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NATURAL COMPONENTS OF SMALL SAMPLES WITH A LARGE NUMBER OF PARAMETERS

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[Article by Professor N. A. Bagrov, USSR Hydrometeorological Scientific Research Institute, submitted for publication 14 July 1978]

Abstract: A new method is proposed for computing the natural orthogonal components in a case when the volume of the sample is less than the number of introduced random variables. This procedure makes possible a considerable reduction in computation work and in some cases one can solve the full problem for a symmetric matrix, earlier beyond the capabilities of modern electronic computers with average capacity. Some historical comments are made in passing.

[Text] The expansion of meteorological fields or in general a random vector in natural orthogonal functions has found extensive application since the publication of [3]. This method is presently given different names by different authors: the main components method, expansion in empirical or statistical orthogonal functions [1, 7, 8, 12], or the Carunen-Loeve expansion [5]. All these names have some basis. However, with respect to the latter, it should be noted that one of the first studies in this direction was made by Hotelling and dates back as far as 1933 [11], whereas the studies by Carunen and Loeve, judging from the citations in [6], date back to 1947 and 1945-1946 respectively.

Now we will briefly examine the entire problem using matrix calculus. Assume there is a random vector F of the dimensionality n, that is, having n components, in general correlated with one another. Its covariation matrix is written in the following way:

$$M = \overline{FF^*} = \begin{Vmatrix} \overline{F_1F_1} & \overline{F_1F_2} & \dots & \overline{F_1F_n} \\ \overline{F_2F_1} & \overline{F_2F_2} & \dots & \overline{F_2F_n} \\ \dots & \dots & \dots & \dots \\ \overline{F_nF_1} & \overline{F_nF_2} & \dots & \overline{F_nF_n} \end{Vmatrix}. \quad (1)$$

Here the asterisk is the transposition sign, whereas the line at the top is the mathematical expectation symbol (empirically -- the averaging symbol).

However, in both theoretical and practical problems it is considerably more convenient to deal with a vector with uncorrelated components. Sometimes, however, instead of the F vector, especially if it has a very great dimensionality, it is desirable to examine some approximation of it. In both these problems the result is achieved by a linear transformation of the F vector

$$F = UA, \tag{2}$$

where U is the transformation matrix-operator (in general, inverse), and A is the new vector. The transformation (2) will retain the general dispersion of the F vector if U is an orthogonal matrix, so that $UU^* = U^*U = I$. In actuality, under this condition we will have

$$F^*F = A^*U^*UA = A^*A. \tag{3}$$

If the U matrix columns are selected in a definite way, for example, in the form of a set of values of some orthogonal functions in a grid of equally spaced points, it is possible to obtain an expansion of the F vector using these functions. This assertion follows from the simple fact that the transformation (2) can be written in a more expanded form

$$F = U_{01}A_1 + U_{02}A_2 + \ldots + U_{0n}A_n, \tag{4}$$

where A_k is a component of the A vector and U_{0k} ($k = 1, 2, \ldots, n$) is a column of the U matrix.

For example, if as the U matrix we take the matrix

$$\left\|\begin{matrix} 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & -1 \\ 1 & -1 & 0 & 1 \\ 1 & 0 & -1 & -1 \end{matrix}\right\|,$$

then after normalization of its columns we obtain an expansion of the F vector in trigonometric functions. The first column of this matrix represents the cosine of zero, repeated four times; the succeeding columns are: $\cos 2\pi t$, $\sin 2\pi t$, $\cos 4\pi t$ for $t = 0, 1/4, 2/4$ and $3/4$. If the last column of this matrix is replaced by zeroes, we obtain an approximate (broken) expansion. Similarly it is possible to obtain an expansion of the random vector in Chebyshev polynomials.

However, in a general case the components of the A vector here will not be mutually orthogonal. On the other hand, obtaining mutually orthogonal components of the A vector can be one of the purposes of the transformation (2). In particular, it was pointed out in [4] how, knowing the covariation matrix of the F vector, it is possible to form the triangular matrix U, by means of which it is possible to obtain a vector with uncorrelated components. By means of a special normalization of the U matrix it is even possible to achieve an equality of the general dispersion of both vectors, that is, retain equations (3).

Among all the transformations of this type the most modern, and probably the most natural will be a transformation following from a representation of the covariation matrix of the F vector through the covariation matrix of the A vector

$$M = \overline{FF^*} = U\overline{AA^*}U^*.$$

If it is now necessary to have a diagonality of the covariation matrix of the A vector

$$\overline{AA^*} = \Lambda = \begin{Vmatrix} \lambda_1 & & & 0 \\ & \lambda_2 & & \\ & & \ddots & \\ 0 & & & \lambda_n \end{Vmatrix},$$

we will have, assuming the U matrix to be orthogonal,

$$M = \overline{FF^*} = U\Lambda U^{-1}.$$

This formula shows that the $\lambda_1, \lambda_2, \ldots, \lambda_n$ values must be the eigenvalues of the covariation matrix M (we will always arrange them in decreasing order), whereas the columns of the U matrix give the corresponding eigenvectors. The transformation (2) of the F vector from such a matrix has another extremal property that it gives the most rapid convergence of series (4) in the sense of an approximation to the general dispersion of the F vector.

Thus, the expansion (4) with satisfaction of equation (5) is obtained in a "natural" way from the properties of the F vector itself.

However, historically the situation had developed in such a way that despite the fact that the fundamental principles of the main components or natural components methods have been known since 1933 they evidentally did not initially come into broad application. Accordingly, in the 1950's, when the possibilities of electronic computers became well known, meteorologists had to discover this method anew. This is indicated by the first "meteorological" publications of Lorenz [12], Bagrov [3] and Obukhov [7].

In practice we will almost always be dealing with the sample values of the vector, and accordingly, we can obtain only an evaluation of the covariation matrix. A sample of the F vector values (we will call it a sample matrix) consists of a set of its realizations

$$F=\left\| \begin{matrix} F_{11} & F_{12}\ldots & F_{1m} \\ F_{21} & F_{22}\ldots & F_{2m} \\ \cdot & \cdot\cdot\cdot\cdot\cdot & \cdot \\ F_{n1} & F_{n2}\ldots & F_{nm} \end{matrix} \right\|. \qquad (6)$$

Here n is the dimensionality of the F vector (the number of its components) and m is the volume of the sample -- the number of individual observed realizations of the F vector. An evaluation of the covariation matrix is obtained in the form of the averaged product of the matrix (6) and its transposed form

$$M=\frac{1}{m}FF^*.$$

It is assumed that the mean value of each component is already excluded. We can add that by virtue of the symmetry of subsequent formulas we will postulate that all elements of the matrix (6) have been divided by $\sqrt{m}$. In this way we avoid division by m in the formula for the covariation matrix.

In hydrometeorological practice it often happens that $n>m$, that is, the dimensionality of the F vector is greater than the sample volume. And such a relationship between n and m is undesirable (by means of a decrease in dimensionality of the F vector) or is impossible (by means of increasing the sample) to change. Such circumstances are rather frequently observed in prognostic practice in meteorology. It makes sense to call samples whose volume is less than the number of introduced variables $(m<n)$ "small samples." For a small sample it is possible to simplify considerably the computation of the eigenvectors and the eigenvalues of the covariation matrix.

In this case the covariation matrix FF^* will have a very great dimensionality $(n \times n)$, but its rank will not be greater than m, that is, not less than $(n - m)$ of its eigenvalues will be equal to zero. In this case in place of the matrix FF^* it is necessary to examine the matrix F^*F, whose dimensionality will be $m \times m$. Henceforth we will assume that all the eigenvalues of this latter matrix will not be equal to zero.

As is known, the eigenvalues of these two matrices [8] coincide; in his study [9] V. L. Sklyarenko used a simple relationship between their eigenvectors. Both these postulates are demonstrated very simply. First of all, for the second (small) matrix we will write a formula for reduction to a diagonal form

$$F^*F=V\Lambda V^*.$$

$$F^*F = V\Lambda V^*. \qquad (7)$$

We will multiply this equation (it makes no difference whether from the right or left) by itself. As a result, by virtue of the property $VV^* = I$

$$F^*(FF^*)F = V\Lambda^2V^*;$$

or after the obvious transformations

$$(V^*F^*)(FF^*)FV = \Lambda^2. \qquad (8)$$

But this is the formula for reduction of the covariation matrix FF^* to diagonal form. Expression (7) makes it possible to conclude that the columns of the FV matrix are orthogonal. The column of this matrix can be orthonormalized by multiplying on the right by $\Lambda^{-1/2}$ and then it will become an orthogonal matrix of the eigenvectors of the FF^* matrix; the diagonal matrix Λ becomes the matrix of eigenvalues. Thus,

$$U = FV\Lambda^{-1/2}. \qquad (9)$$

This is the basis of the relationship between the eigenvectors of the FF^* and F^*F matrices. Incidentally we obtained proof of the equality of the first m eigenvalues of these matrices. Here it must also be noted that formula (9) determines only the first m eigenvectors of the FF^* matrix.

Formula (9) gives a significant representation of the initial matrix

$$F = U\Lambda^{1/2}V. \qquad (10)$$

This known formula [1] is extremely rarely cited in the academic literature.

By a simple multiplication this formula leads back to formulas (5) and (7). We note that the U matrix in formula (10) must, in accordance with the rules for multiplication of matrices, have a rectangular dimensionality (n x m), that is, contain eigenvectors corresponding only to the numbers λ_i, not equal to zero.

Now we will turn again to formula (2). If the F vector is represented by the sample matrix (6), then the vector A must be represented by a matrix; in the case $n > m$ the matrix of eigenvectors U will be incomplete since the eigenvectors for filling up this matrix will not play a role in any case. But it follows from this that the A matrix must be square: m x m.

$$A = \left\| \begin{matrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & \dots & a_{2m} \\ \cdot & \cdot & \cdot & \cdot \\ a_{m1} & a_{m2} & \dots & a_{mm} \end{matrix} \right\|. \qquad (11)$$

An element of the F matrix, according to (2), is expressed by the formula

$$F_{0k} = U_{01} a_{1k} + U_{02} a_{2k} + \ldots + U_{0m} a_{mk},$$

which makes it possible to write a column of the F matrix in the form:

$$F_{ij} = \sum_s U_{is} a_{sj}, \tag{12}$$

where the U_{0s} symbol designates the s-th column of the matrix of eigenvectors U.

Expression (12) is precisely an expansion of the F vector (its realization) in natural orthogonal functions (in eigenvectors of the covariation matrix). The coefficients of this expansion a_{ik} constitute the matrix (11), determined by a formula which is the inverse of (2).

$$A = U^* F. \tag{13}$$

It is easy to see that

$$AA^* = \Lambda$$

or otherwise

$$a_{0k} \cdot a^*_{0k} = a^2_{1k} + a^2_{2k} + \ldots + a^2_{mk} = \lambda_k. \tag{14}$$

Thus, the spur (FF^*) = spur (AA^*).

According to (11), the A matrix contains only m^2 elements, whereas the F matrix contains n x m independent elements. In order to express the lacking $nm - m^2 = m(n - m)$ elements we use variable U. The latter in incomplete form contains n x m elements, of which only the m^2 elements determined from the V matrix are independent. The remaining m(n - m) elements were also expressed precisely using the U matrix in accordance with (10).

However, this indicates that the evaluation of the covariation matrix FF^* by means of the matrix F(n x m) is rather fair.

Similarly, it is possible to express the F^* matrix through the matrix of eigenvectors of the F^*F matrix. We will have

$$F^* = VB. \tag{15}$$

The B matrix in this formula has the dimensionality (m x n). Using the elements of this matrix it is possible to derive a formula similar to (12) for the rows of the F matrix (or the columns of the F^* matrix).

$$F_{k0} = b_{1k} V_{01} + b_{2k} V_{02} + \ldots + b_{mk} V_{0k}. \tag{16}$$

Similarly to formula (14), we can obtain

$$b_{k0} b^*_{k0} = b^2_{k1} + b^2_{k2} + \ldots + b^2_{km} = \lambda_k.$$

There is a simple correlation between the matrices A and B, following from (2) and (15); equating the right-hand sides of these formulas (with transpositioning), we obtain

$$A = (VBU)^*.$$

We write, in accordance with (9),

$$F = UA = FV\Lambda^{-1/2} A.$$

We multiply this equation on the left by V^*F^* and on the right by V; we obtain

$$\Lambda = \Lambda\Lambda^{-1/2} AV$$

or

$$A = \Lambda^{1/2} V^*. \qquad (17)$$

This formula can also be derived directly by a comparison of formula (10) and a matrix analogue of formula (2).

The principal merit of formula (17) is that in order to obtain the A matrix it is not at all necessary to return to the matrix of initial data F.

Assume now that it is necessary to find the regression of some variable Z to the variables $F_1, F_2, \ldots, F_n$ -- the components of the F vector, a sample of which was given by the matrix (6). The sample of the variable Z will evidently be represented by a row of the volume m (of m terms). We will seek a regression not directly to the variables $F_1, F_2, \ldots, F_n$, but to the variables of the A matrix. In this case the regression equation can be written in the following form:

$$\hat{Z} = \varepsilon_1 a_{10} + \varepsilon_2 a_{20} + \ldots + \varepsilon_m a_{m0}, \qquad (18)$$

where $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_m$ are coefficients which for the time being are unknown, whereas the values $a_{10}, a_{20}, \ldots, a_{m0}$ are rows of the A matrix. As a result of orthogonality of the matrix rows (11) and using expression (14), we can write that

$$\varepsilon_i = \frac{1}{\lambda_i} (Za^*_{i0}) = \frac{1}{\lambda_i} (a_{i0} Z^*). \qquad (19)$$

Using formula (17), we can write an expression for the vector-row $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_m$ in the following form:

$$\varepsilon = ZV\Lambda^{-1/2}. \qquad (20)$$

It is understandable that if we expressed the vector-row $\varepsilon = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_m)$ through the U matrix, we would have the expression

$$\varepsilon = ZA^* \Lambda^{-1}.$$

For the derived regression equation (18) it is easy to compute the correlation coefficient. In actuality, since the variables of the equation (18) are mutually orthogonal, the square of the composite correlation coefficient R^2 will be equal to the sum

$$R^2 = r_1^2 + r_2^2 + \ . \ . \ . + r_m^2,$$

in which each term is the square of the correlation coefficient between Z and $a_{i\,0}$. On the other hand, on the basis of the elementary principles of correlation theory it is possible to write $\varepsilon_i = r_i \frac{\sigma_i}{\sigma_{A_i}}$,

where σ_z and σ_{Λ_i} are the standard deviations of the variables Z and $a_{i\,0}$. Hence we easily obtain

$$R^2 = \frac{1}{\sigma_z^2} \sum_i \frac{(Za_{i0}^*)}{\lambda_i}. \tag{21}$$

The composite or general correlation coefficient is determined using the formula

$$r_i = \frac{1}{\sigma_z} \varepsilon_i \sqrt{\lambda_i} = \frac{1}{\sigma_z} (Za_{i0}^*) \frac{1}{\sqrt{\lambda_i}}. \tag{22}$$

In this formula the variable Z, as before, is the vector-row of sample values of the Z variable.

Using the multiple correlation coefficient it is easy to compute the reproducible dispersion of the variable:

$$\hat{\sigma}_z^2 = \sigma_z^2 R^2. \tag{23}$$

Thus, the problem of correlation of Z for the F vector is completely solved.

Now we will proceed to the problem of predicting the Z value from the sample F value. Its prediction in pure form exceeds the limits of this sample because here it is necessary, using the new, (m+1)-th sample value of the F vector, to determine the corresponding sample (m+1)-th Z value. In this case the sequence of operations is almost obvious.

First, we will assume that the regression equation (20) can be applied beyond the limits of the sample from which it was derived. Then, using a single new realization of the vector $\tilde{F}_{m+1}$ we find the values of the parameters $a_1, a_2, \ldots, a_m$, in accordance with the formula

$$a_1 = U^*_{01} F_{m+1},\ a_2 = U^*_{02} F_{m+1}, \ldots, \tag{24}$$

where $U_{0\,i}$ are eigenvectors of the $\overline{FF^*}$ matrix, which were determined earlier using formula (9), whereas F_{m+1} is a new realization of the F vector. The determined values $a_1, a_2, \ldots, a_m$ are introduced into equation (23) and the z_{m+1} value is computed.

As we have already noted, the evaluation of the covariation matrix $\overline{FF^*}$ of the dimensionality (n x n) using a sample of the volume $m < n$ is quite poor, has a weak stability. In actuality, it is sufficient to increase the volume of the sample by unity and a new eigenvalue appears which in general is not equal to zero; there is also a change in the other eigenvalues and the small numbers change relatively more. The eigenvectors corresponding to the small numbers are also less stable than the first eigenvectors corresponding to the large numbers.

It therefore follows that in general in the regression equation (20) it makes no sense to retain all the terms; the last terms, as the least stable, containing much "noise," must be omitted. But how many terms must be kept in equation (20) is a special problem. There can be no general solution here; everything is dependent on the nature of the problem.

When using a regression equation for forecasting purposes it must be taken into account that from the very beginning we divided all the elements of the sample F by $\sqrt{m}$ (m is the volume of the sample). For this reason, if we wish to use formulas (18)-(24) without any changes, we must also divide the new (m+1)-th sample value of the F vector by $\sqrt{m}$. In particular, this applies directly to formulas (24).

We will not discuss some other details of practical computations here. It is obvious that small samples (in the sense that the number of random variables is greater than the volume of the sample) are encountered rather frequently in studies on the analysis and prediction of atmospheric processes. The problem of small samples will also remain pertinent in the future, since each 10-15 years new series of observations of new elements appear in meteorology. The work approach outlined here, with such samples, in definite cases is capable by many times of reducing the purely computational side of the work, and in some cases will make it possible to solve problems which cannot be handled directly even by electronic computers with a rather considerable capacity.

Finally, we will make one more comment. It is possible that some of the mathematical transformations cited in this article may prove to be extremely nonrigorous and even arbitrary. This applies primarily to matrix transformations with a U matrix -- the matrix of eigenvectors of the covariation matrix $\overline{FF^*}$. The U matrix is determined only for the vectors corresponding to the first m numbers, not equal to zero. But we have already mentioned that the U matrix can also be supplemented for the remaining (n - m) numbers, identically equal to zero. Such a supplementation can be carried out by an extremely great many methods, with adherence to only one condition: orthogonality of the full U matrix. After such supplementation of the U matrix (in actuality, of course, it is not necessary to do this) all the computations become completely determined.

Another possibility of justifying all the computations which have been made is use of methods for pseudoinversion of matrices. These methods have been set forth quite completely in the already cited book by Albert [1].

Thus, mathematically it is entirely possible to obtain some number of first natural components for a very large number (several hundreds) of points with use of an electronic computer of average capacity. It can be assumed that these natural components, about half the volume of the sample, will have sufficient stability. Their use, with definite reservations, is admissible on a practical basis and is entirely feasible.

Assume, for example, that it is necessary to represent the natural components of geopotential of the 500-mb isobaric surface in the northern hemisphere with monthly averaging. At present we have observational data for approximately 30 years. This means that the volume of the sample for each calendar month is about 30. It is assumed that the number of points necessary for describing the H_{500} field for the hemisphere can attain 400-500 or even more. We note that the number of so-called "independent" points for a hemisphere, according to different estimates, varies from 40 to 60. Under such circumstances 20-40 points in a hemisphere will scarcely give any good idea concerning the first natural components for a hemisphere. In any case, for the first 10 components it is better to take about 100 points and use the techniques developed in this article. It seems that such recommendations agree entirely with the requirements of climatology, in which it is assumed that a period of 30-40 years is entirely adequate for obtaining virtually stable means. Taking into account some weak nonstationary character of atmospheric circulation processes, it can be said that a lengthening of these times is scarcely desirable.

With respect to the regression equation and its use in predictions, here, as usual, everything is dependent on the volume of the sample and the number of predictors. Although the system of natural components, determined on the basis of sample data for a new (not entering into the original sample) realization, will not be complete, this should not have any significant effect on the regression results, since we cannot take all the components into account. In other words, here there is an ordinary transfer of the statistical properties of the sample to the new realization. It can be noted that some researchers, such as M. I. Yudin [10], consciously very greatly limit the volume of the sample used in the forecast, assuming that large samples are useless as a result of nonstationary processes. In this article we do not give any statistical evaluations of the results obtained. It appears that no classical methods for making such evaluations are applicable here. In many such methods we encounter the mandatory condition $m > n$, that is, the volume of the sample must be greater than the dimensionality of the considered vector.

Thus, for judgments concerning the applicability of these operations, for the time being we can judge their statistical significance only on the basis of general intuitive considerations. Some modeling procedures or empirical computations are also possible.

An empirical checking of the legitimacy and admissibility of use of small samples is possible in two directions: either from a good large sample ($m > n$) form several (2-3 or more) small samples, such that in each ($m_i < n$), and compare the results, that is, compare the eigenvalues and eigenvectors; or vice versa, from one small sample ($m < n$), but where n is sufficiently great, by means of a decrease in dimensionality, form one or two normal samples (in the sense $m > n_i$), by means of a regular thinning of criteria (for example, a decrease in the number of points on the map).

The coordinate system, reducing the covariation matrix of the random vector to a diagonal form, has the optimum property that the entropy of dispersions in this case becomes minimal. This property can be expressed by the formula

$$-\sum_{i=1}^{n} M_{ii} \ln M_{ii} \geqslant -\sum_{i=1}^{n} \lambda_i \ln \lambda_i, \tag{25}$$

where M_{ii} are diagonal elements of the covariation matrix.

As is well known, for thermodynamic systems the change to more probable states is accompanied by an increase in entropy. In our case an increase in entropy in accordance with equation (3) means a change to those coordinates in which the dispersion is distributed more uniformly with respect to different components of the F vector.

It makes sense to trace how this occurs. On the basis of the rules of matrix multiplication, for an element of the M matrix, using equation (5), it is possible to write the expression

$$M_{ij} = \sum_{s=1}^{n} U_{is} \lambda_s U^{*}_{sj} = \sum_{s=1}^{n} U_{is} U_{js} \lambda_s .$$

For diagonal elements of the M matrix this formula gives

$$M_{ii} = \sum_{s=1}^{n} U_{is} \lambda_s . \tag{26}$$

The $U^{(2)}$ matrix, whose elements are equal to the squares of the elements of the orthogonal matrix of the eigenvectors U, evidently will be doubly stochastic, that is, the sums of the elements of each row and each column of such a matrix are equal to unity. It therefore follows that the M_{ii} values are found by some averaging of the values $\lambda_1, \lambda_2, \ldots, \lambda_n$. In particular, this means that $M_{11} \leqslant \lambda_1$, and $M_{nn} \geqslant \lambda_n$, and, as it is easy to see,

$$\sum_i M_{ii} = \sum_\alpha \lambda_\alpha .$$

The inequality (25) was already mentioned by Shannon, the founder of the theory of information. An application to matrix theory was evidently given for the first time in [5], published in 1967.

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SOME CHARACTERISTICS OF WAVE OROGRAPHIC CLOUD COVER OVER THE MIDDLE AND NORTHERN URALS

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Abstract: A study was made of the principal characteristics of wave orographic clouds forming on the leeward slope of the Northern Urals.

[Text] Already for a period of 20 years the Department of Atmospheric Physics of the Physics Faculty Moscow State University has been engaged in a study of air currents in mountains and an investigation of the conditions for formation of orographic cloud cover in different regions of the Soviet Union. As a result, much factual material has been accumulated on the physical properties of altocumulus lenticular clouds of the Ac lent type in the Crimea, in the Caucasus, in the Carpathians and in Central Asia [1, 3, 4].

The studies which are being carried out in the Department of Atmospheric Physics have made it possible to compare the observed wave clouds with theoretical data [2]. In particular, it follows from the theoretical studies of A. F. Dyubyuk and V. N. Kozhevnikov that the profile and configuration of an obstacle exert a considerable influence on the redistribution of meteorological elements on the leeward side [5, 7]. Accordingly, at all times we have striven to find those mountain ranges which could be theoretically investigated within the framework of two-dimensional models and the results (streamlines) are compared with really existing cloud systems [8].

The Urals long ago attracted our attention. A. F. Dyubyuk has repeatedly mentioned the necessity and good prospects for studying the properties of the air flow in the Northern and Middle Urals. In actuality, the Urals Range is oriented almost meridionally, especially in its northern part, is quite elongated, and the westerly flows, perpendicular to the range, as we will see below, are typical.

All this indicates that it must exert a considerable influence on zonal flows and on the leeward side create a stable wave pattern close to the two-dimensional theoretical models [8], which in the first place must be manifested in the field of orographic cloud cover.

Despite the fact that the Urals is of considerable interest for investigators of mesometeorological processes, it has been very poorly studied. For example, in the studies of A. Kh. Khrgian and V. D. Sovetova an investigation was made of the influence of the southern and middle parts of the Ural Range on cloud cover and precipitation [10, 11]. The region to the north of Nizhniy Tagil has remained virtually unstudied.

In the summer of 1972 we made a first attempt at clarifying the conditions and nature of wave formation on the eastern slope of the Northern Urals. The expedition was based on the aerological station at Ivdel', which is located 60 km to the east of the main line of the range and 500 km to the north of Sverdlovsk. Our investigations revealed a good possibility for study of wave movements in this region. In the summer of 1973 we organized a second expedition to the regions of Severoural'sk and Vsevolodovo-Blagodatskiy village. The observation points in this case were situated closer to the main line of the range (at a distance of 20 km), which made possible a more detailed study of the properties of orographic clouds.

For an observer situated on the ground the only evidences of wave movements in the atmosphere are orographic clouds. Therefore, our efforts were directed to a study of cloud systems consisting of Ac lent clouds. We employed an earlier developed stereophotogrammetric method with a simultaneous survey of the entire heavens on the same frame [3]. In addition to instrumental measurements of cloud cover, in order to obtain the mean statistical characteristics of wave cloud cover, extensive use was made of data from the network of meteorological stations.

Frequency of appearance of clouds of the Ac lent type in the Middle and Northern Urals. An investigation of the spatial distribution of the frequency of Ac lent is interesting from two points of view: 1) Due to the fact that the Urals Range is quite extended in a meridional direction, its uniformity from north to south is different. And this means that its individual parts must exert a different influence on perpendicular air flows. 2) Knowing the frequency of appearance of wave clouds over meteorological stations situated at the same latitude but at different distances from the axis of the range, it is possible to estimate indirectly how far the wave pattern is propagated downstream.

In a meridional direction we examined a region with an extent of about 600 km from Burmantov to Sverdlovsk. An analysis of cloud cover was made using data from eight meteorological stations situated on the eastern slope of the Urals (Burmantovo, Ivdel', Severoural'sk, Karpinsk, Serov, Verkhotur'ye, Nizhniy Tagil, Sverdlovsk). From the meteorological records we selected the days when there were clouds of the Ac lent type.

Table 1

Frequency of Appearance of Wave Orographic Clouds of the Ac lent Type in the Northern and Middle Urals Regardless of Season

	Пункт наблюдения 1	Расстояние от хребта, км 2	Число анализируемых дней 3	Число дней с облаками типа Ac lent. 4	Частота появления облаков типа Ac lent. % 5
6	Бурмантово	60 к востоку	1963—1972 3553	890	25
7	Ивдель	50 17 к востоку	1963—1972 3553	781	22
8	Североуральск	35 к востоку	1960—1965 1970—1972 3198	878	27
9	Карпинск	50 к востоку	1965—1972 2822	339	12
10	Серов	70 к востоку	1965—1972 2822	422	15
11	Верхотурье	80 к востоку	1966—1972 2457	146	6
12	Нижний Тагил	60 к востоку	1965—1972 2822	280	10
13	Свердловск	160 к востоку	1963—1972 3553	250	7
14	Шанталь	170 к востоку	1961—1965 1726	70	4
15	Чердынь	120 к западу	1961—1965	225	13
16	Усть-Черная	300 18 к западу	1961—1965 1726	33	2

Key:
1. Observation point
2. Distance from range, km
3. Number of analyzed days
4. Number of days with Ac lent type
5. Frequency of appearance of Ac lent clouds, %
6. Burmantovo
7. Ivdel'
8. Severoural'sk
9. Karpinsk
10. Serov
11. Verkotur'ye
12. Nizhniy Tagil
13. Sverdlovsk
14. Shantal'
15. Cherdyn'
16. Ust'-Chernaya
17. to the east
18. to the west

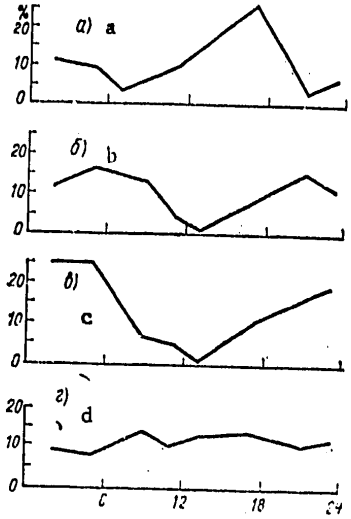
Without regard to season, these data were averaged and we calculated the frequency of recurrence of days with lenticular clouds. Table 1 gives data on the spatial distribution of the frequency of occurrence of wave orographic clouds. It can be seen that in the northern part of the region from Burmantovo to Severoural'sk the frequency of occurrence of wave clouds is maximum (an average of 25%). The range in this region is characterized by a maximum uniformity (mean width of range -- 100 km, elevation 1,100-1,300 m).

To the south of Severoural'sk the main Ural Range deviates somewhat from a meridional direction and is incised by latitudinal valleys. Individual mountain complexes rise here: Ol'vinskiy Kamen' (1,519 m), Konzhakovskiy Kamen' (1,569 m), Kos'vinskiy Kamen' (1,519 m). As a result, the influence of the range in general attenuates and this creates a complex picture of flow around individual peaks which impairs the ordered wave system characteristic for a uniform elongated range. In the cloud cover field this is manifested in a decrease in the frequency of appearance of clouds of the Ac lent type, on the average by 12%.

From Nizhniy Tagil to Sverdlovsk the main range drops down considerably (to 500 m), broadens out (average width of range 200 km) and still more loses its uniformity. The leeward slope of this sector is characterized by a minimum frequency of appearance of clouds of the Ac lent type (on the average 8%).

Thus, most frequently ordered wave movements of air and the lenticular clouds associated with them are formed on the leeward slope (for westerly air flows) of the highest northern part of the Urals Range, from Severoural'sk to Burmantovo. Cloud photographs taken from meteorological satellites show that wave clouds are also frequently observed beyond the Polar Urals, but we do not have a sufficient series of observations for carrying out a statistical analysis.

In order to ascertain the rate of attenuation of the wave flow downstream we analyzed data from meteorological stations situated at the latitude of Ivdel': Ust'-Chernaya, Cherdyn', Ivdel' and Shantal'. Ust'-Chernaya and Cherdyn' are located on the western slope of the Urals Range, 300 and 120 km respectively from the main line of the range, whereas Ivdel' and Shantal' stations are located 60 and 170 km respectively from the main line of the range on the eastern slope. Table 1 shows that at Ivdel' clouds of the Ac lent type are observed rather frequently (22%). With increasing distance from the range the frequency of appearance of wave clouds decreases and for the meteorological station Shantal', situated 170 km to the east of the range line is 4% of all the investigated days. The same picture is observed when there are easterly winds on the western slope of the range. Whereas for Cherdyn' station the frequency of occurrence of clouds of the Ac lent type is 13%, the Ust'-Chernaya meteorological station observes these clouds very rarely (2%).



a. winter

b. spring

c. summer

d. winter

Fig. 1. Diurnal variation of wave orographic clouds of the Ac lent type for different seasons (according to data from Severoural'sk aviation meteorological station).

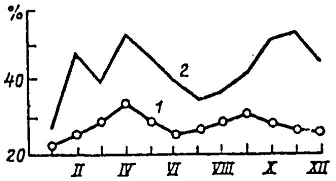


Fig. 2. Seasonal variation of wave orographic clouds of the Ac lent type (according to data from Severoural'sk aerometeorological station) (1) and westerly flows (according to radiosonde data for Perm') (2).

As a result of an analysis of the spatial distribution of the frequency of appearance of clouds of the Ac lent type along latitude it is possible to draw the indirect conclusion that the influence of the Ural Range on the field of orographic cloud cover is reflected downstream to a distance of 200 km.

Diurnal variation of wave orographic clouds. A joint analysis of radiosonde data and a slow motion picture survey of clouds made earlier in the Crimea made it possible to establish that one of the reasons for the destruction of wave clouds is a change in the intensity of convective air movements as a result of heating of the underlying surface [6]. Accordingly, the diurnal variation of wave clouds must essentially be dependent on the season of the year. The observational data on Ac lent make it possible to clarify this problem to some degree. We took data for the aviation meteorological station at Severoural'sk during the period from 1967 to 1973 and analyzed the frequency of appearance of clouds of the Ac lent type during the course of the year. December-February are assigned to the winter season, March-May are assigned to spring, June-August are assigned to summer and September-November to autumn. Figure 1 presents the results of determinations of the frequency of appearance of clouds of the type Ac lent during the day for different seasons.

Table 2

Cloud Cover Accompanied by Clouds of the Ac lent Type (According to Data from Meteorological Stations in the Northern Urals)

1 Форма облачности	2 Количество дней	3 Повторяемость, %
Ac lent., Sc lent., Ci, Cs, Cc	623	47
Ac lent., Sc lent., Cb	57	4
Ac lent., Sc lent., Cu cong.	12	1
Ac lent., Sc lent., Cu med., Cu hum.	48	4
Ac lent., Sc lent., Ac, As	79	6
Ac lent., Sc lent., Sc	168	13
Sc lent.	64	5
Ac lent.	232	18
Ac lent., Sc lent., Cb, Cu, Ci, Cs, Ac, Sc	26	2
4 Итого	1309	100

Key:

1. Form of cloud cover
2. Number of days
3. Frequency of recurrence, %
4. Total

The diurnal variation of wave clouds is clearly traced during the spring-summer seasons with maxima during the morning, evening and nighttime hours. At near-midday hours there is an almost complete absence of wave clouds for the spring-summer seasons. In autumn a diurnal variation of clouds of the type Ac lent is virtually not expressed. In the winter time, on the other hand, during the daytime there is a uniform increase in the frequency of occurrence of wave clouds from morning to evening with a maximum at about 1600 hours.

Thus, in the warm half-year the daytime local circulations developing over the mountains and valleys are propagated to an altitude adequate for destroying the distribution of streamlines behind the range, and this favors the appearance of atmospheric wave movements.

Seasonal variation of wave orographic clouds. The problem of the seasonal variation of wave orographic clouds of the Ac lent type has not yet been completely solved. For example, it was pointed out in [12] that over regions of the Sierra Nevada (United States) and the British Isles wave situations are encountered most frequently during the winter half of the year. The observations of Larrson in Sweden [13] revealed a substantially different peculiarity, to wit: the influence of mountain barriers on air currents is especially great during the transitional periods of spring and autumn. We feel that in order to clarify the seasonal variation of wave clouds it is necessary to know, in particular, the conditions surrounding their formation. If, as mentioned in [2], the perpendicularity of an air flow to an obstacle is one of the decisive factors for the excitation of wave movements on the leeward side of a range, it was especially necessary to clarify the wind regime of the Northern and Middle Urals.

We examined radiosonde data for Perm' for the period from 1968 through 1973. Taking into account that clouds of the Ac lent type, according to our stereophotogrammetric measurements, are observed most frequently at altitudes from 3 to 7 km, we limited ourselves to an analysis of data for the tropospheric layer from 1.5 to 8 km. First of all we determined the type of air flow for eight directions of the compass for each day. Westerly winds, perpendicular to the range, were predominant for all seasons; there is a seasonal variation of westerly flows with a minimum in summer and maxima in autumn and spring. True, deviations from the mean are small -- about ±12% (see Fig. 2).

Next, using data from the meteorological stations Severoural'sk, Ivdel' and Burmantovo we constructed curves of the seasonal variation of the frequency of appearance of clouds of the Ac lent type, which are shown in Fig. 2. It can be seen that there is a definite correlation between the frequency of appearance of wave clouds and westerly flows.

Easterly winds, also perpendicular to the range, are observed quite rarely. Nevertheless, it can be suggested that in summer their number is somewhat greater than in spring and autumn. When there are easterly winds wave clouds should be excited on the westerly slope of the Urals (see data for the Cherdyn' meteorological station in Table 1).

Cloud cover accompanying wave orographic clouds. Convective air movements destroy lenticular clouds, but these same flows are responsible for the formation of cumulus clouds. The intensity of cumulus clouds will be essentially dependent on atmospheric stability, that is, the temperature stratification of the air flow. Therefore, on the basis of the type of cloud forms accompanying wave orographic clouds we can draw the conclusion that there is a stratification of the atmosphere. On the basis of data for the meteorological stations Burmantovo, Ivdel' and Severoural'sk we selected 1,309 days with Ac lent or Sc lent clouds.

Table 3

Altitudinal Distribution of Layers With Ac lent Clouds in August 1973

Число 1	Количество уровней 2	Высоты уровней с облаками типа Ac lent., км 3	Вертикальная мощность облачных слоев, км 4	Вертикальная мощность безоблачных промежутков, км 5	Направление воздушного потока в слое 1—8 км 6
5	5	3,01—4,1 4,33—4,77 5,42—6,43 7,80—8,34 9,1—9,4	1,06 0,44 1,01 0,54	0,230 0,69 1,37 0,76	З 7
2	4	6,77—6,92 7,48—7,74 8,17—8,67 8,89—9,22	0,15 0,26 0,40 0,35	0,56 0,43 0,22	З 7
4	4	4,31—4,46 5,91—6,25 6,88—7,05 9,21—9,44	0,15 0,34 0,17 0,23	1,45 0,63 2,16	З 7
19	4	2,4—2,6 2,7—2,9 3,19—3,36 6,7—7,1	0,20 0,20 0,17 0,4	0,30 0,29 3,34	ЗСЗ 8
12	2	3,3—3,6 5,52—5,70	0,30 0,28	1,92	ЗСЗ 8
9	1	2,3—2,66	0,33		В 9

Key:

1. Number
2. Number of levels
3. Altitudes of levels with clouds of the Ac lent type, km
4. Vertical thickness of cloud layers, km
5. Vertical thickness of cloudless intervals, km
6. Direction of air flow in layer 1-8 km
7. West
8. WNW
9. E

The observed cloud cover was transcribed from the meteorological record books for each specific day. As a result it was possible to discriminate eight groups: when simultaneously with Ac lent or Sc lent, Cc lent there was observation only of cirrus cloud or cumulus- or stratus-type forms, or only middle-level clouds; when only lenticular clouds were observed, and, finally, when all cloud forms were observed simultaneously.

The analytical results are presented in Table 2, from which it follows that almost half of all the days are cases of simultaneous existence of wave and cirrus cloud forms (47%). One of the reasons for this can be that the Urals form not only clouds of the Ac lent type, but als cirrus clouds. In [14] Ludlam already pointed out that upper-level clouds can be formed beyond the mountains. Our stereophotogrammetric measurements of cloud cover registered Cc lent situated at altitudes of 9.3 km. Unfortunately, we had no cloud data for these same days for the oncoming flow, that is, in front of the Urals Range. In the future it would be of interest to carry out a simultaneous comparison of cloud forms in the windward and leeward flows.

In 23% of the cases there were only wave orographic clouds. Table 2 shows that clouds of the Ac lent type, in combination with cumulus clouds, are encountered quite rarely (9% of all cases). This agrees with the fact, as shown by an analysis of radiosonde data, that in the case of wave clouds of the Ac lent type, the atmosphere is stably stratified and at altitudes 2-4 km there are isothermic layers which inhibit the development of convective clouds.

Lifetime of wave orographic clouds. Almost all theoretical studies relate to stationary models. In order to clarify the legitimacy of their application to really existing wave cloud systems it is necessary to know the lifetime of these systems. It follows from our direct observations of clouds of the Ac lent type that the lifetime of a system consisting of wave orographic clouds varies from 2 hours 30 minutes to 10 hours. The individual lenticular clouds entering into the system continuously change form and size. The velocities of horizontal change in individual clouds of the Ac lent type vary from 1 to 3 m/sec and their lifetime is 12-50 minutes.

The processing of the stereophotogrammetric photographs indicated that individual Ac lent pulsated, that is, the lenticular clouds developed in a definite region and at some moment in time attained their maximum size. Then the clouds began to decrease in volume until they had completely disappeared or until they had attained a minimum size. After this, after a definite time interval a cloud similar in size and form again developed at this very same place. The period of the pulsations was 15-35 minutes. The wave cloud system in general in such cases remained quasistationary, that is, the center of gravity of individual cloud bands was almost not displaced relative to the local relief.

Spatial characteristics of wave orographic clouds. During the period of expeditionary work we repeatedly observed cloud systems consisting of clouds of the Ac lent type.

Since stereophotogrammetric measurements of cloud cover were made in the Northern Urals region for the first time, we will now discuss some of the results.

Altitudes of appearance. As a result of processing of the stereo photographs it was possible to detect a characteristic peculiarity: as a rule, clouds of the Ac lent type existed simultaneously at several levels, between which there were cloudless intervals. For example, on 5 August 1973 there were five levels with clouds of the Ac lent type, on 2 August 1973 -- four levels, on 4 August (morning and evening) and on 19 August 1973 -- three levels, on 12 August 1973 -- 2 levels. Table 3 gives some idea concerning the thicknesses of cloud and cloudless layers, their lower and upper levels. Table 3 shows that the levels of cloudy and cloudless layers vary from day to day.

The enumerated situations were observed when there were westerly or nearly westerly winds, when the wave pattern developed on the eastern, leeward slope of the main Urals Range (average elevation 1,000-1,200 m). When there was an easterly air flow, as was the case on 9 August 1973, the region of observations was on the windward side of the main Urals Range, but on the leeward side of the eastern Urals ridges, which are 70 km from the Urals Range and 20 km from the observation site (to the east). The region of the ridges consists of three principal chains: the foothills of the Urals Range with the highest rise being Petropavlovskaya Peak (424 m) and the two chains of the Eastern Urals Ridges.

On 9 August wave orographic clouds of the Ac lent type, which we observed at Lake Svetloye (4 km from Vsevolodov-Blagodatskiy) were formed on the leeward slope of the Urals Ridges. In this case the wave cloud pattern was completely different than in the case of westerly flows. First, there was only one layer with clouds of the Ac lent type. The lower base of the lenticular clouds was situated at altitudes from 2.3 to 2.6 km and the tops attained 3 km. The vertical thickness of individual clouds was 360 m. The cloud system itself was not represented by long bands parallel to the range, as we always observed in the case of westerly flows, but by individual "lenses," whose long axes were parallel to the ridges. The horizontal dimensions (perpendicular to the flow) of individual clouds varied from 2.5 to 8 km.

All this indicates that beyond less high obstacles wave movements are excited at lesser altitudes and their attenuation with altitude occurs considerably more rapidly.

Vertical thickness. In most cases for wave clouds of the Ac lent type it is possible to measure both the lower and upper bases. On stereopairs obtained on different days we measured the vertical thicknesses of individual lenticular clouds entering into the wave systems. As a result, we ascertained the frequency distribution of the vertical thickness of clouds of the Ac lent type. The histogram shown in Fig. 3a shows that most frequently there are clouds having a vertical thickness from 300 to 400 m. The scatter of values varies in the range from 100 to 1,200 m.

Extent of clouds of Ac lent type perpendicular to flow. A distinguishing characteristic of the Northern Urals is that when there are westerly air flows a whole system of wave orographic clouds of the Ac lent type is formed. The individual clouds entering into the system constitute long ribbons parallel to one another and the range. The use in the analysis of cloud photographs taken from meteorological satellites has made it possible to clarify that the wave pattern is extended 400-500 km along the meridian. Our survey apparatus did not make it possible to take in the entire cloud system. Therefore, when we speak of the extent of wave clouds, we have in mind the individual clouds registered on the stereo photographs. Figure 3b, which shows a histogram constructed on the basis of measurements of horizontal dimensions of individual clouds perpendicular to the flow for all days of observations shows that the extent of the clouds varies from 1 to 22 km. At the same time, it must be taken into account that we did not discriminate any definite stage in the development of wave clouds.

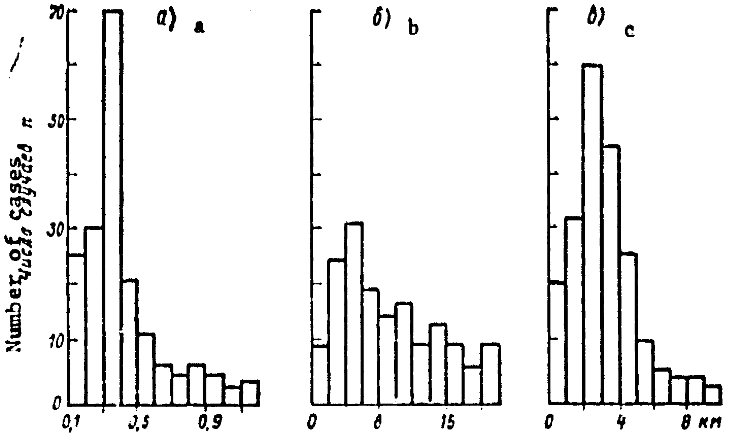


Fig. 3. Frequency distribution of parameters of clouds of Ac lent type. a) vertical thickness, b) length perpendicular to flow. c) width

Thus, the distinct organization of clouds of the Ac lent type into elongated bands gives us a basis for asserting that the flow around the Northern Urals is two-dimensional.

Width of clouds. The width of individual cloud bands varies in a considerably lesser range than their length. Figure 3c shows that it varies from 1 to 5 km. Most frequently there are wave clouds with dimensions from 2 to 3 km perpendicular to the flow.

Downstream propagation of wave pattern. As a rule, cloud systems consisting of wave clouds of the Ac lent type constituted parallel ridges with a total number from 4 to 10. As indicated earlier, a stereophotogrammetric survey made it possible to detect a multilevel nature of wave orographic clouds. The greatest number of bands with the greatest distance from the range downstream was registered for the lower (3-4.5 km) level. We will cite several of the clearest examples.

Fig. 4. Wave orographic clouds of the Ac lent type which were observed on 24 July 1972 at 0825 hours (at Ivdel').

On 5 August 1973 there were nine cloud bands simultaneously; in the layer 3.2-4 km these were propagated downstream for a distance up to 100 km. In the above-lying layer, from 5 to 6 km, there were only four bands with a maximum distance from the range up to 30 km. At the very upper level, at an altitude of 9.3 km, there was only one band which was situated virtually over the main Urals Range [9].

On 21 July 1972 wave orographic clouds were observed from the earliest morning to 1300 hours in the form of long bands parallel to the range, the total number being more than nine. According to measurements, the lower layer with clouds of the Ac lent type was situated at the level 4.3 km. The vertical thickness was 550 m. The average wave length was 9.5 km. By comparing the data from the stereophotogrammetric measurements with data obtained using a wide-angle camera it could be established that the entire cloud system was propagated downstream for a distance of more than 150 km (the cloud bands moved out of the field of view of the survey camera).

According to radiosonde data (at Ivdel'), the wind had a stable westerly direction in the entire thickness of the troposphere. The wind velocity increased with altitude. The wind shear in the layer from 500 m to 2 km was particularly conspicuous. For example, at an altitude of 500 m the wind velocity was 7 m/sec, and at an altitude of 2 km -- 20 m/sec. Aloft the velocity changed little with altitude, on the average remaining 23 m/sec.

The oncoming flow, according to radiosonde data for Perm', was characterized by an increased stability. In the layer 1.5-5 km the vertical temperature gradient was γ = 3.6°C/100 m.

On 24 July 1972 wave orographic clouds of the Ac lent type developed at 0500 hours and lasted until 0950 hours. As in the preceding examples, the clouds were stretched out in long bands parallel to the range. Figure 4 is a photograph of cloud bands at 0825 hours. It is easy to see at least eight bands. We succeeded in establishing that the influence of the Urals Range was reflected in the cloud cover field a distance of more than 140 km.

According to radiosonde data for Perm', the oncoming flow had a stable westerly direction perpendicular to the range. At an altitude of 3 km the wind velocity was 5 m/sec, and at an altitude of 5.5 km -- 25 m/sec. With altitude a wind shear occurred with a gradient of 8 m/sec per kilometer.

As in the preceding case, in the oncoming flow there was a considerable layer with a small vertical temperature gradient. At altitudes from 1.5 to 3 km the vertical temperature gradient γ = 0.4°C/100 m.

Thus, not only indirectly, but also instrumentally, it was possible to establish that the influence of the Urals Range is manifested in the field of orographic cloud cover for a distance of more than 150 km.

We note in conclusion that the Northern Urals is exceptionally favorable for leeward wave formation. When there are westerly air flows the cloud systems consisting of clouds of the Ac lent type correspond to a two-dimensional pattern of flow.

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STATISTICAL INDICES OF SPATIAL DISTRIBUTION OF PRECIPITATION IN THE EXPERIMENTAL METEOROLOGICAL POLYGON

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 25-30

[Article by Candidate of Physical and Mathematical Sciences V. M. Muchnik, Ukrainian Scientific Research Hydrometeorological Institute, submitted for publication 28 March 1978]

Abstract: A study was made of the characteristics of the precipitation field in the Experimental Polygon of the Ukrainian Scientific Research Hydrometeorological Institute. The presence of stable local nonuniformities over the territory of the Experimental Meteorological Polygon (EMP) is demonstrated.

[Text] The organization of the Experimental Meteorological Polygon (EMP) with a dense rain-gage network made it possible to solve many problems relating to artificial cloud modification [6, 8]. In selecting the territory of the EMP particular attention was given to the absence of significant differences in elevation, major rivers and water bodies as factors exerting an influence on the formation of precipitation [8]. But disturbances of the precipitation field must nevertheless exist, since in the territory of the EMP itself and in the nearby areas there are major industrial cities (Krivoy Rog, Dneprodzerzhinsk, Zaporozh'ye, Nikopol') and large water bodies (Kakhovskoye and Dneprodzerzhinskoye Reservoirs). As is well known, large industrial cities exert an appreciable influence on precipitation in the adjacent territory [1, 3, 10]. Accordingly, in the EMP it is possible to expect the existence of a singular areal distribution of precipitation.

L. F. Bogatyr' and A. I. Romov [2], making a study of shower precipitation (intensity maximum greater than 6 mm/hour and duration less than three hours) during June-August 1960-1962, discovered "permanent" maxima in the western and eastern parts of the EMP which were separated by a zone of minimum precipitation.

The existence of local maxima and minima of precipitation over the territory of the EMP is of considerable interest in relation to the problems involved in evaluating the effectiveness of modification [5, 6, 8]. For example, those cases of modification which relate to a territory with a local maximum on the average give exaggerated values in comparison with modifications carried out for a territory with a local minimum.

The presence of local maxima and minima of precipitation at distances of 10-20 km from one another is a factor which must be taken into account in solving a number of pressing problems: long-range forecasting of the quantity of precipitation, planning of sown areas, prediction of the probability of obtaining a harvest of a stipulated level, organization of irrigation systems, etc.

The problem of the existence of local maxima and minima during the modification period (May-August) in convective clouds was examined using precipitation data collected at posts in the EMP during 1966-1970. As demonstrated in [4], the result of modification of well-developed cumulus clouds during this time period was less than 1% of the mean quantity of precipitation and could not exert an influence on its distribution. Therefore, artificial precipitation was not taken into account. The author also did not take into account the possible influence of microclimate on the conditions for measuring precipitation, since during the setting out of precipitation gages particular attention was given to the absence of such influences. When processing the data use was made only of those posts whose observation series had no interruption during the course of this time. As a result, the mean density of posts was about 1 precipitation gage per 18 km^2. These data were used in constructing maps of the monthly and seasonal (May-August) precipitation sums for the period 1966-1970. The maps were used in determining the positions of the centers of the precipitation maxima and minima as the geometric centers of closed isohyets. In cases when the isohyets were not closed at the edges of the map, the position of the centers was determined approximately. The accuracy in determining the position of the centers of the maxima for the most part was 1-2 km and was greater than the accuracy for the minima, which was 2-4 km.

Table 1

Dimensions of Areas of Regions "+" and "-" According to Fig. 1

	Области Regions								
	I_+	II_+	III_+	IV_+	Σ_+	I_-	II_-	III_-	Σ_-
S км²	196	274	184	78	732	66	250	972	1288

As can be seen from the seasonal precipitation map for 1966-1970 (Fig. 1), in the EMP territory there are clearly definable regions of maxima and minima. The isohyet 180 mm can be considered the boundary between zones of increased and decreased quantities of precipitation and the isohyets 160 and 200 mm can be regarded as determining the principal regions of reduced and increased quantities of precipitation respectively. [Henceforth the regions of increased and decreased quantities of precipitation will be designated as regions "+" and "-" respectively.] As a result, it was possible to define the following regions of increased quantity of precipitation (Table 1): I_+ -- in the northwest, II_+ -- in the southwest, III_+ -- in the north, IV_+ -- not closed in the southern part of the EMP, and with a reduced quantity of precipitation: I_- -- not closed in the northwest, II_- -- in the south, III_- -- large, taking in almost all the eastern part of the EMP, within which there is a rather large intermediate region with an increased quantity of precipitation.

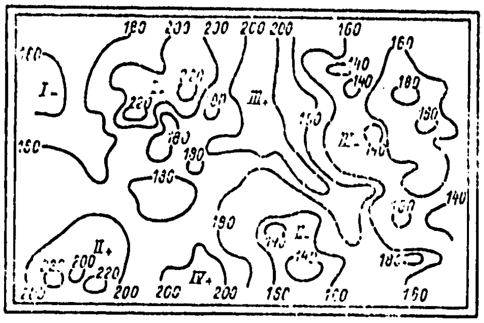

Fig. 1. Seasonal (May-August) precipitation map of the Experimental Meteorological Polygon during period 1966-1970. Regions of quantity of precipitation: increased (> 200 mm) -- I_+, II_+, III_+, IV_+ and decreased (< 160 mm) -- I_-, II_-, III_-.

Table 2

Frequency of Recurrence of Centers of Precipitation by Months and Parameter p for 1966-1970

Центр 1	Май 2	Июнь 3	Июль 4	Август 5	Σ
«+»	23	29	34	22	108
«—»	37	43	41	36	157
«+» и 6 «—»	60	72	75	58	265
p	0,38	0,40	0,45	0,38	0,41
p_1	0,26	0,28	0,33	0,26	0,35
p_2	0,48	0,52	0,57	0,48	0,47

Key:

1. Center
2. May
3. June
4. July
5. August
6. and

Table 3

Frequency of Recurrence of Centers "+" and "-" of Monthly Sums of Precipitation by Regions of Precipitation "+" and "-" in 1966-1970

Месяц 1	I_+		II_+		III_+		IV_+		Σ_+		I_-		II_-		III_-		Σ_-	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
2 Май	3	0	2	1	1	1	0	0	6	2	0	1	0	4	6	7	6	12
3 Июнь	5	0	4	1	2	2	2	0	13	3	0	0	1	2	6	12	7	14
4 Июль	5	1	2	0	4	0	0	0	11	1	0	0	0	6	3	13	3	19
5 Август	3	0	5	1	3	2	1	0	12	3	0	3	1	3	0	13	1	19
Σ	16	1	13	3	10	5	3	0	42	9	0	4	2	15	15	45	17	64

Key:

1. Month
2. May
3. June
4. July
5. August

Table 4

Values of p Parameter and Its Confidence Limits p_1 and p_2 for the Regions "+" and "-" for 1966-1970

1 Область осадков	n	m	p	p_1	p_2
I_+	17	16	0,94	0,71	1,00
II_+	16	13	0,81	0,54	0,94
III_+	15	10	0,67	0,38	0,88
Σ_+	51	42	0,82	0,68	0,92
II_-	17	2	0,12	0.02	0,37
III_-	60	15	0,25	0,15	0,38
Σ_-	81	17	0,21	0,12	0,32

Key:

1. Precipitation region

Local nonuniformities of the precipitation field in the EMP territory are extremely significant. For example, the difference in the mean extremal quantity of precipitation in the northern parts of regions III_+ and III_-

exceeds 90 mm, that is, is comparable to the minimum value in region III_- (128 mm) and constitutes about half the maximum value in the region III_+ (219 mm). With a distance between these points of 16.4 km the gradient of the mean quantity of precipitation is 5.5 mm/km, that is, is extremely great. We will also compare the mean values of the quantity of precipitation by areas in region III_+ and the northern sector of region III_-, determined as the means of the values for individual posts. This gives values of 205 and 145 mm respectively. Since the axes of region III_+ and the northern part of region III_- are -iented parallel to one another, the distance between them can be determined approximately. It was found that the mean values of the quantity of precipitation in these two areas of about 200 km^2, whose axes are approximately 18 km apart, differ by 60 mm. Still greater differences are obtained when comparing data for regions I_+ and II_+ with data for regions II_- and III_-, the distance between which does not exceed 60 km.

Now we will attempt to answer the main question as to whether these regions are a result of a random distribution of precipitation over the territory of the EMP or some constantly prevailing factors. For this purpose we will determine the frequency of recurrence of centers of increased ("+") and decreased ("-") quantities of precipitation from the monthly maps for each year.

According to Table 2, the number of centers in June and July somewhat exceeds their number in May and August. Such a variation in the frequency of occurrence is possibly attributable to the fact that in June and July separation between periods of precipitation is greater than in May and August.

Since only the appearance of centers of precipitation of two signs is possible, their distribution is binomial. Accordingly, for solving the problem of the existence of local disturbances in the distribution of the centers of precipitation it is necessary to check the hypothesis of an invariability of the distribution parameters over the territory of the EMP. For this purpose we will use the parameter $p = m/n$, where m is the number of "+" centers and n is the total number of "+" and "-" centers. For final samples the p parameter can be varied in some limits p_1 and p_2, stipulated by the selected confidence level. If the local disturbances of the precipitation field in the EMP are great and the regions of increased and decreased quantities of precipitation are attributable to them, it must be expected that for the "+" regions the p_1 and p_2 values will differ considerably from their values for the "-" regions. In particular, there can be cases when the entire interval of p_1 and p_2 values for the "+" regions will fall outside the interval of their values for the "-" regions.

In order to determine the confidence limits p_1 and p_2 we will select the sufficiently high 99% confidence level. These limits will be obtained from the p and n values using the nomogram cited in [9].

Table 2 shows that the p value for the entire territory of the EMP, determined on the basis of all data ($n = 265$), is equal to 0.41 with the confidence limits $p_1 = 0.35$ and $p_2 = 0.47$. From month to month the p parameter and its confidence intervals experience small changes. This supports the hypothesis that the conditions for the formation of precipitation in the EMP vary little during the period of time May-August.

Now we will proceed to an examination of the frequency of recurrence of centers of precipitation by oblasts.

Despite the fact that there were 51 centers for all months in all regions with a quantity of precipitation greater than 200 mm and 81 centers with less than 160 mm, their number for individual months is inadequate for obtaining convincing values of the p parameter for individual regions. Therefore, we will use data only from the last line in Table 3 for determining p for individual regions (except for regions IV_+ and I_-) for all months, and also for Σ_+ and Σ_- for individual months.

It follows from Table 4 that the frequency of recurrence of the "+" for regions of precipitation "+" differs sharply from their frequency of recurrence for "-" regions. Thus, the minimum p value for "+" regions is equal to 0.67 (region III_+), whereas its maximum value for "-" regions is 0.25 (region III_-). In addition, it is found that both for the total region Σ_+ and for the remaining "+" regions, cited in Table 4, there is no superposing of the p_1-p_2 intervals with their values for the Σ_- region and the remaining "-" regions. These data make it possible to assert that the conditions for the formation of precipitation over the territory of the "+" regions differ greatly from the conditions over the "-" regions. In actuality, if it is assumed that the observed distribution of centers of precipitation is random, and not due to any local effects, then the p value for the entire territory of the EMP is equal to 0.41 and falls in the confidence limits $p_1 = 0.35$ and $p_2 = 0.47$ (Table 2). Comparing these values with the values in Table 4 for individual regions, we see that in this case as well the confidence limits p_1 and p_2 for all the "+" regions fall for the most part above their values for the entire area of the EMP, but for "-" regions -- lower.

Now we will discuss the problem of the stability of the influence of local factors on the formation of precipitation over the territory of the EMP with time. For this purpose we determine the values of the p parameter and its confidence limits for the total regions of precipitation by months on the basis of the data in Table 3.

According to Table 5, the value of the p parameter experiences relatively small changes with time both for the Σ_+ regions (from 0.75 to 0.92) and for the Σ_- regions (from 0.05 to 0.33). At the same time, the intervals p_1-p_2 for the regions Σ_+ and Σ_- do not overlap one another for the period June-August. Therefore, it can be assumed that for these months there is a well-expressed and constant influence of local factors on the conditions for the formation of precipitation in the territory of the EMP. A somewhat more uncertain problem is that of the existence of such an influence in May, since the p_1-p_2 intervals for the Σ_+ and Σ_- regions overlap. It is possible that the reason for this uncertainty is the extremely small number of observations of centers of precipitation for the Σ_+ region, which is caused, as mentioned above, by the relatively small "breakdown" of the precipitation field in May. Thus, the data in Table 5 make it possible to assume that the local factors exert a constant effect on the conditions for formation of precipitation in the territory of the EMP during the entire period of modification of convective clouds (May-August).

Table 5

Values of p Parameter and its Confidence Intervals p_1 and p_2 by Months for Total Precipitation Regions for 1966-1970

Месяц 1	Σ_+					Σ_-				
	n	m	p	p_1	p_2	n	m	p	p_1	p_2
2 Май	8	6	0,75	0,35	0,97	18	6	0,33	0,13	0,58
3 Июнь	16	13	0,81	0,56	0,96	21	7	0,33	0,14	0,57
4 Июль	12	11	0,92	0,62	0,99	22	3	0,14	0,03	0,36
5 Август	15	12	0,80	0,52	0,96	20	1	0,05	0,01	0,29

Key:

1. Month
2. May
3. June
4. July
5. August

Now we will make an attempt at a qualitative examination of where the sources of modification for the formation of precipitation should be situated in the territory of the EMP.

The regions I_+ and II_+ are adjacent to the territory of Krivoy Rog and it is natural to assume that specifically the peculiarities of a large industrial city exert an influence on the formation of precipitation. The influence of such cities on clouds involves, primarily, first -- the initiating effect of the heat island over them with ascending currents in the limits 10-40 cm/sec, and second -- the effect of an increased content of condensation nuclei in the air [7, 11]. Therefore, it can be assumed that the reason for the formation of precipitation regions I_+, II_+ and III_+ is the influence of Krivoy Rog.

The existence of extremely large gradients of the quantity of precipitation for a month and for a season and the small values of the mean monthly sums (about 30 mm) in the regions of an increased quantity of precipitation is the basis for raising the question: is there a redistribution of precipitation over the territory of the EMP during the warm season of the year?

Is the increase in precipitation near large cities not accompanied by a decrease in precipitation at some distance from these cities? If there are reasons for the more frequent and more intensive resolution of cumulonimbus clouds near cities, this is responsible for a decrease in the number of cases of their resolution at some distance from the cities. If this hypothesis is true, then prior to artificial modification during the warm season of the year the following problem arises: accomplish modification in such a way to eliminate, insofar as possible, the unfavorable influence of a city on the distribution of precipitation near it.

In conclusion, I wish to express appreciation to M. V. Buykov, A. V. Levin and B. Ye. Fishman for useful discussion of the work.

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INCREASE IN THE VISIBILITY RANGE OF LASER BEACONS IN A FOG

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 31-42

[Article by Candidate of Physical and Mathematical Sciences O. A. Volkovitskiy and V. P. Snykov, Institute of Experimental Meteorology, submitted for publication 20 March 1978]

Abstract: This paper gives the results of an investigation of the intensity of scattered radiation of a HeNe laser propagating in a droplet fog with its evaporation by the coaxial beam of a CO_2 laser. During observation toward the ray it is noted that the evaporation of droplets in the affected zone leads to movement of the zone of maximum intensity of scattered visible radiation in the direction of the observer. The results of the experiments and computations were in good agreement. Expressions are derived which make it possible to establish the correlation between the intensity of a CO_2 laser and the range of movement of the zone of maximum intensity of scattered radiation of a HeNe laser. It is shown that for a substantial (by several times) increase in the range of detection of a laser beacon under the conditions prevailing in a real fog it is necessary that the radiation power of the CO_2 laser be several tens of kilowatts.

[Text] At the present time there has been extensive development of optical systems for signaling, transmission of information and navigation based on use of laser radiation. A serious limitation for the use of optical systems operating through the atmosphere is the presence of fog and clouds. The detection of signal lights and orientation by ray in fogs and clouds are made quite difficult or become impossible since over a quite extended path the radiation energy can be virtually completely scattered by cloud elements.

In order to increase the range of detection of a light ray in fogs and clouds the authors of [2] proposed a method based on the fact that beams of visible and infrared radiations (such as that of HeNe and CO_2 lasers) are coaxially directed toward the observer. As a result of the effect of IR radiation a light ray is slightly scattered in a "cleared" zone and becomes visible as a result of aerosol scattering at a distance where the evaporation of cloud elements decreases.

We will examine the laws of change in the intensity of sounding radiation scattered in the zone of effect of a beam of CO_2 laser and we will evaluate the possibility of a substantial increase in the visibility range for laser beacons in a fog on the basis of scattered light.

Formulas for Computing Sounding Radiation Scattered in Affected Zone

The intensity of the radiation of a HeNe laser scattered by an elementary volume ΔV of a homogeneous cloud medium with an attenuation coefficient α_{λ_0} at the angle $\theta°$ to the direction of propagation of radiation, registered by a receiver situated at the distance l from the boundary of the medium (Fig. 1), in the single scattering approximation can be evaluated using the data in studies [6, 8, 12].

The expression for the intensity of scattered radiation $I_\lambda(\theta°)$, normalized to I_{λ_0}, taking into account attenuation along the ray path to the scattering volume ΔV and from ΔV to the observation point can be written in the form

$$\frac{I_\lambda(\theta°)}{I_{\lambda_0}} = \alpha_{\lambda_0}\frac{f(\theta°)}{4\pi}e^{-\alpha_{\lambda_0}\left(x+\frac{z_1}{\sin\theta°}\right)}\frac{\sin^2\theta°}{z_1^2}\;\frac{\Delta V}{\left(1+\frac{\varphi_\lambda x}{d_{\lambda_0}}\right)^2}, \qquad (1)$$

where $f(\theta°)/4\pi$ is the normalized scattering function for radiation in a homogeneous cloud medium;

$$\varphi_\lambda = \left(\frac{4\,\Delta\omega_\lambda}{\pi}\right)^{1/2}$$

is the angle of divergence of the ray of a HeNe laser.

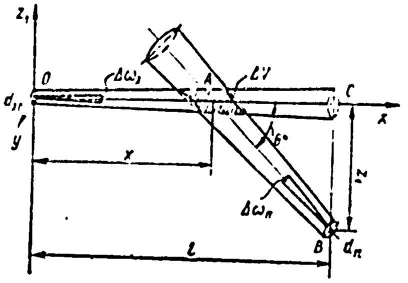


Fig. 1. Schematic representation of arrangement of sounding ray and radiation detector.

In the affected zone the microstructure of the cloud medium is inhomogeneous. In order to determine the field of scattered radiation in the neighborhood of the beam of a CO_2 laser it is necessary to take into account the laws of change of microstructure caused by the exposure.

An approximate expression for determining the radiation intensity of a HeNe laser, scattered in the "clearing" zone formed in a homogeneous droplet cloud medium by the continuous radiation of a CO_2 laser $I_{\lambda\,vis}(\theta\,°)$, can be written using an analytical description of the laser action process examined in [3] with the following assumptions. We will assume that the ratio of the transverse dimensions of the clearing zone d_0 and the diameter of the sounding ray d_{λ_0} is such that the microstructure of the medium within the limits of the transverse section of the sounding ray is uniform and we will assume that the optical scattering section under the influence of the CO_2 laser radiation changes due to a decrease in the size of the droplets although their concentration remains the same. Then the expression for $I_{\lambda\,vis}(\theta\,°)/I_{\lambda_0}$ will have the following form:

$$\frac{I_{\lambda B}(\theta°)}{I_{\lambda_0}} = \alpha_\lambda(x, z)\frac{f_B(\theta°)}{4\pi}\, e^{-\int\limits_0^x \alpha_\lambda(x', z)\,dx'}\, e^{-\alpha_{\lambda_0}\frac{z_1}{\sin\theta°}}\frac{\sin^2\theta°}{z_1^2}\times \tag{2}$$

$$\times\frac{\Delta V}{\left(1+\frac{\varphi_\lambda x}{d_{\lambda_0}}\right)^2},$$

[B = vis]

and $f_{vis}(\theta\,°)4\pi$ is the normalized scattering function of radiation in the affected zone; z is a coordinate determining the position of the sounding ray in the beam of a CO_2 laser (with coincidence of the axes of the beams $z = 0$).

On the basis of (1) and (2) it is possible to write an expression for the ratio of intensities of the radiation scattered by this elementary volume after and before the action of radiation by a CO_2 laser.

$$\frac{I_{\lambda B}(\theta°)}{I_\lambda(\theta°)} = \frac{\alpha_\lambda(x, z)}{\alpha_{\lambda_0}}\frac{f_B(\theta°)}{f(\theta°)}\, e^{\Delta\tau_\lambda(z)}, \tag{3}$$

where

$$\Delta\tau_\lambda(z) = \tau_{\lambda_0} - \tau_\lambda(z) = \alpha_{\lambda_0}x - \int\limits_0^x \alpha_\lambda(x', z)\,dx'.$$

The values $\alpha_\lambda(x, z)$, $\tau_\lambda(z)$, $\Delta\tau_\lambda(z)$ entering into (2) and (3) can be determined using formulas [3, 4]

$$\tau_\lambda(z) = \frac{1}{\tau_\rho}\left\{\frac{2}{3}\ln\frac{\left(e^{\frac{\theta(z)}{3}}-1\right)e^{-\frac{\tau_{\lambda_0}\tau_\rho}{3}}}{\left[1+\left(e^{\theta(z)}-1\right)e^{-\tau_{\lambda_0}\tau_\rho}\right]^{1/3}-1}\right. + \tag{4}$$

$$\left. + \sqrt{3}\left[\operatorname{arctg}\frac{\sqrt{3}}{1+2\left[1+\left(e^{\theta(z)}-1\right)e^{-\tau_{\lambda_0}\tau_\rho}\right]^{-1/3}} - \operatorname{arctg}\frac{\sqrt{3}}{1+2e^{-\frac{\theta(z)}{3}}}\right]\right\}; \tag{5}$$

$$\alpha_\lambda(x, z) = \frac{\alpha_{\lambda_0}}{\left[1+\left(e^{\theta(z)}-1\right)e^{-\alpha_{\lambda_0}\tau_\rho x}\right]^{2/3}},$$

where the thermal effect function is

$$\theta(z) \simeq \frac{CP_0}{2\sqrt{\pi} r_0 v}\left[1 + \mathrm{erf}\left(\frac{z}{r_0}\right)\right]; \tag{6}$$

$$\eta_0 = \frac{A_0}{2}\frac{R_{02}(\mu+3)}{\sqrt{(\mu+1)(\mu+2)}}. \tag{7}$$

Here $C = \frac{3A_0\beta_T\beta_p}{4\rho L}$;

[T = heat; p = scat] L is the heat of evaporation; P_0 is the intensity of the CO_2 laser; r_0 is the radius of the beam of the CO_2 laser at the intensity level $I = I_0 \cdot e^{-1}$; $A_0 = 2 \cdot 10^3$ cm^{-1}; v is wind velocity; β_{heat}, β_{scat} are coefficients taking into account the energy losses of the CO_2 laser in heating of the surrounding medium and scattering of radiation by a droplet medium; R_{02} is the mean square radius; μ is the parameter of gamma distribution of droplets by sizes. For $T_0 = 293$ K, $I = 100$ W/cm², $R_{02} = 5 \cdot 10^{-4}$ cm, $\beta_{heat} \approx 0.75$, $\beta_{scat} \approx 0.6$.

The normalized scattering functions $f(\theta°)/4\pi$ and $f_{ver}(\theta°)/4\pi$ for the initial microstructure of the droplet medium and the droplet medium in the affected zone can be found from tables or graphs with known droplet distribution parameters R_2 and μ. The R_2 values in the affected zone can be computed using the formula

$$R_2(x, z) \simeq \frac{R_{02}}{\left[1 + (e^{\theta(z)} - 1)\, e^{-\eta_0 a_{\lambda_0} x}\right]^{1/3}}, \tag{8}$$

derived from (5) with the assumptions made concerning the optical section on the basis of obvious considerations.

Table 1

$\theta°$	A	R_*, мкм μm
2,0	64	2,0
2,5	40	1,6
3,0	29	1,4
4,0	17	1,2
5,0	12	1,1

In carrying out the computations it is not entirely convenient to use a graphic or tabular representation of $f(\theta°)/4\pi$ as a function of microstructure. In this connection it is desirable to find an approximation of the dependence of $f(\theta°)/4\pi$ on R_2. A satisfactory approximation of this dependence for small observation angles with $R_2 < 7\,\mu$m is the function

$$\frac{f(\theta° = \mathrm{const})}{4\pi} = A\left(\frac{R_2}{R_*}\right)^2 e^{-\frac{R_2}{R_*}}, \tag{9}$$

in which the constants A and R_* can be selected in dependence on the observation angle and the parameter μ . For $\mu = 6$ the A and R_* values are given in Table 1.

The error in computing the function using formula (9) in comparison with the precise value in the range of change of radii $1.5 < R_2 < 7$ m does not exceed 10-15%.

Results of Experimental Study of the Scattering of Visible Radiation in the Neighborhood of a CO_2 Laser Beam

Since the formulas for evaluating scattering in the neighborhood of the zone affected by radiation were derived with important assumptions, an experimental study was made of their applicability.

The experimental apparatus was assembled in an aerosol chamber [1] in accordance with the scheme presented in Fig. 1. As the source of effective radiation we used a CO_2 laser with a power $P_0 \approx 500$ W with a beam diameter $d_0 \approx 1.5$ cm and as the source of sounding radiation we employed a HeNe laser, type LG-38, with a beam diameter $d_{\lambda 0} \approx 3$ mm. The axes of the beams were matched; the length of the path was $l = 13.4$ m. At the end of the path (point C) there was a detector of sounding radiation registering the result of this radiation. A detector of scattered radiation was mounted on a moving platform moving perpendicularly to the x-axis (point B) at the angle $\theta° = 5°$ to the axis. By means of a change in the distance z_1 it was possible to achieve a movement of the scattering volume ΔV along the x-axis. As the detector of scattered radiation an FEU-69 apparatus was employed. The direct radiation was registered using a FD-24K photodiode (point C). The photocurrent from the radiation detectors, after amplification by logarithmic amplifiers, was registered by a multichannel automatic recorder. The angular aperture of the detectors did not exceed 6'; this made it possible to measure the coefficient of radiation attenuation with a sufficient accuracy [7]. The total error in determining $\alpha_{\lambda 0}$ did not exceed 9% when $\alpha_{\lambda 0} = 0.1$ and 1% when $\alpha_{\lambda 0} = 0.8$ m^{-1}. Measurements of scattered radiation were made in a broad range of change in the attenuation coefficient, whose value attained $\alpha_{\lambda 0} = 0.7$-0.8 m^{-1}. As demonstrated by investigations of scattering of radiation in an optically dense medium [9, 10], with values $\alpha_{\lambda 0} > 0.4$ m^{-1} the contribution of multiple scattering to the total radiation flux could become substantial. In addition, an interference in the registry of low levels of scattered radiation was the background caused by "outside" illumination of components of different measuring apparatus. The contribution of multiply scattered radiation to the total flux of registered radiation, generally speaking, can be computed, but, as experience has shown, one variant of computations of the field of multiply scattered light by the Monte Carlo method takes about 100 hours on an M-220 electronic computer [11]. This makes such computations undesirable in routine work.

In our experiments allowance for the influence of multiply scattered light and the background from sources of extraneous irradiation was made by direct measurements of the scattered irradiation by the receiving system, on which the flux of singly scattered laser light was not incident. In the computations we assumed a ratio of the light fluxes

$$\frac{P_\lambda(\theta^\circ)}{P_{\lambda_0}} = \frac{P_{\lambda\,\text{изм}}(\theta^\circ)}{P_{\lambda_0}} - \frac{P_{\lambda\,\text{ф}}}{P_{\lambda_0}}, \tag{10}$$

[ИЗМ = meas; Φ = back(ground)] where $P_{\lambda\,\text{meas}}(\theta^\circ)$ is the radiation flux registered by the detector at the point B; $P_{\lambda\,\text{back}}$ is the flux of the background of multiply scattered light and "outside" irradiation; $P_{\lambda 0}$ is the light flux of a HeNe laser, used in the experiment ($P_{\lambda 0} \approx 5 \cdot 10^{-2}$ W).

The contribution of the $P_{\lambda\,\text{back}}/P_{\lambda 0}$ value to the ratio of the fluxes $P_{\lambda\,\text{meas}}(\theta^\circ)/P_{\lambda 0}$ began to be manifested significantly when $P_{\lambda\,\text{back}}/P_{\lambda 0} < 10^{-9}$ (with values $\alpha_{\lambda 0} > 0.4$ m^{-1}). The background value was $P_{\lambda\,\text{back}} = (2.2\text{-}3) \cdot 10^{-11}$ W.

For comparing the experimentally measured fluxes of scattered radiation with the computed intensity values it is possible to use the expression [6]

$$\frac{P_\lambda(\theta^\circ)}{P_{\lambda_0}} \approx \frac{I_\lambda(\theta^\circ)}{I_{\lambda_0}} \; \frac{S_{iz}\left(1 + \frac{\varphi_n z_1}{d_{\lambda x} \sin\theta^\circ}\right) \sin\theta^\circ}{S_{\lambda x}\left(1 + \frac{\varphi_n z_1}{d_n \sin\theta^\circ}\right)}, \tag{11}$$

where

$$\varphi_n = \left(\frac{4\,\Delta\omega_n}{\pi}\right)^{1/2} \approx \frac{d_i}{f}$$

is the field-of-view angle for the receiving objective; $\Delta\omega_n$ is the solid angle of the field of view receiving objective; f is its focal length; d_i is the diameter of the field diaphragm;

$$d_{\lambda x} = d_{\lambda_0}\left(1 + \frac{\varphi_\lambda x}{d_{\lambda_0}}\right)$$

is the diameter of the sounding ray at the distance x with a divergence angle

$$\varphi_\lambda = \left(\frac{4\,\Delta\omega_\lambda}{\pi}\right)^{1/2}$$

and the initial diameter $d_{\lambda 0}$; $\Delta\omega_\lambda$ is the solid angle of the sounding ray;

$$S_{\lambda x} = \frac{\pi d_{\lambda x}^2}{4}$$

is the cross-sectional area of the sounding ray at the distance x; S_{iz} is the area of the projection (at the angle φ_n) of the field diaphragm onto the ray.

The scattering volume ΔV, entering into (1) and (2), formed by intersection of the two cones, has a complex configuration. However, under the condition that the effective diameter of the receiving objective d_{nz1} exceeds the ray diameter $d_{\lambda x}$ and on the assumption that $d_{\lambda x}$ and d_{nz1} vary little within the ΔV limits, the scattering volume can be computed approximately using the formula

$$\Delta V \approx \frac{\pi d_{\lambda x}^2}{4} \frac{d_{nz_1}}{\sin \theta^\circ}, \tag{12}$$

where

$$d_{nz_1} \simeq d_n \left(1 + \frac{\varphi_n z_1}{d_n \sin \theta^\circ}\right);$$

d_n is the diameter of the receiving objective.

We note that the ΔV value, computed using formula (12) with $\theta^\circ = 90^\circ$ in the most unfavorable case, when $d_{\lambda x} = d_{nz1}$, will exceed the ΔV value found using the more precise formula $\Delta V = 2/3\, d^3_{\lambda x}$ by less than 18%. When

$$\frac{d_{nz_1}}{\sin \theta^\circ} > 2\, d_{\lambda x}$$

the error in computing ΔV will not exceed 5%.

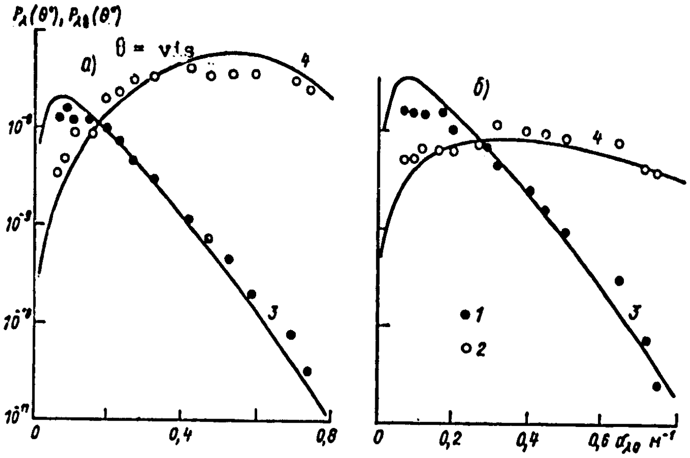
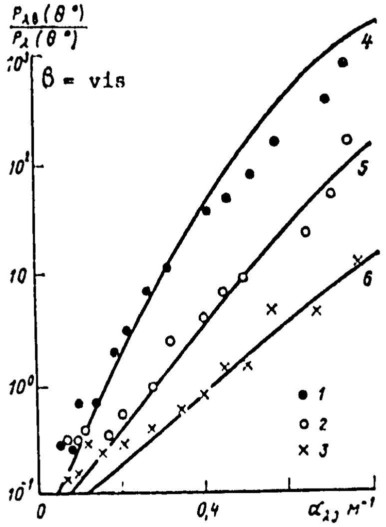


Fig. 2. Dependence of flux of radiation scattered at an angle $\theta^\circ = 5^\circ$ on attenuation coefficient $\alpha_{\lambda 0}$. 1, 2) results of measurements of $P_\lambda(\theta^\circ)/P_{\lambda 0}$ and $P_{\lambda\,vis}(\theta^\circ)/P_{\lambda 0}$ respectively; 3, 4) computations under conditions 1 and 2 respectively; a) x = 12.0 m; b) x = 7.4 m.

The measurements of scattered radiation in the neighborhood of the affected zone were made for several positions of the scattering volume under the influence of a CO_2 laser beam on a "fixed" cloud medium in which a stationary state of clearing was established as a result of the convective current which arises. The experimentally determined dependences

$$\frac{P_\lambda(\theta^\circ)}{P_{\lambda_0}}, \quad \frac{P_{\lambda B}(\theta^\circ)}{P_{\lambda_0}}, \quad \frac{P_{\lambda B}(\theta^\circ)}{P_\lambda(\theta^\circ)}$$

[B = vis] were compared with those computed using the formulas cited above. Since the velocity of the convective flow was not measured in the experiments and since for computations of the thermal effect function $\theta(z)$ it is necessary to know the velocity of movement of the medium, the v value was determined from a comparison of the experimentally determined dependence of the degree of clearing $\Delta\tau_\lambda$ on $\tau_{\lambda 0}$ and the computed value. A good agreement of the results of change in $\tau_{\lambda 0}$ from 1 to 10 was obtained with a value v = 9 cm/sec. This v value was used in computations of the radiation scattered from the affected zone.



1, 2, 3) experimental data with x = 12.0, 7.4 and 5.0 m respectively; 4, 5, 6) results of computations for conditions 1, 2 and 3 respectively.

Fig. 3. Dependence of ratio of scattered radiation fluxes $P_{\lambda\,\mathrm{vis}}(\theta^\circ)/P_\lambda(\theta^\circ)$ on attenuation coefficient $\alpha_{\lambda 0}$ for $\theta^\circ = 5^\circ$.

Figure 2 shows the results of measurements of fluxes of scattered radiation $P_\lambda(\theta^\circ)/P_{\lambda 0}$ in the scattering volume ΔV without an effect with a correction for background irradiation and also the results of measurement of $P_{\lambda\,\mathrm{vis}}(\theta^\circ)/P_{\lambda 0}$ as a function of ΔV with an effect in dependence on the attenuation coefficient $\alpha_{\lambda 0}$ for two values x = 12.0 and 7.4 m. As a comparison we will cite the results of computations of these same dependences using the cited formulas. It can be assumed that a good agreement is obtained between the experimental and computed data.

Figure 2 shows that as a result of the effect from the radiation of a CO_2 laser on a droplet medium there is a considerable change in the dependence of the flux of scattered radiation $P_{\lambda_{vis}}(\theta°)/P_{\lambda_0}$ on the attenuation coefficient α_{λ_0}. Whereas in a cloud medium without such an effect the flux of scattered radiation with an increase in α_{λ_0} is attenuated in accordance with Bouguer's law, in the affected zone to some α_{λ_0} values there is a decrease in the flux of scattered radiation caused by a decrease in the optical section under the influence of the radiation of a CO_2 laser, and then with an increase in α_{λ_0} there is a greater, in comparison without such an effect, flux of scattered radiation.

The dependence of the ratio of fluxes $P_{\lambda_{vis}}(\theta°)/P_{\lambda}(\theta°)$ on the attenuation coefficient α_{λ_0} for three positions of the scattering volume on the beam axis (x = 12.0, 7.4 and 5 m) is shown in Fig. 3. The figure shows that the flux of scattered radiation from the affected zone increases by 2 or 3 orders of magnitude with the α_{λ_0} values, power of the CO_2 laser and geometry of the measuring system used in the experiments. It follows from the cited data that by means of the effect of the radiation of the CO_2 laser on the cloud medium there can be a substantial improvement in the visibility of signal lights in a fog at considerable distances from the radiation source.

Estimating Radiation Power of CO_2 Lasers for Improving Visibility of Laser Beacons

An analysis of equation (2) shows that the intensity of sounding radiation scattered in the affected zone at the angle $\theta°$ attains a maximum value at some distance x_{max} from the beginning of the path. The interrelationship between the distance x_{max} and the power of the affecting radiation can be established from an expression derived after the differentiation of (2), equating it to zero. This expression will have the form

$$\alpha_{\lambda}(x)\left[\frac{2}{3}\,\frac{r_0\left(e^{\theta(z)}-1\right)e^{-\alpha_{\lambda_0} r_0 x_{\max}}R_3(x)}{R_{01}}-1\right]+ \tag{13}$$

$$+\frac{f'_{\theta}(0°,\,x_{\max})}{f_{\theta}(0°,\,x_{\max})}=0.$$

Using an approximation of the scattering function in the form (9), (13) can be transformed to the form

$$1-\frac{3}{4}\,\frac{(1+Q_1)^{1/3}}{r_0 Q_1}-\frac{R_{02}}{4R_*}\,\frac{1}{(1+Q_1)^{1/3}}=0. \tag{14}$$

where

$$Q_1=\left(e^{\theta(z)}-1\right)e^{-\alpha_{\lambda_0} r_0 x_{\max}}. \tag{15}$$

By means of replacing $(1 + Q_1) = y^3$ (14) is reduced to a fourth-degree equation

$$y^4 - \frac{R_{02}}{4R_*}y^3 - \frac{3}{4\tau_0}y^2 - y + \frac{R_{02}}{4R_*} = 0. \tag{16}$$

Table 2

R_{02}, μm	y	$Q_1 = y^3 - 1$	$\ln Q_1$
3	1,785	4.689	1,545
5	1,625	3,287	1,191
7	1,605	3.138	1,144

An analysis of this equation shows that it has two fictitious and two real roots, only one of which satisfies the condition of the problem. The values of this root with $\theta° = 2°$ are given in Table 2.

Finding the roots of equation (16), from (15) we obtain a simple expression relating x_{max} and the thermal effect function $\theta(z)$

$$x_{max} = \frac{S_M}{4\tau_0} \ln \frac{e^{\theta(z)} - 1}{Q_1}, \tag{17}$$

where S_M is the meteorological range of visibility ($S_M \approx 4/\alpha_{\lambda 0}$), correct for $\theta(z) > 0.7$.

In a case when $\theta(z) \gg 1$, it is possible to write

$$x_{max} = \frac{S_M}{4\tau_0} [\theta(z) - \ln Q_1]. \tag{18}$$

Graphs of the dependence of $\theta(z)$ on x_{max} are given in Fig. 4. The distance at which there will be registry of the radiation scattered in the affected zone, if $I_{\lambda\,vis}(\theta°)$ exceeds some threshold intensity I_{thr}, exceeds the x_{max} value. This distance x_{reg} can be evaluated using the formula (if $z_1 = 0$)

$$x_{reg} \approx x_{max} + x_{thr}, \tag{19}$$

where

$$x_{thr} = \frac{S_M}{4\tau_0} \ln \frac{I_\lambda (x = 0, \theta°)}{I_{пор}}$$

is found from the consideration that at the distance x_{thr} from the source the intensity of the radiation scattered in the fog without an effect is attenuated to I_{thr}. As an illustration we have given the results of computations of several specific examples of a change in scattered visible radiation propagating in the fog along an extended path in the zone of action of the CO_2 laser.

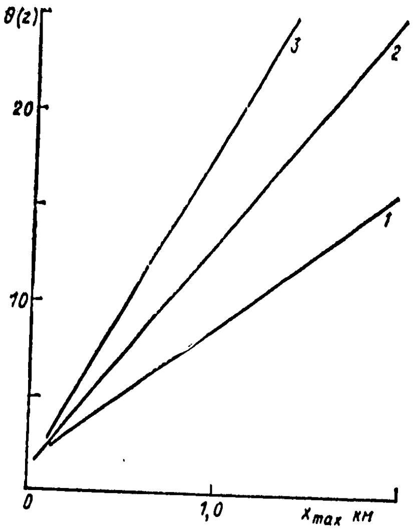


Fig. 4. Dependence of thermal effect function on x_{max} for different fog microstructures for S_M = 200 m. 1, 2, 3) R_{02} = 3, 5 and 7 μm respectively (μ = 6).

Table 3

№	P_0 квт a	d_0 см	φ рад b	$\frac{P_0}{d_0}$ квт/см c	I_0 вт/см² d
1	5	2	0	2,5	1593
2	25	5	0	5	1274
3	32,5	13	10^{-4}	2,5	245
4	65	13	10^{-4}	5	490

Key:

a) kW
b) rad
c) kW/cm
d) W/cm²

Now we will examine the change in the patterns of scattered radiation from the beam of a HeNe laser caused by the effect of CO_2 laser radiation on a fog, whose optical density is characterized by a meteorological range of visibility S_M = 200 m ($\alpha_{\lambda 0}$ = 0.02 m^{-1}) on a path with the length $\ell = 2$ km with a wind velocity 1 m/sec at a temperature $T^\circ = 20^\circ$C. We will assume that the microstructure of the fog is characterized by a gamma distribution of droplet sizes with the parameters $R_{02} = 5\,\mu$m, $\mu = 6$. The computations are made for a case when the observer moves parallel to the ray at the distance z_1 (see Fig. 1) and registers the intensity of scattered radiation at the angle θ° at the distance $x + z_1/\mathrm{tg}\,\theta^\circ$. We select the angle of ray observation quite small, such as $\theta^\circ = 2^\circ$, since in the case of small observation angles the increase in the intensity of scattered radiation as a result of an increase in the function $f(\theta^\circ)/4\pi$ exceeds the attenuation of scattered radiation at the distance $AB = z_1/\sin\theta^\circ$ from the scattering volume to the observer. The specific P_0 and d_0 values for the nondiverging ($\varphi = 0$) and diverging beams (the divergence is assumed to be close to the diffraction value), used in the computations, are cited in Table 3.

The parameters of the sounding beam are selected in such a way that the diameter $d_{\lambda 0}$ is much less than d_0, divergence does not exceed the diffraction level and the intensity I_λ is equal to 1 W/cm^2. Under these conditions in the first example $P_\lambda = 0.1$ W and $d_{\lambda 0} = 0.36$ cm; in the remaining cases $P_\lambda = 1$ W and $d_{\lambda 0} = 1.13$ cm.

A laser ray can be detected from singly scattered radiation if its intensity at the observation point exceeds the background level caused by outside irradiation and multiply scattered radiation, and also exceeds some threshold illumination which can already be discovered visually or using an instrument. In computations of the intensity of scattered light, in (1) and (2) we assume $\varphi_n = 6'$, which corresponds to the mean angular resolution of the eye. We will not take into account the background irradiation, which in principle can be eliminated using interference (constant background) and polarization (multiple scattering background) filters, and we note that the threshold illumination for a red color, clearly distinguishable to the eye, applicable to the conditions for nighttime signaling in aviation and navigation, is $I_{\mathrm{thr}} = 6\cdot 10^{-14}$ W/cm^2, and the absolute light threshold is $I_{\mathrm{thr}} = 3\cdot 10^{-16}$ W/cm^2 [5].

Now we will examine the conditions under which the ray of a HeNe laser will be observed in the neighborhood of the affected zone. We will assume that the observer is situated at the distance $z_1 = 10$ m from the laser ray. The results of computations of the ratios of intensities of the scattered radiation

$$I_{\lambda\,\mathrm{ver}}(\theta^\circ)/I_\lambda(x = 0, \theta^\circ), \quad I_\lambda(x, \theta^\circ)/I_\lambda(x = 0, \theta^\circ)$$

[B = vis] (left scale) and the intensities of scattered radiation $I_{\lambda\,\mathrm{vis}}(\ell, \theta^\circ)$ and $I_\lambda(\ell, \theta^\circ)$ (right scale) are presented in Fig. 5. It can be seen from the graphs that with the selected geometry at a distance $\ell \approx 600$ m from the radiation source the observer ceases to distinguish the ray of a HeNe laser with the intensity $I_{\lambda 0} = 1$ W/cm^2 in a fog with a stipulated attenuation coefficient ($\alpha_{\lambda 0} = 0.02$ m^{-1}). The effect exerted on a fog

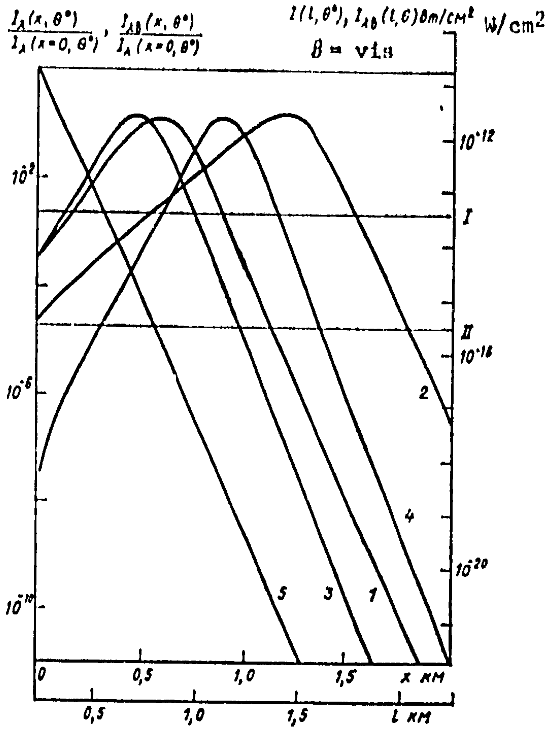


Fig. 5. Dependence of functions $I_\lambda(x,\theta°)/I_\lambda(x = 0, \theta°)$, $I_{\lambda\,ver}(x, \theta°)/I_\lambda(x = 0, \theta°)$ (left scale) and intensity of scattered radiation $I_\lambda(l, \theta°)$, $I_{\lambda\,ver}(l, \theta°)$ for $z_1 = 10$ m (right scale) on x, l respectively. 1-4) same as in Table 3; 5) $P_0 = 0$. I) threshold intensity for red light applicable to nighttime signaling conditions in aviation and navigation; II) absolute light threshold.

when the wind velocity is 1 m/sec in the case of the beam of a CO_2 laser with a power of 32.5 KW, $d_0 = 13$ cm, $\varphi = 10^{-4}$ rad makes it possible to move this level of the intensity of scattered radiation to the distance $\ell \approx 1,100$ m (Fig. 1). A better effect is attained using the beam of a CO_2 laser with a power of 65 kW with the same divergence or using a nondivergent beam with a power of 25 kW (ℓ = 1,500 and 1,900 m respectively). The computations show that at the distance where scattered radiation begins to be discriminated the intensity of the direct effect of sounding radiation is reduced to safe limits.

The time in which a stationary state of fog clearing is established, leading to an improvement in the visibility of laser beacons, can be estimated using the expression $t = d_0/v$. In our examples it will not exceed 0.13. It therefore follows that a considerable (by approximately an order of magnitude) decrease in the mean intensity of the effective radiation can be attained by the use of pulsed sources with a pulse length $t \approx 0.15$ sec and with a pulse duty factor of about 1.5 sec.

Changes in the distance z_1 from the laser ray, observation angle and geometrical parameters of the receiving system, attenuation coefficient $\alpha_{\lambda 0}$ and other parameters lead to different quantitative estimates. It must be noted that a decrease in the temperature of the medium and an increase in wind velocity, all other conditions being equal, cause a decrease in the effect from the radiation. An increase in the intensity of the radiation necessary for compensating the influence of these factors is easily estimated from an analysis of the expression for the thermal effect function, from which it follows that with $\theta(z)$ = const the effect will be identical.

The results of computations of the intensity of scattered radiation in the neighborhood of the zone affected by the beam of a CO_2 laser, cited here, indicated the fundamental possibility of increasing the range of detection of laser beacons in a fog on the basis of scattered radiation by the method proposed in [2]. The formulas derived in this study make it possible to make the necessary evaluations of the intensity of scattered radiation for other meteorological situations and for the parameters of beams of CO_2 lasers, which can be used for increasing the effectiveness of specific laser navigation systems.

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SPRING RESTRUCTURING OF THE TEMPERATURE AND PRESSURE FIELD IN THE SOUTHERN HEMISPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 43-49

[Article by Candidate of Geographical Sciences L. A. Uranova, USSR Hydrometeorological Scientific Research Center, submitted for publication 17 March 1978]

Abstract: A study was made of restructuring of winter cyclonic circulation to summer anticyclonic circulation in the southern hemisphere stratosphere. On the basis of an analysis of pressure pattern charts for the 50, 30, 20 and 10 mb surfaces and spatial-temporal sections constructed using data from aerological and rocket soundings it was possible to determine the date of the restructuring. The results of the analysis indicated that for the most part the restructuring of the temperature and pressure field in the southern hemisphere stratosphere occurs the same as in the northern hemisphere.

[Text] During the last decade a rather great number of studies have been devoted to an investigation of the processes of restructuring of circulation in the northern hemisphere stratosphere [1-11]. In these studies the authors for the most part proposed qualitative characteristics for determining the dates of restructurings of the temperature and pressure field in the stratosphere. As the date of the restructuring it is customary to use the day when the spring stratospheric anticyclone was to the north of the cyclone and vice versa, when the anticyclone was to the south of the cyclone in autumn. In addition, the author determined the dependence of the seasonal restructurings of the stratospheric temperature and pressure field on different factors.

In [8] the author found the dependence between restructuring of the temperature and pressure field in the atmosphere and restructuring of the field of total ozone content. The gradient Ω_{40-p}, obtained by D. A.

Ped' [4], was used as a characteristic of the restructuring. Under the influence of an intensive influx of solar radiation, after the winter solstice there is a restructuring of the field of the total ozone content, and then the stratospheric temperature and pressure field begins to be restructured.

As is well known, after the winter solstice an intensive flux of UV radiation is incident on the upper boundary of the stratosphere in the southern part of the temperate latitudes (30-40°N); under its influence, as a result of photochemical reactions, a marked increase in the quantity of ozone begins. First the ozone increases in the stratopause region, and then lower. Naturally, this leads to a temperature increase in the stratosphere. This, in turn, changes the geopotential field and first causes a weakening of the westerly winds prevailing before this and then their replacement by easterly winds.

An analysis of charts of stratospheric levels (50-10 mb) for a 20-year period indicated that usually the spring restructuring begins with the appearance of a small heat region at 30-40°N along the shores of North America in the Atlantic Ocean or along the shores of Japan in the Pacific Ocean or at the center of Eurasia at the isobaric surface 10 mb. Then this focus begins to be displaced almost strictly to the north and after several days enters the polar basin. This is followed by pressure field transformation. Incidentally, the relationship between the movement of heat foci and foci of growth of the total ozone content was already noted in an analysis of stratospheric winter warmings in [7]. It was noted there that first a region of increase in the total ozone content is formed and then a region of a temperature increase.

Unfortunately, for altitudes greater than 30 km there are still no sufficiently good temperature data for the hemisphere that would make it possible to trace the movement of heat foci.

There are very few studies devoted to an investigation of the seasonal restructurings of the stratospheric field in the southern hemisphere. E. Farkas [10], in an analysis of variation in the total ozone content in the course of the year at different latitudes, relates these data to the similar temperature variation at the isobaric surfaces 100 and 50 mb. These data were used in computing the Ω_{40-85} values for O_3 for each month over a period of 10 years and were used in this study for determining the mean times of restructuring the field of the total ozone content. The mean monthly Ω_{40-p} values for the isobaric surface 10 mb in the southern hemisphere were taken from charts constructed by L. A. Zhdanov for a four-year period.

A joint analysis of the monthly distribution of Ω_{40-p} values for ozone and geopotential H_{10} for the southern hemisphere with the Ω_{40-p} values for the northern hemisphere (Fig. 1), plotted on the graph from [11], indicated that restructuring of the field of total ozone content in the southern hemisphere, the same as in the northern hemisphere, occurs sooner than the restructuring of the geopotential field at the isobaric surface 10 mb. The same as in the northern hemisphere, the change in circulation at the H_{10} surface begins when the restructuring of the ozone field has already occurred, that is, when $\Omega_{40-pO_3} = 0$.

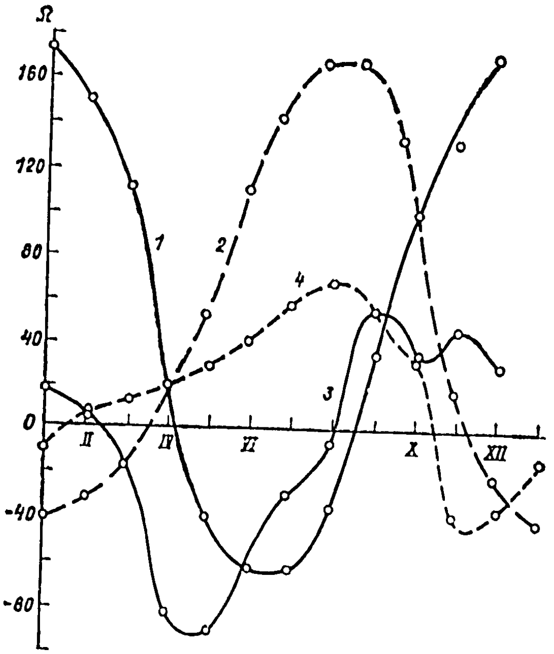

Fig. 1. Mean long-term Ω_{40-p} values and geopotential H_{10} for the southern hemisphere (1), southern hemisphere (2), total ozone content in the northern (3) and southern (4) hemispheres.

It must be noted that the time interval between restructurings of the ozone field and geopotential H_{10} ($\Delta\tau$) in the southern hemisphere (Table 1) in both spring and in autumn is greater than in the northern hemisphere. The spring restructuring of the geopotential field occurs more rapidly (22 days) than the autumn restructuring (56 days), whereas in the northern hemisphere, on the other hand, the spring restructuring is considerably longer (46 days) than the autumn restructuring (18 days). It is also interesting to note that the spring restructuring in the northern hemisphere (Table 1) and the autumn restructuring in the southern hemisphere occur almost at the same time (February-March).

The autumn restructuring in the northern hemisphere occurs two months earlier than in the southern hemisphere. The fact that the spring restructuring of the temperature and pressure field in the southern hemisphere stratosphere occurs on the average twice as fast as in the northern hemisphere can evidently be attributed only to the influence of the underlying surface. This is indicated by the data in Table 2, which shows the duration (in months) of cyclonic ($\Omega_{40-p} > 0$) and anticyclonic circulation ($\Omega_{40-p} < 0$) in the stratosphere of both hemispheres. The duration of cyclonic circulation in the southern hemisphere is not much greater than in the northern hemisphere, whereas the differences in the lifetime of the field of the total content of ozone of the same sign are very great. For example, whereas the minimum in the northern hemisphere polar basin ($\Omega_{40-p} > 0$) persists for 6.5 months, in the southern hemisphere it is observed over a period of 9 months. As is well known, the amplitude of the variations between the maximum and the minimum in the total ozone content in the annual course is less than in the northern hemisphere.

Table 1

Mean Times of Onset of Seasonal Restructurings

1	Северное полушарие			2 Южное полушарие		
	$Д_{O_3}$	$Д_{H_{10}}$	$\Delta\tau$, дни 3	$Д_{O_3}$	$Д_{H_{10}}$	$\Delta\tau$, дни 3
$Д_в$ D_{spr}	28 II	15 IV	46	2 XI	24 XI	22
$Д_о$ D_{aut}	15 VIII	2 IX	18	3 II	1 IV	56

Note: D_{spr} and D_{aut} are the dates of the spring and autumn restructurings, D_{O_3} is the date of restructuring of the ozone field, $D_{H_{10}}$ is the date of restructuring of the geopotential field at the isobaric surface 10 mb, $\Delta\tau$ is the time interval between restructurings of the ozone and geopotential fields. 1) Northern hemisphere; 2) Southern hemisphere; 3) days

All this taken together is evidently the reason for the rapid spring and delayed autumn restructurings of the geopotential field in the southern hemisphere.

Now having an idea concerning the mean times of seasonal restructurings of the temperature and pressure field in the stratosphere in both hemispheres, we will proceed to an analysis of the spring restructuring in the southern hemisphere in 1977. For this purpose, during the period of the 19th voyage of the "Akademik Shirshov" scientific research vessel we constructed pressure pattern charts for the 50-, 30-, 20- and 10-mb surfaces for the southern hemisphere for November and in part for December, charts of the trajectories of movement of the centers of cyclones and anticyclones at these levels and the spatial-temporal sections for both temperatures and winds from 5°N to 50°S along 95°E and from 20 to 50°S along 65°E.

The spatial-temporal section along 95°E from 30 to 50°S for the period 11-19 November 1977 indicated that in the entire thickness of the stratosphere, from 22 to 45 km, where the stratopause was situated at this time, there were easterly winds. This indicates that the restructuring of the stratospheric temperature and pressure field at these latitudes over the Indian Ocean has already occurred. Above the stratopause, in the mesosphere, at an altitude of 50-56 km at 40°S westerly winds with a velocity of 20 m/sec were already observed on 13 November. On 16 November westerly and southwesterly winds with velocities up to 15 m/sec were observed at 45°S already at an altitude from 56 to 59 km, whereas at 50°S westerly winds occurred only above 65 km. Thus, the boundary of the westerly winds rose at the rate of 2 km/day. It can also be seen in this section that at an altitude of 30 km at 40°S from the beginning of November there was a temperature -40 - -45°C, whereas during winter the temperature at this altitude here drops to -60°C. The spatial-temporal section along 65°E from 30 to 50°S and back from 25 November through 3 December also indicated that in the entire stratosphere and mesosphere there were easterly winds in this region and accordingly a spring restructuring had already occurred.

Table 2

Duration (in Months) of Positive and Negative Ω_{40-p} Values of Field of Total O_3 Content and Geopotential Field H_{10}

	Северное полушарие 1		Южное полушарие 2	
	$\Omega_{40-\text{п}} > 0$	$\Omega_{40-\text{п}} < 0$	$\Omega_{40-\text{п}} > 0$	$\Omega_{40-\text{п}} < 0$
H_{10}	7,5	4,5	8	4
O_3	6,5	5,5	9	3

Key:

1. Northern hemisphere
2. Southern hemisphere
3. surf

Unfortunately, a small delay in departure on the voyage did not make it possible to trace the entire restructuring process because it began at the very beginning of November, as is indicated by the pressure pattern charts 50-10 mb for the southern hemisphere, constructed and analyzed during the 19th voyage of the "Akademik Shirshov" scientific research vessel.

As in the northern hemisphere, the spring restructuring in the southern hemisphere began with the formation of heat foci in the subtropical zone (Table 3). The data in the table do not give a complete picture of movement of heat foci toward the pole, but on the basis of these data it is possible to obtain a general idea concerning this. For example, during the period 6-9

November foci with a temperature -40 - -44°C appeared in different regions of the subtropics (23-25°S) at the isobaric surface 10 mb, and already on 11 November a focus with a temperature -31°C was observed along the shores of Antarctica. On 27 November, at the altitude of the isobaric surface 20 mb, a heat focus with a temperature -20°C was traced at Amundsen-Scott station, that is, at the south pole.

Table 3

Maximum Temperatures at Stratospheric Levels in the Southern Hemisphere in November 1977

1 Число	Координаты 2		Изобарическая поверхность, мб 5	Температура, °C 6
	южная широта, град 3	восточная долгота, град 4		
6	25	135	10	−40
7	23	95	10	−44
8	30	95	10	−49
9	23	165	10	−44
10	54	160	30	−42
11	66	85	30	−31
12	66	110	50	−33
13	66	85	30	−29
13	37	95	10	−47
13	25	135	10	−41
14	66	85	20	−29
14	42	95	10	−45
16	70	25	10	−28
16	69	40	20	−31
17	69	40	20	−28
17	62	55	20	−39
17	23	165	20	−37
18	66	85	20	−30
18	69	40	20	−28
18	62	55	10	−35
20	67	47	10	−24
20	70	20	20	−31
21	66	85	10	−28
21	70	20	10	−30
27	67	142	10	−26
27	90	—	20	−27
28	69	40	20	−28

Key:

1. Number
2. Coordinates
3. South latitude, degrees
4. East longitude, degrees
5. Isobaric surface, mb
6. Temperature, °C

After movement of heat foci to the south, stratospheric anticyclones began to move in this same direction from the subtropical latitudes: one from the Indian Ocean sector, and the other from the Pacific Ocean sector lying in the southern hemisphere. By 17 November, as shown on the map of trajectories of movement of cyclones and anticyclones, at the 10-mb isobaric surface (Fig. 2) the anticyclone of the Pacific Ocean sector approached the shores of Antarctica (66°S, 170°E). At the same time, the center of the circumpolar cyclone, rapidly filling, began to move northward and on 17 November was already at 65°S, 15°E. Thus, using the definition given in [1], it is possible to regard 17 November as the day of spring restructuring of circulation in the southern hemisphere stratosphere in this year. The position of the centers of cyclones and anticyclones (Fig. 2) for 9, 18 and 28 November 1977 reveals three stages in the process of spring restructuring of the stratospheric temperature and pressure field. On 9 November the center of the circumpolar cyclone (3020 dam) was situated at 85°S, 20°E. On 18 November the center of the circumpolar cyclone (3100 dam) was already at 65°S, 15°E, and on 28 November it was filled.

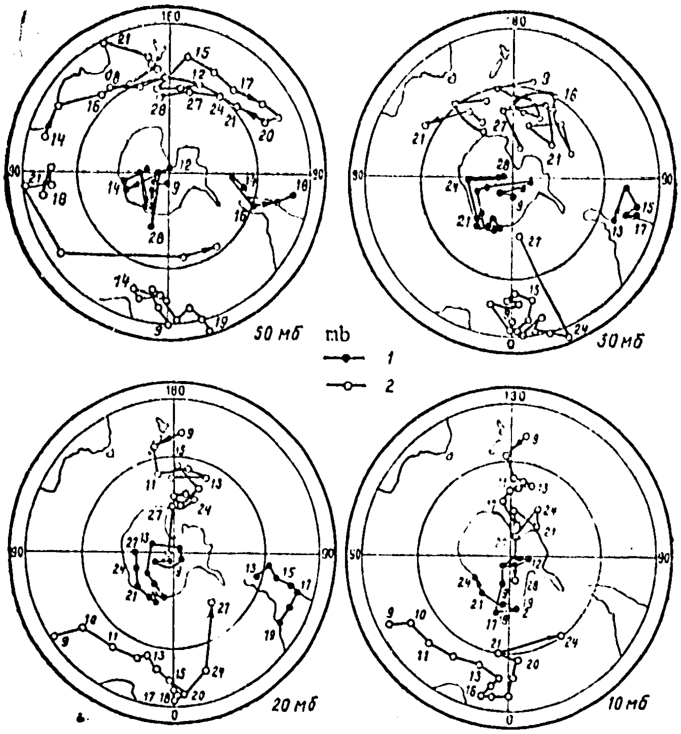

Fig. 2. Charts of trajectories of movement of cyclones (1) and anticyclones (2) at isobaric surfaces 50, 30, 20 and 10 mb in November 1977. Southern hemisphere.

In order to determine how the process of restructuring of the stratospheric temperature and pressure field occurred at the isobaric surfaces 50, 30, 20 and 10 mb, for each day, from 9 through 28 November 1977 we computed the values of the gradient Ω_{40-p} by the D. A. Ped' method [4]. A graph of the distribution of Ω_{40-p} values during the indicated period (Fig. 3) indicated that the restructuring began simultaneously at all four isobaric surfaces, from 50 to 10 mb, and it occurred first and most rapidly at the isobaric surface 20 mb. As is well known, the maximum of the ozone content in its vertical distribution is situated, on the average, at the 20-mb level.

But beginning on 13 November the restructuring process occurred considerably more rapidly at the isobaric surface 10 mb, whereas at all the remaining surfaces it was considerably delayed. Thus, on 17 November the restructuring occurred at the isobaric surface 10 mb and on 18 November at the isobaric surface 20 mb. At the isobaric surfaces 30 and 50 mb the restructuring occurred on 27 and 28 November respectively, that is, when at the isobaric surface 10 mb the anticyclone was already over the pole and had many closed isohypses. It must be noted that at the isobaric surface 20 mb, although the restructuring was noted on 18 November, up to the 27th the Ω_{40-p} values at all times varied around zero, and only after 27 November did it finally occur.

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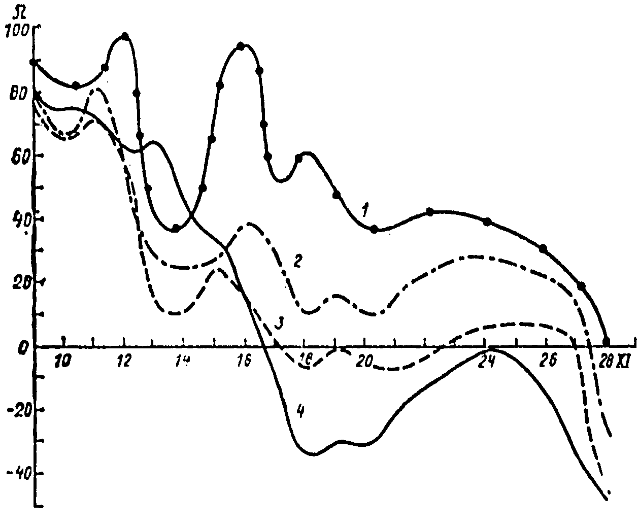

Fig. 3. Ω_{40-p} values at isobaric surfaces 50 (1), 30 (2), 20 (3) and 10 (4) mb in November 1977. Southern hemisphere.

During this period the distribution of the total ozone content is unknown, but on the basis of indirect data it can be assumed that the restructuring of the ozone field occurred at the end of October.

As a result of generalization of all the analyzed material it can be concluded that in the southern hemisphere, as in the northern hemisphere, a restructuring of the temperature and pressure field in the stratosphere transpires after the restructuring of the field of the total ozone content. The heating of the stratosphere caused by an intensive increase in ozone leads to a change in the direction of the temperature gradient and then a restructuring of the geopotential field. The spring restructuring of the stratospheric temperature and pressure field begins in the layer of the ozone maximum (20-30 km) almost simultaneously, but ends sooner at the isobaric surface 10 mb than in the lower-lying layers.

In addition, the spring restructuring of the geopotential field at the isobaric surface 10 mb occurs in the southern hemisphere twice as rapidly as in the northern hemisphere, whereas the autumn restructuring in the southern hemisphere transpires (according to mean values) three times more slowly than in the northern hemisphere. This is evidently attributable to the influence of the underlying surface, that is, the difference in the distribution of land and ocean.

In the spring of 1977 the restructuring of the temperature and pressure field in the stratosphere transpired more rapidly than according to the mean times and at the isobaric surface 10 mb had already occurred on 17 November; at the remaining lower-lying stratospheric levels it was 10 days later.

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RELATIONSHIP BETWEEN ATMOSPHERIC PRESSURE AND THE LEVEL OF THE NORTHWESTERN PART OF THE PACIFIC OCEAN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 50-55

[Article by Candidate of Physical and Mathematical Sciences S. S. Lappo, A. V. Skripnik and A. B. Rabinovich, Sakhalin Multidiscipline Scientific Research Institute Far Eastern Scientific Center USSR Academy of Sciences, submitted for publication 22 March 1978]

Abstract: The authors have made a joint analysis of two-month series of levels and atmospheric pressure at five points on the Pacific Ocean side of the Kuriles Ridge. The general energy maxima at frequencies of 0.08, 0.3 and 0.65 cycles per day were discriminated. It is shown that the "reverse barometer" law is satisfied well for all stations, except one, where the amplitude characteristic is considerably greater than unity. A joint analysis of level and atmospheric pressure indicated that low-frequency disturbances are propagated along the Kuriles Ridge to the northeast with a characteristic velocity 50 km/hour. The phase shifts in the reduced levels were used in computing the wave numbers, which coincide well with the first mode of continental shelf waves.

[Text] It has been traditionally assumed that ocean level and atmospheric pressure are related by the "reverse barometer" law. Numerous investigations carried out during recent years have shown that this law is well satisfied for isolated island systems [12, 17], but at stations situated at the continental boundaries there are strong deviations from it [13, 14, 15]. It is assumed by most researchers that the observed anomalies are related to the presence of continental shelf waves and other shelf effects (effect of the wind on level in shallow waters, shelf resonance, etc.) [7, 8, 15, 16]. The actual phase shift between the reduced levels at different stations confirms the presence of shelf waves. It is unquestionable that they have a definite relationship to atmospheric processes, although the mechanism of this relationship remains debatable. A study of reaction of the level to changes in atmospheric pressure is of great interest from the point of view of prediction of storm surges and spectral methods were very effective here [2, 3, 10]. A spectral analysis makes it possible to clarify the interrelated elements, which in the future will be important in formulating physical models [12].

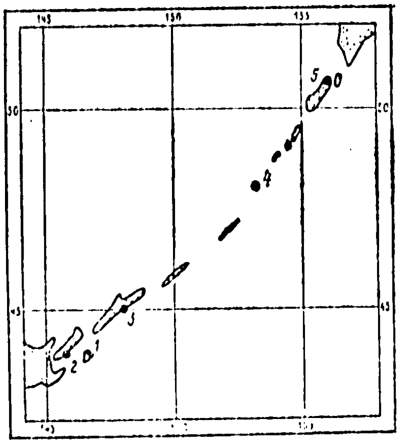

Fig. 1. Map of distribution of observations.

In this paper we make a joint analysis of two-month series of levels and atmospheric pressure at five points situated on the Pacific Ocean side of the Kuriles (Fig. 1) during August-September 1975. This region is convenient for such an analysis for the following reasons: a) the Kurile Islands are located in a zone of intensive atmospheric disturbances: cyclones penetrate from the west and typhoons, which are most frequent in August-September, penetrate from the south; b) an elongated linear slope, making it possible to check the hypothesis of the existence of shelf waves associated with atmospheric processes; c) a great depth in the neighborhood of the ridge makes it possible in the first stage in the analysis to neglect the influence of the wind; d) the poor study of this region.

In addition to the problem of the relationship between the observed and hydrostatic levels, the purpose of the study was a clarification of the principal energy-carrying frequencies in the level and atmospheric pressure spectra and an examination of the spatial variability of different characteristics.

Method. In the analysis we used series with a discreteness of 3 hours. We eliminated from the level series the 20 principal tidal waves (diurnal and semidiurnal), computed first by the least squares method [5]. In this process we achieved a quite high quality of filtering of tides and at the same time there was no distortion of the nontidal frequencies. Subsequent spectral analysis of the residual fluctuations demonstrated that in actuality at the frequencies of the semidiurnal tides (2 cycles/day) there are no explicit energy maxima exceeding the general noise level. At the same time, there are appreciable extrema at frequencies of about 1 cycle/day (Fig. 2A). It is doubtful that their presence is associated only with tidal waves or radiation effects which have not been taken into account. One of the possible hypotheses explaining the existence of these extrema will be set forth below.

A spectral analysis of the observations was made using the procedure of a "fast Fourier transform." A study was made of the relationship between the level and pressure at a single point and between levels, pressures and reduced levels at different points.

Proceeding on the basis of the difference in the spectra, the analyzed points can be divided into two groups. For the southern group (points 1-3) there is a characteristic coincidence in the level and atmospheric pressure spectra for all frequencies below 0.7 cycles/day. General maxima are discriminated at the frequencies 0.08, 0.5 and 0.65 cycles/day (Fig. 2Ab). For the northern group (4-5) the variation of the level spectra duplicates the corresponding variation in the spectra of atmospheric pressure at the low frequencies. The main maxima fall at the frequencies 0.08, 0.33 cycles/day (Fig. 2Aa).

In the frequency range 0-0.7 cycle/day for all stations, and also in the ranges 1.1-1.8 cycles/day for 4 and 1.1-1.4 cycles/day for 5, the coherence between level series and atmospheric pressure falls above the 90% level of significant coherence, which is evaluated using the formula [12]

$$F(R^2 < x^2) = 1 - (1 - x^2)^{\frac{n}{2} - 1}, \tag{1}$$

where R^2 is the square of coherence; n = 10 is the number of degrees of freedom of the equivalent distribution χ^2, used for computing the coherence confidence interval, 1 - F is the probability that the square of coherence of uncorrelated events exceeds x^2. For F = 0.9 $x^2 = 0.44$.

It can be assumed that the level variations at these frequencies are determined by the variation in atmospheric pressure (Fig. 2B).

We will represent the level $\eta(t)$ in the high coherence region to atmospheric pressure as a function at the output of a linear system to whose input is fed atmospheric pressure P_a at the time $t - \tau$

$$\eta(t) = \int\limits_0^\infty P_a(t - \tau)\, h(\tau)\, d\tau + u(t), \tag{2}$$

where u(t) is the noise component at the output, uncorrelated with $P_a(t)$, $h(\tau)$ is the "impulse" transfer function.

The frequency characteristic $\hat{H}(\omega)$ of the system can be evaluated using the expression

$$\hat{H}(\omega)=\frac{\hat{G}_{xy}(\omega)}{\hat{G}_{xx}(\omega)}, \tag{3}$$

where $G_{xy}(\omega)$ is the evaluation of the cross-spectrum of the processes $\eta(t)$ and $P_a(t)$; $G_{xx}(\omega)$ is the evaluation of the spectrum of the process $P_a(t)$; ω is frequency.

It is more correct to consider the level to be the signal at the output of a linear system at whose input, in addition to $P_a(t)$, the velocity components or wind friction are fed [17], but also in the case of several inputs (2) it is possible to obtain the unbiased characteristic of the system under the condition that the inputs cannot be correlated [1, 6].

We will represent the frequency characteristic in the form

$$\hat{H}(\omega)=|H(\omega)|\,e^{i\Delta\varphi(\omega)}, \tag{4}$$

where $|H(\omega)|$ is the amplitude characteristic of the system and $\Delta\varphi(\omega)$ is the phase characteristic, that is, the phase shift of the process $\eta(t)$ relative to $P_a(t)$ at the frequency ω.

Assuming that $|H(\omega)| = 1$, and $\Delta\varphi(\omega) = \pi$, in the entire range of frequencies where the level variation is caused by the variation in atmospheric pressure, we determine the limits within which the mentioned characteristics must fall, without refuting this assumption. The formulas determining the error in measuring the amplitude and phase characteristics have the form [1]

$$F=F\,|\,||H(\omega)|-1|<\sin\varepsilon;\ |\Delta\varphi(\omega)-\pi|<\varepsilon|\simeq 1-\left[\frac{1-R^2(\omega)}{1-R^2(\omega)\cos^2\varepsilon}\right]^{\frac{n}{2}}, \tag{5}$$

where F is the probability of finding the characteristics in the indicated intervals, n = 10. For F = 90%

$$\sin\varepsilon=0{,}25;\quad \varepsilon\approx 15^\circ.$$

In all the indicated frequency range the difference in the phase characteristic from π was less than ε (Fig. 2B). For values of the amplitude characteristic exceeding the limits determined by formula (5) the confidence evaluations were computed taking into account the true coherence values (Fig. 2B).

These computations show that for all the points, except point 4, the "reverse barometer" law is satisfied quite well. The high coherence between the level and pressure at point 4 makes it possible to construct the amplitude characteristic not only in the range 0-0.7 cycle/day, as for the remaining points, but also in the range 1.1-1.8 cycles/day. However, precisely for this point the "reverse barometer" law is not satisfied -- the amplitude characteristic in the indicated ranges considerably exceeds unity (Fig. 2B). The reasons for this are not clear. Possibly a decisive role is played by its geographic position -- it is situated in the region of a deep-water strait.

Obtaining an inverse discrete Fourier transform of the function $\hat{H}(\omega)$ we obtain the weighting function $h(\tau)$ (response function), that is, the regression dependence of sea level at a particular moment on pressure at the given and preceding moments in time. With a zero lag the barometric factor for all the points, other than 4, has a value close to -1. For $\tau > 0$ it tends to zero. At the point 4 $h(0) = -1.4$.

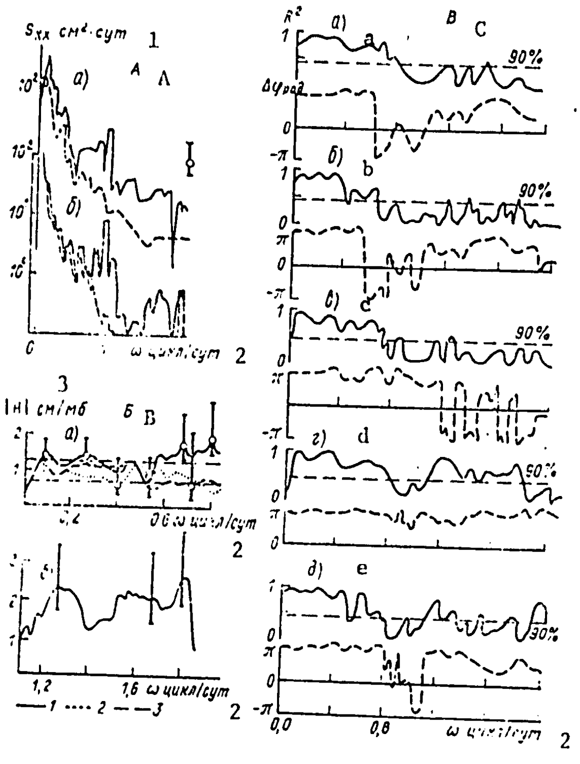

Fig. 2. A -- spectra of level (1) and atmospheric pressure (2) at points 4(a) and 2(b), B -- amplitude characteristics at points 4(1), 3(2) and 5(3), C -- coherence and phase shift between atmospheric pressure and level at points 1(a), 2(b), 3(c), 4(d) and 5(e).

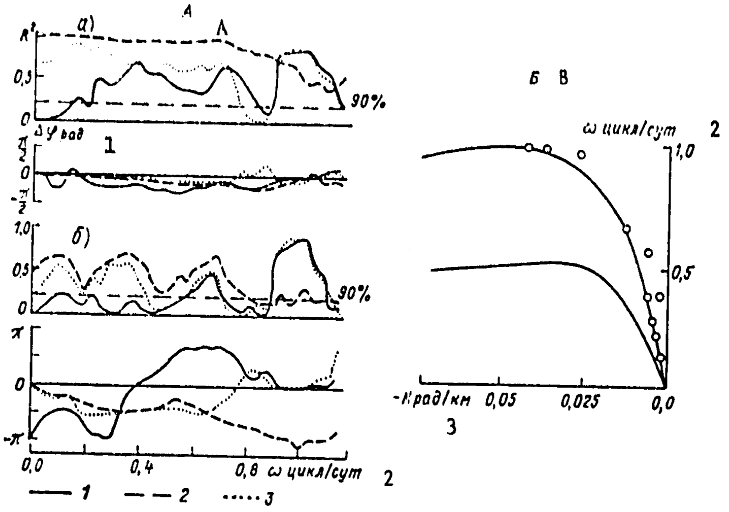

Fig. 3. A -- coherence and phase shift at level (1), atmospheric pressure (2) and reduced level (3) between points 2-3 (a) and 3-5 (b), B -- dispersion curves of first and second modes of continental shelf waves, computed for shelf -- continental slope of Kuriles Ridge.

Key:

1. rad
2. cycles/day
3. rad/km

For a study of the nature of propagation of low-frequency processes we carried out a joint analysis of atmospheric pressure, level and reduced level

$$\left(\tilde{\eta}_1(t) = \eta_1(t) + \frac{P_1(t)}{\rho g}\right)$$

between different points.

At near-lying points there is a high coherence of atmospheric processes up to a frequency of 1.2 cycle/day, and the level to a frequency of 0.7 cycle/day and in the range 0.9-1.1 cycle/day (Fig. 3Aa). For remote points the coherence between the levels, as between atmospheric pressures, is highest at those frequencies at which there were maxima in the autospectra (0.08, 0.3, 0.65 cycle/day) (Fig. 3Ab). The higher coherence at frequencies 0-0.7 cycle/day between pressures shows that the correlation radius in the atmosphere is greater than in the ocean.

On the basis of the phase shifts at frequencies 0-0.3 cycle/day it was determined that atmospheric disturbances during the period of the observations were propagated along the Kuriles Ridge to the northeast at a rate of about 50 km/hour.

The coherence between the reduced levels for the most part falls below the 90% confidence level, but there are definite extrema coinciding with the atmospheric pressure extrema (for example 0.7 cycle/day -- Fig. 3Ab). Such a picture was also noted in a study by Mysak and Hamon [15], in which it was postulated that these extrema are attributable to the presence of continental shelf waves generated by atmospheric processes. In order to investigate this hypothesis, from [4] we took the dispersion curves of the first and second modes of shelf waves, constructed for the real Kurile shelf, and on these we plotted the wave numbers for those frequencies at which the coherence between the reduced levels was sufficiently great (Fig. 3B). The wave numbers k_i were determined using the formula

$$k_i = \frac{\Delta\varphi(\omega_i)}{\Delta x}, \qquad (6)$$

where Δx is the distance between stations. Coincidence with the first mode was found to be quite good.

The author of [11] has postulated, later experimentally confirmed in [9], that the maximum in the energy of shelf waves must be expected at frequencies where their group velocity becomes equal to zero. In our case for the first mode this corresponds to a frequency close to 1 cycle/day; accordingly, the extremum in the level spectra observed at this frequency and the high coherence between the reduced levels (Fig. 3A) can be attributed not only to the presence of tidal residues, but also to the presence of shelf waves at these frequencies. In this case the waves should have a length of about 100 km and the distance between stations is too great for an unambiguous determination of the wave number. In Fig. 3B we have plotted the possible wave numbers, determined from the phase shifts at near-lying points (1-2, 1-3, 4-5).

Thus, a joint analysis of atmospheric pressure and level indicated their intercausality up to a frequency of 0.7 cycle/day, and at point 4, also in the range 1.1-1.8 cycle/day. The "reverse barometer" law is well satisfied for all points, except for point 4, where the amplitude characteristic is appreciably greater than unity. In the level and atmospheric pressure spectra there are general maxima at frequencies 0.08, 0.3 and 0.65 cycle/day.

A spatial analysis of the observations between different points demonstrated that low-frequency disturbances of level and atmospheric pressure are propagated along the Kuriles Ridge with a characteristic velocity 50 km/hour. The zones of increased coherence in the reduced levels are possibly associated with continental shelf waves propagating in the opposite direction. It is not impossible that the maxima in the level energy spectra at frequencies of about 1 cycle/day are also associated with shelf waves.

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EQUILIBRIUM MODEL OF LANGMUIR CIRCULATION IN THE OCEAN

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Abstract: The paper gives the principal results of actual observations of Langmuir circulation. The author examines an equilibrium model of Langmuir circulation based on an approach developed for describing final disturbances in the case of hydrodynamic instability of flow. Within the framework of this method the form of the disturbance is determined from the linear theory and the amplitude is found from the energy equation for final disturbances of an already known form, which are written for an equilibrium (in the sense of energy transfer by the the final disturbances) state. The model reproduces the principal characteristics of Langmuir circulation, agreeing in order of magnitude with the experimental data.

[Text] The increasing number of observations made in the ocean is leading to the conclusion that Langmuir circulation occurs widely, refuting the long-held opinion that it is sporadic. The presence of powerful vertical currents, created by this circulation, is an important factor for a whole series of problems in ocean dynamics, and in particular, for understanding the mechanisms of mixing and formation of the upper quasihomogeneous layer in the ocean. Recent investigations indicate a correlation between Langmuir circulation and the wind waves and drift currents processes. An important concept [10] is that Langmuir circulation is a connecting link in energy transfer from wind waves (receiving the greater part of the wind energy) to small-scale turbulence. The conclusion that Langmuir circulation is not sporadic requires caution in determining the representativeness of measurements of the characteristics of small-scale interaction between the atmosphere and the ocean, since the circulation evidently leads to an impairment in the horizontal uniformity of these characteristics, usually a priori postulated.

Usually Langmuir circulation is visually determined from the zones of convergence of surface currents in which there is an accumulation of algae, foam or floating matter cast onto the sea surface and which, the same as regular bands of smooth water, characterized by an absence of ripples, sometimes are called wind bands. Observations at sea have established the principal characteristics of a Langmuir circulation, which here we will simply enumerate, without citing the corresponding sources, which are mentioned, for example, in the reviews [10, 18, 19] and in studies [2, 7, 16]:

1. In the upper layer of the ocean, as a result of the wind action (with velocities greater than 3 m/sec), ordered eddy movements are formed which are elongated in the direction of the wind, with an opposite direction of rotation of the particles in adjacent circulation cells.

2. The spatial scales of eddies are characterized by a considerable variability (from several to hundreds of meters) and intermittence: eddies of different scales can exist simultaneously.

3. The velocity of descending flows in the region of the wind bands has a characteristic value of about 5 cm/sec and as a rule increases with an increase in wind velocity. The transverse velocities of the currents at the surface have the same order of magnitude.

4. The longitudinal (relative to the wind) velocity at the sea surface in the region of the wind bands (windrows) (zones of surface convergence) is greater than between them, that is, zones of intensive descending movements are situated under zones of maximum longitudinal current velocity at the surface.

5. The time required for restructuring of the wind bands (windrows) at the sea surface with a marked change in wind direction is 20-30 minutes.

6. The distance between the bands is approximately equal to the depth of the upper quasihomogeneous layer.

7. In the northern hemisphere the axes of the eddies are deflected by some angle to the right of the wind direction. According to experimental data this angle is about 13°.

In addition to these properties, established in a number of experimental studies, it is possible to note the following properties which are indicated only by individual observations or which are established on the basis of indirect criteria:

8. The velocity of the descending flows exceeds by several centimeters a second the velocity of the ascending flows.

9. The circulation cells are characterized by asymmetry: the centers of the eddies are displaced toward the surface and toward the wind bands (windrows).

10. There is lateral shifting of the system of longitudinal eddies at velocities up to 14 cm/sec [1].

Any theoretical model making a pretense at describing a Langmuir circulation must reproduce at least the most important of the mentioned characteristics of circulation. We note that as test characteristics of this kind for a model of Langmuir circulation the authors of [7] mention properties 1, 4, 8; in place of 3 it is necessary to compare the comparability of the velocities of descending currents and drift currents.

In order to explain the Langmuir circulation a number of mechanisms have been proposed (a review of the most important of these is given, for example, in [10, 18, 19]. Despite their diversity, recently on the basis of experimental and theoretical results it has been possible to define a relatively narrow direction within whose framework it has been possible to formulate models taking into account the interaction of the surface waves and drift currents processes. The basis for the priority in this direction has been given, in particular, in [7, 10, 18]. In our opinion, the most realistic description of the participation of these processes in the formation of the Langmuir circulation is attained in models examining the hydrodynamic instability of the friction layer in the ocean, in support of which there are also additional proofs: first, the laboratory investigations of Faller [8] and other authors indicate that the instability of the laminar Ekman layer is manifested in the appearance of longitudinal eddy movements close in structure to a Langmuir circulation; second, observations at sea reveal the specific properties of a Langmuir circulation (deviation of the eddy axis from the wind direction and lateral displacement of the system of eddies), which are explicable from the point of view of the mechanism of hydrodynamic instability of the friction layer; third, new measurements of the parameters of longitudinal eddies in the atmospheric boundary layer reveal an agreement with a model of an unstable Ekman layer [5, 6, 12, 13, 17].

An important difference between the friction layer in the ocean and the atmospheric layer is the presence of wave movements. Allowance for surface waves leads to the conclusion that Stokes drift plays an important role in the generation of a Langmuir circulation [7, 14-16]; therefore, in the proposed model the effects of a Stokes drift are taken into account in the hydrodynamic instability of the friction layer. The model is a development of [2] and to some degree is intermediate between the Craik-Leibovich model [7, 14, 15] and a model of an unstable Ekman layer [6, 17].

In order to take into account nonlinear effects in an examination of instability of the friction layer it is possible to use two approaches to description of the final disturbances. The first involves a numerical solution of the equations of motion with a retention of the nonlinear terms [11]. An alternative approach, based on the ideas of Landau [3], was developed for a description of instability of some types of currents in the studies of Stuart (for example [20]), and applicable to the boundary layer of the atmosphere -- in a study by Brown [6]. Within the framework of this method the form of the final disturbance is determined from linear theory, whereas the amplitude is found from the energy equation for final disturbances of an already known form. Adhering to this approach, in the further exposition of the model we will first examine the procedure of linearization of the equations, making it possible to compute the form of the secondary movements in the friction layer; then we obtain the energy equation for an equilibrium state determining the amplitude of the secondary movements.

The equations of motion for the upper layer of the ocean are written in the following form, henceforth using a right-hand coordinate system with an X-axis directed along the wind and a Z-axis directed downward from the the origin of coordinates at the free surface:

$$\frac{d\mathbf{v}}{dt} + 2\,\Omega \times \mathbf{v} = -\frac{1}{\rho}\,\nabla P + \nu\Delta\mathbf{v} + g\,\mathbf{k}; \qquad (1a)$$

$$\nabla\mathbf{v} = 0, \qquad (1b)$$

where ν is the coefficient of turbulent viscosity; the remaining notations are those generally employed.

The main flow in the friction layer of the ocean will be represented in the form of the sum

$$\mathbf{v}_{\text{OCH}} = \mathbf{v}_E + \mathbf{v}_B \qquad (2)$$

[OCH = main; B = wave] of the velocity of the drift flow (v_E), stipulated by the Ekman model, and the wave part of the velocity field (v_{wave}), which is assumed to be stipulated in the potential theory approximation. We will cite explicit expressions for (2) for a situation when two identical waves are propagated at angles which are equal in magnitude but opposite in sign to the wind direction (the two-dimensional wave spectrum is usually described by a function which is symmetric relative to the wind direction). In this case, with displacements of the surface $\zeta_{1,2} = a\cos(\alpha x \pm \beta y - \omega t)$, caused by these waves, for the components (2) we have the known expressions

$$\mathbf{v}_E = \{U_E,\ V_E,\ 0\} = \left(C_0 e^{-z\sqrt{l/\nu}}\right)\left\{\cos\left(\frac{\pi}{4} + \sqrt{\frac{l}{\nu}}\,z\right),\right.$$
$$\left.\sin\left(\frac{\pi}{4} + \sqrt{\frac{l}{\nu}}\,z\right),\ 0\right\}; \qquad (3a)$$

$$\mathbf{v}_B = \{u_B,\ v_B,\ w_B\} = \left(\frac{2a\omega}{k}\,e^{-kz}\right)\{-\alpha\cos\beta y\,\cos\chi,\ \beta\sin\beta y\,\sin\chi,$$
$$k\cos\beta y\sin\chi\}; \qquad (3b)$$

$$\mathbf{v}_s = \overline{\nabla\mathbf{v}_B\int_0^t \mathbf{v}_B\,dt} = \{u_s,\ 0,\ 0\} = (2a^2\omega\alpha e^{-2kz})\times$$

$$\times\left\{\left(1+\frac{a^2}{k^2}\cos 2\beta y\right),\ 0,\ 0\right\}, \tag{3c}$$

where $k=\sqrt{\alpha^2+\beta^2}$ is the wave number; $2a$, ω is wave height and frequency;

$$\chi=\alpha x-\omega t;$$

2ℓ is the Coriolis parameter; C_0 is the surface velocity of the drift current.

Equation (3c) represents the components of the Lagrangian velocity (Stokes drift) of the order of ε^2, where ε is wave steepness [4], which with averaging can be examined in Euler variables.

Since $v_{wave} = \varepsilon v_1$ [4], where $v_1 = \{u_1, v_1, w_1\}$ and $\varepsilon = ak$ is a small parameter, examining perturbed motion in the friction layer of the ocean, the velocity field can be represented in the form of a series

$$\mathbf{v}_{\text{возм}}=\mathbf{v}_E+\varepsilon\mathbf{v}_1+\varepsilon^2\mathbf{v}_2+\ldots. \tag{4}$$

[ВОЗМ = per]

Second-order motion (v_2) will be represented in the form of a superpositioning of second-order mean motion and the second harmonic [2]; in addition, since in (2) it is understood that v_{wave} is described by potential theory, then the second-order effect, Stokes drift, known from this same theory, will follow. Thus,

$$\mathbf{v}_2=\mathbf{v}(y,\ z,\ t)+\mathbf{v}_s(y,\ z,\ t)+\mathbf{v}_{22}(x,\ y,\ z,\ t). \tag{5}$$

Here $v = \{u, v, w\}$ is mean second-order motion (secondary motion), v_{22} is a component containing the second harmonic, whose influence, like that of higher-order terms, henceforth will also be neglected. On the basis of (1), (4), (5), we obtain a system of equations describing secondary motion in the friction layer of the ocean [2], which with use of the stream function (ψ) has the following form (subsequent computations are cited for dimensionless variables):

$$\left(\frac{\partial}{\partial t}+V_E\frac{\partial}{\partial y}\right)(u+u_s)+\frac{dU_E}{dz}\frac{\partial\psi}{\partial y}=\mathrm{Re}^{-1}\,\underline{(-2v+\Delta u}+\Delta u_s)- \tag{6a}$$

$$-\overline{\left(v_1\frac{\partial u_1}{\partial y}+w_1\frac{\partial u_1}{\partial z}\right)};$$

$$\left(\frac{\partial}{\partial t}+V_E\frac{\partial}{\partial y}\right)\Delta\psi-\frac{d^2V_E}{dz^2}\frac{\partial\psi}{\partial y}=\mathrm{Re}^{-1}\underline{\left(\Delta\Delta\psi-2\frac{\partial u}{\partial z}\right.}\left.-2\frac{\partial u_s}{\partial z}\right)+$$

$$+\frac{\partial}{\partial z}\left(\overline{v_1\frac{\partial v_1}{\partial y}+w_1\frac{\partial v_1}{\partial z}}\right)-\frac{\partial}{\partial y}\left(\overline{v_1\frac{\partial w_1}{\partial y}+w_1\frac{\partial w_1}{\partial z}}\right); \tag{6b}$$

$$v=-\frac{\partial\psi}{\partial z},\quad w=\frac{\partial\psi}{\partial y},\quad \mathrm{Re}=\frac{C_0 D}{\nu}=\frac{C_0}{\sqrt{\nu l}},\quad D=\sqrt{\frac{\nu}{l}}. \tag{6c}$$

The author of [2] examined a mechanism of generation of secondary movements in the friction layer by means of the action of Reynolds stresses caused by the interaction of the velocity wave field with the shift of drift currents and which is described by the terms on the right-hand sides (6a,b) with averaging (line at the top). In the case of potential waves these terms are identically equal to zero, but the Stokes drift effects remain as a possible mechanism of generation of longitudinal vorticity.

Since the Reynolds number is of the order of 10^2, it is natural to discard the terms describing the viscous effects. However, system (6) becomes singular and a simplification of its solution is not attained. Therefore, it is customary to retain higher-order terms. In our case it is desirable to retain the terms emphasized in (6a,b) describing diffusion (in order to eliminate the singularity) and the influence of Coriolis force (since the equations of the system are related through them).

For a more general situation than in 3b,c), $u_s = u_{s\,1}(z)\cdot\exp[i\gamma(y-ct)]$ and equations (6) have solutions in the form

$$\psi=f(z)\,e^{i\gamma(y-ct)};\quad u=\mu(z)\,e^{i\gamma(y-ct)}, \tag{7}$$

where $\gamma = 2\beta$ and $c = c_r + ic_i$ can be interpreted as the complex velocity of the perturbation, its real part characterizes the displacement, and the fictitious part characterizes the increase in the amplitude of the perturbation. For determining the amplitude functions we obtain a system of ordinary differential equations

$$\begin{gathered}\mu''-[\gamma^2+\gamma\,\mathrm{Re}\,c_i+i\gamma\,\mathrm{Re}\,(V_E-c_r)]\,\mu+2\,f'-\\-i\gamma\,\mathrm{Re}\,U'_E f=\gamma\,\mathrm{Re}\,c_i u_{s\,1}+i\gamma\,\mathrm{Re}\,(V_E-c_r)\,u_{s\,1};\end{gathered} \tag{8a}$$

$$\begin{gathered}f^{IV}-[2\,\gamma^2+\gamma\,\mathrm{Re}\,c_i+i\gamma\,\mathrm{Re}\,(V_E-c_r)]\,f''+[\gamma^4+\gamma^3\,\mathrm{Re}\,c_i+\\+i\gamma^3\,\mathrm{Re}\,(V_E-c_r)+i\gamma\,\mathrm{Re}\,V''_E]\,f-2\,\mu'=0;\end{gathered} \tag{8b}$$

with the boundary conditions [7]:

when $z = 0$ $\qquad f=\mu'=f''=0;$ (8c)

when $z\to\infty$ $\qquad f=\mu=f'=0.$ (8d)

The described model is correct in the case of small perturbations and here it is used for determining only the form of the perturbation. For computing the amplitude of the perturbation, as already noted, we use the energy equation for an equilibrium state, from which is found the normalization factor for $|\psi|$, denoted henceforth by A. The final perturbations by means of Reynolds stresses deform the initial profile of the current and therefore the velocity field in the friction layer must be represented as follows

$$\mathbf{v}_{\text{пол}} = \mathbf{v}_0(z) + \mathbf{v}_{\text{в}}(x, y, z, t) + \mathbf{v}(y, z, t) + \mathbf{v}_s(y, z, t), \qquad (9)$$

[ПОЛН = per; В = wave] where $v_0(z)$ is the horizontally uniform mean current (not now describable by an Ekman spiral) and v is a periodic secondary current of the form (7), already a finite value.

Substituting (9) into (1) and carrying out horizontal averaging, we obtain equations describing the mean current $v_0 = \{U, V, 0\}$:

$$U'' - 2V = \mathrm{Re}\left[\overline{(u + u_s)w}\right]'; \qquad (10a)$$

$$V'' + 2U = \mathrm{Re}(\overline{vw})'. \qquad (10b)$$

The energy equation for secondary motion $E = (u^2+v^2+w^2)/2$ is obtained in the usual way from the equations of motion and in a nonviscous approximation has the form

$$\frac{\partial E}{\partial t} + V\frac{\partial E}{\partial y} + (V - c)\, u \frac{\partial u_s}{\partial y} + \frac{\omega}{2\alpha} v \frac{\partial u_s}{\partial y} - \frac{\omega k}{\alpha} w u_s + $$
$$+ uw\frac{dU}{dz} + vw\frac{dV}{dz} + v\frac{\partial p}{\partial y} + w\frac{\partial p}{\partial z} = 0. \qquad (11)$$

Here p is a pressure component corresponding to the secondary motion [2].

Integrating (11) for the layer occupied by secondary motion and averaging along the direction of the y-axis, with use of the expression $u + u_s = [U'/(V-c)]\,\psi$ (following from (6a) in a nonviscous approximation with the replacement of v_E by v_0), we obtain the expression

$$\frac{\partial \overline{E}}{\partial t} = \int_0^H \overline{vw}\, V'\, dz = -\int_0^H V' \overline{\left(\frac{\partial \psi}{\partial y}\frac{\partial \psi}{\partial z}\right)}\, dz. \qquad (12)$$

In an equilibrium state $\partial \overline{E}/\partial t = 0$ and the energy equation is interpreted in the following way. The secondary motion of finite amplitude, receiving energy from the mean flow, by means of Reynolds stresses redistributes it, which leads to a change in the initial current profile. The modified profile can become more stable, and in this case a stationary state is attained, provided that the energy transfer from mean motion is balanced by dissipation, or, with neglecting of the latter (the term describing dissipation contains the factor Re^{-1}), is equal to zero.

We will divide the mean flow by the Ekman part and some increment describing modification of the mean flow by the final perturbations: $v_0 = v_E + v_m$. From (10), taking into account the mentioned expression for u, we obtain equations describing $v_m = \{u_m, v_m, 0\}$:

$$u''_m - 2v_m = 0, \quad v''_m + 2u_m = \mathrm{Re}\,\overline{(vw)}' \tag{13}$$

with the boundary conditions

$$u'_m(0) = v'_m(0) = u_m(H) = v_m(H) = 0. \tag{14}$$

In (12), (13) discriminating explicitly the sought-for normalization factor A, we obtain an equation for its determination

$$A^3 \int_0^H V_E \frac{\partial}{\partial z} \overline{\left(\frac{\partial\psi}{\partial y} \frac{\partial\psi}{\partial z}\right)} dz + A^4 \int_0^H v_m \frac{\partial}{\partial z} \overline{\left(\frac{\partial\psi}{\partial y} \frac{\partial\psi}{\partial z}\right)} dz = 0. \tag{15}$$

The model was realized numerically; the computations were made using the following model. From the linearized system of equations (8) we determined the components of secondary motion u, v, w, ψ. The necessary parameters for waves and drift current were computed the same as in [2]. System (8) was solved by the matrix adjustment method using a uniform grid and employing a difference scheme with a second order of accuracy. For reducing the system of difference equations to a "three-point" form we introduced the additional unknown function $F(z) = f''$. Using (13), (14) we found a modification of the Ekman profile u_m, v_m. Formula (15) was used to determine the amplitude factor A; in this case the integrals were computed using the Simpson formula. We computed the value of the fields (ψ, u, v, w, u_m, v_m), corresponding to an equilibrium state.

Figure 1 gives an example of computation of the stream function for secondary motion, which also shows isolines of the vertical velocity and second-order longitudinal velocity ($u + u_s$). The structure of secondary motion does not essentially differ from the structure of the Langmuir circulation. It should be noted that the region of maximum descending movements is situated beneath the zone of the maximum longitudinal velocity at the surface.

Numerical experiments demonstrated a weak influence on the secondary current by the parameter c_i, which can be regarded as an index of growth of waves during a developing wave situation. As a characteristic of the degree of instability of the friction layer we employed $|f(z)|_{\max}$, characterizing the quantity of water entrained in the secondary motion. The velocity of movement of the system of eddies along the Y-axis exerts a more significant influence. It appears that the friction layer is most unstable when the velocity of movement of the perturbations (c_r) is close to the transverse velocity V_E at the point of inflection of its profile (V_E^i), as takes place in the case of a classical Ekman layer [17]. This result can be related to the phenomenon, noted under actual conditions, of lateral displacement of the wind bands (windrows) at the sea surface caused by the Langmuir circulation [1].

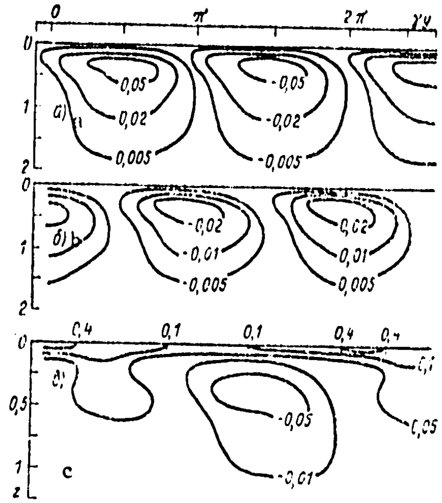

Fig. 1. Stream function for secondary motion (a), isolines of vertical velocity w (b) and total longitudinal velocity $u + u_s$ (c) in dimensionless form, computed for C_6 = 8 m/sec, = $c_r = c_i = 0$.

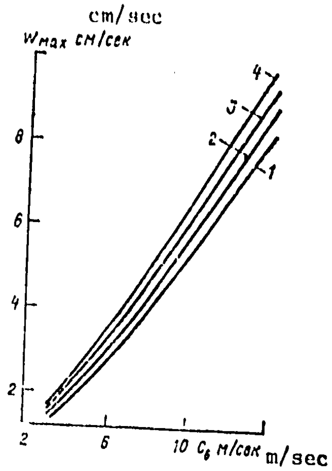

Fig. 2. Dependence of maximum rate of water subsidence (w_{max}) on wind velocity (C_6) with $\varphi = c_i = 0$, $c_r = V_E^1$. (Curves 1, 2, 3, 4 corresponds to γ = 0.2; 0.3; 0.4; 0.5).

We also modeled situations with an orientation of the perturbations at the angle φ to the wind direction. With small γ the maximum instability is displaced in the direction of the negative angles ($\varphi \approx -10°$); with a decrease in wavelength ($2\pi/\gamma$) a greater instability is noted with deflection to the right from the wind direction by approximately the same value ($\varphi \approx 10°$).

Figure 2 shows the dependence of the maximum velocity of descending movements on wind velocity at a height of 6 m (C_6) with different γ values. The computed values agree with numerous measurements of the rate of water subsidence in wind bands and indicate a direct dependence on wind velocity.

As might be expected, secondary motion is an effective mechanism for the redistribution of momentum. Figure 3 shows examples of a modification of the Ekman spiral for several situations.

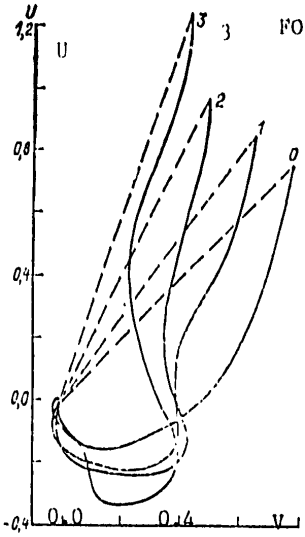

Fig. 3. Modification of the Ekman spiral (0) by secondary movements of finite amplitude (in dimensionless form).
1) C_6 = 8 m/sec, φ = 10°, c_i = 0.012, γ = 0.5
2) C_6 = 10 m/sec, $\varphi = C_i = 0$, γ = 0.4
3) C_6 = 10 m/sec, $\varphi = c_i = 0$, γ = 0.1

In all cases $c_r = V_E^i$.

Now we will formulate the principal conclusions.

1. An examination of the process of interaction between the drift current and surface waves, stipulated by the Ekman spiral and potential theory respectively, demonstrated that as a result of hydrodynamic instability a secondary motion arises which is similar to a Langmuir circulation. The "forcing force," determining the form of the perturbation, is Stokes drift in the case of three-dimensional waves modeled in the simplest case by the intersection of two ordinary plane waves.

2. A model considering secondary motion as an equilibrium motion explains a number of properties of Langmuir circulation (1-4, 7, 10) known from observations.

3. Secondary motion causes a substantial transfer of momentum, commensurable with transfer as a result of small-scale turbulence. A modification of the Ekman spiral by secondary motion leads, in particular, to a decrease in the angle between surface flow and wind shearing stress, and also causes a narrowing of the velocity hodograph in the upper layer, and this means a greater uniformity of the flow with depth.

4. The reproduction in the model of the principal peculiarities of a Langmuir circulation, established experimentally, makes it possible to hope for success in the approaches used in solving the problem. At this stage it is most important to develop a model of Langmuir circulation for taking into account stratification for the purpose of determining the role of circulation in processes of formation of the upper quasihomogeneous layer in the ocean.

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IMPROVED MODELS OF WATER DISCHARGE AND EVALUATIONS OF ACCURACY OF ITS MEASUREMENT BY THE "VELOCITY-AREA" METHOD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 65-73

[Article by Doctor of Technical Sciences I. F. Karasev, State Hydrological Institute, submitted for publication 28 March 1978]

Abstract: The article gives analytical dependences for new models of water discharge and their measurement errors, obtained on a correlation-hydraulic basis.

[Abstract] "Velocity-area" methods constitute the principal metrological basis for fluvial hydrometry. A determination of discharge on the basis of the results of registry of its elements -- a modification of indirect measurements, having a definite analytical basis -- is a water discharge model. Although the concept of a discharge model developed considerably earlier than many other hydrological models, until recently it remained extremely imperfect. This made it necessary to carry out the investigations whose results are presented in this article.

In general form water discharge in an open channel is modeled as some fluid body formed by the elementary volumes $dW = vd\omega$, where v is the current velocity at the center of gravity of the area $d\omega$ normal to it.

The entire diversity of existing models and methods for computing water discharge on the basis of measurement data was governed primarily by the difference in the methods for spatial-temporal averaging of current velocities and computation of the "discharge body" W.

The analytical and graphic methods used at the present time are based on an interpolation of the measured mean velocities on the verticals v_i, v_j (Fig. 1) as precise values, without taking into account the error in their determination and variation in the width of the section. In the case of linear interpolation the averaged velocity in the section is determined as the half-sum of the mean velocities on the verticals

$$v_s = 0{,}5\,(v_i + v_j), \tag{1}$$

which leads to a computation formula for a standard analytical method for computing the water discharge (we will call it a linear-determined model):

$$Q = \alpha_1 v_1 \omega_1 + \alpha_N v_N \omega_N + \sum_{s=2}^{s=N-1} 0{,}5\,(v_i + v_j)\,\omega_s, \tag{2}$$

where α_1 and α_N are the "edge" coefficients for computing velocity in shore sections, N and ω_s are the number and area of the sections between the velocity verticals.

In the United States use is made of a determined model of a different type [12]. The model combines measurement and velocity verticals and the determined elementary discharges are applied to their neighborhood or are linearly interpolated in the interval between them b_s.

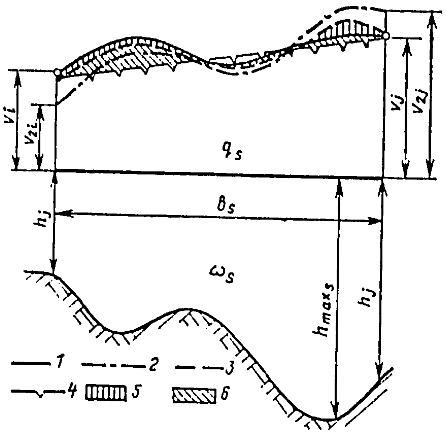

Fig. 1. Distribution of mean flow velocities on verticals in width of section. 1) actual distribution of velocities, 2) hydraulic components, 3) linear interpolation-hydraulic model, 4) linear-determined model; deviations of velocities from actual values: 5) curve (3), 6) straight line (4).

There are more perfect discharge models which take into account the nonlinear nature of change in velocity in the width of the section. In the graphic processing of water discharge the velocity curve is reproduced in the form of a smooth curve. In the analytical variant the change in velocities is represented using a parabolic interpolation model or in dependence on the local depths in the section (A. P. Braslavskiy).

In all the cited cases the discharge model remains determined. In actuality, however, the measured mean velocities on the verticals can be broken down into at least three components.

[Г = h]

$$v = v_{\text{г}} + w + f_v,$$

where v_h is a determined value, hydraulically governed by local depth, the slope of the free surface and channel roughness; w is the structural deviation of velocity caused by the action of different disturbing factors and large-scale turbulent formations; f_v is a value reflecting the influence of the local turbulent fluctuation of velocities and the errors in determining mean velocity of different origin, including instrumental and methodological, dependent on the number of points for measuring velocity.

Each component, naturally, must have different methods for its spatial interpolation in the width of the flow.

The determined value v_h follows the change in depths on the verticals in accordance with the Chezy-Manning formula

$$\bar{v}_{\text{г}} = \frac{h^{2/3} I^{1/2}}{n} = ah^{2/3}. \tag{3}$$

[Г = h]

The parameter

$$a = \frac{I^{1/2}}{n} = \frac{Q}{\omega h_{\text{cp}}^{2/3}} \tag{4}$$

[cp = mean] (where ω and h_{mean} are, respectively, the area and mean depth of the cross section) serves as one of the hydraulic characteristics of the flow, used by M. A. Velikanov [1] in computing the plan of currents.

For computing v_h with the use of expression (3) it is necessary to know the distribution of depths in the width of the channel. An analytical approximation of the outlines of the river channel transverse profile in each specific case is quite complex. However, in order to obtain the mean velocity v_{h_S} in the section ω_S it is not mandatory to reproduce the true configuration of the channel under the condition that the used approximation gives an equally "guaranteed" distribution of depths. The analytical expression for such approximations was proposed by V. N. Goncharov [3]:

$$h = h_{\max}\left(\frac{y}{B}\right)^z, \tag{5}$$

where B and h_{max} are the width and maximum depth of the channel respectively; y is the distance from one of the water edges; for the exponent we have

$$z = \frac{h_{\max} B}{\omega} - 1 = \varphi - 1.$$

Here φ' is the characteristic of completeness of the section; its value varies from 2 to 1 for triangular and rectangular profiles respectively. For natural river channels of complex configurations $\varphi \gg 1$.

The hydraulic dependence for the determined component (4) and the approximation (5) is also applied to the sections between the velocity verticals. Therefore, the v_{h_s} value can be represented as follows:

$$[\Gamma = h] \qquad a_s = q_s / \omega_s h_{\text{cp}_s}^{2/3}. \tag{6}$$

where a_s is determined from the values of the partial discharge q_s, area ω_s and mean depth in the sections between the velocity verticals:

$$[\text{cp} = \text{mean}] \quad v_{r_s} = \frac{1}{b_s}\int_0^{b_s} a_s h^{2/3}\,dy = \frac{1}{b_s}\int_0^{b_s} a_s h_{\max_s}^{2/3}\left(\frac{y}{b_s}\right)^{2/3(\varphi-1)} dy = \frac{3\,a_s h_{\max_s}^{2/3}}{2\varphi+1}. \tag{7}$$

With respect to the velocity components -- structural w and random f_v -- together they are determined as deviations of the measured mean velocities on the verticals from their hydraulic components:

$$\Delta v_{i(j)} = w_{i(j)} + f_{v_{i(j)}} = v_{i(j)} - v_{r_{i(j)}}.$$

The Δv_k values on the intermediate verticals are a random function of the transverse coordinate y. They can be obtained by means of interpolation of the deviations Δv_i and Δv_j in the interval between the velocity verticals. The Δv_s value, averaged in the width of the section, in general form is represented in the following way:

$$\Delta v_s = P_s(\Delta v_i + \Delta v_j). \tag{8}$$

In the simplest case of linear interpolation $P_s = 0.5$. However, for the best approximation to the real value it is necessary to take into account the correlation of Δv_i and Δv_j. For this purpose it is possible to use the optimum interpolation method [2], interpreted by us applicable to hydrometric problems [6].

Using a separate representation of the components of mean velocity in the section v_{h_s} using (7) and Δv_s using (8), we will synthesize the interpolation-hydraulic model of water discharge:

$$Q = \sum_{s=1}^{s=N}\left[\frac{3\,a_s h_{\max_s}^{2/3}}{2\varphi_s+1} + P_s\left(v_i - a_s h_i^{2/3} + v_j - a_s h_j^{2/3}\right)\right]\omega_s. \tag{9}$$

For P_s we obtained the approximate expression

$$P_s = \frac{\tilde{\zeta}_k}{\eta\tilde{\zeta}_k + 2\tilde{\zeta}_k + 2}, \tag{10}$$

where $\tilde{\zeta}_k = \zeta_k / b_s$ is determined on the basis of the autocorrelation function of the structural deviations w [6]; η is the measure of errors in measurement of velocity on the vertical:

$$\eta = \frac{\sigma_H^2}{\overline{w_i^2}} = \frac{\sigma_H^2}{\overline{(\Delta v_i^2)} - \sigma_H^2}.$$

[H = meas] (The line at the top denotes statistical averaging for the set of varying parameters.)

The basis for model (9) is the hydraulic nucleus of the flow (the first term under the sum sign). But, in contrast to the linear-determined model (2), model (9) contains a varying part (second term). Depending on the interpolation method, the varying part of the discharge interpolation-hydraulic models is subdivided into two modifications:

-- a linear interpolation-hydraulic model, which corresponds to the constant value $P_s = 0.5$;
-- an optimum interpolation-hydraulic model in which the weighting factors P_x are determined on a correlation-statistical basis using expression (10).

The modifications of the models are successively interrelated. For example, if the structural deviations of velocity have a random character, P_s assumes a zero value and the water discharge is expressed only by the sum of the hydraulic components of the discharges in the sections ω_s. With approach to a determined distribution of velocities $P_s \rightarrow 0.5$. The water discharge model in this case is reduced to a linear interpolation-hydraulic model. And finally, if in supplementation to these conditions we use as a point of departure a linear bottom profile between the velocity verticals, a linear-determined model is precise (2).

Interpolation-hydraulic models do not require the introduction of the edge coefficients α_1 and α_N, since formula (9) ensures the necessary averaging of velocity in the first and last sections with the values $v_i = 0$, $h_i = 0$ and $v_j = 0$, $h_j = 0$ respectively.

The values entering into formula (9) represent the directly measured water discharge elements or are computed using measurement data (φ, a_s). The a_s coefficient is determined using formula (7), in which as a first approximation the partial discharges q_s are computed by a standard analytical method on the basis of model (2). Thus, the new model (9) is successively related to the presently used model (2) and gives a second approximation for water discharge.

The relative mean square error in measuring water discharge $\tilde{\sigma}_Q$ is characterized by a set of special errors in determining its elements. On the assumption of a mutual independence of the latter, on the basis of expression (2) and the obvious expressions

$$\frac{\partial q_s}{\partial v_s} = \frac{q_s}{v_s}, \quad \frac{\partial q_s}{\partial \omega_s} = \frac{q_s}{\omega_s},$$

we will have

$$\tilde{\sigma}_Q = \left[\frac{\beta}{N} (\tilde{\sigma}^2_{\omega_s} + \tilde{\sigma}^2_{v_s}) \right]^{1/2}, \tag{11}$$

where $\tilde{\sigma}_{\omega_s}$ and $\tilde{\sigma}_{v_s}$ are the relative measurement errors for the areas of the sections between the velocity verticals and the mean flow velocities in these sections respectively; β is a metrological parameter dependent on the hydraulic structure of the flow and the degree of discretization of the measurements,

$$\beta = \frac{N \sum_1^N q_s^2}{Q^2}.$$

With a uniform distribution of velocity verticals in the width of the flow in a rectangular channel $\beta = 1$, in a river without floodplains, $\beta = 1.2\text{-}1.8$, in the presence of floodplains $1.8 < \beta < 3.0$. In general, the smaller the value, the more rational is the measurement process. In a channel with a complex configuration the velocity verticals must be placed in such a way that approximately equal fractions of the water discharge pass between them; this ensures a maximum effect of the spatial smoothing of the special errors in measuring discharges in the sections between the velocity verticals. This principle, adopted in the United States as an emprical rule, follows directly from the formulas cited below (12)-(14).

The mean square error in determining the area of the sections is dependent on the instrumental errors of the instruments employed in making measurements (markers, sounding leads, echo sounders) and the reliability of the geodetic base of the hydrometric work. The errors in determining distances from a constant beginning and the width of the sections usually mutually compensate one another in sign and value and therefore do not exert an influence on the accuracy in determining ω_s. Deviations of the measuring ship from the hydrological line introduce a definite error into the measurement of ω_s; these constitute a source of so-called morphometric errors [5]. However, the principal factor determining the accuracy in measuring the area of the channel is the number of measuring verticals. Although the error in representing the continuous profile by a series of discrete measurements of depth can be evaluated theoretically, it is better to use more reliable empirical data directly. For example, with 20 or more measureement verticals the mean square error in measuring the cross-sectional area (according to data from O. N. Borsuk) assumes the almost constant value 2%.

A decisive influence on the accuracy in measuring water discharge is exerted by the errors in measuring mean velocities on the verticals $\sigma_{v_{ver}}$ and their averaging in the section σ_{v_s}. The error $\sigma_{v_{ver}}$ is dependent on the accuracy of the measuring instruments, the duration of their exposure at the measuring points where velocity is determined and the number of these points in the depth of the flow. The duration of instrument exposure determines the pulsation error in measuring velocity and the number of points determines the error in discretization of the curve of distribution of velocities on the vertical. Estimates of the error $\sigma_{v_{ver}}$ and its components can be found in numerous sources, including publications of the hydrometry section of the State Hydrological Institute [5, 7]. In combination with adherence to the standard method for hydrometric work, the accuracy in measuring the mean velocity is: the detailed (five-point) method -- 2-3%, the main method (two-point) -- 4-5%.

With respect to the error in averaging velocities in the section σ_{v_s}, it is represented as the average error in interpolating the measured values v_i and v_j in the interval between the velocity verticals, since in computing v_s use is made of only one (averaged) value of the weighting coefficient P_s. In general form the evaluation of the mean errors in linear and optimum interpolation is given in [6]. Using approximate estimates of the error σ_{v_s}, we obtain the following expressions for the relative mean square errors in measuring water discharge in the variants:

linear interpolation-hydraulic model

$$\tilde{\sigma}_Q = \left[\frac{\beta}{N}\left(\tilde{\sigma}^2_{v_s} + \frac{5}{3}\tilde{\sigma}^2_w e^{-1,4\,\zeta_k/b_s} + 0,5\,\tilde{\sigma}^2_{v_B}\right)\right]^{1/2}; \tag{12}$$

optimum interpolation-hydraulic model

$$\tilde{\sigma}_Q = \left[\frac{\beta}{N}\left(\tilde{\sigma}^2_{v_s} + \tilde{\sigma}^2_w e^{-1,4\,\zeta_k/b_s} + 0,5\,\tilde{\sigma}^2_{v_B}\right)\right]^{1/2}; \tag{13}$$

standard analytical method (linearly determined model)

$$\tilde{\sigma}_Q = \left[\frac{\beta}{N}\left(\tilde{\sigma}^2_{v_s} + \frac{5}{3}\tilde{\sigma}^2_w e^{-1,4\,\zeta_k/b_s} + 0,5\,\tilde{\sigma}^2_{v_B} + \tilde{\sigma}^2_{v_M}\right)\right]^{1/2} \tag{14}$$

[B = ver] [M = morphometric] The error in determining the water discharge on the basis of a standard linearly determined model includes the entire set of errors in the linear interpolation-hydraulic model and also the morphometric error in determining mean velocity in the section σ_{v_M}, equal to the difference in the mean values of the hydraulically governed velocities in accordance with formula (7) and the half-sums of the values computed for the verticals limiting the section. In a special case for a rectangular or nearly rectangular channel, when $\varphi \to 1$, $h_i \approx h_j \approx h_{max}$, we have $\sigma_{v_M} \approx 0$, and for an estimate of the error in determining water discharge, processed on the basis of an interpolation-determined model, the formula (12) becomes applicable. If, in addition, there is such a close correlation between the measured mean velocities on the verticals that the correlation radius is substantially greater than the distances between them ($\zeta_k \gg b_s$), the error σ_Q is evaluated by means of a simple dependence, cited in our earlier studies, such as in [5]:

$$\sigma_Q = \left[\frac{\beta}{N}\left(\sigma^2_{v_s} + 0,5\,\sigma^2_{v_B}\right)\right]^{1/2}.$$

[B = ver]

Table 1

Error in Water Discharge Models According to Computed Dependences σ_Q and Actual Data $\delta Q(\%)$

Количество скоростных вертикалей 1	Модель расхода воды 2					
	линейно-детерминированная 3		линейная-интерполяционно-гидравлическая 4		оптимальная интерполяционно-гидравлическая 5	
	σ_Q	δQ	σ_Q	δQ	σ_Q	δQ
6 Вахш — кишлак Туткаул, 1960—1961 гг. $\tilde{\sigma}_w=11{,}8\%$; $\tilde{\zeta}_k=\zeta/h=5{,}3$						
8	2,9	—	2,9	—	2,7	—
3	5,6	3,0—6,0	5,6	1,0—4,0	4,6	1,0—4,0
2	7,1	1,0—6,0	7,1	1,0—7,8	5,7	1,0—4,6
7 Сырдарья — кишлак Кзылкишлак, 1976 г. $\tilde{\sigma}_w=40{,}0\%$; $\tilde{\zeta}_k=\zeta/h=8{,}1$						
18	2,7	—	2,6	—	2,6	—
9	3,0	0,0—5,2	2,9	1,0—5,0	2,7	0,9—2,9
3	8,0	8,4—22,5	3,9	3,7—13,8	3,4	1,0—4,8
8 Волхов — д. Бурнги, 1968 г. $\tilde{\sigma}_w=21{,}6\%$; $\tilde{\zeta}_k=\zeta/h=8{,}0$						
9	3,9	—	3,9	—	3,4	—
3	11,4	3,0—12,0	11,2	1,0—10,0	8,8	0,5—6,6
2	17,5	16,0—32,0	17,3	4,0—23,0	13,6	3,0—23,0

Key:

1. Number of velocity profiles
2. Water discharge model
3. Linearly determined
4. Linear-interpolation-hydraulic
5. Optimum interpolation-hydraulic
6. Vakhsh-Tutkaul village
7. Syrdar'ya-Kzylkishlak village
8. Volkhov-Burigi village

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In contrast to the formulas cited by other authors, such as [4], including foreign authors [9-11], the dependences (12)-(14) contain parameters reflecting the degree of discretization of measurements and correlation of the errors in determining current velocity. It is inadmissible to evaluate the accuracy in measuring the water discharge by simple summation of the special errors, and in determining the weighting coefficients for each of them there should be no change in the degree of discretization of the discharge model. The nonadherence to this latter condition distorts the relationship of the errors determining the accuracy in measuring the water discharge. A similar inconsistency was allowed by G. V. Zheleznyakov and B. B. Danilevich [4]. In their formula, as indicated by the computations of N. K. Sibiryakova [8], the weight of the errors in measuring velocity exceeded by 4-6 orders of magnitude the values of the remaining coefficients. In other words, the accuracy in measuring water discharge was not dependent on the error in determining the cross-sectional area. Failure to take into account the correlation of the special errors leads to an understatement of the combined error in measuring water discharge.

The correlation-hydraulic characteristics of the water discharge models and the errors in measuring its elements were also studied on the basis of materials from methodological investigations on the rivers and canals of Central Asia, the Northern Caucasus, the Northwest and Belorussia. Table 1 gives the $\tilde{\sigma}_W$ and $\tilde{\sigma}_k$ values for three characteristic rivers: mountainous (Vakhsh), semimountainous (Syrdar'ya) and lowland (Volkhov). In the absence of flow disturbances in a prismatic channel, such as the Vakhsh River, both characteristics assume a minimum value: σ_W in this case differs little from the errors in measuring velocity, not having correlation. On the other hand, if the distribution of velocities under the influence of above-lying disturbing factors is not entirely hydraulically governed (inadequately corresponds to depths), there is an increase in $\tilde{\sigma}_W$ and ζ_k; this peculiarity is characteristic of the Volkhov and Syrdar'ya stations.

The correlation-hydraulic characteristics of the flow velocity structure must be determined for each specific station on the basis of the results of preceding observations. With respect to the data in Table 1, they can be used as a preliminary basis for use of interpolation-hydraulic models and evaluating the accuracy in measuring water discharges in rivers with similar hydrological regimes.

As is well known, fluvial hydrometry does not have absolute standards for water discharge measured by the "velocity-area" method. Under these conditions the effectiveness of its different models can be evaluated only on the basis of measurements with increased discreteness, in our case -- deviation δQ of the discharge values in the case of a reduced number of velocity verticals from the more precise values obtained without such a reduction. Table 1 gives the relative mean square errors δ_Q, computed using formulas (12)-(14) respectively and compared with the δQ deviation. The latter were obtained using data from hydrometric expeditions of the State Hydrological Institute. To be sure, it is impossible to expect a complete coincidence of the theoretical and empirical evaluations of the error. Nevertheless, the closeness of the compared values was acceptable and in any case there were not those considerable discrepancies which were registered in an analysis of existing formulas for evaluating the accuracy in measuring water discharge [8].

The effectiveness of interpolation-hydraulic models in most cases is the greater the lesser the number of velocity verticals. This means that in many hydrological sections it is possible to decrease the number of velocity verticals and accelerate the measurement of discharge without decreasing its accuracy.

There are also other modifications of the "velocity-area" method ensuring acceleration of measurements. In particular, we will mention integration methods for measuring flow velocity both using hydrometric current meters and employing ultrasound. The investigations carried out at the State Hydrological Institute indicate that these methods are quite promising, although they require the development of special equipment for hydrometric sections. (Such a characterization of integration methods exceeds the framework of this article.)

The use of new models with a restricted number of velocity verticals differs fundamentally from the use of the correlations between water discharge and its so-called representative elements, for example, the maximum depth and velocity values in the cross section [7]. The accuracy of these models is considerably lower and is 15-20% due to the instability of the coefficients for conversion from representative elements to water discharge.

Summary

1. New (interpolation-hydraulic) water discharge models make possible a considerable acceleration of its measurement by "velocity-area" methods without a decrease in accuracy in comparison with the employed standard methods.

2. The determined dependences for evaluating the error in measurement of discharge follow directly from the analytical basis of its models. In contrast to those proposed earlier, these dependences take into account the correlation and weighting coefficients of the special errors as characteristics of the velocity structure of the flow. The metrological parameter β contained in them reflects the degree of discretization of the velocity field. It can serve as one of the criteria for optimizing measurements on the basis of the maximum effect of spatial smoothing of the special errors.

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DETERMINATION OF THE PARAMETERS OF GROUND PERMEABILITY FROM UNSTABLE INFILTRATION CURVES

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[Article by Candidate of Technical Sciences V. M. Denisov, submitted for publication 22 March 1978]

Abstract: The article examines the laws of water movement in the aeration zone and gives the derivation of the equations for the reduced rate of vertical filtration and a new method is proposed for determining the parameters of permeability of virtually homogeneous ground.

[Text] As is well known, hydrological computations of rain-induced runoff are closely associated with determination of possible water losses due to its infiltration into the ground.

Upon entering into the soil, the water can completely fill its pores in some volume or layer, or only a part of them. In the first case there is a two-phase soil-water system, and the medium (ground) is water-saturated. With partial filling of the pores the medium is not water saturated and thus is already a three-phase soil-water-air system.

Under real conditions, even within the limits of a single profile, it is possible to encounter different degrees of ground water saturation. The law of water movement in saturated soil media is described quite well by the well-known Darcy equation

$$v = K_{\Phi} i, \tag{1}$$

[Φ = fil]

where K_{fil} is the filtration coefficient; v is the reduced filtration rate; i is the hydraulic slope.

In the case of vertical filtration in water-saturated ground (downward filtration) the hydraulic slope is formed only due to the distribution of hydrostatic head

$$i = \frac{h + l}{l}, \qquad (2)$$

where h is the water layer on the soil surface; l is the length of the filtration path.

In the case of water filtration in unsaturated ground the picture is greatly complicated. The interaction of uncompensated forces [2] is complex in nature. These are caused by the potential of the moisture content gradient P_W, the osmotic potential P_O arising as a result of the presence of water-soluble salts, capillary-film potential P_c, potential of the soil moisture configuration caused by the energy of the water-air phase discontinuity P_γ, the potential of entrapped air P_e and other possible potentials.

It must be noted that all these forces, other than the osmotic potential, are formed at the water-soil-air discontinuity in the unsaturated zone where there is a moisture content gradient.

The vertical filtration of water in unsaturated ground is a complex process when there is a change in moisture content both along the profile and with time at each point on this profile. Usually the upper zone of this profile rapidly comes into a state of complete water saturation and a region of unsaturated ground arises on the filtration front. With the downward advance of the filtration front the layer of water-saturated ground also increases and the region which is not saturated drops downward. It should be noted that water filtration occurs progressively from the surface region through the water saturated ground layer into its unsaturated part. There is a simultaneous and progressive filtration through the water saturated and unsaturated ground. Thus, a decrease in the water in the surface layer corresponds to an increase in the volume of water-saturated ground and the volume and moisture content of its unsaturated part.

Taking into account the sequence and interdependence of the filtering of water through the saturated and unsaturated ground zones, in our opinion it is necessary to regard this process as a single process and express it by some one generalizing equation.

For this purpose we will express the total effect of all the uncompensated forces on the filtering water, arising in the region of the unsaturated part of the ground, the so-called equivalent potential

$$P_s = P_w + P_o + P_\kappa + P_e + P_\gamma + \ldots, \qquad (3)$$

[o = osmotic; K = capillary-film] where P_S is the equivalent or total potential, having the dimensionality of length (in millimeters of a water column).

We will find the hydraulic gradient and the reduced rate of vertical filtering of water into the ground, having a different degree of water saturation.

As is well known, under conditions of laminar filtration there is an equality of the forces caused by a drop in the hydrostatic head and the effect of the total potential of the part of the ground not saturated with water, on the one hand, and the resistance force (friction), proportional to the first power of the filtration rate, acting on the filtration path, on the other.

For one-dimensional filtration we have

$$\gamma(z_2-z_1)+\gamma P_s=clv, \qquad (4)$$

where γ is the volumetric weight of the water; z_1 is the reading for the filtration front; z_2 is the reading for the level of the water present at the soil surface.

For the vertical filtering of water into the ground we have

$$z_2-z_1=h+l. \qquad (5)$$

Substitution of the value $z_2 - z_1$ from (5) into (4) gives

$$\gamma(h+l+P_s)=clv, \qquad (6)$$

hence

$$v=\frac{\gamma}{c}\frac{h+l+P_s}{l}=\frac{\gamma}{c}\,i. \qquad (7)$$

For reducing formula (7) to the known Darcy equation the proportionality factor c must be

$$c=\frac{\gamma}{K_{\Phi}}. \qquad (8)$$

[Φ = fil] The replacement of the c parameter in equation (7) by its value from (8) leads to a final expression for the reduced rate of vertical filtering of water into the ground

$$v=K_{\Phi}i=K_{\Phi}\left(1+\frac{h+P_s}{l}\right). \qquad (9)$$

[Φ = fil] It must be noted that the equivalent or total potential P_s, as demonstrated in numerous experiments, can have not only a positive, but also a negative (repulsing) value. Thus, using equation (9) it is possible to describe the process of water infiltration into the ground in the aeration zone.

Under field conditions the infiltration process is most frequently simulated by means of a Nesterov infiltrometer, in which, due to the presence of two concentrically arranged cylinders, some buffer zone is created which reduces the outflow of water from the inner cylinder. However, it must nevertheless be noted that when using this instrument some methodological "nonclosures" arise. The results frequently lead to exaggerated percolation characteristics as a result of the weak restriction of lateral outflow. Evidently, the extensive use of these instruments is related to the desire to obtain the filtration characteristics of the unimpaired ground under natural conditions.

These characteristics can be determined more precisely when using ground monoliths selected under natural conditions without disruption of their structure and mechanical properties. However, this cannot always be done on a practical basis (especially for weakly bound ground) and therefore, knowingly expecting some loss in the accuracy of the results, use is nonetheless made of the Nesterov infiltrometers, regarding infiltration from the inner cylinder of this instrument to be approximately one-dimensional.

At the present time we know of several methods for the field determination of permeability of ground, which can be divided into two principal groups:
1) methods based on the theory of steady water movement,
2) methods using the theory of unsteady movement.

The first group includes methods developed by N. S. Nesterov, A. K. Boldyrev and N. K. Girinskiy [3], but these methods have a number of shortcomings:
-- only the filtering coefficients are determined;
-- attainment of a steady water discharge is dependent on a great time expenditure on carrying out an experiment and a great volume of water, which sometimes is in short supply;
-- in the process of prolonged wetting of the ground there can be a change in its mechanical structure as a result of swelling of the particles and also calmatation of the upper layer at the water-soil discontinuity.

The second group includes the methods of N. N. Bindeman, N. N. Verigin [3] and V. V. Badov [1]. These methods considerably reduce the time spent on the experiments, but for determining capillary pressure forces (more correctly, evidently, total potential P_s) and inadequacy of saturation it is necessary to expose the ground to the depth of its moistening.

Also of definite interest is the somewhat original method of instantaneous water applications developed by V. V. Badov in which a study is made of the filtration process with a free decrease in the water level (surface head) after an instantaneous application of water. However, the determination of the reduced rate of filtration or the intensity of decrease in the level of the free surface ($v = -dh/dt$) by means of the tangent contructed by eye to some point on the decrease curve ($h = f(t)$) can introduce a substantial error into the computations. V. V. Badov recommends that the shortage in saturation also be determined by means of exposure of the ground to the depth of its moistening or use of a constant equal to 0.2 (in fractions of unity).

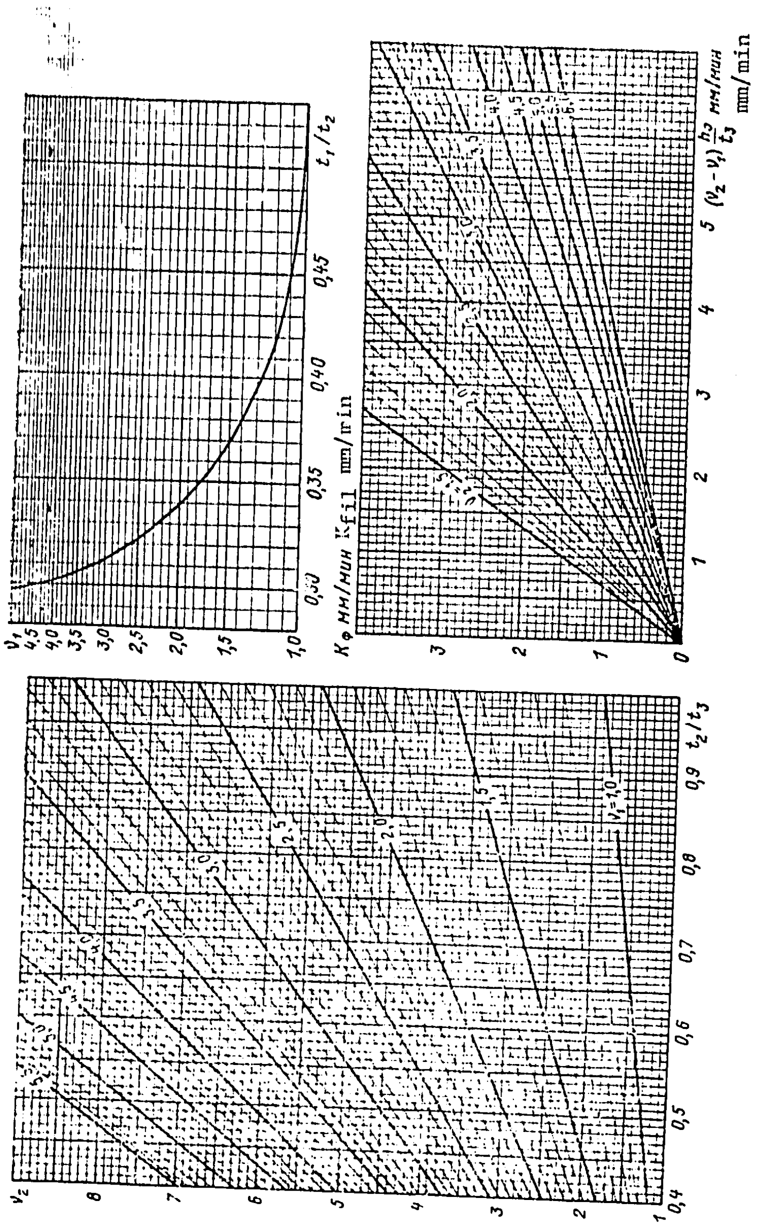
t_1/t_2
0,30
0,35
0,40
0,45
v_1
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
$K_ф$ мм/мин K_{fil} mm/min
3
2
1
0
1
2
3
4
5
$(v_2-v_1)\frac{h_2}{t_3}$ мм/мин
mm/min
t_2/t_3
0,4
0,5
0,6
0,7
0,8
0,9
v_2
1
2
3
4
5
6
7
8
v_1=1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0

Fig. 1.

Taking into account what has been said above, we developed a new, rather simple and not time-consuming method for determining the permeability of virtually homogeneous ground using unsteady infiltration curves. The proposed method is based on use of unsteady water infiltration when there is a variable surface head (free infiltration). The experience with determining the hydrophysical parameters of the ground involves observations of change in level (surface head) of the filtering water to its total infiltration. It can be used under both laboratory (with monoliths) and under field conditions. The most precise results are usually obtained in an investigation of monoliths in the laboratory. There conditions are created which impede the outflow of water through the lateral surface of the monolith (application of paraffin or smearing of the lateral surface with plasticine). This favors the creation of a rigorous one-dimensional filtration flow. When carrying out laboratory investigations the volume of the water passed through the monolith must be approximately 8-10 times less than the volume of the sample.

Under field conditions the Nesterov infiltrometer usually used for these purposes can be employed.

Below we present the theoretical basis of the proposed method and an example of computations of the parameters of ground permeability.

We will express the temporal change (decrease) in some initial volume of water filtering into the ground by the known equation

$$-\frac{dW}{at} = Q, \tag{10}$$

where W is the volume of the filtering water; t is time; Q is the water discharge through the filtration surface.

Dividing the left and right sides of equation (10) by the area ω through which filtration occurs, we obtain

$$-\frac{dh}{dt} = \frac{Q}{\omega} = v. \tag{11}$$

For determining the filtration rate we will use formula (9), in which the length of the filtration path is expressed through the relationship of the percolating water layer h_0-h to the value of the free or active ground porosity μ:

$$l = \frac{1}{\mu}(h_0 - h), \tag{12}$$

where h_0 is the initial layer (initial surface head) of filtering water.

Substituting the l value from equation (12) into (9), we find that

$$v = K_{\Phi}\left[1 + \frac{\mu (h + P_s)}{h_0 - h}\right]. \tag{13}$$

With repeated application of some volume of water its filtration conditions will differ somewhat from the filtration conditions for the first volume. This difference is associated with the forming filtration column for the first volume to which water was applied.

Thus, the filtration rate u for the second volume to which water was applied, in a case when it is equal to the first, is

$$u = K_{\Phi}\left[1 + \frac{h + P_s}{\frac{h_0}{\mu} + \frac{h_0 - h}{\mu}}\right] = K_{\Phi}\left[1 + \frac{\mu (h + P_s)}{2 h_0 - h}\right]. \tag{14}$$

[Φ = fil]

We will find the time for the filtering of water through the first volume with a change in surface head from the initial value to some adopted value.

$$v = -\frac{dh}{dt} = K_{\Phi}\left[1 + \frac{\mu (h + P_s)}{h_0 - h}\right]. \tag{15}$$

[Φ = fil]

hence

$$-\int_{h_0}^{h} \frac{dh}{1 + \frac{\mu (h + P_s)}{h_0 - h}} = K_{\Phi}\int_{0}^{t} dt. \tag{16}$$

Integration gives

$$t = \frac{h_0}{(1 - \mu) K_{\Phi}}\left[(1 - n_t) - (\nu_1 - 1) \ln \frac{\nu_1 - n_t}{\nu_1 - 1}\right], \tag{17}$$

where $n_t = h_t/h_0$ is the relative surface head (in fractions of the initial value), corresponding to the time t.

$$\nu_1 = \frac{1 + \mu \frac{P_s}{h_0}}{1 - \mu}. \tag{18}$$

Similarly we find the water filtration time with repeated application of water

$$t = \frac{h_0}{(1 - \mu) K_{\Phi}}\left[(1 - n_t) - (\nu_2 - 2) \ln \frac{\nu_2 - n_t}{\nu_2 - 1}\right], \tag{19}$$

$$\nu_2 = \frac{2 + \mu \frac{P_s}{h_0}}{1 - \mu}. \tag{20}$$

The water filtration time with a change in surface head in the interval from h_0 to h for both water applications can also be determined from an experiment with observation of the change in the level of the filtering water in the inner cylinder of the instrument. For this purpose, using data from the experimental applications of water, curves were constructed showing the change in the surface head of water with time ($h_t = f(t)$) for the first and second water applications.

The equations (17) and (19) include three unknowns: filtering coefficient K_{fil}, active (free) porosity μ and total potential P_s. For finding these unknowns we will write three equations, stipulating specific intervals in the change in surface head.

For the first volume of filtering water we noted two intervals of change in surface head, from which their filtration time is determined. The first interval is determined by a change in surface head from h_0 to $0.5h_0$, or

$$n_1 = \frac{0,5\,h_0}{h_0} = 0,5.$$

The second interval is from h_0 to $0.05h_0$, or

$$n_2 = \frac{0,05\,h_0}{h_0} = 0,05.$$

For the second application of water the interval of change in surface head is adopted in the range from h_0 to $0.05\ h_0$, or

$$n_3 = \frac{0,05\,h_0}{h_0} = 0,05.$$

Thus, using the selected intervals of change in surface head and formulas (17) and (19), we write a system of three equations

$$\left.\begin{aligned} t_1 &= \frac{h_0}{(1-\mu)\,K_\phi}\left[0,5-(\nu_1-1)\ln\frac{\nu_1-0,5}{\nu_1-1}\right] \\ t_2 &= \frac{h_0}{(1-\mu)\,K_\phi}\left[0,95-(\nu_1-1)\ln\frac{\nu_1-0,05}{\nu_1-1}\right] \\ t_3 &= \frac{h_0}{(1-\mu)\,K_\phi}\left[0,95-(\nu_2-2)\ln\frac{\nu_2-0.05}{\nu_2-1}\right] \end{aligned}\right\}, \qquad (21)$$

where t_1, t_2 and t_3 is the time of change in surface head in the selected intervals.

For determining the ν_1 value we will solve the first two equations in system (21):

$$\frac{t_1}{t_2} = \frac{0,5-(\nu_1-1)\ln\dfrac{\nu_1-0,5}{\nu_1-1}}{0,95-(\nu_1-1)\ln\dfrac{\nu_1-0,05}{\nu_1-1}}. \qquad (22)$$

The ν_1 parameter is found from the graph of equation (22), since in explicit form it is not solved relative to this parameter.

The ν_2 parameter is determined by solving the second and third equations in system (21).

$$\frac{t_2}{t_3} = \frac{0{,}95 - (\nu_1 - 1)\ln\frac{\nu_1 - 0{,}05}{\nu_1 - 1}}{0{,}95 - (\nu_2 - 2)\ln\frac{\nu_2 - 0{,}05}{\nu_2 - 1}} \tag{23}$$

Due to the fact that equation (23) is not solved in explicit form relative to the ν_2 value, it is found using a nomogram of this equation (Fig. 1).

For determining the active (free) porosity we will solve the system of equations (18) and (20), excluding from it the value

$$\mu\frac{P_s}{h_0}:$$

$$\left.\begin{aligned} \nu_1 &= \frac{1 + \mu\frac{P_s}{h_0}}{1 - \mu} \\ \nu_2 &= \frac{2 + \mu\frac{P_s}{h_0}}{1 - \mu} \end{aligned}\right\}. \tag{24}$$

The solution of the system gives

$$\mu = 1 - \frac{1}{\nu_2 - \nu_1}. \tag{25}$$

Similarly, from these same equations we find the total potential:

$$P_s = h_0\frac{2\nu_1 - \nu_2}{\nu_2 - \nu_1 - 1}. \tag{26}$$

For determining the filtration coefficient for ground we substitute expression 1 - μ from formula (25) into the third equation of system (21).

The formulation gives

$$K_ф = \frac{(\nu_2 - \nu_1)h}{t_3}\left[0{,}95 - (\nu_2 - 2)\ln\frac{\nu_2 - 0{,}05}{\nu_2 - 1}\right]. \tag{27}$$

For the purpose of facilitating computations, Fig. 1 gives a graph of equation (22) and nomograms of equations (23) and (27).

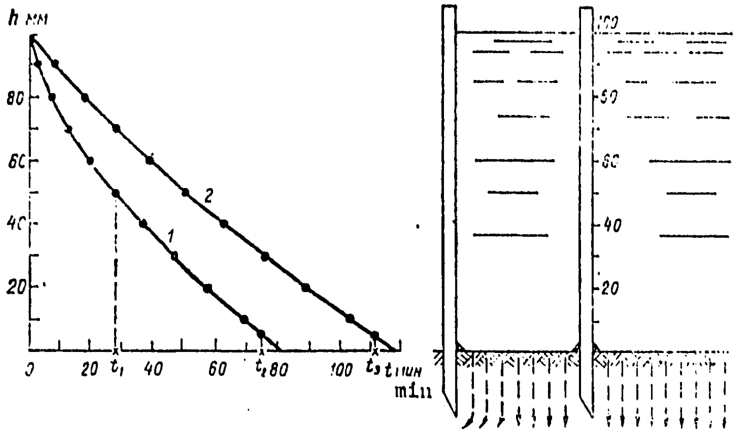

Fig. 2.

As already mentioned above, the proposed speedy method for determining the parameters of ground permeability is applicable for the most part only for a virtually homogeneous soil profile for the entire filtration depth ($\ell = 2h_0/\mu$).

The presence of a sharply expressed layer-by-layer ground inhomogeneity at this depth can lead to substantial errors in the experimental results.

With respect to the evaluation of the accuracy in determinations by the proposed method it should be noted that the author did not carry out special investigations of this problem.

Evidently, the mean error in laboratory determinations can be: for the filtration coefficient ±(3-5%), and for active porosity and total potential ±(5-10)%.

During field determinations with use of the Nesterov infiltrometer there can be a systematic error as a result of the presence of lateral outflow on the average by 5-10%.

Now we will examine the sequence of formulation of the experiment and an example of determination of ground permeability by the proposed speedy method.

The experiment was carried out under field conditions with use of a Nesterov infiltrometer. The instrument was set up on an even and virtually horizontal soil area (sandy loam). For the purpose of elimination of water flow from the inner cylinder clay was smeared between the instrument rings and the soil surface.

In order to obtain an initial head equal to 100 mm with an area of filtration from the inner cylinder of 400 cm^2 a total of 4,000 cm^3 (4 liters) of water is poured into it. For the purpose of limiting the lateral outflow water was also poured into the outer ring; its level was equal to the water level in the inner cylinder (the water volume is dependent on the diameter of the outer cylinder of the instrument).

Figure 2 shows graphs of the experimental water applications in the Nesterov infiltrometer. The decrease in water levels during the time of the experiment, with its filtration from the inner cylinder, is characterized by the following data:

Surface head

h_i мм . . .	100	90	80	70	60	50	40	30	20	10	5
n_i	1,0	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0,05

Filtration time t, minutes

Water application I	0	3	7	12,5	19	28	37,5	48	59	69	75
Water application II	0	8,5	18	28	39	51,5	64	77	90	105	112

Now we will determine the time of decrease of surface head in the selected intervals for the first and second water applications and we will cite computations of the filtration parameters using the graphs of water applications in Fig. 2 and the nomograms in Fig. 1.

As a result of the computations we have:

$$t_1 = 28.0 \text{ min}; \qquad t_2 = 75.0 \text{ min}; \qquad t_3 = 112 \text{ min}$$

$$\frac{t_1}{t_2} = 0{,}373; \qquad \frac{t_2}{t_3} = 0{,}70; \qquad \gamma_1 = 1.45; \quad \gamma_2 = 2.70$$

$$\mu = 0{,}20; \qquad P_s = 80 \text{ мм}; \qquad K_{fil} = 0.75 \text{ mm/min}$$

Thus, using the proposed method it is possible relatively rapidly and simply to determine the principal parameters of ground permeability.

Experience in application of this method demonstrates the high stability in determining all the water absorption parameters.

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EVALUATION OF SOIL-CLIMATIC CONDITIONS APPLICABLE TO THE CULTIVATION OF WINTER WHEAT

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[Article by Candidate of Geographical Sciences I. V. Svisyuk, Weather Bureau, Rostov-on-Don, submitted for publication 30 May 1978]

Abstract: The author proposes a method for evaluating the agrometeorological conditions for the cultivation of winter wheat in the administrative regions of Rostovskaya Oblast. The evaluation takes into account both soil and agrometeorological conditions and can be used in evaluating the standards for the cultivation of winter wheat in a rayon and oblast.

[Text] During recent years an evaluation of agricultural standards has assumed great importance. However, for the time being agricultural workers are forced to do this on the basis of fragmentary data. In this study we have attempted to develop a method for a complex evaluation applicable to winter wheat, bringing together the principal factors exerting an influence on the formation of its yield. Such factors are soil fertility and the agrometeorological conditions of growth. Both soil fertility and the agrometeorological conditions in the different administrative regions of any oblast differ considerably. Taking this into account, we carried out a mean long-term soil-climatic evaluation for each administrative region in Rostovskaya Oblast.

For our computations we used two independent complex evaluations: first -- soil bonitet, which takes in an evaluation characterizing the thickness of the horizon A + B, an evaluation of the humus supply in the soil and an evaluation dependent on the mean long-term yield;

second -- evaluation of the climatic peculiarities of the region, which takes in the following indices most important for the cultivation of winter wheat: depth of wetting of the soil at the onset of renewal of the growing season of winter crops in spring; the severity of conditions for the wintering of winter crops (sum of negative mean daily temperatures in winter); an overall evaluation of the state of winter crops at the beginning of the spring growing season; the sums of active temperatures during the period from the renewal of the growing season to earing and separately from earing to golden ripeness, and finally, the precipitation sums during these same periods. The average of these two complex evaluations, that is, the evaluations of soil bonitet and the climatic characteristics of the region, also gives an evaluation which we called the soil-climatic evaluation of the conditions for the cultivation of winter wheat in the region.

Computations of the mean long-term soil-climatic evaluation were carried out in the following way. On the computation sheet (Table 1) we first enter the computed (for each administrative region) mean weighted region soil bonitet, and for each oblast -- the mean oblast soil bonitet.

As a convenience in computations the mean oblast bonitet (94%) was assigned the value 100% and then the soil bonitet for each region is calculated relative to the oblast bonitet. These values are also used as an evaluation of the region soil quality. In deriving evaluations of the climatic conditions we enter the mean long-term values for the depths of soil wetting in spring (DSW) for each region and as an average for the oblast and then the overall evaluation of the state of winter crops in spring (on the basis of data from a spring investigation), and the sum of negative mean daily temperatures for winter for each region. Then we enter the sums of active temperatures and precipitation sums for the two mean long-term periods: from renewal of the growing season to the earing of winter wheat (first period) and from earing to golden ripeness (second period). For each of the considered elements we find the mean oblast values, which are assigned the value 100%, and these are used in computing the percentage (evaluation) of each element for a specific administrative region.

The evaluations for the depth of soil wetting, the overall evaluation of the state of winter crops in spring and the precipitation sum for the two periods are assigned a "+" sign, because these elements, with their increase, improve the conditions for growth and development of winter wheat and increase the formed wheat yield. The evaluations obtained from the sum of negative mean daily temperatures during winter and the sum of active temperatures for the periods from the renewal of the growing season to earing and also from earing to golden ripeness are assigned a "-" sign because with an increase in their absolute values they worsen wintering conditions and the spring-summer development of winter wheat and in the last analysis reduce crop yield.

After carrying out the computations the evaluations of all the elements by administrative regions are algebraically summed and we obtain the sums of the evaluations for all the agrometeorological (climatic) elements. Having such sums of evaluations for all regions, we compute the mean long-term sum of climatic evaluations for the oblast. It is assigned the value 100% and it is used in computing the percentage (evaluation) for the sum of climatic elements for each region. This is the mean climatic evaluation.

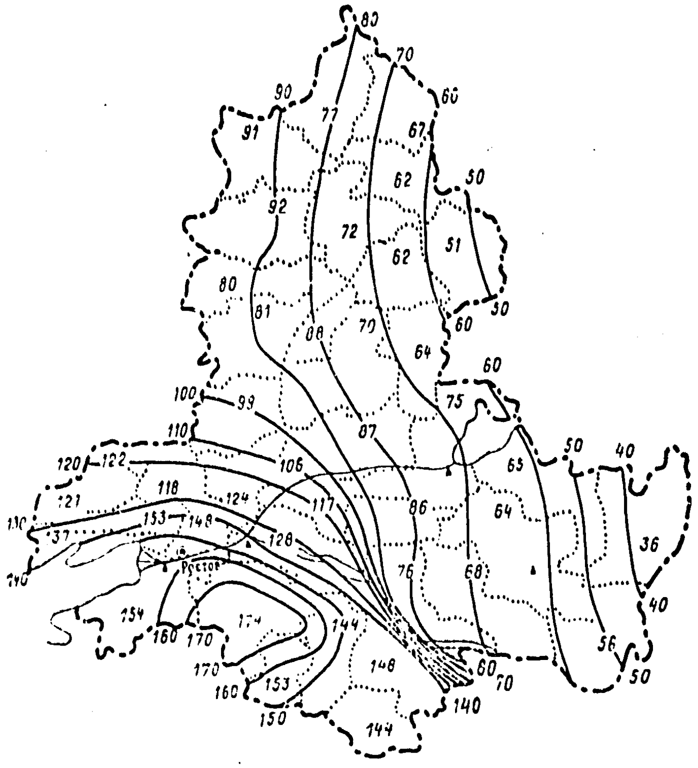

Fig. 1. Soil-climatic evaluation of conditions applicable to cultivation of winter wheat in Rostovskaya Oblast.

The two evaluations -- the mean evaluation for soil bonitet and the mean long-term climatic evaluation -- are used in computing the mean long-term soil-climatic evaluation. Its distribution by the rayons in Rostovskaya Oblast is shown on the map (Fig. 1). It increases from 40-60% in the east to 90-100% in the northwest and to 150-160% in regions of the southern zone.

In our opinion, this method can be used in evaluating the conditions for the cultivation of winter wheat in each administrative region of the oblast. It can also be used in evaluating the standards for agriculture for the cultivation of winter wheat. For this purpose, using the mean long-term agrometeorological indices, employing our methods [1, 2], for each region

Table 1

Computation of Mean Long-Term Soil-Climatic Evaluation for Winter Wheat by Administrative Regions of Rostovskaya Oblast

1	Оценка почвенных условий 3		2 Оценка климатических условий														Суммарная оценка по климатическим условиям (2) 18	Средняя почвенно-климатическая оценка $\frac{(1)+(2)}{2}$ 19
			ГПП 4		суммарная оценка состояния озимых 5		сумма отрицательных температур за зиму 6		сумма активных температур по периодам 7				сумма осадков по периодам 8					
Район	бонитет почвы, % 9	% к средней по области (1) 10	ГПП, см 11	% к средней по области 12	оценка по весеннему обследованию 13	% к средней по области 14	сумма среднесуточных температур 15	% к средней по области 10	от возобновления вегетации до колошения 16	% к средней по области 10	от колошения до восковой спелости 17	% к средней по области 10	от возобновления вегетации до колошения 16	% к средней по области 10	от колошения до восковой спелости 17	% к средней по области 10		
20 Вешенский	74	79	93	96	300	98	785	—143	750	—96	630	—104	75	106	50	98	75	67
21 Верхнедонской	75	80	93	96	300	98	744	—135	667	—85	619	—102	74	104	48	94	72	77
22 Чертковский	89	95	100	103	301	98	736	—134	838	—107	604	—99	85	110	54	106	87	91
23 Боковский	74	79	87	90	300	98	745	—135	833	—93	599	—98	66	93	46	90	45	62
24 Миллеровский	86	92	104	107	303	99	682	—121	853	—109	609	—100	93	116	56	110	93	92
25 Кашарский	84	90	90	93	305	100	669	—122	871	—102	621	—103	72	101	45	88	55	72
26 Тарасовский	82	87	95	98	305	100	630	—118	853	—100	609	—100	72	101	47	92	73	80
27 Каменский	79	84	88	91	310	101	620	—113	775	—99	606	—99	72	101	49	96	78	81
28 Красносулинский	92	98	95	98	310	101	580	—105	775	—99	606	—99	75	106	50	98	100	99
29 Белокалитвинский	90	96	86	89	305	100	617	—112	784	—100	635	—104	75	106	50	93	77	88
30 Тацинский	93	78	85	88	301	98	613	—111	731	—93	615	—101	68	96	44	86	63	70
31 Морозовский	69	73	83	86	300	98	658	—120	731	—93	595	—98	62	87	49	96	56	64
32 Милютинский	67	71	86	89	300	98	675	—123	731	—93	595	—98	62	87	49	96	56	62
33 Обливский	56	60	82	85	300	98	682	—124	894	—114	636	—105	75	106	49	96	42	51
34 Константиновский	86	92	90	93	300	98	548	—100	720	—99	613	—101	68	96	45	88	82	87
35 Усть-Донецкий	99	106	111	114	305	100	546	—99	784	—100	613	—101	70	98	48	94	106	106
36 Цимлянский	82	87	85	88	290	95	550	—100	727	—85	612	—101	58	82	43	84	63	75
37 Мартыновский	85	91	93	96	305	100	522	—95	756	—96	600	—99	64	90	44	86	82	86
38 Семикаракорский	107	125	111	114	320	104	516	—94	782	—100	613	—101	70	98	45	88	109	117

Continuation of Table 1

	Район 1	Оценка почвенных условий 3		2 Оценка климатических условий														Суммарная оценка по климатическим условиям (2) 18	Средняя почвенно-климатическая оценка $\frac{(1)+(2)}{2}$ 19
				ГПП 4		суммарная оценка состояния озимых 5		сумма отрицательных температур за зиму 6		сумма активных температур по периодам 7				сумма осадков по периодам 8					
		бонитет почвы, % 9	% к средней по области (1) 10	ГПП, см 11	% к средней по области 12	оценка по весеннему обследованию 13	% к средней по области 14	сумма среднесуточных температур 15	% к средней по области 10	от возобновления вегетации до колошения 16	% к средней по области 10	от колошения до восковой спелости 17	% к средней по области 10	от возобновления вегетации до колошения 16	% к средней по области 10	от колошения до восковой спелости 17	% к средней по области 10		
39	Багаевский	120	127	123	127	330	108	434	—79	890	—114	595	—98	61	86	50	98	128	128
40	Аксайский	120	127	115	119	310	101	460	—84	779	—97	600	—99	79	111	61	120	169	148
41	Октябрьский	112	119	111	114	310	101	543	—90	747	—95	592	—97	76	107	50	98	129	124
42	Мясниковский	121	128	115	119	520	104	430	—78	779	—99	600	—99	79	111	61	120	178	153
43	Неклиновский	122	130	112	115	320	104	380	—69	759	—97	595	—98	63	89	51	100	144	137
44	Матвеево-Курганский	113	121	107	110	300	98	418	—81	759	—97	595	—98	63	89	51	100	121	121
45	Куйбышевский	113	121	107	110	300	98	448	—81	759	—97	595	—97	63	89	52	100	122	122
46	Родион.-Несветайский	108	115	109	112	300	98	500	—91	751	—96	593	—97	69	97	50	98	121	118
47	Азовский	130	138	117	121	320	104	376	—68	802	—102	626	—103	75	106	57	112	170	154
48	Зерноградский	142	152	123	127	330	108	429	—78	751	—96	594	—98	78	110	63	124	197	174
49	Егорлыкский	137	146	115	119	325	106	479	—80	761	—97	592	—97	69	97	57	112	160	153
50	Целинский	134	143	105	108	320	104	451	—82	761	—97	592	—97	69	97	57	112	145	144
51	Сальский	119	127	102	105	317	101	425	77	782	—100	609	—100	81	114	63	124	170	148
52	Песчанокопский	116	123	100	103	310	101	420	—76	782	—100	609	—100	81	114	63	124	166	144
53	Пролетарский	84	89	91	94	300	98	530	—86	860	—112	689	—113	64	97	45	90	62	76
54	Орловский	80	86	82	85	300	98	531	—86	860	—112	680	—112	76	98	48	94	50	68
55	Зимовниковский	67	71	76	78	300	98	531	—96	870	—112	615	—101	65	92	50	98	57	64
56	Дубовский	66	70	75	77	290	95	570	—102	840	—108	603	—99	66	93	49	95	60	65
57	Ремонтненский	55	59	68	70	290	95	539	—98	759	—97	609	—100	57	80	42	82	32	56
58	Заветинский	39	42	61	63	280	92	609	—111	850	—110	630	—101	60	84	41	86	30	36
59	По области	94	100	97	100	306	100	550	—100	783	—100	608	—100	71	100	51	100	—	—

Key to Table 1

1. Region
2. Evaluation of climatic conditions
3. Evaluation of soil conditions
4. Depth of soil wetting
5. Overall evaluation of state of winter crops
6. Sum of negative temperatures during winter
7. Sum of active temperatures by periods
8. Sum of precipitation by periods
9. Soil bonitet
10. % of mean for oblast
11. Depth of soil wetting, cm
12. % of mean for oblast
13. Evaluation according to spring investigation
14. % of mean for oblast
15. Sum of mean daily temperatures
16. From renewal of growing season to earing
17. From earing to golden ripeness
18. Overall evaluation based on climatic conditions
19. Mean soil-climatic evaluation
20. Veshenskiy
21. Verkhnedonskiy
22. Chertkovskiy
23. Bokovskiy
24. Millerovskiy
25. Kasharskiy
26. Tarasovskiy
27. Kamenskiy
28. Krasnosulinskiy
29. Belokalitvinskiy
30. Tatsinskiy
31. Morozovskiy
32. Milyutinskiy
33. Oblivskiy
34. Konstantinovskiy
35. Ust'-Donetskiy
36. Tsimlyanskiy
37. Martynovskiy
38. Semikarakorskiy
39. Bagayevskiy
40. Aksayskiy
41. Oktyabr'skiy
42. Myasnikovskiy
43. Neklinovskiy
44. Matveyevo-Kurganskiy
45. Kuybyshevskiy
46. Rodion.-Nesvetayskiy
47. Azovskiy
48. Zernogradskiy
49. Yegorlykskiy
50. Tselinskiy
51. Sal'skiy
52. Peschanokopskiy
53. Proletarskiy
54. Orlovskiy
55. Zimovnikovskiy
56. Dubovskiy
57. Remontnenskiy
58. Zavetinskiy
59. For oblast

we compute the mean yield of winter wheat. If the latter is higher than the average computed value for the oblast, these cultivation "standards" for winter wheat in the region are higher than the mean oblast level. However, if the actual yield is lower than the computed value, these "standards" for the cultivation of winter wheat in the region are lower than the average for the oblast.

The soil-climatic evaluation can be used in evaluating the cultivation "standards" for winter wheat in a specific year.

Having the values of the parameters entering into the agrometeorological evaluation, it is possible to evaluate the cultivation "standards" for winter wheat in any rayon in the oblast under the conditions prevailing in a specific year. For this purpose the computations of the rayon yields are made using data for a specific year and are compared with the actual yield for this same year. In the evaluation of agricultural "standards" the mean long-term periods from the renewal of the growing season to earing and from earing to golden ripeness always remain constant -- mean long-term values for each administrative region.

The proposed method makes it possible to evaluate complexly the conditions for the cultivation of winter wheat in each administrative region of the oblast both for the long-term period and for a specific year and to determine the level of agricultural "standards" relative to the mean oblast agricultural "standards."

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FORMING OF ARCHIVES OF OBSERVATIONAL DATA FOR THE FIRST GLOBAL EXPERIMENT GARP

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[Article by O. A. Aldukhov, All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center, submitted for publication 17 March 1978]

Abstract: The problem of the forming of archives at the II-b level for the First Global Experiment GARP, obtained from different territorial and specialized subcenters, is described in terms of the theory of sets. The article presents a method for realizing the program of combining FGGE archives in assembler language with application of structural programming principles.

[Text] During 1978-1979 plans call for carrying out the First Global Experiment (FGGE) under the GARP program. One of the objectives of the experiment is the creation of the most complete archives of data from ordinary and special observation systems, which can serve as a basis for the testing of presently available and yet-to-be-developed numerical forecasting models [7].

In accordance with the international plan for FGGE data control [1], the Soviet Union in this experiment is to carry out the function of a number of centers for the collection of data at the so-called II-b level, including both data received at a real time scale and delayed data, including the function of a data center for the collection and integration of synoptic and aerological data for the entire earth, received from the six territorial and special subcenters (United States, Great Britain, Japan, West Germany, USSR).

In order to carry out these functions it is necessary to create a set of programs for integrating the archives obtained from the different subcenters, their checking and reforming in accordance with the requirements of the general FGGE format [7].

The exchange of FGGE data among centers will be accomplished using 10-day accumulations of data. We will denote by A^j ($j = 1,\dots,6$) the accumulation of data for the particular 10-day period, obtained from the j-th subcenter. For $\forall\, j = 1,\dots,6$ the elements of the A^j data accumulation are the sets F_i^j ($i = 1,\dots, m_j \leqslant 600$), each of which is entered on the magnetic tape in the form of an individual file, and

$$A^j = \sum_{i=1}^{m_j} F_i^j. \tag{1}$$

For $\forall\, j$, i the set F_i^j, in turn, represents an accumulation of data whose elements are communications on the observations R_{ik}^j ($k = 1,\dots,n_{ji}$)

$$F_i^j = f_i^j + \sum_{k=1}^{n_{ji}} R_{ik}^j. \tag{2}$$

The set f_i^j is the heading of the file F_i^j. The file heading indicates:
a) t_i^j is the date and the main synoptic observation time (0000, 0600, 1200, 1800 GMT), entered in the particular file;
b) d_i^j is the number of the model, using which data are entered in the file (at the present time eight models have been developed, one each for aerological, aircraft, meteorological and oceanographic observations, three models for satellite observations and one model for observations of drifting buoys:
c) the vector $\vec{S}_i^j = (S_{i\,1}^j,\dots,S_i^j)$ ($\ell \leqslant 7$ and $S_{i,r} < S_{i,\,r+1}$ for $\forall\, r = 1\dots \ell - 1$), which indicates the types of data present in this file. All the types of data planned for exchange during the FGGE period are given in Table 1. As a rule, one type of data is entered into one file, but in a number of cases data of similar types, such as oceanographic, can be combined in one file.

For $\forall j = 1,\dots,6$ the sets (files) F_i^j ($i = 1,\dots,m_j$) are orderly arranged on a magnetic tape at three levels:
1) with respect to increase in t_i^j;
2) with respect to increase in d_i^j for equal t_i^j;
3) with respect to increase in S_i^j for equal t_i^j and equal d_i^j.

One mass of A^j data can be entered into several volumes of magnetic tape if one volume is inadequate for its entry. In this case each volume of magnetic tapes is formed in such a way as if that part of the data accumulation which is entered in it does in fact constitute the entire data accumulation from the particular subcenter. The only requirement is that files of data having an identical date and main synoptic observation time not be entered into different volumes of magnetic tapes.

For $\forall j$, i, k the communication R_{ik}^j consists of the heading of the communication r_{ik}^j and the meaningful part of the communication H_{ik}^j. The heading of the communication contains the following characteristics: a_{ik}^j is the

Table 1

Types of FGGE Data

Indices in FGGE format	Types of Observations
11, 12	Radiosonde, rawin, pilot balloon
13	Wind, from ships outfitted with radars (TWOS, RADAR)
14	Wind, from ships outfitted with NAVAID system
15	From instruments dropped from aircraft
16	From constant-level balloons
21, 22, 23, 24	Aircraft (ASDAR, AIREP, CODAR, AIDS)
31, 32	Visual and automatic from ground stations (SYNOP)
33, 34	Sea meteorological from fixed and commercial ships (SHIP)
35	Sea meteorological from outfitted buoys
41	Satellite sounding
51	Satellite observations of cloudless sky
61	Satellite wind observations
62	Satellite observations of cloud cover
63	Satellite measurements of sea surface temperature
71, 72, 73, 74, 75, 76, 77	Oceanographic
81	Drifting buoys

type of data in the communication, α^j_{ik} is the latitude, β^j_{ik} is the longitude of the place of observation, b^j_{ik} is the precise time of observation, N^j_{ik} is the number of entries in the communication.

The main part contains the values of the meteorological elements; the values for pressure, temperature, humidity, wind direction and velocity must be accompanied by quality control criteria.

The sequence of placement of communications R^j_{ik} in each file F^j_i is determined:

1) by the increase in 10° latitude intervals from -90 to +90°;
2) by the increase in 10° longitude intervals from 0 to 360° for equal latitude intervals;
3) by the increase in b^j_{ik} -- the observation time for equal 10° latitude intervals and equal longitude intervals;
4) by the increase in the type of data for equal preceding criteria.

With a coincidence of the headings

$$\left(r^{j_1}_{i_1 k_1} = r^{j_2}_{i_2 k_2} \right)$$

two communications are considered duplicates

$$\left(R^{j_1}_{i_1 k_1} = R^{j_2}_{i_2 k_2} \right).$$

The presence of duplicated communications in the masses of data arriving from the FGGE territorial subcenters is determined by the very plan for the control of FGGE data, since by agreement, each of the subcenters must collect shipboard meteorological, aerological and aircraft observations arriving through the GST channels from the entire earth. Due to the different reliability of reception, different for different centers, and also due to the different procedures for quality control in the territorial subcenters, the meaningful parts of the communication can differ, despite the coincidence of headings.

We will denote that $F^{j_1}_{i_1} \cap F^{j_2}_{i_2} = 0,$

if for $\forall\, l = 1, \ldots, n_{j_1 i_1} \forall \quad m = 1, \ldots, n_{j_2 i_2}$

there is satisfaction of the condition. $R^{j_1}_{i_1 l} \neq R^{j_2}_{i_2 m}.$

Otherwise $F^{j_1}_{i_1} \cap F^{j_2}_{i_2} \neq 0.$

Similarly $A^{j_1} \cap A^{j_2} = 0,$ if for $\forall \quad p = 1, \cdots, m_{j_1} \quad \forall \quad q = \ldots, m_{j_2}$

there is satisfaction of the condition $F^{j_1}_p \cap F^{j_2}_q = 0,$

Otherwise $A^{j_1} \cap A^{j_2} \neq 0.$

Under the FGGE conditions, for $\forall j = 1,\ldots,6$ the accumulation of data A^j cannot contain duplicated communications, that is, for $\forall i_1, i_2 = 1,\ldots, m_j$ $(i_1 = i_2)$ there must be satisfaction of the condition

$$F^j_{i_1} \cap F^j_{i_2} = 0.$$

But, possibly, as was mentioned above, $\exists\, j_1, j_2 = 1,\ldots, 6$ $(j_1 \neq j_2)$ such that

$$A^{j_1} \cap A^{j_2} \neq 0.$$

The task of the Data Center for Ground Systems is the creation of a full mass of data for each 10-day period in the experiment on the basis of six masses of data sent by the subcenters without duplicated communications.

We will denote by A the mass of all data for a given 10-day period, which mutually unambiguously correspond to the observations carried out. Then

$$A = \bigcup_{j=1}^{6} A^j = \sum_{j=1}^{6} A^j - \sum_{n<p} (A^n \cap A^p). \tag{3}$$

Due to the considerable complication of the problem with an increase in the number of data masses to be combined, it was decided to combine the data accumulations in pairs. Despite the almost double increase in the need for computer time with such a sequence of work, the paired combination method has the following indisputable advantages:

-- the program for combining the two data masses is considerably simpler than the program for simultaneous combining of the six masses of data, it is more flexible and it is possible to introduce local changes;
-- it is known that the time of receipt of data masses from "subordinate" subcenters will not be identical and the program for paired combining will make it possible to begin this "combining" process prior to the receipt of all data masses;
-- the paired combining program requires the availability of three input-output devices, whereas the program for combining six data masses would require seven such devices.

Thus, we will examine the problem of combining two masses A^1 and A^2. In accordance with (3) we have

$$A = A^1 + A^2 - A^1 \cap A^2 = \sum_p F^1_p + \sum_q F^2_q - \sum_p \sum_q (F^1_p \cap F^2_q). \tag{4}$$

Since the combined data mass must satisfy the FGGE format, the sequence of arrangement of files in the output volume of magnetic tapes must also satisfy the above-mentioned "orderliness" levels.

The FGGE format for data registry is described in greater detail and more formally in [1, 7].

The task of combining FGGE data masses was carried out using a YeS-1022 electronic computer. The program was prepared in assembler language. In developing the program use was made of the principles of structural programming in combination with the method of "top-down" programming [4-6, 9].

Structural programming is a programming method when the program is prepared from structural elements of only the three following types (base structures):
-- sequential structure or enumeration;
-- distribution structure or choice;
-- repetitive structure or repetition.

The most important and distinguishing peculiarity of the enumerated structures is the presence of a single control input and output point in them. This rule must be satisfied for any combination of structures, that is, for the entire program as a whole. In the structured program the relationships between parts of the program are localized and ordered; this assumes primary importance when debugging the program and introducing changes [2, 3].

The essence of the "top-down" programming method can be briefly summarized as follows. The first step is preparing the programming segment (the basis of the future program) from symbolic names and propositions in the selected programming language with a length of not more than 40-50 lines. This is achieved by discriminating the most important (from the functional point of view) sectors of the future program and substituting into the text of the first interval the symbolic names of these sectors. In the second step the first step method is applied to each of the defined functionally important sectors, that is, some plan of a sector of symbolic names and commands, etc. is applied to each of the defined functionally important sectors.

As a result, we obtain a hierarchical system of quite short segments and the upper-level segments are referenced to the lower-level segments. The segments of the lowest level are already prepared completely in programming language.

The combining of the "top-down" programming method with structural programming means that each of the formed segments must satisfy the requirements of structural programming, that is, the satisfaction of each segment begins from the top (from the first operator of the segment) and ends at the bottom (with the last operator) and there is no means for entering it or emerging from it by any other method.

The assembler language selected for developing the program for combining the FGGE data masses has a well-developed macrolanguage which is most suitable for realizing the hierarchical structure of the programs with the "top-down" programming method.

However, it must be noted that the development of special macrodeterminations is necessary for realizing basic structures in assembler language.

Such a macrodetermination was presented in [8], but it is inapplicable in the processing system of the YeS electronic computer, and the development of similar macrodeterminations by oneself is quite time-consuming. Therefore, the basic structures were realized with use of commands of conditional and unconditional control transmissions. Although this is a violation of structural programming in its pure form, the very fact of construction of the program from three basic structures is very useful, since it leads to a considerable ordering of the logic of the program and facilitates understanding of the program.

The result of the first step in the program for combining two data masses is recorded on magnetic tape in the FGGE format with the exclusion of duplicated communications and registry of the combined mass into magnetic tape volumes in the FGGE format, that is, the actual program itself has the following form:

```
 1) SECOND    BEGIN
 2)           CLEARANG
 3) DOWHILE   EQU *
 4)           FOREOV
 5)           ANALISIS SIGN
 6)           IF SIGN=Ø THEN MERGE
 7)           IF SIGN=1 THEN FILE ONE
 8)           IF SIGN=2 THEN FILE TWO
 9)           ENDWHILE DOWHILE
10)           ENDWORK SECOND
11) EOVOUT    UNLOAD OUT
12)           SETNEW OUT
13)           SETINPUT
14)           B        DOWHILE
```

Propositions 1-10 correspond to segments which determine:
1) standard heading ("cap") of any program in assembler language;
2) initial forming of the volumes of magnetic tapes, printing of the heading of the processing form and obtaining the first record-headings $f^1_{i_1}$ and $f^2_{i_2}$ of the files $F^1_{i_1}$ and $F^2_{i_2}$ ($i_1 = i_2 = 1$);
3) commencement of cycle of combining of data masses;
4) storage of the numbers of the input and output files from which the new six-hour data blocks begin;
5) output of the processing forms and analysis of the headings $f^1_{i_1}$ and $f^2_{i_2}$ of the two input files $F^1_{i_1}$ and $F^2_{i_2}$. The parameters $t^1_{i_1}$ and $t^2_{i_2}$, $d^1_{i_1}$ and $d^2_{i_2}$, $\vec{S}^1_{i_1}$ and $\vec{S}^2_{i_2}$ are compared; a coincidence of all three parameters means that the two input files must be combined into one file;
6) the combining (in the case of coincidence of the parameters t, d and $\vec{S}$) of the two files $F^1_{i_1}$ and $F^2_{i_2}$ into a single file with the exclusion of duplicated communications;
7)-8) registry of the file $F^1_{i_1}$ or $F^2_{i_2}$ on the output tape;

9)-10) analysis at the end of the cycle of combining of the data mass and termination of processing -- final forming of the magnetic tape output volume.

Propositions 11-13 are for processing a situation when for registry of a combined data mass it is not sufficient to have one magnetic tape volume alone and it is necessary to employ an additional volume for the output data mass.

All the segments whose names were used in the main segment of the program, cited above, other than the segment designated MERGE, have 1-2 more levels in depth and are quite simple. The MERGE segment, which is for the combining of the two data files into one, is more complex and its depth is measured with six levels. We will cite an example of the MERGE segment:

```
 1)            MACRO
 2)            MERGE
 3)            HEADER
 4) DOWHILER   EQU *
 5)            SOLUTION PRIS
 6)            IF PRIS=0 THEN QUALICON
 7)            IF PRIS=1 THEN REPORT ONE
 8)            IF PRIS=2 THEN REPORT TWO
 9)            FINISH DOWHILER
10)            OFORMIT
11)            NEXTFILE
12)            MEND
```

Here proposition 1 is the heading of the macrodetermination; proposition 2 -- a prototype of a macrocommand -- determines the symbolic name of the particular segment.

Proposition 3 corresponds to a segment which creates the heading of the file obtained with the combining of two input files and introduces the headings $r^1_{i_1 k_1}$ and $r^2_{i_2 k_2}$ of the first ($k_1 = k_2 = 1$) communications $R^1_{i_1 k_1}$ and $R^2_{i_2 k_2}$. Proposition 4 serves as the commencement of the cycle of combining of two files into one. After one passage of the part of the program corresponding to this cycle (propositions 4-9) there is a changeover to the next communication in one of the combined files or in both.

Proposition 5 corresponds to the segment for carrying out a comparative analysis of the headings $r^1_{i_1 k_1}$ and $r^2_{i_2 k_2}$ of the communications $R^1_{i_1 k_1}$ and $R^2_{i_2 k_2}$. An analysis is made of the parameters a^j_{ik}, α^j_{ik}, β^j_{ik}, b^j_{ik}, present in the heading of each communication. Depending on which of the two communications $R^1_{i_1 k_1}$ and $R^2_{i_2 k_2}$ is preferable to be registered first, the PRIS criterion is assigned the value 1 or 2. If the above-mentioned criteria are inadequate for a solution (this means that the communications are duplicated), the PRIS criterion is assigned the value 0.

Table 2

Weights for Reliability Criteria

Value of reliability criterion	Description	Weight
0	No checking	3
1	Correct value	5
2	Questionable value	2
3	Erroneous value	0
4	Value changed in checking process	1

Proposition 6 corresponds to the segment which with a value of the PRIS criterion equal to 0 a comparative analysis is made of the communications $R^1_{i_1 k_1}$ and $R^2_{i_2 k_2}$. The analysis is made on the basis of the quality control criteria for the principal elements in the communication supplied by the territorial subcenters. Each quality control criterion is assigned some weight (Table 2).

Using a recoding command (TR) each control criterion encountered in a particular communication is converted into the corresponding weight and the total weight of the particular communication P^j_{ik} is determined (segment QUALICON). In this same segment there is a comparison of the total weights $P^1_{i_1 k_1}$ and $P^2_{i_2 k_2}$ of the communications $R^1_{i_1 k_1}$ and $R^2_{i_2 k_2}$.

If $P^1_{i_1 k_1} < P^2_{i_2 k_2}$, then the PRIS criterion is assigned the value 2 and there is a reading of the heading $r^1_{i_1 k_1}$ of the next ($k_1 = k_1 + 1$) communication $R^1_{i_1 k_1}$ (that is, the worst of the duplicated communications is omitted). However, if $P^1_{i_1 k_1} \geq P^2_{i_2 k_2}$, the PRIS criterion is assigned the value 1 and we read the heading $r^2_{i_2 k_2}$ of the next ($k_2 = k_2 + 1$) communication $R^2_{i_2 k_2}$.

Proposition 7 corresponds to a segment which (if the value of the PRIS criterion is equal to 1) accomplishes registry of the communication $R^1_{i_1 k_1}$ into the combined file and then the input of the heading $r^1_{i_1 k_1}$ of the next ($k_1 = k_1 + 1$)-th communication $R_{i_1 k_1}$.

Proposition 8 corresponds to a segment which (if the PRIS criterion value is equal to 2) performs the same operations as the segment in proposition 7, but with respect to the communication $R^2_{i_2 k_2}$.

Propositions 9-11 correspond to the segments which perform an analysis at the end of the cycle of combining of files, finalize the combined file in accordance with the requirements of the FGGE format, and accomplish the input of the headings of the next files in both input data masses. Proposition 12 is the end of the macrodetermination, determining the segment.

Thus, although the use of assembler language in this program did not make it possible to create a fully structured program, the application of the structured programming principle in organizing the program was extremely useful in the debugging stage in the program and the introduction of changes (caused primarily by changes in the FGGE format) and made it possible to reduce the time required for debugging of the program and making preparations for the FGGE test period.

The program was used for combining the masses of test data received from the United States, Sweden, Great Britain and Japan and prepared in Soviet FGGE centers.

The time for operation of the program with the merging of two magnetic tapes with 10-day data masses is about 30 minutes.

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AUTOMATION OF COLLECTION, PROCESSING AND ANALYSIS OF OCEANOGRAPHIC INFORMATION ON THE BASIS OF SMALL ELECTRONIC COMPUTERS

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[Article by V. A. Volkov, Yu. A. Grodetskiy and V. V. Lukin, Arctic and Antarctic Scientific Research Institute, submitted for publication 6 January 1978]

Abstract: The authors examine the basic principles for the routine processing, systematizing and analysis of information on the basis of small electronic computers under expeditionary conditions corresponding to the present-day nature of oceanographic research and the modern requirements on data processing. The article gives the procedures for use of small programmable electronic keyboard computers (PEKC) as the basis for computation centers for expeditions not having large electronic computers. There is emphasis on the desirability of using PEKC for automating the collection and primary processing of data on scientific research vessels outfitted with large computers. The article also gives an analysis of experience in operation of a computer complex on the basis of the "Iskra-125" PEKC on the high-latitude air expeditions "Sever" of the Arctic and Antarctic Scientific Research Institute of the Main Administration of the Hydrometeorological Service.

[Text] Oceanographic investigations long ago ceased to have a purely geographical, descriptive character. Now purposeful investigations are being made of the laws of physical processes transpiring in the waters of the world ocean. Recently the investigations assumed exceptionally greater scales, which is attributable to the ever-increasing importance of the ocean and its resources for man's economic activity.

Oceanographic expeditions are very diversified in their objectives, the personnel employed and the equipment used. In addition to purely scientific objectives, problems of a practical nature are being formulated and solved, such as the collection of hydrometeorological information for prognostic purposes, planning and research work and the quest for fish. Major experiments at sea have now become commonplace; they cover relatively large but localized ocean areas (these expeditions: Atlantic Hydrophysical Polygon-70, TROPEKS-74, POLEKS-Sever-76, POLIMODE and others). Such investigations are no longer being carried out by individual scientific research ships, but by detachments of ships, frequently belonging to different departments or even different countries.

Oceanologists are turning more and more to investigations of fine hydrological structures, small-scale interaction between the ocean and the atmosphere, which requires the development and use of self-contained low-inertia measuring apparatus giving a considerably greater flow of information than ordinary instruments.

Thus, the volume of information obtained on a modern oceanographic expedition is undeviatingly increasing and researchers are being faced with the problem of its processing, the solution of which is impossible without the use of computers. The processing of observational data must be carried out routinely, which is dictated, first of all, by the necessity of transmission of data for the forecasting services; second, by the necessity in a number of cases to introduce corrections into the research program as results are obtained, that is, carry out so-called "controllable experiments," which corresponds to a purposeful nature of present-day research in the ocean. At the same time, routine processing makes possible a constant monitoring of the quality of observational data.

The processing of the information collected on an expedition can be divided into three types: primary processing, systematization of observational data, analysis.

The primary processing of observational data can be reduced essentially to computations and introduction into the instrument readings of all possible corrections -- with the use of traditional (nonautomatic) measurement instruments and methods which at the output yield an electric signal -- and also a conversion of coded data into the generally employed form. In the second case the problem also arises of compression of information at a real time scale.

Until now the systematizing of data has involved the compilation of different specialized and composite tables. Now, when virtually all types of oceanographic information are being subjected to analysis on electronic computers, the collected information must be incorporated on a computer carrier (punched tape, magnetic tape) and it would be natural, parallel with forming these tables, to create archives of hydrometeorological data on a carrier suitable for input into an electronic computer. The systematization also includes the process of sorting of data and preparation of all possible intermediate and sample files.

The final form of data processing is analysis. The specific forms of analysis are determined by the researcher himself in accordance with the purposes of the experiment. This class of problems is the most diversified.

Thus, the systematizing of material is the logical ending of primary processing and is the basis for analytical computations. It is necessary to be guided by this thesis in formulating principles for the mathematical support of systems for the automated processing of observational data using electron computers.

The Hydrometeorological Service system has already acquired definite experience in the use of electronic computers under expeditionary conditions on large scientific research vessels on which intermediate-class electronic computers of the "Minsk-32," YeS-1022 and other types have been installed. The application of this experience to oceanographic expeditions based on small and intermediate ships (and they are the great majority -- several hundreds), drifting stations, etc. is not feasible and frequently it is simply impossible due to unwieldiness, expense and complexity in operation of the mentioned machines.

As is well known, there are also electronic computers of a smaller size. The first computers, later given the name "minicomputers," were the PDP-5 and PDP-8 computers produced by the American DEC company, appearing in 1963 and 1965 respectively. The idea of a minicomputer is very simple: in these instruments there is a programmed performance of all elementary transformations of data in an arithmetical-logic device, in the last analysis performing some operation. Such an approach made possible a marked reduction in the size and cost of the electronic computers (although at the expense of some qualities -- speed, volume of the directly addressable memory). In a whole series of cases it has proven justifiable to place such an electronic computer at the disposal of an individual laboratory or scientist. Minicomputers have come into extensive use in scientific experiments and in the control of production. The best known modern computers of this class in the USSR are the M-6000 and M-400, and abroad -- the DEC family of computers PDP-11.

Further improvement in the technology of components and new ideas in the architectural designing of electronic computers have led to the appearance of minicomputers, with respect to their size being virtually personal table-top machines for the researcher and having considerable functional capability.

Among these computers we can mention those which can arbitrarily be called program-controllable electronic keyboard computers (PEKC). Their characteristic peculiarities are the form of storage of the programs in the operational memory unit (OMU).

As is well known, the usual sequence for carrying out a program involves its introduction into an electronic computer in some initial high-level language, such as FORTRAN, its translation into an objective code --

the program in a computer code and work with the resulting program. Such a method makes it possible to obtain an effective program, but requires the availability of a large-volume memory unit for holding the program-translator. Additional mathematical support is required for debugging the program in computer codes.

A different principle is used in PEKC. In the PEKC OMU the program is stored in the initial language and the program is carried out by means of successive interpretation of the operators. The program for the interpreter is stored together with the other controlling programs in the permanent memory unit (PMU).

As a result, the PEKC is very simple and convenient to use. It is ready for operation immediately upon being turned on and does not require initial warmup. The programming for it is not complex since its input language is a high-level language. The debugging of the programs is very simple because the PEKC is provided with a display on which it is possible to indicate the program, places where there are malfunctions or stoppages, and the editing is accomplished directly from the computer keyboard by checking the text of the program on the display screen. With a PEKC provision is usually made for the attachment of a large array of external devices. In addition, the PEKC can perform the function of automated collection of information by connecting measuring instruments to it. Such an approach reflects the modern trends in the construction of measurement complexes as programming-instrument complexes.

Among the foreign PEKC it is possible to mention, for example, the Wang-2200 and the very high-capacity IBM-5100. In the Soviet Union the "Iskra-125" PEKC is being produced, the "Iskra-1256" is being made ready for production and the four-program "Iskra-126" has been developed.

It is easy to see that this modification of the minicomputer is the most successful and universal means for automating the processing of observational data under expeditionary conditions. Precisely PEKC, having a considerable computer capacity and making it possible to create complexes with a great number of external devices, have, despite a small size, a quite high degree of operability and a maximum simplicity in servicing; the programming system is simple and graphic.

On the basis of the analysis which has been made of the problems facing oceanographic detachments and the experience now available in the operation of PEKC, it is possible to determine precisely the complex of apparatus for an expeditionary computation center and the characteristics of individual apparatuses.

In addition to the PEKC, the complex must include:
-- an alphabetical-digital input-output printer with a wide carriage;
-- 1-2 memory devices with direct access -- storage on magnetic disks;

-- 2-3 memory devices with consecutive access -- cassette storage units on magnetic tape (KNML);
-- curve plotter;
-- punch tape equipment -- puncher and photoinput;
-- matching devices with research instrumentation.

The printout unit is intended both for dialogue control and monitoring of problems and also for the input-output of the computation results. The length of a line for the printout unit must not be less than 65-70 symbols in order that there be a possibility of printout of standard oceanographic documents, such as the TGM-3M table (by parts), KGM-6 and other tables. At the present time the most reliable device of such a type, despite the fact that it is outmoded, is the teletype.

The presence in the apparatus of storage units with direct access is necessary for the storage of programs and reference data, such as instrument certificates. The use of such storage units removes the restrictions imposed by the small volume of the PEKC OMU. The most suitable with respect to size, cost and speed of exchange of information are elements of the type of storage units on flexible magnetic tapes.

Magnetic tape storage elements are intended for the organization and storage of data archives. Among the tape elements, cassette storage elements are the most compact and reliable and the most suitable for expeditionary conditions. The mentioned number of units (2-3) is necessary for the sorting of information, the preparation of intermediate and sample files.

The purpose of the curve plotter is obvious -- representation of the results of individual observations or computations in graphic form.

Punch tape devices must be reserve equipment for the input and output of information and also are used for the input of data prepared, for example, in such a widely used apparatus as the teletype.

In order to control the mentioned complex of apparatuses effectively and carry out computations, the PEKC must have an OMU volume of about 2-8 kb and a speed of about 10^3 operations per second. It is desirable that there be an "interruption" system and a channel for direct access to the memory for speeding up its loading. The operation of the PEKC with its external devices must be supplied with input language microprogramming operators.

At the present time Soviet-produced PEKC do not meet all the mentioned requirements simultaneously, but the "Iskra-1256" PEKC, whose production is beginning in 1978, already makes it possible to create an expeditionary computer complex in full volume. The brief specifications of this computer are as follows: volume of OMU -- 4 kb; input language -- BEYSIK (Basic); interruption -- present; display -- television (8 lines with 32 symbols each); built-in KNML -- present; direct access channel -- present; dimensions -- 480 x 520 x 400 mm; mass -- 39 kg.

The effectiveness of the computation systems is determined not only by the technical specifications of the apparatus, but also by the programming support.

The architecture of programming support, that is, the logical tie-in, interaction and some standardized formulation of programs, must reflect its end purpose. Among the architectural peculiarities of the set of oceanographic programs we must include:
-- tie-in of the programs to the archives,
-- nondependence of the programs for the processing of primary information on the form of its input and the type of the carrier,
-- nondependence of the data processing programs on the output programs,
-- monitoring of the implementation of tasks in a dialogue regime through the dispatcher's panel.

The first point is the most important because the purpose of all oceanographic expeditions is the collection of information on some region and an archives of the results of observations stored on any technical carrier is the object and essence of virtually all programs. The presence of specialized detachments on any expedition and the singularity of determination methods results in a nonuniformity of the receipt of the results for individual elements at the computation center and therefore the optimization of organization of archives for facilitating access to individual elements of the formed files and the availability of sorting programs are a mandatory condition for the effectiveness of all programming support.

The requirement for a nondependence of the processing programs on input-output programs is making it possible to limit the number of modifications of one and the same programs and is increasing their quality at the structural level.

The use of a dialogue regime for monitoring and controlling tasks will make it possible to avoid excess manipulations with the PEKC keyboards and makes the control process simple and graphic. This is very important because under expeditionary conditions at times it is necessary to use specialists who do not have special training as operators.

At the present time, specialists at the Arctic and Antarctic Institute have already accumulated definite positive experience in the automation of expeditionary oceanographic work using PEKC. Such work has been carried out at the institute since 1975, when a computation center for the processing of observational data on the basis of two "Elektronika-S50" minicomputers functioned on the high-latitude aerial expedition "Sever-27." During subsequent years work on automation received further development. Computation complexes were created on the basis of the more powerful and modern model of the "Iskra-125" PEKC.

The inclusion in the standard outfit of the "Iskra-1251" of an additional "magazine-type" unit for storage on magnetic tape, a teletype, a two-coordinate curve plotter (LKD-4) and also FS-1501, PL-80 punched-tape input and output devices, although it was necessary to develop devices for a link-up with the PEKC itself, to a considerable degree there was a broadening of the capabilities of the computer complex.

For this complex the specialists at the computation center and in the oceanology division of the Arctic and Antarctic Scientific Research Institute have created a set of purposeful and systems programs. The purposeful programs cover the primary processing of all standard types of deep-water hydrological and hydrochemical observations with the simultaneous plotting of information on a technical carrier (magnetic tape, punched tape) and with a printout, by means of teletype, on specially developed report forms close to those generally adopted (KGM-6, KGM-9, etc.); systematization, output of systematized material in the form of "hard copies" to the teletype (TGM-3M table) and also some forms of analysis: T-S classification of water masses, computations of their heat content, calculation of circulation of waters by the dynamic method, calculation of vertical stability of waters and elements of autumn-winter convection, calculations of the speed of sound, etc.

The availability of means for clearing the OMU of the PEKC and the possibility of segment-by-segment loading of the programs from the external storage units (KNML [storage on magnetic tape], photoinput) made it possible to formulate programs considerably exceeding the volume of the PEKC OMU. Thus, the program for computations and printout of the TGM-3M table has a length of 7,000 elements with the OMU volume in the PEKC having only 876 elements.

The need for systemic programs arose due to the use of nonstandard external devices not ensured with microprogramming input language operators, and also for convenience in checking and sorting the information recorded on the magnetic tape.

The monitoring of the programs is accomplished in a dialogue regime by means of teletype. Provision is made for checking the correctness of data input. Operation of the computer complex demonstrated its high effectiveness and reliability. The work productivity in processing of observational data increased by three or four times.

The specifics of operation of the high-latitude aerial expedition "Sever," carrying out an oceanographic survey of the Arctic Ocean, was such that the site of basing of the expeditionary computation center (ECC) frequently changes. This results in a repeated repacking of equipment and prolonged aerial transport. For example, during two months of work in the spring of 1977 the ECC operated at five different Arctic points, including the drifting station "Severnyy Polyus-22," covering a path in the air of about 20,000 km.

The positive results of operation of the ECC on the "Sever" expeditions were obtained under conditions which evidently are the most severe of all those which can be encountered on any oceanographic expeditions. This also confirms the point expressed in this article that it is necessary to construct expeditionary computation centers on the basis of PEKC and on the effectiveness of the proposed architecture of the complex and its programmed support.

In conclusion it should be noted that the described computer complexes should be used for monitoring the collection, primary processing and systematizing of observational data and also on scientific research vessels outfitted with large computers, in each of the detachments, assigning to the large electronic computer the function of analysis and the higher systematization stages. This makes the entire system for collection, processing, systematization and analysis more reliable, flexible and universal and simplifies its operational system.

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METHODS OF IMAGE RECOGNITION THEORY IN PROBLEMS INVOLVING ANALYSIS AND PREDICTION OF METEOROLOGICAL FIELDS

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[Article by Candidate of Physical and Mathematical Sciences Yu. V. Semenovskiy, Central Aerological Observatory, submitted for publication 31 May 1978]

Abstract: The article describes a method for the analysis and prediction of meteorological fields based on the ideas of the theory of image recognition. A new version of the recognition method is given. The axiomatics of a universal classifier is given and a numerical algorithm of the classification has been developed.

[Text] Introduction. The image recognition theory methods intensively developing during the last decade are now also beginning to penetrate into meteorology. It is sufficient to mention the work cycles carried out at the Central Asian Regional Scientific Research Hydrometeorological Institute under the direction of G. V. Gruza and at the Hydrometeorological Center under the direction of N. A. Bagrov. The attractiveness of these methods is attributable to the fact that they are a natural generalization of statistical methods in the problem of extracting the maximum information from meteorological archives and therefore they are a convenient and at the same time an exceptionally effective method for the analysis and prediction of meteorological fields. It is no secret that the actually used long-range forecasting methods are in essence synoptic-statistical methods. Therefore, the possibility of increasing the effectiveness of synoptic-statistical forecasting methods is the chief premise for employing image recognition methods.

Another peculiarity of image recognition theory methods is that they constitute a mathematical approach for the formalization of synoptic methods, for objective search for and analysis of the natural states of the atmosphere. It therefore seems that recognition methods will help in closing the gap between synoptic-statistical methods, on the one hand, and numerical hydrodynamic modeling, on the other.

The problem of the maximum use of already available meteorological information for analysis and prediction has two sides. The first side is technical. This is the creation of a general meteorological archives on computer carriers, special meteorological archives, the theory of representation of meteorological fields, systemic complexes of programs for both exploitation and retrieval. The second side of the problem is in the essence of the methods used in data processing and their effectiveness in computations.

In this study we give the general outlines of a method based on the ideas of image recognition theory, making it possible, in the author's opinion, to make appreciable advances in the effective use of the meteorological prehistory for the purposes of analysis and prediction of meteorological fields. In addition to the term "recognition," we will use the narrower terms "grouping" or "classification."

The principal premises of the method are as follows:

1. Existing statistical methods for the analysis and prediction of meteorological fields contain very strong assumptions concerning the statistical nature of the processes. Therefore, the optimum method must not encumber the statistical structure with data, but must reveal this internal structure.

2. The method must be based on a clear general mathematical axiomatics, be quite flexible and allow variations. The number of axioms and undetermined parameters must be minimum.

3. The method must allow a tie-in to hydrodynamic models.

4. The method must have a high computation effectiveness.

These diverse requirements also led to the well-developed approach of image recognition theory or (more narrowly) a machine classification. Otherwise this method is known as learning without a teacher, grouping, etc. The device (computation program) for effectuating these methods is called the classifier of the objects. In application to weather forecasting, the general formulation of the problem is beyond the limits of machine classification and constitutes the following chain of problems.

Representation-Classification-Prediction

The first stage involves an effective description of the specific states of the atmosphere in the form of criterial vectors. In the second stage, classification, on which the emphasis is placed in this study, there is a breakdown of the sample of the criterial vectors into classes, the internal structure of the sample is thereby determined, and the data are analyzed. The third stage, prediction, operates with the statistics of causal-temporal transitions between classes.

The principal physical idea of the method can be summarized as follows:

"The representative sample of states of the atmosphere is a set of inhomogeneous point sets, which, differing in internal structure, form nonintersecting classes."

This assertion is in essence the hypothesis of the existence of stable meteorological states (classes) in the atmosphere. The available series of evidences in support of this hypothesis (for example, see [6, 7]) is still not decisive. The final objective answer can be obtained only on the basis of a machine classification of a representative sample of meteorological states of the atmosphere.

Now we will proceed to a detailed exposition of the principal stages in the proposed method.

Representation

This stage in the method is essentially clear. The procedures for reconstructing the fields of meteorological elements on the basis of data from point measurements (objective analysis) have been well developed. These are the methods of generalized Fourier series, in accordance with the continuous fields giving the vector of the Fourier coefficients; sometimes expansions in natural orthogonal functions, etc. are used. This means that the representation problem is solved if the representation axiom (RA) is stipulated.

RA: There is a rule R establishing a correspondence between the continuous (field) description of the state of the atmosphere at a specific moment (or in a specific period) in time and the discrete criterial vector $\vec{x} = \{x_k\}$. Thereby the inverse rule R^{-1} has been determined and exists; this makes it possible, using the $\vec{x}$ vector, to reconstruct the initial state of the atmosphere.

But in the practical application of representation methods, especially for the representation of three-dimensional global fields of meteorological elements, the effectiveness of representation, that is, the information content of components of the $\vec{x}$ vector, begins to play a highly important role. The well-known "curse of large dimensionalities" has the result that many well-developed methods are forced to yield before the necessity for operating with objects whose dimensionality is of the order of 10^2. In light of what has been said it is clear that pure computer technology, based on specific algorithms, has unquestionable advantages. As an example, we point out [4] that programs classifying objects with a dimensionality of about a hundred or more are already successfully functioning.

In order to increase the effectiveness of representation, that is, for reducing the dimensionality of $\vec{x}$, there are special methods, such as, for example, the correlation-regression method, image recognition theory methods, and others [1].

Procedures such as the use of meteorological standards as base functions can be proposed for testing; these are specific for meteorology. Meteorological standards can be obtained formally on the basis of image recognition theory, but it is simpler to use a small number of stylizations of typical synoptic processes already firmly established in meteorological practice (for example, "cyclone," "center of action," "planetary wave," etc.).

It can also be useful to apply the physically clear parameterization procedure similar to the way in which it is used in numerical hydrodynamic forecasting models. The higher Fourier harmonics of the field expansions are averaged either over the entire wave spectrum or in its parts and this (one or more) averaged parameter is included in the vector of criteria characterizing field mesostructure.

Here it is fitting to mention still another characteristic feature of representation for the purposes of long-range forecasting. The rule R must evidently describe only the "principal," "planetary" characteristics of meteorological fields, and the small-scale processes must be parameterized. In addition, it is useful to include additional components in the vector of criteria which a priori can represent some prognostic value. These almost undoubtedly should be nonadiabatic factors; they can be the parameters of solar activity, the characteristics of the world ocean, etc. Therefore, the representation of R, on the one hand, is somewhat less informative than the initial fields due to the "coarsening" of the description of mesoscale phenomena, but, on the other hand, it contains additional information.

In summarizing what has been said, it must be concluded that there are no general "formulas" for selecting an effective representation. The specific form of the initial data, together with the specific formulation of the long-range forecasting problem, should themselves determine the optimum combination of the approaches enumerated above. It remains only to assert, proceeding on the basis of the simplest evaluations, that the dimensionality of the vector of criteria, with different degrees of effectiveness of representation of three-dimensional meteorological fields, falls in the range from fifty to several hundreds, which makes the meaningful problem of long-range forecasting entirely realizable for computer analysis methods.

Classification

The idea of using classification for the purposes of analysis and prediction of meteorological fields is not new. Approaches which are extremely close in essence are the prediction methods based on analogues, investigations operating with such concepts as rhythm, natural synoptic season, etc. These studies are associated with the names N. A. Aristov, N. A. Bagrov, G. V. Gruza, N. I. Zverev, A. L. Kats, S. T. Pagava, D. A. Ped' and many other well-known meteorologists. As a result, that which is presented below must be regarded simply as a mathematical realization in most part of already known ideas, as an effective computation tool making it possible to realize these ideas for a meaningful planetary prognostic problem on the basis of representative meteorological archives. It can be hoped, to be sure, that the use of this new computation technique will also lead to qualitatively new results, but this is a matter of the future.

Now we will proceed to classification. We will assume that the representation problem is solved. We have a set of vectors of state (criterial vectors) -- a sample. Each vector $\vec{x}_m$, in accordance with the R representation, corresponds to the state of the atmosphere at a definite moment (in a definite period) in time. The volume of the sample is M, the dimensionality of the vectors is N. The components x_{mn} of the vector $\vec{x}_m$ are identically informative up to the classification procedure. For this the criteria x_n of the vector $\vec{x}$ are normalized and centered, so that the dispersion of all the criteria in the sample is equal to 1 and the mathematical expectation is equal to 0. This procedure is not mandatory, but is convenient, if a universal classification is proposed.

Definition 1. The classifier is said to be universal if its axiomatics does not contain assertions concerning the nature, structure or peculiarities of the teaching sample of data.

The sample $\vec{x}_m$ represents points in sample space D with the dimensionality N. The first axiomatic classification, naturally, is the axiom of the metrics A-I.

A-I. A rule is established which in accordance with the indicated pertinent vectors $\vec{x}_i$, $\vec{x}_j$ determines the nonnegative value $\rho(\vec{x}_i, \vec{x}_j)$ -- the distance between the points satisfying the triangle inequality.

There is a great diversity of the metrics used in the classification [2, 9]. It is reasonable for a universal classification to use very simple quadratic Euclidean metrics, since the more complex metrics already themselves contain implicitly some classification principles. Thus, Euclidean metrics makes it possible, at least, not to increase the number of axioms.

Naturally, the most meaningful are the axioms of the classification principles. The fact is that the classification problem is in essence the problem of formation of concepts [8]. The necessity of recognizing the class property for some group of points in sample space is equivalent to the formation of a new concept. Accordingly, the universality of the classifier is to a certain degree conditional, like the universality of the axiomatics. But the practical difference in the known classification principles was small. This was convincingly demonstrated in [4]. Evidently, today the bottleneck in image recognition theory is not the classification principles, but the effectiveness of the numerical algorithms for their realization.

Among the best known image recognition methods we should mention the following:

1. The method of linear decision functions, historically related to the studies of Fisher.
2. The Braverman potential functions method.
3. The Bayes method.
4. The method of extrema of a sample distribution density, frequently attributed to Parzen.

Definition 2. The problem of classification of an "unmarked" sample with an unknown number of classes is called taxonomy, grouping, learning without a teacher.

Below, among the enumerated recognition methods, for the considered taxonomy problem we selected a method based on an analysis of sample density. This choice was dictated by two factors. First, the classification axioms for this method are more general, more formal; these correspond better to the spirit of universal classification. Second, precisely for this method it was possible to construct an extremely economical numerical algorithm, which is important in problems with a great dimensionality.

The method was subjected to considerable editing. The principal change relates to determination of sample density and is reflected in the density axiom A-II.

A-II. There is, determined in the sample $\vec{X}_m$, a positive function $f_r(\vec{x})$, known as the sample density in the averaging radius r, monotonically dependent on the number of sample points falling in a hypersphere G with the radius r and with a center in $\vec{x}$ and it can be dependent on the local structure of a point set belonging to the mentioned hypersphere.

A peculiarity of this definition is that the sample density is calculated for a particular element of the sample with the use of only those elements of the sample which are distant by not more than r from the initial element (moving averaging). The next factor which must be taken into account with a sample $f_r(\vec{x})$ is the very low density of the point set in the sample space of a great dimensionality. Therefore, in order to still further increase the smoothness of $f_r(\vec{x})$ in the sample it is desirable to draw on information on the microstructure of the point set within the hypersphere G.

The following variants of the choice $f_r(\vec{x})$ illustrate this problem:

$$f_r^{(1)}(\vec{x}) = \overline{S_r(\vec{x})}, \tag{1}$$

$$f_r^{(2)}(\vec{x}) = S_r(\vec{x})/\overline{\rho(\vec{x})}, \tag{2}$$

$$f_r^{(3)}(\vec{x}) = \sum_{\vec{x}_l \in G,\ \vec{x}_l \neq \vec{x}} 1/\rho(\vec{x}_l, \vec{x}). \tag{3}$$

Here $S_r(\vec{x})$ is the number of points $\vec{x}_i$, such that $\vec{x}_i \in G$, $\vec{\rho}$ is the mean distance of the points $\vec{x}_i \in G$ to the point $\vec{x}$.

Formulas (2) and (3), in addition to the local numerical density, take into account in some way the connectivity of the points $\vec{x}_i \in G$ with the center of the hypersphere. This, generally speaking, is not introduced into the classification, since the idea of connectivity is already contained in the definition of classes as nonintersecting sets. There are, to be sure, other possibilities for taking the microtopology of the sample into account. In other words, all the arbitrariness in the classification in the considered method is concentrated in the averaging parameter r and in the choice of the form of sample density $f_r(\vec{x})$, which is more attractive than the use of a Parzen sample density [10]. The Parzen density is computed in the entire sample using correlation matrices, the form of its problems; the single parameter h does not have such a clear interpretation as the averaging radius r.

The last axiom of the universal classification is the classification principle axiom.

A-III. The maxima in the sample density $f_r(\vec{x})$ in the sample are the centers of the classes, the "passes" and "valleys" in the surface $f_r(\vec{x})$ -- the limits of the classes.

The axiomatics of the universal classification is completed. It can be shown that the objective has not been attained; indeed, the number of clases has not been determined. The function C(r), where C is the number of classes, was obtained, but the optimum r (that is, C) was not selected. A natural axiom, formally closing the classifier, is the "object" axiom (quality of the classifier). The point of view of the author of this study is that the "object" axiom must fall outside the universal classification and determine the so-called optimum classifier.

Definition 3. The classifier is said to be optimum if its axiomatics includes the "object" axiom (quality function, grouping criterion, "object" function, etc.).

The reasons for such a discrimination of the "object" axiom are clear. The universal classifier operates only with an abstract structure of the data. At its output it gives only possible variants of the breakdown of data into classes (C = C(r)). It does not use information on the physical nature of the object and the objects of recognition are unknown to it. The researcher must stipulate all this by means of the "object" axiom. For the weather forecasting problem the minimizing of the forecasting error can be such an axiom.

Classification Algorithm. Description of Classes

The computation aspects of the classification problem are frequently overshadowed by the circumstance that the first practical results were obtained for relatively small dimensionalities of sample space. This matter has been given due attention only now, when the need has arisen for manipulating objects described by several hundreds of parameters. As clearly indicated in the monograph [3], from the computation point of view the most effective classification algorithms are the methods using the ideas of the theory of graphs. In these methods only the distances between pairs of points are computed, that is, the number of computation operations of the order N, the dimensionality of sample space. These considerations served as a basis for the classification algorithm presented below for the sample density extrema method.

The essence of the algorithm is as follows. We find the element $\vec{x}_1$ of the sample Q in which $f_r(\vec{x})$ attains a maximum value. This element is a first-class center. The sample vectors, belonging to the first class, are determined as follows. We form a sequence of chains (similar to the minimum covering graph), each of which satisfies the following rules.

The chain $l_k(\vec{x}_1)\colon \vec{x}_1 \to \vec{x}_2 \to \ldots \to \vec{x}_{l_k}$.

1. The element $\vec{x}_{i+1}$ is the closest to $\vec{x}_i$; for the sample $Q \setminus \{\vec{x}_1, \ldots, \vec{x}_{i-1}\}$.

2. $$f_r(\vec{x}_{i+1}) < f_r(\vec{x}_i).$$

3. The element $\vec{x}_{l_k} \in \Gamma_k(\vec{x}_1)$ is a set of first-class boundary points.

The transition from k to k + 1 involves a truncation of the sample $Q = (Q \setminus l_k) \cup \vec{x}_1$. Transition to the second class is accomplished by truncation of the sample

$$Q := Q \setminus \{l_1(\vec{x}_1), \ldots, l_k(\vec{x}_1)\} \qquad \text{etc.}$$

A result of operation of this procedure is a breakdown of the sample into classes with a stipulated averaging radius r. The following information is known about each class: list of elements, number of the central element, set Γ of boundary points.

Since the initial sample is considered as a teaching sample, for the new elements, if their number is small and there is no need to "reteach" the classifier, it is necessary to formulate an identification procedure. This is usually achieved by computation of the separating functions. In the considered case the problem to a certain degree is simplified by the presence of information on the boundary points of each class; therefore it is possible to use, in accordance with [5], the very simple algorithm of dividing standards. If a hypersphere is used as a standard, the procedure of description of class will seem quite simple. The first hypersphere is constructed from the center of a class with a radius equal to the distance to the nearest boundary point. The class elements entering into it are excluded from the class list, then the next element, giving the maximum of the function $f_r(\vec{x})$, is found. It is used as the center of the second hypersphere. Its radius is equal to the distance to the nearest remaining boundary points, etc. Thus, the description of the class consists of a series of hypersphere parameters. Such parameters are the centers of the hyperspheres, radii, number of sample points entering into the hypersphere (weight of the standard).

This method for describing a class is interesting in that it makes it possible to obtain the accompanying statistical information. Indeed, the curve connecting the centers of the description hyperspheres (standards) in essence determines a nonlinear intraclass regression. A comparison of these curves for different classes can to a certain degree characterize the quality of the classification and thereby be a quantitative argument in the key problem of the existence of stable states (classes) in the atmosphere.

Prediction

Since the elements in the sample are the meteorological states of the atmosphere, they are interrelated to one another by causal-temporal relationships. The use of classes instead of sample elements makes it possible to study the statistics and structure of the temporal transitions between classes. This, indeed, is the principal difference between recognition methods and prediction using analogues. A classifier, similar to a weatherman, finds the common characteristics in many meteorological records and combines them into groups. The only difference is in the computation capabilities of an electronic computer and the objective nature of the classification.

Thus, in the prediction stage the object of the investigation becomes the oriented forecasting graph, the "peaks" of which are classes, whereas the sides are the temporal transitions between classes. Generally speaking, recognition methods here also suggest a formal procedure for selecting the final number of classes. This is the so-called decomposition problem, involving a breakdown of the graph into parts most strongly related to one another.

However, it seems that the "object" axiom must not be formal. In the prediction, as already mentioned, it is natural to require a minimum of the forecasting error. A requirement which is close in sense is the optimization of the forecast with respect to information content simultaneously with the statistical significance of the transitions between classes.

There can be other variants of the classification criterion. It is only clear that the case of one class $C = 1$ is not of interest, whereas the case $C = M$, where M is the sample volume, leads to a prediction by the analogues method. Accordingly, there is an optimum (in some sense) number of classes $C_{op} = C(r_{op})$. We will satisfy ourselves only with a statement of this situation, carrying out more specific investigations in connection with the formulation of the corresponding optimization problems. Then we will assume that the number of classes C is known and we will define a possible forecasting scheme.

We will arrange the sample undergoing the classification stage in a chronological series. Assume that $A_1, \ldots, A_C$ are the classes of states, $1 \leq C < M$. Then A_i^t denotes that at the moment in time t the atmosphere was situated in a state of the class A_i. The chronology of the meteorological states in the language of classes has the form

$$A^{t_M}_{i_M} \to A^{t_{M-1}}_{i_{M-1}} \to \ldots \to A^{t_2}_{i_2} \to A^{t_1}_{i_1}. \qquad (4)$$

Assume that $t = t_0$ is the moment in time at which the forecast is issued. Using the prehistory (4) we will compute the matrix of conditional probabilities in the following form:

$$\pi = \left\| \begin{array}{llll} P(A_1), & P(A_2) & , \ldots, & P(A_C) \\ P(A_1/A_{i_1}), & P(A_2/A_{i_1}) & \ldots\ldots & P(A_C/A_{i_1}) \\ P(A_1/A_{i_2}, A_{i_1}), & P(A_2/A_{i_2}, A_{i_1}), & \ldots, & P(A_C/A_{i_2}, A_{i_1}) \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \end{array} \right\|. \qquad (5)$$

Here, for example, $P(A_k/A_{i_1}, A_{i_2})$ is the probability of the appearance of the class A_k in series (4) after the two classes A_{i_2}, A_{i_1}, approximately equated to the value $\nu(A_{i_2}, A_{i_1}, A_k)/\nu(A_{i_2}, A_{i_1})$, where $\nu(\ldots)$ are the frequencies of appearance of the corresponding classes in the chronological series of the prehistory (4). To be sure, only those elements of the matrix (5) for which the corresponding frequencies $\nu \gg 1$ make sense.

A prediction using a matrix of conditional probabilities π can be given in categorical form, selecting the maximum matrix element, or in stochastic form.

The cited prediction model is unquestionably extremely simplified, but no significant efforts have been made to apply it to more complex cases, for example, to a variable time interval of the prehistory (4), etc.

Relationship to Hydrodynamics

The simplest conjugation with hydrodynamic models appears in a case when the representation is based on generalized Fourier series. In this case the "field" part of the criterial vector is the Fourier coefficients of expansion of meteorological fields, and this suggests a variant of a hydrodynamic model, specifically a spectral prediction model; it is convenient to select the latter in a variation interpretation. More specifically this is expressed in computation of the integral square nonclosure of the hydrodynamic system of equations with substitution of a finite Fourier series into it. Thus, in the sample space we determine a hydrodynamic functional in the form

$$I(S) = \int_S dl \int_G |\hat{N}\vec{\psi} + \vec{F}|^2 \, dx\, dy\, dz. \qquad (6)$$

Here $\hat{N}\vec{\psi} + \vec{F} = 0$ is the matrix form of the equations of hydrodynamics,

$$\vec{\psi} = \sum_{\alpha, \beta, \gamma} \vec{A}_{\alpha, \beta, \gamma}(t)\, \varphi_\alpha(x) \cdot \varphi_\beta(y) \cdot \varphi_\gamma(z);$$

G is the region of the solution, S is some curve in sample space between the points $\vec{x}_1$ and $\vec{x}_2$. It is easy to see that if the base system of functions is complete, and the series is infinite, then $\min_S I(S) = 0$ and represents a precise solution of hydrodynamic equations.

The minimizing of the hydrodynamic functional (HF) is the same as the Ritz method. If for a simplification it is assumed that S is a straight line, then the HF will be dependent only on the position of the initial point $\vec{x}_1$ and the final point $\vec{x}_2$, that is, $I(S) = I(\vec{x}_1, \vec{x}_2)$.

Assume then that $\vec{x}_1$ and $\vec{x}_2$ are the centers of the classes B_1 and B_2; then $I(\vec{x}_1, \vec{x}_2)$ is the hydrodynamic weight of the transition between these classes. An interesting situation is observed. The chronological series (4) determines the statistical weights of the transitions between classes; the weights of some transitions are equal to 0, that is, transitions are physically forbidden. At the same time, for all transitions the hydrodynamic weights are determined. A problem of unquestionable interest is the correspondence between hydrodynamics and statistics in the mentioned interpretation. It can be hoped that its solution will prove to be extremely useful for the problem of long-range hydrodynamic forecasting.

In conclusion, we should mention that the form of the HF (6) is not the only one but is the simplest in a case when there is no information on such properties of the operator $\hat{N}$ as linearity, self-conjugability and positive determinancy.

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TWENTY-FIFTH ANNIVERSARY OF THE TRANSCAUCASIAN SCIENTIFIC RESEARCH HYDROMETEOROLOGICAL INSTITUTE

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[Article by Professor G. G. Svanidze and Candidate of Physical and Mathematical Sciences Z. I. Tskvitinidze, Transcaucasian Scientific Research Hydrometeorological Institute, submitted for publication 30 May 1978]

Abstract: The article presents concise historical information on the work of the Tbilisi Geophysical Observatory, on the basis of which the Transcaucasian Scientific Research Hydrometeorological Institute was organized in 1953. The authors tell about the principal tasks facing the institute, the successes attained and the prospects for the development of scientific research.

[Text] The year 1978 marked the 25th anniversary of organization of the Transcaucasian Scientific Research Hydrometeorological Institute. This same year is the 135th anniversary of founding of one of the oldest scientific institutes in the Caucasus -- the Tbilisi Geophysical Observatory, on the basis of which the Transcaucasian Scientific Research Hydrometeorological Institute was organized in 1953.

The history of the Tbilisi Geophysical (former Tiflis Physical) Observatory to a considerable degree is the history of development of Russian science in the Transcaucasian republics, and especially, the natural sciences. From the day of founding the observatory became the principal meteorological institute in the Caucasus, together with observational activity carrying out a major complex of scientific research work.

The observatory's observational data were used in the writing of a number of important scientific studies, covering the climatic characteristics of the Caucasus: the monographs of well-known scientists: A. I. Voyeykov, I. V. Figurovskiy, K. S. Veselovskiy, and others.

Well-known scientists have worked at different times within the observatory walls: Academicians USSR Academy of Sciences N. I. Muskhelishvili and I. N. Vekua; Academicians Georgian Academy of Sciences A. I. Didebulidze, A. N. Dzhavakhishvili, Ye. K. Kharadze, F. F. Davitaya and B. K. Balavadze; Professors A. M. Benashvili, R. V. Khutsishvili, M. Z. Nodiya, S. T. Pagava, K. L. Sulakvelidze, S. U. Guniya, K. I. Papinashvili, D. Dolidze, I. G. Kurdiani and many others. I. V. Stalin worked here in 1898-1901 as an observer and computer. The first director, V. P. Lominadze, made a special contribution to organization of the Transcaucasian Scientific Research Hydrometeorological Institute and the development of scientific research there.

Continuing the glorious traditions of the observatory, the Transcaucasian Scientific Research Hydrometeorological Institute during the 25 years of its existence has traveled a long path of development and has been transformed into a major scientific research and scientific methodological center of Transcaucasia. The institute is outfitted with modern technical equipment and is staffed by a large body of professional hydrometeorologists capable of implementing the tasks assigned to the institute and capable of solving a number of problems in mountain hydrometeorology not only at the scale of the Transcaucasian region, but at the scale of the USSR Hydrometeorological Service in general.

The Transcaucasian Scientific Research Hydrometeorological Institute does the following work:

-- development and improvement of methods for meteorological, agrometeorological, glaciological and hydrological forecasts and methods for artificial modification of harmful hydrometeorological phenomena (avalanches, hail, etc.);

-- search for effective means for regulating precipitation (inducing and redistributing precipitation) applicable to the mountainous conditions in Transcaucasia;

-- study of hydrometeorological, climatic and agrometeorological conditions and resources, development of recommendations on their use;

-- study of the peculiarities and development of methods for predicting atmospheric contamination over industrial centers of Transcaucasia, rivers and reservoirs, and also soils from industrial effluent and poisonous chemicals;

-- introduction and determination of effectiveness of use of the results of the carried-out investigations in the national economy and the subdivisions of the Hydrometeorological Service in Transcaucasia.

The institute, including the Baku Division and the Yerevan Section, has 22 scientific sections and laboratories with about 400 specialists, including 60 Doctors and Candidates of Science.

The results of scientific research are presented in 20 monographs prepared by Institute specialists and in 70 collections of articles TRUDY ZakNIGMI (Transactions of the Transcaucasian Scientific Research Hydrometeorological Institute).

A considerable contribution to study of regional peculiarities of synoptic processes in Transcaucasia has been made by specialists of the Section on Investigation of Atmospheric Processes and Weather Forecasts. The method for weather forecasting for a month in advance for Transcaucasia was awarded the Multanovskiy Prize. On the basis of these studies it was possible to create methods for predicting such phenomena as hail, thunderstorms, severe cold, frosts, shower precipitation, strong winds, etc. During recent years physical-statistical and hydrodynamic methods for investigating atmospheric processes and predicting meteorological elements have been especially developed.

In the operational subdivisions of the Administrations of the Hydrometeorological Service of the Transcaucasian republics extensive use is made of the methods for predicting weather phenomena developed at the Transcaucasian Scientific Research Hydrometeorological Institute. In particular, among the scientific developments of recent years which have found practical application we should mention the method for hydrodynamic short-range forecasting of vertical movements in Caucasus regions within the framework of an adiabatic approximation, a method for predicting the development of squalls on the Black Sea shores of the Caucasus, a method for predicting vertical air movements for the Caucasus, with relief taken into account, a computation model for the short-range forecasting of thunderstorms during the cold season of the year for the territory of the Caucasus, etc.

Further investigations were directed to a deeper study of atmospheric processes over Transcaucasia under the influence of mountainous relief, the Black and Caspian Seas against a background of large-scale atmospheric processes in the northern hemisphere.

The Section on Meteorological and Climatological Research, in collaboration with the Aerological Research and Atmospheric Electricity Laboratory, carries out work on the study of natural and anthropogenic climatic variations, heliopower resources, scientific-climatic studies of new industrial regions, city construction, development of curortology and tourism in the Transcaucasian republics; it carries out investigations for determining processes and phenomena in the upper layers of the atmosphere, taking into account the peculiarities of local circulation, and carries out investigations of atmospheric electricity phenomena in the surface layer and in the free atmosphere. The results of scientific research in these directions are being used effectively in the national economy, in particular, by planning and design organizations, subdivisions of the Administrations of the Hydrometeorological Services of the Transcaucasian republics, etc.

Investigations for the development and improvement of methods for agrometeorological forecasts for the principal agricultural crops grown in Transcaucasia are carried out by specialists in the Section on Agricultural

Meteorology and Agrometeorological Forecasts and the Agrometeorology Section of the Yerevan Section of the Transcaucasian Scientific Research Hydrometeorological Institute. Particular mention should be made of the successes achieved in creating forecasting methods for the principal phases of growth and development, moisture supply, average republic yields of grapes, citrus and fruit crops, tea, tung, tobacco, winter wheat, corn and other crops.

During the last seven years alone the subdivisions of the Administrations of the Hydrometeorological Services of the Transcaucasian republics have adopted more than 10 different methods for agrometeorological forecasting which are used in routine practice.

At the institute studies are made of the agroclimatic resources of Transcaucasia for the principal branches of the national economy for the purpose of rational distribution of the leading agricultural crops over the region. Agroclimatic regionalization diagrams and maps are successfully used at national economic organizations. They are used extensively in studying the agroclimatic resources and agrometeorological conditions in mountainous and high-mountain regions of Georgia. The Paravanskaya Agrometeorological Expedition organized for this purpose carries out a major complex of studies in the high-mountain Samsarskiy Meteorological Polygon (2,200 m above sea level). The results of investigations of the growth and development of annual and perennial agricultural crops from the work done in this polygon served as a basis for extremely valuable recommendations on the introduction into agricultural production of root crops for animal and human consumption, vegetable and berry crops. These recommendations have now been introduced in the agriculture of a number of high-mountain regions in Georgia and give a considerable economic effect.

Scientific research in the field of cloud physics and artificial modification has been developed considerably at the institute. A method for contending with hail by the procedures developed at the Transcaucasian Scientific Research Hydrometeorological Institute has been deemed an invention and is used for the protection of valuable agricultural crops in Eastern Georgia (protected area 350,000 hectares). From this work alone the determined economic effect is more than 3 million rubles per year. Great attention is being devoted to work on the problem of an artificial increase in precipitation in the mountainous conditions of Transcaucasia. This has great importance for the national economy because the objective is an artificial increase in the available water resources used for the irrigation of lands, for irrigation purposes, for hydroelectric power purposes, and for the water supply of major industrial centers.

Being the scientific hydrometeorological center of Transcaucasia, the Transcaucasian Scientific Research Hydrometeorological Institute has as one of its principal goals a study of the water regime and water resources of the rivers and water bodies in this region. In hydrological investigations the hydrologists have established the hydrological and glaciological processes and their patterns in different physiographic regions of Transcaucasia and have formulated recommendations on preventing and predicting the onset of situations dangerous for the national economy. These recommendations and methods are used extensively in the practical routine work of the administrations of the Hydrometeorological Service of the Transcaucasian republics for satisfying the needs of hydroelectric power, water management and construction organizations and the Transcaucasian railroad.

During the last seven years alone, 15 different kinds of hydrological and glaciological forecasts have been introduced in the prognostic subdivisions of the Administrations of the Hydrometeorological Services of the Transcaucasian republics and these forecasts have had a high level of reliability.

Jointly with the USSR Hydrometeorological Center and the Administration of the Hydrometeorological Service Georgian SSR, specialists developed an automated scheme for the prediction of rain-induced high waters on the Rioni River, based on a mathematical model. The following methods developed at the institute and used in routine practice are of great importance: conditions of formation and prediction of the descent of different types of avalanches in the mountains of Transcaucasia; prediction of the monthly, quarterly and seasonal runoff of rivers in individual parts of the considered region; prediction of the times of passage of maximum discharges of spring high water; territorial prediction of the spring runoff of rivers, etc.

It is particularly necessary to note the results of investigations for study of the nature of mudflows, the conditions for their formation and propagation. In the studies of the leading specialists of the Section on Mudflows and Channel Processes there has been a generalization of the results of many years of multisided investigations in developing forecasting methods and methods for computing the principal hydrological, rheological, kinematic and dynamic characteristics of mudflows, channel deformations, elements of rupturing of natural dams, etc. Engineering computations were made for anti-mudflow construction and rational and effective anti-mudflow constructions of an industrial type have been created. This work was noted by a special prize of the Council of Ministers Georgian SSR and is being introduced both at the scale of the Soviet Union (in Georgia, Armenia and Kazakhstan) and abroad (in Yugoslavia).

One of the principal tasks of the institute is a study of the hydrometeorological aspects of environmental contamination. In the investigations in this direction there has been reflection of the results attained in developing methods for predicting contamination of the environment -- the air basin and soil and ground in individual regions of Transcaucasia.

The Section on Investigation of Atmospheric Contamination is carrying out work for the most part in two directions: monitoring and investigating radioactive contamination of the environment in the territories of the Administrations of the Hydrometeorological Services of the Azerbaydzhan, Armenian, Georgian, Moldavian and Ukrainian SSRs and the Northern Caucasus Administration of the Hydrometeorological Service and investigation of industrial contamination of atmospheric air in large cities and industrial centers in Transcaucasia. Among the broad complex of investigations made we should mention development of the method for predicting dangerous air contamination for the cities of Tbilisi and Rustavi. This method has been handed over to the Administration of the Hydrometeorological Service Georgian SSR for practical use.

Professional contacts with different institutes of the USSR are expanding for the purpose of a multisided study of the state of the air medium. In collaboration with the Department of Physics of the Atmosphere at Leningrad State University, the Main Geophysical Observatory and the Administration of the Hydrometeorological Service of the Georgian SSR, the complex energy experiment "KENEKS-72" was carried out in the industrial complex of cities Tbilisi-Rustavi-Gardabani for a thorough study of the peculiarities of composition of the atmosphere caused by gas and aerosol effluent from industrial enterprises.

Jointly with the Institute of Astrophysics and Atmospheric Physics Georgian Academy of Sciences, the "Astro" subsatellite experiment was carried out in the Samsarskiy Meteorological Polygon for the purpose of comparing data from complex measurements of the aerosol component of the atmosphere from the earth and from space.

In 1966 a Section on Meliorative Hydrology was established in the Transcaucasian Scientific Research Hydrometeorological Institute, and in 1972 a Laboratory of Hydrochemical Research was organized in this section. Due to the activity of these subdivisions there has been intensive development of the theoretical and experimental investigations of elements of the water balance, heat and salt balances, moisture exchange of surface and ground water, the process of evaporation of moisture from the surface of the land and movements of water-soluble salts in the aeration zone in the territories of Transcaucasia which can be improved (drained and irrigated). Recommendations are being developed on improving the state of meliorated lands and methods for water management computations are being improved with respect to providing a hydrometeorological basis for the planning of irrigated and drained systems. In investigations of transformations of individual chemical compounds in water and in the soil-water and soil-plant systems model laboratory experiments and complex experimental studies are carried out on a broad scale for determining the chemical composition and quality of surface, ground and waste collection basin-drainage waters over the territory of Transcaucasia. Recommendations are being developed for evaluating the aggressiveness of natural waters during hydraulic construction and their use in communal and technical water supply, for the purposes of irrigation and the flushing of saline soils, repeated use of waste water, etc.

The principal hydrometeorological investigations for the Armenian SSR have been concentrated in the Yerevan Section of the Transcaucasian Scientific Research Hydrometeorological Institute. The leading specialists in this section make a substantial contribution to the detection of regional peculiarities of meteorological, hydrological and agrometeorological phenomena over the territory of Armenia.

Among the most important results of scientific investigations in the section we should mention the determination of the variation of meteorological elements in the boundary layer under mountainous conditions in dependence on the synoptic situation and relief forms; formation of the water and heat regimes of the soil in the aeration zone and determination of the patterns of expenditure of ground water on evaporation; the water and heat balances of the territory of Armenia and sound meteorological setting of the norms and the regime of irrigated agricultural fields under mountainous conditions, etc.

The Baku Division of the Transcaucasian Scientific Research Hydrometeorological Institute, in close contact with the main body of institute personnel, carries out a complex study of the hydrometeorological regime of the territory of the Azerbaydzhan SSR, Dagestan ASSR and the water area of the Caspian Sea. Here specialists generalize the results of investigations for study of the hydrometeorological regime of the Caspian Sea and the mouth regions of the rivers flowing into it.

The greatest attention is devoted to investigations of the principal hydrometeorological elements acting on petroleum industry hydraulic structures -- wind, waves, currents. The results of long-term investigations found their reflection in the ATLAS VOLNENIYA I VETRA (Atlas of Waves and Wind), which is a regime-reference prognostic and navigational aid. Together with this atlas, successful use is made of a method for predicting wind waves in the Middle and Southern Caspian, developed by section specialists. A method for predicting the summer low waters on rivers in the republic was developed and adopted at the Baku Weather Bureau.

During recent years the institute has been intensively supplied with modern equipment and computers. The Computation Center functions on the basis of the Section on Mathematical Support and Programming Methods. With this center institute scientists are able to carry out work for numerical solution of the complex equations of atmospheric hydrothermodynamics, to establish the patterns in the investigated regions, and also to put their developments and findings in the hands of others for routine use by the prognostic agencies of the Administration of the Hydrometeorological Service Georgian SSR where each day there is routine calculation of prognostic charts for the Tbilisi Weather Bureau.

The Transcaucasian Scientific Research Hydrometeorological Institute is maintaining close contact with the institutes of the Hydrometeorological Service, the scientific institutes of the Academies of Sciences and other departments. In the task of forming and training young scientific specialists the institute is rendered great assistance by Tbilisi State University, USSR Hydrometeorological Center, Main Geophysical Observatory, Central Aerological Observatory, State Hydrological Institute and many key institutes of the USSR Academy of Sciences. The Scientific Council of the Transcaucasian Scientific Research Hydrometeorological Institute includes leading specialists of the Administrations of the Hydrometeorological Services of the Transcaucasian republics and also well-known scientists working in fields closely related to hydrometeorology.

For the successes achieved the personnel of the Transcaucasian Scientific Research Hydrometeorological Institute have been awarded the Diploma of Honor of the Central Committee Communist Party of Georgia, the Presidium of the Supreme Soviet Georgian SSR, the Council of Ministers Georgian SSR and the Georgian Republic Council of Trade Unions, and repeated commendations have been received from the Main Administration of the Hydrometeorological Service of the USSR Council of Ministers.

The 25th anniversary of the date of organization of the Transcaucasian Scientific Research Hydrometeorological Institute and the 135th anniversary of the Tbilisi Geophysical Observatory are being greeted by institute personnel with new successes in scientific research and a major rise in creativity.

WORK OF A. A. FRIDMAN IN THE FIELD OF HYDROLOGY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 109-112

[Article by Professor Ye. S. Selezneva]

Abstract: This article gives information on the first period (1913-1916) in the work of the outstanding scientist A. A. Fridman in the field of geophysics, poorly reflected in biographies. During this five-year period he devoted great energy to the then-new problems of aerology and aerial navigation and did much in the organizing of observations and the servicing of aviation.

[Text] The year 1978 marked the 90th anniversary of the birth of the outstanding scientist Aleksandr Aleksandrovich Fridman, the founder of Soviet dynamic meteorology and the author of exceptionally important theoretical studies in the field of cosmogony. The studies of A. A. Fridman have received broad recognition in these fields. The high evaluation of their importance by leading scientists is given in a series of articles published in an appendix to the selected works of this scientist [1], in one of the issues of USPEKHI FIZICHESKIKH NAUK (Advances in the Physical Sciences) [7], and in other publications.

In biographical articles and recollections there is usually only a fleeting mention of the work of A. A. Fridman at the Aerological Observatory and in aviation units during the war of 1914-1918. This is briefly told in the main, most complete biography, written by the closest associate of Fridman, P. Ya. Kochina [1, 3]. However, his work in the field of aerology and aerial navigation has not passed without a trace either for him or for aerology. This energetic, high-initiative young scientist did not follow well-trod paths: there were no such paths in aerology at that time -- it was in its initial stage of development. Precisely during this first period (1913-1918) of practical and experimental work A. A. Fridman exhibited his great organizational capabilities, and at the same time he further developed his interest in the study of atmospheric processes, in various observations of weather phenomena. This interest also persisted later, despite his profound dedication to theoretical problems.

It is possible to obtain some idea concerning the activity of A. A. Fridman during the "aerological five-year period" in particular from his biography [1], which in chronological sequence lists the principal stages and individual events of this time. Evidently, this record lists precisely those events which the author regarded as particularly important and therefore they can be used as a basis in reconstructing the most important aspects of the scientist's activity. The brief autobiographical information can be supplemented using the reports of the Main Physical Observatory and its affiliate -- the Aerological Observatory, and also using the articles of scientists with whom he chanced to work during this period. These were B. I. Izvekov [2], A. F. Gavrilov [1, 7] and M. M. Rykachev [6]. Finally, the scientific articles of A. A. Fridman published during these years reflect his practical work and scientific interests.

A. A. Fridman went to work at the Main Physical Observatory in the spring of 1913 [1] and was sent by the director, B. B. Golitsyn, to the Aerological Observatory, which was located at Pavlovsk (a suburb of Petrograd - Leningrad). This observatory was just formed on the basis of an aerological division and a balloon station which until then had been part of the Magnetic-Meteorological Observatory (Pavlovsk Subdivision of the Main Physical Observatory). V. V. Kuznetsov headed the Aerological Observatory, and earlier a division. He was already a well-known scientist who did much in organizing aerological observations and constructing the necessary instruments. In aerological work use had long been made of the extremely convenient Kuznetsov theodolite for observations of pilot balloons and meteorographs for sounding the atmosphere with kites and pilot balloons. Aerological observations multiplied and they began to be carried out at affiliated observatories (Yekaterinburgskaya, Tiflisskaya) and other places. The need arose for standardizing the processing of their data.

The first study which was assigned to the new specialist of the Aerological Observatory was the preparation of instructions on the processing of meteorograms. For its preparation the author had to familiarize himself with methods for sounding of the atmosphere and evidently mastered them, since his instructions, according to the comments of B. I. Izvekov [2] "introduce considerable simplifications into the practice of aerological observations, and saves time." Later, Fridman, together with another specialist, P. A. Nadeyev, prepared instructions on the processing of pilot balloon observations and they gave a simplified method for computing the coordinates of pilot balloons [4].

In this same year, 1913, A. A. Fridman was engaged in investigations of the temperature distribution in the atmosphere, to which, it must be assumed, he was attracted by his familiarity with data ftom aerological soundings. At this time aerologists were concerned with the problem of the reality of the recently discovered "upper temperature inversion," as the stratosphere was then called. Everyone was interested in an explanation of this unexpected temperature inversion. A. A. Fridman wrote a long article on the temperature distribution with altitude, which was immediately included in the GEOFIZICHESKIY SBORNIK [16]. He again returned to this matter in 1920 and examined it from a theoretical point of view [14].

It is interesting to note that at this same time A. A. Fridman did not abandon his mathematical interests and in the autumn of 1913 he took his master's examinations at the university.

A. A. Fridman mentioned two events in his activity during the first half of 1914 in his autobiography: in the spring of 1914 he was sent to Leipzig to work with Professor V. Bjerknes. There he became familiar with new synoptic methods and the compilation of streamline maps. He carried out processing of data from one of the international aerological days and constructed charts of the distribution of meteorological elements. These results were published in SYNOPTISCHE DARSTELLUNGEN, but without the author being mentioned [2]. After this period of service and training with Bjerknes Fridman drew practical conclusions and already late in 1914 published an article entitled "Importance of Streamlines for Aerial Navigation" [9]. The article gave a number of practical indications on the construction of streamlines and their use in aviation.

The second event noted by Fridman was not seen through to the end, but it undoubtedly interested him. For example, he writes: "In the summer of 1914 I participated in the preparation and development of measures for aerological observations which were to be made during the total solar eclipse of August 1914; for this purpose a number of flights were made in dirigibles" [1]. The intended observation plan was not carried out due to the beginning of the war.

At the beginning of the war A. A. Fridman and other specialists at the Aerological Observatory (M. M. Rykachev, N. N. Andreyev, V. S. Abramov) went to the front as volunteers. They were all enlisted in aviation and balloon units and had to supply them with aerological data. Fridman very actively participated in this work. His activity at the front was rather diversified. He organized aerological stations, taught soldiers how to make observations and processed the results. He did much for reconnaissance and for observations of atmospheric phenomena. Concerning his work in the first war years Fridman wrote in [1]: "I worked in the aviation detachment first on the northern front (at Osovets and Lykov) and then on other fronts in organizing aerological observations and in general an aerial navigation service." And then: "In the spring of 1915 I organized the central aerological station of the sixth aviation company and also a number of aerological stations in different aviation detachments." Here it was pointed out that "during the time of the flights a series of observations was made of the nature of atmospheric eddies." Later in his scientific articles A. A. Fridman made reference to his own observations from an aircraft.

Fridman participated in flights for the purpose of military reconnaissance as well. In many cases these were dangerous situations and he wrote B. B. Golitsyn concerning this [1].

In his autobiography A. A. Fridman particularly mentions flights over the German-occupied fortress Peremyshl' for precise bombing for the purpose of clarifying the aeroballistic properties of aviation bombs. Taking into account his own experience in bombing Fridman made ballistic computations and then jointly with A. F. Gavrilov [1, 7] organized computations of ballistic tables. Later (1920-1923) he returned to this work in the mathematics bureau at the MFO. P. Ya. Polubarinova-Kochina, working in this bureau, recalls: "Everyone participated in the computations of the ballistic tables, to which Fridman returned in order to make different refinements in them" [3].

In 1916 A. A. Fridman worked in aviation organizations in Kiev. There he presented lectures on aerial navigation in the school of aerial observers. Later, for his successful results attained in aerial reconnaissance, Fridman was awarded the title of aerial observer. He reported this with some pride to B. B. Golitsyn [1].

Then, in 1916, in the Kiev region, Fridman carried out several flights with a thermometer and meteorograph for measuring temperature from aboard an aircraft. In essence, these were the first aircraft soundings of the atmosphere. Only five-six years later this experience was repeated near Moscow (at Klin). However, the aircraft method for investigating the atmosphere, which Fridman recommended, was developed only after construction of a special meteorograph, that is, toward the end of the 1920's.

In the 1950's the pilot with whom A. A. Fridman flew near Kiev unexpectedly announced himself. He wrote to B. L. Dzerziyevskiy, in a letter from Tallin requesting confirmation of the scientific value of these flights, information which he needed in connection with pension matters. Boris L'vovich and I then certified in writing the great importance of these, what might be called, historic flights. But now, unfortunately, there is no possibility of naming this pilot (an Estonian); his last name and address have been lost.

During 1916-1917 the activity of A. A. Fridman in aviation became still more diversified. In addition to the enumerated flight and instruction work at the central aeronavigation station he organized workshops for the repair of instruments and raised the question of creating a special plant for the fabricating of aeronavigation and aerological instruments. Then he headed up the working out of a plan for the factory and participated in its creation in Moscow. In the summer of 1917 the plant began to operate. In this plant Fridman headed the design-computation section and temporarily performed the tasks of director. A. F. Gavrilov [1, 7], who was a participant in this work, told about the practical activity of A. A. Fridman.

The plant did not exist for a long time. During the first post-revolutionary years there was no possibility of keeping this enterprise and it was shut down in 1918. A. A. Fridman proceeded to Perm', where he had been called for presenting lectures at the university.

The successful work of Fridman during the wartime period was summarized in [4]:

"The network of military aerological stations in light aircraft became particularly well developed. The organization and direction of this network was in the hands of a specialist at the Aerological Observatory, A. A. Fridman. The service which he created, in addition to an enormous number of aerological observations, left behind a number of publications in the form of instructions, manuals, etc. In addition, steps were taken for finding new research methods. In 1916, at Kiev, rather successful attempts were made at suspending a meteorograph on an aircraft, etc."

We note in passing that at that time the aerological service for air ships was organized by M. M. Rykachev, whereas the aerial navigation service in the hydroplane service of the Baltic Sea was organized by the youngest of the aerologists -- P. A. Molchanov [4, 6]. These aerologists also did much which was useful and new in the development of aerological methods.

Despite his great workload with organizational matters, in these same war years A. A. Fridman wrote several scientific articles which are also of interest for the modern aerologist. These studies were based on pilot-balloon data and the author drew important conclusions concerning the appearance of eddies in the atmosphere and on the relationship between them and the formation of cumulus clouds; also given here are formulas for determining the velocity of vertical movements. Also of interest are articles on determining the velocity of vertical currents by means of observations of pilot balloons [12, 13].

In 1920 A. A. Fridman returned from Perm' to Petrograd and again began to work at the MPO. He created what is now the mathematical bureau, soon to become the the section on theoretical meteorology, and in accordance with the principal direction of his interests was intensively engaged in the fields of mathematics and dynamic meteorology [1, 3]. However, even during these last years of his activity Fridman did not break his bonds with aerology. Thus, according to the recollections of P. Ya. Kochina [3], in the summer of 1922 he worked in the Aerological Observatory at Pavlovsk. In the TRUDY AEROLOGICHESKOY OBSERVATORII (Transactions of the Aerological Observatory), published in this year, Fridman published an article entitled "Atmospheric Eddies and Wind Gustiness" [8]. Fridman had the best relationship with the director of the Aerological Observatory in those years -- P. A. Molchanov. With respect to personal matters, Fridman has written with high praise about Molchanov's activity.

It is impossible to overlook still another study directed to the servicing of aviation and aerial navigation in which A. A. Fridman actively participated, being one of its initiators. During 1915-1916 B. B. Golitsyn established an editorial committee and a team of authors for preparation of the academic manual OSNOVNYYE SVEDENIYA PO AEROLOGII I SINOPTICHESKOY METEOROLOGII

DLYA LETCHIKOV I VOZDUKHOPLAVATELEY (Basic Information on Aerology and Synoptic Meteorology for Airmen and Aerial Navigators). The manual was written and published by the MPO by the lithographic method in 1917 already after the death of Golitsyn. The book consists of 12 chapters, written by different authors, for the most part N. N. Kalitin, V. I. Popov, P. A. Molchanov and D. F. Nezdyurov. Chapter 9, entitled "Weather Science," was written by A. I. Asknaziy, B. P. Multanovskiy and M. F. Petelin. A. A. Fridman wrote the Introduction, which defines the subject of aerial navigation and the objectives of the course. In addition, in connection with the death of B. B. Golitsyn, he served as general editor of the course. In the foreword it is noted: "The objective of publication of this book is filling the gap in Russian meteorological literature with respect to aerological subject matter." Five of the 12 chapters are purely aerological; they were written by P. A. Molchanov.

In July 1925, two months before his death, A. A. Fridman and the aviator, later stratonaut, P. F. Fedoseyenko, made a flight in a balloon to an altitude of 7,400 m. This bold act of the theoretical scientist cannot be understood without taking into account his preceding aerological activity, enthusiastic aspiration to learn about the real atmosphere and visually observe meteorological phenomena. This side of the scientist's activity is also reflected in one necrology, entitled "Memorial to a Professor, Flier-Observer."

The premature death of the enthusiastic scientist A. A. Fridman, occurring on 16 September 1925, was a great loss for Soviet science.

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REVIEW OF BOOK BY V. V. KUPRIYANOV: "HYDROLOGICAL ASPECTS OF URBANIZATION" (GIDROLOGICHESKIYE ASPEKTY URBANIZATSII), Leningrad, Gidrometeoizdat, 1977, 184 pages

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 113-115

[Book review by A. V. Karaushev and B. G. Skakal'skiy]

[Text] A book by V. V. Kupriyanov has now been published. Entitled "Hydrological Aspects of Urbanization" (GIDROLOGICHESKIYE ASPEKTY URBANIZATSII), for the first time it gives a systematic exposition of the principal problems in the hydrology of urbanized areas. The formulating of a new independent branch of hydrology of the land has taken place. Whereas in foreign studies urbanization hydrology is understood very narrowly and includes the problems involved in only calculations of rain-induced runoff from urbanized areas, calculations of sewers and determination of the quality of waste water, the reviewed book gives an extremely broad treatment of this branch of hydrology. V. V. Kupriyanov, in developing this new branch of hydrological science, includes an examination of research methods and methods for solving problems relating to the two following directions: hydrology of urbanized areas proper (hydrology of cities) and hydrology of the territories surrounding cities which exert an influence on the water resources, regime and quality of the waters in these territories.

From an integrated point of view the book examines a wide range of problems: transformation of the landscape of urbanized areas; global processes caused by urbanization; water consumption; transformation of the water regime; annual, minimum and maximum runoff; water and water management balances of urbanized areas; sources of contamination and water quality; balance of chemical substances; problems in eutrophication, thermal contamination and self-purification of surface waters; erosion, runoff of alluvium and channel processes within the limits of urbanized areas.

The book covers extremely diversified interests and reveals the author's great erudition. A major merit of the presentation is the wealth of illustrative material taken from the author's own work and from an impressive number of Soviet and foreign articles and books. The bibliography contains 114 items in the Russian language and 83 in foreign languages.

The degree and nature of the influence of urbanization on hydrological processes are different, and as indicated by the author, must be regarded specially in the following three stages of urbanization: 1) the period of building up and exploitation of a territory, 2) the period of stabilization upon completion of construction, 3) the period of a stable regime in the normal rhythm of urban life. In particular, it is emphasized that the problems of the quantity and quality of water must be examined inseparably.

Dwelling on the problems involved in the effect of cities on the hydrological cycle, the author devotes attention also to the climatic factors and the influence of cities on global moisture cycle processes.

In a special section of the book there is a discussion of the problem of transformation of the landscape during the urbanization process. In touching in general on the problem of the anthropogenic influence on landscapes, the author correctly notes that the greatest changes are introduced specifically by urbanization, leading to significant changes in the heat and moisture balances in the territory. The book enumerates the principal hydrological characteristics of an urbanized area.

It is characteristic that despite the relatively small areas of urbanized territory (on the earth about 2%), the latter even now are exerting an influence on the hydrological cycles over great areas, and in the future this influence will considerably increase.

The author points out that in general for the earth the gross water consumption for the urban population is about 58 km^3 annually and for the rural population is approximately 40 km^3 annually. It is noted that the increasing water consumption (for household-living needs and for industrial production) is creating strained conditions for the water balance of individual areas, but does not constitute a threat of exhaustion of world resources of fresh water. A highly important problem is the preservation of natural waters against contamination, as the author writes, "from qualitative exhaustion" (p 33).

The prospects for water resources in our country are evaluated rather optimistically, but at the same time the need for a territorial redistribution of runoff is correctly raised.

This is followed by a rather complete description of changes in the moisture cycle and climate as a result of urbanization. It is noted that the influence of urbanization on global moisture cycle processes is determined by two factors: 1) change in the temperature regime and the annual composition of the atmosphere and 2) regulation and redistribution of runoff. Also mentioned, with citation to a study by M. I. Budyko, is possible global changes in climate as a result of the anthropogenic factor. The author gives a detailed examination of the problem of the climatic characteristics of cities and urbanized areas. The monograph contains very interesting graphs of the increment of maximum temperature due to urbanization, represented as a function of the number of urban inhabitants.

The fourth chapter of the book is devoted to erosion, the runoff of alluvium and channel processes in an urbanized territory. The author defines two stages in the effect of urbanization on erosion and the runoff of alluvium: the construction period, when erosion and the runoff of alluvium increase greatly (sometimes by many times), and the period after completion of construction, when the erosional process dies down and then as a result of the laying down of asphalt pavement and presence of buildings the erosion becomes less pronounced.

The construction period merits special attention. While comparing the approaches to quantitative and qualitative evaluation of water erosion developed in the USSR and in the United States, and while accentuating the work done at the State Hydrological Institute, the author, unfortunately, does not express his attitude toward these approaches. However, it is evident that the approach of the State Hydrological Institute, based on a genetic analysis of the erosional process, taking into account the discreteness of slope runoff, occurring through a network of microchannels forming in the erosional process, is more promising than the purely empirical method for solving this problem used in the United States.

The mention of the dangerous effects of an "impairment of the natural saturation of watercourses with sediments" is very correct. It is known that this leads to an imbalance of the natural process of interexchange of sediments between the flow and the channel and an impairment in the equilibrium state of the channel, that is, to its erosion or silting. In his subsequent presentation in this book the author reveals a profound understanding of this process. However, in proceeding on to an examination of the problem of channel deformations, the author seemingly forgets about this key "interaction" principle and about balance methods for analysis of the direction followed in the channel process. He limits himself to an examination solely of the morphological theory of channel processes, which is given in an extremely schematic form. It remains unclear how it is possible to apply this theory, proceeding on the basis of the principles presented by the author above.

In the two chapters devoted to the annual, minimum and maximum runoff and its intraannual distribution the author examines the conditions for formation of runoff and the peculiarities of the water regime of urban territories. The book covers the most important parameters figuring in the computation formulas and the computation parameters are presented.

The method for determining the areas of the zones of influence of cities on snow melting developed by the author is very rational, and therefore, it is important in studying spring runoff. The method is based on an analysis of space photographs, on which it is possible to trace the "aureoles of the influence of cities" (p 85). It is to be hoped that the author will successfully carry to an end the work which he has begun.

It is pointed out in the book that applicable to urbanized territories the most suitable method for computing the runoff hydrograph is the isochrones method. Also considered are methods for calculating rain-induced high waters from urbanized areas used in the United States. The author writes that his task included emphasizing the inevitability of change in the hydrological cycle as a result of urbanization and pointing out the possible dangerous consequences of such changes. As an example the author considers the inundations caused by urbanization.

In the book much attention is devoted to the water and water management balances in urbanized areas (Chapter 7). The author gives a detailed analysis of the water balance structure for such a territory and studies the changes in the role of individual balance components as a result of man's economic activity. Also considered is a general formulation of the problem and numerous specific examples are cited.

Evidently, it would not be erroneous to regard Chapter 7 as central in the reviewed book because it virtually ties together most of the principal hydrological aspects of urbanization considered in other chapters of the book. Indeed, it would be desirable to place this chapter at the beginning of the book, for example, after Chapter 3. Incidentally, it should be noted that the chapter devoted to erosion and sediments (Chapter 4) was not in its proper place. The exposition would be more rigorous if it was placed after Chapter 6 or at the end of the book.

The monograph includes the long Chapter 8, devoted to the anthropogenic influence (especially, urbanization) on water quality. Noting the great influence of the anthropogenic factor on the quality of natural waters, the author mentions the waste waters from industrial production and household-living waste waters. We should also mention agricultural contamination, whose role is constantly increasing and with which it is particularly difficult to contend.

Clear examples are cited of the contamination of large water bodies in the countries of Western Europe, United States and Japan.

In analyzing the totality of factors determining the effect of an urbanized territory on water bodies, the author notes the possibility of discriminating those of them which can be subject to spatial generalization in their hydrological-geographical aspect. Such an approach is extremely valuable because it can lead to an improvement in prediction of the influence of cities on water resources in different natural zones. In this connection the characteristics of household waste water and the surface runoff forming in urban areas acquire considerable importance.

Considerable attention is being devoted to the anthropogenic eutrophication of water bodies due to the excessive entry of biogenous substances into them. While correctly noting the major role of urbanization in the development of this negative influence, the author at the same time passes over in silence the process of agricultural contamination, which here frequently plays the primary role.

In touching on thermal contamination, the author cites extremely interesting figures on the consumption and discharge of water by thermal and atomic electric power stations. For example, by 1980 electric power stations in the United States will use for the cooling of the plants about 1/5, and by 2000 -- about 1/3 of the annual runoff of the rivers in this country.

In the section devoted to self-purification and dilution of waste waters in rivers, lakes and reservoirs, the dilution process is correctly regarded as a component part of self-purification. The book gives a simplified method for computing dilution, by no means being universal and inapplicable to lakes and reservoirs. It is to be regretted that the more modern and quite universal method for computing dilution developed at the State Hydrological Institute has not been covered in the book under review, although it is well known that this method is extremely widely used in practical work.

Among the shortcomings we must note a definite noncorrespondence between the title of section 8.4 and the material presented therein. It gives only methods for computing the mean concentration of contaminating substances in river flows, whereas methods for evaluating the quality of river water are not really touched upon.

In summarizing the results of this analysis of the monograph by V. V. Kupriyanov, we note, in particular, that this book must be regarded as the first, but nevertheless a successful generalizing work on the hydrology of urbanized areas, including all its principal aspects. Each of the aspects is examined in a separate chapter giving the characteristics of the process and an evaluation of the changes introduced by urbanization into any element of the hydrological cycle and also in most cases including recommendations on the computation method.

The Hydrometeorological Publishing House has produced a very useful and very presentable book. It is intended for a wide range of specialists engaged in a study of anthropogenic changes and preservation of the environment, for hydrologists, geographers and workers in the fields of communal and water management.

SEVENTIETH BITHDAY OF NIKOLAY ALEKSANDROVICH BAGROV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 p 116

[Unsigned article]

[Text] Professor Nikolay Aleksandrovich Bagrov, Doctor of Physical and Mathematical Sciences, Deputy Chief Editor of the journal METEOROLOGIYA I GIDROLOGIYA, a leading professional meteorologist, creator of a new direction in the field of weather forecasting on the basis of a physical-statistical description of atmospheric processes, marked his 70th birthday on 10 December.

SIXTIETH BIRTHDAY OF VASILIY IVANOVICH SAPOZHNIKOV

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 p 117

[Article by a group of fellow workers at the Hydrometeorological Center]

[Text] Doctor of Geographical Sciences Vasiliy Ivanovich Sapozhnikov, senior scientific specialist at the USSR Hydrometeorological Center, marked his 60th birthday on 21 December.

V. I. Sapozhnikov is a leading scientist in the field of hydrological forecasts.

Graduating from the Higher Military Hydrometeorological Institute in December 1941, he took part in the Great Fatherland War. For his successful execution of tasks at the front he was awarded the orders Fatherland War (Second Degree), Red Star and many medals.

Proceeding in 1946 to the post of engineer in the Division of Short-Range Forecasts at the Central Institute of Forecasts, V. I. Sapozhnikov has continuously worked at that institute (transformed in 1966 into the USSR Hydrometeorological Center), combining scientific and routine work in servicing different branches of the national economy with hydrological forecasts. Over a long period he headed first a section and then the water forecasts laboratory for lowland rivers of the USSR.

He has written about 70 scientific studies, including the monographs OSNOVY PROGNOZA STOKA PO ZAPASAM VODY V RECHNOY SETI (Principles of Forecasting of Runoff from the Water Supplies in the River Network) (1956) and PROGNOZ STOKA REK V BASSEYNE VOLGI PO RUSLOVYM ZAPASAM VODY I PRITOKU VODY V RECHNUYU SET' (Prediction of Runoff of Rivers in the Volga Basin from the Channel Supplies of Water and Water Inflow into the River Network) (1960).

In his scientific work he exhibits the greatest interest in problems relating to short- and long-range forecasting of high waters on rivers on the basis of a determination of the intensity of spring melting of the snow, the distribution of runoff and the travel-time of water in the river network. Heading investigations in this field in the Service, he gives much methodological assistance to specialists at other scientific institutes and local administrations and directs graduate students and workers gaining additional experience.

V. I. Sapozhnikov participated in the work of the Third and Fourth All-Union Hydrological Congresses, a number of union and international conferences and seminars on hydrology, presenting scientific reports at them.

Over a number of years he was a member of the Scientific Council USSR Hydrometeorological Center; at the present time he is a member of the Hydrology Section of the Council. He is a member of the CPSU. He has been elected Secretary of the Party organization of the Hydrometeorological Center, Chairman of the Professional Committee of Hydrological Sections, and has taken an active part in many public measures.

Vasiliy Ivanovich is full of strength and energy. We wish him further productive scientific activity for the welfare of Soviet science.

AT INSTITUTES OF THE STATE COMMISSION ON HYDROMETEOROLOGY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 117-119

[Article by N. N. Podgayskiy and G. V. Gruza]

[Text] A session of the Technical Council of the Ural Administration of the State Commission on Hydrometeorology was held on 29 June. There was a discussion of the problem of the accuracy of chemical measurements in a study of contamination of the environment -- atmospheric air, water and soil.

In opening the session, the chief of the administration V. N. Babchenko noted that the discussed problem is of great scientific and practical importance, especially in connection with the fact that the study of the qualitative state of the environment is the concern not only of the Hydrometeorological Service, but also many Ural organizations of the Ministries of Water Management, Health, Ferrous Metallurgy, Gosstroy, etc. However, these studies are being carried out in different organizations by different methods, and in particular, in the taking, transport and analysis of samples and their computation. This is reflected extremely clearly in the reliability of the results of the qualitative state of atmospheric air, water and soil and leads to contradictory conclusions.

The Technical Council, in whose work representatives of different organizations participated (Ural Scientific Research Institute of Water Management, Oblast Sanitary-Epidemiological Station, Ural Division of the Institute "Teploelektroproyekt," Sverdlovsk Division of the Institute "Soyuzvodokanalproyekt" and others), deemed it necessary to standardize methods for carrying out chemical measurements in all media.

The Sverdlovsk Hydrometeorological Observatory was assigned the responsibility of formulating recommendations for increasing the quality of chemical measurements, taking into account the peculiarities of the water, soil and climate regimes of the territory of the Urals.

N. N. Pogayskiy

An American scientist, Doctor A. Murphy, a specialist from NOAA (Boulder, United States), was in the Soviet Union during the period 17 June-16 July. He is the director of a team for investigating the interaction between nature and society and visited the State Commission on Hydrometeorology for studying the problems relating to the statistical analysis of meteorological information and the exchange of scientific research data between the USSR and the United States.

Murphy is actively working in the field of evaluation of the quality of stochastic weather forecasts, methods for preparing subjective stochastic forecasts, and is also engaged in a determination of the value or economic effectiveness of such forecasts. He has published several tens of articles in the leading journals of the American Meteorological Society.

The guest visited the Central Asian Regional Scientific Research Hydrometeorological Institute (Tashkent), where he familiarized himself with the procedures for preparing stochastic short-range weather forecasts, the USSR Hydrometeorological Center (Moscow), the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center (Obninsk) and the Main Geophysical Observatory (Leningrad).

During his visit Doctor Murphy presented several lectures and carried out a great number of conversations with Soviet scientists. It follows from the collected information that in the United States, since 1965, specialists in the National Weather Service have everywhere initiated the preparation of stochastic forecasts, or, as we sometimes say, forecasts in a stochastic form, but for all practical purposes meaning a forecast of the probabilities of the fact of falling of precipitation. These forecasts are prepared by weathermen by the method of subjective evaluation of the probability of the fact of falling of precipitation. Use is made of all data at the disposal of the weatherman (analyses, numerical forecasts, satellite data, etc.). These forecasts in stochastic form are transmitted to the population. At first there was inadequate understanding and resistance to the introduction of these forecasts, but now they are in universal use and have won the widest recognition.

In addition to these subjective stochastic precipitation forecasts, NOAA also prepares stochastic forecasts by objective methods. Objective forecasts are prepared in the so-called "MOS" system (Model Output Statistic) on the basis of a statistical analysis of the results of numerical forecasts using hydrodynamic models. In this system a stochastic forecast of different weather phenomena is given: the fact of the falling of precipitation, altitude of the lower cloud boundary, visibility, etc. This information is basic auxiliary information for weathermen at 120-130 large cities in the United States. This information is used both in the preparation of subjective stochastic precipitation forecasts and in remaining synoptic forecasts as an auxiliary method. The works of Doctor Murphy give a profound and thorough analysis of the quality of these subjective stochastic forecasts and their high reliability is demonstrated (reality, that is, correspondence of the predicted probabilities to the actually observed frequencies) and also the fair accuracy (Breier evaluation).

Another direction in the studies of Doctor Murphy is an evaluation of the economic effectiveness or value of meteorological and climatic information. Numerous interesting results were also obtained in this field and the basic conclusion is drawn that forecasts in stochastic form are the most valuable and their value surpasses both the categoric forecasts (adopted in the USSR) and the value of the climatic information. It seems that the conclusion about the value of stochastic forecasts must be attentively studied and used in forecasting practice in the Soviet Union.

An interesting theme was touched upon as a result of analysis of change in the quality of weather forecasts during recent decades. A study was made of many different data on the temporal change in the quality of hydrodynamic forecasts and weather forecasts by different weather bureaus and prognostic institutes. It was found that during recent years there has been a considerable decrease in the increase in the quality of the forecasts, and in many cases on the curve there is a "plateau" or even some deterioration in the quality of the forecasts. In the United States some experiments have been carried out for clarifying the reasons for this situation. Murphy himself is a supporter of the point of view that the cessation of an increase in the quality of forecasts is associated with some negative effect exerted on the weatherman by the availability of computer objective forecasts. Since computer methods are used in the United States for obtaining weather forecasts, and not only for forecasts of the general situation, weathermen have begun to think less and make more use directly of forecasts obtained using computers. In America this phenomenon is called "meteorological cancer." Thus, the interaction between man and machine in practical forecasting is the object of serious investigation.

Below we give the basic conclusions from the reports of Doctor Murphy in his own formulation.

1. Objective and subjective stochastic weather forecasts are issued in the United States on a routine basis. Objective stochastic forecasts are produced in the "MOS" system for a number of weather elements (statistics of the results of numerical models) and are transmitted to forecasters at local prognostic agencies as basic auxiliary information. Subjective stochastic forecasts are formulated by forecasters only for precipitation and are transmitted to the population.

2. Experienced forecasters can give a reliable and correct subjective quantitative evaluation of the uncertainty inherent in weather forecasts, both with the assistance of objective stochastic forecasts and without them.

3. The rates of improvement in the quality of forecasts of meteorological fields and weather forecasts have slowed down during recent years. Moreover, the curve of increase in the quality of weather forecasts in 1970

evidently attained a "plateau," which means either an absence of improvement or even an insignificant deterioration in the forecasts.

4. Objective weather forecasts, used as basic information, can exert an unfavorable effect on forecasters (psychological, etc.), in the last analysis on the quality of subjective weather forecasts formulated by man. The problem of interaction between man and machine in routine weather forecasting requires serious investigations (at least in the United States).

5. Entirely reliable stochastic forecasts (that is, those in which the predicted probability corresponds to the observed frequency of the phenomenon) are more valuable for the user than categoric and climatological. This conclusion was also correct for forecasts with different degrees of "reliability."

6. In definite situations and under some conditions there are sequential or even functional relationships between the measures of accuracy and the subsequent evaluation of the value of the stochastic forecasts. Therefore, in some cases such relationships can give additional information on the value of the forecasts. However, in situations with more than two states (or events) there can be cases when more precise forecasts are less valuable (with a subsequent evaluation).

7. Investigations of the value of weather forecasts almost always show that the gain associated with the proper use of these forecasts exceeds (frequently significantly!) the expenditures on obtaining them. These are pleasant results, but they must be viewed with caution, especially since the investigations are usually made on the basis of many assumptions and also because these investigations are made by the forecasters themselves.

G. V. Gruza

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 pp 119-121

[Article by N. P. Smirnov and E. I. Sarukhanyan]

[Text] The second Soviet-American Conference on the Program "POLEX-South-International Program for Investigation of the Antarctic Ocean" was held during the period 13-15 June at Cambridge, Massachusetts, in the halls of the Massachusetts Institute of Technology. It met for a discussion of the results of joint studies in the Antarctic Ocean in the course of 1977-1978 and the prospects for further investigations.

The Soviet delegation, including seven specialists, was headed by Corresponding Member USSR Academy of Sciences A. F. Treshnikov. The United States delegation, which organized the conference, was headed by Professor G. Baker, co-chairman of the executive committee of the International Program for Investigation of the Antarctic Ocean. In addition to Professor Baker, a number of leading specialists in the field of study of the Antarctic Ocean participated in the conference on the American side.

The Soviet and American specialists presented 14 reports containing the principal results of recent investigations in the Antarctic Ocean. A number of reports also contained proposals for specific experiments which will be carried out in the summer of 1978/1979 in the region between Africa and Antarctica, in Drake Strait and to the southeast of New Zealand. The second half of the conference was devoted to a discussion of the direction for further cooperation between the USSR and the United States in investigation of the Antarctic Ocean.

Without dwelling in detail on the reports presented by the participants, we will note the principal scientific results discussed at the conference.

The principal results of the three years of joint cooperation in the field of investigations of the Antarctic Ocean were presented in a report by Corresponding Member USSR Academy of Sciences A. F. Treshnikov, who, while giving a positive evaluation of the results of the cooperation, proposed a number of major directions in which Soviet-American cooperation should develop during the coming years. In other reports by Soviet participants the most detailed exposition was for the results of investigations carried out in the Scotia Sea during the summer of 1977/1978. Also presented were the results of instrumental measurements of velocities of the Antarctic Circumpolar Current, its structure and dynamics in the region of passage across the South Antilles sill (report by A. F. Treshnikov, E. I. Sarukhanyan, N. P. Smirnov). The unique data collected by Soviet researchers are indicative of the unidirectionality of water flow in the Antarctic Circumpolar Current in this particular region and the presence of high bottom velocities (60-70 cm/sec). The report of N. P. Smirnov gave the results of geostrophic computations of water circulation in the Scotia Sea and an estimate of the water balance in the sea.

American researchers presented the results of a study of level fluctuations using underwater mareographs in the neighborhood of Drake Strait (report by D. Baker). Three annual series of level observations demonstrated the presence of well-expressed fluctuations with 14-day and semi-annual periods and also the existence of a trend. American researchers attribute the first of these fluctuations to long-period semimonthly tides. They regard the semiannual fluctuation to be a result of the total effect exerted on the ocean level by tidal disturbances with a semiannual period and semiannual variations of atmospheric processes.

The results of a study of the structure and dynamics of the zone of the Antarctic polar front were examined in a report by B. V. Afanas'yev and N. P. Smirnov. A report by W. Emery discussed the results of long-term American observations of the Antarctic polar front in the neighborhood of Drake Strait. The conclusions drawn by American researchers coincide with the results of Soviet investigations in the Scotia Sea, in particular: the relative stability of the mean position of the frontal zone and the variability scales, associated with formation of meanders and eddies.

A report presented by A. Gordon proposed a hypothesis concerning the formation of a quasistationary polynia in the Weddell Sea and also the role which the presence of such a polynia can play in the formation of Antarctic bottom waters. As a result of the discussion, the hypothesis of a decisive role of the upwelling of deep waters in the formation and maintenance of the polynia in the Weddell Sea was subjected to criticism. However, the opinion was expressed that bottom waters can be formed in the polynia region.

In the reports of American researchers great attention was devoted to an analysis of the horizontal and vertical correlation of the variability of currents in Drake Strait on the basis of instrumental observations (report by F. Skiremammano). The principal objective of these investigations was obtaining scientifically sound criteria for the planning of a new major experiment for study of the structure and dynamics of the Antarctic Circumpolar Current in Drake Strait in 1979-1980.

At the conference there was also a discussion of the results of modeling of water circulation in the Antarctic Ocean. For example, in a report by V. V. Guretskiy, V. O. Ivchenko and E. I. Sarukhanyan the authors presented an original diagnostic model of circulation in the Antarctic Ocean and proposed methods for the parameterization of mesoscale eddies in problems involving description of global circulation.

K. Fendri gave an estimate of barotropic water transfer through Drake Strait.

In the field of study of energy exchange between the ocean and the atmosphere and the energetics of the atmosphere, as before, the principal studies were carried out by Soviet researchers.

A review of the results of instrumental observations of currents in Drake Strait under a three-year program and a description of the structure of the new "Drake-79" oceanic experiment were presented in a report by J. Morrison. The experiment will be carried out in January 1979 and will involve the placement of about 20 buoy stations with submerged buoys with current meters and temperature meters over the entire area of Drake Strait for the purpose of a quantitative description of the spatial-temporal variability of the field of currents in this region at different scales.

A report by N. A. Kornilov and E. I. Sarukhanyan was devoted to an exposition of the results of long-term investigations on a section along 20°E and a draft of a program for the oceanic experiment "POLEKS-Yug-79." The experiment will be carried out in the region between Africa and Antarctica during the first special observation period of the FGGE and will include the carrying out of a complex of aerometeorological observations on ships, placement of FGGE drifting buoys, setting out of buoy stations with sumergible buoys, a hydrological survey of the water area and work in the polar frontal zone.

Thus, in the course of the conference there was a presentation of the principal results of Soviet and American investigations in the region of Drake Strait and the Scotia Sea, carried out during recent years. The investigations carried out within the framework of cooperation and represented in the conference reports made it possible to advance considerably in an understanding of hydrophysical processes in the Antarctic Ocean, to determine in considerable detail the structure of the Antarctic Circumpolar Current and the Antarctic polar front in the investigated regions, to obtain an evaluation of water transport, and to evaluate the degree of influence of the hydrological front on atmospheric processes. Thus, due to the joint investigations there has been a marked increase in the effectiveness of scientific research work.

This feeling is shared by both Soviet and American specialists, who in the course of the discussion expressed complete satisfaction with the results of the joint three-year cooperation in the Antarctic Ocean and expressed the opinion that it must be continued and intensified for the longest possible period. In the opinion of both sides, the main efforts must be directed to solution of the problems in large-scale energy interaction between the atmosphere and ocean, the structures and dynamics of the

Antarctic Circumpolar Current and the Antarctic polar front, as well as the formation of Antarctic bottom waters.

The Soviet and American specialists agreed on specific measures for the exchange of specialists on ships and observational data. The opinion was also expressed that it is desirable to exchange specialists in the field of numerical modeling of circulation in the Antarctic Ocean between the scientific research institutes of the USSR and the United States. The proposal of American researchers that there should be organization of a joint oceanic experiment in the neighborhood of the Weddell Sea polynia was also met with understanding.

Thus, this conference once again confirmed the effectiveness of Soviet-American cooperation in the field of investigations of the Antarctic Ocean and the desirability of its development in the future.

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 1978 p 121

[Article by B. I. Silkin]

[Text] Smog arises primarily from interaction between automobile exhaust and atmospheric oxygen in the presence of solar radiation forming an adequate quantity of ozone for this purpose. However, the processes of interaction between ozone and the remaining atmospheric components, leading to the appearance of such a phenomenon, have still been studied inadequately.

A recent discovery, made by the physicists R. Suenram and F. Lovas (US Bureau of Standards), casts definite light on such processes. They established the existence of a new class of organic substances -- dioxyrans, represented by a simple three-ring molecule consisting of carbon, hydrogen and oxygen atoms and serving as an "intermediary" in the smog formation process.

This discovery has led to a reexamination of the formulated models of smog which laid responsibility for this on the free radicals (unstable chemical substances) forming during the interaction of automobile exhaust with ozone. The investigations show that the reason lies in the appearance of less active molecular compounds, such as dioxyran, created in the reaction between ozone and ethylene, ejected by internal combustion engines.

The existence of dioxyran was postulated for the first time by the American chemists W. R. Wodt and W. A. Doddard in 1975, but such a molecule could not be discovered due to the fact that at the ordinary temperatures at which the reaction transpires the lifetime of dioxyran is extremely short. Suenram and Lovas succeeded in doing this due to the use of low-temperature microwave spectrography which stabilized matter for a time adequate for its observation.

Then they studied the reaction between ozone and other final olefins (the family of hydrocarbons to which, in particular, ethylene belongs). The next stage in the investigation will be to determine specifically what dioxyran component plays what particular role in smog formation. This will probably help in contending with smog, causing great damage to the health of the population in large cities.

The eddylike currents recently discovered in the world ocean are now being investigated from space. For example, from aboard the American artificial earth satellite "Landsat," situated at an altitude of 915 km above the planetary surface, it was possible to take a space photograph on which at least eight individual formations of this type could be distinguished.

The processing of the photograph, carried out at the US Geological Service, Reston, Virginia, under the direction of R. S. Williams, made it possible to detect the existence of three well-developed double annular eddies attaining a length of 70 km. Some of these "rings" have a diameter of not less than 30 km.

A study of the newly discovered phenomenon plays a major role in meteorology and oceanology, including in the investigation of interaction between the ocean and the atmosphere, in the tracing of the processes of contamination of the water medium, in measuring plankton productivity, etc.

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According to the concepts now prevailing among specialists, the movements of water masses, especially those associated with action of the atmosphere, are small at great depths in the ocean and cannot exert an influence on bottom relief. However, recent investigations carried out in the Atlantic Ocean, in the region of the Gillis underwater volcano (to the notheast of Bermuda), have demonstrated that very significant movements of sedimentary rocks are occurring on its slopes which it is difficult to explain on the basis of such concepts.

Around the Gillis submarine mountain, whose peak is situated at an elevation of approximately 3 km above the ocean floor surrounding it, specialists placed a network of automatic current recorders on its slopes and at depths attaining 5,000 m. The data registered by these instruments indicated that directly after the passage of hurricanes, which attain a great intensity in the Bermuda region, new currents appear in the bottom layer, even at a depth of 5 km. In three cases there was found to be a rather considerable rate of movement of the water masses, attaining 30 cm/sec; this happened each time after a hurricane.

Such sporadically arising and disappearing currents can fully explain the redistribution of sedimentary materials on the slopes of Gillis volcano and the significant change in local relief which is observed there.

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