 *см*) (XI—2 декада II)
11	Полесье	<1	1—5	0—5	10—40
12	Лесостепь	1—10	1—15	0—15	10—40
13	Степь северная	1—20	6—20	5—35	10—35
14	Степь южная	20—60	6—>20	10—40	10—25
15	Предкарпатье	<1	<1	—	—
16	Закарпатье	<1	<1	—	—
17	Предгорье Крыма	20—30	6—10	~10	—
18	Южный берег Крыма	—	<3	<5	—

The degree of development of agrarian-industrial complexes (AIC) in individual geographic zones does not coincide, which determines the differences in the scales and forms of control of AIC at the local and national levels.

In the territory of the UkrSSR, according to data from economic geographers, there are 214 AIC, including 92 viticultural, 8 ether oil and 106 sugar combines. Involved are 231 sovkhoz and 8 kolkhoz establishments and 225 industrial enterprises [7].

With respect to territorial-branch affiliation the production combines are usually organized within the limits of an administrative region on the basis of cooperation among major specialized interfarm enterprises which determine the directions of specialization in the production of commodities at each sovkhoz and kolkhoz establishment. They jointly take measures for putting on an industrial basis all the branches of agricultural production within the framework of the combine.

With respect to branch affiliation the AIC are created in dependence on the volumes of production and the location of specialized farms for this type of production in one or more administrative rayons, oblasts and economic regions of the republics.

Evidently, in this connection there must also be improvement and specialization of the forms of agroclimatic information in the form of reference manuals and aids, taking into account the distribution of AIC. Then the establishments of this complex interested in such information will be

Table 3

Dangerous for Agriculture

6 Повторяемость (%) лет с притертой ледяной коркой (XI—III)	7 Средняя продолжительность безморозного периода, дни	8 Число дней с оттепелью (XII—II)	9 Средняя продолжительность (часы) обильных осадков (IV—X)	10 Число дней с градом в год
20—>80	150—170	25—50	10—12	1—2
20—>80	160—180	25—50	9—13	2—4
20—80	160—200	30—50	7—9	1—3
<20—40	170—220	>50	7—8	1—3
<20	~180	40—45	12—14	1—3
<20	~190	50—60	9—10	1—3
<20	~180	>50	7—8	1—3
<20	220—240	>50	7—8	1—2

KEY:

1. Zone
2. Probability of droughts in warm season (IV-XI), %
3. Number of days with hot searing winds (IV-X)
4. Maximum annual number of days with duststorms
5. Probability (% of years) with minimum soil temperature -14°C and below at depth of tillering node (3 cm) (XI-second 10-day period in II)
6. Frequency of recurrence (%) of years with ground-in ice crust (XI-III)
7. Mean duration of frost-free period, days
8. Number of days with thaw (XII-II)
9. Mean duration (hours) of abundant precipitation (IV-X)
10. Number of days with hail per year
11. Poles'ye
12. Wooded steppe
13. Northern steppe
14. Southern steppe
15. Ciscarpathia
16. Transcarpathia
17. Crimean foothills
18. Southern shore of Crimea

able to use it for the problems involved in the planning and distribution of sown areas, the technology of cultivation of agricultural crops, etc. Agroclimatic information must be purposeful, timely, complete, profitable and reliable in order to meet the needs of control of agriculture.

Everything set forth above indicates that despite the considerable industrialization of agricultural production, its dependence on climatic conditions is not only not reduced, but is becoming more significant.

Technical progress is making necessary a more complete and clear allowance for the role of climate in all branches of agriculture.

In accordance with the instructions of the State Committee on Hydrometeorology on improvement in the furnishing of agricultural production with agroclimatic information, the Ukrainian Scientific Research Hydrometeorological Institute has studied the problem of the need of some administrative agencies and scientific institutions for agroclimatic information.

In order to solve current and long-range problems in the planning of meliorative and agricultural measures, the development of the optimum technology for the cultivation of agricultural crops, the optimization of their distribution over the territory of the republic, programming of crop yield, etc. there is a need for extensive climatic and agroclimatic information and also forecasting: anticipated weather conditions, agrometeorological and agroclimatic conditions for a year or more.

Considerable scientific information has now been accumulated on the influence of hydrometeorological conditions on the yield of agricultural crops; these data are contained in reference publications, atlases and other sources.

Among the available sources in the literature the KRATKIY AGROKLIMATICHESKIY SPRAVOCHNIK UKRAINY (Concise Agroclimatic Handbook of the Ukraine) merits approval; it was prepared by the Ukrainian Scientific Research Hydrometeorological Institute and published by the Gidrometeoizdat in 1976. It makes it possible to use, in a new interpretation, climatic data for the purpose of validating and correcting a great complex of agricultural studies under conditions of further specialization and concentration of agricultural production.

Users have concluded that for the most part the agroclimatic data meet their needs. However, a number of institutions expressed the desire that the agroclimatic handbooks be revised by lengthening the series of observations, supplementing the materials by complex indices, data on solar radiation, evaporation from a water surface, surface runoff, showers and other phenomena dangerous for agriculture, generalizing data on soil-climatic zones, the left bank, right bank, etc.

A number of proposals are being advanced on the development of problems which are in need of scientific and scientific-methodological solution.

The strengthening of the economy of agricultural production requires an optimization of all plant cultivation processes. Therefore, the need has arisen for determining the influence of climatic conditions on the technical aspects of agricultural production. In particular, applicable to crop cultivation there is a need for predicting the optimum times for pitting the roots of seed sugar beets, the sowing of early spring grain crops on floodplains in the Poles'ye, it is necessary to improve methods for the agrometeorological prediction of the yield of agricultural crops, taking into account the irrigation norm, under the condition of its decrease, etc.

It is necessary to formulate recommendations for determining the feasibility of producing sugarbeet seeds in different oblasts, and in dependence on soil-climatic conditions, on the distribution of potatoes in fields in need of melioration with dual regulation, on the distribution of potatoes in the Poles'ye region, without carrying out melioration work, on evaluating new methods for the working of soils, application of minerals, digging of ditches and holes, and furrowing in different zones and subzones of the UkrSSR in contending with the accumulation and retention of moisture in the soil. It is necessary to develop an agrometeorological model of the yield of vegetable crops. The wishes and proposals of different organizations concerning joint work have also been expressed.

Taking into account the needs for specialized agricultural production in the territory of the republic, the Ukrainian Scientific Research Hydrometeorological Institute proposes that attention be concentrated on the preparation of specialized agroclimatic handbooks. Such handbooks on grain crops and sugarbeets may be among the most timely and important for the Ukraine.

Agroclimatic information can find use in determining the state standards for the differentiation of expenditures of fuel, the efficiency of harvesting machines, norm-setting for fertilizers, contending with diseases and predators, planning of livestock shelters, buildings for the storage and processing the harvest, etc. by climatic zones. Taking into account the rates of development of agricultural production in our country, the practical importance of such information will increase with each passing year.

In conclusion it should be noted that agroclimatic information must be directed to the satisfaction of the needs for the development of agriculture, expressed in the processes of intensification of production, its further specialization and concentration.

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UDC 551.(509.313+543)

CONSERVATIVE VALUE IN A BAROTROPIC MODEL WITH ALLOWANCE FOR RELIEF

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 104-105

[Article by Candidate of Physical and Mathematical Sciences Z. V. Khvedelidze, Tbilisi State University, submitted for publication 22 May 1979]

Abstract: The law of conservation of relative vorticity in the absence of mountains is demonstrated. With allowance for the influence of a mountain this conservation is impaired and the more strongly the greater is the difference between the parameters characterizing the influence of the mountains.

[Text] The equations of hydrothermodynamics for a barotropic atmosphere, taking into account the influence of relief in a σ-coordinate system can be reduced in a standard way to the form [1, 3]

$$\frac{\partial \Omega}{\partial t} + u\frac{\partial (\Omega + l)}{\partial x} + v\frac{\partial (\Omega + l)}{\partial y} = -l\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + b\frac{\partial}{\partial x}\left(\sigma\frac{\partial \Phi}{\partial \sigma}\right) - a\frac{\partial}{\partial y}\left(\sigma\frac{\partial \Phi}{\partial \sigma}\right), \quad (1)$$

where u and v are the horizontal wind velocity components along the x and y axes respectively (the x axis is directed eastward in the direction of the parallel, y is directed to the north along the meridian); Φ is geopotential; l is the Coriolis parameter; $\sigma = p/p_s$; p is pressure; p_s (x, y, t) is pressure at the earth's surface;

$$a = \frac{1}{p_s}\frac{\partial p_s}{\partial x}, \quad b = \frac{1}{p_s}\frac{\partial p_s}{\partial y}$$

are parameters characterizing the influence of relief.

From the continuity equation we determine plane divergence and substitute into the vorticity equation. We obtain

$$\frac{\partial \Omega}{\partial t} + u\frac{\partial (\Omega + l)}{\partial x} + v\frac{\partial (\Omega + l)}{\partial y} = \frac{l}{p_s}\left(\frac{\partial p_s}{\partial t} + u\frac{\partial p_s}{\partial x} + v\frac{\partial p_s}{\partial y}\right) + b\frac{\partial}{\partial x}\left(\sigma\frac{\partial \Phi}{\partial \sigma}\right) - a\frac{\partial}{\partial y}\left(\sigma\frac{\partial \Phi}{\partial \sigma}\right) \quad (2)$$

or

$$\frac{d}{dt}(\Omega + l - l \ln p_s) = b \frac{\partial}{\partial x}\left(\sigma \frac{\partial \Phi}{\partial \sigma}\right) - a \frac{\partial}{\partial y}\left(\sigma \frac{\partial \Phi}{\partial \sigma}\right);$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} + v \frac{\partial}{\partial y}.$$

In a geostrophic approximation the equation assumes the form

$$\frac{d}{dt}[\Delta\Phi + l^2(1 - \ln p_s)] = b \frac{\partial}{\partial x}\left(\sigma \frac{\partial \Phi}{\partial \sigma}\right) - a \frac{\partial}{\partial y}\left(\sigma \frac{\partial \Phi}{\partial \sigma}\right). \quad (3)$$

If an influence of a mountain is absent, that is, a = b = 0 (or the extent of the mountain along x and y is identical), then the value

$$\Delta\Phi + l^2(1 - \ln p_s) = \text{const}. \quad (4)$$

With the replacement of p_s by the geopotential values we find that

$$\Delta\Phi_s + k\,\Phi_s = \text{const}, \quad (5)$$

where $k = 0.2 \cdot 10^{-12}\ \text{m}^{-2}$.

Thus, in the absence of the influence of relief there is conservation of the value determined from (5). With allowance for a mountain this conservation is impaired and the more strongly the greater is the difference between the parameters a and b.

The correctness of expressions (5) and (3) was checked on the basis of numerical data (using the AT_{500} chart) for a rectangular grid region with the grid unit measuring 26 x 22 [2]. The evaluation was made using the 70 grid squares in the central region for the territory of the Caucasus. Good results were obtained when checking formula (5) for 24 and 48 hours (the maximum difference did not exceed 2.6 dam).

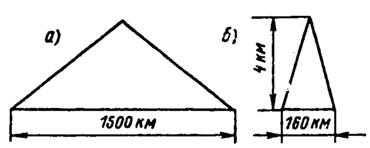

Fig. 1. Profiles of Caucasus Range. a) section along parallel, b) section along meridian.

In computing the right-hand side of equation (3) the Caucasus Mountains were represented in the form of a rectangular pyramid (see figure). The a and b mean values were determined [4]: $a = 0{,}68 \cdot 10^{-6}\ м^{-1}$; $b = 6{,}4 \cdot 10^{-6}\ м^{-1}$.

As might be expected, the values of the parameter

$$b\frac{\partial}{\partial x}\left(\sigma\frac{\partial\Phi}{\partial z}\right)-a\frac{\partial}{\partial y}\left(\sigma\frac{\partial\Phi}{\partial y}\right)$$

varied greatly for each point in the grid.

The results make it possible to conclude that the numerical scheme which was used in [2] can be applied for short-range prediction of geopotential under mountainous conditions.

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OZONE CONTENT IN AN URBAN ATMOSPHERE IN DEPENDENCE ON METEOROLOGICAL CONDITIONS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 105-108

[Article by Candidate of Biological Sciences V. A. Popov, L. N. Chernykh and Candidate of Medical Sciences Ye. V. Pechennikova, Institute of Applied Geophysics and Institute of General and Social Hygiene, submitted for publication 16 May 1979]

Abstract: The article gives data from observations of photochemical contamination of the atmosphere in Moscow and Yerevan. The results of a correlation analysis indicated a relationship between the photochemical formation of ozone and such components of exhaust gases of motor vehicles as nitrogen oxides, hydrocarbons and carbon monoxide, and also a number of meteorological factors. The role of the level of atmospheric contamination and meteorological factors in the formation of ozone was essentially dependent on time of day.

[Text] Using an automated system of gas analyzers we studied the possibility and peculiarities of formation of photochemical contamination of the atmosphere in cities, an index of which is the ozone content [4].

Data from around-the-clock measurements of ozone (O_3) in Moscow during 1974-1975 were close to the data published by A. S. Britayev [1] both with respect to the nature of the annual variation of O_3 and with respect to its maximum concentration (up to 0.07 mg/m^3). The dynamics of concentrations of nitrogen oxides (NO_x) did not indicate a photochemical nature of O_3, the greater part of which probably had a natural origin. The correlation of the daily O_3 maxima with the intensity of solar UV radiation at 1200 hours was low ($r = 0.27$). [Data on the intensity of solar UV radiation were obtained by the Moscow State University meteorological station.] All this indicated the absence of photochemical smog in Moscow.

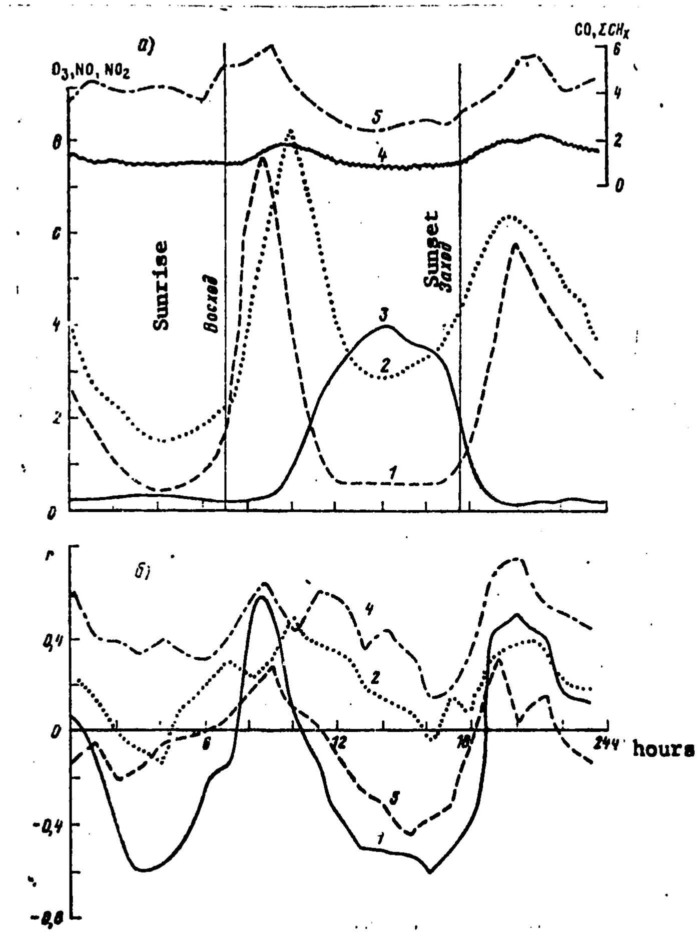

Fig. 1. Diurnal variation of concentrations in relative units (a) and time correlation functions of diurnal maxima of ozone and 30-minute concentrations (b) of NO (1), NO_2 (2), ozone (3), sums of hydrocarbons (4) and CO (5) in atmosphere at Yerevan.

In the figure, a represents the averaged daily dynamics of concentrations of the principal atmospheric admixtures at the center of Yerevan during the period 6 October - 9 November 1976. The fact that the concentrations of the "precursors" of O_3 correlate with one another in the morning indicated a prevailing influence of a single source of atmospheric contamination -- autotransport. The photochemical formation of O_3 was definitely noted in the course of 28 days for the most part under anticyclonic conditions with weak winds. Due to the autumn period the mean monthly O_3

at 1430 hours, however, was only 0.069 mg/m^3. In the figure the onset of an increase in O_3 only upon completion of rapid oxidation of NO ejected by auto transport into its dioxide after sunrise as a result of reaction with O_3 and free radicals, as we observed in the laboratory modeling of a photochemical smog [2], is characteristic.

Correlation Coefficients of Concentrations of Principal Admixtures in the Atmosphere at Yerevan With Meteorological Elements

(H is the height of atmospheric mixing, p is atmospheric pressure, u is air humidity, t is air temperature, d is wind velocity, v is wind direction, Q is total solar radiation)

	r		r
Макс. O_3 — H (8)	−0,59	Макс. O_3 — t макс.	+0,67
Макс. O_3—H (14)	+0,61	O_3 (0—24) — t (0—24)	+0,58
NO (7—9) — H (8)	−0,76	NO (7—9) — t (7—9)	−0,24
NO (14) — H (14)	−0,73	NO (9—21) — t (9—21)	−0,28
NO_x (8) — H (8)	−0,67	ΣCH_x (9—21) — t (9—21)	+0,03
NO_x (14) — H (14)	+0,03	CO (0—24) — t (0—24)	−0,11
ΣCH_x (6—9) — H (8)	−0,40	H (8) — t (6—9)	+0,03
ΣCH_x (14) — H (14)	+0,46	H (14) — t (14)	+0,18
CO (6—9) — H (8)	−0,40	O_3 (0—24) — d (0—24)	+0,25
CO (14) — H (14)	−0,54	O_3 (0—24) — v (0—24)	+0,32
O_3 (0—24) — p (0—24)	+0,03	O_3 (10—18) — v (10—18)	+0,12
Макс. O_3 — u (7—13)	−0,77	Макс. O_3 — Q (12.30)	+0,55

*Data from meteorological and aerological observations were obtained at the Yerevan Hydrometeorological Observatory. Макс = Max

In order to clarify the relationships between O_3 and the other admixtures we obtained the time correlation functions showing the change of the linear correlation coefficients between the daily O_3 maxima and the concentrations of the other substances each 30 minutes of the day (Figure, b). All the r values above 0.33 on the curves are statistically reliable. The figure shows that the role of different admixtures in the formation of the daily O_3 maxima was closely related to time of day. Whereas the positive correlations of O_3 with other admixtures at 0700-1000 hours must be attributed to its photochemical formation in reactions with their participation (including quite inert carbon monoxide (CO), these correlations at 1900-2100 hours can hypothetically be related to the phenomenon of intradiurnal inertia of atmospheric contamination, similar to the known phenomenon of its day-to-day inertia [3]. A possible confirmation of this is the cross-correlability of the morning and evening NO and NO_2 maxima and the sums of hydrocarbons (ΣCH_x).

During daytime, probably as a result of lessening of the intensity of solar UV radiation, there is a decrease in the rate of photochemical synthesis of ozone and a marked increase in the role of reactions destroying O_3, especially with the participation of NO. This is manifested in negative values of the correlation coefficients in Fig. 1b. The loss of O_3 in its slower reactions with $\sum CH_x$ and NO_2 is probably relatively small and therefore r for these substances during the daytime do not assume negative values. CO and O_3 virtually do not enter into reaction with one another and their negative correlation during daytime could be attributed to the positive correlation between CO and NO, which destroys O_3 at this time. However, the absence of a correlation between CO and NO at 1500 hours makes it possible to postulate the existence of complex reactions of destruction of O_3 with the participation of CO.

The table gives the results of a correlation analysis of the relationships between the principal admixtures present in the atmosphere at Yerevan and the meteorological elements. In parentheses we have given the local time for which the values of the factors to be correlated were taken. Despite the limited volume of data, and as a result, the statistical unreliability of a part of the correlation coefficients between H and the air content of admixtures, it is possible to trace a general tendency to an increase in their concentration with a decrease in the altitude of the blocking layer both in the morning and during the daytime. A change in the sign of the correlation coefficient between H and O_3 during the daytime in comparison with morning can indicate that H does not so much directly influence the air content of photochemical O_3 as indirectly through an influence on its concentration of "precursors," and, in turn, most importantly NO, being an antagonist of O_3 during the daytime. A qualitative analysis also indicated that the formation of increased daytime O_3 maxima is favored by a stable stratification of the atmosphere in the morning, whereas an unstable stratification during the daytime at least does not hinder the accumulation of O_3.

With a higher air temperature there were higher O_3 concentrations. The absence of a correlation between temperature and such substances as NO, NO_x, $\sum CH_x$, CO and also H indicates that the sole reason for this correlation probably could only be the direct influence of temperature on the rate of photochemical reactions. The O_3 maxima were in a close inverse correlation with air humidity and correlated directly with the intensity of total solar radiation, which serves as additional proof of the photochemical nature of O_3 in the atmosphere at Yerevan.

Conclusions

1. The low ozone content in the atmosphere at Moscow and the dynamics of nitrogen oxides not characteristic for smog are evidence of absence of a photochemical type of atmospheric contamination in this city.

2. In the atmosphere at Yerevan there are photochemical reactions with the formation of ozone in which nitrogen oxides, hydrocarbons and CO participate.

3. Atmospheric contamination by exhaust gases of autotransport played a dual role: whereas in the morning it favored ozone formation, during the daytime it reduced its atmospheric content.

4. Only morning temperature inversions increased the daytime ozone maxima, at the same time that during the daytime unstable atmospheric stratification did not hinder its atmospheric accumulation. The formation of photochemical ozone in the atmosphere at Yerevan was favored by an increase in air temperature and a decrease in humidity, and also an increase in the intensity of total solar radiation.

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CALCULATIONS OF AIR HUMIDITY OVER THE SEA FROM THE WATER-AIR TEMPERATURE DIFFERENCE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 109-111

[Article by Candidate of Geographical Sciences V. G. Snopkov, Institute of Oceanology, USSR Academy of Sciences, submitted for publication 18 May 1979]

Abstract: On the basis of data from shipboard hydrometeorological and gradient observations in different parts of the world ocean (more than 500 observations) the author has determined the dependence of the ratio of water vapor elasticity at the temperature of the water surface on the water-air temperature difference in the form of an exponential function which makes it possible to determine water vapor elasticity in the near-water layer of the atmosphere under different temperature stratification conditions over the world ocean.

[Text] In analytical and predictive practice cases are encountered when it is necessary to reconstruct lost or lacking meteorological and aerological information at the earth's surface and at different altitudes: this is one of the important problems in the routine weather service.

In this article we propose one of the possible methods for determining the elasticity of water vapor (e_z mb) above the ocean surface at the level of shipboard observations ($z \approx 10-14$ m) from the water-air temperature difference.

It is known that air humidity is dependent on temperature and the saturating elasticity of water vapor E_0 is determined completely by the water temperature in the surface layer of the ocean, that is, $E_0 = f(t_0)$. The water-air temperature difference $\Delta t_{0-z} = t_0 - t_z$ characterizes the stratification of the near-water layer of the atmosphere, on which is dependent the intensity of convective-turbulent processes, especially under conditions far from neutral stratification. The value $\Delta t_{0-z}/\bar{z}$ is the vertical temperature gradient in the near-water layer of the atmosphere, proportional to the turbulent heat flux. Thus, the parameters E_0 and e_z are dependent on t_0 and t_z and the difference Δt_{0-z} regulates the direction and intensity of convective-turbulent heat and moisture fluxes in the near-water layer of the atmosphere. Since the above-mentioned parameters are interrelated, it is natural to use this possibility in order to establish a regular correlation and express it by a formula and graph.

For this purpose we used data from more than 500 shipboard and gradient observations made in different parts of the world ocean, excluding the polar parts.

The figure shows the dependence between Δt_{0-z} and e_z/E_0, the ratio of water vapor elasticity e_z to the saturating elasticity of water vapor with a water surface temperature E_0. This figure shows that Δt_{0-z} over the ocean varies from -4.5°C to 12.5°C, that is, the change is 17°C. Almost half of all the observations fall in the interval Δt_{0-z} from -0.5°C to 1.4°C, characteristic for the usual, most frequently encountered conditions of stratification over the ocean. The negative values $\Delta t_{0-z} <$ -1.0°C for the most part are observed in those regions of the oceans where there are cold currents, such as the Bengal, Canaries, Peru, West Australian, California and others. The positive values $\Delta t_{0-z} >$ 2.5°C are associated with regions of the oceans with warm currents, such as the Gulf Stream, Kuroshio, Tsusimi and others. Values Δt_{0-z} from 4 to 12°C are observed only in winter, when the strongly cooled air from North America or the Asiatic continent advances onto the warm waters of the Gulf Stream or Kuroshio.

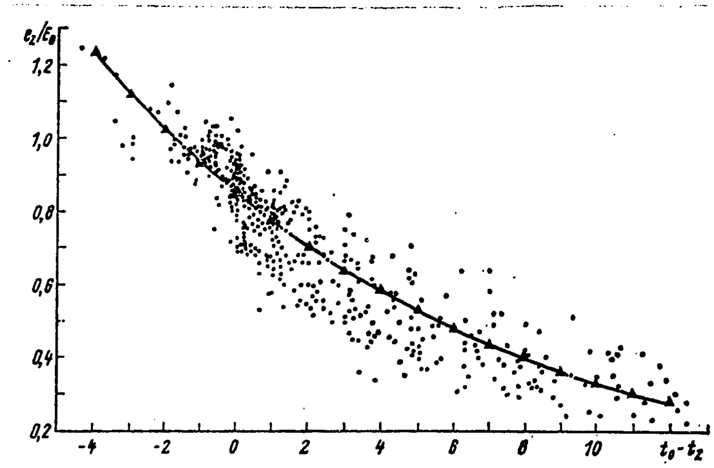

Fig. 1. Dependence of ratio e_z/E_0 on temperature difference $\Delta t = t_0-t_z$.

Table 1

Comparison of e_z Values Using Data from the Atlas "TIKHIY OKEAN" in August at the 180th Meridian

Широта, град 1	t_0 °C	t_z °C	Δt_{0-z} °C	e_z/E_0	e_a мб 2	e_z мб	$\frac{e_a - e_z}{e_a}$ %
60	7,6	10,0	—2,4	1,06	10,0	10,7	0,7
50	11,0	11,5	—0,5	0,9	12,1	11,5	5,0
40	20,6	21,0	—0,4	0,89	21,0	21,1	0,5
30	26,5	27,3	—0,8	0,92	28,0	31,2	11,0
20	28,2	27,2	1,0	0,76	30,0	28,4	5,0
10	28,3	28,0	0,3	0,82	31,5	30,9	0,2
0	28,6	28,0	0,6	0,80	29,6	30,6	3,4
40	13,6	11,8	1,8	0,72	10,5	10,9	4,0
50	8,3	7,9	0,4	0,81	8,1	8,6	5,0

Note: e_a is the elasticity of water vapor according to data in the atlas "TIKHIY OKEAN"; e_z are the water vapor elasticity values computed from Δt.

It is entirely to be expected that there is a considerable scatter of points relative to the mean position of the curve drawn by the least squares method. It is caused by the varied conditions for exchange in the near-water layer of the atmosphere and also the errors in shipboard observations. The exclusion of measurement errors by means of averaging of data to a considerable degree reduces the scatter of points. This can be seen in the example of the long-term mean monthly values t_0, t_z, and e_z taken from the atlas [1]. The equation for the curve is expressed by the exponential function

$$\frac{e_z}{E_0} = 0,85 \cdot 0,91^{\Delta t_{0-z}}$$

or

$$e_z = 0,85\, E_0 \cdot 0,91^{\Delta t_{0-z}}. \quad (1)$$

Thus, on the basis of water temperature t_0, using psychrometric tables, we first determine the maximum elasticity of water vapor E_0; then, using formula (1) it is also possible to determine e_z. We note that the E_0 parameter is dependent on the salinity of sea water. Therefore, this factor must be taken into account. In mass computations formula (1) can be programmed and the computations can be made on an electronic computer. Figure 1 can be used for the rapid determination of e_z.

Now we will cite several examples of checking of the derived dependence for individual observations and the mean monthly values under different temperature stratification conditions in the near-water layer of the atmosphere.

1) Conditions close to neutral stratification.

The following data were obtained on 9 June 1974 in the southern part of the North Sea at the point 52°24'N and 0°27'E at 1200 hours aboard the ship "Professor Vize.": water temperature t_0 = 11°C, air temperature t_{14} = 11.2°C, water vapor elasticity e_{14} = 10.0 mb. Using Fig. 1, we determine the ratio e_{14}/E_0 = 0.8. Hence e_{14} = 13.4·0.8 = 10.5 mb. The discrepancy between the measured and computed e_{14} values is 0.5 mb or 5%.

2) Strong instability conditions.

The following data were obtained on 3 March 1963 at 1200 hours on the ship "Polyus" in the Gulf Stream area for the point 36°38'N, 70°24'W: t_0 = 21.3°C, t_{12} = 9.2°C, t = 12.1°C, e_{12} = 7.5 mb. Proceeding the same as in the first case, we obtain e_{12} = 6.7 mb. The discrepancy between the measured and computed e_{12} values is 0.8 mb, which is 10% of the measured value.

3) Strong stability conditions.

For this case we will also take observations on the ship "Polyus" on 6 March 1963 at the point 39°59'N, 67°32'W. For 1200 hours t_0 = 5.2°C, t_{12} = 9.6°C, Δt = -4.4°C, e_{12} = 10.8 mb. Proceeding similarly, we find e_{12} = 11.0 mb. The discrepancy is 0.2 mb or 2%.

The table gives an example of comparison of the mean long-term e_z values obtained using data from the atlas TIKHIY OKEAN (Pacific Ocean). All the cited examples indicate a good agreement between the measured and computed water vapor elasticity values under different temperature stratification conditions in the near-water layer of the atmosphere.

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ATMOSPHERIC INVESTIGATIONS ABROAD USING AIRCRAFT LABORATORIES

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 112-119

[Article by Candidates of Physical and Mathematical Sciences Yu. V. Mel'nichuk, A. N. Nevzorov and G. N. Shur, Central Aerological Observatory, submitted for publication 5 June 1979]

Abstract: This is a brief review of the characteristics of foreign aircraft laboratories and also the principal instrument complexes with which these laboratories are outfitted.

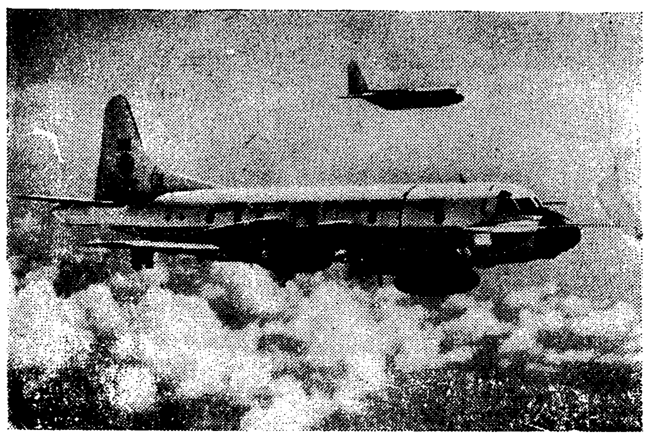
[Text] Introduction. Aircraft - flying laboratories, together with radiosondes, meteorological satellites and rockets, surface and shipboard radar apparatus, long ago permanently became parts of the arsenal of means employed for investigating the processes transpiring in the atmosphere.

They are used extensively in carrying out special experiments associated with both study of naturally transpiring atmospheric processes and with monitoring of the changes occurring as a result of artificial modification. The aircraft is also employed for the modification itself.

During 1974 the international tropical experiment TROPEKS-74 was carried out in the Eastern Atlantic. Twelve aircraft laboratories from four countries participated in the experiment; these included 2 aircraft from the Soviet Union. The authors of this article worked aboard a Soviet IL-18Ts aircraft. While the experiment was being conducted the scientists and specialists of the participating countries had the opportunity to become mutually acquainted with flying laboratories, their scientific equipment, methods for measurements, processing and analysis of data.

In the course of carrying out the experiment the scientists and specialists of one country participated in the scientific research flights of other countries, which made it possible to become acquainted with the operation of the measuring, recording and analyzing instrumentation directly in flight. The cooperation of specialists also continued in the analysis of data from aircraft experiments. In 1977 the authors of this article during the time of a visit to the flight research center in Miami (USA) were afforded the opportunity of becoming directly acquainted in flight with the newly outfitted flying laboratory WP-3D, intended for the most part for experiments in studying tropical hurricanes and their modification [6].

We feel that the principal characteristics of foreign aircraft laboratories, as well as data on individual instrument complexes used aboard these aircraft, are of interest to a broad range of specialists, both those who are engaged in the experimental study of atmospheric processes and those who use these experimental data.



WP-3D aircraft laboratory in flight. In background -- WC-130B.

Technical Specifications of Foreign Aircraft - Flying Laboratories

Table 1 gives the principal technical specifications of aircraft - flying laboratories used in the United States, Great Britain and France [1, 6].

With respect to the aircraft themselves on the basis of which the flying laboratories of these countries were created, all are of American production. The DC-6 aircraft laboratory listed in the table, taking an active part in the BOMEX and GATE (TROPEKS-74) experiments, in 1975 was disassembled and replaced by the WP-3D. The outfitting of the WP-3D aircraft has now been completed and it is one of the most modern flying laboratories in the United States. The figure shows the WP-3D aircraft in flight.

The multipurpose aircraft laboratories are the most universal: L-188 Electra, belonging to the interuniversity National Center of Atmospheric Research in the United States and the WP-3D, belonging to NOAA Research

Flight Center. The KC-135A aircraft is used in weather reconnaissance and is used only for sounding the atmosphere using dropsondes. The WC-130B belonging to the RFC NOAA, in addition to the main equipment for measuring the thermodynamic parameters of the atmosphere and navigational flight parameters, has the most complete complex of instruments for investigating clouds and precipitation. The WC-130B aircraft, together with the WP-3D and CV-990 aircraft, is now being employed in artificial modification work [6].

The Sabreliner aircraft is intended for the most part for radiation investigations of the atmosphere at great altitudes [3]. The Queen Air aircraft, with a short operating range, is outfitted with instrumentation for investigating turbulence and microphysics in the atmospheric boundary layer.

The table shows that a rather broad class of aircraft is being used abroad for research purposes. Most of these have a high ceiling and flight duration.

Table 1

Flight-Technical Specifications of Foreign Flying Laboratories

Самолет 1	Страна 2	Тип и количество двигателей 3	Скорость км/ч 4	Высота полета, м 5		Максимальная продолжительность полета, ч 8
				крейсерская 6	максимальная 7	
DC-6	США 9	Поршневой 12 4	360	4000	6000	12
WC-130B	США	Турбовинт. 13 4	480	8000	12000	11
KC-135A	США	Реактивный 4	630	11000	12000	9
CV-990	США	Реактивный 14 4	950	12000	13500	7
L-188 Electra	США	Турбовинт. 4	580	7500	9500	11
WP-3D	США	Турбовинт. 4	580	7000	10000	12
Sabreliner	США	Реактивный 2	720	13000	15000	4
Queen Air	США	Поршневой 2	300	4300	9000	6,5
C-130	Англия 10	Турбовинт. 4	500	5300	11000	12
DC-7	Франция 11	Поршневой 4	450	4000	6300	24

KEY:

1. Aircraft
2. Country
3. Type and number of engines
4. Speed, km/hour
5. Flight altitude, m
6. Cruising altitude
7. Maximum altitude
8. Maximum flight duration, hours
9. United States
10. Great Britain
11. France
12. Piston
13. Turboprop
14. Jet

Table 2

Summary Table of Equipment on Foreign Aircraft Laboratories

	1 Наименование приборов	DC-6	WC-130B	KC-135	CV-990	L-188	WP-3D	Sabreliner	Queen Air	C-130	DC-7
2	Система единого времени	+	+	+	+	+	+			+	
3	Инерциальная навигационная система	+	+	+	+	+	+	+	+	+	+
4	Допплеровская навигационная система	+	+	+	+		+				+
5	Система ОМЕГА	+	+				+				+
6	Измеритель барометрической высоты	+	+	+	+	+	+	+	+	+	+
7	Радиоальтиметр	+	+		+	+	+	+		+	+
8	Лазерный альтиметр малых высот	+					+				
9	Измеритель воздушной скорости	+	+	+	+	+	+	+	+	+	+
10	Измеритель курса	+	+	+	+	+	+	+	+	+	+
11	Измеритель температуры наружного воздуха	+	+	+	+	+	+	+	+	+	+
12	Измеритель влажности (температуры точки росы)	+	+		+	+	+	+	+	+	+
13	Измеритель скорости ветра	+	+		+	+	+	+	+	+	+
14	Система измерения порывов	+				+	+		+	+	
15	Рефрактометр	+					+				+
16	Измеритель коротковолновой радиации	+	+		+	+	+	+		+	+
17	Измеритель длинноволновой радиации	+	+		+	+	+	+		+	+
18	Измеритель температуры подстилающей поверхности	+			+	+	+		+	+	+
19	Измеритель температуры CO_2 на уровне полета	+			+	+	+				
20	Измеритель профиля температуры под самолетом				+						
21	Сканирующий радиационный термометр				+						
22	Измеритель спектра облачных капель	+	+			+	+				

Continuation of Table 2

	Наименование приборов 1	DC-6	WC-130B	KC-135	CV-990	L-188	WP-3D	Sabreliner	Queen Air	C-130	DC-7
23	Измеритель спектра капель осадков	+	+			+	+	+			
24	Измеритель водности облаков	+	+			+	+	+	+	+	+
25	Измеритель полного влагосодержания		+			+	+				
26	Измеритель жидкой воды	+	+				+				
27	Счетчик кристаллов		+								
28	Измеритель ядер конденсации	+					+				
29	Измеритель ледяных ядер	+					+				
30	Репликатор облачных частиц		+				+				
31	Измеритель пыли	+					+				
32	Заборник проб аэрозоля	+				+					
33	Радиолокатор донный 5 *см* с горизонтальным обзором 360°						+				
34	Радиолокатор хвостовой 3 *см* с вертикальным обзором 360°	+					+				
35	Радиолокатор носовой 5 *см* с обзором 240°		+				+				
36	Радиолокатор носовой 3 *см* с обзором 220°									+	
37	Радиолокатор носовой 3 *см* с обзором 180°	+			+	+		+			+
38	Радиозонды сбрасываемые		+	+							
39	Фотокамеры	+	+			+	+				
40	Кинокамеры	+	+			+	+				
41	Компьютер бортовой с внешними устройствами	+	+		+	+	+				

KEY TO TABLE 2

1. Name of instruments
2. Standard time system
3. Inertial navigation system
4. Doppler navigation system
5. OMEGA system
6. Instrument for measuring barometric altitude
7. Radioaltimeter
8. Low-altitude laser altimeter
9. Air-speed indicator
10. Course indicator
11. Instrument for measuring outside air temperature
12. Humidity (dew point) indicator
13. Wind speed indicator
14. Gust measurement system
15. Refractometer
16. Instrument for measuring SW radiation
17. Instrument for measuring LW radiation
18. Instrument for measuring temperature of underlying surface
19. Instrument for measuring CO_2 temperature at flight altitude
20. Instrument for measuring temperature profile below aircraft
21. Scanning radiation thermometer
22. Instrument for measuring spectrum of cloud droplets
23. Instrument for measuring spectrum of precipitation droplets
24. Instrument for measuring cloud liquid-water content
25. Instrument for measuring total moisture content
26. Liquid water indicator
27. Crystal counter
28. Instrument for measuring condensation nuclei
29. Instrument for measuring ice nuclei
30. Cloud particle replicator
31. Dust indicator
32. Aerosol sample intake
33. 5-cm bottom radar with horizontal scan 360°
34. 3-cm tail radar with vertical scan 360°
35. 5-cm prow radar with 240° scan
36. 3-cm prow radar with 220° scan
37. 3-cm prow radar with 180° scan
38. Dropped radiosondes
39. Cameras
40. Motion picture cameras
41. On-board computer with external devices

Aircraft Instrument Complexes

Navigation equipment. All the long-range aircraft carry inertial navigation systems INS LTN-51. These systems carry out measurement and double integration of the linear and angular accelerations of the aircraft and on this basis calculation of the ground speed and drift angle and calculation of the course, as well as measurement and differentiation of the pitching, banking and course angles. An inertial navigation system contains a computer which constantly feeds out the current value of the coordinates of the aircraft and navigation data for putting the aircraft in the prestipulated eight points on the trajectory. The error in determining coordinates does not exceed 1.5 km in one hour of flight. In addition, the inertial navigation system is one of the main parts of the scientific equipment on the aircraft. Its data are used for determining the parameters of the wind and turbulent fluctuations of the wind vector components [1].

A number of aircraft, for correction of errors in the inertial navigation system, accumulating during multihour flights, carry an "Omega" radionavigation system. The system uses the phase method for measuring coordinates, employing three transmitting stations operating at frequencies of 10.2-13.6 KHz. The accuracy in determining coordinates is not worse than 0.1 km.

Instruments for measuring the principal meteorological parameters. The total and static pressure are measured using Pitot tubes. In the immediate neighborhood of the receivers there are primary converters: capacitive (on the L-188 aircraft) or inductive (on the WC-130B and WP-3D aircraft) [1]. As a rule several Pitot tubes are installed aboard each aircraft. The pressure converters are connected to an on-board computer which accomplishes averaging and mean pressure values already enter into all the computations.

Geometric altitude is measured with radioaltimeters. One of the WP-3D aircraft carries a laser altimeter [6], making it possible to execute flights at altitudes from 15 m above the water surface.

The principal temperature sensor on all the aircraft is a wire resistance thermometer with vortex shielding. The time constant of the thermometer is about 1 sec; the coefficient of restitution is about 0.95. The accuracy in measuring ambient air temperature in the clear sky is not worse than 0.5°C.

On NCAR L-188 and Queen Air aircraft, in addition, there are reverse flow thermometers. These sensors are not wetted even in a zone of strong precipitation [1]. However, this does not mean that the presence of drops does not exert an influence on the accuracy in measuring temperature in clouds.

In order to obtain the current values for wind direction and velocity in the on-board computer, as already mentioned, data on ground speed and drift angle are received from the inertial navigation system. Course data arrive from a course system, usually autonomous; data on air speed are received from a Pitot tube with a pressure converter [1].

For measuring air humidity all aircraft use a dewpoint (hoarfrost) thermo-hygrometer. The error in measuring temperature is about 1°C. The instrument time constant is 2-3 sec. The instrument output is connected to an on-board computer [3].

Each aircraft carries a standard time system based on a quartz digital electric clock [3].

The on-board computers process data arriving from the measuring instruments and feed out to recorders and displays the true values of the principal meteorological parameters and the flight parameters: barometric altitude, geometric altitude, air speed, ambient temperature, wind velocity and direction, air humidity (dew point temperature). In addition, current time, latitude, longitude, banking, pitching and course angles are fed for registry and display.

Apparatus for investigating turbulence. The mentioned L-188, WP-3D, Sabreliner, Queen Air and C-130 aircraft, for measuring the turbulent fluctuations of velocity components, fluctuations of temperature and humidity, and also turbulent fluxes of heat, moisture and momentum, use a system for measuring gusts (the Gust Probe, developed at the NCAR (USA) [1, 3].

The measuring complex includes sensors for: instantaneous angles of attack and slippage of the oncoming flow (braked or free vanes), accelerations, total and static pressures, temperature, coefficient of air refraction. The instrument for measuring the coefficient of air refraction -- a microwave radiorefractometer -- is used for obtaining information on humidity fluctuations. The sensors for the remaining parameters give information both on the mean values and on fluctuations of the measured parameters [4].

All the enumerated sensors extend forward on special shafts, insofar as possible in the undisturbed flow in front of the nose of the fuselage, except for the accelerations sensors, situated within the shaft.

The system for measuring gusts has its own computation unit which receives information from the sensors mounted on a shaft, and in addition, from the sensors and systems aboard the aircraft: from the gyrovertical and the course gyroscope, from the inertial navigation system (or Doppler navigation system), from the system for measuring pressure.

Aboard those aircraft where the registry and processing of data and their display are accomplished using an on-board computer, the computation unit in the system for measuring gusts is connected to the common aircraft information system.

The system for measuring gusts makes it possible to obtain the instantaneous values of the fluctuations of all components of velocity, temperature and humidity in the frequency range from 0.02 to 10 cps.

Instruments for radiation measurements. All the aircraft carry instrumentation for measuring the integral hemispherical fluxes of radiation, descending and ascending. For this purpose use is made of stationary pyranometers and Eppley pyrheliometers, operating in the spectral ranges 0.2-3.0 μm and 4.0-50 μm respectively [1].

The L-188, WP-3D and WC-130B aircraft, as well as the C-130 and DC-7, are outfitted with PRT-5 radiation thermometers oriented at the nadir. The radiometers operate in the band of atmospheric transparency 9.5-11 μm and are intended for measuring temperature of the underlying surface or the upper cloud boundary [1].

A similar instrument, but with a ray scanning from the zenith to the nadir, with an angle of view 2°, with interchangeable filters in the range 8-20 μm, was carried on the American aircraft L-188, WP-3D, CV-990 and Sabreliner [1, 6].

The CV-990 aircraft carried an IR radiation thermometer with a filter in the CO_2 absorption band 14.5-15.5 μm. The instrument looks to one side, has an angle of view 2° and is used for measuring the static temperature of the outside air in the clear sky. Measurements in the clouds can be made using a far broader-band filter, which will make possible a considerable increase in instrument response. The instrument continues to perform in droplet clouds, in which measurements with contact sensors are encumbered with serious errors.

The CV-990 aircraft carries an IR radiation thermometer, scanning in frequency, oriented downward. It operates at the edge of the CO_2 absorption band and is intended for restoring the vertical temperature profile under the aircraft [6]. The CV-990 aircraft is outfitted with a filter pyrgeometer for spectral measurements of direct solar radiation [6].

In addition to the enumerated instruments, the CV-990 and Sabreliner aircraft carry a number of special radiometric systems, for the most part intended for measurements of the structure and properties of underlying surfaces [1, 3-6].

Apparatus for investigating clouds and atmospheric aerosol. Among the aircraft participating in TROPEKS-74, the fullest set of measuring instruments for determining cloud parameters was carried by NOAA (USA) DC-6 and WC-130 aircraft. Since 1976 the aircraft WP-3D has also been employed; it is outfitted with a broad range of cloud measuring instruments [1, 6, 7].

These aircraft carried measuring instruments of different generations, beginning with the models of the 1950's and ranging through unique models and variants of newly developed instruments. In making observations of the phase and disperse composition of clouds and precipitation use is made of a large-particle impactor, based on the foil method, and a replicator of cloud particles in a Formvar layer. Among the modern instruments for this purpose there is a photoelectric polarization counter of crystals and automatic laser discrete spectrometers for cloud and precipitation particles, the PMS [1, 2, 3, 5].

The PMS instruments consist of standardized measuring and recording units and different modifications of sensors, making it possible to cover the range of particle sizes from 3 to 4500 μm. Instrumentation has recently been developed for the registry of two mutually perpendicular sizes and forms of particles. This instrumentation is being used with increasing frequency on foreign aircraft laboratories. In addition to being carried by the WP-3D and the WC-130B, the PMS instruments are carried by the L-188 and Sabreliner, DC-7, and possibly, on other aircraft [2, 5].

The Johnson-Williams cloud moisture content instrument is used extensively. This instrument, based on the "hot wire" method, although it does not have a high accuracy and response (measurement range 0.2-6.0 g/m^3), is quite simple and is in standard production. Most foreign aircraft are outfitted with instruments of this type for measuring liquid water content [1, 3].

In addition, NOAA aircraft carry an instrument for measuring liquid-water content with a constant temperature of the sensor, ensuring a higher accuracy and response. The method of two hygrometers developed at NOAA, using Lyman-alpha absorption line UV hygrometers and a direct-flow evaporator, makes it possible to measure air humidity and total moisture content and obtain information on the liquid-water content of clouds and precipitation [2, 6].

Measurements of cloud nuclei are carried out only at NOAA from a WP-3D aircraft (earlier from a DC-6); condensation nuclei -- using a small thermodiffusion chamber supplied with a camera; and ice nuclei -- using a cold chamber and acoustic counter. This apparatus was developed at NOAA [6].

The NCAR and NOAA aircraft are used in carrying out investigations of atmospheric aerosol. Instruments developed by these organizations are used for these purposes: a counter of Aitken nuclei, six-stage impactor, photoelectric counter of aerosol particles measuring more than 0.1 μm.

In addition, in flight there is sampling of aerosol on a filter -- a backing -- for subsequent laboratory analysis of its morphology and chemical composition [1, 2, 6, 7].

Aircraft radar apparatus. For making observations of the distribution of the radar images of clouds and precipitation most of the foreign aircraft carry standard navigational scanning radars with antennas placed on the fuselage nose. Such radars operate in the ranges 3 and 5 cm and have a scanning angle in the horizontal plane from ±90 to ±120°. Using them it is possible only to determine the extent and location of zones of precipitation and large-droplet clouds and evaluate qualitatively the intensity of the reflected signals in the forward hemisphere along the aircraft course [1, 6].

The NOAA WP-3D aircraft is outfitted with two additional radars specially for research purposes.

One of them, operating at a wavelength of 5 cm, has an antenna placed in a radiotransparent fairing under the fuselage. The angle of horizontal scanning of the antenna is 360°. A similar type of radar was installed on the DC-7 aircraft. The circular-scan display has a sweep which is strictly tied in to a northerly direction.

Such a system for spatial scanning and display makes it possible to carry out observations of the evolution of cloud systems directly in the course of an experiment even in the case of complex aircraft flight trajectories. The antenna of the second 3-cm radar on the WP-3D aircraft is situated in a tail fairing and performs circular scanning in the vertical plane. Such a system makes it possible to ascertain the vertical dimensions of clouds and precipitation in the plane perpendicular to the flight direction [6].

The two radars are joined to a computer which accomplishes digital coding of the image with registry on a magnetic tape. The computer makes it possible to obtain punchcards and also to convert back to videoimages on displays.

The CV-990 aircraft carries a side-scan radar system with a synthesized directional diagram. The apparatus is a duplication of that which was used on the "Apollo-17" spaceship and is used for a study of the fine structure of the underlying surface.

Aircraft systems for processing, registry and display of data. The L-188, WP-3D, WC-130B, CV-990, C-130 and DC-7 aircraft carry systems for the processing, registry and display of data on the basis of on-board computers and auxiliary devices connected to them [3].

These systems differ from one another with respect to the type of main computer, design of the memory and recording units, and also displays and external control devices.

A multichannel analog-code converter makes it possible to use the information from the sensors and systems having an analog output. This converter is fed data on temperature, deceleration, dew-point, radiation temperature, etc. The systems for measuring pressures (total and static) are connected with a computer through its digital converters [3].

The sensors for measuring angles and having selsyn outputs are connected to the computer through selsyn-digital converters.

The standard time system is connected to the computer by a digital output. The inertial navigation system is also connected to the computer by digital outputs for all the measured parameters. Many measuring systems require two-directional communication with the computer. As already mentioned above, for example, the gust-measuring system requires information from the inertial navigation system and gyroscopes. The computer has an output converter making it possible to feed out the processed information in both digital and analog forms [3].

Radar images are also coded and in digital form are fed into the computer. The recording and survey cameras carried aboard the aircraft operate by commands arriving from the computer and the photographs taken (their code) are registered through the computer in a magnetic storage unit.

The magnetic storage unit has two-directional communication with the computer. Control tests are fed from it and it stores the output information. Intermediate information and the necessary work programs are in the operational memory of the computer. In the on-board computers there is continuous computation of a total of about 100 parameters which are fed to the magnetic storage unit with a frequency of 50 cps.

The system of displays connected to the computer makes it possible to receive, at several work places, visual, radar and textual information.

The values of up to 25 of these 100 parameters can be fed out to the digital display. The choice of parameters is made through the control panel of the system. The data usually fed out to the displays include: date, current flight time, latitude, longitude, barometric and geometric (radio-altimeter) altitude, course, true air speed, static pressure, ambient air temperature, dew point, potential temperature, wind velocity and direction, ground speed, banking, pitching and yawing angles, maximum vertical acceleration, cloud liquid-water content, etc. [3].

The on-board systems have rather good mathematical support. The set of programs on the aircraft makes it possible to obtain in the course of the experiment a temporal record of any of the measured parameters on a display screen during a time segment from that selected on the panel up to the current moment and also to carry out a visual comparison of synchronous records of two parameters, etc. The data carrier in the magnetic memory is a standard magnetic tape. The information itself is registered in a standard code and can be reproduced in a stationary computer on the ground.

The system for processing, registering and visually representing the data is quite universal. It can be joined to any sensors and instruments if their output parameters are matched with the input parameters of one of the already mentioned conversion devices.

Summarized table of equipment aboard foreign flying laboratories. In the preceding sections we have enumerated the principal instrument complexes included among the equipment of flying laboratories operated by the United States, Great Britain and France. For a more graphic representation of this information the data on instrumentation aboard the aircraft laboratories has been summarized in Table 2. Using this table, the reader, familiarizing himself with the results of foreign investigations carried out aboard different aircraft, will readily be able to visualize what information, in general, could be available to authors of articles.

However, when using the table it must be remembered that some of the instrumentation carried aboard the aircraft is experimental and is in the stage of testing and adjustment [1, 6, 7].

Conclusion

The brief review of the characteristics of foreign aircraft - flying laboratories cited above, as well as the instrument complexes with which these laboratories are outfitted, will make possible a better understanding of the nature of the experimental data which foreign scientists may have and an evaluation of the possibilities of international flight experiments in combination with other methods for investigating the atmosphere.

In conclusion we will take the opportunity to thank American scientists and specialists of NCAR and NOAA, and also the meteorologists and pilots of France and Great Britain for affording us the opportunity for detailed familiarization with aircraft - flying laboratories.

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SIXTIETH BIRTHDAY OF IVAN PAVLOVICH VETLOV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 p 120

[Article by the Board of the USSR State Committee on Hydrometeorology and Environmental Monitoring]

[Text] Doctor of Physical and Mathematical Sciences Ivan Pavlovich Vetlov marks his 60th birthday on 8 February. He is a professional meteorologist, the author of a number of profound and original investigations in the field of synoptic, dynamic and satellite meteorology, the organizer of satellite meteorological investigations at the State Committee on Hydrometeorology, the Director of the State Scientific Research Center for Study of Natural Resources, a member of the Working Group of the Executive Committee of the WMO on Meteorological Satellites, chairman of the Section of the Interdepartmental Scientific Council on the Problem "Space Meteorology," recipient of the State Prize, holder of the Red Banner of Labor order and the "Emblem of Honor," and member of the editorial board of the journal METEOROLOGIYA I GIDROLOGIYA.

In sincerely greeting Vetlov on this noteworthy date we wish him good health, personal happiness and long years of productive creative work for the well-being of Soviet science.

SEVENTIETH BIRTHDAY OF ALEKSEY ALEKSANDROVICH SOKOLOV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 121-122

[Article by the Board of the USSR State Committee on Hydrometeorology and Environmental Monitoring]

[Text] Professor Aleksey Aleksandrovich Sokolov, Doctor of Geographical Sciences, Meritorious Worker in Science and Technology RSFSR, marks his 70th birthday on 20 February. He is Director of the Order of the Red Banner of Labor State Hydrological Institute.

Professor A. A. Sokolov is a leading scientist in the field of hydrology of the land. His life and scientific activity in the course of almost a half century have been inseparably associated with the development and establishment of Soviet hydrological science.

In 1931, after graduating from Leningrad State University, Aleksey Aleksandrovich went to work at the State Hydrological Institute. He progressed there from hydrological engineer to director of the institute, in which post he worked from 1968 to the present time.

A. A. Sokolov is the author of more than 100 scientific studies in the field of hydrology and hydrography of the USSR and foreign countries, on engineering hydrology, history and methodology of hydrological science, on the problem of anthropogenic changes in the hydrosphere.

One of his first studies was the monograph CHUDSKO-PSKOVSKOYE OZERO (Chudsko-Pskovskoye Lake), up to now being the most fundamental publication on this water body. The later activity of A. A. Sokolov was later in large part devoted to the problems involved in water inventories. He is one of the directors and active participants in fundamental hydrological studies of the first (1931-1940) and second (1959-1973) editions of the USSR water inventory, which in scientific and practical importance have no equal in world hydrology.

A result of the many years of investigations of A. A. Sokolov in the field of studies of waters of the land was the monograph GIDROGRAFIYA SSSR (USSR Hydrography), published in 1952, in which in systematic form he examined the principal geographical patterns of distribution of the water regime, balance and use of all types of waters of rivers, lakes and swamps, ground water and glaciers and their unity and interrelationship.

During the period of the Great Fatherland War A. A. Sokolov headed work on the preparation of special aids on hydrology for the Soviet Army.

During 1955-1959, as Chief Hydrologist of the Water Management Ministry, A. A. Sokolov exerted many-sided scientific and technical assistance in the development of hydrological investigations in China.

In the 1960's, with the creative participation of A. A. Sokolov, specialists at the State Hydrological Institute carried out investigations in the field of hydrological engineering computations, as a result of which for the first time in the history of hydrology All-Union Standards were introduced on an interdepartmental basis for planning purposes. During these years A. A. Sokolov carried out investigations of the formation of runoff of spring high water and prepared standard recommendations on computing elements of the high-water hydrograph and the maximum water levels in the planning of hydraulic structures, cities and industrial enterprises.

For his great creative contribution to solution of a highly important scientific and practical problem in the field of hydrology, he, among other participants, was awarded the State Committee on Hydrometeorology Prize imeni V. G. Glushkov and V. A. Uryvayev.

In the scientific activity and works of A. A. Sokolov a significant place is occupied by the methodological and historical aspects of hydrological science. He published a series of articles which dealt with questions relating to the paths of development of hydrological science. In 1972, in collaboration with A. I. Chebotarev, he published a monograph on the history of hydrology which for the first time gave a review and presented a scientific analysis of the development of hydrology in the USSR during the years of Soviet rule.

With the great personal creative participation of A. A. Sokolov in 1971-1973 the personnel of the State Hydrological Institute, Main Geophysical Observatory, Arctic and Antarctic Scientific Research Institute and Institute of Water Problems USSR Academy of Sciences carried out fundamental generalizations of the world water balance and the earth's water resources. The monograph and atlas published as a result of these investigations were presented as a contribution of Soviet scientists to the program of the International Hydrological Decade and have a high scientific evaluation from the scientific community at a conference on the results of the IHD and at the present time have been translated by UNESCO into English.

During recent years A. A. Sokolov has been the director and participant in major investigations of the State Hydrological Institute for study of the water resources of the USSR and their changes under the influence of economic activity.

As chairman of the section on "Surface and Ground Water Resources" of the Council of the State Committee on Science and Technology on Multisided Use of Water Resources he conducts the major scientific and organizational work on interdepartmental coordination and the formulation of plans for scientific research in our country in the field of hydrology.

A. A. Sokolov was one of the organizers of the Fourth All-Union Hydrological Congress (1973), a number of all-union conferences and seminars, as well as the International Symposium on Hydrological Computations for Water Management Planning (1979).

The scientific studies and active scientific-organizational activity of A. A. Sokolov are well known abroad.

As a member of the USSR Interdepartmental Committee on International Cooperation in Hydrology and chairman and member of a number of working groups of UNESCO, A. A. Sokolov is taking an active part in the development of international scientific projects and presents scientific reports on the most important problems in modern hydrological science. An international manual on computations of water balance elements (1974) and a collection of examples (Casebook) of methods for computing high-water runoff (1976) were published under his editorship. In these there was a generalization of world experience in these branches of hydrology.

For successful work on the training of personnel, in 1966 A. A. Sokolov was awarded the academic title of professor. In 1972, for services in the field of hydrography, hydrological engineering and the training of highly skilled personnel the Presidium of the Supreme Soviet RSFSR awarded him the honorary title of Meritorious Worker in Science and Technology RSFSR.

A. A. Sokolov is a member of the editorial council of the Gidrometeoizdat and a member of the editorial board of the journals METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), IZVESTIYA GEOGRAFICHESKOGO OBSHCHESTVA SSSR (News of the USSR Geographical Society) and the popular science collection of articles CHELOVEK I STIKHIYA (Man and Natural Calamities). He is the author and editor of a number of articles in the "Hydrology" section in the Large Soviet Encyclopedia (second-third edition).

A. A. Sokolov is a member of the Presidium and Scientific Council of the USSR Geographical Society, where he carries out active work, presenting lectures and reports.

For his major services to Soviet geography and the USSR Geographical Society in 1975 he was awarded the Diploma of Honor by the society presidium. For the results of scientific investigations favoring the development of the USSR national economy A. A. Sokolov was awarded a diploma of honor, gold and silver medals of the All-Union Exhibition of Achievements in the National Economy.

The work of A. A. Sokolov constitutes a major contribution to water science. His work is used extensively in the national economy for water management planning and hydrological computations in construction planning and gives, as indicated by the experience of its application, a high economic effect.

The scientist and Communist A. A. Sokolov, together with his scientific and scientific-pedagogic activity, is carrying out much public work. He has been elected to the Plenum of the Vasileostrovskiy Rayon Committee CPSU, is a member of the Party Bureau of the State Hydrological Institute, is a director of the Philosophical Methodological Seminar of the State Hydrological Institute, and a member of the Leningrad Committee for the Defense of Peace.

The long-term and productive activity of A. A. Sokolov has been highly appreciated by the Motherland: he was awarded the orders of the Red Banner of Labor, the Great Fatherland War Second Degree, Red Star, "Emblem of Honor" and medals.

In congratulating A. A. Sokolov on his 70th birthday, we wish him many years of good health and activity as equally productive as before for the welfare of the Motherland.

PROFESSOR YE. G. POPOV HONORED

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 p 122

[Unsigned article]

[Text] By a decree of the Presidium Supreme Soviet RSFSR, dated 5 November 1979, Professor Yevgeniy Grigor'yevich Popov, Doctor of Geographical Sciences, division chief at the USSR Hydrometeorological Scientific Research Center, was awarded the title of Meritorious Worker in Science RSFSR for his services in scientific activity and training of highly qualified personnel.

AT THE USSR STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 122-123

[Article by V. N. Drozdov]

[Text] On 11 October 1979 there was a regular session of the Scientific Council of the State Committee on Hydrometeorology on the Problem "Study of the Oceans and Seas" under the chairmanship of V. M. Popov, head of the Marine, Arctic and Antarctic Administration. The Council was attended by representatives of the State Oceanographic Institute, Arctic and Antarctic Scientific Research Institute, Murmansk Affiliate of the Arctic and Antarctic Scientific Research Institute, USSR Hydrometeorological Center, Main Geophysical Observatory, All-Union Scientific Research Institute of Hydrometeorological Information and Far Eastern Scientific Research Hydrometeorological Institute.

A. N. Zuyev (Murmansk Affiliate Arctic and Antarctic Scientific Research Institute), in a report entitled "Results of Investigations of the Dynamics of the Ice Cover in the Bering Sea During 1974-1978," told about the program of experimental and theoretical investigations of dynamics of the ice cover carried out at the Murmansk Affiliate of the Arctic and Antarctic Scientific Research Institute, directed to the development of new methods for ice forecasts and computations in the Bering Sea or providing national economic organizations with qualitatively new ice information. Specialists have developed a numerical method for computing the redistribution of ice in the Barents Sea and a method for processing aerial films on an electronic computer. The speaker noted that during the winter of 1978-1979, using the methods developed at the Murmansk Affiliate of the Arctic and Antarctic Scientific Research Institute, specialists carried out an experimental operational support of Yamal' operations with short-range numerical forecasts of dense and thin ice cover. The new type of servicing has been approved by the directors of the Murmansk Marine Navigation Service and the Amderma Convoy Service.

V. P. Tunegolovets (Far Eastern Scientific Research Hydrometeorological Service) reported on the program "Complex Investigations of the Northwestern Part of the Pacific Ocean in 1980." In his report he noted that the hydrometeorological data obtained on the expedition will make it possible to refine the mechanism of variability of both circulation of waters and the processes of large-scale interaction between the ocean and the atmosphere and that these investigations will be a considerable contribution of the USSR to the program for study of the Kuroshio and adjacent regions. The speaker told in detail about the program for the runs of ships and the studies to be made aboard them.

The deputy head of the Arctic and Antarctic Marine Administration, A. V. Shishkov, reported on "Prospects for the Development of the Scientific Research Fleet of the State Committee on Hydrometeorology During the Eleventh Five-Year Plan."

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 pp 123-126

[Article by Yu. G. Slatinskiy, A. P. Khain and O. M. Kastin]

[Text] On 14 June 1979, at Kiev, at the UGKS UkrSSR, there was a conference for examining the results of a comprehensive inspection of marine stations and posts on the Sea of Azov. The conference was attended by key workers of the UGKS UkrSSR, representatives of the UAAM of the State Committee on Hydrometeorology, Sevastopol' Division of the State Oceanographic Institute and the Marine Division of the Crimean Hydrometeorological Observatory. The results of the inspection were reported by G. V. Yatsevich (Crimean Hydrometeorological Observatory) and Yu. G. Slatinskiy (Sevastopol' Division State Oceanographic Institute).

In the reports and communications of the conferees it was noted that during recent years the UGKS UkrSSR has carried out much work on the rationalization of the sea network and types of observations and an increase in the quality of hydrometeorological information received for the servicing of national economic organizations and forecasting agencies of the State Committee on Hydrometeorology. Particularly great efforts are being undertaken for broadening work on monitoring the environment. Suffice it to mention that during the last 1 1/2 years alone the subdivisions of the UGKS UkrSSR in the Sea of Azov and Sivash have carried out observations at about a thousand hydrological stations and have made more than 23,000 hydrochemical determinations. The results are routinely published in quarterly bulletins, annual reviews and yearbooks of the GVK.

The sea stations of the UGKS UkrSSR, under the direction of the Sevastopol' Division of the State Oceanographic Institute, annually carry out a great volume of observations under the programs for scientific research themes. In particular, the Opasnoye Marine Hydrometeorological Station for many years has been carrying out investigations of water and salt exchange between the Black Sea and the Sea of Azov through Kerch Strait. The Genichesk Marine Hydrometeorological Station is studying water exchange between the Sea of Azov and the Sivash through Tonkiy Strait. The Zhdanov Marine Hydrometeorological Station is participating in implementation of programs for observations in the mouth regions of rivers. Reports from the stations on the work done are presented regularly in a section of the Scientific Council Sevastopol' Division State Oceanographic Institute.

Investigations of the ice regime in the sea are also being made intensively. Specialists of the Zhdanov Marine Hydrometeorological Station are particularly active in this work. During the past year alone, at the height of the ice season, they carried out more than 50 runs in icebreakers and collected extensive information on the state of the ice cover in the central part of the sea. These data are routinely used in the support of convoying of ships on the most important routes and also for correcting charts.

The marine stations of the UGKS UkrSSR are taking an active part in carrying out experimental studies. For example, the Opasnoye Marine Hydrometeorological Station, in collaboration with the Leningrad Division of the State Oceanographic Institute, is participating in the development of methods for making aerial observations of the qualitative state of sea waters. Specialists at the Zhdanov, Opasnoye and Genichesk Marine Hydrometeorological Stations are engaged in making chronometric measurements for the developing of norms for active expenditures of work time on hydrometeorological observations by sea posts which make hydrometeorological observations and carry out processing, technical monitoring and generalization of the collected data.

While noting definite achievements in the organization of operation of the marine network operated by the UGKS UkrSSR in the Sea of Azov, the conferees also noted a number of yet unsolved problems.

Yu. G. Slatinskiy

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A Pacific Ocean Scientific Congress was held at Khabarovsk during the period 20 August-1 September 1979. It transpired in 14 scientific committees. Their work took in an extremely broad range of problems from preservation of the environment and public health to the marine sciences and geography.

The work of the committee "Sea Sciences" (Committee F) took place during the period 23-30 August. The committee chairman was V. I. Il'ichev; the co-chairmen were A. S. Monin, A. V. Zhirmunskiy, K. V. Beklemishev, P. A. Moiseyev and S. M. Konovalov. On the morning of 23 August there was a plenary session of the committee at which reports of a general nature were presented: A. S. Monin and Ye. A. Romankevich -- on problems of biogeochemistry of the world ocean, A. V. Zhirmunskiy -- on the importance of physiological ecology of marine animals for the intensive development of fishing, M. N. Glantets (United States) -- on climatological limitations on the exploitation of oceanographic resources in the Pacific Ocean region and others.

Then the committee's work was held in sections, which, in turn, were divided into symposia. There were four sections in committee F: "Physical Oceanology," "Marine Biology," "Biological Productivity of the Pacific Ocean" and "Marine Geology." The section "Physical Oceanology" was subdivided into 11 symposia, which included: "Typhoons and the Ocean, Upwelling" (F1.1, F1.12); "Interaction Between the Ocean and the Atmosphere, Problems in Long-Range Weather Forecasting. Role of the Pacific Ocean in Climatic Fluctuations" (F1.3, F1.11); "Synoptic Eddies in the Pacific Ocean" (F1.4); "Kuroshio and Tropical Circulation of Pacific Ocean Waters" (F1.2, F1.5); "Turbulence, Small-Scale Variability, Internal Waves and Fine Structure in the Pacific Ocean" (F1.8) and others.

On the evening of 23 August there was a plenary session of the section "Physical Oceanology." It heard the following reports: A. S. Monin, K. N. Fedorov and V. P. Shevnov -- "Fine-Layered Water Structure in the Ocean," K. Wyrtki (United States) -- "Prediction of El Nino," K. Inda (Japan) and L. S. Hwang (United States) and S. A. Solov'yev (USSR) -- "Achievements and Problems in Study of Tsunamis" and, finally, a report by V. G. Fedorov (USSR) and I. Takenuchi (Japan) -- "Program: 'Joint Investigations of the Kuroshio'."

Below we will discuss the work of three symposia in greater detail: F1.1, F1.12 -- conveners V. N. Ivanov (USSR), I. Kurihara (United States); F1.3, F.1.11 -- conveners Yu. A. Shishkov (USSR), K. Wyrtki (United States), G. R. Seckel (United States); F1.2 and F1.5 -- conveners A. M. Muromtsev (USSR) and K. Hikada (Japan).

The first symposium received 24 reports, of which 17 were read. An interesting report entitled "Principal Results of Modeling of Tropical Cyclones" was presented by I. Kurihara (United States). Kurihara concisely formulated the results of numerical modeling of a tropical cyclone in the following way. The development of a tropical cyclone requires the appearance of a warm nucleus at its center. Moisture content in the boundary layer and static stability in the free atmosphere are decisive for this process. The structure of the spiral bands is similar to the structure of internal gravitational waves. The intensity of model tropical cyclones is highly dependent on the temperature of the ocean surface, determining the evaporation rate. Models with embedded grids at the present time describe quite well the dimensions and intensity of a cyclone. The use of these models for predicting the movement of a tropical cyclone makes analysis and initiation problems of primary importance.

V. N. Ivanov, in behalf of a group of co-authors, described the tasks and some results of the expeditions Tayfun-75 and Tayfun-78. More than 150 synchronous soundings of the atmosphere were grouped in accordance with the synoptic situation in the sounding region. An analysis of thermodynamic parameters of the atmosphere was made for all the defined situations. Then an analysis was made of the conditions for generation of a tropical cyclone. A report by A. P. Khain gave results obtained using a 12-layer axially symmetric model of a tropical cyclone. The model includes parameterization of convective heating and convective transport of heat, moisture and momentum; there is parameterization of the boundary layer.

C. Newman (United States) gave a similar comparative analysis of schemes for predicting the movement of a tropical cyclone. The problem of statistical analysis of movement of a tropical cyclone was the subject of a report by P. D. Gres'ko and G. V. Gruza. The reaction of the upper layer of the ocean to a moving tropical cyclone was the subject of a report by G. G. Sutyrin. The thermodynamic structure of the track of tropical storm Virginia was discussed in a report by V. D. Pudov and S. A. Petrichenko. A report entitled "Interannual Variations of the Frequency of Recurrence, Intensity and Localization of Typhoons" was presented by N. I. Pavlov. Changes in the frequency of recurrence of tropical cyclones were related by the speaker to year-to-year variations in general circulation of the atmosphere and ocean.

Probably the most significant report at symposia F1.3 and F1.11, at which 15 reports were presented, was a report by A. S. Monin and D. V. Chalikov entitled "Numerical Modeling of Large-Scale Interaction Between the Ocean and the Atmosphere." The model consists of three principal "blocks": atmospheric circulation, evolution of the upper active layer of the ocean and climatic regime of the deep ocean. As a result of the computations it was possible to obtain the mean annual distribution of temperature and currents, agreeing fairly well with available observational data. A report entitled "Observations of the Climatic Variability of the Ocean - Atmosphere System in the Tropical Pacific Ocean" was given by B. K. Wier (United States). A. F. Treshnikov and Yu. V. Nikolayev in a report examined the influence of interaction between the ocean and the atmosphere on the formation of long-lived weather anomalies. Their analysis indicated that after the "discharge" of a great quantity of heat into the atmosphere there will be fluctuations in the velocity of movement of long waves, which favors a transition from zonal to meridional atmospheric circulation. In this process an important role is played by the duration of heat flow anomalies from the ocean. A report by P. S. Lineykin and A. V. Frolov discussed the evolution of temperature anomalies in the ocean, which is caused by nonlinear interaction between the current velocity and density fields. A report by W. W. White, R. L. Bernstein and G. P. McNally (United States) analyzed the large-scale reaction of internal regions in the northern part of the Pacific Ocean to an unsteady atmospheric disturbance.

Fourteen reports were received by symposia F1.2 and F1.5, of which 10 were heard.

A report by A. D. Nelezin, entitled "Frontal Zones in the Equatorial-Tropical Latitudes of the Pacific Ocean," dealt with the results of investigation of the variability of the thermohaline structure and circulation of waters in the indicated region of the Pacific Ocean and revealed that the regions of greatest changes are associated with zones of divergence (convergence) of waters, which are regarded as frontal zones. A. A. Sarkis'yan and Yu. L. Demin gave a report "On Numerical Modeling of the Equatorial Circulation." For computations of currents and the density field in the equatorial zone of the ocean they proposed a nonlinear numerical model whose system of equations includes two complete nonlinear equations of motion, the continuity and hydrostatics equations, an equation for the level surface of the ocean, and also an equation for density diffusion. We note the report of K. Wyrtki (United States) entitled "Low-Frequency Variations in Equatorial Circulation." Changes in ocean level associated with a large meander of the Kuroshio were discussed in a report by M. Kawabe (Japan). We should mention the reports of Yu. A. Rassadnikov, entitled "Spatial-Temporal Fluctuation of the Temperature Field in the Kuroshio Zone" and V. V. Pokulov and K. O. Vel'yast, entitled "Interannual Changes in the Entry of Water and Heat With the Kuroshio Current into the Temperate Latitudes of the Pacific Ocean During the Winter Periods 1966-1978."

At symposium F1.8 we should mention the report of V. G. Pak and V. N. Nabatov, entitled "Measurements of Small-Scale Turbulence by Freely Moving Instruments" and a report by T. Nan-Niti (Japan) entitled "Turbulent Diffusion in the Atmosphere and Ocean."

In conclusion we should note the exceptionally good organization of the congress and the hospitality of the residents of Khabarovsk.

A. P. Khain

A branch seminar on the exchange of experience on the introduction and operation of programmed support of electronic computers of the YeS series and on the matter of maintaining a branch archives of algorithms and programs was held during the period 26-29 September 1979 at Tbilisi at the Transcaucasian Scientific Research Hydrometeorological Institute. The seminar was organized by the Technical Administration for Development and Operation of the State System for Observations and Environmental Monitoring and Climate of the State Committee on Hydrometeorology, the Georgian UGKS, All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center and the Transcaucasian Scientific Research Hydrometeorological Institute. Participating in the work of the seminar were specialists from 26 organizations of the State Committee on Hydrometeorology and 16 organizations of other ministries and departments. A total of 15 reports and 9 communications were presented.

The seminar was opened by G. G. Svanidze, Director of the Transcaucasian Scientific Research Hydrometeorological Institute. He familiarized the participants with the tasks and the work program of the seminar.

Two communications of a general character were presented first: by A. V. Vakulenko (Chairman of the Technical Administration of the State Committee on Hydrometeorology); he briefly characterized the prospects for outfitting the institutes of the State Committee on Hydrometeorology during the Eleventh Five-Year Plan with electronic computers of the YeS series, and by V. M. Pan'kov (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center), who gave a review of the status and prospects for development of the mathematical support for these electronic computers and its use in the organizations of the State Committee on Hydrometeorology.

At the present time, noted V. M. Pan'kov, at most organizations in the branch use is being made of a YeS operational system (OS) and at only a few organizations is use being made of a DOS operational system for the YeS, but at these organizations plans are being made for a changeover to the OS operational system for the YeS after a corresponding further addition to the electronic computers available there. For the YeS OS there are a number of packets of applied programs whose introduction will favor a broadening of the capabilities of the organization in the course of processing of hydrometeorological information and solution of research tasks. Late in 1979 developers will make available the YeS OS in version 6.1, having considerably greater capabilities in comparison with the now widely used YeS OS version 4.1.

All the reports and communications presented hereafter can be divided on the basis of subject matter into three groups:
-- operation of the OS system for YeS computers;
-- development of programmed support;
-- maintaining a branch archives of algorithms and programs.

The first group of reports was devoted to experience in introducing and monitoring the YeS OS accumulated at a number of organizations: All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center (V. P. Platokov), USSR Hydrometeorological Center (I. I. Zhabina, T. V. Il'ina, O. M. Kastin, T. S. Chekulayeva), Main Geophysical Observatory (T. V. Nosova, O. A. Smirnova, V. G. Sterlin), West Siberian Regional Computation Center (A. I. Sychev, I. V. Kolotovkin), Transcaucasian Scientific Research Hydrometeorological Institute (B. A. Mikishavidze) and others. As one of the principal ways to bring about a further increase in the effectiveness of use of mathematical support for YeS computers most of the speakers looked to centralization of preparation of systems programmers and computer operators.

An important element in organizing the operation of computation systems is the inventorying, monitoring and planning of use of resources. V. P. Platokov (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center) told about the system developed for these purposes; it is based on use of data accumulated by a systemic monitoring program.

A high percentage of the proposals for programmed support for YeS computers examined at the seminar constitute ways to improve the programming technology or broadening the possibilities for solving problems on electronic computers. The following reports dealt with these matters: A. M. Trofimov (State Scientific Research Center for the Study of Natural Resources) -- on means for structural programming in two measurements and their application with ASSEMBLER YeS; V. M. Shershakov (Institute of Experimental Meteorology) -- on a system making it possible for developers of programmed support to carry out easily the accumulation and modification of texts, translation, editing of communications, implementation of programs and readout of volumes in ML and MD and sets of the latter; V. M. Pan'kov (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center) -- on use of peripheral attachments of YeS computers (displays and storage units using magnetic disks) for increasing the effectiveness of preparation of programs and operation of electronic computers; A. Ye. Norok (Institute of Experimental Meteorology) -- on ways to increase the effectiveness of use of graphic recording devices of YeS computers in work with an operational system and some others.

Several reports were devoted to the capabilities of programmed systems developed for solution of definite practical problems.

For example, V. M. Veselov and I. R. Pribylskaya in their report told about experience in use of translation methods with nonprocedural languages for describing data and describing processes in the procedural language of interpreter commands in the system for the monitoring of data, being one of the principal components of programmed support of the automated data system for the processing of regime information developed at the All-Union Scientific Research Institute of Hydrometeorological Information-World Data

Center; I. V. Kolotovkin, Yu. P. Papkov and V. D. Chizhkov (West Siberian Regional Computation Center) noted that the experience which they had accumulated in the processing of hydrometeorological information on an electronic computer was evidence of the limitations on the possibilities of direct use of existing packets of applied programs and they told about an attempt undertaken at the West Siberian Regional Computation Center to rework some of the algorithms and programs of the mentioned packets for a more complete satisfaction of the needs for the processing of hydrometeorological information; V. A. Gorbachev, V. A. Zhukov and M. A. Korolev (All-Union Scientific Research Institute of Agricultural Meteorology) examined the peculiarities of realization of an automated system for the collection, monitoring, processing of agricultural information and its incorporation in the hydrometeorological archives, bringing about the processing of operational and regime agrometeorological information arriving via telegraphic communication channels in a unified flow.

The problems involved in the organization, management and use of the branch archives of algorithms and programs and its interaction with the state archives were examined in great detail.

A report by I. F. Karlov (VNIIPOU [expansion unknown] of the State Committee on Science and Technology) was devoted to an examination of the most important and complex aspects of work on the preparation of new regulations on the state archives of algorithms and programs being carried out at the VNIIPOU of the State Committee on Science and Technology.

S. S. Starovoyt (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center) reported on the role and functions of the branch archives and the prospects for its development and read a review prepared by A. F. Goroshko on the activity of the archives of algorithms and programs of the enterprises of the State Committee on Hydrometeorology and their interaction with the branch archives. The report emphasized the important role of a composite plan for programming (prepared on the basis of plans of individual enterprises), determining the possibilities of supplementing the branch archives with unpublished materials, and the need for a more attentive approach to its preparation.

Z. R. Rubinstein in his report told of the experience accumulated at the USSR Hydrometeorological Center in organizing the functioning of the internal archives of algorithms and programs and its interaction with the branch archives.

S. D. Gatich (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center) familiarized the seminar participants with the principal problems dealt with in the recently established mathematical support section of the hydrometeorological archives, being the key subdivision dealing with the automated servicing of users with hydrometeorological information on the basis of electronic computers and spoke on the status of use of YeS computers for processing of archival data at the

All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center, making use of the programmed support available in the branch archives of algorithms and programs for the hydrometeorological service.

The seminar participants noted the considerable successes attained recently in the field of introducing, organizing operation and developing programmed support of YeS electronic computers and in managing the branch archives of algorithms and programs.

In addition, the seminar made a number of recommendations, which were addressed to the State Committee on Hydrometeorology, computation centers of scientific research institutes and administrations of the hydrometeorological service and the branch archives of algorithms and programs. These recommendations are directed to an improvement in the coordination of activities of organizations in the development and mastery of programmed support for electronic computers, expansion of work on the training of specialists for the application of mathematical support, and further improvement in the organization of accumulation and increasing the effectiveness of use of the branch archives of algorithms and programs.

O. M. Kastin

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 2, Feb 80 p 127

[Article by V. I. Silkin]

[Text] As reported in SCIENCE NEWS, Vol 115, No 5, p 73, 1979, the so-called "tea belt" in Kenya, where most of the tea plantations of that country are located, is one of the regions on earth most subject to hailstorms. In that area on the average there are 132 days per year when hail falls, which is ten times greater than the area in the United States which is most subject to hailfalls.

In a report presented at a conference of the American Geophysical Union in San Francisco in December 1978 the scientific specialists Suan Tan-Schnell (Atmospheric Research Center, Boulder, Colorado) and Russel S. Schnell (NOAA, Boulder) presented the results of their own study of this phenomenon.

They established that scraps of leaves and other vegetation waste left by the tea harvesters constitute ideal condensation nuclei in the concentration of droplets of supercooled atmospheric moisture which are transformed into hail. The experiments revealed that these wastes are better condensation nuclei than dust or waste from other plants.

It became clear that the dust formed by particles of "tea" origin can favor the formation of hailstones from supercooled moisture even at a temperature of -5°C, which is much higher than the condensation temperature under conditions when its nucleus is more usual. When using particles of other plant or soil origin there was no condensation if the temperature was higher than -9° or even -15°C.

As a result, hail can be formed over tea plantations when the weather is substantially warmer than over other regions, and accordingly, more frequently than in surrounding regions.

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As reported in SCIENCE, Vol 203, No 4376, pp 165-167, 1979, work has been completed on the processing of oceanological data obtained on an expeditionary voyage carried out by an American icebreaker in December 1977 in the Arctic Ocean in the region to the north of the Spitzbergen Archipelago. The objective of the expedition was a study of the structure of the upper water layers and a determination of the hypothetical vertical movement, the reason for which may be the wind effect.

Earlier observations indicated that at least during the summer there is a layer of cooled water of arctic origin from the zero surface to a depth of approximately 150-200 m. Beneath it there is a warmer layer of Atlantic origin, having a higher salinity. However, the winter structure of these waters has remained unknown, although a number of theoreticians have pointed out that prolonged constantly directed exposure to winds, lasting as a minimum for two days, can lead to the setting in of an anomalous warm structure of polar waters.

December measurements, carried out at the very boundary of the heavy pack ice, indicated the correctness of the hypotheses of the possibility of such anomalies and revealed a number of new details remaining unknown to oceanologists up to this time.

Observations were made along lines directed perpendicular to the edge of the pack ice. Twelve-twenty oceanological stations were occupied on each profile.

At one of the measurement points, situated at the very boundary of the pack ice, it was established that there is an anomalous water layer lying between the surface and the 140-m depth reading. This layer had a density, temperature and salinity almost completely coinciding with such characteristics of waters in the Atlantic Ocean and thereby decisively differed from the surrounding waters of the Arctic Ocean. At all the remaining measurement points the structure of the water masses virtually coincided with the summer structure.

The analysis of the weather maps of this region which was then made revealed that prior to the observations themselves the meteorological conditions had a character corresponding to the formation of anomalous conditions. The winds and atmospheric pressure prevailing during this time period could without question lead to movements of Atlantic water masses, squeezing out the waters of polar origin, initially situated over them.

The boundary of the pack ice in the northern polar basin is a line extending for many thousands of kilometers. Therefore, such anomalous conditions, until now hidden from the eyes of researchers, can be a characteristic phenomenon in this region. Its scales in this case are such that they must be a planetary factor in the formation of weather and climate and they must be appropriately taken into account in meteorology and climatology of the entire hemisphere. In addition, the presence of vertical water movements with temperatures higher than in the surrounding medium probably also exerts an influence on the biological productivity of this region of the Arctic Ocean.

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