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SOME PROBLEMS OF METEOROLOGY OF THE STRATOMESOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 5-13

[Article by G. A. Kokin, doctor of physical and mathematical sciences, Central Aerological Observatory, manuscript submitted 9 Jun 80]

[Text]

Abstract: The author examines some problems in the present status of the stratomesosphere. The article discusses methods for collecting the information, climatic characteristics of the upper atmosphere, problems involved in intraseasonal and interseasonal restructurings, different factors in the formation of the thermal and dynamic regimes, as well as individual aspects of solar-atmospheric relationships.

The region of altitudes 20-120 km is constantly attracting the attention of researchers. This is attributable not only to the theoretical, but also the practical aspects, which are determined by the needs of aerospace science and radio communication, but also synoptic and climatological study of the troposphere. The latter circumstance is associated with the fact, in particular, that such catastrophic phenomena as winter stratospheric or stratomesospheric warmings are accompanied by the blocking of tropospheric processes, and the climate of the troposphere to a definite degree is dependent on radiation and dynamic processes in the stratomesosphere.

All this has stimulated international scientific organizations to propose the global research project MAP (Middle Atmosphere Program) (IAMAP), which is to be implemented during the period 1979-1985.

Most of the data on temperature and wind in the indicated altitude region have been obtained using radiosondes (to altitudes 30 km), rockets, and recently, IR satellite radiometers.

The methods for measuring atmospheric parameters with radiosondes are well known; rocket methods are more diversified, different with respect to accuracy characteristics, varying with respect to working range of altitudes, complexity, and accordingly, degree of use. For example, the rocket grenade method, to a considerable degree without significant systematic errors, is so complex in application that it has not come into wide use, and according to data at our disposal at the present time is not in use at all. Other methods, such as the Pitot tube method or the method of light falling spheres, are used sporadically at individual points. The principal mass of data has been accumulated by means of rocket probes in which the temperature sensor used is a thermistor or resistance thermometer and the wind sensor used is a parachute. The sounding is accomplished for the most part from the network of rocket sounding stations in the USSR and the United States. In addition, a mass of regular data is obtained in Japan (Riori), in India (Tumba polygon, in collaboration with the USSR), and more limited masses of data -- in Great Britain and France. Measurements of temperature and wind by means of rockets were earlier made at Woomer (Australia), and also in some other countries. Rocket measurements for measuring classical meteorological parameters, used in different countries, have different systematic and random errors, but as indicated by their comparisons, the discrepancies in data are small to 60 km. Above this level the differences become substantial and special attention is being devoted to the correlation and collation of the different methods.

Unfortunately, satellite methods applicable to the considered levels are more of a semiquantitative character because the basis for the processing of data is the regression relationships between the radiation flux measured with radiometers and temperature or geopotential difference, determined by direct methods, and also geopotential charts for the principal lower levels. Despite this, the satellite method makes possible the best study of macroscale processes in the upper atmosphere. Recently surface radioelectronic methods have come into increasing use for investigation of dynamic parameters in the upper atmosphere. The method of radar observation of meteor trails and the radio fading method for determining wind in the upper mesosphere have come into extensive use.

Successful attempts have been undertaken for studying movements in the stratomesosphere by the method of incoherent scattering of radio waves, but due to its high cost this method cannot be employed on a network basis, although it makes it possible to obtain continuous series of observations, which is especially important in a study of diurnal and more short-period atmospheric fluctuations. Attempts to use the method of partial reflections of radio waves have been undertaken for these same purposes.

The composition of neutral and charged components is determined by remote (optical, spectrophotometric, radiometric, laser and radiophysical) and contact (mass spectrometers with cryogenic evacuation, collection of samples into cylinders, chemiluminescent instruments, thin silver films, resonance-luminescent instruments, aluminum oxide and coulometric sensors, sensors of aerosol particles, d-c probes, high-frequency and impedance probes, special capacitors, etc.) methods.

Unfortunately, not one of the enumerated methods or instruments for the time being has become a network instrument or method, although optical methods have come into quite broad use, especially in satellite limb sounding.

Now we will examine in greater detail some peculiarities of the structure and processes in the stratomesosphere. The seasonal change in the direction of zonal flow, caused by the seasonal inversion of the temperature gradient, is a characteristic feature of the considered layers of the atmosphere.

The summer period is characterized by an almost zonal distribution of temperature and a predominance of easterly zonal flow, determined by the stratomesospheric anticyclonic vortex, whose center virtually coincides with the geographical pole. In the stratosphere of the summer northern hemisphere the temperature gradient is directed from the high to the middle latitudes. At an altitude of about 60 km there is a change in the sign of the thermal gradient. At an altitude of 80 km in the middle latitudes the temperature is approximately -90°C, whereas in the polar regions it is -100°C or lower.

During the summer in the southern hemisphere there is a similar picture, but on the basis of a relatively limited volume of observations the conclusion can be drawn that the gradient in the stratosphere between the middle and high latitudes somewhat exceeds the similar values for the northern hemisphere, the inversion of the gradient occurs at altitudes 65-70 km, and the value of the temperature gradient itself at these levels is approximately the same as for summer in the northern hemisphere.

During one and the same summer season the interhemisphere differences in wind velocity at similar altitudes are manifested particularly strongly in the upper stratosphere and lower mesosphere of the low latitudes (in the southern hemisphere the wind velocity is 20-30 m/sec greater in the region of the tropics). In the middle latitudes the interhemisphere differences decrease and do not exceed 5-10 m/sec (in the southern hemisphere the wind velocity is greater). These fluctuations are associated with the asymmetry of the annual variation in the tropical and equatorial zones of both hemispheres. According to some data, in the stratosphere of the summer hemisphere (20-35 km) there are traveling waves in the temperature and wind fields moving in the general flow with a velocity exceeding the velocity of the latter. The nature of such formations for the time being has not been clarified. Since in the tropical and equatorial latitudes there is a predominance of the semiannual harmonic in temperature fluctuations, the temperature gradient between the temperate and tropical latitudes varies considerably in both the summer and winter seasons.

The winter period is characterized by a westerly flow caused by a cyclone whose center is situated in the high latitudes and also a substantial impairment of zonality in the distribution of temperature and wind. In the northern hemisphere these impairments are more substantial than in the southern hemisphere. In the northern hemisphere a temperature decrease to 30-50 km continues up to the high latitudes. In the upper stratosphere of the southern hemisphere the region of lowest temperatures is displaced in a meridional direction into the region 50°S. This can be associated with the formation of a region of relatively high temperatures in the upper stratosphere over Antarctica in the second half of the winter. As a result, in the zone 50-70°S during the greater part of the winter period there is an inversion of the mean meridional temperature gradient at altitudes greater than 30-35 km. In the northern hemisphere, however, a similar inversion in general is not observed. There are different hypotheses concerning the temperature rise in the mesosphere of the winter hemisphere. A hypothesis can be expressed concerning the nature of the interhemisphere differences in this phenomenon, but all this for the time being does not have an unambiguous explanation.

The value of the positive temperature contrasts in the upper stratosphere in the subtropical and middle latitudes of the winter southern hemisphere is greater than in the winter northern hemisphere. This is one of the reasons for the interhemisphere differences in wind velocity in the upper stratosphere. According to some data, the interhemisphere differences in the zonal wind velocity in the mean winter stratosphere of the extratropical latitudes exceed 40-50 m/sec (in the southern hemisphere the wind velocity is greater).

A change in the nature of the circulation in the stratomesosphere occurs in spring and autumn for each of the hemispheres, clearly delimiting the summer and winter periods. In addition to interseasonal restructurings, in the stratomesosphere there are large intraseasonal restructurings accompanied by stratospheric or stratomesospheric warmings. It must be noted at once that despite the general similarity, the restructurings in the northern and southern hemispheres have many significant differences. The nature of the interseasonal restructurings of circulation is clear and is determined by the annual variation of the thermal regime in the stratomesosphere. However, the processes developing with a change in the thermal regime of the stratomesosphere and determining the nature of the interseasonal restructurings are different. For the most part they have a dynamic character, but in individual years the contribution of radiation processes is substantial.

It was discovered earlier that the spring reversal of circulation occurs first at altitudes greater than 80 km, and then this process moves down as far as the velopause; the autumn reversal, on the other hand, begins from the middle stratosphere and is propagated upward and downward. The duration of the spring restructuring is greater than the duration of the autumn restructuring. It was established in later investigations, making it possible to create high-level pressure-pattern charts, that the spring restructuring, like the autumn restructuring, begins for the most part in the middle stratosphere and is propagated into the upper and lower layers. It was noted that sometimes the spring restructuring also begins in the upper mesosphere simultaneously with restructuring in the middle stratosphere. The times of onset of the spring restructuring, in contrast to the autumn restructuring, migrate rather greatly and this is also true of its duration. As a result, it is possible to distinguish early, intermediate and late spring restructurings. The onset of an early restructuring is in the second half of March, the onset of an intermediate restructuring is about the middle of April, and the onset of a late restructuring is in late April or early May. The time of onset of the autumn restructuring is the second half of August and the duration is approximately 20 days.

We note that in the southern hemisphere the times of onset of the spring restructuring migrate less and its duration is also less than in the northern hemisphere.

A number of investigations have been carried out for the purpose of determining the relationship between the time of onset of the spring restructuring and the phase of the quasi-two-year equatorial cycle of circulation, and also the nature and times of intraseasonal restructurings, but, in our opinion, unambiguous relationships have not yet been established.

Although the morphology of the intraseasonal restructurings has been investigated in sufficient detail, their physical nature still has not been thoroughly clarified.

The development of high-altitude anticyclones (Pacific Ocean and Atlantic) is attributed by a number of authors to the propagation of long traveling waves from the troposphere into the stratosphere, arising as a result of instability of the westerly general flow. The propagation of these waves into the stratosphere is related to the development of unstable stratification of temperature and wind in the stratosphere. However, until now this concept has not been thoroughly developed and a number of features of intraseasonal restructurings have not yet been explained. In particular, problems relating to the morphology of development of high-altitude anticyclones are unclear, their migration paths have not been explained, the fact of appearance of centers of heat associated with the mentioned high-altitude formations is not fully understood, etc. The opinions cited in the literature have more the form of hypotheses than rigorous theories.

Synoptic research methods have made it possible to establish that intraseasonal restructurings and the warmings in the northern hemisphere associated with them are macroscale processes, in contrast to processes in the southern hemisphere, where they rarely arise, have a local character and have a relatively low intensity, not exerting any significant influence on circulation processes.

According to the modern WMO classification, intraseasonal restructurings can be classified as strong, weak and local. Each of them, as indicated above, is associated with the development of a high pressure region. In addition to the two anticyclones mentioned above, recently such an anticyclone was discovered in the Indian Ocean and the warmings associated with it were propagated to the Central Asia and Siberia regions. In addition, it was established that the spring restructuring is associated with the intrusion of the Pacific Ocean and Atlantic anticycones into the polar latitudes. It was emphasized that the more powerful the intraseasonal restructuring, and the later it occurs, the later will be the onset of the spring restructuring. During recent years (beginning in 1974) it was discovered that powerful final warmings can undergo direct transition into spring restructurings. With the approach of anticyclones to circumpolar space the velocity of the anticyclonic vortex increases, which is a result of a sharp increase in the pressure gradient. With velocities of approximately 70 m/sec a heat wave arises, propagating downward from great altitudes. The horizontal propagation of heat occurs across the flow and along the frontal discontinuity with velocities exceeding the velocity of propagation of heat due to turbulent heat conductivity. Theoretical investigations have shown that this propagation of heat is a wave process. In the case of strong warmings the temperature of the upper stratosphere increases by 40-60°C. It was noted that in a case when the upper boundary of the anticyclones attains the upper mesosphere there will be mesospheric or stratomesospheric warmings. Ionospheric sounding has indicated that periods of warming are accompanied by the anomalous absorption of radio waves and direct measurements in this period have revealed an increase in the electron concentration in the ionospheric D region. This indicates, evidently, a change in the composition of atmospheric air due to powerful vertical mixing. True, it was recently demonstrated that an increase in the electron concentration in the ionospheric D region apparently occurs only in the case of mesospheric or stratomesospheric warmings.

Some authors have attempted to attribute winter warmings to the direct effect of corpuscular streams with an increase in solar and geomagnetic activity. However, the apparently real temporal coincidence of these phenomena which has been noted cannot be regarded as their direct correlation. Some facts indicate that if such a correlation does exist, it is indirect and more complex. We emphasize that during a period of warmings there is a marked temperature decrease in the lower stratosphere and troposphere, not only in the region of warmings, but even in the tropical latitudes; hence, evidently, there is a partial transport of energy into the higher latitudes. In general, the winter season is characterized by a decrease in the solar energy accumulated by the atmosphere and therefore the role of dynamic factors increases to a considerable degree.

Now we will proceed to an examination of some processes in the tropical region. As indicated above, the thermal regime in this zone is characterized by the presence of both semiannual and annual harmonics. The wind regime is characterized by the presence of semiannual, annual and quasi-two-year cyclicity, that is, with such a frequency the easterly flow is replaced by a westerly flow. Already in the 1950's it was established that the easterly circulation of the summer hemisphere in the middle stratosphere is propagated into the winter hemisphere; the zone of propagation in different geographical regions is different and varies from year to year. Accordingly, it can be surmised that the annual cycle in the tropical zone is caused by the annual variability of atmospheric parameters in the middle and high latitudes. The nature of the quasi-two-year circulation cycle has not yet been precisely established, although there are several theoretical attempts at its explanation. One of these is based on the correlation of this cycle with the two-year cycle in the variation of solar radiation caused by the migration of the earth's orbit around the sun; another theory attributes this phenomenon to parametric resonance arising as a result of the annual variation of solar radiation.

We note at once that quasi-two-year cyclicity is also observed in the intensity of galactic cosmic rays, in the variability of the planetary geomagnetic index, in the indices of zonal and meridional circulation, in the intensity of winter stratospheric warmings, etc. Accordingly, we feel that the solar radiation hypothesis of quasi-two-year cyclicity is preferable. It was also noted that the duration of the easterly phase of the quasi-two-year cycle is dependent on the degree of solar activity. The energy of the tropical and equatorial zones probably plays a substantial role in formation of the high-altitude Pacific Ocean, Atlantic Ocean, and possibly, Indian Ocean anticyclones.

The polar regions are characterized by an unstable stratification, which creates conditions for the propagation of wave disturbances in them. If it is taken into account that the stratosphere and thermosphere of the tropical and equatorial regions are accumulators of solar electromagnetic energy, whereas the polar region is an accumulator of corpuscular energy, it can be postulated that precisely these regions determine many processes in the middle latitudes. However, this hypothesis requires further confirmation.

Both the zonal background distribution of structural and dynamic parameters of the stratomesosphere and the factors determining energy transitions in the atmosphere are caused by the absorption of solar energy of wave and corpuscular nature. Some of the absorbed energy is then radiated as IR radiation into space; part generates dynamic and dissipative processes in the atmosphere itself.

The principal components responsible for the absorption of solar UV energy in the considered range of altitudes are molecular oxygen and ozone. The short-wave part of the UV spectral range is absorbed above 100 km and causes the dissociation of molecular oxygen (Schumann-Runge continuum); the longer-wave part of the UV radiation dissociates molecular oxygen at lesser altitudes, causing ozone formation. In turn, ozone, being an active accumulator of radiation energy in the range of wavelengths 2600-3500 A, is responsible for the heating of the upper atmosphere and lower mesosphere. Some of the solar energy in the visible part of the spectrum is absorbed by ozone in the lower stratosphere, and although the absorption coefficient in this spectral region is extremely small, a definite effect from absorption of this radiation is observed, because this spectral region takes in a considerable part of the solar wave energy. Some of the wave energy is absorbed and scattered by the aerosol component, but computations of these mechanisms are difficult due to the extremely limited information available on the physicochemical nature of stratomesospheric aerosols.

The ozone heating function is dependent on the system of chemical reactions determining its equilibrium state in the atmosphere. Despite the great number of studies which have appeared recently in connection with the problem of artificial modification of ozone, the question of receipts and losses in the photochemistry of atmospheric ozone additional to those set forth in the Chapman theory for the time being still remains open and this limits the possibility of parameterization of radiant receipts and losses of energy, which is extremely necessary for creating three-dimensional models of general circulation of the atmosphere. Some of the solar UV radiation is absorbed above 60 km by water vapor, which leads to the formation of additional quantities of hydroxyl and atomic hydrogen, actively participating in ozone cycles. The emission of the radiation part of the energy occurs for the most part in the IR range.

The principal emitters are carbon dioxide (15μm), ozone (9.6μm) and water vapor (2.7; 6.3μm and > 20μm). In the lower thermosphere a definite part of the IR energy is emitted by atomic oxygen (63μm). Whereas carbon dioxide is a quite stable component, the other components are extremely variable. This applies, in particular, to water vapor and atomic oxygen. The computations show that the main fraction of the emitted energy falls in the CO_2 band 15μm. However, these computations assumed a model of an almost "dry" atmosphere. The latest, now quite numerous measurements have indicated that a model of a "dry" atmosphere does not correspond to reality and the ratio of the mixture can attain 10^{-4} g/g_{air}) at altitudes 70-80 km. In addition, the mixing ratio has a tendency to an increase from the low to the high latitudes. If these data are confirmed, water vapor must be assigned a more significant place in formation of the heat and dynamic regimes of the stratomesosphere, especially during the period of the polar night in the high latitudes.

It appears that corpuscular solar streams to a definite degree can exert an influence on the dynamic and thermal regimes of the stratomesosphere. Their energy is extremely inadequate for exerting a direct influence on the state of the upper atmosphere, but they can play the role of an additional catalyst of some processes.

First, solar cosmic rays, according to some data, exert a definite effect on molecular nitrogen, generating a nitrogen oxide cycle of ozone destruction. Second, they are an additional source of atomic oxygen, which in turn can lead to the additional formation of ozone. These mechanisms for the time being are not indisputable and there is a need for experimental and theoretical investigations directed to their study. Third, solar cosmic rays are an additional source of ionization. Their role is particularly conspicuous in formation of the nighttime ionosphere. An increase in the electron concentration in the ionospheric E region results in an increase in the intensity of the polar electrojet, and this in turn determines the strength of the induced electric field in the atmosphere, and accordingly, the dynamics and thermal regime of the lower thermosphere and upper mesosphere.

We note that the creation of theoretical models of circulation and the thermal regime is impossible without sufficiently complete information on the tensor of turbulent diffusion, and also on the contribution of wave processes to the energy of the upper atmosphere. Although a number of studies devoted to an examination of the mentioned mechanisms have recently appeared, for the time being they have a strictly exploratory character.

It should be noted that solution of the problem of wave generation in the atmosphere is closely related to solution of the problem of the relationship between the underlying surface and the atmosphere.

In particular, the highly promising attempt at explaining the generation of long waves is related to clarification of the mechanism of the influence of the orographic and thermal nonuniformity of the underlying surface on the general flow. We feel that such an examination is only part of the more general problem. The general flow is exchanged with the underlying surface not only by momentum and kinetic energy. As a result of the processes of turbulent thermal conductivity and turbulent diffusion there is a transfer of thermal energy and matter through the atmospheric boundary layer. This must certainly be taken into account in solving such important problems relating to the upper atmosphere as the formation of standing and traveling waves, receipts and losses involved in ozone formation.

It remains to emphasize that a decisive role in these processes is also played by cloud particles, for the upper atmosphere constituting a singular underlying surface. We note that at the present time these matters only now are being mentioned in the literature and the problems are only being formulated.

Finally, we will examine the problem of the relationship between processes in the stratomesosphere, solar and geomagnetic activity. We have already dealt with some of its aspects before.

Whereas the problem of the relationship between solar and geomagnetic activity, on the one hand, and weather tropospheric processes, on the other, still remains open to a considerable degree, evidently due to the fact that clear and unambiguous relationships between these phenomena cannot be established because of characteristic tropospheric "noise," it is easier to establish such relationships with stratospheric and mesospheric processes, despite the fact that these regions have their own characteristic "noise."

The correlation between the diurnal variation of temperature and wind in the stratomesosphere and the diurnal variation of the radiation flux of the quiet sun has been established quite reliably both theoretically and experimentally.

It has also been discovered that during individual periods the amplitudes and phases of diurnal and semidiurnal fluctuations of temperature and wind in the stratomesosphere are disrupted and there are substantial differences from the values predicted by theory. An analysis indicated that these phenomena evidently occur during solarly and geomagnetically disturbed periods. At the present time it is extremely difficult to draw a final conclusion concerning the correlation of these phenomena due to the substantial errors in rocket measurements. It is obvious that during periods of solar disturbances, accompanied by the intrusion of solar cosmic particles into the stratosphere, there are sharp changes in the dynamic and temperature regimes of the stratomesosphere in both the polar and in the temperate latitudes. A singular wave disturbance is propagated from the upper stratosphere upward and downward and the amplitude of this disturbance increases with an increase in altitude and attenuates with its decrease. Five to seven days after this phenomenon in the winter period there are substantial changes in the thermopressure regime of the stratomesosphere, which is evidently attributable to the migration of high-altitude anticyclones into the polar regions.

A spectral analysis which was made indicated that approximately such a periodicity after the onset of a disturbance is observed in the increase in mean temperature of the mesosphere. Since during periods of proton flares, accompanied by the intrusion of solar corpuscular streams into the earth's atmosphere, substantial perturbations were noted in the vertical ozone profile, the conclusion can be drawn that during these periods in the upper atmosphere there is a change in the radiation regime. If it is taken into account that the change in the radiation regime can exert an influence on characteristic atmospheric instability, ways to explain these effects should be considered. It is probable that the above-mentioned fact of correlation of winter warmings with solar and geomagnetic disturbances is explained by these effects. There is also a correlation between 27-day variations of solar activity and the change in the regime of the stratomesosphere. An amplitude of the pressure variations in the stratosphere with a period of approximately 27 days is predominant. Attempts have been made to attribute this phenomenon to resonance phenomena in the atmosphere. We note that such a periodicity is also observed in an analysis of changes in the ozone concentration.

Since uniform series of rocket observations are still relatively short, but nonetheless cover an almost 20-year period, it is possible to establish a correlation between the 11-year solar cycle and a similar periodicity in variations of stratomesospheric parameters.

It can be assumed that the facts of an increase in mesospheric temperature with an increase in solar activity, and also the correlation between geopotential height at the centers of the winter circumpolar vortex and the Pacific Ocean anticyclone and solar activity, have been quite reliably established. It has been found that with an increase in solar activity there is a decrease in the geopotential height of the 10-mb level in an anticyclone and an increase in the geopotential height of this same level at the center of a cyclone. In the summer there is a direct correlation between the level of solar activity and the geopotential height of the 10-mb level at the center of the anticyclonic vortex.

The nature of the correlation between solar activity and the intensity of stratospheric formations is also confirmed by the results of investigations of circulation processes. In particular, it was established that during periods of increased solar activity of the 11-year cycle the velocity of the zonal flow at the 10-mb level decreases, whereas meridionality increases.

Estimates of the contribution of the energy of the polar electrojet to the energy of the upper atmosphere have recently appeared.

The computations indicated that during periods of geomagnetic storms the earth's magnetosphere receives 10^{18} J of energy, which is adequate for the heating of the atmosphere in the auroral zone at an altitude of 100 km by 90 K, and at an altitude of 30-35 km -- by 10 K. In turn, this can lead to a change in the atmospheric reflection coefficient for long waves, characterizing weather processes.

Such is an incomplete and quite fleeting review of the problems characterizing the present status of the meteorology of the stratomesosphere. Solution of the problem of the relationship between processes in the troposphere and in the high layers of the atmosphere in the light of recently accumulated data is now acquiring special significance not only for understanding tropospheric climate, which we have already mentioned above, but also for solution of the problem of long- and superlong-range weather forecasts.

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ON THE PREDICTION OF AIR TEMPERATURE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 14-26

[Article by A. I. Snitkovskiy, candidate of geographical sciences, USSR Hydrometeorological Scientific Research Center, manuscript submitted 13 Jun 80]

[Text]

Abstract: The author examines the status of prediction of the minimum and maximum temperature for 1-3 days in advance and the possibility of improving the prediction of air temperature on the basis of the "model output statistics" (MOS) concept using regression equations.

In routine forecasting work, due to the lack of hydrodynamic models of prediction of the minimum and maximum temperatures, a short-range prediction of air temperature for 1-3 days is prepared by the synoptic method. In the prediction for the first day advection, transformation and the diurnal variation of air mass temperature are taken into account quantitatively [2, 5, 9]; for the second and third days the temperature prediction is prepared for the most part on the basis of general concepts concerning the nature of development of atmospheric processes in the middle troposphere and at the ground, and, in particular, on the position and intensity of the high-altitude frontal zone, the resulting possible change in the pressure field at the ground level, and accordingly, air temperature. Such an approach to temperature prediction for 48, 60, 72 and 84 hours was dictated by the lack of reliable surface pressure prognostic fields for the corresponding times, as well as the temperature and humidity fields in the middle and lower troposphere.

The work carried out during recent years for the objectivization of short-range forecasting of weather phenomena and elements on the basis of the MOS concept [7, 8, 11, 12] indicates an increase in the quality of objective forecasts, that their quality surpasses the quality of synoptic forecasts, and this is manifested particularly clearly with an increase in advance time [11]. These objective forecasts to a considerable degree are responsible for the increase in the success of numerical prognostic fields of meteorological elements, on the basis of which the initial data used in statistical correlations, objectivization of the choice of predictors and selection of decision rules are determined.

In this study we will examine the status of prediction of temperature for 1-3 days and in the example of prediction of minimum and maximum temperatures for Moscow and Moskovskaya Oblast for 24, 36, 48 and 60 hours we will point out possible ways to carry out objectivization and increase the quality of air temperature prediction.

Status of Problem

The existing status of prediction of minimum and maximum air temperatures for 24, 36, 48, 60, 72 and 84 hours will be examined in the example of routine synoptic forecasts for Moscow and Moskovskaya Oblast in 1979. We will turn to the data in Table 1, where we have given the absolute (δ) and relative (ε) errors in synoptic forecasts (S) of temperature for individual seasons of the year. As a comparison, we have also given evaluations of inertial forecasts (I), in accordance with which the temperature tomorrow, on the second and third days should be the same as today. In the third column of the table we have given the standard deviation for temperature (σ) obtained from daily minimum and maximum temperatures averaged for seasons of the year. The relative error $\varepsilon = \delta / \sigma$ given in the table is indicative for a comparison of the synoptic and inertial forecasts for different times and is convenient for subsequent comparison of the relative errors in the prediction and inertia of temperature at different stations. In order to obtain δ, ε and σ the actual temperature was averaged using observational data for 30 meteorological stations in Moscow and Moskovskaya Oblast and the predicted temperature was represented as the mean value of the anticipated temperature gradation (the temperature values in the terms "local," "in part of a territory," "in clearings" etc. were included in the predicted temperature with a weight of 1/3).

Table 1

Evaluation of Predictions of Minimum and Maximum Air Temperatures for 24, 36, 48, 60, 72 and 84 Hours for Moscow and Moskovskaya Oblast and Their Comparison With Inertial Forecasts in 1979

1	2	3							4						
		σ	24 ч 5		48 ч		72 ч		σ	36 ч		60 ч		84 ч 5	
			δ	ε	δ	ε	δ	ε		δ	ε	δ	ε	δ	ε
6	C	4,7	1,4	0,30	2,6	0.54	2,9	0,62	5,2	2,1	0,46	3,4	0,68	3,6	0,72
	И		2,4	0,72	3,9	0.84	4,5	0,96		2,6	0.56	4,0	0,79	4,6	0,92
7	C	3,0	1,4	0,48	2,1	0,70	2.3	0,76	3,1	1,7	0.62	2,4	0.85	2,8	0,94
	И		2,4	0,78	3,4	1.13	3.6	1,19		2,3	0.78	3,3	1.06	3,7	1,21
8	C	4,3	1.7	0,43	2,5	0,62	2,6	0,66	4,9	1,7	0,39	2,2	0,52	2,5	0,56
	И		2,2	0,56	2,6	0,66	2,9	0,72		2.0	0,47	2,9	0,67	3.5	0,78
9	C	7,6	2,3	0,27	4,1	0,55	4,7	0,64	5,7	2,2	0,47	3.1	0,55	3,9	0,69
	И		4,4	0,59	7,1	0,96	8,0	1,07		3,1	0,55	4.6	0.81	5,8	1,02
10	C	4,9	1,7	0.39	2,8	0,61	3,1	0,67	4,7	1,9	0,49	2.8	0,65	3,2	0.73
	И		2,8	0,61	4,2	0,90	4,8	0,99		2,5	0.59	3,7	0,83	4,4	0.98

KEY:

1. Season
2. Forecasts
3. Minimum temperature
4. Maximum temperature
5. hours
6. Spring
7. Summer
8. Autumn
9. Winter
10. Year

C = synoptic
И = inertial

An analysis of the data in Table 1 makes it possible to draw the following conclusions:

-- in general, synoptic forecasts for 1-3 days are appreciably better than inertial forecasts, but in months when the inertia is great the quality of the synoptic forecasts is not much higher than for inertial forecasts;

-- the absolute error in predicting temperature for 48 and 72 hours in comparison with the error in prediction for 24 hours on the average is greater by a factor of 1.6 and 1.8, whereas the absolute error in predicting maximum temperature for 60 and 72 hours in comparison with the error in prediction for 36 hours on the average is greater by a factor of 1.5 and 1.7;

-- due to the greater variability of nighttime temperature in comparison with daytime temperature in the autumn and winter the absolute error in predicting the minimum temperature for 24, 48 and 72 hours is greater than the absolute error in predicting maximum temperature for 36, 60 and 84 hours.

To be sure, an analysis of 365 cases of the prediction of minimum and maximum temperatures for 24, 36, 48, 60, 72 and 84 hours (Table 1) possibly does not fully reflect the quality of temperature forecasts, but during the last five years routine evaluations of temperature forecasts for 1-3 days in advance for Moscow and Moskovskaya Oblast indicate their stability at the level 87-83% in accordance with the current Instructions on the Evaluation of Forecasts [6].

How good are the synoptic forecasts of temperature whose evaluations are given in Table 1? According to the data in [11], the absolute error in objective forecasts of the minimum temperature in the United States (winter of 1975/76, checked on the basis of data for 126 stations) on the basis of the MOS concept for 24 and 48 hours is 2.3 and 2.9°C; for the maximum temperature for 36 and 60 hours -- 2.5 and 3.1°C respectively. (Unfortunately, the literature pertaining to evaluations of temperature forecasts in the United States do not give the relative forecasting errors and this naturally affords no possibility for a sufficiently adequate statistical analysis.) However, it can be seen from the comparison that the synoptic forecasts for Moscow for the first day are better than in the United States, whereas for 48 and 60 hours they are inferior.

In France, where an objective forecast of the minimum air temperature is accomplished in accordance with the "perfect prognosis" (PP) concept for seven cities in the country with an advance time up to 96 hours, the results of forecasts for the first day also are inferior to synoptic forecasts for Moscow, but on the second and third day are close [10]. For example, the absolute error in objective forecasts in the summer of 1979 for 24 hours was 1.6, inertia 1.8°C, relative error 0.65; for 48 and 72 hours the absolute error in forecasts was 1.7 and 2.1°C, inertia 2.0 and 2.3°C, relative error 0.68 and 0.84. It must be remembered that in France objective forecasts use only information on tropospheric geopotential fields.

From a comparison of evaluations of temperature forecasts in the Soviet Union, United States and France the conclusion can be drawn that the objectivization of temperature forecasting already after 24 hours makes it possible to enhance the capabilities of the weather forecaster.

In the early 1970's specialists at the USSR Hydrometeorological Center undertook an attempt to objectivize the prediction of nighttime (for 0300 hours) air temperature for 24 hours on the basis of the current hydrodynamic model of pressure field forecasting [1]. The prediction was prepared at the points of intersection of a regular grid with a 300-km interval. The absolute error in predicting nighttime temperature cited in [1] is about 3°C, considerably greater than the absolute errors of synoptic temperature forecasts, and naturally such a forecast cannot be used in operational work.

During recent years another attempt was undertaken at the objective forecasting of air temperature. Beginning with mid-1979, on an experimental basis, specialists at the USSR Hydrometeorological Center almost daily have used a synoptic-hydrodynamic model for predicting pressure at the ground level, a hydrodynamic forecast of the geopotential field at the 850-mb level and a model of the trajectories of air particles at these two surfaces in preparing air temperature forecasts at the ground level for 2100 hours on the current day, 0300 hours on the next night and 1500 hours on the next day at points of grid intersection with an interval of 300 km [5, 9]. Our comparison of objective forecasts for 24 and 36 hours with the actual temperatures at Moscow at 0300 and 1500 hours indicates that the absolute error in objective forecasts for the period November 1979-April 1980 for 24 hours is 3.2°C, for 36 hours -- 3.6°C. During this same period of time the errors in synoptic forecasts were: for 24 hours -- 2.0°C, for 36 hours -- 2.1°C. What is the reason for the low quality of the objective temperature forecasts? In our opinion, there are several. First, due to insignificant errors in the pressure field at the earth there can be considerable errors in finding the initial points of the trajectories of air particles and the use of mean coefficients for conversion from the velocity of the geostrophic wind to the actual wind does not reflect the real wind pattern at the earth. Second, the use of inadequately close correlations between the dew point spread at the 850-mb level and the quantity of lower-level clouds for determining the diurnal temperature variation. In addition, the low level of objective temperature forecasts is also related to the quality of objective analysis of temperature and humidity.

A common shortcoming of the mentioned models of objective forecasting of temperature [1, 5] is the absence of forecasts of extremal temperatures in these models. If the difference between the maximum temperature and the temperature at 1500 hours is relatively small, averaging 1-3°C, the difference between the minimum temperature and the temperature at 0300 hours is relatively great. In autumn, winter and spring in the temperate latitudes, when the temperature minimum is at 0600-0900 hours, the difference attains 4-6°C. Accordingly, in numerical models for the prediction of extremal temperatures it is evidently necessary to use statistical correlations for determining the minimum and maximum temperatures.

"Sifting" of Predictors and Evaluation of Regression Equations

In order to include independent predictors in the regression equation we carried out "sifting" of a large group of predictors using the algorithm set forth in [4], the sense of which is as follows.

In the interval L we select the maximum (in absolute value) paired correlation coefficient between the predictant and predictors $r_{zT}^{(L)}$ and the sequence number T of this predictor (z = 1, 2,...,m) is stored. Then we find the paired correlation coefficient r_{jT} between the selected predictor T and the others.

After this we carry out orthogonalization of the system of values of the predictors relative to the predictor T selected in the interval L:

$$\Delta x_{ij}^{(L+1)} = \Delta x_{ij}^{(L)} - r_{jT}^{(L)} \cdot \Delta x_{iT}^{(L)} \frac{\sigma_j^{(L)}}{\sigma_T^{(L)}}, \tag{1}$$

where $\Delta x_{ij}^{(L+1)} = x_{ij} - \bar{x}_j$, $j = 1, 2, \ldots, k$,

z are the values of the variables in deviations from the means; σ_j and σ_T are the standard deviations.

As a result of this procedure

$$\Delta x_{iT}^{(L-1)} = 0.$$

Then the statistical characteristics are again computed for the already transformed orthogonal predictors. The paired correlation coefficients between the predictant and orthogonal predictors are computed, the maximum $r_{zT}^{(L+1)}$ is selected and the number of the predictor is again stored. All these operations are carried out L times.

In each interval L the multiple correlation coefficient $R^{(L)} = \sqrt{D^{(L)}}$ and the accumulated total dispersion of the predictant, caused by the use of the selected predictors,

$$D^{(L)} = r_{zT}^{(1)} + r_{zT}^{(2)} + \ldots + r_{zT}^{(l)}, \tag{2}$$

and also the difference of the accumulated dispersions in adjacent intervals

$$S = D^{(L)} - D^{(L-1)}. \tag{3}$$

are computed.

If the value (3) is less than the stipulated threshold (in our case 0.03), the computations stop.

Thus, there is a ranking of predictors and thereafter the contribution of the predictors to the dispersion of the predictant is determined.

After the ranking of predictors a linear multiple regression is constructed using the algorithm in [3], in which the number of predictors ensuring the best quality of construction of the regression is determined.

The regression is constructed using the method of ordered minimizing of risk, the essence of which is as follows.

In the ordered set of predictors the least squares method is used in constructing a regression for 1, 2, 3,...k predictors. Assume that α_i^0 are regression coefficients found by the least squares method. For each constructed regression we ascertain its quality -- evaluation of the I(k) parameter:

$$I(k) = \int \left(y - \sum_{i=1}^{k} \alpha_i^0 x^i \right)^2 P(x, y)\, dx\, dy. \tag{4}$$

where I(k) is the mean risk; y is the predictant; $x = (x^1, x^2, \ldots, x^k)$ is the vector of predictors; P(x,y) is the joint density of the distribution of probabilities x and y.

It is known from theory [3] that with the probability $1 - \eta (0 < \eta \leq 1)$ the following evaluation is correct:

$$I(k) \leq \frac{I_э(k)}{1 - \sqrt{\frac{k\left(\ln \frac{n}{k} + 1\right) + \ln \eta}{n}}}, \tag{5}$$

where

$$I_э(k) = \frac{1}{n} \sum_{j=1}^{k} \left(y_i - \sum_{i=1}^{k} \alpha_i^0 x^i \right)^2, \tag{6}$$

[Э = em]

$I_{em}(k)$ is the empirical risk; k is the number of predictors used; n is the length of the sample.

Thus, such a number k of predictors is selected so that the right-hand side of the inequality (5) attains a minimum.

The function giving the minimum (5) determines the minimum guaranteed mean risk value (4). The lesser the I(k) value, the lesser is the error of the regression equation which should be expected in the examination.

A comparison of the I(k) values of the different groups of predictors was a basis for selecting from the many regression equations the one required for testing on the basis of operational data.

Data Analysis

An attempt was made to objectivize a synoptic forecast of the minimum and maximum air temperatures at Moscow and in Moskovskaya Oblast for 24, 36, 48 and 60 hours with use of the MOS concept for ascertaining the statistical correlations.

As the initial data for 1976-1979 we selected 184 cases of minimum and maximum temperatures for each of the four seasons of the year. The writing and evaluation of regression equations for 24 and 36 hours were carried out separately for Moscow (the predictant was averaged for 10 stations) and Moskovskaya Oblast (averaging for 20 stations), for 48 and 60 hours as a whole for Moskovskaya Oblast (averaging for 30 stations).

An improvement in the quality of the forecasts in comparison with [7] was sought in the direction of a broadening of the archives of data, a search for new predictors, their "sifting" and evaluation of the regression equations using the mean risk.

Below we give a list of the potential predictors used in the "sifting" procedure. After "sifting" of all the predictors 8-10 usually remained.

Table 2

Regression Equations for Predicting Minimum Temperature for 24 Hours and Maximum Temperature for 36 Hours at Moscow and in Moskovskaya Oblast

Season	Minimum temperature: Moscow		Minimum temperature: Московская область C		Maximum temperature: Moscow		Maximum temperature: Московская область C	
	Предикторы A	Коэффициенты регрессии B	Предикторы A	Коэффициенты регрессии B	Предикторы A	Коэффициенты регрессии B	Предикторы A	Коэффициенты регрессии B
Spring	$I(k)=2,0$		$I(k)=2,3$		$I(k)=3,5$		$I(k)=3,1$	
	Θ_{925}	0,23	T_3	0,22	T_{925}	0,68	T_{925}	0,70
	T_{min}	[illegible]	T_{925}	0,48	λ	0,029	λ	0,03
	λ	0,007	λ	0,012	T_{max}	0,16	T_{max}	0,15
	T_{925}	0,23	T_{max}	-0,21	OB_3^{850}	-0,48	OB_3^{850}	-0,49
	b	- C4,6	T_{min}	0,32	b	2,5	b	2,1
			b	-1,5				
Summer	$I(k)=1,7$		$I(k)=1,9$		$I(k)=3,4$		$I(k)=3,2$	
	T_{925}	0,51	T_{925}	0,41	T_{max}	0,23	T_{700}	0,45
	T_{min}	0,22	OB_3^{700}	0,37	T_{700}	0,16	T_{max}	0,22
	T_{d_3}	0,13	T_{min}	0,22	v	0,24	v	0,24
	b	2,6	b	-0,4	b	17,2	b	16,9
Autumn	$I(k)=2,1$		$I(k)=2,5$		$I(k)=2,4$		$I(k)=2,3$	
	T_3	0,25	T_3	0,24	$T_{min}^{пр}$	0,24	$T_{min}^{пр}$	0,38
	T_{max}	0,16	T_{max}	0,15	T_{max}	0,10	T_{max}	0,27
	T_{925}	0,22	T_{925}'	0,22	T_{925}	0,56	T_{925}	0,34
	$T_{d_{925}}$	0,25	$T_{d_{925}}$	0,25	λ	0,016	λ	0,011
	b	0,5	b	-0,4	b	-0,5	b	-0,5
Winter	$I(k)=3,4$		$I(k)=4,0$		$I(k)=4,0$		$I(k)=3,9$	
	T_{min}	0,16	T_{min}	0,23	$T_{min}^{пр}$	0,49	$T_{min}^{пр}$	0,52
	$T_{d_{925}}$	0,29	$T_{d_{925}}$	0,34	T_{925}	0,41	T_{925}	0,43
	T_{850}	0,30	T_3	0,24	$T_{d_{925}}$	-0,10	Tb_{925}	-0,09
	T_3	0,26	T_{850}	0,31	b	0,6	b	0,4
	v	0,12	$\sum_{850}^{700}(T-T_d)$	-0,08				
	b	-0,7	b	0,2				

пр = predicted
OB = PW
A) Predictors
B) Regression coefficients
c) Moskovskaya Oblast

Potential Predictors for Predicting Temperature for 24 and 36 Hours

T_3 -- temperature at 0300 hours, °C;
T_{min} -- minimum temperature, °C;
T_{max} -- maximum temperature, °C;
T_{dgr} -- dew point at the ground, °C;
T_{925} -- temperature at the level 925 mb, °C;
T_{d925} -- dew point at the level 925 mn, °C;
T_{850} -- temperature at the level 850 mb, °C;
T_{d850} -- dew point at the level 850 mb, °C;
T_{700} -- temperature at the level 700 mb, °C;
T_{d700} -- dew point at the level 700 mb, °C;
$(T - T_d)_{850}$ -- dew point spread at the level 850 mb, °C;
$(T - T_d)_{700}$ -- dew point spread at the level 700 mb, °C;
u, v -- wind velocity components at the ground, m/sec;
u_{850}, v_{850} -- wind velocity components at the level 850 mb, m/sec;
θ_{925} -- potential temperature at the level 925 mb, K;
θ_{850} -- potential temperature at the level 850 mb, K;
θ_{700} -- potential temperature at the level 700 mb, K;
PW^{850}_{3} -- quantity of precipitable water in the layer ground-850 mb, mm;
PW^{700}_{3} -- quantity of precipitable water in the layer ground-700 mb, mm;
λ -- length of day, min;
T^{pr}_{min} -- minimum temperature °C predicted using the regression equation.

Regression equations were written and evaluated using I(k) for each of the seasons of the year for all the predictors selected after the "sifting" operation. Then successively discarding from the end one, two... predictors, we were able to compare I(k) for the regression equations for different groups of predictors. The group of predictors in which the I(k) value was minimum was selected as the main group and the regression equation written for this group was the working equation used in preparing operational forecasts.

Table 2 gives the working regression equations for predicting the minimum temperature for 24 hours and the maximum temperature for 36 hours at Moscow and in Moskovskaya Oblast for the four seasons of the year. Also given here is an evaluation of the equations on the basis of I(k). It can be seen from an analysis of the data in what seasons of the year one should anticipate greater or lesser errors in predicting temperature than in other seasons. In winter the predictions of minimum and maximum temperature on the average will have a greater error than in other seasons of the year.

During different seasons the minimum mean risk for the regression equations for predicting one and the same temperature is given by different predictors (Table 2). In predicting the minimum temperature use is almost always made of information on T_3, T_{min}, T_{max} and T_{925}. In autumn and spring when there is a decrease and increase in the length of day it is desirable that this predictor be used, whereas in summer and winter, due to the transition of the length of day values through an extremum the use of λ loses sense. It can be noted that from winter to summer in predicting the maximum temperature it is better to have information on temperature from the 850 and 700 mb levels than from the level 925 mb, where the diurnal variation exerts a considerable effect. What has been stated confirms the known fact of the summertime propagation of a dry-adiabatic vertical temperature gradient to great altitudes. Allowance for the quantity of precipitable water (PW_3^{850} = 1.5 $q_3 + q_{850}/2$, in mm, where q_3 and q_{850} are the specific humidities at the ground and at the 850-mb level in g/kg) in spring reflects the influence of cloud cover on the diurnal variation of air temperature. Again, as in [7], information on advective values $T - T_d$ at different levels plays virtually no role with this approach to the prediction of temperature.

Now a few words about data at the 925-mb level. It is known that no prediction is made for the geopotential field of the 925-mb surface. Accordingly, in selecting the initial data for 925 mb the nature of the 925-mb prognostic field was identified with the prognostic pressure field at the ground. A comparison of evaluations of the regression equations using I(k), employing and not employing data on T and T_d at the 925-mb level, indicates that on the average information on T and T_d at the 925-mb level decreases the I(k) value by 20%. The latter indicates an exceptionally great significance of data on T and Td at the 925-mb level in predicting temperature at the ground.

The prognostic pressure fields at the 500-mb level, which have clearly justified themselves, are the basis for predicting air temperature for 48, 60, 72 and 84 hours. A specialist, using the future pressure fields and the position of atmospheric fronts on the first day, the prognostic 500-mb fields for the second and third day, the actual distribution of the minimum and maximum temperatures, as well as his experience and intuition, prepares a prediction of surface temperature for 48, 60, 72 and 84 hours. Such an approach to temperature prediction in rare cases makes it possible to give a detailed forecast for day and night and therefore rather frequently the anticipated minimum and maximum temperatures for the second and third days are one and the same.

As a result of the circumstances mentioned above, in the first stage of the investigation it was decided to clarify the statistical relationships between the minimum and maximum temperatures at the earth and the atmospheric parameters at the 500-mb level. We could not apply the MOS concept in selecting the initial data because we did not have archives of 500-mb prognostic fields which had been thoroughly validated. For this reason the initial archives was prepared on the basis of synchronous data, that is, the PP concept was applied. The testing of such an approach was carried out for the winter season of the year when the air temperature variability was the greatest.

Below we give a listing of the potential predictors at the 500-mb level, and Table 3 gives the results of data processing.

Potential Predictors at 500-mb Level for Predicting Temperature for 48, 60, 72 and 84 Hours

H_{500} -- absolute geopotential, dam;
ΔH_{500} -- Laplacian, dam/(500 km)^2;
T -- temperature, °C
u, v -- wind velocity components, m/sec;

AM -- air mass -- warm or cold;
L -- distance to the high-altitude frontal zone (HAFZ), km;
u_{HAFZ}, v_{HAFZ} -- wind velocity components in HAFZ, m/sec;
dH/dn -- geopotential gradient, dam/1000 km.

Table 3

Correlation Coefficients Between Minimum and Maximum Temperatures and Different Atmospheric Parameters at 500-mb Level, Explicable Dispersion of Predictant and Evaluation of Regression Equations (1976-1979, Winter for 184 Cases)

Predictant	H_{500}	ΔH_{500}	T	u	v	AM	L	u_{HAFZ}	v_{HAFZ}	$\frac{dH}{dn}$	A Предикторы, отобранные просеиванием	Объясняемая дисперсия предиктанта, % B	$I(k)$
T_{min}	0,21	0,04	0,39	0,01	0,33	0,22	-0,09	0,05	0,33	0,03	T, ΔH_{500} v, L	26	4,3
T_{max}	0,28	-0,07	0,34	0,05	0,25	0,23	-0,10	0,04	0,22	-0,11	T, ΔH_{500} v	17	5,6

KEY:
A) Predictors selected by "sifting"
B) Explicable dispersion of predictant, %

Table 4

Correlation Coefficients Between Minimum and Maximum Temperatures and Different Atmospheric Parameters, Explicable Dispersion of Predictant and Evaluation of Regression Equations for Prediction for 48 and 60 Hours (1976-1979, in Spring, 184 Cases)

Predictant	T_3	T_{min}	T_{max}	v	T_{850}	$T_{d\,850}$	OB_3^{850} OB = PW	λ	Θ_{850}	Predictors selected by sifting	Объясняемая дисперсия предиктанта, % A	$I(k)$
T_{min}	0,82	0,82	0,79	-0,02	0,73	0,62	0,74	0,78	0,67	T_3, λ, T_{min}, T_{850}, OB_3^{850}	82	3,1
T_{max}	0,69	0,66	0,73	-0,04	0,69	0,51	0,64	0,82	0,68	λ, Θ_{850}, T_3	80	4,6

KEY:
A) Explicable dispersion of predictant, %

It was found that the correlation coefficients between temperature at the ground and atmospheric parameters at the 500-mb level in general are low and the group of "sifted" predictors explains no more than a quarter of the dispersion of the predictant. Despite this, we wrote regression equations, carried out their evaluation using I(k) and evaluated the success of equations on the basis of operational material. Already from an examination of I(k) in Table 3 it follows that the mean risk, despite the PP concept, is high. Checking on the basis of operational materials also indicated low results of the forecast. In January and February 1980 the absolute error in synoptic forecasts of minimum temperature for 48 hours was 4.3 and 4.2°C, for 72 hours -- 4.4 and 4.2°C; for maximum temperature for 60 hours -- 4.2 and 3.0°C, for 84 hours -- 3.7 and 3.8°C. At the same time the absolute error in temperature forecasts using regression equations for each of these time intervals was greater by 0.6-1.0°C. Thereby we confirmed that the use of data at the 500-mb level in itself cannot lead to success.

Table 5

Absolute Error of Synoptic (S) and Regression Equation (R) Forecasts of the Minimum and Maximum Temperatures for Moscow and Moskovskaya Oblast for November, December 1979 and January-May 1980

Month	Fore-casts	24 hours		36 hours		48 hrs	60 hrs
		Moscow	MO	Moscow	MO	MO	MO
November	C P	1,5 1,2	1,2 1,2	1,6 1,4	1,6 1,5		
December	C P	2,5 2,4	2,7 2,6	1,8 1,6	1,9 1,8		
January	C P	2,9 2,2	3,0 2,6	2,3 2,6	2,5 2,8		
February	C P	2,0 1,9	2,0 2,2	2,6 2,4	2,4 2,6		
March	C P	1,9 1,5	2,7 3,0	1,6 1,8	2,0 1,9	2,6 2,4	2,3 2,2
April	C P	1,9 1,5	2,7 3,0	1,6 1,8	2,0 1,9	1,8 1,7	3,3 3,1
May	C P	— —	— —	— —	— —	2,0 1,6	2,7 3,0
Mean	C P	2,1 1,8	2,4 2,4	1,9 1,9	2,1 2,1	2,1 1,9	2,8 2,8

MO = Moskovskaya Oblast C = synoptic, P = regression equations

The question arises as to why there are satisfactory results of prediction of the mean temperature and precipitation for several days when the prognostic information for 72 and 84 hours is only the geopotential field for the 500 mb level?

It is obvious that a factor of importance here is the weatherman's experience. Correcting the objective forecast, he evaluates the advection and transformation of air masses, that is, uses short-range forecasting methods.

If this assumption is correct, is it possible, using the fundamental approach to the prediction of temperature for 24 and 36 hours, to increase the quality of forecasting for 48 and 60 hours (for the time being we leave aside the forecasting for 72 and 84 hours due to methodological difficulties in manual construction of the prognostic pressure fields at the ground for the third day).

For this purpose, manually, having a prognostic chart of pressure and atmospheric fronts for 36 hours at the ground, using predictions of the 500-mb level for 48, 60 and 72 hours, we constructed the surface pressure field and the position of fronts for 48 and 60 hours, and also evaluated possible changes in the pressure field at the 850-mb level for 48 and 60 hours. In accordance with the MOS concept for the spring season of the year (1976-1979) at the initial points of the trajectories for 48 and 60 hours at the ground and at 850 mb we ascertained the predictors which better than the others for the forecast for 24 and 36 hours described the change in temperature (due to the lack of a 925-mb prognostic chart it was, unfortunately, impossible to take the initial data at this level). Table 4 gives a listing of these predictors, their evaluation and an evaluation of the regression equations. With respect to all indices the results given in Table 4 are substantially better than in Table 3. This indicates the correctness of the selected approach to the prediction of temperature for 48 and 60 hours, and also the legitimacy of the use of the derived regression equations in operational checking, as we have done.

Results of Operational Checking

Forecasts for 24 and 36 Hours. The daily operational comparison of synoptic temperature forecasts and regression equation forecasts for 24 and 36 hours has been carried out about 1 1/2 years. The mean absolute error in predicting minimum temperature for 24 hours for the period January-October 1979 for Moscow for synoptic forecasts was 1.5°C, using the regression equations -- 1.6°C; the corresponding figures for the maximum temperature were 1.8 and 2.2°C. After analyzing the reasons for the lower evaluations of forecasts made using the regression equations in comparison with the synoptic forecasts, we concluded that the finding of initial data on the basis of the formal trajectories of air particles using prognostic and actual pressure maps, unfortunately does not always prove successful (the principal reasons for this were mentioned above). Accordingly, since November 1979 the initial data at the ground and at the 925-mb level have been determined in those parts of the pressure formations and frontal zones which were expected at the forecasting point, in the process taking into account the hours of the day of their possible passage or influence. Such an approach to the selection of initial data was quickly reflected in an increase in the success of the forecasts.

Table 5 gives the absolute errors in operational temperature forecasts made by the synoptic and regression equation methods for 24 and 36 hours. It can be seen that the results are identical for the three forecasts and the minimum temperature at Moscow when using the regression equation method is predicted better. It appears that if the temperature forecasts made by the regression equation method are prepared by a regular forecaster, having great experience in practical forecasting work, the absolute forecasting errors can be somewhat less.

Complexities sometimes arise in the forecasting of temperature for 24 and 36 hours by the regression equations method when selecting the initial data. In winter the greatest difficulty arises when predicting the minimum temperature in stable synoptic situations -- anticyclones, when the cooling of the air occurs only in the lowest surface layer. In this case the direct use of temperature at the 925-mb level usually led to an exaggeration of the minimum temperature. Accordingly, making a series of experiments, in anticyclonic situations, when an inversion existed in the boundary layer, instead of temperature at the 925-mb level we took the temperature which was observed at the lower boundary of the blocking layer, situated below 925 mb (in rare cases this also could be the ground surface).

In spring, when due to dense cloud cover and rains the diurnal temperature variation was small and the maximum temperature was low, the computations led to an exaggeration of the maximum temperature as a result of an increase in the length of day.

Prediction for 48 and 60 hours. The right-hand side of Table 5 gives the absolute errors in predicting temperature for 48 and 60 hours for the spring of 1980. It follows from the data in the table that the results of forecasting using regression equations in general are better than when using synoptic forecasts.

An attempt at objectivizing the synoptic temperature forecast for 48 and 60 hours was successful. However, when making a forecast for the second day, as on the first day, there are difficulties involved in the prediction of maximum temperature, as follows from an analysis of I(k) (Table 4) and the absolute errors of forecasts in spring for 60 hours (Table 1). Real forecasting using regression equations confirmed this circumstance. The difficulty is in determining the diurnal temperature variation for the second day. The synoptic methods and predictors selected in the regression equations cannot with sufficient accuracy determine the diurnal temperature variation. In addition, the spring of 1980, in which the regression equations was checked, was anomalous, especially March and May. In mid-spring and in May 1980 the variability of the maximum temperature was 5.6°C; May was exceptionally cold and for almost ten days in May the daytime temperature differed from the norm by 2σ.

An improvement in the forecast of maximum temperature for 60 hours using regression equations is possible with expansion of the archives and the use of new predictors, especially at the 925-mb level.

Summary

The results obtained in predicting air temperature for 24, 36, 48 and 60 hours on the basis of the MOS concept using linear multiple regression equations indicate a promising way for predicting temperature.

An increase in the success of synoptic forecasts and methods for computing weather phenomena and elements can be expected when the initial data are determined in those parts of pressure formations which are anticipated according to the forecast, making use of objective methods for evaluating the selected atmospheric parameters and decision rules.

An improvement in the quality of numerical models of the pressure, temperature and humidity fields, including in the atmospheric boundary layer, even in the immediate future, will make it possible on the basis of the MOS concept to compute weather phenomena and elements for practical purposes.

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STRUCTURE OF ATMOSPHERIC FRONTS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 27-30

[Article by A. Kh. Khrgian, professor, and V. P. Bysik, Moscow State University and All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center, manuscript submitted 13 May 80]

[Text]

Abstract: The article gives an example of analysis of atmospheric fronts, taking into account the acceleration of circulation which is created by considerable precipitation and intensive transformation of potential energy into kinetic energy in a frontal region and accordingly the region of considerable wind velocities in the upper troposphere over the front.

The structure of fronts and frontal cloud systems is of interest not only from the point of view of prediction of weather conditions, but also because in a frontal region there is a transformation of potential latent energy into kinetic energy maintaining the general circulation of considerable regions of the atmosphere. This transformation, the realization of the baroclinic energy of the front, is evidently also associated with the process of water vapor condensation and the formation of precipitation.

Observations reveal that over a warm front there are usually two zones of intensified condensation and increased liquid-water content. The first of these, which can be denoted as zone A, is situated approximately over the surface line of the front; the second, zone B, is situated considerably higher and in front of this line. The first zone is probably associated with convergence in the boundary layer; the second, according to the ideas of V. A. Bugayev, is associated with the concentration of circulatory solenoids in this region, creating considerable vertical movements here [1].

Precisely from such a visualization of frontal structure, below we have examined examples of warm fronts passing over the European territory of the USSR. In the mentioned study V. A. Bugayev proposed as well a simple method for determining the number of circulatory solenoids, which he used, in particular, in evaluating the climatological role of the fronts passing over Central Asia.

The first of the considered fronts, very well expressed in the fields of movement, temperature, etc., was associated with a rapidly moving and deep cyclone on 7-8 January 1973 (Fig. 1). The center of this cyclone was displaced from a point under 71°N, to the north of Iceland, where it was situated at 0300 hours on 7 January (Moscow time), to Kandalakshskiy Gulf after 24 hours and after another 12 hours to the neighborhood of Yemtsa station, to the south of Arkhangel'sk. By this time the pressure at the center of the cyclone had fallen below 975 mb. The warm front of this cyclone could be relatively thoroughly studied using the results of surface observations in Moscow and aerological soundings at Dolgoprudnyy. The frontal line passed Moscow on 8 January at about 14 hours; 12 hours before this the air pressure had fallen from 987 to 976 mb and the temperature had risen from -10.4° to -1.2°C after the passage of the front. A light snowfall began in Moscow beginning at 0700 hours on 8 January. This intensified and continued to 1700 hours when it was replaced by mixed snow and rain. A total of 5.7 mm of precipitation fell during the period 0700-1900 hours -- a quantity significant for winter conditions, when in Moscow, for example, an average of 27 mm falls during the whole of January.

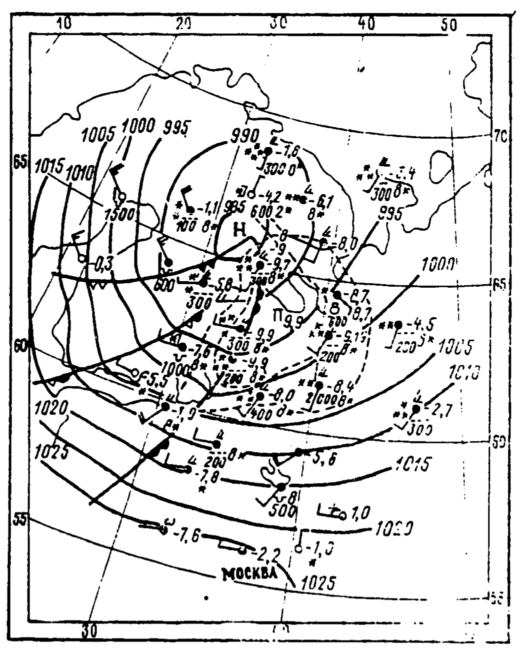

Fig. 1. Structure of cyclone on 8 January 1973.

Vertical sounding carried out at Dolgoprudnyy on 8 January at 0235 hours made it possible to describe a very characteristic structure of a warm front (Fig. 2). In the cold air over the frontal surface there was a small inversion to an altitude of 0.56 km, whereas aloft in it the vertical temperature gradient increased to $\gamma = 0.88°C/100$ m and the stratification near the frontal surface became unstable. [The altitudes in all cases are given above sea level. Dolgoprudnyy is situated at an elevation of 0.19 km.] A transition zone with small γ was between 2.37 and 2.79 km, whereas aloft, in a very sharp frontal zone, extending to 3.11 km, the temperature increased from -21.7 to -17.8°C. The slope of the frontal surface was thus about 1/220. Then there was a layer of essentially moist instability to an altitude of at least 7.2 km. Still higher, in the layer 8-9 km, other individual still more unstable layers were observed. Unfortunately, there were no observations of cirrus clouds on this day and it was not possible to relate these layers to them.

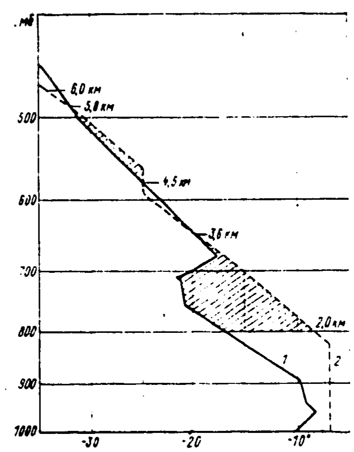

Fig. 2. Data from vertical sounding of front over Moscow at 0235 hours (1) and at 0827 hours (2) on 8 January 1973.

The wind distribution was also characteristic. Downward in the cold air there was predominance of a fresh westerly wind directed from the azimuth $\alpha = 279°$ with a velocity up to 12-14 m/sec. In the frontal zone, between 2.79 and 3.11 km, the wind rotated sharply to the right, to $\alpha = 334°$, whereas aloft, retaining this direction, it intensified still more with altitude -- up to 25 m/sec at 4 km, to 40 m/sec at 7 km and to 50 m/sec at 9.6 km. Such a strong thermal wind should correspond to a great horizontal temperature gradient -- about 13°C at 1000 km up to the tropopause itself. This shows directly that at this time a considerable baroclinicity prevailed in the entire troposphere.

A later sounding on 8 January at 0827 hours even seemingly revealed the presence of two jet streams over the front: one between 1.5 and 4.1 km (with a velocity up to 30 m/sec) and another, with an axis between 8.6 and 9.3 km, with a velocity up to 50 m/sec.

According to the assumption of V. A. Bugayev, the acceleration of circulation near the front, and accordingly, the ascending movements over it and the intensity of condensation should be related to the number N of circulatory solenoids in the baroclinic zone of the front. Computations of this number for zone A are difficult due to the influence of friction, but are very simple for zone B, for example, for the layer from 2 to 6 km. We determined this number for the front of 8 January using an aerological diagram. By plotting the sounding data in two parts of a transverse section of the front on the diagram in the coordinates (T, ln p), it is possible to determine N using the area between the two corresponding curves.

A high concentration of solenoids over the front should correspond to a large quantity of precipitation. A considerable value N = 359 (see Table 1) in actuality corresponded to a large quantity of falling precipitation on 8 January, as we have already mentioned.

Table 1

Number of Solenoids Over Surface of Two Warm Fronts

8 January 1973		16 December 1971	
Layer, km	N	Layer, km	N
2.0-3.6	+356.4	2.2-3.3	+60.7
3.6-4.5	-26.4	3.3-3.6	-13.2
4.5-5.8	+37.0	3.6-3.8	+7.9
5.8-6.0	-7.9	3.8-5.4	-79.2
		5.4-6.0	+29.0
$\sum$ +359.1		$\sum$ +5.2	

The table also gives data on N for the warm front of 16 December 1971 for which with its passage over Moscow the sum of the solenoids was only 5 and accordingly the quantity of falling precipitation was close to 0.

In the investigation of the cyclone and warm front passing in the neighborhood of Moscow on 7-8 January we also used photographs from the satellite NOAA-2. The most suitable photographs for this were those taken on 7 January at 1218 and 2008 hours respectively. The center of the cyclone was then situated near 72°N and 8°E and 70°N and 23°E respectively. The photographs clearly described the vortical structure of the cyclone, especially in its central part, and also the position of the front, noted due to a broad band of cloud cover. In the central part of the cyclone there was a particularly clear expression of the characteristic structure of two cloud concentrations: one, more dense, with the zone of cloud cover being situated directly over the frontal line, and the second -- 500-600 km in front of it. They are separated by a more transparent (darker on the photographs) space and evidently correspond to the mentioned zones A and B. They are blurred and attenuate with increasing distance from the center of the cyclone where the clearings in the frontal clouds become broader and darker.

This double structure of frontal cloud cover unquestionably merits a more detailed statistical investigation.

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STATISTICAL CHARACTERISTICS OF INSTANTANEOUS WIND SHEARS IN THE LOWER LAYER OF THE ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 31-38

[Article by N. L. Byzova, doctor of physical and mathematical sciences, and Z. I. Volkovitskaya, candidate of physical and mathematical sciences, Institute of Experimental Meteorology, manuscript submitted 1 Apr 80]

[Text]

Abstract: The authors propose an indirect method for computing the characteristics of instantaneous vertical wind shears in the atmosphere on the basis of the statistical characteristics of the wind vector at two levels between which the shear is computed (mean values, dispersions of fluctuations, characteristics of correlation between the levels). Experimental data on these characteristics are given for the 300-m layer of the atmosphere in different spectral ranges on the basis of measurements on the high mast of the Institute of Experimental Meteorology. On this basis the proposed method for computing the statistical characteristics of wind shear is tested: comparison of the mean values and dispersions of the modulus, confidence evaluations of the instantaneous values of wind shears by a direct and indirect method using one and the same records. The results of this comparison revealed their satisfactory agreement.

As is well known [4], the vertical wind shear is the difference in the wind velocity vectors at the boundaries of a stipulated layer of the atmosphere $\vec{\Delta V} = \vec{V_2} - \vec{V_1}$. For the purposes of comparability the wind shear is computed in layers with a thickness of 30 m [4] or is reduced to a unit length; it can be expressed through the derivatives of two wind velocity components.

In the atmospheric boundary layer wind shears arise due to different factors. For practical purposes it is necessary to know the resultant shear in those cases when its modulus

$$|\Delta \vec{V}| = \Delta V = \sqrt{V_1^2 + V_2^2 - 2\, V_1 V_2 \cos \varphi} \tag{1}$$

exceeds the critical limits [4] (V_1 and V_2 are the moduli of the wind vectors at the levels z_1 and z_2, φ is the angle between them).

We will represent the total wind shear at a particular moment in the form

$$\overrightarrow{\Delta V} = (\overrightarrow{\Delta V})_{mean} + (\overrightarrow{\Delta V})_{meso} + (\overrightarrow{\Delta V})_{ter} + (\overrightarrow{\Delta V})_{turb} \qquad (2)$$

Here the first term on the right-hand side is related to peculiarities of the profile of the mean wind in the atmospheric boundary layer under different meteorological conditions; the second is related to brief mesoscale phenomena; the third is related to the influence of terrain characteristics (relief, built-up areas, etc.); the fourth is related to the influence of turbulence. Each of the components in (2) relates to different time scales and requires a different approach for its computation.

The methods for computing $(\overrightarrow{\Delta V})_{mean}$ on the basis of boundary layer models and on the basis of the generalized results of aerological measurements are examined in [2, 15]. The form of the wind profile in the boundary layer is dependent on the stability parameter, which can be determined by different methods [3]. The modulus $(\overrightarrow{\Delta V})_{mean}$ is determined by the value of the stability parameter and the wind velocity at a stipulated level. The results of investigations of the wind profiles and mean vertical shears [8, 14] show that in the case of an unstable stratification the shears should be greater in the lower part of the layer, whereas in the case of a stable stratification -- in its middle part. Baroclinicity, fronts and uplifted inversions distort the wind profiles in comparison with standard profiles and therefore, for example, the maximum shears according to measurements on the high mast at the Institute of Experimental Meteorology [14] are several times greater than the standard shears [15] as a result of broadening of the selected weather conditions. In particular, when the wind velocities are moderate there is a local maximum of the maximum wind shears at a height of 75-150 m due to uplifted inversions [14].

The $(\overrightarrow{\Delta V})_{meso}$ and $(\overrightarrow{\Delta V})_{ter}$ values are related to mesoscale temporal or spatial phenomena. In the first case these are such weather systems as squalls, thunderstorms, fronts and the deviations of the wind shears from normal have a brief character. In the second case they are associated with the characteristics of relief, built-up areas and vegetation. All that part of the wind shear which can be considered random is assigned to the $(\overrightarrow{\Delta V})_{turb}$ value.

Combining the first three terms on the right-hand side in (2), for the total shear at a particular moment we have

$$\overrightarrow{\Delta V} = |\overrightarrow{\Delta V}|_{mean} + (\overrightarrow{\Delta V})_{turb}. \qquad (3)$$

In order to determine the statistical characteristics of the modulus of the vector (3) from the statistical characteristics of wind velocity and direction, we transform expression (1), introducing the half-sum U, half-difference δ of the moduli of the wind velocity vectors at the boundaries of the layer, where the wind shear is computed, and the half-difference of the directions ψ:

$$\Delta V = 2\sqrt{\delta^2 + (U^2 + \delta^2)\sin^2\psi}. \qquad (4)$$

The U, δ and ψ values entering into (4) in the first approximation can be regarded as statistically independent, and their dispersions have the form

$$\sigma^2_{U,\delta,\psi} = \frac{1}{4}\left(\sigma_1^2 + \sigma_2^2 \pm 2\, r_{V,\varphi}\, \sigma_1 \sigma_2\right), \tag{5}$$

where the + symbol is used for σ^2_U, the - sign is used for σ^2_δ and σ^2_ψ, σ^2_1 and σ^2_2 are the dispersions of velocity fluctuations (for σ_δ and σ_U) or fluctuations of wind direction (for σ_ψ) at the levels z_1 and z_2, $r_{V,\varphi}$ are the correlation coefficients of these fluctuations at two levels.

We first of all note that the modulus of the mean shear $\overline{\Delta V_1}$ does not coincide with the mean shear modulus $\overline{\Delta V_2}$. However, it is easy to show that for all cases except for small $\overline{\psi}$ and $\varepsilon = \overline{\delta}/\overline{U}$ (the line at top denotes averaging), the corresponding displacement is small and it can be neglected. With $\overline{\psi} = \overline{\varepsilon} = 0$, evidently, $\overline{\Delta V_1} = 0$ and the second moment of the shear modulus (relative to $\overline{\Delta V_1}$) is

$$S^2_{\Delta V} = 4\left(\sigma_\delta^2 + U^2 \sigma_\psi^2\right). \tag{6}$$

Using a two-dimensional Maxwell distribution [1], it is also easy to determine $\overline{\Delta V_2} = 0.89\ S_{\Delta V}$ and the central moment of the shear modulus (dispersion) $\sigma^2_{\Delta V} = 0.21\ S^2_{\Delta V}$. However, in actual practice it may be more useful to use precisely $S^2_{\Delta V}$, since $\overline{\Delta V_1}$ is well known, and $\overline{\Delta V_2}$ is not known.

In accordance with the rules for determining the dispersion of the functions of the random values [1], for $\overline{\psi} \neq 0$, $\overline{\delta} \neq 0$ it is easy to obtain

$$\sigma^2_{\Delta V} \cong \Delta_\delta^2 \sigma_\delta^2 + \Delta_U^2 \sigma_U^2 + \Delta_\psi^2 \sigma_\psi^2, \tag{7}$$

where

$$\Delta_\delta^2 = \frac{4\,\varepsilon^2 \cos^4 \overline{\psi}}{\varepsilon^2 + (1-\varepsilon^2)\sin^2 \overline{\psi}}, \quad \Delta_U^2 = \frac{4 \sin^4 \overline{\psi}}{\varepsilon^2 + (1-\varepsilon^2)\sin^2 \overline{\psi}},$$

$$\Delta_\psi^2 = \frac{(1-\varepsilon^2)^2 \sin^2 2\overline{\psi}}{\varepsilon^2 + (1-\varepsilon^2)\sin^2 \overline{\psi}};$$

and for the case $\overline{\psi} = 0$, $\overline{\delta} \neq 0$

$$\sigma^2_{\Delta V} = 4\left[\sigma_\delta^2 + 2\,\overline{U}^2 \left(\sigma_\psi^2\right)^2 \frac{(1-\varepsilon^2)^2}{\varepsilon^2}\right]. \tag{8}$$

If ε and $\overline{\psi}$ are small, and the turbulence is close to uniform ($\sigma^2_{1V} = \sigma^2_{2V} = \sigma^2_V$, $\sigma^2_{\varphi 1} = \sigma^2_{\varphi 2} = \sigma^2_\varphi$), then for an approximate evaluation from (6) and (5) we have

$$S^2_{\Delta V} \cong 2\left[\sigma_V^2 (1 - r_V) + \overline{U}^2 \sigma_\varphi^2 (1 - r_\varphi)\right] > \sigma^2_{\Delta V}. \tag{9}$$

In the case of isotropy ($\sigma_\varphi = \overline{U}\sigma_V$, $r_V = r_\varphi = r$) instead of (9) we obtain

$$S^2_{\Delta V} = 4\,\sigma_V^2 (1 - r). \tag{10}$$

The choice of computation formulas from (7)-(10) in this case is dependent on the relationship between σ_φ and $\overline{\psi}$, $\overline{\delta}$ and σ_V. In particular, expressions (9) and (10) are useful in the case of small mean shears and considerable fluctuations.

The dispersions of wind velocity and direction can be expressed in the form $\sigma^2_{V,\varphi} = I^2_{V,\varphi}\overline{V}^2$, where I_V is the intensity of turbulence of the longitudinal component. For the transverse component, assuming the angle of wind deflection from the mean direction to be small, we have a similar expression in which the role of intensity I_φ is played by σ_φ, expressed in radians. Then from (10) we have

$$S^2_{\Delta V} = 4 I^2 \overline{V}^2 (1-r). \tag{11}$$

With r = 1 the fluctuating part of the vertical wind shear is absent. It has a maximum value with r = -1, but negative r in the boundary layer are atypical. With arbitrary $\overline{\delta}$ and $\overline{\psi}$, different from zero, it follows from expression (7) in the case of approximate uniformity that

$$\sigma^2_{\Delta V} = \overline{U}^2 \, [I^2_V(A_1 + B_1 r_V) + I^2_\varphi C_1 (1 - r_\varphi)], \tag{12}$$

and in the case of approximate isotropy

$$\sigma^2_{\Delta V} = \overline{U}^2 I^2 (A + Br). \tag{13}$$

In formula (13) with small $\mathcal{E}$ (that is, close $\overline{V}_1$ and $\overline{V}_2$) $A \cong 2$ for all $\overline{\varphi}$, but with $\overline{V}_1 \ll \overline{V}_2$ and $\overline{\psi} = 45°$ this value has a minimum equal to unity. The B coefficient is almost not dependent on $\mathcal{E}$ and with a change in $\overline{\psi}$ from 0 to 90° changes from 2 to -2. Under the most usual conditions ($\overline{\psi} \leqslant 15°$, $\mathcal{E} < 0.5$) both coefficients are close to 2.

Knowing the mean value and dispersion of the modulus of vertical wind shear, it is possible to make approximate confidence evaluations of its instantaneous values, as a first approximation using a normal distribution law. The possibility of using this hypothesis follows from the results of investigation of the distribution of vertical wind shears in the atmosphere [16, 18]. In cases when a normal law is unsuitable, refinements are possible on the basis of use of other distribution laws. The initial data for the computations are the statistical characteristics of the wind vector at two levels between which the shear is computed: the mean values of the moduli, the mean difference of the directions, the dispersion of fluctuations of the moduli and the wind directions at these levels, as well as the correlation coefficients. In order to ascertain $\sigma^2_{\Delta V}$ it is necessary to have information on the dependence of the enumerated parameters on measurement altitude, state of boundary layer stability in the atmosphere and spectral range.

The spectral range in which the statistical characteristics of wind velocity and direction fluctuations are determined must be selected in dependence on the considered practical problem, including on the period of averaging of the initial data. It is well known that in meteorology use is made of a 10-minute averaging but in practical problems of aviation meteorology use is made of initial data on the wind with an averaging period from 2 to 10 minutes. In an evaluation of the characteristics of the instantaneous vertical wind shears within this range it is necessary to have data on the dispersion and the correlation coefficients in a range with periods from seconds to 2 or 10 minutes respectively. However, on the basis of these same data it is possible to make stochastic evaluations within the limits of the lower-frequency range (up to 1-2 hours) if the statistical characteristics of the wind vector are known in this range. In problems related to the dynamics of maneuvers during the takeoff and landing of aircraft, whose duration is approximately 100 sec, both these and other evaluations in principle can be useful.

The region of the spectrum of fluctuations with periods less than 2 min is assigned entirely to the turbulent range, and in the limits from 2 min to 1-2 hours -- partially to the turbulent, but for the most part to the least-studied mesoscale region of the spectral minimum [12]. The circumstance that the mean wind velocities, as indicated in [13], with the use of 2- and 10-min averaging, differing in a range of not more than 5 and 10% respectively from the mean hourly values, is related precisely to this. Accordingly, when determining the mean part of the wind shear modulus the use of any averaging period in the limits from 2 min to 1 hour does not introduce a great error. However, the described approach and the statistical characteristics cited below cannot be used directly in cases involving sharply expressed brief mesoscale phenomena, which were discussed above.

The statistical characteristics of the wind vector cited below were obtained in measurements on the high mast at the Institute of Experimental Meteorology; on the average they are close to the similar data known in the literature, but their detailed comparison and a determination of the standard values, which could be recommended for practical applications, is the subject of a separate study. The measurement and processing method was described in [5, 6, 10].

Table 1 gives the mean (within the limits of the lower 300-m layer) intensities of fluctuations of wind direction and velocity with their normalization to the wind velocity at the height of the vane V_8 (in principle any other normalization can be used).

The weak dependence of the σ_V and $\sigma_\varphi \overline{U}$ values on height within the limits of the lower 300-m layer made it possible to represent data unified for this entire layer in which we clearly see their dependence on the spectral range and nature of the stability. The mean values of the correlation coefficients between the fluctuations of wind velocity and direction are given in Table 2. We note that in the turbulent range (1 sec-10 min) the following formula has been proposed [17]

$$r = \exp\left[-\frac{af\Delta z}{\overline{V}}\right],$$

where f is the mean frequency of the range, Δz is the difference in heights, $\overline{V}$ is the mean wind velocity.

The a values are of the order of 8-10.

Table 3 gives the results of comparisons of the statistical characteristics of wind shears obtained from simultaneous records of wind direction and velocity by a direct method -- directly from the instantaneous values of the wind shears and using the cited formulas with the use of the statistical characteristics of the wind at each level. Here P is the probability of the ΔV values in stipulated limits. The spectral range is determined by the discreteness interval in registry of the wind modulus and direction $\Delta\tau$ and the duration of the registry of T.

In the turbulent range of the spectrum (2 sec - 60 min) the statistical characteristics of the wind shears were obtained by a direct method in [9] in one series of data at the levels 8, 25 and 49 m with V_8 = 12 m/sec. Indirect computations were made using formulas (8) and (10), whereas the $\overline{\Delta V}$ value was determined on the assumption of a logarithmic wind velocity profile. Wind direction fluctuations were not taken into account; the I and r values were taken from Tables 2-3. The computed $P(\Delta V > 4$ m/sec) value was not obtained for the modulus, but for the shear itself. For the layer 25-49 m computations on the basis of all parameters gave entirely good agreement with the direct method. For the layer 8-25 m the discrepancies in P are evidently associated with the difference between the law of distribution of instantaneous ΔV values and the normal law [9], which in this case can be caused by the spacing of the sensors not only vertically, but also horizontally (by 200 m) in the case of a not entirely homogeneous underlying surface between their supports.

Table 1

$\sigma_V/\bar{V}_8$ Values in the Atmospheric Boundary Layer

Spectral range	Stratification: slightly stable	neutral	unstable
Longitudinal component			
1 sec - 30 min	0.12	0.15-0.20	0.35
2.5-25 min	0.10	0.14	0.25
2.5-90 min	----	0.18	0.30
Transverse component			
2.5-25	0.10	0.08-0.12	0.20
2.5-90	0.10-0.15	0.1-0.15	0.25

Table 2

Correlation Coefficients Between Fluctuations of Wind Velocity and Direction at the Levels 25 m and z

Stratification	z m: 50	120	300
Longitudinal component 1 sec-30 min			
Stable	0.45	0.17	0.17
Unstable	0.35	0.10	0.02
Neutral	0.70	0.40	0.20
Wind velocity modulus 2.5-90 min			
Neutral	0.85	0.45	0.05
Unstable	0.90	0.60	0.40
Wind direction 2.5-90 min			
	0.23	0.10	0
	0.70	0.55	0.30

In the spectral range 2.5-90 min both the direct values $\overline{\Delta V}$ and $\sigma_{\Delta V_1}$ and the values needed for indirect computations were determined from one and the same synchronous records of wind velocity and direction at the working levels of the high mast. Within the limits of the discretization interval (2.5 min) the averaging was ensured by the inertia of the sensors and the registry system. In the layers 8-25 m and 73-120 m the $\bar{\psi}$ and σ_φ values, as well as $\bar{\delta}$ and σ_V, were close respectively and ε was 0.21 in the first case and 0.04 in the second. The best agreement was

Table 3

Results of Comparisons of Statistical Characteristics of Instantaneous Wind Shears by Direct and Indirect Computation Method

Layer, m	Compared value	When computed by direct method	indirect method	Computation method
		a $\Delta\tau=2$ с, $T=60$ мин		
8—25	$\overline{\Delta V}$ м/с (на 30 м) b	2,8	2,6	По логарифмическому профилю g
	$\sigma_{\Delta V}$ м/с (то же) c	4,2	3,8	$\overline{\psi}=0$, $\sigma_{\varphi}=0$
	$P(\Delta V>4$ м/с)% d	62	42 h	По σ, $\overline{\Delta V}$ прямым i
			45 h	По σ, $\overline{\Delta V}$ косвенным j
25—49	$\overline{\Delta V}$ м/с (на 30 м) b	1,7	1,6	По логарифмическому профилю g
	$\sigma_{\Delta V}$ м/с (то же) c	1,8	2,1	$\overline{\psi}=0$, $\sigma_{\varphi}=0$
	$P(\Delta V>4$ м/с)% d	20	21	По σ, $\overline{\Delta V}$ прямым i
			21	По σ, $\overline{\Delta V}$ косвенным j
		$\Delta\tau=2,5$ мин, $T=90$ мин e		
8—25	$\overline{\Delta V}$ м/с d	3,4	3,3 h	По (4) при k $\overline{\psi}$, $\overline{\delta}$, $\overline{U}$
	$\sigma_{\Delta V}$ м/с	0,85	1,1	По (9)
			0,81	По (7)
25—49	$\overline{\Delta V}$ м/с	1,6	1,3	По (4) при k $\overline{\psi}$, $\overline{\delta}$, $\overline{U}$
	$\sigma_{\Delta V}$ м/с	0,54	1,1	По (9)
			0,61	По (7)
73—120	$\overline{\Delta V}$ м/с	1,8	1,4	По (4) при k $\overline{\psi}$, $\overline{\delta}$, $\overline{U}$
	$\sigma_{\Delta V}$ м/с	0,87	1,2	По (9)
			0,99	По (7)
		d $\Delta\tau=2$ мин, $T=15$ ч f		
8—25	$P(0<\Delta V<2$ м/с)%	99,4	92,8	По σ, $\overline{\Delta V}$ косвенным j

KEY:

a) sec...min
b) m/sec (at 30 m)
c) m/sec (same)
d) m/sec
e) min...min
f) min...hours
g) On logarithmic profile
h) Using...
i) direct method
j) indirect method
k) with...

obtained as a result of use of formula (7) with $\overline{\psi}$ values of several degrees. In the layer 25-49 m $\overline{\psi} = 0.2° \ll \sigma_{\varphi}$, and the best $\sigma_{\Delta V}$ evaluation is obtained using (9), taking into account the relationship between σ and S.

In the range 2 min-15 hours a direct evaluation $P(0 \leqslant \Delta V \leqslant 2$ m/sec) for the layer 8-25 m from the records of wind velocity and direction at these levels is given in [7]. For the computed evaluation we used the statistical characteristics of fluctuations of wind velocity and direction in the range 2.5-90 min, taken from Tables 1-2.

Source [7] also gives evaluations of $\sigma_{\Delta V}$ with different times of averaging of initial data, obtained by the direct method (different averaging of the initial series prior to computation of the instantaneous wind shears). We note that similar evaluations can be made on the basis of the described method, but for this it is necessary to have complete data on the spectral correlation of the wind components with vertical spacing of the sensors. In particular, the $\sigma_{\Delta V}$ evaluation for the spectral ranges 2 sec-30 min and 2.5 min-30 min for the case $V_8 = 10$ m/sec leads to values 2.4 m/sec and 1.1 m/sec. These data show that the dispersion, and accordingly, the maximum wind shear values for some fixed time interval are essentially dependent on the averaging period and with inclusion of the turbulent range increase greatly in comparison with standard averaging for 2-10 minutes.

We note in conclusion that the approach developed in this article can be easily applied for the case of horizontal wind shears, for which it is necessary to have a knowledge of wind velocity fluctuations in the horizontal plane. There are also no complexities in the inclusion of vertical wind velocity fluctuations if their statistical characteristics and their dependence on altitude are known.

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REMOTE MONITORING OF GAS EFFLUENT BY THE COMBINED LIGHT SCATTERING METHOD

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[Text]

Abstract: The article describes the first experience in use of the combined light scattering method in the USSR for remote monitoring of gas effluent of industrial enterprises. The authors characterize the parameters of the lidar created for this purpose. Also examined is the associated noise. Estimates are given for the minimum contamination levels registered in the plumes of effluent from heat and electric power plants at distances up to 200 m from the mouths of the stacks: for SO_2 -- 200 $mill^{-1}$; NH3 -- 100 $mill^{-1}$; CO -- 1000 $mill^{-1}$; CO_2 -- 300-500 $mill^{-1}$. Ways to increase lidar response are noted.

A new scientific-technical problem has arisen before the scientific and network organizations of the USSR State Committee on Hydrometeorology and Environmental Monitoring: creation of a system for monitoring sources of effluent of contaminating substances into the atmosphere. Among the various methods for monitoring of industrial effluent a special place is occupied by remote methods. They make it possible to determine the quantity of effluent and its characteristics in those cases when ordinary methods are ineffective. The possibilities of remote determination of the aerosol component of effluent by use of a lidar were examined in [4].

In an investigation of the gas components of effluent, in addition to monitoring the volume of effluent, as in the case of aerosols, a number of complex problems arise. The most important of these are determination of the concentration of individual gas components and their lifetime in the plume, obtaining information on their transformation into new compounds. Precisely these processes determine the final toxicity of the effluent with its propagation in the environment, and accordingly, are the criterion for determining the norms of the maximum admissible effluent. In this case reliable results can be obtained only with direct measurements in the plume, since the rate of the reaction is determined by the temperature of the plume, the concentration of gases and their ratio to one another. The carrying out of such investigations, despite their obvious timeliness, is only beginning. The principal restraining factor is the lack of adequately effective measurement methods. It appears that appreciable progress here can be attained with the use of remote methods having a high selectivity, speed and satisfactory response.

In this article we give the first results of an experimental study of gaseous contaminants in the plumes of effluent of industrial plants by the method of remote spectroscopy of combined light scattering (CLS).

Theory of Method and Requirements on Apparatus

The analytical possibilities of the combined light scattering method are based on its following peculiarities:

-- during the irradiation of the investigated volume of the atmosphere with laser radiation with the frequency ν_0 in the spectrum of scattered light there will be not only the exciting frequency ν_0, but also a number of combined frequencies $\nu_0 - \nu_1$, $\nu_0 - \nu_2 \ldots \nu_0 - \nu_i$. The frequency shifts $\nu_1, \nu_2, \ldots, \nu_i$ are the vibrational frequencies of molecules of the matter present in the investigated volume. These vibrational frequencies are strictly individual for each molecule, as a result of which it is possible to detect separately the presence of molecules of different contaminating substances virtually without any interference associated with the presence of other molecules;

-- the intensity of CLS is always proportional to the number of particles per unit volume (density) regardless of the temperature of matter. This property makes it possible to determine its concentration;

-- the light source, especially a laser, exciting the CLS can operate at a fixed frequency;

-- the virtual inertialess character of CLS processes makes it possible, using a pulsed laser, to ascertain the distance to a contaminated sector and its extent.

The nitrogen molecules present in the atmosphere in a known concentration can be used as a point of reference or comparison element in determining the absolute concentration of concentrating substances.

The shortcomings of the method are determined in actuality by a single circumstance -- the smallness of the CLS process section. Its typical values for most atmospheric components are $10^{-29} - 10^{-31}$ cm^2/sr.

The apparatus for remote registry of the CLS spectra includes a laser source for exciting the spectrum, a telescope receiving back-scattered radiation, an element for selecting spectral lines, and a photodetector with the corresponding electronic circuitry for the registry of signals.

The strength of the signal N_e, expressed by the number of photoelectrons registered at the photodetector output, can be determined using the following expression:

$$N_e = N_0 n \eta(\lambda) k_1(\lambda) S \frac{d\sigma}{d\Omega} \int_{R_1}^{R_2} e^{-\alpha(\lambda_0) R} e^{-\alpha(\lambda) R} k_2(R) \rho(R) R^{-2} dR, \qquad (1)$$

where N_0 is the number of photons in a laser pulse, n is the number of pulses, $\alpha(\lambda_0)$, $\alpha(\lambda)$ are the coefficients of atmospheric absorption at the laser wavelength λ_0 and the shifted radiation λ; $k_1(\lambda)$ is a coefficient taking into account the losses in absorption and reflection in the receiving optical system; $\eta(\lambda)$ is the quantum effectiveness of the photodetector (taking into account the collection of electrons from the photocathode); S is the effective area of the receiving unit; $d\sigma/d\Omega$ is the differential scattering section of the investigated gas; k_2R is the lidar geometrical factor; ρ(R) is the concentration of the investigated matter (the number of molecules per unit volume); R_1 and R_2 are the limits of the investigated volume of the atmosphere.

The minimum detectable concentration (MDC) of molecules of any impurity is dependent on the required reliability of detection, which is determined by the statistical signal-to-noise ratio (S/N). In the registry of the signal by the method of counting of "photons" the S/N ratio is determined using the following expression:

$$S/N = Ne/\sqrt{N_e + 2\ (N_{back} + N_{dark})}, \qquad (2)$$

where N_{back}, N_{dark} are the noise signal in the photoelectrons, caused by the background of the sky, and the dark current of the photomultiplier during the time of measurement of the CLS signal T = nt, $t = 2(R_2 - R_1)c$ is the time of measurement of a signal allocated to one laser pulse, c is the speed of light.

The number of photoelectrons caused by radiation of the sky background is found from the expression

$$N_{back} = \frac{k(\lambda)\, \eta(\lambda)\, \Delta\lambda\, S\, \Omega\, T B(\lambda)}{h\nu}, \qquad (3)$$

where $k(\lambda)$ is a coefficient taking into account the total losses of the background radiation in the optical part of the measurement unit; $\Delta\lambda$ is the width of the registered part of the spectrum; Ω is the solid angle of collection of sky airglow; $B(\lambda)$ is the spectral density of the energy brightness of the sky background; $h\nu$ is the energy of a photon in the registered part of the spectrum.

In order to determine the MDC of the measured contaminant it is necessary to stipulate the required S/N ratio (or the required accuracy in measurement). Expression (2) is used in determining the necessary minimum number of photoelectrons $N_{e_{min}}$. If it is assumed that the concentration ρ in the limits of the sounded sector $R_2 - R_1$ is constant, we can then write

$$[\text{МИН}] = \text{min}] \qquad \rho_{MDC} = \frac{N_{e_{\text{мин}}} R^2}{N_0 n \eta(\lambda) k_1(\lambda) S \frac{d\sigma}{d\Omega} \int_{R_1}^{R_2} e^{-\alpha(\lambda_0) R} e^{-\alpha(\lambda) R} k_2(R)\, dR} \qquad (4)$$

The response and effective radius of the CLS system are determined for the most part by the optimum choice of the working parameters of all the units in the system and the possibilities of their technical realization.

Laser. The principal parameters determining the effectiveness of excitation of the CLS spectrum are the power and wavelength of the light radiation.

It can be seen from expressions (1)-(3) that the received signal is amplified with an increase in the energy of the laser pulse and the number of pulses (total radiation energy). The wavelength of radiation does not enter in direct form into these equations, in the last analysis determining the MDC value, but to a strong degree it governs such parameters as the quantum effectiveness of the photodetector, the scattering cross section of molecules and the intensity of the background glow of the day sky. For the photocathodes the maximum of the quantum yield falls in the near UV and the visible regions of the spectrum and its value for the best models of photomultipliers attains 0.3. In the red region of the spectrum (first harmonics of a ruby laser and a neodymium glass laser) $\eta(\lambda)$ is tenths of a percent or less.

The CLS section in the absence of resonance conditions, as is well known [5], is proportional to the fourth power of the frequency of scattered light. In the range of wavelengths shorter than 300 nm the spectral density of the brightness of the sky background $B(\lambda)$ is virtually equal to zero due to absorption by ozone in the upper atmosphere, but in the region shorter than 250 nm strong absorption by atmospheric oxygen begins to exert an effect. Accordingly, for increasing the response of the laser to CLS and in order to be able to work in the daytime it is better to use lasers radiating in the range of wavelengths 250-300 nm.

At the present time solid-state ruby pulsed lasers (second harmonic) and alumoyttrium garnet lasers (alloyed with neodymium) (second, third and fourth harmonics), as well as Excimer lasers [10], satisfy the enumerated requirements most completely.

Receiving unit. In accordance with equation (1), the received CLS signal is proportional to the effective area of the receiving unit and therefore it is selected as large as possible and is limited both by design considerations and the possibility of matching with the employed spectral instrument. In actuality the diameter of the receiving unit in known apparatus varies in the range 0.3-1 m [3, 9].

Unit for selecting spectral lines. The principal requirements imposed on such an apparatus include a high luminosity, a high transmission in the working range of wavelengths and a high degree of suppression of scattered light for the main laser frequency ν_0. In the real atmosphere scattering at this frequency is caused by aerosols. Its value with a range of visibility of about 5 km exceeds the molecular scattering value in the visible and UV spectral regions by a factor of approximately 20-100. Accordingly, for the registry of a contaminant with a relative concentration ρ it is necessary to have suppression by at least a factor of $10^5/\rho$. It therefore follows that for measuring concentrations of 10 $mill^{-1}$ the suppression of scattered light at the nondrifting frequency must be about 10^{10}. Atmospheric precipitation, dust particles, etc., increasing the scattering, lead to the need for increasing this value. The required suppression can be ensured by a set of narrow-band filters, their combination with spectral instruments, or by a spectral instrument with triple monochromatization.

Photodetector. In the successive registry of contaminants use is made of photomultipliers having a high quantum yield in the working part of the spectrum, a high amplification factor necessary for the registry of each photoelectron knocked from the photocathode and having the maximum possible time resolution. An important advantage of the CLS method is the possibility for simultaneous registry of all or several contaminants present in the investigated volume of the atmosphere. In order to exploit this advantage it is necessary to use multichannel photodetectors with the corresponding electronic circuitry.

System for the registry and processing of data. In order to exclude the influence of instability of the source of excitation of the CLS spectra, the atmospheric parameters along the sounded path and the instabilities of the apparatus on the accuracy in measuring the absolute concentration of different substances in the remote registry of CLS spectra use is made of relative measurements employing the line of atmospheric nitrogen as a concentration reference point. This is accomplished most simply in a multichannel system for the registry of spectra. In addition, the multichannel system makes possible a substantial reduction in measurement time and an increase in the effectiveness of use of the laser capabilities.

The reliability of the results of measuring small CLS signals is increased with the accumulation of readings of the series of laser pulses and therefore the registry system (both single- and multichannel) must have a unit for accumulating or integrating the photodetector signals. The registry system must ensure measurement of interfering signals (the dark current of the photodetector, sky background, atmospheric fluorescence and fluorescence of impurities, etc.).

The data processing system is usually assigned the functions of control of the lidar components, computation and documentation of the results of measurements by means of a digital printout, monitoring of parameters of the apparatus and also implementation of different measurement programs. Its structure and specific embodiment are determined by the range of tasks assigned to the entire system for monitoring the sources of contamination in the atmosphere.

Experimental Investigations

At the Spectroscopy Institute USSR Academy of Sciences specialists have created a mobile apparatus for remote monitoring of the composition of industrial effluent (CLS lidar) in accordance with joint technical specifications prepared by specialists of the Institute of Applied Geophysics of the State Committee on Hydrometeorology. The apparatus is mounted in the interior of a PAZ-672 bus [1]. Its distinguishing characteristics, making it different from similar systems [3, 9], are: a) the use of laser radiation with a wavelength of 266 nm, which made it possible to carry out measurements during the daytime; b) use of a spectrograph with triple monochromatization; c) presence of two registry systems -- three-channel for a photomultiplier and multichannel television system (MTS). Both systems operate in a photon counting regime; d) registry of the profile of the contaminant along the sounded path on a display; e) automation of the output of wavelengths in the spectrograph and processing of the measurement results using a 15 VSM-5 programmable calculator. As a result of careful processing of individual lidar components [2] it was possible to improve some of its parameters. The quantity of scattered spectrograph light is reduced to 10^{-12}. The inverse line dispersion was reduced to 2.5 A/mm. The system for registry from the photomultiplier has a mean noise value of 1 reading per 10^5 laser pulses.

The MTS with respect to its response (in one channel) is inferior to the photomultiplier system due to a lower quantum yield of the image converter photocathode (5-9% versus 25% for the selected photomultiplier models) and high noise.

The purpose of the experimental measurements made at industrial enterprises was:
-- clarification of the interfering factors limiting the fundamental possibilities of the method;
-- measurement of the contaminating substances in the atmosphere and industrial effluent.

In the process of measurements with a lidar in the atmospheric CLS spectra there was registry of a continuous background caused by atmospheric fluorescence. It was pointed out in [7], in particular, that when working with an argon laser (458-515 nm) there was fluorescence of atmospheric aerosols in a broad spectral range. Atmospheric fluorescence can also be caused by some contaminating substances -- SO_2, NO_2, petroleum products and other organic matter present in the form of vapor and aerosol. However, reports on observations of atmospheric fluorescence under the influence of radiation in the near-UV spectral region could not be found. Accordingly, measurements were made of the fluorescence level and a study was made of the distribution of its intensity by wavelengths with excitation by the two wavelengths most preferable for remote sounding of the atmosphere by the CLS method: 266 and 347 nm. The total fluorescence was not determined, but its intensity was measured at different points of the working range of wavelengths. It was found that the intensity of the fluorescence spectrum increases smoothly toward the long-wave end of the working range. At the shift frequency 3000 cm^{-1} it is approximately 3 times greater than at a frequency of 500 cm^{-1} (the intensity of scattered light, on the other hand, increases with approach to the exciting line). The measured values of the atmospheric fluorescence level in the frequency range 2000-3000 cm^{-1} are given in Table 1.

The intensity of fluorescence in Table 1 and elsewhere is given in the equivalent concentration of nitrogen. By this is meant such a concentration of uniformly distributed nitrogen with which the CLS signal is equal to the fluorescence signal. In order to facilitate a comparison of the measurement results at different wavelengths they were all scaled to an identical width of the discriminated spectral sector, equal to 10 cm^{-1}. The table shows that the fluorescence of atmospheric precipitation is more intense when working with the second harmonic of a ruby laser, whereas for the fourth harmonic of a YAG laser the fluorescence noise is less. Measurements of the fluorescence level were made under different atmospheric conditions and were separated by large time intervals. Accordingly, Table 1 gives the limits of the averaged values. Using the already introduced value of the equivalent concentration of nitrogen ρ_{equiv} it is easy to compute the signal strength N_{fl} in the photoelectrons caused by fluorescence. For this purpose in equation (1) it is necessary to introduce the factor $\Delta\nu_{work}/10\ cm^{-1}$, taking into account the width of the working spectral interval $\Delta\nu_{work}$ in cm^{-1}. In most cases when the ratio of the concentration of the fluorescent impurity ρ_{equiv} to the concentration of the measured gas ρ does not change within the limits of the sounded sector $R_2 - R_1$, N_{fl} can be expressed through the CLS signal, N_e of the measured gas in the following way:

$$N_{fl} = \frac{\Delta\nu_{work}}{10}\frac{\rho_{equiv}}{\rho\sigma_{rel}} N_e, \tag{5}$$

where $\sigma_{rel} = \frac{d\sigma}{d\Omega} / (\frac{d\sigma}{d\Omega})_{N2}$ is the relative CLS section of the measured gas.

Thus, the S/N ratio during fluorescence deteriorates in comparison with (2) and can be expressed as follows:

$$(S/N)_{fl} = N_e/\sqrt{N_e + 2(N_{dark} + N_{back} + N_{fl})} \tag{6}$$

Using expressions (5) and (6) and the measurement results given in Table 1 it is possible to estimate the sensitivity of the CLS method in sounding of the atmosphere, taking into account the interfering effect of fluorescence. For example, with $\Delta\nu$= 30 cm^{-1}, accumulation of the signal for 10^4 laser pulses and a S/N ratio 2 the response is limited for NH_3 to 40 $mill^{-1}$ and for SO_2 to 15 $mill^{-1}$ (without taking into account the resonance amplification of the CLS section).

A fluorescence of the effluent from a heat and power plant was also discovered. The measured fluorescence values as a function of the type of fuel used at the heat and power station are given in Table 2.

The measurements also indicated the presence of fluorescence of effluent from cars and trucks. For example, the level of fluorescence of the exhaust gases from a diesel engine was 500 $mill^{-1}$ and its spectrum extended from 1500 cm^{-1} and beyond into the red region.

Table 1

Level of Atmospheric Fluorescence in the Range 2000-3000 cm^{-1}, $\Delta\nu$= 10 cm^{-1}

Wavelength, nm	Equivalent concentration of nitrogen in $mill^{-1}$	
	fog, rain, snow	without precipitation
347	300-500	50-200
266	20-100	20-50

Table 2

Intensity of Fluorescence of Effluent of Heat and Power Plants as Function of Type of Fuel Employed

Wavelength, nm	Equivalent concentration of nitrogen in $mill^{-1}$		
	mazut, gas	coal	gas
532	500-1000	100-300	---
266	300-1000	200-500	20-50

The MDC for contaminants distributed uniformly in the atmosphere and atmospheric components were estimated using measurements in a special cell and directly in the atmosphere.

The following results were obtained when determining the MDC for some gases in a specially fabricated cell with a length of 12 m set up at a distance of 100 m: for C_6H_6 -- 10 $mill^{-1}$, NH_3 -- 100 $mill^{-1}$, kerosene vapors -- 0.1 $mill^{-1}$. The low response in determining CO is attributable to the inadequate selectivity of the spectral instrument, as a result of which it is not possible to separate noise from the vibrational-rotational structure of N_2. Figure 1 shows the relative positioning of the CO line and the N_2 structure. The dashed line represents the instrument function of the spectral apparatus and the three-channel system for registry from the photomultiplier. A high response for kerosene vapors was obtained with their registry in the fluorescence spectrum in the region 270-300 nm (it was not possible to discriminate the CLS line due to the high fluorescence level). We should note some characteristics and difficulties in making the cell measurements. In particular, these include the fluorescence of the cell windows, absorption by the cell walls, difficulties in admitting the gas and taking samples.

It was established that in measurements of CO_2 in the atmosphere for R = 100 m and ΔR = 20 m the MDC value was 50 $mill^{-1}$.

Measurements in the plumes of effluent were made at heat and power plants operating on different fuels (coal, mazut, gas). The distance to the mouth of the stacks was 200 m. The cross section of the plume was 10-15 m.

In our first tests [1] we noted a strong absorption of laser radiation in the working region of frequencies (266 nm) by the solid particles, aerosols and SO_2 gas present in the plume of effluent. In cold weather the plume became "milky" and translucent due to the formation of aerosols during the condensation of water vapor both for laser radiation and for sunlight, as was easily observed visually.

One of the problems solved at heat and power plants was the separate estimation of the absorption of laser radiation by SO_2 gas and solid particles. Since absorption by dust and soot was virtually nonselective, by two-frequency sounding it is possible to measure the absorption caused by SO_2.

The sounding was carried out at wavelengths 266 and 532 nm. Radiation at 532 nm is not absorbed by SO_2 [11] and NO_2 [8]. In this experiment the influence of water aerosols could be neglected because the measurements were made in warm, dry weather (3-17 September 1979).

Figure 2 shows oscillograms of the signal of scattered radiation at 266 and 532 nm. It can be seen that the plume of effluent is completely opaque for radiation at 266 nm. The mean SO_2 concentration measured at this time (at a wavelength of 532 nm) was 750 $mill^{-1}$. Computations made in [11] using the absorption coefficients for SO_2 at a wavelength of 266 nm confirmed that with such a SO_2 concentration the radiation of the fourth harmonic of a YAG laser (266 nm) should be completely absorbed. The dashed curve in Figures 2 and 3 shows the shape of the signal for a case when there is no absorption in the plume.

Figure 3 shows oscillograms of signals at the nonshifted frequency 266 nm for the effluent of a heat and power plant operating on coal and gas. It can be seen that the absorption by effluent of a heat and power station operating on gas is not great. In this case the SO_2 concentration, measured by the sunlight absorption method, was 30 $mill^{-1}$. The SO_2 concentration was measured by this method at wavelengths 303.8 and 305.0 nm, at which the absorption coefficient has extremal values. A concentration of 30 $mill^{-1}$ was not registered from the CLS spectra; this can mean that there is no strong resonance increase in the SO_2 section for radiation at 266 nm, as was asserted in [6].

In addition to measurement of sulfur gas, attempts were made to detect NO_2, H_2S and CH_4. However, signals were not reliably registered. Accordingly, it is only possible to speak of an upper limit of the content of these gases in the plume of effluent, determined by the response of the apparatus, that is, the content of the mentioned gases was lower than 100-500 $mill^{-1}$. Such a relatively low lidar concentration response when sounding the effluent from heat and power plants is attributable to the low effective extent of the sounded layer, which due to the absorption of laser radiation at 266 nm by SO_2 gas was only 1-2 m, instead of the 10-15 m extent of the plume.

When making measurements at the stack mouth the effluent of contaminating substances can be determined using the expression

$$Q = \bar{c}V,$$

where $\bar{c}$ is the mean concentration, V is the volumetric rate of gas escape.

Estimates indicated that the discrepancies between the measured values of sulfur gas effluent and the computed values obtained with allowance for the composition of the fuel did not exceed a factor of 2. This discrepancy falls in the limits of computation accuracy.

In order to evaluate the possibilities of measuring effluent from cars and trucks by the CLS remote spectroscopy method we carried out measurements of the exhaust gases of a KRAZ vehicle with a diesel engine. The distance to the vehicle was R = 100 m, the direction of the exhaust was perpendicular to the laser ray, passing approximately 5 m from the side of the vehicle. CO with a concentration 1500 $mill^{-1}$ and SO_2 with a concentration of 200 $mill^{-1}$ were registered in the exhaust.

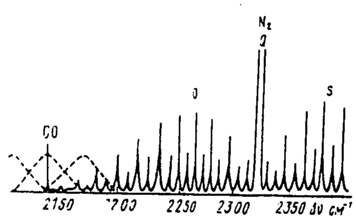

Fig. 1. Relative positioning of vibrational line of CO and vibrational-rotational structure of N_2.

Scattering in telescope

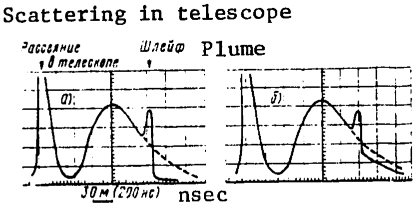

Fig. 2. Oscillograms of signals of scattered radiation for 266 nm (a) and 532 nm (b) obtained with two-frequency sounding of plume of effluent from heat and power plant.

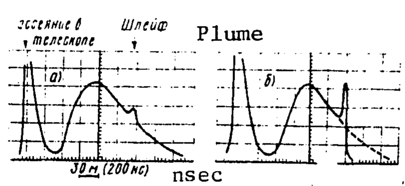

Fig. 3. Oscillograms of signals at nonshifted frequency 266 nm showing dependence of laser radiation absorption on type of fuel (content in SO_2 effluent). a) gas, b) coal.

Summary

1. An examination of the characteristics of the CLS method made it possible to evaluate its possibilities applicable to remote detection of gas effluent of industrial enterprises and formulate the principal requirements on the apparatus. The CLS lidar created on the basis of these requirements is in no way inferior in its characteristics to similar foreign apparatus, and with respect to a number of technical solutions is superior to them.

2. In the course of lidar tests for the first time there was found to be fluorescence of the real atmosphere and the gas effluent of heat and power plants, cars and trucks. Its intensity was measured under different atmospheric conditions and with the use of different fuels. This phenomenon fundamentally limits the analytical possibilities of the method. At the same time, it was demonstrated that careful selection of the laser radiation wavelength can lessen this influence.

3. Experimental operation of the CLS lidar revealed the possibility of detecting at distances 100-200 m different gases with the following concentrations: CO_2 -- 200 $mill^{-1}$, NH_3 -- 100 $mill^{-1}$, CO -- 1000 $mill^{-1}$, SO_2 -- 300-500 $mill^{-1}$. The discrepancies with the computed values of the concentrations in the effluent of heat and power plants, obtained with allowance for the composition of the fuel and the combustion regime, do not exceed a factor of 2, which falls in the limits of computation accuracy.

The response of the developed CLS lidar can be substantially increased by improving its energy characteristics (use of a more powerful laser, coating of optical parts, improvement of matching of the receiving telescope with the spectrograph). With the present-day status of optical and laser instrument making the energy characteristics of the lidar can be realistically increased by a factor of approximately 1000.

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UDC 551.501:519.24

METHOD FOR THE INTERPOLATION OF DATA FROM A FIELD EXPERIMENT

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 48-53

[Article by V. Ye. Lagun, V. F. Romanov, candidate of physical and mathematical sciences, V. A. Safronov, and N. P. Smirnov, doctor of geographical sciences, Arctic and Antarctic Scientific Research Institute, manuscript submitted 11 Apr 80]

[Text]

Abstract: The article gives the results of numerical experiments for studying the accuracy and filtering properties of different interpolation methods in model and real fields. This makes it possible to select the method most acceptable for the creation of the initial network necessary for a spline approximation. A method is proposed for interpolation of data from aerological sounding of the atmosphere based on a combination of the finite elements and spline approximation methods. The method is applicable in the processing of aerological information of the "POLEKS-Sever-79" experiment.

Investigation of the large-scale interaction between the atmosphere and ocean and evaluation of the relative contribution of "subgrid" processes to the energy balance for their parameterization in models of global circulation and climate are among the principal purposes of field experiments under the POLEKS program [13].

In the formulation of a theory of climate as a mean relative to a set of synoptic records the emphasis must be on investigation of the structure, energy characteristics and influence exerted on the mean fields by synoptic disturbances in the atmosphere.

The aerological information collected in the course of a field experiment as a basis for further analysis consists of data from radiosonde measurements of the atmosphere, which is carried out at aerological stations, and also on weather ships and on the ships carrying out the field experiment. The existing network of aerological stations and expeditionary observation facilities do not make it possible to carry out measurements over sea areas with a spatial discreteness of less than 600 km.

Even when computing the advective energy influxes integral for the area of the experiment on the basis of regularly scheduled data such a discreteness is inadequate for explicit allowance for processes of a synoptic scale. Synoptic disturbances are "subgrid" and cannot but introduce errors into the integral evaluations.

In order to investigate synoptic processes in the atmosphere it is necessary that the total duration of the observations and the extent of the experimental polygon correspond to the values of the characteristic temporal and spatial scales of global circulation. In addition, the spatial-temporal discreteness of the observations must be adequate for an explicit description of synoptic disturbances.

It follows from what has been said that it is necessary to develop methods for interpolation of data from the existing network of observations to the points of intersection of a more detailed grid. A qualitative analysis of the system of equations shows that a 12-hour discreteness of observations is adequate for describing the evolution of synoptic processes. This makes it possible to emphasize spatial interpolation.

The fields obtained as a result of interpolation must be smooth and retain the principal statistical properties of the meteorological elements, to a minimum distorting the harmonics with scales of the processes to be studied in the spatial spectrum of the fields to be interpolated.

The methods of optimum [2] and polynomial [8] interpolation are the most important of the linear interpolation methods used in meteorology. It was noted in [2] that a fundamental shortcoming of the polynomial method is an arbitrariness in the choice of the polynomials regardless of the properties of the meteorological fields. Being free of this shortcoming, optimum interpolation requires the stipulation of the statistical structure of the field, which is difficult for regions where field experiments are carried out which are poorly supplied with information.

During recent years work has been carried out on development of a method for representing meteorological fields using the spline functions method [1]. Being a solution of the variational problem, splines give not only a smooth and consistent approximation, but also have a clear physical interpretation: in splines there is realization of a minimum of the potential energy of some mechanical system [6]. [In general, it is unclear how it is related to the actual potential energy of a meteorological (synoptic) process.] The latter circumstance advantageously discriminates spline interpolation from other polynomial methods.

The classical formulation of interpolation by splines is the interpolation of a grid function [6]. Accordingly, a necessary preparatory stage for the use of splines is the creation of an initial grid region. The observation points in a field experiment do not form such a grid.

In [7] it was proposed that climatic and prognostic data be used for filling in the lacking information.

An initial grid region, which we will call a "base" region, can be obtained using ordinary polynomial interpolation or the finite elements method (FEM) [12].

The essence of the FEM method is a breakdown of the region of stipulation of the function into simple subregions (triangles, rectangles) with the vertices at the observation points and polynomial interpolation of the function in each subregion.

The smoothness of the field is retained with an alternation of the subregions (elements). The degree of the approximating polynomial is determined by the number of stations forming the element. For territories with a thin network of stations it is only possible to use two-dimensional simplex-elements.

For example, for a simplex-element with three vertices (x_i, y_i), (x_j, y_j), (x_k, y_k) at which the field values T_i, T_j, T_k are stipulated the interpolation formula has the form [10]

$$T = N_i T_i + N_j T_j + N_k T_k, \tag{1}$$

where

$$N_i = \frac{1}{2A} [(x_j y_k - x_k y_j) + (y_j - y_k) x + (x_k - x_j) y],$$

$$N_j = \frac{1}{2A} [(x_k y_i - y_k x_i) + (y_k - y_i) x + (x_i - x_k) y],$$

$$N_k = \frac{1}{2A} [(x_i y_j - x_j y_i) + (y_i - y_j) x + (x_j - x_i) y],$$

A is the area of the triangle, x, y are the current coordinates.

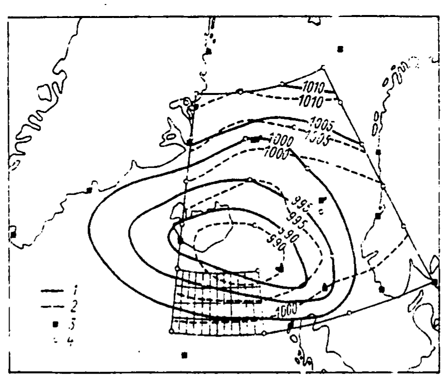

Fig. 1. Diagram of distribution of aerological sounding stations, computation grids and surface pressure field (1 -- real and 2 -- computed). 3) aerological stations; 4) points of intersection of base grid; example of computation grid -- lower left corner of polygon.

After creation of a base grid the function to be interpolated in each "square" of the grid region is represented in the form of a bicubic polynomial

$$T_{ij}(x, y) = \sum_{k=0}^{3} \sum_{l=0}^{3} a_{kl}^{ij} (x - x_i)^k (y - y_j)^l, \tag{2}$$

where $i = \overline{0, n}$, $j = \overline{0, m}$ and satisfies additional conditions at the boundary of the region. Source [6] gives an algorithm for finding the coefficients a_{ki} and the convergence of the method is demonstrated.

The results of studies for comparison of different interpolation methods [3, 4] make it possible to conclude that a priori it is difficult to give preference to any of the methods. It is necessary to make a special investigation for the purpose of selecting the method most acceptable for the problem considered. In this case as test material it is possible to use model fields constructed in accordance with the processes to be studied. Examples of model fields are given in [3, 4].

Below we give the results of numerical experiments for studying the accuracy and filtering properties of some interpolation methods in model fields for the purpose of selecting a method for the processing of data from aerological sounding in the field experiment "POLEKS-Sever-79." A diagram of the location of sounding st tions is shown as Fig. 1. The model fields simulated synoptic formations. The real network of stations was used in the computations.

The experiments were carried out with the following types of interpolation: a) interpolation into the computation grid region by means of algebraic polynomials by the least squares method (LSM); b) interpolation into the base grid by the LSM with subsequent spline interpolation into the computation grid region; c) interpolation into the computation grid region using the FEM method; d) interpolation into the base grid by the FEM method with subsequent spline interpolation into the computation grid region.

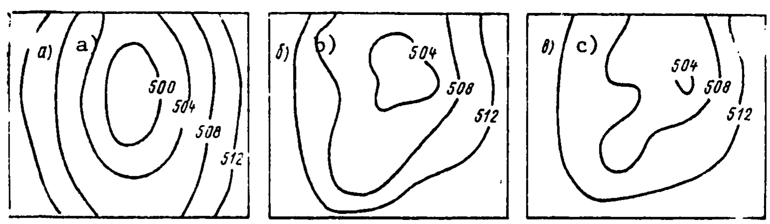

Fig. 2. Example of interpolation of model field (a) into base grid by FEM, into computation spline approximation (b) and by FEM in two stages (c).

Figure 2 shows a precise model field, and fields obtained by interpolation by methods (c) and (d). The figure shows that the spline field in general is close to the initial field, whereas the simplex variant of the FEM gives a highly smoothed approximation.

It follows from the cited experiments that: 1) polynomial interpolation in the case of a determined field ensures a high accuracy of the analysis; 2) spline interpolation in a "true" base grid has good interpolation properties (the relative interpolation error is less than 1%); 3) a spline interpolation in a base grid constructed by the FEM considerably corrects its smoothing effect; 4) the introduction of a random component into a model field is reflected to an insignificant degree in the spline approximation; if the base grid is constructed by the FEM method, on the other hand, there is a marked decrease in the accuracy of interpolation by polynomials using the least squares method.

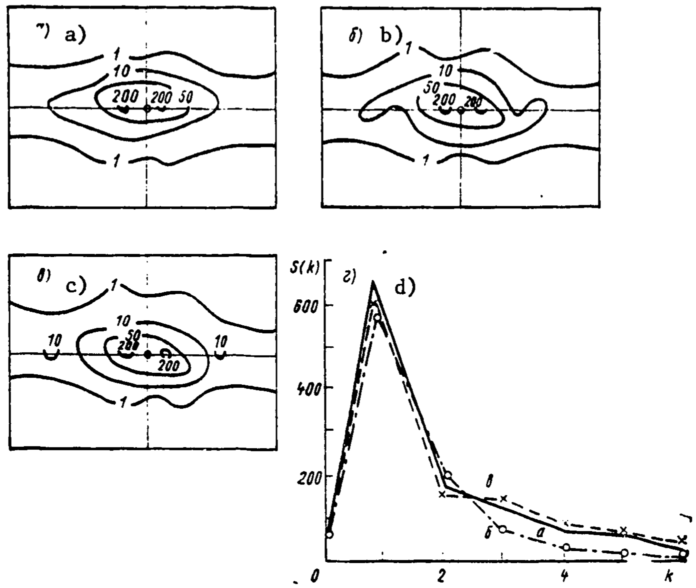

Fig. 3. Evaluations of two-dimensional spectra of model fields. a) evaluation of spectrum of precise model field; b) evaluation of spectrum of field constructed by spline interpolation in base grid by FEM method; c) evaluation of spectrum of field constructed by FEM method in two stages; d) one-dimensional representations.

In order to clarify the filtering properties of the interpolation we used spectral analysis methods. The statistical processing of the interpolated fields included computation of the elementary statistical characteristics and evaluation of the two-dimensional correlation functions and spectral densities [10].

For greater clarity the two-dimensional functions can be reduced to one-dimensional summation of the values of the field of evaluations for the determined wave numbers.

Figure 3 shows evaluations of two-dimensional spectra of fields shown in Fig. 2 and the one-dimensional analogues corresponding to them.

An analysis of the one-dimensional representations shows the degree to which the statistical structure of the field changed as a result of interpolation. For example, the field obtained by the FEM method is characterized by a minimum dispersion. The most informative part of the spectrum (the region of large wavelengths) is considerably distorted and the short-wave part is smoothed.

The spectrum of the spline field is closer to the true spectrum; only the short-wave part is insignificantly distorted. The harmonics of a synoptic scale are virtually not distorted.

Numerical experiments convincingly indicate that spline interpolation, in addition to technical simplicity, makes it possible to obtain the fields of meteorological elements which meet the requirements imposed on initial data when analyzing the results of a field experiment.

The computations of real fields (Fig. 1) confirm the conclusion which was drawn.

Thus, the proposed interpolation method for data from aerological sounding in a field experiment involves two stages. The first stage is preparatory and involves the creation of a rough grid region whose interval corresponds to the characteristic dimensions of the studied pressure formations. In the second stage the spline interpolation of the fields of meteorological elements is carried out at the points of intersection of the computation grid.

The further improvement of the method involves a refinement of the method for obtaining the base grid and also the development of a sufficiently simple algorithm for spline interpolation of the function with a nonuniform distribution of points of intersection.

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ANNUAL BUDGET OF EXCHANGE OF OXYGEN BETWEEN THE OCEAN AND THE ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 54-61

[Article by Yu. I. Lyakhin, candidate of geographical sciences, Leningrad Hydrometeorological Institute, manuscript submitted 14 Apr 80]

[Text]

Abstract: On the basis of generalization of materials from hydrochemical observations in the world ocean for the period 1960-1978 the author has constructed mean seasonal maps of the distribution of the concentrations of dissolved oxygen at the ocean surface. Computations were made of the rate and mean annual budget of oxygen exchange between the ocean and the atmosphere. It was established that with respect to oxygen exchange the world ocean is close to equilibrium with the atmosphere.

The dynamics of dissolved oxygen in the surface layer of the ocean is determined by the relationship of the processes of oxygen production in photosynthesis and consumption in the oxidation of organic matter, as well as the influence of horizontal advection and exchange with the lower-lying layers. As a result the surface waters in some regions are supersaturated with oxygen, whereas others are undersaturated; accordingly, the oxygen flux will be directed from the ocean into the atmosphere, or vice versa. The world ocean directly participates in the formation and regulation of the chemical composition of the atmosphere and therefore a quantitative estimate of the receipts and losses in the gas exchange budget in the ocean-atmosphere system is one of the most important problems in chemical oceanography.

The oxygen flux (ΔO_2) per unit time through a unit area of the ocean-atmosphere interface is dependent on several factors:

[И = invasion, Э = evasion]

$$\Delta O_2 = n_t n_{\mathrm{V}} \alpha_{\mathrm{И,Э}} \Delta C, \qquad (1)$$

where ΔC(ml/liter) is the difference between the equilibrium concentration (solubility of oxygen at a given temperature and salinity [11]) and the actual oxygen content in the surface water, α_i is the invasion constant (22.0±2.2 liter/(m^2·hour) at 20°C [10]), when $\Delta C > 0$, α_e is the evasion constant (11.5±1.1 liter/(m^2·hour)

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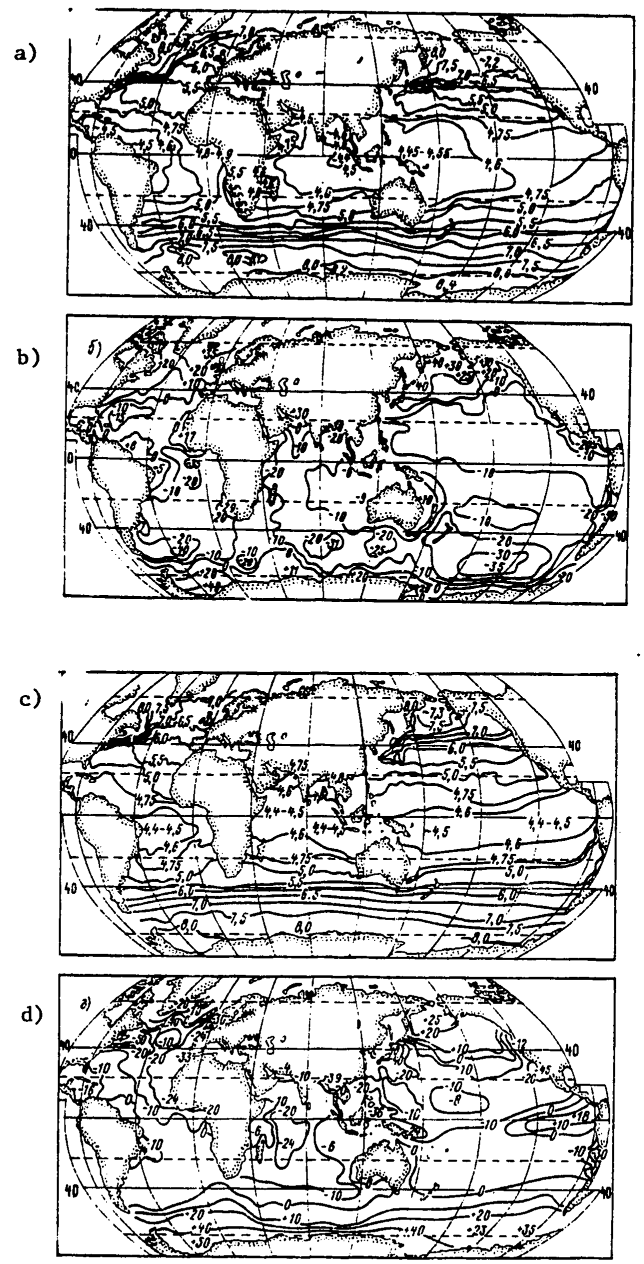
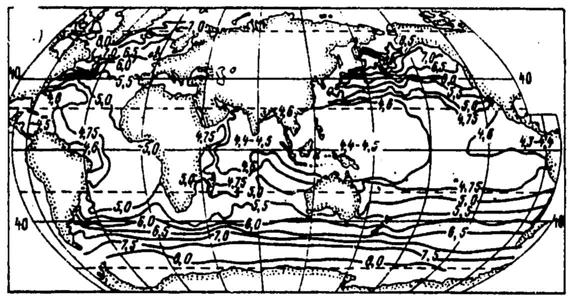


Fig. 1. Content of dissolved oxygen (ml/liter) in surface water of world ocean according to actual data (a, c, e, g) and distribution of ΔC ($\times 10^{-2}$ ml/liter), averaged by 5° trapezia at the surface of the world ocean (b, d, f, h).

e)



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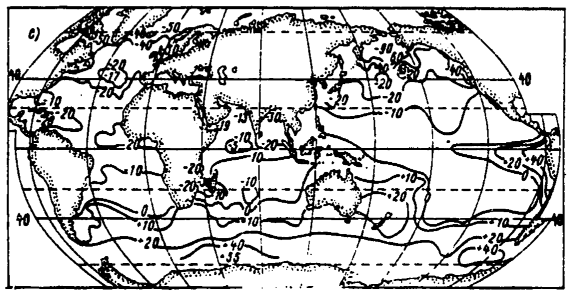

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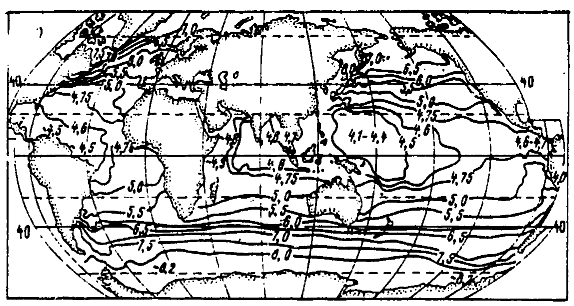

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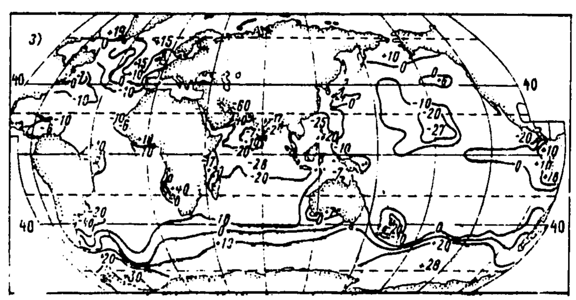

(+) -- absorption of oxygen by ocean, (-) release of oxygen from ocean and atmosphere. a, b -- January-February, c, d -- April-May, e, f) July-August, g, h) October-November.

at 20°C [10]), where n_V is an integral coefficient [9] showing by how many times the rate of gas exchange increases with different wind velocities (V) in comparison with an ideal calm ($1 + 0.27\ V^2$ with $V < 8$ m/sec, $-7.38 + 0.40\ V^2$ with $V > 8$ m/sec), n_t is a temperature coefficient for reducing the exchange constants from 20°C to the observed water temperature [10], linearly related to temperature (0.75 at 6°C and 1.10 at 25°C).

Computations of transport of oxygen masses across the ocean surface requires a knowledge of the Δ C values at all nodal points in the world ocean, not as an average for the year or for a half-year, but for each season of the year because averaging at large time scales can substantially distort the result. The surface oxygen fields represented in the ATLAS OF THE OCEANS [2, 3] represent an averaging of observational data for the warm and cold half-years in the northern hemisphere, whereas it is necessary to have a more detailed idea concerning the nature of the oxygen distribution in the surface water of the ocean from season to season. For this purpose we carried out processing of bathometric data (TGM-3M tables) available at the World Data Center (Moscow) for 1960-1978 for the periods January-February, April-May, July-August, October-November. We used observational data from USSR expeditions (departments of the USSR Academy of Sciences, Academy of Sciences Ukrainian SSR, State Committee on Hydrometeorology, All-Union Institute of Fishing and Oceanography, USSR Navy), expeditions of the United States, Great Britain, Japan, Sweden, Brazil, Chile, Argentina, Australia and African countries.

The basis for evaluating the quality of the initial data was the principles formulated by the author of [7]. The total number of observations remaining after the discarding of doubtful and erroneous values is given in Table 1.

The greatest number of stations was in the Atlantic Ocean; the Pacific Ocean was covered with a less dense number of observations. The distribution of stations over the ocean area was also nonuniform. The greatest number of stations (up to 30 in a 5° grid square) was in the regions of the Gulf Stream, Kuroshio, shelves of Africa and South America, and in fishing areas. There were up to 10 stations each in the 5° grid squares of the northern parts of the oceans. There were far fewer stations (often 1-2 each 5° grid square) in the central regions of the southern halves of the oceans and in the Antarctic Ocean. Nevertheless, the total number of stations during the last eight years increased considerably. This made it possible with an adequate degree of reliability to construct maps of the distribution of the concentrations of dissolved oxygen for the four seasons of the year (Figure 1a, c, e, g). In constructing the maps the values falling in a 1° square were averaged; the others were used as the result of one-time observations. Sources [6, 14, 15] were used as auxiliary sources.

The figures show that the general patterns of distribution of oxygen concentrations at the surface of the oceans and the shape of the isolines persist during the entire year with insignificant variations in the tropical and temporal latitudes. Appreciable changes in the fields from season to season are noted in the high latitudes (to the north and south of 50°S). A "zone of uncertainty" of arrangement of the lines of equal oxygen concentration has a maximum width (up to 5° in longitude, 2-3° in latitude) in the tropical and equatorial latitudes; in other regions it does not exceed 1-2° in latitude. In general, the seasonal oxygen fields have a zonal character, revealing a similarity to the temperature fields and diagrams of circulation of surface water masses. The distribution of ΔC values characterizing the direction and intensity of oxygen exchange (Fig. 1b, d, f, h) reflects the mean seasonal relationships between oxygen production, the biological absorption coefficient, temperature regime and convective processes. The principal centers of oxygen absorption from the atmosphere are the Antarctic Ocean and the regions to the north of 45°N (all seasons, except summer), and also the east-tropical part of the Pacific Ocean (all seasons, except January); a weak invasion close to equilibrium is usually observed around Australia; the remaining regions of the world ocean are characterized by the release of oxygen from the water into the atmosphere.

Table 1

Number of Stations With Determinations of Dissolved Oxygen in Oceans (1960-1978) Used in Constructing Fig. 1

Ocean	Season				Total
	January-February	April-May	July-August	October-November	
Atlantic	2227	2679	2314	2355	9575
Indian	1320	1105	1237	960	4622
Pacific	2602	1813	1339	1750	7504

The rates of oxygen exchange between the ocean and the atmosphere, computed using the mean monthly water temperature and wind velocity values from [2, 3], were compared on characteristic profiles intersecting the oceans from the extreme northern to the extreme southern latitudes (Fig. 2). In the tropics and subtropics of the oceans during the entire year there is a predominance of the evasion of oxygen with rates of 10-20 ml/(m^2·hour). In the temperate and high latitudes, where atmospheric processes are more intense and the wind velocities increase, the release or absorption of oxygen, depending on season, attain 100 ml/(m^2·hour). The general character of the variability of the oxygen fluxes by latitudes coincides with the data in [1], obtained by another method. The fields of dissolved oxygen and the gas exchange parameters (Fig. 1) serve as a basis for computing the annual budget of gas exchange for the area of the world ocean using the equation

$$M_{O_2} = \tau S n_t n_V \alpha_{\text{invasion, evasion}} \rho \Delta C, \tag{2}$$

where τ is the number of hours in a season, S is the area of a 5° square in dependence on the geographic latitude [11], ρ is oxygen density under normal conditions (1.429 mg/ml).

The summing of exchange masses of oxygen by 5° squares gives the budget for each season and as an average for the year for the entire world ocean. When making the computations we took into account the generally accepted boundaries between the oceans [13] and the position of the ice edge from [2, 3]. The results of the computations are generalized in Table 2, from which it is easy to see the seasonal differences in the absorption or release of oxygen in latitude zones in the oceans. The total absorption and release of oxygen in the world ocean (more than $52 \cdot 10^9$

tons/year) are comparable with the production of oxygen by continental vegetation ($235 \cdot 10^9$ tons/year) and by phytoplankton in the ocean ($154 \cdot 10^9$ tons/year) [4, 5], but the resultant annual budget is not great ($-0.54 \cdot 10^9$ tons/year). The errors introduced into the results of the computations are created primarily by the errors in determinations of the oxygen content (±0.02 ml/liter) and the deviations ΔC from the mean values in 5° grid squares as a result of the intraseasonal and spatial variability. The mean relative error in the ΔC and M_{O_2} values will evidently be not less than 10% (Table 3) and the resultant annual oxygen exchange budget is only 1% of the total exchange masses. Accordingly, it can be stated with certainty that with respect to oxygen exchange the world ocean is in a state close to equilibrium with the atmosphere.

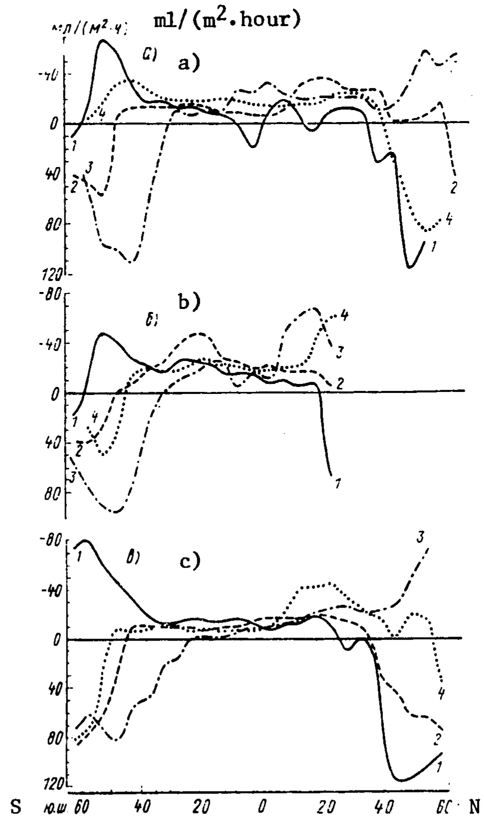

Fig. 2. Rate of passage of oxygen through the ocean surface. a) along the meridian 30°W, b) along the meridian 60°E, c) along the meridian 160°W. 1) winter, 2) spring, 3) summer, 4) autumn (in the northern hemisphere). (+) absorption by the ocean, (-) release from the ocean.

Table 2

Oxygen Exchange Between Oceans and Atmosphere (10^9 tons) in Different Seasons by Latitude Zones

Ocean	Latitude zone	Seasons (in northern hemisphere): winter +	winter −	spring +	spring −	summer +	summer −	autumn +	autumn −	Entire year +	Entire year −	Resultant
Atlantic A	Севернее 60° с. ш. C	0,38	0	0,14	0,01	0	0,18	0,13	0,01	0,65	0,20	+0,45
	60° с. ш. — 40° с. ш. D	2,67	0	0,14	0,84	0	1,09	0,84	0,21	3,65	2,14	+1,51
	40° с. ш. — 35° ю. ш.	0,98	1,77	0,04	2,47	0,22	3,11	0,05	2,70	1,29	10,05	−8,76
	35° ю. ш. — 55° ю. ш.	0	1,53	1,17	0,25	2,84	0,01	0,13	1,08	4,14	2,87	+1,27
	Южнее 55° ю. ш.	0,05	0,14	0,96	0	0,24	0	0,14	0	1,39	0,14	+1,25
	Sum	4,08	3,44	2,45	3,57	3,30	4,39	1,29	4,00	11,12	15,40	−4,28
Indian	25° с. ш. — 35° ю. ш.	0,12	1,97	0,04	2,61	0,29	3,11	0,03	2,98	0,48	10,67	−10,19
	35° ю. ш. — 55° ю. ш.	0,02	2,02	0,79	0,53	4,69	0	1,32	0,53	6,82	3,08	+3,74
B	Южнее 55° ю. ш.	0,16	0,30	1,29	0	1,21	0	0,56	0	3,22	0,30	+2,92
	Sum	0,30	4,29	2,12	3,14	6,19	3,11	1,91	3,51	10,52	14,05	−3,53
Pacific A	Севернее 40° с. ш.	3,95	0,03	1,70	0,09	0	1,83	0,34	0,51	5,99	2,46	+3,53
	40° с. ш. — 35° ю. ш.	2,37	4,30	0,76	4,44	3,69	3,15	0,33	4,38	7,15	16,27	- 9,12
	35° ю. ш. — 55° ю. ш.	0,01	2,59	2,77	0,17	4,64	0,10	1,49	0,44	8,91	3,30	+5,61
B	Южнее 55° ю. ш.	0,20	1,27	3,08	0	2,68	0	2,56	0	8,52	1,27	+7,25
	Sum	6,53	8,19	8,31	4,70	11,01	5,08	4,72	5,33	30,57	23,30	+7,27
All oceans		10,91	15,92	12,88	11,41	20,50	12,58	7,92	12,84	52,21	52,75	−0,54

Notes: (+) absorption by ocean, (−) release from ocean. A) North of; B) South of; C) N; D) S

Table 3

Averaged Errors in Computing ΔC and M_{O_2} in 5° Grid Squares in Different Zones

Latitude zone	Standard deviation ΔC, ml/liter	Maximum deviation ΔC from mean, ml/liter	Mean relative error M_{O_2}, %
25°N-25°S	0.02	up to 0.04	10
25°-40°	0.03	up to 0.05	10
North and south of 40°	0.04	up to 0.06	10

The general conclusion finds a satisfactory explanation when using data on the balance of organic matter in the ocean. It was shown in [5] that about 2% of the organic carbon (10^9 tons C_{org}) produced by photosynthesis in the world ocean enters bottom deposits. The remaining oxygen must be a pure increment and be released into the atmosphere. But, on the other hand [12], approximately the same quantity of allochthonous dissolved organic carbon enters with the continental runoff and is virtually completely oxidized in the water masses of the ocean. Thus, the balance is closed: that quantity of oxygen which remains with the transfer of organic matter into the bottom deposits is expended on the oxidation of organic matter in continental runoff. For the time being it is evidently premature to examine the problem of an excess of oxygen produced in the ocean and its role in the earth's atmosphere [8].

It should be noted that the computations discussed here were made without taking into account the possible presence of organic films on the ocean surface. At the present time there are still no reliable data on the chemical composition, thickness and structure of surface films and therefore a quantitative estimate of the film effect is a matter of the future.

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USE OF SATELLITE MEASUREMENTS OF THE SURFACE TEMPERATURE FIELD IN A NUMERICAL MODEL OF THE UPPER LAYER OF THE OCEAN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 62-70

[Article by V. P. Kochergin, professor, I. Ye. Timchenko, doctor of physical and mathematical sciences, V. I. Klimok and V. A. Sukhorukov, candidates of physical and mathematical sciences, and V. M. Talanov]

[Text]

Abstract: A numerical model of the upper quasihomogeneous layer of the ocean was used in assimilation of data from satellite and contact measurements of the surface temperature field. A statistical procedure is proposed for adjusting the results of these measurements. The data used were materials from the Soviet-French expedition in the Gulf of Lyons in 1976.

The different problems involved in the interaction between the atmosphere and ocean are of great importance with respect to monitoring the state of the ocean, weather forecasting, solving navigational problems and optimizing the process of search for concentrations of fish. The formation of a quasihomogeneous layer at the ocean surface plays an important role in the transfer of heat reaching the ocean surface into the ocean.

The monitoring of the state of the ocean involves tracking the spatial-temporal evolution of the principal fields in the ocean in the investigated region. In carrying out such monitoring it is necessary to use not only contact measurements of the fields, but also information on oceanic processes at the ocean surface which can be obtained from satellites. In recent years, due to the use of scanning measuring instruments on satellites, it has become possible to obtain images of the ocean surface in the IR range [13]. Such images constitute a virtually instantaneous photograph of the surface temperature field at the time when the satellite trajectory intersects the investigated region. The purpose of calibration of satellite information is its joint use with contact data for the ocean.

One of the first experiments for adjusting the measurement results was made by French scientists [12] during the second Soviet-French expedition "Sovfrans-II" in the Gulf of Lyons in 1976 [8, 14]. In the course of the experiment simultaneous remote and contact measurements were made of the surface temperature of the gulf (scientific research ship "Suroit" and the American satellite "NOAA-4"). These measurements were accompanied by density surveys from aboard the scientific research ship "Akademik Vernadskiy" [10]. The totality of collected measurement data makes it possible to carry out numerical experiments for the joint use of the results of satellite and contact observations in a model of the upper quasihomogeneous layer (UQL). The satellite carried a radiometer with a very high space resolution (0.9 km) which gave an image of the ocean in the IR range.

Evaluations of the assimilation of data from real satellite and contact observations obtained in the course of "Sovfrans-II" are given in [12]. Observation of the temporal change in the characteristics of physical conditions in the ocean medium is best accomplished using maps of the fields of these parameters obtained in the course of computations on the basis of theoretical models of ocean dynamics [3, 11] or direct processing of the results of observations in a polygon [2].

At the present time, in addition to these traditional approaches, increasing use is being made of the four-dimensional analysis method or the dynamic-stochastic approach to the modeling of fields and construction of their maps [9]. In this article the author proposes a dynamic-stochastic model of the behavior of the upper quasihomogeneous layer of the ocean; provision is made for the assimilation of data from remote and contact sounding of the surface temperature field.

The dynamic part of the model makes it possible to compute the changes in the time-averaged and spatially smoothed components of hydrothermodynamic fields in the ocean. The method for computing the characteristics of the upper layer in the ocean used in the model was developed at the Computation Center Siberian Department USSR Academy of Sciences and set forth in a number of studies [3, 5].

The fundamental system of equations, written in a Cartesian coordinate system with the x and y axes in the direction 30 and 120°, has the following form:

-- equations of motion

$$\frac{\partial u}{\partial t} - lv = -\frac{1}{\rho_0}\left(\frac{\partial P_a}{\partial x} + g\frac{\partial}{\partial x}\int_H^{\zeta}\rho\,dz\right) + \frac{\partial}{\partial z}K\frac{\partial u}{\partial z} + A_l\Delta u, \quad (1)$$

$$\frac{\partial v}{\partial t} + lu = -\frac{1}{\rho_0}\left(\frac{\partial P_a}{\partial y} + g\frac{\partial}{\partial y}\int_H^{\zeta}\rho\,dz\right) + \frac{\partial}{\partial z}K\frac{\partial v}{\partial z} + A_l\Delta v; \quad (2)$$

-- continuity equation

$$\frac{\partial w}{\partial z} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0; \quad (3)$$

-- density diffusion equation

$$\frac{\partial\rho}{\partial t} + u\frac{\partial\rho}{\partial x} + v\frac{\partial\rho}{\partial y} + w\frac{\partial\rho}{\partial z} = \frac{\partial}{\partial z}K\frac{\partial\rho}{\partial z} + A_l\Delta\rho; \quad (4)$$

-- coefficient of vertical turbulent exchange, an analogue of the Obukhov formula with a turbulence scale proportional to the thickness of the surface turbulent layer -- the Prandtl mixing path [4]

$$K = (0{,}05\ h)^2 \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 - \frac{g}{\rho_0}\frac{\partial \rho}{\partial z}}; \tag{5}$$

-- Mamayev equation of state

$$\rho = 1 + [(28{,}152 - 0{,}0735\ T - 0{,}0469\ T^2)\cdot 10^{-3} + (0{,}802 - 0{,}002\ T)(S - 35)\cdot 10^{-3}], \tag{6}$$

where S = 38.2°/oo is the mean salinity in the polygon.

The boundary conditions for equations (1)-(4) have the following form:

-- at the surface (z = 0)

$$K\frac{\partial u}{\partial z} = -\frac{\tau_x}{\rho_0},\quad K\frac{\partial v}{\partial z} = -\frac{\tau_y}{\rho_0},\quad w = 0,\quad \rho = \rho^0(t,\ x,\ y); \tag{7}$$

-- at the depth H_1 (geostrophic currents, $z = H_1$)

$$u_g = \frac{1}{l\rho_0}\left(\frac{\partial P_a}{\partial y} + g\frac{\partial}{\partial y}\int_H^{H_1}\rho\,dz\right),\quad v_g = \frac{1}{l\rho_0}\left(\frac{\partial P_a}{\partial x} + g\frac{\partial}{\partial x}\int_H^{H_1}\rho\,dx\right), \tag{8}$$

$$\rho = \rho^1(t,\ x,\ y). \tag{9}$$

At the lateral boundaries of the polygon the values of the density anomaly and current velocities u and v are stipulated:

$$\rho|_\Gamma = \rho_\Gamma(t,\ x,\ y,\ z),\quad u,\ v\,|_\Gamma = u_\Gamma,\ v_\Gamma(t,\ x,\ y,\ z). \tag{10}$$

At the initial moment (3 July) the velocity, density anomaly and vertical turbulent exchange values are stipulated over the entire region of the polygon:

$$t = 0:\quad \left.\begin{aligned} u,\ v &= u_0,\ v_0(x,\ y,\ z)\\ \rho &= \rho_0(x,\ y,\ z)\\ K &= K_0(x,\ y,\ z)\end{aligned}\right\}. \tag{11}$$

In equations (1)-(11) use is made of the following notations: P_a is atmospheric pressure in the near-water layer, τ_x, τ_y are the components of wind shearing stress, g is the acceleration of free falling, H(x,y) is bottom relief, h is the depth of the upper quasihomogeneous layer, $l = 0.976\cdot 10^{-4}$ sec^{-1} is the Coriolis parameter, corresponding to the location of the "Borha-II" buoy laboratory.

In the model in the first approximation in the equations of motion allowance is made only for lateral exchange. The level surface is determined by the dynamic method [11].

$$\zeta = -\frac{1}{\rho_0}\int_0^H \rho\,dz. \tag{12}$$

The wind shearing stress is computed using the Ackerblom formulas using data on near-water pressure for each day from 3 through 27 July 1976.

$$\tau_x = -\sqrt{\frac{K_a}{2l}}\left(\frac{\partial P_a}{\partial x} + \frac{\partial P_a}{\partial y}\right), \quad \tau_y = \sqrt{\frac{K_a}{2l}}\left(\frac{\partial P_a}{\partial x} - \frac{\partial P_a}{\partial y}\right), \tag{13}$$

where $K_a = 10^5$ cm^2/sec is the coefficient of vertical turbulent exchange in the atmosphere.

The thickness of the upper quasihomogeneous layer h is determined by the first computation point z_k, where the following condition is satisfied

$$(0{,}05\ z_k)^2 \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 - \frac{g}{\rho_0}\frac{\partial \rho}{\partial z}} \leqslant K_{min}. \tag{14}$$

In the computations it was assumed that $K_{min} = 0.1$ cm^2/sec. As the boundary values for the density anomaly we used real data obtained in the course of density surveys [10] on 3 and 27 July, linearly interpolated between them; deeper than H_1 (H_1 = 200 m) the density anomalies to the real depth H were linearly interpolated from $\rho^1(t, x, y, H_1)$ to 0.

The boundary conditions for the velocity of horizontal motion (8) were found as a result of diagnostic computations of equations (1), (2), (5) in a stationary approximation without allowance for lateral exchange for 3 and 27 July with subsequent linear interpolation for the entire period of the experiment. The initial conditions (11) were determined as a stationary solution of equations (1)-(5). Use was made of a numerical method based on use of two nested grids in the vertical coordinate [6]. The computations were made from 3 through 27 July with a time interval of 12 hours.

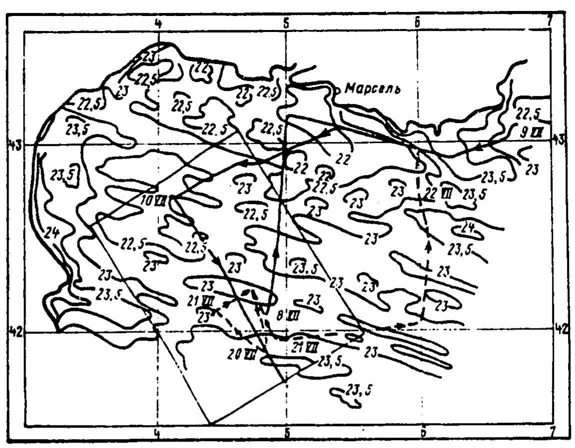

Fig. 1. Map of surface temperature of Gulf of Lyons on 9 July 1976, constructed using data from the "NOAA-4" satellite [12]. The hydrophysical polygon is represented by a rectangle.

The stochastic part of the model, consisting of statistical algorithms for the assimilation of observational data developed at the Marine Hydrophysical Institute Academy of Sciences Ukrainian SSR, makes it possible to carry out a joint analysis of observations obtained by remote and contact soundings of the ocean. Satellite measurements made on 9 and 21 July covered parts of the Gulf of Lyons which differ in area. The southern boundary of the satellite measurements on 9 July passed along latitude 41°55'S, on 21 July -- along latitude 41°35'N. Contact measurements of surface temperature carried out along the trajectory of motion of the "Suroit" are extremely nonuniformly distributed over the area of the polygon and therefore the observations made on 8-10 and 20-22 July were assigned to 9 and 21 July respectively. Satellite data of 9 July (in the form of isotherms) and the trajectories of motion of the "Suroit" are given in Fig. 1.

Using statistical analysis algorithms [9] the results of contact and remote measurements of the surface temperature field were investigated for anisotropy. The computations of the correlation functions of the temperature field for 9 and 21 July along the directions ($\Delta\varphi = 30°$) and on the assumption of uniformity indicated that with allowance for the width of the confidence intervals (30%) there is satisfaction of the hypothesis of uniformity and isotropicity of the mentioned fields. The correlation functions of the random temperature component fields were approximated by a dependence in the form

$$K_i(|\vec{X}|) = \exp(-\alpha_i|\vec{X}|) \cdot \cos\beta_i|\vec{X}|. \tag{15}$$

The values of the coefficients α_i and β_i are summarized in the table.

Type of measurement	Date of measurement	α_i km^{-1}	β_i km^{-1}
Remote	9 July	0.0346	0.0157
(NOAA-4) same	21 July	0.0097	0.0143
Contact	9 July	0.0425	0.0415
("Suroit") same	21 July	0.0616	0.0449

The prefiltering operation was carried out on the basis of the theory of measurements and interpolation of random fields developed by Petersen and Middleton in [15, 16]. The representation of satellite data in the form of a map of the measured ocean field was examined in detail in [1]; therefore, we will discuss only the principal results. We will examine the values of the field measured from a satellite $f(\vec{X})$ as the sum of the values of the smoothed component of the true field $s(\vec{X})$ and the measurement error $\eta(\vec{X})$, which we will assume to be in the form of "white noise."

$$f(\vec{X}) = s(\vec{X}) + \eta(\vec{X}), \quad \vec{X} = (x, y). \tag{16}$$

The "informative" component of the satellite frame, which is represented by the the field values at the points of intersection in a regular grid, can be discriminated in the process of averaging of the field $f(\vec{X})$ with some weighting function $\gamma(\vec{X})$, characterizing the measurement method.

$$s(\vec{V}_{[m]}) = \int\limits_{(\vec{X})} f(\vec{X})\, \gamma(\vec{V}_{[m]} - \vec{X})\, d\vec{X}. \tag{17}$$

The evaluation of this component is determined by the linear interpolation formula

$$s(\vec{X}) = \sum_{[m]} [g^f(\vec{X} - \vec{V}_{[m]}) \cdot s(\vec{V}_{[m]})]. \tag{18}$$

Minimizing the mean square interpolation error $\varepsilon(\vec{X}) = E\{|s(\vec{X}) - \hat{s}(\vec{X})|^2\}$, on the assumption of uniformity and isotropicity of the random field S(X), we obtain a system of Kolmogorov equations for determining the optimum weighting coefficients of the interpolation correlation algorithm

$$K_{ss}(\vec{X} - \vec{V}_{[m]}) = \sum_{[m]} [g^f(\vec{X} - \vec{V}_{[m]}) \cdot K_{ss}(\vec{V}_{[m]} - \vec{V}_{[n]})]. \tag{19}$$

It was demonstrated in [15, 16] that if the measured field is represented at the points of intersection of a regular grid and is uniform and isotropic, there is a definite form of the weighting coefficients. In the case of a square measurement grid the optimum weighting coefficients are determined as

$$g^f(x, y) = \frac{\sin 2\pi Bx}{2\pi Bx} \cdot \frac{\sin 2\pi By}{2\pi By}, \tag{20}$$

and the spectral algorithm for optimum interpolation at arbitrary points $\vec{X}$ assumes the form

$$\hat{s}(\vec{X}) = \sum_{[k]} [g^0(\vec{X} - \vec{V}_{[k]}) \cdot s(\vec{V}_{[k]})], \tag{21}$$

where $\vec{V}_{[m]}$ is a grid in which the prefiltration field values were determined.

We will use an algorithm for prefiltering the field $f(\vec{X})$, that is, replacement of a set of initial satellite data by a representative set in a thinner grid,

$$\hat{s}_{[k]}(0) = f(\vec{X}_{[k]}) \int\limits_{(\vec{X})} \gamma(0 - \vec{X})\, g^c(\vec{X} - \vec{X}_{[k]})\, d\vec{X} \tag{22}$$

or in the spectral form

$$\hat{s}_{[k]}(0) = \frac{f(\vec{X}_{[k]})}{(4\pi)^2} \int\limits_{(\vec{\omega})} \Gamma(\vec{\omega})\, G(\vec{\omega}) \exp(-i\vec{\omega} \cdot \vec{X}_{[k]})\, d\vec{\omega}, \tag{23}$$

where $\Gamma(\vec{\omega})$ and $G(\vec{\omega})$ are Fourier transforms of the weighting functions. Requiring satisfaction of the relationships between $\Gamma(\vec{\omega})$ and $G(\vec{\omega})$ as conditions for the representativeness of the $\hat{s}(0)$ values, we obtain expressions for the $s(\vec{V}[m])$ values as a result of prefiltering of the satellite frame

$$s(\vec{V}_{[m]}) = \sum_{[k]} \left[f(\vec{X}_{[k]}) \cdot \left(\frac{1}{a^2} \frac{\sin 2\pi Bx}{2\pi Bx} \frac{\sin 2\pi By}{2\pi By} \right) \right], \tag{24}$$

where a is the dimension of a cell of the initial observation grid, $2\pi B$ is the upper limiting cutoff frequency of the field to be filtered, separating the informative low-frequency part of the spectrum from the high-frequency noise. The noise level is assumed to be equal to 10% of the power of the entire received signal. In connection with approximation of the correlation functions of satellite measurements by a dependence in the form (15) for constructing the generatrix of the two-dimensional spectrum of these fields use was made of the results in [7] and the upper limiting cutoff frequency was ascertained. It was 0.0792 km^{-1}. The interval of the new grid was 39.3 km, which is three times greater than the interval of the initial grid of satellite observations. The prefiltering of satellite data made it possible to obtain representative "measurements" of temperature from a satellite. Optimum interpolation of these "measurements" was carried out at the points of intersection in the polygon and at the point of contact measurements in accordance with the optimum interpolation spectral algorithm (20), (21). The correlation algorithm (19) was used for the optimum interpolation of contact measurements at the polygon points of intersection. At the points of contact measurements we form the nonclosures $r(\vec{X}_k)$ between the values of the contact measurements $f_2(\vec{X}_k)$ and the prefiltered satellite data $\hat{s}(\vec{X}_k)$:

$$r(\vec{X}_k) = f_2(\vec{X}_k) - \hat{s}(\vec{X}_k) = f_2(\vec{X}_k) - \sum_{[n]} [g(\vec{X}_k - \vec{V}_{[n]}) \cdot s(\vec{V}_{[n]})]. \quad (25)$$

After interpolation of the nonclosures (25) by the correlation optimum interpolation method (19) at polygon points of intersection we carried out an assimilation of satellite and contact measurements of the field of surface temperature. The fields of ocean surface temperature were transformed into density fields at the ocean surface using the equation of state (6).

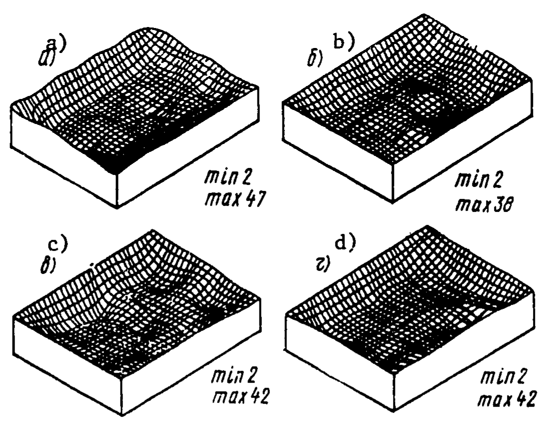

Fig. 2. Surfaces of lower boundary of QHL on 23 July 1976, constructed using the results of computations. a) without assimilation of information on the surface temperature field; b) with assimilation of contact data; c) with assimilation of satellite data; d) with assimilation of matched satellite and contact measurements.

Thus, as a result of use of the stochastic part of the model for 9 and 21 July we computed the boundary conditions for the density field at the surface using both data only from remote and contact soundings of the ocean surface and with their matched values.

The computed density fields were introduced into a numerical scheme of the dynamic part of the model as "fresh" boundary conditions effective 9 and 21 July. We note that in computations with correction of the boundary conditions the interpolation of surface boundary conditions was accomplished from the moment of the receipt of fresh information (9 and 21 July) to the time of the second survey (27 July).

In the course of numerical experiments there was found to be an influence of modified boundary conditions on the behavior of one of the finest characteristics of the upper quasihomogeneous layer -- the spatial distribution of its depth h during the period 3-27 July.

The greatest depth of the QHL was attained on 23 July when the field of wind shearing stress assumed maximum values $|\vec{\tau}|_{max} = 1.76$ H/M^2. A factor exerting a great influence on formation of depth of the upper quasihomogeneous layer is the local value of the wind shearing stress and medium stratification. For example, on 23 July the wind stress assumed a value in the range $1.19 \leqslant |\tau| \leqslant 1.84$ H/M^2; nevertheless, the h distribution is close to uniform. This result is the effect of an exceedingly high stable stratification on the density jump ($\partial\rho/\partial z \sim 10^{-6}$ g·cm^{-4}), which, despite the nonuniformity of the wind stress, cuts off a turbulent layer which is relatively uniform horizontally. Similarly, one can speak of the depth on the remaining days: it is determined by the local wind stress value and the vertical density distribution. Figure 2 shows the surfaces of the lower boundary of the QHL obtained on 23 July, as the boundary conditions at the surface using contact (Fig. 2b), satellite (Fig. 2c) and matched satellite and contact data (Fig. 2d). Figure 2a shows the topography of the lower boundary of the QHL on 23 July obtained without correction of the upper boundary conditions. The depth of the QHL in computations using intermediate correction of the boundary conditions is appreciably less.

A comparison of the vertical density gradients (for example, density fluxes at the surface) explains the difference in Figures 2a, 2b, 2c and 2d. The vertical density gradient increases in variants of computations with correction, which characterizes the influence of real boundary conditions. An increase in the positive flux causes a decrease in the depth of the QHL, as follows from expression (5).

We compared the topographies of depth of the QHL, computed with correction of the upper boundary conditions using data from contact and satellite measurements. We note that computations with the assimilation of satellite information gives a more detailed topography of the QHL surface.

Thus, data from remote measurement of surface temperature in dynamic-stochastic models of the QHL increase the reliability of the results of computations. Since the modern technology of remote measurement of ocean temperature ensures an accuracy of about 1° C [13], the use of satellite data is promising for the monitoring of the state of the ocean.

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UDC 551.465.553

EVALUATION OF THE ACCURACY OF NUMERICAL COMPUTATIONS OF STATIONARY WIND-DRIVEN CURRENTS ON THE SHELF

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 71-75

[Article by V. F. Kozlov, candidate of physical and mathematical sciences, and V. G. Makarov, Far Eastern State University, manuscript submitted 4 Mar 80]

[Text]

Abstract: Using the current fields computed for specific regions of the shelf on the basis of an Ekman diagnostic model in barotropic and baroclinic variants, the authors evaluate the contribution of individual terms to the nonclosure of the full equations. The conclusion is drawn that horizontal advection plays an appreciable role and the nature of the influence of baroclinicity is ascertained.

As is well known, the dynamic regime of shelf waters is characterized by great complexity and diversity. Accordingly, even in an investigation of processes of individual classes (for example, stationary wind-driven currents) it is an important step to formulate an adequate mathematical model. It is possible to obtain a rough evaluation of the individual factors which must be taken into account by carrying out a scale analysis of the full ("primitive") equations of hydrothermodynamics and computing the similarity test. However, evaluations of this type inevitably are of an integral character and do not make it possible to trace changes in the spatial-temporal balance of individual terms in the full equations, especially when taking into account the regional characteristics of the considered water areas. The most natural and reliable method for checking the quality of any model, involving a comparison of the computed fields of oceanological characteristics with the observed fields, to all intents and purposes is inapplicable due to the lack of an adequate volume of representative data. There is another, indirect method which is possible. It involves an evaluation of the nonclosure arising with the substitution of solution of simplified equations into full equations. In this case the relative role of the individual factors which were ignored in the formulation of the simplified model can be evaluated with respect to the degree of their contribution to the computed nonclosure. This latter method is also employed in this study in the example of diagnostic computations of stationary currents in two stipulated shelf regions of Far Eastern seas on the basis of a linear Ekman model. Using the numerically obtained solutions it is possible to evaluate the role of nonlinearity and lateral turbulent exchange and also analyze the balance of individual terms in the density diffusion equation.

As the full equations in the stationary problem we will use the equation of horizontal motion, taking into account the nonlinear, Coriolis and turbulent terms, the hydrostatic equation and the continuity (incompressibility) equation. In diagnostic computations, when density is stipulated from observations, the density diffusion equation is assumed to be satisfied identically, but the practical checking of this assumption is of interest. For our purposes it is sufficient to write only one of the equations of horizontal motion (for example, along the x-axis) and the density diffusion equation. In dimensionless variables they have the form

$$\underbrace{R\,(uu_x + vu_y}_{1}\ -\ \underbrace{wu_z)}_{2} - v = \zeta_x - \gamma \int_0^{\zeta} \rho_x\,dz + \underbrace{E_L \Delta u}_{3} + E\,u_{zz}, \tag{1}$$

$$\underbrace{u\rho_x + v\rho_y}_{1} + \underbrace{w\rho_z}_{2} = \underbrace{\frac{1}{P_L}\Delta\rho}_{3} + \underbrace{\frac{1}{P}\rho_{zz}}_{4}, \tag{2}$$

where we have introduced the dimensionless parameters: Rossby number $R = U^*/\Omega L^*$, the Ekman number $E_L = A_L/\Omega L^{*2}$, $E = A/\Omega H^{*2}$ and the Peclet number $P_L = L^*U^*/K_L$, $P = H^{*2}U^*/KL^*$, as well as the baroclinicity parameter $\gamma = g\delta^*H^*/\rho_0 L^*U^*\Omega$. Here the asterisks denote the characteristic scales of the vertical and horizontal extent of H^* and L^*, the horizontal velocity U^*, density disturbance δ^*; the scales for vertical velocity and level decrease of the free surface are equal to $W^* = U^*H^*/L^*$ and $\zeta = L^*U^*\Omega/g$; the Coriolis parameter Ω and the coefficients of turbulent viscosity and diffusion A, A_L, K, K_L are assumed to be constant. The remaining notations are those in common use. In equations (1)-(2) the underlined terms accordingly determine the horizontal advection 1, vertical advection 2, horizontal diffusion and exchange of momentum 3 and vertical diffusion 4.

Assuming for the shelf the characteristic values $L^* = 100$ km, $H^* = 100$ m, $\delta^* = 10^{-3}$ g/cm^3, $U^* = 10$ cm/sec, $A = K = 10^2$ cm^2/sec, $A_L = K_L = 10^6$ cm^2/sec, we obtain $W^* = 10^{-2}$ cm/sec, $\zeta^* = 10$ cm, and also $R = 10^{-2}$, $\gamma = 1$, $E_L = 10^{-4}$, $E = 10^{-2}$, $P_L = 10^{-2}$, $P_L = 10^2$, $P = 1$. While being quite rough (primarily due to the uncertainty in the turbulence coefficient), these evaluations nevertheless show that in the dynamic balance it is geostrophic equilibrium which is decisive. In computation of wind currents it is necessary to take vertical turbulent exchange into account since only in this case is it possible to have a correct mathematical formulation of the problem. On the other hand, under specific physiographic conditions the contribution of nonlinear and viscous effects to the dynamic balance can be quite significant. The necessary evaluations can be obtained by solving a problem of a diagnostic type, when only the emphasized terms (Ekman model) are retained in equation (1) and equation (2) is assumed to be satisfied. The problem is solved by a standard procedure using the integral stream function; the principal expressions and the basic computation scheme are given, for example, in [1] and [3]. A feature of the formulation is the use of the condition of free flowthrough at the free boundary and the use of a class of monotonic second-order difference schemes in the integration of an equation of an elliptical type for the integral stream function [2].

Table 1

Mean Values of Ratios-Functions at Standard Horizons

z, м	Barotropic model			Baroclinic model						
	f_{v1}	f_{v2}	f_{v3}	f_{v1}	f_{v2}	f_{v3}	$f^4_{\varphi 1}$	$f^4_{\varphi 2}$	$f^3_{\varphi 1}$	$f^3_{\varphi 2}$
0	0.18	—	0,03	—	—	—	—	—	—	—
5	0.39	0.18	0.09	—	—	—	—	—	—	—
10	0,15	0.19	0,05	0.18	0,01	0,01	0.23	0.01	44,6	14.8
20	0.1	0,19	0.07	0,03	0,003	0,003	0,15	0,08	56,3	17,8
30	0.22	0,02	0.14	0,04	0,005	0,002	0.24	0,09	58,7	15,2
40	0.11	0,01	0.04	—	—	—	—	—	—	—
50	0,05	0,01	0,02	0,04	0,002	0.003	0,43	0,16	17,6	6.7
60	0,1	0.02	0.05	—	—	—	—	—	—	—
70	0,05	0.01	0,05	—	—	—	—	—	—	—
75	—	—	—	0,05	0,007	0,005	0,11	0.04	12,8	7,1
80	0,1	0,02	0,06	—	—	—	—	—	—	—
90	0,08	—	0,28	—	—	—	—	—	—	—
100	0,14	—	0,1	—	—	—	—	—	—	—

The computed three-dimensional velocity field is then used in computing the ratios of the terms emphasized in (1) to the Coriolis force: f_{u1}, f_{u2}, f_{u2}; for example, $f_{n1} = -R(uu_x + vu_y)/v$. The same f_{vi} values are computed for the second equation of motion. Similarly, in equation (2) the ratios $f^4{}_1$, $f^4{}_2$, $f^3{}_1$, $f^3{}_2$ are evaluated, where the subscript indicates the numerator and the superscript denotes the denominator of the corresponding ratio; for example, $f^4{}_1 = P(u\,\sigma_x + v\,\sigma_y)/\sigma_{zz}$. An analysis of these ratios, computed at all the points of intersection of the spatial grid, makes it possible to give an indirect evaluation of the relative role of the investigated terms in the corresponding equations and thereby obtain some idea concerning the error arising with the discarding of these terms in the full equations (1)-(2). It goes without saying that such an approach does not make it possible to judge the quantitative errors in current velocities, but it gives a qualitative evaluation of the simplified model used, in any case, in the specific considered situations, and shows whether its further refinement is desirable.

Now we will proceed to an examination of the computations which were made.

The barotropic model is a special case of a diagnostic model when the density field is assumed to be uniform ($\Upsilon = 0$). It was used in computing stationary wind currents in Peter the Great Gulf, taking into account the real bottom topography and the configuration of the shoreline with an interval of about 5 km. One of the variants (southeasterly constant wind) was subjected to the analysis described above. The computed horizontal velocities at the surface on the average are about 30 cm/sec and are directed almost to the north. Closer to the bottom their value decreases and the direction is reversed. The vertical velocities, being about 10^{-2} cm/sec, increase in absolute value with increasing distance from the sea surface.

The $f_{u1},\ldots,f_{v3}$, taken in absolute value, will henceforth for brevity be called "ratios-functions" (RF). At each of the computational horizons we computed the minimum, maximum and mean values of the RF and also determined the number of points of intersection in the grid at which the RF value fell into the stipulated ranges of values.

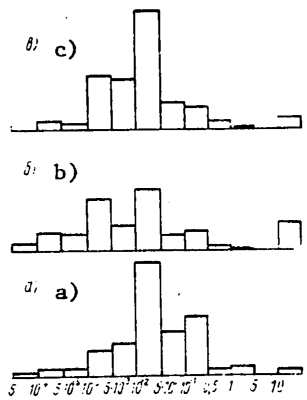

Fig. 1. Histograms of distribution of RF values in barotropic case. a) f_{v1}, b) f_{v2}, c) f_{v3}.

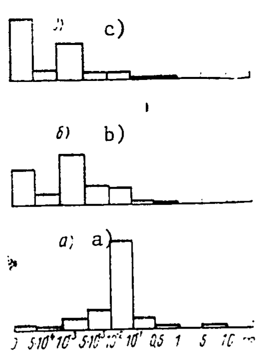

Fig. 2. Histograms of distribution of RF values in baroclinic case. a) f_{v1}, b) f_{v2}, c) f_{v3}.

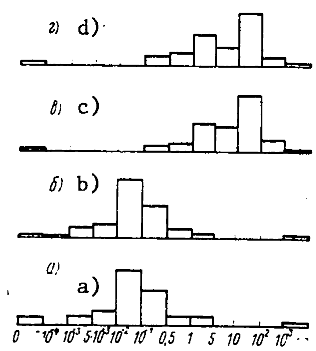

Fig. 3. Histograms of distribution of RF values for density diffusion equation. a) $f^4_{\rho 1}$, b) $f^4_{\rho 2}$, c) $f^3_{\rho 1}$, d) $f^3_{\rho 2}$.

The table shows the computed mean RF values at individual horizons. Since in the selected computation variant the values of the meridional velocity component v are almost an order of magnitude higher than the zonal value, the table gives somewhat higher RF values for the meridional equation of motion. The mean contribution of horizontal advection (by horizons) exceeds 12%, in the upper layers (5 m) attaining up to 40%, which is evidence of its significance in the dynamic balance. The total contribution of vertical advection does not exceed 6%, but in the upper horizons it is considerably greater and attains 19%.

The computed mean values are greatly influenced by individual high RF values and therefore for sounder conclusions it is desirable to consider in what intervals most of the values fall. Figure 1 shows histograms for each of the RF, which were constructed using the formula

$$\varphi^j = \sum_i \eta_i^j \xi_i$$

where i is the number of the standard horizon, j is the sequence number of the interval of RF values, η_i^j is the number of points at which the values of the considered RF function fall in the j-th interval at the i-th standard horizon, ξ_i is the total number of points at the i-th horizon.

Despite the fact that the maximum of the $|f_{v1}|$ values falls in the interval 0.01-0.05, more than 25% of the RF exceed some value 0.1, which indicates an appreciable contribution of horizontal advection, especially at some horizons close to the surface, where the number of such values in individual cases exceeds 50%.

The remaining RF are characterized by a bimodal distribution with a tendency to decrease of the second mode in the interval 10^{-3}-$5\cdot10^{-3}$, but even after deducting values greater than 10 (which are evidently the result of large errors in the numerical differentiation of velocities at the boundary points of intersection), more than 8% of the RF f_{v2} and about 10% of the RF f_{v3} exceed 0.1. Most of the $|f_{v2}|$ values exceeding 0.1 occur in the upper horizons (to 30 m), where they constitute up to 30% of all the values, whereas the $|f_{v3}|$ distribution is more uniform for all horizons.

Baroclinic diagonal model. It is postulated that there is an inhomogeneous density field which is assumed to be known from observations. On the basis of such a model computations were made of currents on a part of the shelf of Sakhalin Island with a horizontal grid interval of about 15 km; the resulting data were used in computing the RF generated by equations (1) and (2). The mean RF values for the computational horizons are given in the table and histograms of the distribution of RF values in the entire region are given in Figures 2 and 3. The maximum contribution of horizontal and vertical advection and lateral turbulent exchange is attained in the upper horizons. Most of the $|f_{v1}|$ values fall in the interval 10^{-2}-10^{-1} and only about 12% exceed 0.1. The greatest number of $|f_{v2}|$ values falls in the interval 10^{-3}-$5\cdot10^{-3}$; values exceeding 0.1 constitute about 2% and are rather uniformly distributed by horizons. There are still fewer $|f_{v3}|$ values: for the most part they do not exceed $5\cdot10^{-4}$.

Comparison of these results with similar data for a barotropic model shows that allowance for baroclinicity appreciably decreases the contribution of the nonlinear effects and lateral turbulent exchange. To be sure, it must be remembered that in part such a decrease can occur as a result of the smoothing caused by an increase of the computation grid interval approximately by a factor of three.

The data cited in the table and in Fig. 3 show that in the density diffusion equation (2) the terms for the horizontal and vertical density advection are of the same order of magnitude and are entirely comparable with the contribution of vertical diffusion if the somewhat exaggerated value of the K coefficient is taken into account. The shift of the RF mode to the right in Fig. 3c,d by several orders of magnitude indicates that the role of horizontal turbulent diffusion of density is negligible.

The results described above were obtained on the basis of computations for specific physiographic conditions and therefore, strictly speaking, the conclusions drawn have only regional significance. However, it can be anticipated that they have a broader applicability because in general they agree well with theoretical estimates.

We will concisely formulate the principal conclusions:

1) Applicable to computations of stationary wind currents on the shelf in regions of homogeneous density the classical Ekman model considerably underestimates the horizontal advection of momentum, especially in the upper layers.

2) In the shelf regions baroclinicity is a factor which in the dynamic balance substantially reduces the role of vertical advection and horizontal turbulent exchange. To a far lesser degree it exerts an influence on the contribution of horizontal advection.

3) In constructing prognostic models on the shelf in the density diffusion equation (2) without the introduction of substantial errors it is possible to neglect only one effect -- horizontal turbulent diffusion.

In conclusion the authors express appreciation to N. P. Nechiporuk and V. Yu. Subocheva who participated in carrying out a number of computations.

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HYDROMETEOROLOGICAL VALIDATION FOR INTERZONAL REDISTRIBUTION OF RIVER RUNOFF

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 76-81

[Article by A. A. Sokolov, professor, State Hydrological Institute, manuscript submitted 4 Mar 80]

[Text]

Abstract: The article briefly sets forth the essence of the problem of shifting of part of the runoff of northern and Siberian rivers to the southern slope of our country. Suggested ways to solve the problem are discussed.

Until recently transformations of the water regime and water balance in the process of economic activity in river basins were tied in with the solution of large, but nevertheless special national economic problems (construction of hydroelectric power stations, connecting water routes, irrigation canals, etc.).

With the development of the economy and culture water management measures became larger in scale and acquired a complex character. They now take in entire river basins: Volga, Dnepr, Syrdar'ya, Angara, and others.

During recent years there has been a continuous increase in water consumption in all branches of the national economy. There is a need for an ever-greater quantity of water, especially in the southern part of our country, most favorable for agricultural production with respect to climatic conditions, but having little water. Its water management balance is becoming increasingly strained, and in a number of basins is negative.

This in turn gives rise to the problem, unprecedented in its scale, of the spatial redistribution of river runoff no longer within individual basins, but at the scale of the largest regions of the European and Asiatic continents. Reference is to the shifting of part of the runoff of the northern rivers of our country for replenishing the dwindling resources of river runoff in the south.

The novelty of formulation of this problem is that it is proposed that some of the river runoff be taken from one natural zone (a zone of excess moistening) and shifted to other regions -- the semiarid zone of our country. Such a macroscale melioration of nature by means of the interzonal redistribution of river runoff will have great socioeconomic importance. It will stimulate the development of many branches of the national economy. The redistribution of runoff will lead to an improvement in life and an enhancement of the economy of extensive areas in the European USSR, Western Siberia, Kazakhstan and Central Asia.

A complex aspect of the problem of interzonal redistribution of runoff is the need for a long-range forecast of the influence of this type of disruption of the established equilibrium in nature on the environment: the climate, water regime, water balance, flora and fauna of the regions affected by the territorial redistribution of river runoff. This requires a considerably higher level of knowledge of the interrelationships in nature in comparison with those which science has had until now. The revealing of these interrelationships requires the extensive coordination of the efforts of specialists and scientists of different disciplines in the unified science of the earth, which has become highly differentiated in our day.

Among scientists and specialists there still prevails to a certain degree a cautious attitude toward the problem of interzonal redistribution of river runoff due to its exceptional complexity and the need for great capital investments, amounting to tens of billions of rubles. Accordingly, we will briefly discuss what the water balance of the southern part of our country is like at the present time and what it will be like in the future.

As indicated by data from the inventory of use of water in the national economy, at the present time about 300 km^3 of water is constantly being withdrawn from the rivers and water bodies of the USSR each year. According to predictions of scientists of the State Committee on Hydrometeorology, in the long run, taking into account the increase in population, the development of industry, agriculture and other branches of the national economy, the need for water by the beginning of the coming century will approximately double, that is, will increase to 600 km^3/year. Most of this demand increase will be in the southern part of the territory of the USSR, which has little water. It is related to implementation of the task set by the Party and government of bringing about the universal development of irrigation for ensuring high and stable yields.

With respect to the potential resources of river runoff in the southern part of the country (about 900 km^3/year), the need for water by the year 2000 will be about 2/3 of the runoff of all its rivers. However, this does not mean that the supplementation of the water resources of the southern part of our country can be thought of only in terms of the remote future.

The fact is that the potential resources of river runoff in the southern part of the country represent the mean annual runoff of rivers, the total use of which, by virtue of the great intraannual and long-term variations, is virtually unattainable. The real (exploitable) water resources in this zone, taking into account the possible regulation of runoff, are not more than 40-50% of the mean annual runoff. True, after use part of the runoff will again be returned to the rivers and water bodies and can be used again, but in such cases the water is returned in the form of not always purified industrial and communal waste water. All this will make the water balance of the southern zone extremely strained in the future.

The acuteness of the water problem in the southern part of our country is attributable not only to the shortage of river runoff and the threatening contamination of rivers. The principal reason is that the overwhelming part of the rivers on the southern slope flow into internal water bodies -- Caspian Sea, Aral Sea, Lake Balkhash, Issyk-Kul', Sea of Azov. The use of the water resources of the rivers feeding these water bodies, Volga, Ural, Don, Kuban', Amudar'ya, Syrdar'ya, Ili and others, inevitably will result in a decrease in the level of the internal water bodies, a deterioration of their water-salt regime, which will inflict a great, frequently irreversible loss on fishing and many other branches of the national economy closely associated with the present-day level of these water bodies. As is well known, as a result of the intensive use of these rivers the level of the Caspian during recent decades has dropped by almost 3 m, the Aral Sea -- by 6 m, Lake Balkhash -- by 1 m, and Lake Issyk-Kul' -- by 7 m. [This drop is associated not only with the intensive use of runoff; it is attributable in part to climatic factors.] In the semiclosed Sea of Azov the decrease in the inflow of fresh water has been expressed in a deterioration of its water-salt balance and a marked reduction in its importance for fishing.

In essence the renewable water resources in the southern part of our country in the basins of the internal water bodies were expended long ago. The development of construction for water management purposes, related to the moistening of the land and the broadening of irrigated agriculture, is being accomplished here so to speak by borrowing, that is, at the expense of depletion of the secular reserves of internal water bodies and with a deterioration of their salt balance.

It is obvious that it is no longer possible to continue development of irrigation in the arid regions of the Trans-Volga area, the Northern Caucasus, Kazakhstan and Central Asia with the mentioned plans without reckoning with the losses to the regime and balance of internal water bodies.

Taking this into account, the 25th CPSU Congress, as a pressing problem in the field of water management construction, set the task of formulating and validating variants for shifting part of the runoff of northern rivers into the southern regions of the country.

Scientists and specialists of many planning and scientific institutes and academic institutes of the Ministry of Water Management, State Committee on Hydrometeorology, Power Ministry, Ministry of Higher and Intermediate Education and other ministries and departments, as well as the USSR Academy of Sciences, in the course of recent years, have carried out major scientific research and planning work associated with solution of this problem. Technical-economic validations of two fundamental variants of interzonal redistribution of river runoff have been prepared and are undergoing expert evaluation:

-- shifting of part of the runoff of northern European rivers to the south, into the Volga basin, along the Volga-Baltic Sea route and the Kama-Pechora canals;

-- shifting of part of the runoff of the Ob' River into Central Asia via the so-called Turgayskiy downwarp, through which in the Quaternary period passed the runoff of glacial waters from the West Siberian Lowland into the Turanskaya depression.

The most thoroughly developed (in scientific and engineering-technical respects) is a variant for the southward shifting of a part of the runoff of the northern rivers of the European USSR, whose implementation will simultaneously solve three highly important problems: the possibility of development of irrigation in the Trans-Volga area, stabilization of the level and maintenance of fish reserves in the Caspian Sea.

The basins of the Neva, Onega, Severnaya Dvina, Pechora and others, rivers with an abundance of water, are situated in the northern European USSR. Their total runoff is about 400 km^3/year, which considerably exceeds the water needs of the economy in these northern regions. According to the technical-economic validation of the first stage in the plan for the shifting of runoff for replenishing the water resources of the Volga (Caspian), it will be necessary to extract about 40 km^3 of water annually, which is 10% of the runoff of the mentioned rivers. [At the present time this need is being covered in part by the cutting off of the Kara-Bogaz-Gol gulf from the Caspian, which results in a saving of water of about 5 km^3 annually due to a reduction in evaporation.]

It seems at first glance that the withdrawal of such a water volume from the northern rivers cannot in any way substantially affect the natural conditions and economy of these northern regions. This, however, is not entirely so; the withdrawal of river runoff, to be sure, inevitably involves some costs. It is important that these costs be minimum and that the advantages which will be obtained from the use of the runoff of the northern rivers in the southern part of the country will substantially exceed the losses inflicted on the donor basins with the partial withdrawal of their runoff.

Therefore, it is necessary to consider the most effective use of water resources by shifting part of them into the southern regions of the country, which have the heat resources, where the water shortage is holding back the development of measures for the development of irrigation, so important for our country.

As indicated by planning work, the proposed withdrawal of runoff cannot be taken from any one northern basin. It must be "collected" by parts from a number of basins gradually: from the basin of the Neva -- 3-7 km^3, Onega -- 1.8 km^3, Severnaya Dvina -- 4.8-15 km^3, Pechora -- 13.8 km^3 annually. This is attributable to the fact that for a concentrated withdrawal of water from one basin it would be necessary to create a reservoir of exceedingly great capacity, which under the conditions of lowland relief in the northern regions would require the inundation of vast areas of highly productive forests.

The most favorable conditions for the withdrawal of water are in the basin of the Neva River, whose waters are regulated by extremely large water bodies: Lake Onega and Lake Ladoga.

It would seem that the enormous reserves of fresh water in these water bodies can with excess cover the need for water necessary for shifting to the south. But great withdrawals of water from Lakes Onega and Ladoga could inflict great losses on Leningrad. The waters of these lakes feed the Neva River, playing an enormous sanitary role in the life of the city and the western part of the Gulf of Finland adjacent to it. Accordingly, in the technical-economic validation of the plan for the shifting of runoff provision is made for withdrawals from Lake Onega in a minimum volume, a total of 3-7 km^3 annually, which is 3-9% of the mean annual runoff of the Neva River (80 km^3/year). To be sure, the withdrawal of 3-7 km^3 of water annually from Lake Ladoga will inflict some loss on the cascades of Svir hydroelectric power stations (the production of electric power will be reduced), but this loss will be more than compensated by the "work" of this water in the cascades of Volga hydroelectric power stations.

The relatively small volumes of runoff withdrawals from the Onega, Severnaya Dvina (Sukhona) and Pechora Rivers provided for in the technical-economic validation were also determined taking into account the need for inflicting minimum losses on their water regime, especially during the low-water period, in reaches below the sites of the planned water intake.

The variant of the technical-economic validation for the shifting of part of the runoff of northern rivers to the south, developed at the present time, as indicated by its expert evaluation, evokes a series of fundamental comments. There are a number of problems related to the proposed variant for the shifting of waters which require additional investigations in order that it be really implemented.

In particular, these pertain to the need for examining the possible tendencies of variations and change of climate in the next 20-30 years. As is well known, in the last 20-year period of the 20th century there could well be onset of an increased water volume phase with a corresponding rise in the level of the Caspian and this could radically alter the present-day water management situation.

One of the important shortcomings of the formulated technical-economic validation is a poor scientific validation of the volume of water to be shifted (40 km^3 annually) and the regime for the withdrawal of runoff. Depending on the water volume available in a particular year, the volume of shifted water obviously should be variable. In determining the need for water for shifting elsewhere, related to the development of irrigation, it is desirable that the heat and water balance method for computing the irrigation norms and regime developed by the State Hydrological Institute be used; it has already been adequately developed in actual practice.

There is a need for a considerably more thorough validation of the proposal for the transport of the mentioned volume of runoff along the Volga-Baltic route without its substantial reconstruction. There are also a number of other critical comments with respect to the technical-economic validation of the first stage for the shifting of part of the runoff of northern rivers to the south.

It seems desirable to examine the fundamentally new alternative solution which has recently been advanced: the withdrawal of water not from all basins gradually, but from one source. According to a proposal of Soyuzgiprovodkhoz (State All-Union Water Management Institute), such a source could be Onega Bay, in the White Sea, if part of it was cut off by a dam and thus transformed into a reservoir which would ensure the necessary volume of withdrawal and shifting of runoff (40 km^3 annually). However, this variant remains undeveloped, to all intents and purposes, in scientific and technical respects. This is particularly true of the possibility of freshening of the waters in Onega Bay and how long this would take.

The formulation and validation of the plan for shifting part of the water resources of such a giant river as the Ob', whose mean annual runoff is equal to almost 400 km^3 annually, into Central Asia, has a long history. As is well known, for this purpose in the recent past it was proposed, as a variant, that an enormous water body be created in the lower reaches of the Ob' with the erection of a dam and hydroelectric power station near Salekhard. This variant in its time was subjected in the press to serious and proper criticism and was rejected as inflicting great losses on the environment and economy of Western Siberia.

After careful research, a considerably more realistic variant has now been advanced and developed, although it is also characterized by considerable complexity. The present-day variant of the technical-economic validation provides that in the first stage of withdrawal there will be a removal of 25 km^3 of water from the Ob' basin with a subsequent increase (second stage) to 60 km^3 annually. It is proposed that the shifting of runoff take place through a channel of enormous extent -- about 2,300 km, with a width of 160-170 m and a depth of 15-16 m. A channel of such an extent and dimensions has never been known in world hydraulic engineering.

The route of the Irtysh-Central Asia canal will have its beginning in the neighborhood of the entry of the Tobol into the Irtysh, below whose confluence the creation of a dam is planned. [At the present time a variant of water intake into the canal from the Ob' River near Belogor'ye is being considered.] Then it will pass along the Tobol valley, continuing through the Turgayskiy downwarp to the lower reaches of the Syrdar'ya. Water with a mean discharge of 800 m^3/sec will then be raised to the water divide by means of powerful pumps through a cascade of low-head reservoirs. South of the water divide the water will flow through the channel by gravity.

There is a whole series of complex problems related to the possibility for implementing this project. Among these the most important is possibly the determination of the dimensions of the canal and its carrying capacity. There is basis for assuming that channel processes can develop and ridges can be formed in a channel with unreinforced sides. From the relatively narrow and deep channel provided for in the project it can be transformed into a broad flat watercourse which cannot carry the intended flow (800 m^3/sec). During the autumn-winter period ice jams or water-over-ice can form in the channel, and these phenomena can also reduce its carrying capacity.

Among the important problems relating to the hydrometeorological support of the first stage in the shifting of part of the runoff of the Ob' into Central Asia we must include the need for refining the prediction of entry and transport, losses on evaporation and infiltration, influence of the channel on the regime of the watercourses and water bodies adjacent to it, and also on hydrogeological conditions and a number of others.

Particularly important is the need for a more reliable validation of prediction of the possible change in the hydrochemical regime along a route of such enormous extent. There is the apprehension that when crossing the arid steppe and semidesert regions of Kazakhstan the water in the channel will increase its mineralization above the admissible level.

Still more complex problems will arise in the validation of the second stage with a volume of transfer of 60 km^3 annually. An evaluation of possible changes of the ice-thermal and hydrochemical regimes of the mouth region of the Ob' and the part of the Kara Sea adjacent to it is also of interest and has great practical importance. The withdrawal of part of the Ob' runoff at the same time will mean the removal of a considerable quantity of heat and this could have the effect of deterioration of navigation conditions on the trajectory of the Northern Sea Route.

The shifting of part of the Ob' runoff into Central Asia with its subsequent use for irrigation from the hydrological point of view will mean an increase in evaporation in the region of internal runoff. The entry of an additional 25-60 km^3 annually to some degree will exert an effect on change in the moisture cycle in the atmosphere in the central region, but also will influence the climate of regions adjacent to the route of the canal.

With a considerable increase in the area of irrigated lands there can be some southward shifting of the zone of cultivation of fine-fiber varieties of cotton. The presently formulated prediction of possible changes in climatic conditions as a result of the redistribution of river runoff (and accordingly evaporation) requires further refinement.

As was noted above, both of the considered variants for the shifting of part of the runoff of northern rivers to the south in the European and Asiatic parts of the country are in the stage of technical-economic validation. In order to refine the predictions of hydrological and ecological consequences, final adoption of a decision and subsequent hydrometeorological support of technical planning, construction and operation of the projected water management system it is necessary to broaden hydrometeorological observations in the regions of withdrawal, transport and use of the shifted runoff. This relates to hydrological, hydrochemical, ice-thermal and other observations in river reaches below the projected water intakes, including the mouths of rivers and the embayments adjacent to them, in small water-courses and water bodies along the routes used in the transport of runoff, in the Caspian Sea, Aral Sea and Sea of Azov, in Lakes Balkhash and Issyk-Kul'.

This applies to a not lesser degree to the need for broadening meteorological, and in particular, aerological observations.

An improvement in the system for observing and monitoring changes in climate and the water regime of rivers and water bodies will make it possible to obtain the data necessary for more reliable hydrological validation of the shifting of runoff and refinement of the prediction of changes in their hydrometeorological regime as a result of withdrawal of part of the runoff of northern and Siberian rivers and its transport to the south.

This work must begin without awaiting completion of all the technical plans and the beginning of implementation of projects for the shifting of runoff in order to obtain reliable background characteristics of the natural regime which in the future can be used as initial data for evaluating the change in the water regime and balance after the presently planned measures for interzonal redistribution of river runoff are put into operation. It should be noted that the problems involved in the hydrometeorological support of the economic exploitation of large regions should be examined in good time prior to the onset of the planning studies.

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PREDICTION OF DISTRIBUTION OF HIGH-WATER RUNOFF BY MONTHS IN THE MIDDLE AND LOWER COURSES OF THE OB' AND IRTYSH RIVERS

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[Article by V. I. Sapozhnikov, doctor of geographical sciences, USSR Hydrometeorological Scientific Research Center, manuscript submitted 28 May 80]

[Text]

Abstract: The article describes methods for predicting the distribution of runoff in the Ob' River at Prokhorkino village, Belogor'ye village and Salekhard city and in the Irtysh River at Tobol'sk city by months from April through September, based on computations of transformations down to the most downstream gaging stations using the influence functions for the discharges of water through the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations and the predicted hydrographs of lateral inflow for several parts of a basin. The distribution of lateral inflow is predicted using standard hydrographs and the modular coefficients of the maximum water reserves in the snow cover observed prior to the day of preparation of the prediction (31 March). The standard hydrographs are determined from the water levels on the rivers on the day of the prediction and the 10-day air temperature anticipated on the basis of a weather forecast. The use of data on channel reserves and water inflow into the river network after onset of its maximum facilitates more precise prediction of the distribution of monthly runoff.

Long-range predictions of high-water hydrographs on the Ob' and Irtysh Rivers are necessary for the servicing of the petroleum production industry and river transportation. The basis of such predictions is the method for computing the monthly water discharges on the basis of runoff data in several parts of a basin and discharges from the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations.

As the points for which the prediction was developed we used: in the middle course of the Ob' -- Prokhorkino, in its lower course -- Belogor'ye and Salekhard, and also in the lower course of the Irtysh -- Tobol'sk (see Fig. 1). In order to predict runoff at these stations, taking into account the spatial-temporal nonuniformity of its formation, the total area of the drainage basins of the Ob' and Irtysh Rivers is divided into the following parts: Ob' River to the Novosibirskaya Hydroelectric Power Station (232,000 km^2), Novosibirskaya Hydroelectric Power Station-Kolpashevo (254,000 km^2), Kolpashevo-Prokhorkino (252,000 km^2), Tobol'sk on the Irtysh-Belogor'ye (453,000 km^2), Belogor'ye-Salekhard (270,000 km^2), Irtysh to the Ust'-Kamenogorskaya Hydroelectric Power Station (146,000 km^2), Ust'-Kamenogorskaya Hydroelectric Power Station-Omsk (175,000 km^2), Omsk-Tobol'sk (648,000 km^2).

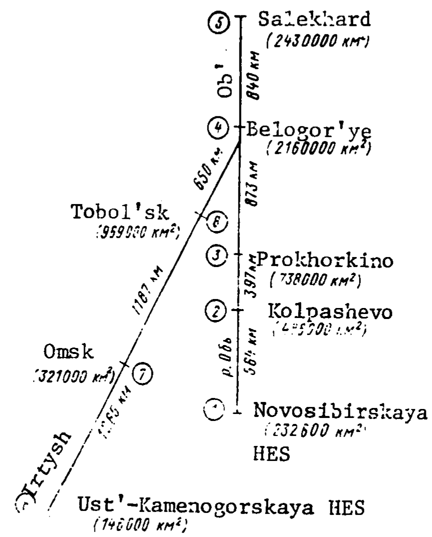

Fig. 1. Diagram of Ob' Basin.

The initial material for developing the method for computing and predicting the distribution of runoff at the time of high water was the mean monthly water discharges for all the principal points on the Ob' and Irtysh Rivers (see Fig. 1).

For the part of a basin bounded by upstream and downstream gaging stations the hydrographs of lateral inflow $Q_{lat,t}$ were computed from the difference between the water discharges at the time t at the downstream station $Q_{down\ t}$ and the transformed water discharges at the upstream gaging stations Q_{up} using the equations

$$Q_{lat\ t} = Q_{down\ t} - \sum_{\tau=1}^{\tau_{max}} Q_{up\ t-\tau+1} r_{\tau}. \tag{1}$$

where r_τ are the ordinates of the influence function for the runoff travel time curve for the reach, τ and τ_{max} are the water travel time and its maximum value.

Table 1

Ordinates of Influence Functions for Computing Monthly Discharges of Lateral Water Inflow in Reaches of the Ob' and Irtysh Rivers

Month	Ob'				Irtysh		
	Novosibirskaya HES-Kolpashevo (1-2)	Kolpashevo-Prokhorkino (2-3)	Prokhorkino-Belogor'ye (3-4)	Belogor'ye-Salekhard (4-5)	Ust'-Kamenogorskaya HES-Omsk (6-7)	Omsk-Tobol'sk (7-8)	Tobol'sk-Belogor'ye on Ob' (8-4)
T	0,81	0,44	0.19	0.26	0.37	0,31	0,54
$T-1$	0,19	0,56	0.79	0.73	0.63	0,69	0,46
$T-2$	—	—	0.02	0.01	—	—	—

Special attention has been devoted to an analysis of water travel time conditions in the enumerated reaches and determination of the influence functions r_τ for computing the transformation of channel runoff. These functions were determined using observational data on water discharges for each two days. The procedures currently employed in practical work were used in their selection [1, 2]. In most cases for these reaches use was made of high waters and floods with a minimum lateral inflow varying little with time. The constant influence functions for reaches of the Ob' and Irtysh Rivers which were obtained were checked by computations of the transformation of high waters and floods. Then, by moving averaging of their ordinates, it was possible to obtain the distributions of 10-day influence functions, and from them, also the monthly influence functions for computing the hydrographs for monthly time intervals; these are given in Table 1.

For the Ob' River at Prokhorkino computations of the runoff hydrograph are made using the equation

[MP = max]

$$Q_{3,t} = \sum_{\tau=1}^{\tau_{MP}} Q_{1,\, t-\tau+1}\, r'_{1-3,\tau} + \sum_{\tau=1}^{\tau_{MP}} Q_{1-2,\, t-\tau+1}\, r_{2-3,\tau} + Q_{2-3,\, t} \qquad (2)$$

where $Q_{1,t}$ are the discharges of the Novosibirskaya Hydroelectric Power Station (HES) at the time t, $Q_{1-2,t}$ and $Q_{2-3,t}$ are the discharges of lateral inflow of water in the reaches Novosibirskaya Hydroelectric Power Station - Kolpashevo and Kolpashevo - Prikhorkino respectively, $r'_{1-3,\tau}$ and $r_{2-3,\tau}$ are influence functions for computing the transformations of the discharges of the Novosibirskaya Hydroelectric Power Station and the lateral inflow from Kolpashevo to Prokhorkino.

In equation (2) the lateral inflow from two parts of the basin for the monthly water discharges is computed using formula (1) in the following form:

$$\overline{Q}_{1-2,\,T} = \overline{Q}_{2,\,T} - 0{,}81\ \overline{Q}_{1,\,T} - 0{,}19\ \overline{Q}_{1,\,T-1}, \tag{3}$$

$$\overline{Q}_{2-3,\,T} = \overline{Q}_{3,\,T} - 0{,}44\ \overline{Q}_{2,\,T} - 0{,}56\ \overline{Q}_{2,\,T-1}, \tag{4}$$

where $\overline{Q}_1$, $\overline{Q}_2$, $\overline{Q}_3$ are the mean monthly water discharges of the Ob' at Novosibirsk below the hydroelectric power station, at Kolpashevo and Prikhorkino, taken for the successive months T and T - 1, $\overline{Q}_{1-2}$ and $\overline{Q}_{2-3}$ are the monthly discharges of lateral inflow in the reaches Novosibirsk-Kolpashevo and Kolpashevo-Prokhorkino.

The coefficients on the water discharges denote the ordinates of the influence functions for computing the transformation of runoff in these reaches (taken from Table 1).

The water discharges of the Irtysh at Tobol'sk Q_8 are computed using the equation

[MP = max]

$$Q_{8,\,t} = \sum_{\tau=1}^{\tau_{MP}} Q_{6,\,t-\tau+1}\, r'_{6-8,\,\tau} + \sum_{\tau=1}^{\tau_{MP}} Q_{6-7,\,t-\tau+1}\, r_{7-8,\,\tau} + Q_{7-8,\,t}, \tag{5}$$

where Q_6 are the water discharges of the Ust'-Kamenogorskaya Hydroelectric Power Station, Q_{6-7} and Q_{7-8} are the lateral inflow water discharges in the reaches: Ust'-Kamenogorskaya Hydroelectric Power Station-Omsk and Omsk-Tobol'sk. The monthly lateral inflow discharges in these reaches are computed using the equations

$$\overline{Q}_{6-7,\,T} = \overline{Q}_{7,\,T} - 0{,}37\ \overline{Q}_{6,\,T} - 0{,}63\ \overline{Q}_{6,\,T-1}, \tag{6}$$

$$\overline{Q}_{7-8,\,T} = \overline{Q}_{8,\,T} - 0{,}31\ \overline{Q}_{7,\,T} - 0{,}69\ \overline{Q}_{7,\,T-1}, \tag{7}$$

where $\overline{Q}_7$ and $\overline{Q}_8$ are the monthly water discharges of the Irtysh at Omsk and Tobol'sk. Here the coefficients were taken from Table 1 for these reaches.

Computations of the runoff hydrographs for the Ob' at Belogor'ye and Salekhard were made in accordance with the formula

[MP = max]
ГЭС = HES,
б = lat]

$$Q_{4,\,5,\,t} = \sum_{i=1}^{2}\sum_{\tau=1}^{\tau_{MP}} Q_{i,\,\text{ГЭС},\,t-\tau+1}\, r'_{i,\,\tau} + \sum_{j=1}^{N}\sum_{\tau=1}^{\tau_{MP}} Q_{б,\,j,\,t-\tau+1}\, r'_{j,\,\tau}, \tag{8}$$

in which $Q_{i,HES}$ are the water discharge of the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations, $Q_{lat,j}$ are the lateral inflow water discharges from N parts of the basin, $r'_{i,\tau}$ and $r'_{j,\tau}$ are special travel time curves for the discharge from the hydroelectric power stations and the lateral inflow from parts of the basin to the lowest-lying gaging stations at Belogor'ye and Salekhard.

In computations of the hydrographs for monthly time intervals, making use of expression (8), use is made of the monthly values of lateral inflow, computed using formulas (3), (4), (6), (7), and in addition, using formulas (9), (10) for reaches situated between the gaging stations Prokhorkino-Belogor'ye and Tobol'sk-

Belogor'ye on the Irtysh,

$$\overline{Q}_{3,\,8-4,\,T} = \overline{Q}_{4,\,T} - 0{,}19\,\overline{Q}_{3,\,T} - 0{,}79\,\overline{Q}_{3,\,T-1} - 0{,}02\,\overline{Q}_{3,\,T-2} - 0{,}54\,\overline{Q}_{8,\,T} - 0{,}46\,\overline{Q}_{8,\,T-1}, \tag{9}$$

and also Belogor'ye-Salekhard on the Ob'

$$\overline{Q}_{4-5,\,T} = \overline{Q}_{5,\,T} - 0{,}26\,\overline{Q}_{4,\,T} - 0{,}73\,\overline{Q}_{4,\,T-1} - 0{,}01\,\overline{Q}_{4,\,T-2}. \tag{10}$$

Here $\overline{Q}_3$, $\overline{Q}_4$, $\overline{Q}_5$ are the monthly water discharges at Prokhorkino, Belogor'ye, Salekhard on the Ob' and $\overline{Q}_8$ at Tobol'sk on the Irtysh. The transformation of water discharges in the reaches Prokhorkino-Belogor'ye and Tobol'sk-Belogor'ye is accomplished using formula (9).

The special influence functions $r'_{k,\tau}$, necessary for making computations using formulas (2), (5) and (8), making it possible to transform the runoff from the upstream to the lowest-lying gaging stations, are found through the functions $r_{1,\tau}$, $r_{2,\tau}$, ..., $r_{k,\tau}$ for individual reaches using the expression

$$r'_{k,\tau} = \sum_{\tau=1}^{\tau_k} r_{k,\tau} \cdots \sum_{\tau=1}^{\tau_2} r_{2,\tau}\, r_{\tau-\tau_1-\tau_2-\cdots-\tau_{k+1}}. \tag{11}$$

For this purpose usually each of the ordinates of the function characterizing the transformation of runoff in the upper reach (Table 1) is multiplied by all the ordinates for the next reach and are summed with allowance for time shifts of the product [3]. The ordinates of the runoff transformation curves from the upper to the lowest-lying gaging stations, computed using expression (11) for monthly time intervals, are given in Table 2.

Table 2

Ordinates of Influence Functions for Predicting Monthly Water Discharges of the Ob' at Prokhorkino, Belogor'ye, Salekhard and Irtysh at Tobol'sk

Months	Ob'						Irtysh-Ob'					
	Новосибирская ГЭС — Прохоркино (1—2) 1	Новосибирская ГЭС — Белогорье (1—4) 2	Новосибирская ГЭС — Салехард (1—5) 3	Колпашево — Белогорье (2—4) 4	Колпашево — Салехард (2—5) 5	Прохоркино — Салехард (3—5) 6	Усть-Каменогорская ГЭС — Тобольск (6—8) 7	Усть-Каменогорская ГЭС — Белогорье (6—8) 8	Омск — Белогорье (7—4) 9	Усть-Каменогорская ГЭС — Салехард (6—5) 10	Омск — Салехард (7—5) 11	Тобольск — Салехард (8—5) 12
T	0,26	0	0	0,01	0	0	0.02	0	0,05	0	0	0,03
$T-1$	0,73	0,44	0,05	0,61	0,07	0,42	0,64	0,29	0,77	0,02	0,21	0,74
$T-2$	0,01	0,55	0,60	0,38	0,70	0,57	0,34	0,66	0.18	0,47	0,71	0.23
$T-3$	—	0,01	0.35	—	0,23	0,01	—	0,05	—	0,49	0,08	—
$T-4$	—	—	—	—	—	—	—	—	—	0,02	—	—

Left to right: 1) Novosibirskaya HES-Prokhorkino; 2) Novosibirskaya HES-Belogor'ye; 3) Novosibirskaya HES-Salekhard; 4) Kolpashevo-Belogor'ye; 5) Kolpashevo-Salekhard; 6) Prokhorkino-Salekhard; 7) Ust'-Kamenogorskaya HES-Tobol'sk; 8) Ust'-Kamenogorskaya HES-Belogor'ye; 9) Omsk-Belogor'ye; 10) Ust'-Kamenogorskaya HES-Salekhard; 11) Omsk-Salekhard; 12) Tobol'sk-Salekhard

Table 3

Example of Preparation of Long-Range Prediction of High-Water Hydrograph for Ob' River at Belogor'ye Using Data for 31 March 1975

Month	Discharge of Novosibirskaya HES	$\bar{Q}_{1-2,T} = K_{1-2}\bar{\bar{Q}}_{1,2,T}$	$\bar{Q}_{2-3,T} = K_{2-3}\bar{Q}_{2,3,T}$	$\bar{Q}_{3,8-4,T} = K_{3,8-4}\bar{Q}_{3,8-1,T}$	Discharge of Ust'-Kamenogorskaya HES	$\bar{Q}_{6-7,T} = K_{6-7}\bar{\bar{Q}}_{6-7,T}$	$\bar{Q}_{7-8,T} = K_{7-8}\bar{\bar{Q}}_{7-8,T}$	Computation of transformation using formula (15)	(16)	(17)	(18)	(19)	(20)	(14)	$Q_{\text{ф}}$, Ф = actual, пр = predicted	$\Delta Q = \frac{\bar{Q}_{\text{ф}} - \bar{Q}_{\text{пр}}}{\bar{Q}_{\text{ф}}} 100\%$
I	562	—	—	—	395	—	—	—	—	—	—	—	—	—	—	—
II	532	492	590	—	383	27	—	—	—	—	—	—	—	—	—	—
III	629	400	619	—	339	10	156	—	—	—	—	—	—	—	—	—
IV	2480	3270	558	986	1240	244	1240	576	464	606	371	25	738	3770	4410	14,5
V	2560	10100	6370	9480	513	1560	4340	1440	2210	1650	603	268	2910	18600	18900	1,6
VI	4260	7310	3050	5390	493	1360	2880	2480	7690	6040	983	1310	3550	27400	25000	−9,6
VII	3050	2770	2480	5020	519	668	1760	3310	8550	4930	543	1360	2280	26000	25300	2,8
VIII	1410	1370	776	3590	527	360	882	3710	4600	2210	502	780	1290	16700	20100	16,9
IX	1210	1580	1620	2730	569	256	692	2340	1720	973	520	410	780	9470	10700	11,5

Notes: Monthly water discharges of the Novosibirskaya $(\bar{Q}_{1,T})$ and Ust'-Kamenogorskaya Hydroelectric Power Stations $(\bar{Q}_{6,T})$ are the actual values; the modular coefficients of snow reserves on 31 March in the reaches were: $K_{1-2} = 1.18$; $K_{2-3} = 1.24$; $K_{6-7} = 1.24$; $K_{7-8} = 0.97$ and $K_{3.8-4} = 108$.

The equation for computing and predicting the runoff hydrograph during the time of high water by months for Prokhorkino on the Ob' is written in the following form:

$$\overline{Q}_{3,T} = 0{,}26\ \overline{Q}_{1,T} + 0{,}73\ \overline{Q}_{1,T-1} + 0{,}01\ \overline{Q}_{1,T-2} + 0{,}44\ \overline{Q}_{1-2,T} + 0{,}56\ \overline{Q}_{1-2,T-1} + \overline{Q}_{2-3,T}, \tag{12}$$

where $\overline{Q}_1$, $\overline{Q}_3$ are the monthly water discharges at Novosibirsk and Prokhorkino respectively, taken for the months T, T - 1 and T - 2, $\overline{Q}_{1-2}$ and $\overline{Q}_{2-3}$ is the monthly lateral inflow in the river reaches from Novosibirsk to Kolpashevo and from Kolpashevo to Prokhorkino, computed using expressions (3) and (4).

The monthly water discharges of the Irtysh at Tobol'sk Q_8 are computed using the equation

$$\overline{Q}_{8,T} = 0{,}02\ \overline{Q}_{6,T} + 0{,}64\ \overline{Q}_{6,T-1} + 0{,}34\ \overline{Q}_{6,T-2} + 0{,}31\ \overline{Q}_{6-7,T} + 0{,}69\ \overline{Q}_{6-7,T-1} + \overline{Q}_{7-8,T}, \tag{13}$$

where $\overline{Q}_6$ are the monthly discharges from the Ust'-Kamenogorskaya Hydroelectric Power Station, $\overline{Q}_{6-7}$ and $\overline{Q}_{7-8}$ are the monthly discharges of lateral runoff from parts of the basin -- Ust'-Kamenogorskaya Hydroelectric Power Station-Omsk and Omsk-Tobol'sk, computed using expressions (6) and (7). The distribution of monthly water discharges during the high water of the Ob' at Belogor'ye is computed using equation (8), which is written in the following form:

$$\overline{Q}_{4,T} = \overline{Q}'_{1-4,T} + \overline{Q}'_{(1-2)-4,T} + \overline{Q}'_{(2-3)-4,T} + \overline{Q}'_{6-4,T} + \overline{Q}'_{(6-7)-4,T} + \overline{Q}'_{(7-8)-4,T} + \overline{Q}_{3,8-4,T}. \tag{14}$$

The terms entering into this equation, characterizing the transformation of the discharge waters of the hydroelectric power station and lateral inflow from upstream stations to Belogor'ye, are computed using formulas derived taking into account the coefficients cited in Tables 1 and 2:

$$\overline{Q}'_{1-4,T} = 0{,}44\ \overline{Q}_{1,T-1} + 0{,}55\ \overline{Q}_{1,T-2} + 0{,}01\ \overline{Q}_{1,T-3}, \tag{15}$$

$$\overline{Q}'_{(1-2)-4,T} = 0{,}01\ \overline{Q}_{1-2,T} + 0{,}61\ \overline{Q}_{1-2,T-1} + 0{,}38\ \overline{Q}_{1-2,T-2}, \tag{16}$$

$$\overline{Q}'_{(2-3)-4,T} = 0{,}19\ \overline{Q}_{2-3,T} + 0{,}79\ \overline{Q}_{2-3,T-1} + 0{,}02\ \overline{Q}_{2-3,T-2}, \tag{17}$$

$$\overline{Q}'_{6-4,T} = 0{,}29\ \overline{Q}_{6,T-1} + 0{,}66\ \overline{Q}_{6,T-2} + 0{,}02\ \overline{Q}_{6,T-3}, \tag{18}$$

$$\overline{Q}'_{(6-7)-4,T} = 0{,}05\ \overline{Q}_{6-7,T} + 0{,}77\ \overline{Q}_{6-7,T-1} + 0{,}18\ \overline{Q}_{6-7,T-2}, \tag{19}$$

$$\overline{Q}_{(7-8)-4,T} = 0{,}54\ \overline{Q}_{7-8,T} + 0{,}46\ \overline{Q}_{7-8,T-1}. \tag{20}$$

In the same way we derived an equation for computing and predicting the distribution of the monthly water discharges of the Ob' at Salekhard

$$\begin{aligned}\overline{Q}_{5,\,T} = {} & 0{,}05\,\overline{Q}_{1,\,T-1} + 0{,}60\,\overline{Q}_{1,\,T-2} + 0{,}35\,\overline{Q}_{1,\,T-3} + 0{,}07\,\overline{Q}_{1-2,\,T-1} + \\ & + 0{,}70\,\overline{Q}_{1-2,\,T-2} - 0{,}23\,\overline{Q}_{1-2,\,T-3} + 0{,}42\,\overline{Q}_{2-3,\,T-1} + 0{,}57\,\overline{Q}_{2-3,\,T-2} + \\ & + 0{,}01\,\overline{Q}_{2-3,\,T-3} + 0{,}02\,\overline{Q}_{6,\,T-1} + 0{,}47\,\overline{Q}_{6,\,T-2} + 0{,}49\,\overline{Q}_{6,\,T-3} + \\ & + 0{,}02\,\overline{Q}_{6,\,T-4} + 0{,}21\,\overline{Q}_{6-7,\,T-1} + 0{,}71\,\overline{Q}_{6-7,\,T-2} + 0{,}08\,\overline{Q}_{6-7,\,T-3} + \\ & + 0{,}03\,\overline{Q}_{7-8,\,T} + 0{,}74\,\overline{Q}_{7-8,\,T-1} + 0{,}23\,\overline{Q}_{7-8,\,T-2} + 0{,}26\,\overline{Q}_{3,\,8-4,\,T} + \\ & + 0{,}73\,\overline{Q}_{3,\,8-4,\,T-1} + 0{,}01\,\overline{Q}_{3,\,8-4,\,T-2} + \overline{Q}_{4-5,\,T}.\end{aligned} \qquad (21)$$

In equations (14), (16), (17), (19)-(21) the lateral inflow from five parts of the basin is determined using equations (3), (4), (6), (7), (9) and (10).

The method for long-range prediction of the high-water hydrograph for the Ob' at Prokhorkino, Belogor'ye, Salekhard and the Irtysh at Tobol'sk is based on the use of equations for computing the monthly water discharges (12), (13), (14) and (21) in which the monthly water discharges of lateral inflow for river reaches predicted by one method or another are taken in dependence on the advance time of the forecast. Different methods can be used for their prediction, using as a point of departure the real hydrometeorological conditions in the basin.

In order to write computation equations in prognostic form it is necessary to replace time in the subscripts in (12)-(14), (21) by $T = n + T_1$, where n is the day of preparation of the forecast, T_1 is the advance time, having the values 1, 2, 3, etc. of the month.

Predictions of the high-water hydrograph in the basin of the Ob' and Irtysh were to be prepared at the end of each spring month. With the onset of snow melting in the upper parts of the basin the first prediction of the high-water hydrograph using formulas (8) or (14) and (21) is prepared on 31 March, taking into account the planned discharges of the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations, typical distributions of the anticipated spring lateral inflow and its transformation from each part of the basin to the lowest-lying gaging stations. In this case the lateral inflow $\overline{Q}_{lat,\,T}$ for each part of the basin entering into formulas (14) and (21) is predicted using the expression

$$\overline{Q}_{lat,\,T} = \frac{y}{\overline{\overline{y}}}\,\overline{\overline{Q}}_{kT}\,. \qquad (22)$$

where y_j is the volume of the high water and its norm $\overline{\overline{y}}$ anticipated in a particular year on the basis of the snow reserves and the characteristics of runoff losses, Q_{kT} are typical high-water hydrographs, reduced to the norm, determined for each part of the basin using criteria taking into account the state of the water volume at the time of the forecast and subsequent snow melting [4]. The actual water volume is estimated from the water levels in the river at the time of the forecast. Subsequent snow melting is characterized by the anticipated air temperature for the 10-day period after the date of preparation of the forecast.

Using the water level values at the time of the forecast H_n and the anticipated 10-day air temperature $\overline{\theta}_{n\ n+T_1}$ (n is the date of the forecast, T_1 = 10 days), for each part of the basin we determined their mean values for the observation period $\overline{H}_n$ and $\overline{\overline{\theta}}_{n+10}$. On the basis of these classification criteria all the years were divided into four groups which are arbitrarily designated as follows:

$H_n > \overline{H}_n;\ \overline{\theta}_{n+10} > \overline{\overline{\theta}}_{n+10}$ early with rapid thawing of snow

$H_n > \overline{H}_n;\ \overline{\theta}_{n+10} < \overline{\overline{\theta}}_{n+10}$ early without rapid melting of snow

$H_n < \overline{H}_n;\ \overline{\theta}_{n+10} > \overline{\overline{\theta}}_{n+10}$ late with rapid melting of snow

$H_n < \overline{H}_n;\ \overline{\theta}_{n+10} < \overline{\overline{\theta}}_{n+10}$ late without rapid melting of snow

For the years included in each of these groups we computed the mean hydrographs of lateral inflow, computed from expressions (3), (4), (6), (7), (9) and (10) from each part of the basin. These hydrographs are reduced to the norm by multiplying their water discharges by the value of the ratio of the mean long-term volume of lateral inflow to its mean volume for the years characteristic for the particular type. The standard hydrographs obtained for each part of the basin, reduced to the norm by means of the corresponding influence functions (Tables 1, 2), are transformed to the lowest-lying stations and entered into tables. Then, for the first, earliest forecast prepared on 31 March, using known classification criteria -- the water levels or the sums of water discharges in the rivers of the sector and the anticipated 10-day air temperatures -- from these tables for each part of the basin we determine the particular type of distribution of lateral inflow. Its ordinates are multiplied by the modular coefficient of the anticipated volume of spring lateral inflow, equal to the ratio of the volume of this inflow in a particular year to its norm. As an approximate indicator of this volume for the discriminated parts of the basin we took the modular coefficients of the observed (up to 31 March) maximum snow reserves $K = h/\overline{h}$, where h is their mean value and $\hat{h}$ is the norm on this date.

The lateral inflow hydrographs predicted in this way for each part of the basin, transformed to the lowest-lying stations, are summed together with the transformed planned water discharges of the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations, which gives a hydrograph of the anticipated runoff at each of the considered lowest-lying stations.

Table 3, as an illustration, gives a forecast of the high-water hydrograph for the Ob' at Belogor'ye prepared on 31 March 1975 using equation (14). In this table we used the planned monthly water discharges of the Novosibirskaya ($\overline{Q}_1$) and Ust'-Kamenogorskaya ($\overline{Q}_6$) Hydroelectric Power Stations. The anticipated hydrographs of lateral inflow from three parts of the Ob' and two parts of the Irtysh are determined using formula (22), in which the distributions of the particular types of lateral inflow are taken from the tables on the basis of the classification criteria. The distributions are multiplied by the corresponding modular coefficients of the maximum snow reserves observed up to 31 March. The hydrographs obtained in this way in the first columns of Table 3 are then transformed in the subsequent columns and are finally summed for the lowest-lying gaging station -- Belogor'ye.

A prediction of the monthly water discharges at the time of high water on the Ob' at Prokhorkino, Belogor'ye, Salekhard and on the Irtysh at Tobol'sk is made using equations (12)-(14) and (21) for different times in advance, for one, two, three months, etc. Depending on the advance time of the forecast and the real conditions prevailing in the basin at the time of the forecast, in these equations allowance must be made for the monthly water discharges in the lateral inflow, predicted using expression (22) or using hydrometric data.

Whereas on 31 March the lateral inflow hydrographs are predicted on the basis of allowance for the volume of spring runoff anticipated on the basis of snow reserves and its corresponding standard distribution in time with subsequent summing of the transformed partial hydrographs, on 30 April, when melt water is flowing into the river network in the basins, in formulas (12)-(14) and (21) some monthly water discharges $\overline{Q}_{i,n+1}$ of rivers flowing in can be predicted in these sectors after the maximum inflow of water into the river network on the basis of hydrometric data using the equation

$$\overline{Q}_{i,\,n+1} = aW_n + bq_n, \tag{23}$$

in which W_n and q_n are the channel water volumes and inflow into the river network at the time of the prediction n, a and b are constant values. For this purpose for each part of the basin a method is developed for predicting the monthly water discharges in the lateral inflow on the basis of hydrometric data for the rivers flowing in this area [1, 2]. The first step is a determination of the dependence of the monthly water discharges, obtained in the reaches $\overline{Q}_{lat,\,T}$ on the basis of formula (1), on the sum of monthly discharges

$$\sum_{i=1}^{N} \overline{Q}_i,$$

of N rivers flowing in within the defined sector. These correlations usually have the form

$$\overline{Q}_{lat,T} = A \sum_{i=1}^{N} \overline{Q}_{i,\,T}, \tag{24}$$

where A is a constant coefficient.

The monthly water discharges of lateral inflow in the defined river reaches are determined using the equation

$$\overline{Q}_{lat,T} = A\left(a \sum_{i=1}^{N} W_{i,\,n} + b \sum_{i=1}^{N} q_{i,\,n}\right), \tag{25}$$

obtained on the basis of (23), (24), in which the channel water volumes and inflow into the river network at the time of the forecast n is taken into account for N rivers flowing in within the defined sectors.

For example, the total volume of lateral inflow computed using formula (1) in the Ob' reach from the Novosibirskaya Hydroelectric Power Station to Kolpashevo is also determined for this reach on the basis of expression (25) with A = 1.1, a = 0.89 and b = 0.33. The channel water volumes and inflow into the river network of four rivers (Inya, Tom', Chulym and Chaya) are determined on the basis of the water discharges determined each two days at seven gaging stations. The lateral inflow in the Ob' reach from Kolpashevo to Prokhorkino, where the Ket', Parabel', Vasyugan and Pim Rivers flow in, is predicted for a month on the basis of equation (25) with the coefficients A = 2.0, a = 0.38 and b = 0.35. The channel volumes and water inflow of four rivers into the river network are computed at six gaging stations for two-day intervals.

The refinement of the high-water hydrograph on the basis of hydrometric data is usually prepared after onset of the maximum of inflow into the channels. The water discharges of lateral inflow for two reaches predicted for the next month on the basis of equation (25) are taken into account in equation (12) in a prediction of Ob' runoff at Prokhorkino for a month in advance:

$$\overline{Q}_{3,\,n+1} = 0{,}26\ \overline{Q}_{1,\,n-1} + 0{,}73\ \overline{Q}_{1,\,n-1} + 0{,}01\ \overline{Q}_{1,\,n-2} + 0{,}42 \sum_{i=1}^{4} W_{1-2,\,i,\,n} + 0{,}15 \sum_{i=1}^{4} q_{1-2,\,i,\,n} + 0{,}56\,(\overline{Q}_{2,\,n-1} - 0{,}81\ Q_{1,\,n-1} - 0{,}19\ Q_{1,\,n-2}) + 0{,}76 \sum_{j=1}^{4} W_{2-3,\,j,\,n} + 0{,}70 \sum_{j=1}^{4} q_{2-3,\,j,\,n}; \tag{26}$$

and for two months in advance:

$$\overline{Q}_{3,\,n+2} = 0{,}26\ \overline{Q}_{1,\,n+2} + 0{,}73\ \overline{Q}_{1,\,n+1} + 0{,}01\ \overline{Q}_{1,\,n-1} + 0{,}44\ K_{1-2}\,\overline{\overline{Q}}_{1-2,\,n+2} + 0{,}54 \sum_{i=1}^{4} W_{1-2,\,i,\,n} + 0{,}18 \sum_{i=1}^{4} q_{1-2,\,i,\,n} + K_{2-3}\,\overline{\overline{Q}}_{2-3,\,n+2}. \tag{27}$$

For three months in advance in (12) use is made of values predicted using (22):

$$\overline{Q}_{3,\,n+3} = 0{,}26\ \overline{Q}_{1,\,n+3} + 0{,}73\ \overline{Q}_{1,\,n+2} + 0{,}01\ \overline{Q}_{1,\,n+2} + 0{,}44\ K_{1-2}\,\overline{\overline{Q}}_{1-2,\,n+3} + 0{,}56\ K_{1-2}\,\overline{\overline{Q}}_{1-2,\,n+2}. \tag{28}$$

In equations (26)-(28) the monthly water discharges Q_1 of the Novosibirskaya Hydroelectric Power Station are taken into account for the two months up to the time of the forecast and the planned discharges for three months; the actual monthly water discharges at Kolpashevo $\overline{Q}_2$, channel volumes and water inflow into the river network for four rivers in the reach Novosibirskaya Hydroelectric Power Station-Kolpashevo and four rivers in the reach Kolpashevo-Prokhorkino, and the modular coefficients of the anticipated volume of lateral inflow in the reaches K_{1-2} and K_{2-3} (see Fig. 1) are also taken into account.

The use of hydrometric data somewhat improves the results of predicting the high-water hydrograph based on classification procedures.

Thus, the described method for the long-range prediction of the high-water hydrograph by months makes it possible to take into account the hydrometeorological conditions in different parts of the basin prevailing up to the time of the forecast and anticipated later, including the course of the anticipated (planned) water discharges of the Novosibirskaya and Ust'-Kamenogorskaya Hydroelectric Power Stations, the spring lateral inflow anticipated on the basis of snow reserves and hydrometric data, the 10-day air temperature at the time of snow melting predicted on the basis of a weather forecast and the travel time of runoff from a part of the basin to the lowest-lying gaging station.

The computations of the monthly water discharges of the Ob' at Prokhorkino and Belogor'ye from April through September for 16 years (1960-1975), made by Z. I. Rubtsova using equations (12) and (14), are characterized by a mean error (in %) of the actual monthly water discharges at Prokhorkino of 3.4% (it varies by months from 1.6 to 5.2%), at Belogor'ye -- 3.2% (1.8-4.7%). The same computations for the Irtysh at Tobol'sk for 20 years (1956-1975), made by V. T. Kurbatova using equation (13), give a mean error for six months of 1.7% (0.5-6.1%). Control forecasts of monthly water discharges with allowance in expression (22) for the modular coefficients of maximum snow reserves up to the day of the forecast of 31 March for these same years and months give a mean error in percent for the actual monthly water discharges of the Ob' at Prokhorkino of 19.3% (15.3-24.0%), at Belogor'ye -- 16.1% (11.5-25.9%) and for the Irtysh at Tobol'sk -- 24.8% (19.3-29.9%).

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COMPUTATION OF THE MAIN HYDROPHYSICAL CHARACTERISTIC OF SOILS USING DATA ON SOIL-HYDROLOGICAL CONSTANTS

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[Article by Yu. G. Motovilov, candidate of geographical sciences, USSR Hydrometeorological Scientific Research Center, manuscript submitted 23 May 80]

[Text]

Abstract: Formulas derived by the author and a number of other researchers are given which can be used in approximate computation of the dependence of soil moisture potential on moisture using data on soil-hydrological constants. Evaluations of the accuracy in approximation were made for each formula by means of comparison of the computed curves and the actual dependences of the basic hydrophysical characteristic on the basis of data for 53 soils of different types. An analysis of the errors makes it possible to recommend the formulas proposed by the author for use in practical computations of moisture transfer in the aeration zone.

Definite experience has now been accumulated in hydrology in the modeling of melt and rainwater runoff with the use of dynamic models of moisture transfer in the ground [3, 4, 8]. In a one-dimensional variant in the simplest models for describing the dynamics of moisture in the soil use is made of the equation

$$C\frac{\partial\psi}{\partial t}=\frac{\partial}{\partial z}\left(K\frac{\partial\psi}{\partial z}-K\right), \tag{1}$$

where ψ is the capillary-sorption potential of soil moisture; K is the moisture conductivity coefficient; $C = \partial W/\partial\psi$ is the differential moisture capacity; W is soil moisture content; z is the vertical coordinate with a positive direction downward from the soil surface; t is time.

The dependences of capillary-sorption potential on moisture content in the "moistening-dessication" process were subjected to hysteresis, which is manifested, in particular, with high soil moisture content values. However, in actual practice hysteresis phenomena are usually neglected, and as the computational dependence of capillary-sorption potential on moisture content use is made of its desorption branch. This dependence is also called the main hydrophysical soil characteristic (MHSC) or moisture content characteristic [11].

The soil moisture potential has the dimensionality of work related to a unit quantity of water and can be expressed in specific energy units (J/kg), pressure units (Pa, bar, atm) and pressure head units (m H_2O, cm H_2O). In soil science it is also common to employ the parameter $pF = lg(\psi/cm\ H_2O)$. The ψ, K and C parameters are hydrophysical characteristics and for a specific soil are functions of moisture content W. The form of these functions is determined by such properties of the ground as mineralogical composition, structure, specific surface, etc.

The distribution of these characteristics over an area, even for small homogeneous terrain sectors, has a stochastic character. It is possible to take into account the spatial variation of factors governing the permeability of ground in a drainage basin by use of models of the formation of runoff with distributed parameters, for example, using two-dimensional models [4]. The dynamic-stochastic approach to modeling of infiltration [1, and others] is most promising. A peculiarity of this approach is the carrying out of large-scale computations using an equation of type (1) with different combinations of soil hydrophysical characteristics. In an operational regime the carrying out of such computations is limited due to the lack of data on the hydrophysical characteristics and statistical parameters of their distribution over the area of the drainage basin. The existing situation can be attributed to the exceedingly great expenditures of time required when using traditional methods for determining the hydrophysical characteristics of one soil sample and at the same time the small number of specialized laboratories for the carrying out of such work.

In addition, much material has now been accumulated on soil-hydrological constants, which are the generalized characteristics of the water-retaining capacity of the ground in definite soil moisture pressure ranges. Data on the constants for different agricultural fields in the network of agrometeorological stations are published in regional agrohydrological handbooks of soil properties. A number of investigators have used information on the soil-hydrological constants for approximate stipulation of the dependences $\psi = f(W)$. We will give a brief review of the investigations which have been made.

As early as 1939 M. B. Russell [17] proposed a parabolic dependence in the following form for approximating the main hydrophysical characteristic in the pressure range $4.2 > pF > 2.5$

$$pF = 7.0 - 3.3/WM\ W + 0.53/WM^2\ W^2. \tag{2}$$

In this formula the sole characteristic of the water-retaining capacity of the soil is the wilting moisture (WM) of plants, and according to the determinations of M. B. Russell, $pF_{WM} = 4.18$.

I. S. McQueen and R. F. Miller [14] proposed a method for constructing the moisture content curve. The essence of this method is the breakdown of the main hydrophysical soil characteristic into three segments: stably adsorbed moisture (pF = 5.0-7.0), adsorbed films (pF = 2.5-5.0) and capillary moisture (pF = 0.0-2.5) with subsequent approximation of the moisture characteristic curve for each segment using a dependence of the type

$$pF = c_i - m_i W. \tag{3}$$

Here c_i and m_i are constants which are determined from the two known moisture content values and the potential values corresponding to them. In the absence of physical measurements as such reference points of the main hydrophysical soil characteristic curve use is made of the values of the soil-hydrological constants, such as, a) WM ($pF_{WM} \approx 4.2$) and the minimum moisture capacity (MM, $pF_{MM} \approx 2.5$), or b) maximum hygroscopicity (MH, $pF_{MH} \approx 4.7$) and MM ($pF_{MM} \approx 2.5$).

K. K. Pavlova and I. L. Kalyuzhnyy [9], on the basis of an analysis of actual data, for an approximation of the desorption branch of the main hydrophysical characteristic with W > WM, proposed the exponential dependence

$$\psi = 10220 \exp\ (-3.58\ W - WM/MM - WM). \tag{4}$$

A. S. Rogowski [16], for approximate computation of the main hydrophysical characteristic curves in the pressure range from 15 bar (corresponds closely to the pressure of soil moisture at the WM) to the pressure of "entry of air into the system" (bubbling pressure ψ_e at which the soil moisture content W_e is close to saturation) proposed the logarithmic dependence

$$W = W_e + (W_{15} - W_e)\frac{\ln(\psi - \psi_e + 1)}{\ln(\psi_{15} - \psi_e + 1)}. \tag{5}$$

Brooks and Corey [12] in the approximation of the main hydrophysical characteristic used the dependence

$$S_e = \left(\frac{\psi_e}{\psi}\right)^{\lambda}, \tag{6}$$

where $S_e = \frac{S - S_r}{1 - S_r}, \quad S = \frac{W}{P}, \quad S_r = \frac{W_r}{P},$

P is porosity, W_r is the soil moisture content at which the hydraulic permeability of the medium is assumed to be equal to zero, λ is the porosity factor characterizing the distribution of pores in the medium by size. Formula (6) is used extensively in the foreign practice of hydrological investigations for approximation of the main hydrophysical characteristic on the basis of actual data for the purpose of determining the value of the λ parameter, which then is used for approximate computation of the curve relating hydraulic permeability to the moisture content of the ground.

Dependence (6) can be used in approximate computations if at least three points on the main hydrophysical characteristic curve are known. If as W_r we use the maximum hygroscopic moisture, W_e and ψ_e are moisture content and the pressure of "entry of air into the system" and as the intermediate point we take a point with the coordinates WM and ψ_{WM}, computation of the main hydrophysical characteristic with the use of dependence (6) can be carried out using the formula

[MΓ = MH]
[B3 = WM]

$$\psi = \psi_e \left(\frac{P - M\Gamma}{W - M\Gamma}\right)^{\frac{\lg \psi_e - \lg \psi_{B3}}{\lg (B3 - M\Gamma) - \lg (P - M\Gamma)}}. \tag{7}$$

In 1956 E. E. Miller and R. D. Miller [15] advanced the hypothesis of similarity of porous media, within the framework of which the main hydrophysical characteristic curves for different monodisperse media were generalized by means of transformation of the Laplace equation on the basis of similarity theory.

A further development of this hypothesis for polydisperse media was obtained in the studies of B. N. Michurin [5]. Assuming that adsorption pressure is in an inverse dependence on the thickness of the water film (h), whereas capillary pressure is proportional to surface tension (σ) and the specific surface of soils (S_0), B. N. Michurin obtained a similarity invariant, so-called reduced capillary-sorption pressure P", in the form of the combination

$$P'' = \frac{\psi h}{\sigma S_0}. \tag{8}$$

Using this criterion, the correlations between capillary-sorption pressure and moisture content for different types of soils in the range of change in the specific surface 20-150 m^2/g were reduced to the single dependence P" = f(W) [5]. The correlation equation has the form

$$\frac{\psi h}{\sigma S_0} = 1{,}35\ W^{-2.46}. \tag{9}$$

If the thickness of the water film is expressed as $h = W/S_0$, we obtain

$$\frac{\psi}{\sigma S_0^2} = 1{,}35\ W^{-3.46}. \tag{10}$$

In [6, 7] dependence (10) was used by the author as a basis in deriving computation formulas for approximating the main hydrophysical characteristic curves and the phase composition of moisture at negative temperatures using data on the maximum hygroscopicity of soils. The following formula was derived for computing the main hydrophysical characteristic

$$\psi = \psi_{MH}\ (MH/W)^{3.46}. \tag{11}$$

A formula similar in structure was proposed on the basis of an analysis of the actual main hydrophysical characteristic curves by P. Fageler [10]:

$$\psi = \psi_{MH}(MH/W)^{n}, \tag{12}$$

where n is a parameter dependent on the nature of the exchange cation. The author found the mean value of this parameter to be equal to 3.

The results of computations of the phase composition of moisture with the use of dependence (11) in general can be characterized as positive [6, 7]. However, a comparison of the computed and actual main hydrophysical characteristic curves indicates that in a number of cases, especially with high soil moisture values, the results are unsatisfactory. In a detailed analysis of the initial material it becomes apparent that the graph of the correlation $\psi h/\sigma S_0 = f(W)$ constitutes a field of points with a definite degree of scatter grouped around the curve

$$\psi W/\sigma S_0^2 = 1.35\ W^{-2.46}.$$

In constructing this graph at a logarithmic scale the individual curves $\psi W/\sigma S_0^2 = f(W)$ are straightened; the slopes of the straight lines, that is, the numerical values of the exponent on W are different for different types of soils, although they do not differ greatly from the mean value -2.46.

It is known from theoretical considerations that the mechanism of retention of moisture by the soil is determined not only by the degree of dispersion of the medium, whose main characteristic is the specific surface, but also to a high degree by the structure and aggregate state of the ground. In order to take this factor into account, we will assume that porous media similar in structure are characterized by the same slope of the straight line $\psi W/\sigma S_0^2 = f(W)$ at a logarithmic scale, and for them we write criterion (10) in the form

$$\psi = AW^{-n}, \tag{13}$$

where $A = \varphi(S_0)$ is a constant for the particular type of soil, characterizing the adsorptivity of the ground, n is a parameter reflecting the structure of porous soil space.

For a specific soil the values of the parameters A and n can be determined using data on the soil-hydrological constants. It is known that the maximum hygroscopicity to a considerable degree characterizes the degree of dispersion of the medium and its specific surface [5]. With the substitution of the MH and ψ_{MH} values into formula (13) we obtain $A = \psi_{MH}MH^n$, then

$$\psi = \psi_{M\Gamma}\left(\frac{M\Gamma}{W}\right)^n. \tag{14}$$

In order to determine the value of the n parameter we will use data on the minimum moisture capacity of the soils, MM is a soil-hydrological constant which reflects the structure and aggregate state of the soil. Substituting MM and ψ_{MM} into formula (14) in place of W and ψ and reducing the resulting expression to logarithmic form, we find

$$n = \lg\psi_{MH} - \lg\psi_{MM}/\lg MM - \lg MH. \tag{15}$$

Thus, the final expression for approximate computation of the main hydrophysical characteristic curves will have the form

[MΓ = MH; HB = MM]

$$\psi = \psi_{M\Gamma}\left(\frac{M\Gamma}{W}\right)^{\frac{\lg\psi_{M\Gamma} - \lg\psi_{HB}}{\lg HB - \lg M\Gamma}}. \tag{16}$$

In order to make computations using formula (16) it is necessary to have information on four parameters of the ground: MH, ψ_{MH}, MM and ψ_{MM}. As already noted, information on MH and MM was generalized in agrohydrodynamic handbooks. The potential ψ_{MH} is a constant whose numerical value is dependent on the method for determining MH: by the Mitcherlich method $\psi_{MH} \approx 5\cdot10^4$ cm H_2O, by the Nikolayev method $\psi_{MH} \approx 3\cdot10^4$ cm H_2O, ψ_{MM} is a unique characteristic which is not measured in the network, and in addition is a variable parameter. According to data published by F. Dyushofur [2], the mean ψ_{MM} value for sandy ground is 10^2 cm H_2O, for clayey loam soils -- approximately $3\cdot10^2$ cm H_2O and for clayey soils -- $\psi_{MM} \approx 10^3$ cm H_2O. For practical computations ψ_{MM} can be estimated using a $pF_{MM} = f(MM)$ correlation graph, which we constructed using data on the actual main hydrophysical characteristic curves for 53 soils of different types from different regions of the earth (see Fig. 1). The SH values for these soils were ascertained by us using a $W_{1/3}$ correlation graph (moisture content with a pressure of soil moisture 1/3 atm) with an SH value cited in an article by E. A. Coleman [13]. The analytical expression for the curve in Fig. 1 can be written in the form

$$pF_{MM} = 5.2 \cdot 10^{-6}\ MM^{3.5} + 2.1. \tag{17}$$

where MM is expressed in percentage of the weight of dry soil.

In the absence of data on MH, in evaluatory computations it is possible to use data on the wilting moisture WM. According to numerous investigations, $pF_{WM} \approx 4.2$. In this case instead of MH and ψ_{MH}, in formula (16) it is necessary to substitute the WM and ψ_{WM} values respectively.

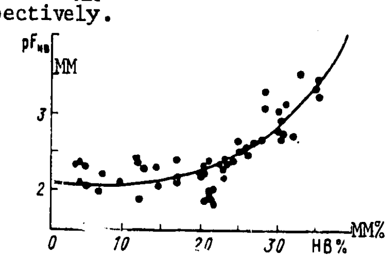

Fig. 1. Dependence of soil moisture potential with MM on MM value.

All the formulas cited above, generally speaking, were computed in an approximation of the main hydrophysical characteristic with $W < W_e$. However, in the range $W_e < W < P$, according to actual measurements, $\psi < \psi_e$, and in addition, with $W \to P$ there should be satisfaction of the condition $C = \partial W / \partial \psi \to 0$. Since the ratio $P - W_e / P$ is usually less than 0.1 [14, 16], in practical computations of moisture transfer with use of one of the formulas for computation of the main hydrophysical characteristic the calculations are made using a uniform difference scheme with $W < P$, whereas in the case $W = P$ the values $\psi = 0$ and $C = 0$ are established. Such an operation creates additional difficulties in application of the algorithm on an electronic computer. These difficulties can be avoided if for computing the main hydrophysical characteristic we adopt an expression of one of the approximate formulas, multiplied by some operator which virtually does not change the value of the function in the main range of change of the argument W and only with $W \to P$ do the values of the ψ function and the derivative $\partial W / \partial \psi$ tend to zero. One of the variants of the dependence satisfying such requirements can be an expression derived on the basis of formula (16),

[MΓ = MH]

$$\psi = \psi_{M\Gamma} \left(\frac{M\Gamma}{W}\right)^{nk_2} K_1 \left(1 - \frac{W}{P}\right)^{k_3}, \tag{18}$$

where

$$K_1 = \left(1 - \frac{M\Gamma}{P}\right)^{-k_3}, \tag{19}$$

[MΓ = MH; HB = MM]

$$K_2 = 1 + K_3 \frac{\lg\left(\frac{P - M\Gamma}{P - HB}\right)}{\lg\left(\frac{\psi_{HB}}{\psi_{M\Gamma}}\right)}. \tag{20}$$

In these formulas W, MH, MM and P are expressed in volumetric units. The para-

The K_3 parameter was selected by minimizing the mean square error between the computed and actual values for ψ and W. Its value was found equal to 0.42.

Table 1

Evaluations of Errors in Approximating Main Hydrophysical Characteristic for Different Formulas

Range, cm H_2O	Formula	$\frac{S_W}{\sigma_W}$	$\frac{S_\psi}{\sigma_\psi}$	$\frac{S_{pF}}{\sigma_{pF}}$	S_{tot}
0—15000	12	1,02	1,32	0,96	3,30
	11	0,93	1,10	0,96	2,99
	2	0,65	0,32	0,59	1,56
	3	0,57	1,03	0,65	2,25
	3*	0,47	0,30	0,54	1,31
	4	0,48	0,51	0,76	1,75
	5	0,44	0,56	0,55	1,55
	16	0,28	0,65	0,39	1,32
	18	0,27	0,70	0,35	1,32
	7	0,39	0,33	0,47	1,19
	16*	0,27	0,24	0,35	0,86
	18*	0,25	0,25	0,31	0,81
0—100000	12	0,84	0,38	0,69	1,91
	11	0,77	0,36	0,69	1,82
	3	0,48	0,36	0,47	1,31
	3*	0,41	1,18	0,41	2,00
	16	0,24	0,31	0,29	0,84
	18	0,24	0,31	0,26	0,81
	16*	0,23	0,49	0,28	0,99
	18*	0,22	0,49	0,24	0,95

For evaluating the accuracy in approximation of the actual main hydrophysical characteristic curves by different formulas we considered several criteria. They included the mean square errors in computations for potential (S_ψ) and the logarithm of potential (S_{pF}) with known moisture content values W and also moisture contents (S_W) with known potential values ψ. These errors were normalized relative to the dispersion σ_i of the corresponding characteristics. The S_ψ/σ_ψ criterion reflects well the accuracy of approximation of the main hydrophysical characteristic with high soil moisture potential values, whereas the S_{pF}/σ_{pF} criterion reflects well the accuracy in the case of its low values. In addition, we computed the value of the total criterion S_{tot}, that is, the value

$$S_{tot} = \frac{1}{53}\sum_{1}^{53}\left(\frac{S_\psi}{\sigma_\psi} + \frac{S_{pF}}{\sigma_{pF}} + \frac{S_W}{\sigma_W}\right). \tag{21}$$

Table 1 gives the computation errors for all the formulas cited in this article with the actual values of the parameters (all the parameters necessary for the computations were taken from the main hydrophysical characteristic curves) using data for 53 soils. The asterisks in the table denote formulas in which the constants WM and ψ_{WM} are used instead of the parameters MH and ψ_{MH}. We will give a brief analysis of the results.

The greatest error in approximation in the investigated ranges of soil moisture pressure are given by computations using formulas (11) and (12). They are one-parameter in their structure. In both formulas it is the maximum hygroscopic moisture MH which is used as the unique characteristic of the water-retaining capacity of the soil. The greatest errors in computations using these formulas are noted in the region of high saturation of the ground.

The Russell formula (2) is suitable for computing the main hydrophysical characteristic in a quite narrow range of soil moisture pressure $\psi_{WM} > \psi > \psi_{MM}$. Beyond these limits computations made using formula (2) give what are known to be incorrect results.

Considerable computation errors are obtained when using the formula (3) derived by McQueen and Miller. In practical computations use of the dependence (3), in our opinion, is undesirable, because there is an impairment of the smoothness of the ψ function and its derivatives at the points of intersection of segments of the main hydrophysical characteristic for different segments. The method is also unsuitable for $pF_{MM} > 2.9$.

Fair results in computations of the main hydrophysical characteristic are obtained using the formula derived by Pavlova and Kalyuzhnyy (4). The errors in computations using formula (4) to a considerable degree are caused by its structure, which for different soils assumes constant values of the potentials with WM and MM equal to ψ_{WM} = 10220 and ψ_{MM} = 285 cm H_2O respectively.

A higher approximation accuracy is attained when making computations using the Rogowski (5) and Brooks and Corey (7) formulas. However, in these formulas as one of the parameters use is made of a point with the coordinates W_e and ψ_e, which are not measured systematically. Formulas (4), (5) and (7) are suitable for computing the main hydrophysical characteristic when $W >$ WM.

Entirely satisfactory results are obtained when making computations using formulas (16) and (18). It is assumed that they can be used in the entire range of change in soil moisture content. In formulas (3*), (16*) and (18*) in place of MH and ψ_{MH} use is made of the values of the parameters WM and ψ_{WM} respectively. As a result of this replacement in the range of pressures 0-$1.5 \cdot 10^4$ cm H_2O the approximation errors are considerably reduced, obviously as a result of a more precise stipulation of the upper end of the main hygrophysical characteristic curve. In the pressure range 0-10^5 cm H_2O, on the other hand, the errors increased somewhat.

In our opinion, in practical computations it is desirable to use formulas in which MH and ψ_{MH} values are used, not WM and ψ_{WM}, because the method for determining the WM by the vegetation method can give considerable errors since it is not without an element of subjectivism and much is dependent on the experience and skills of the specialist making the measurements and also on the conditions for carrying out the experiment. The inaccuracies in determining WM by the vegetation method can result in a considerable error in stipulating ψ_{WM}, and accordingly, large errors in computing the main hygrophysical characteristic on the basis of formulas employing this parameter. The method for determining a characteristic close to the WM by direct measurement of the moisture content with a soil moisture pressure $1.5 \cdot 10^4$ cm H_2O ("15-atm moisture content") is free of subjective errors.

We note in conclusion that the stipulation of the ψ_{MM} parameter in the computation formulas using the approximate dependence (17) slightly distorts the results of the computations. In particular, the values of the total criterion S_{tot} for formulas (16), (18), (16*) and (18*) were in the pressure range $0-1.5\cdot10^4$ cm H_2O 1.40, 1.38, 0.95 and 0.90 respectively, and in the range $0-10^5$ cm H_2O were 0.89, 0.87, 1.05 and 1.01 respectively.

On the basis of an analysis of the errors it is possible to recommend the formulas which we have proposed for operational use in practical computations of moisture transfer in the aeration zone.

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PHYTOCLIMATIC FEATURES OF A RICE FIELD IN THE SOUTHERN UKRAINIAN SSR

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 102-106

[Article by V. M. Prosunko, candidate of geographical sciences, Ukrainian Regional Scientific Research Institute, manuscript submitted 7 May 80]

[Text]

Abstract: The diurnal variation of air temperature and humidity in a rice field and at a meteorological site was investigated. In the rice field at a height of 0.5 m in the course of the entire growing season the mean daily air temperature is 0.5-1.8°C lower and the mean daily relative humidity is 8-19% higher than at the meteorological site. Regression equations are presented for three interphase periods in the development of rice, limited by the phases "sprouting," "leaf tube formation," "heading of panicles" and "gold ripeness." These make it possible, using data on the mean diurnal air temperature at the meteorological site, water level in the rice paddy and the height of plants to compute the mean diurnal air temperature values (at a height of 0.5 m), as well as the diurnal temperature of the water (in the middle of the layer) and soil (at the depth of the tillering node) in a rice field.

Investigations for study of the phytoplankton of a rice field have been carried out in Central Asia [1-3, 5], in the Northern Caucasus [4] and in the Far East [9]. In these studies the authors have developed methodological approaches to investigation of the problem and have obtained quantitative indices characterizing the microclimatic differences between a rice field and the underlying surface of the meteorological site. A comparison of these indices indicates that while conforming to an identical law they differ from one another in value. The latter is attributable to the dissimilar regime of hydrometeorological elements in different climatic regions, under whose influence the phytoclimate of the rice field is formed. This made it necessary to ascertain the phytoclimatic indices for each zone of rice cultivation.

In order to ascertain the phytoclimatic features of a rice field applicable to the conditions prevailing in the southern Ukraine the author generalized data from special observations and field experimental studies carried out in 1972-1978 in rice fields in the zone of rice cultivation in the Ukrainian SSR.

The features of the temperature and humidity regime in a rice field are formed in the first stages of development for the most part by the water temperature, and after closing of the rice stand, by the intensity of plant transpiration. Accordingly, the data from parallel phytoclimatic observations in a rice field and at a meteorological site were grouped by interphase periods: "sprouting-leaf tube formation," "leaf tube formation-heading of panicles" and "heading of panicles-gold ripeness." These periods in the development of rice are characterized by different states of the field (density, height, area of the leaf surface of the plants) and the regime of flooding of the field with a water layer.

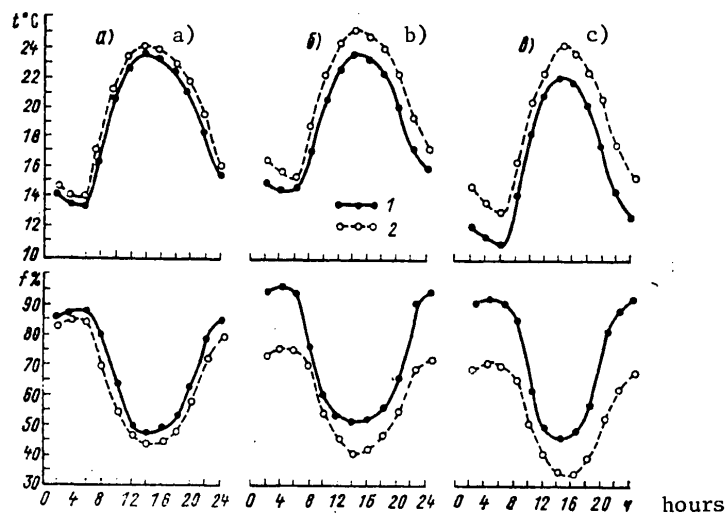

Fig. 1. Diurnal variation of mean air temperature and mean relative humidity in a rice field at a height of 0.5 m (1) and at the meteorological site at a height of 2 m (2) during interphase periods.

An analysis of gradient observations in the rice field indicated that in the interphase period "sprouting-leaf tube formation," when the plants form an unclosed stand, the air temperature in the field is close to its values over the field or somewhat lower. With the closing of the stand the intensified transpiration of the plants favors a greater cooling of the air and its temperature acquires lower values at the water surface. Accordingly, an inversion vertical temperature distribution predominates in the field. The vertical distribution of air humidity is characterized by its decrease with height.

Figure 1 shows the diurnal variation of temperature and relative humidity at a height of 0.5 m in a rice field and at a standard height (2 m) at the meteorological site, determined using thermographs and hygrographs. In the course of the growing season the rice field is characterized by a lower temperature and a higher humidity. The difference between the values of the mentioned elements in the rice field and at the meteorological site on the average for the period "sprouting-leaf tube formation" is 0.5°C and 8%, "leaf tube formation-heading of panicles" -- 1.6°C and 14%, "heading of panicles-gold ripeness" -- 1.8°C and 19%. The reduction in air temperature in the rice field is attributable to an increased heat expenditure on total evaporation (transpiration of plants and evaporation from the water surface). The heat accumulated during the day by the water layer somewhat compensates the cooling of the air in the rice field at nighttime and the microclimatic differences of air temperature between the rice field and the meteorological site are smoothed.

In the diurnal variation of relative humidity at a height of 0.5 m in the rice field there is a maximum which sets in prior to sunrise (0400-0600 hours) and a minimum which is observed at about midday (1200-1400 hours).

The amplitude of the variation of the mean diurnal temperature and relative humidity in the rice stand during the entire growing season is less than at the meteorological site (Table 1).

As a result of a correlation analysis of data from parallel observations of temperature in the rice field and at the meteorological site it was possible to derive linear regression equations characterizing the correlation between mean air temperature in the field (0.5 m) and its value at the meteorological site (2 m) during individual interphase periods (Table 2).

The correlation between the mean diurnal soil temperature at a depth of 3 cm in the field (y) and the mean diurnal air temperature at the meteorological site (x) is also expressed by a straight-line equation with a regression coefficient 0.51 and a free term 8.0. The equation can be used in determining the optimum sowing times. The correlation coefficient for this correlation is $r = 0.83 \pm 0.05$. The error of the equation is $S_y = \pm 1$°C. The equation is applicable with $x = 9.8$-18.5°C. There was a closer correlation between soil temperature, measured using AM-17 maximum-minimum thermometers placed at a depth of 3 cm in the field and at the meteorological site. This correlation is expressed by a straight-line equation with a regression coefficient 0.92 and a free term 1.4. The correlation coefficient is $r = 0.98 \pm 0.03$. The error of the equation is $S_y = \pm 0.7$°C. The equation is applicable with $x = 9.0$-17.6 °C. These equations can be used for obtaining information on the soil temperature in the rice field prior to its flooding on the basis of data for the nearest meteorological station.

We also computed equations for the correlation between soil temperature at the depth of the tillering node in the field and air temperature at the meteorological site, water level in the rice paddy and the height of the plants (Table 3). They can be used in evaluating the influence of agrometeorological conditions on the growth and development of rice in different parts of the growing season.

Table 1

Diurnal Amplitude of Temperature and Relative Humidity in a Rice Field (First Line) and at Meteorological Site (Second Line)

Interphase period	Air temperature, °C	Relative humidity, %
"Sprouting-leaf tube formation"	21.5	72
	25.4	76
"Leaf tube formation-heading	15.8	63
of panicles"	19.0	69
"Heading of panicles-gold ripe-	18.6	62
ness"	20.00	65

Table 2

Correlation Between Mean Daily Air Temperature in Rice Field (y) and Mean Daily Air Temperature at Meteorological Site (x)

Interphase period	Regression coefficient		Correlation coefficient	Mean square error	Number of cases
	angular	free term			
"Sprouting-leaf tube formation"	0.66	7.3	0.84	0.9	80
"Leaf tube formation-heading of panicles"	0.82	3.3	0.79	0.8	94
"Heading of panicles-gold ripeness"	0.55	8.0	0.76	1.2	78

Table 3

Dependence of Mean Daily Soil Temperature at Depth of Tillering Node of Rice (t) on Mean Daily Air Temperature at Meteorological Site (x), Water Level in Paddy (y) and Plant Height (z)

Interphase period	Regression equation	Multiple correlation coefficient	Mean square error	Number of cases
"Sprouting-leaf tube formation"	$t_1 = 0.164x - 0.021y + 0.02z + 18.5$	0.73	1.1	84
"Leaf tube formation-heading of panicles"	$t_2 = 0.212x - 0.080y + 0.08z + 12.7$	0.81	0.7	116
"Heading of panicles-gold ripeness"	$t_3 = 0.134x - 0.077y + 0.09z + 6.9$	0.76	0.5	92

Table 4

Dependence of Mean Daily and Minimum Temperature in Middle of Water Layer in Rice Field ($\bar{u}$), (u) on Mean Daily Air Temperature at Meteorological Site (x) and Depth of Water Layer (y)

Interphase period	Regression equation	Multiple correlation coefficient	Mean square error, °C	Number of cases
"Sprouting-leaf tube formation"	$\bar{u}_1 = 0.437x+0.218y+10.175$	0.73	1.0	68
	$\underline{u}_1 = 0.179x+0.163y+9.768$	0.76	1.2	82
"Leaf tube formation-heading of panicles"	$u_2 = 0.097x+0.144y+19.094$	0.83	0.9	74
	$\underline{u}_2 = 0.143x+0.198y+11.806$	0.80	0.9	74
"Heading of panicles-gold ripeness"	$u_3 = 0.808x+0.660y-8.463$	0.77	0.8	62
	$u_3 = 0.030x+1.110y-6.294$	0.74	0.6	62

The thermal regime of the water in the rice paddy exerts a great influence on the formation of side sprouts and the formation of the fruit-bearing organs [8]. However, the measurement of water temperature in the rice field involves definite technical difficulties. Therefore, we computed regression equations (Table 4) characterizing the correlation between the mean daily and minimum water temperatures in the middle of the water layer in a rice field and the mean daily air temperature at the meteorological site and the water depth in the rice paddy. The statistical characteristics of these equations indicate the possibility of using them for computing the water temperature when measurement data are lacking.

The cited equations correlating the elements of the thermal regime in a rice field with the factors determining them make it possible to take into account the phytoclimatic characteristics of a rice field in the hydrometeorological servicing of agriculture in the rice cultivation zone.

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UDC 551.577.21(477)

SOME CHARACTERISTICS OF HEAVY PRECIPITATION IN THE UKRAINE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 107-109

[Article by T. N. Zabolotskaya, candidate of geographical sciences, and V. M. Muchnik, candidate of physical and mathematical sciences, Ukrainian Regional Scientific Research Institute, manuscript submitted 18 Feb 80]

[Text]

Abstract: It is shown that heavy precipitation of the shower type at a station most frequently is a result of passage of several centers of precipitation. The time between the onset of the maxima of intensity of two successive centers and the distance between their midpoints are determined.

Heavy rains are those in which 30 mm or more of precipitation falls at a station in the course of 24 hours [3]. These rains can cause great losses (especially in mountain regions) and therefore are considered dangerous for the national economy. Their study is necessary for the purpose of prediction and warning, and also for developing methods of modification for the purpose of regulating rainfall.

It was noted earlier in [2] that the intensive development of a center of precipitation is accompanied by the combining of a main center with a center forming to the rear of it. However, the authors of [2] gave only one case and therefore it was important to ascertain how frequently such cases occur and whether such processes are typical for the formation of heavy precipitation, that is, whether heavy rains are caused by the passage of one center or several centers, one following the other.

As the initial data for the investigation we used data from the pluviometric and precipitation gage network in the Experimental Meteorological Polygon of the Ukrainian Scientific Research Institute during the summer of 1977 and also data from radar observations during this same period. Since the radar observations were made during the daytime, for selecting the cases with heavy rains we employed the semidiurnal precipitation sums (for the observation time 2000 hours), but the initial sum selected was 30 mm or more, that is, the selected rains can be called "heavy." Attention was given to those cases when the precipitation was in the form of showers, not continuous.

Despite the fact that the polygon region is a region with inadequate moistening, the occurrence of heavy precipitation at individual stations is not a rare phenomenon. For example, in June the hydrometeorological posts registered the falling of abundant precipitation over the course of 12 days, in July -- 8 days, and in August -- 7 days. During this time heavy precipitation was observed at 102 posts. The frequency of recurrence of the quantity of falling precipitation during a half-day at individual points was as follows:

Gradations of quantity of precipitation, mm	30.1-40	40.1-50	50.1-60	60.1-70	70.1-80	>80
Frequency of recurrence, %	49	23	10	7	7	4

It can be seen that in almost 30% of the cases individual posts register a very great quantity of precipitation per half-day (more than 50 mm).

During this period the program for radar observations provided for conical sections at different angles of antenna elevation with calibrated attenuation of the signal. Series of such sections were obtained each 10 minutes. In general, such a program made it possible to determine the boundaries of individual centers, track the moments of their formation and further development, but in some cases (during intensive processes of precipitation formation) it was difficult to carry out such an analysis, since the 10-minute interval between observation series exerted an influence. Accordingly, the need arose for checking whether the number of centers passing over a station agrees with the record of rainfall intensity on the pluviometric tapes.

Such checking was carried out at 31 posts (48 rains). It was found that the number of centers passing over an observation point according to radar data agrees rigorously with the number of maxima on the curve of variation of intensity.

As an illustration, using radar observations with the MRL-2 we will examine the falling of precipitation on 13 June over a station (see Fig. 1). The semidiurnal sum of precipitation at this post was 50.2 mm. The figure shows observational data each 10 and 20 minutes from 0830 hours for a two-hour period. Observations were made at the ground surface with a response of the radar detector 18 db below its total response and aloft with its total response. Thus, it was possible to make a more precise determination of the position of the centers. The figure shows that four centers were formed in the neighborhood of the post.

The first center was detected at the ground surface as early as 0740 hours and for about 1 hour developed very weakly both in area and in height. At 0830 hours (Fig. 1a) its development was intensified and at its rear at a distance of about 10 km at an altitude of about 2.9 km at a vertical angle of 10° center 2 was already discovered. It is interesting that according to data from a radiosonde launched at 0955 hours at the place where the radar was set up the altitude of the isotherm 0°C was about 2.8 km. According to [1], with the appearance of the first echo at the level of or above the 0°C isotherm the center has a tendency to development, which in actuality was not the case. Thus, after approximately 10 min center 2 reached the ground surface (Fig. 1b), whereas after 30 min (Fig. 1d) its altitude already exceeded 4.5 km. Later the altitude of centers 1 and 2 was more than 8 km, that is, these centers became centers of thunderstorms [4]. According to observations at the ground surface, during this period a thunderstorm was noted.

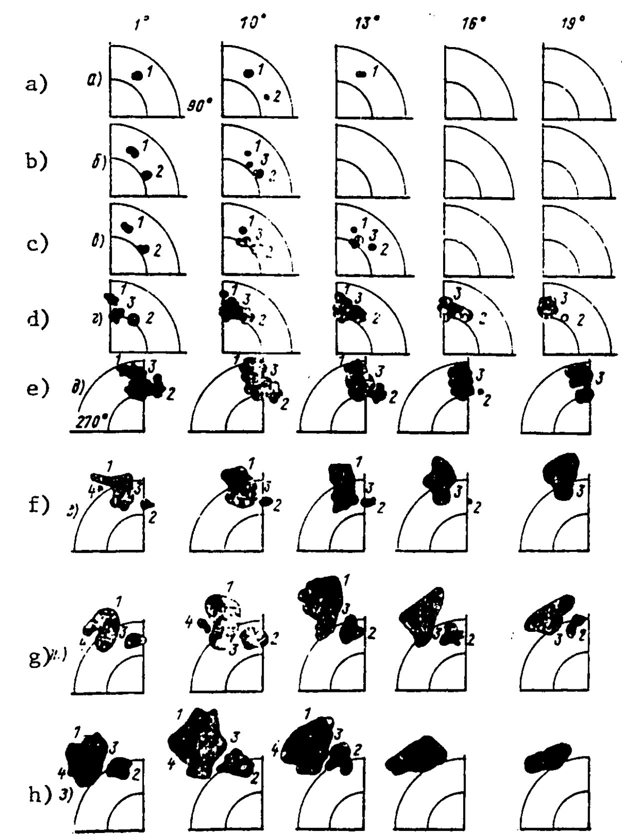

Fig. 1. Projection of centers according to radar observations on 13 June 1977. At angle of elevation 1° -- contour of radio echo 18 db below its total response, at an angle of 10, 13, 16, 19° -- at full response. Range marks each 10 km. a) 0830 hours; b) 0840 hours; c) 0850 hours; d) 0910 hours; e) 0930 hours; f) 0950 hours; g) 1010 hours; h) 1030 hours.

Center 3 appeared at 0840 hours between centers 1 and 2 (Fig. 1b). It can be assumed that this center is dynamically related to centers 1 and 2. All three centers were situated in a line in the direction of their movement. Accordingly, they also passed over the post one after another, creating abundant rainfall.

The data from radar observations are confirmed by pluviometric observations at the post. For example, according to these data there are three rainfall maxima: the first -- at 0940 - 0947 hours, I_{max} = 0.56 mm/hour, second -- at 0959 - 1006 hours, I_{max} = 0.64 mm/hour and third -- at 1020 - 1025 hours, I_{max} = 1.55 mm/hour.

At 0950 hours the center 4 (Fig. 1f) appears at the ground surface somewhat to the left of the system of centers 1 and 3, which by this time had succeeded in joining together. By 1010 hours all the centers mentioned above had joined into one enormous multicell, the individual centers of which, except for center 2, cannot be traced either at the ground surface or aloft. The passage of this multicell also caused the formation of heavy precipitation.

Using radar and pluviometric data it was possible to analyze all cases of the falling of heavy precipitation during 1977. It was found that only 20% of the cases (20 posts) of heavy rain were caused by the passage of a single center, at 22 posts the passage of two centers was noted, at 33 posts -- three centers; at 11 posts the passage of 4 and 5 centers was observed and at 5 posts -- 6 centers; the average quantity of falling precipitation in these cases was 33, 45, 46, 41, 49 and 64 mm. Thus, it can be assumed that heavy precipitation at a station most frequently is a result of the passage of several centers.

It can be concluded on the basis of the material set forth above that with artificial modification the problem is to act upon the subsequent centers in order to extinguish the process of intensive development. Accordingly, it is of interest to determine the time between the onset of the intensity maxima of two successive centers at a particular point on the basis of pluviometric observations. This time averaged 21 minutes. The distances between successive foci of the centers were computed taking into account the velocity of movement of the centers for each day and are presented below:

Distance gradation, km	<5	5.1-10	10.1-15	15.1-20	>20.1
Frequency of recurrence (%) of distances between foci of successive centers	37	38	13	9	3

As we see, in 75% of the cases the distance between successive centers does not exceed 10 km, averaging 7.7 km.

In the future it is desirable that such investigations be continued for the purpose of studying the synoptic conditions under which such processes arise for creating a prediction method.

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RELATIONSHIP BETWEEN TURBULENT DIFFUSION COEFFICIENTS FOR A DRIFTING SPOT AND THE MEDIUM

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 110-111

[Article by V. L. Lebedev, candidate of geographical sciences, Moscow State University, manuscript submitted 5 Jun 80]

[Text]

Abstract: A formula is derived for the conditions of stationary turbulence in the ocean. It makes it possible to transform the diffusion coefficient for a drifting spot into the self-diffusion coefficient for the medium. It is shown that the "4/3 law" for the considered limited case can be reduced to the L. Prandtl formula for the coefficient of turbulent exchange.

Information on the horizontal mixing of ocean waters is collected for the most part by those methods which limit its use because they do not characterize the process of mixing at fixed points in the ocean, but the process of diffusional spreading of drifting spots. The two mentioned processes are fundamentally different. Drift together with a current reduces the destruction of spots. However, in spreading, the spots enter a region of different currents. This accelerates the diffusion and makes it dependent on the size of the spot (the rate of spot diffusion usually increases with an increase in its size).

In order not to confuse the diffusion coefficient for a medium at a fixed point in a field with the diffusion coefficient for a drifting spot (it is sometimes called the relative diffusion coefficient and sometimes the relative separation of particles function), we will use different notations: K -- for a fixed point in the field, $\hat{K}$ for a drifting and expanding spot.

Now we will turn to the dependence of the $\hat{K}$ value on the scale of the phenomenon. According to R. V. Ozmidov, the dependence has the form of a stepped line for which sloping segments alternate with horizontal segments and in their slope conform to the "4/3 law" formulated by Richardson and Obukhov. The law has the following expressions (the first, experimental, is from L. Richardson, and the second, theoretical, is from A. M. Obukhov):

$$\hat{K} = ar^{4/3}; \quad \hat{K} = c\varepsilon^{1/3} r^{4/3}, \tag{1}$$

where r is the mean "radius" of the spot, a is a dimensional proportionality factor obtained by the processing of observations of the spot, c is a dimensionless factor, ε is the rate of dissipation of the energy of molar motion into heat, related to a unit mass.

The second of the cited formulas makes it possible to take the step from diffusion of the spot to the diffusion of the medium, since it contains both the radius of the spot r and the field characteristic ε . We will assume that the intensity of mixing of the medium remains constant in time and turbulence is stationary. Then the dissipation of energy of molar movements into heat should be compensated by the generation of turbulent movements from the kinetic energy of the averaged current. The rate of generation, related to a unit mass, in the simplest case of a plane translational flow can be written as follows [1]:

$$\Gamma = K_M \left(\frac{du}{dl}\right)^2, \tag{2}$$

where K_M is the coefficient of turbulent kinetic viscosity, u is the velocity of the averaged current, l is the normal to the direction of velocity.

We will assume that in the horizontal plane the coefficients of turbulent kinematic viscosity and mixing are identical: $K_M = K$. Also taking into account that for the considered situation there is the equality $\Gamma = \varepsilon$, we substitute (2) into (1) in place of ε and we find the dependence between $\hat{K}$ and K:

$$K = \hat{K}^3 c^{-3} r^{-4} (du/\delta l)^{-2} \sim \sim \hat{K}^3 r^{-4} (\delta u/\delta l) \tag{3}$$

Here δ is the finite difference symbol, c is a value of the order of magnitude of unity.

Substituting equation (1) into (3), we will return to equation (2), but in a form modified by the assumptions made. We also take into account that it follows from (1) that $\varepsilon = a^3c^{-3}$, and c is considered a value of the order of magnitude of unity.

$$K = \varepsilon (du/dl)^{-2} \sim a^3 (\delta u/\delta l)^{-2}. \tag{4}$$

These formulas make it possible to convert from observations of the spot to the diffusion coefficient at the field point. For example, as a result of generalization of large-scale observations Ulson and Ichiye found that a = 0.025 [1]. Substituting this into (4), we find that for δ u = 0.1 m/sec, $\delta l = 10^5$ m, $K = 10^2$ m^2/sec (or 10^6 cm^2/sec).

It is of interest to clarify the problem of the applicability of the "4/3 law" to the diffusion of the medium ("autodiffusion"). We will assume that the diffusion of the medium at a fixed field point is also related with this law through some scale L, different in its nature from the spot scale, which in our new reasonings is entirely absent. We will write this relationship in a form similar to (1),

$$K = c\,\varepsilon^{1/3} L^{4/3}. \tag{5}$$

Substituting (2) into (5), we obtain

$$K = c\left\{K\left(\frac{du}{dl}\right)^2\right\}^{1/3} L^{4/3},$$

hence

$$K = c^{3/2} L^2 \left|\frac{du}{dl}\right| \sim L^2 \left|\frac{du}{dl}\right|. \tag{6}$$

Thus, the hypothesis of a dependence of the diffusion coefficient for the medium at a fixed field point on some scale L in conformity to the "4/3 law" leads to formula (6), serving as a basis for semiempirical turbulence theory and also expressing a hypothesis widely checked under laboratory conditions. This shows the agreement between the two hypotheses and their mutual confirmation within the framework of an analysis of the results of horizontal mixing in the sea. This makes it possible to understand the nature of L as the spatial scale of time disturbances of the velocity field in the neighborhood of a particular point. Returning to a comparison with the spot, it can be said that L is the mean size of that current zone which by means of direct contact interacts with the considered field point.

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REVIEW OF MONOGRAPH BY YE. M. DOBRYSHMAN: 'DYNAMICS OF THE EQUATORIAL ATMOSPHERE' (DINAMIKA EKVATORIAL'NOY ATMOSFERY), LENINGRAD, GIDROMETEOIZDAT, 1980

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 112-113

[Review by I. Sitnikov]

[Text] Already for more than a decade the tropical zone of the earth's atmosphere has been evoking special interest from the meteorologists carrying out its investigation. Soviet meteorologists are at the forefront of these investigations. The expeditions "TROPEKS-72" and "TROPEKS-74" and the participation of Soviet scientists in the Global Experiment and the Monsoonal Program made it possible to accumulate a great volume of experimental data. Hundreds of articles are devoted to their analysis and scientific generalization. It is therefore not a matter of chance that precisely in our country two monographs devoted to the most timely problems of tropical meteorology have already been published. The first of these is a monograph by A. I. Fal'kovich entitled DINAMIKA I ENERGETIKA VNUTRITROPICHESKOY ZONY KONVERGENTSII (Dynamics and Energy of the ICZ), which appeared in 1979, and the second is the book reviewed here, DINAMIKA EKVATORIAL'NOY ATMOSFERY (Dynamics of the Equatorial Atmosphere), by Ye. M. Dobryshman.

In leafing through its pages it can be seen that this monograph is a regular and systematic generalization of many earlier studies by the author written during a 20-year period. These studies were almost always directed specifically to an analysis of the atmosphere at the equator, but they dealt with both general theoretical problems of atmospheric movements and analysis of meteorological information in the tropical zone.

It is therefore natural that the author, after a Foreword and Introduction (where, in particular, the contents are set forth clearly and the importance of the international program for investigating the tropical zone is demonstrated), in Chapter I raises the extratropical problem of interaction of the pressure and wind fields in the atmosphere. Then he discusses in detail the role of variability of the Coriolis parameter in the study of adaptation processes, introducing the β-plane approximation known in the literature. The time diagram of the adaptation process shows how complex this process must be in the low latitudes in the absence of closeness of the wind to geostrophic.

The somewhat formal (at first glance) problem of determining the width of the equatorial zone from the point of view of astronomical (climatic), dynamic and purely experimental considerations (Chapter II) assists the author in determining the framework of the discussion and subsequent exposition of the subject. The arbitrary breakdown of the tropical zone into three parts (with respect to dynamic processes), which he proposes on page 38, seems entirely justified. He differentiates an equatorial part (±4-5° in latitude), transitional part (from 5 to 15° in each hemisphere) and from 15° to the tropics or even to 30°.

Proceeding in Chapter III to some peculiarities of atmospheric processes in the transition zone 5-15° latitude, the author, taking into account that this zone has received quite detailed treatment in a large number of studies, gives an interesting analysis of empirical material and compares different definitions of the intertropical convergence zone (ICZ). An interesting aspect is the additional definition of the ICZ which he introduces as a zone of "interaction between planetary and equatorial boundary layers" (p 55).

The author demonstrates (p 77) that for an analysis of processes in the latitude zone 5-15° it is necessary from one direction -- from the equator -- to take into account vertical movements, and from the other -- the influence of the meridional component of velocity -- the principal result of adaptation of the pressure and wind fields under the strong influence of the Rossby effect. Precisely in such a formulation, within the framework of a zonal model, it is possible to obtain a clearly expressed semidiurnal pressure wave in the lower troposphere characteristic for the tropics (p 81).

Chapter IV is the first in the monograph completely devoted to the equatorial zone: here the author gives a simplification of the equations of hydrothermodynamics for this zone. For this purpose a study is first of all made for the peculiarities of distribution of the principal meteorological elements at the equator: their small variability, the tendency of the fields to be drawn out along the circles of latitude, the closeness of the vertical distribution of temperature in the troposphere to linear and (in a somewhat different aspect) the peculiarity that tropical cyclones are never generated in the equatorial zone and never pass through it. It is noteworthy that the second of the mentioned peculiarities -- quasizonality of the fields, almost invalidates, in the author's opinion, the concept of large-scale disturbance and isotropicity in the equatorial zone, and also gives the author basis (possibly emphasized in a somewhat exaggerated degree) as one of the simplifications of the equations to use thereafter the assumption of a possibility for employing zonal models (p 89). The system of equations of a zonal model obtained in this chapter (correct, as is emphasized on p 94, primarily for "not large" B and C scales) serves as a basis for many subsequent constructions.

One of these is the problem of determining wave movements in the equatorial zone with a stipulated temperature field (Chapter V) and the more complex problem of studying the reaction of the atmosphere in this zone to heat sources (Chapter VI). Precisely in these chapters, in particular, does the author make use of the most intricate mathematical approaches employed in solving extremely complex problems in linear and nonlinear dynamics. In our opinion an extremely valuable conclusion (Chapter V, p 110) is that in the equatorial zone the current regime is determined by both vertical and horizontal stability and that the characteristics of the regime are dependent, accordingly, on the ratio of the stability parameters vertically and horizontally. There is an interesting formulation of the problem for a moist-unstable layer (Chapter VI, pp 157-159), where a negative value of the parameter $\Gamma_{in} = (\gamma_{ma} - \gamma)$ (γ_{ma} is the moist adiabatic vertical temperature gradient, γ is the vertical temperature gradient) radically changes the mathematical structure of the system of equations, leading to the appearance of exponential solutions.

Finally, we feel that investigations of solitary waves (solitones) (Chapter VI, pp 159-181) are promising. These will make it possible to determine the reaction of the temperature and velocity fields to a localized disturbance of the heat influx in the layer with a moist-unstable stratification. The processing of GATE data already gives qualitative confirmation of some of these investigations (p 170).

In contrast to single-component solutions examined in the preceding chapters, the next two chapters are devoted to a description of possible types of circulation in the entire equatorial zone. Beginning with physically simpler stationary models (Chapter VII), the author in Chapter VIII proceeds to nonstationary models in the low latitudes, giving them an original and exhaustive classification.

Some problems in the third group, belonging to this classification -- problems relating to the stability of stationary (including periodic) movements -- are analyzed in detail in the last, ninth chapter of the monograph. The author's range of comprehension in his approach to this problem -- is noteworthy. After discussing the stability concept in the broad sense employed in physics, proceeding to some definitions and concepts refining the main definition of stability, giving examples of stable and unstable movements, the author advances closer to the problem of particular interest to him, the stability of the atmosphere in the low latitudes.

Giving a critical analysis of the hypothesis of convective instability of the second kind (CISK) (pp 259-262), he makes clear that detailed description of many atmospheric processes characteristic for the tropics, especially the ICZ in tropical cyclones, requires the creation of a more modern and perfect mechanism of parameterized description of convective movements.

The Summary gives concise conclusions and a list of the most important problems, both zonal and azonal, which must be solved first.

The monograph of Ye. M. Dobryshman seems to us to be valuable primarily in three respects:

1) devoted for the most part to the problems of dynamic meteorology of the lowest latitudes, it is a sort of expanded introduction to equatorial meteorology, encouraging researchers to concentrate more of their efforts on its problems;

2) the book, being for the most part a theoretical investigation, is unusually closely related to the practical problems of tropical meteorology of recent decades: to its field experiments, to international and national programs. In this respect it is noteworthy that in the appendix to the bibliography (pp 284-285) the author for the first time in the different publications in wide circulation gives a full list of publications of the WMO and international commission on GARP and its tropical subprogram;

3) in connection with the World Climatic Program recently approved by the WMO the monograph will facilitate the forming of points of view of scientists concerned with problems relating to the theory of climate in that part which is

associated with a detailed climatic study of the tropical and equatorial zones and their influence on the climate of our entire planet.

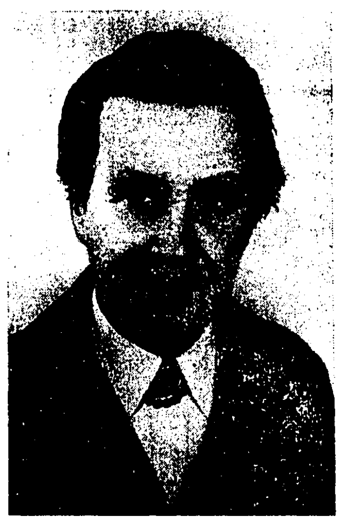
The diversity of physical and mathematical problems considered in the monograph makes it of interest to an extremely broad range of readers. Accordingly, it can only be lamented that the book is available in such a small printing.

EIGHTIETH BIRTHDAY OF TAISIYA VASIL'YEVNA POKROVSKAYA

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 p 114

[Article by specialists of the Main Geophysical Observatory]

[Text] One of the leading and most authoritative climatologists of the Soviet Union, Doctor of Geographical Sciences Professor Taisiya Vasil'yevna Pokrovskaya, marked her 80th birthday on 16 October 1980.



In 1924 T. V. Pokrovskaya graduated from the Physics-Mathematics Faculty of Leningrad State University and in 1925 began to work as a computer in the Climatology Section of the Main Geophysical Observatory. By 1930 she had become a junior scientific specialist and then a graduate student at the Main Geophysical Observatory. The theme of the dissertation defended by Taisiya Vasil'yevna for her Candidate's degree was a climatic description of Leningrad.

In 1934 Taisiya Vasil'yevna was assigned the responsible task of compiling a climatic description of the region of drift of the legendary "Chelyuskin" party. For executing this task at a high scientific level and in the shortest possible time

T. V. Pokrovskaya was given a prize by the government commission for the rescue of the Chelyuskin party. The ideas of the prepared description were further developed in her monograph entitled KLIMATICHESKOYE OPISANIYE SEVERNOGO MORSKOGO PUTI (Climatic Description of the Northern Sea Route). Later, heading the climatological subdivisions of the Main Geophysical Observatory, Taisiya Vasil'yevna in her investigations examined many problems related to heliophysics, the influence of cosmic factors on variations in climate and weather. She developed a synoptic-climatological method of long-range weather forecasting. In the monograph SINOPTIKO-KLIMATOLOGICHESKIYE I GELIO-GEOFIZICHESKIYE DOLGOSROCHNYYE PROGNOZY POGODY (Synoptic-Climatological and Helio-Geophysical Long-Range Weather Forecasts) (1969) she generalized the results of many years of studies along these lines. For this work Taisiya Vasil'yevna was awarded the academic degree of Doctor of Geographical Sciences.

During recent years Taisiya Vasil'yevna has been doing much work on investigation of the reasons for the formation of droughts and development of a method for their prediction, taking into account circulation and heliogeophysical factors.

The results of the investigations of T. V. Pokrovskaya are set forth in monographs, articles, reviews, study aids and other publications (more than 100 of them). Taisiya Vasil'yevna is devoting much attention and time to editing, review of scientific studies, direction of young specialists and graduate students. Broad erudition and deep, thorough education, invariable good will, respectful attitude to her work comrades, attention and constant readiness to come to assistance -- such are the qualities of Taisiya Vasil'yevna, who enjoys invariable authority, love and deep respect among all who have the good fortune to know her. The services of Taisiya Vasil'yevna Pokrovskaya to Soviet science were rewarded with high government awards -- the Order of Lenin, the Order of the Red Banner of Labor, the order "Emblem of Honor," medals and other marks of distinction.

We sincerely wish Taisiya Vasil'yevna good health and further creative successes.

SEVENTIETH BIRTHDAY OF NIKOLAY VLADIMIROVICH PETRENKO

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 115-116

[Article by specialists of the USSR Hydrometeorological Scientific Research Institute]

[Text] Nikolay Vladimirovich Petrenko marked his 70th birthday on 19 December. He began his work activity in 1928 after graduating from the general machine building technical school as a design-technician and designer in the construction of the factories "Azovstal'" and "Zaporozhstal'." His familiarization with meteorology, becoming his specialization during his entire subsequent life, began in 1935, when he entered the Moscow Hydrometeorological Institute.

After successful completion of his studies in 1939, he was sent to work at the Central Institute of Forecasts, later the USSR Hydrometeorological Center, where he worked for 40 years.

A high sense of duty and great responsibility for assigned work, together with a constant striving to broaden his knowledge in the selected field of specialization, as well as the ability to take practical requirements into account, rapidly advanced N. V. Petrenko into the ranks of the leading professional weathermen. In the years of the Great Fatherland War he was delegated the responsible task of supplying forecasts for combat operations of Far Eastern aircraft. N. V. Petrenko was awarded the Order of the Red Star for successful performance of this task.

After the war N. V. Petrenko continued routine work as a forecaster, first as a senior scientific specialist and then head of the section on short-range weather forecasts. It was at this same time that his inclination toward scientific work was manifested. Without interruption of his main routine work he carried out an investigation of the crossing of cyclones over mountain ranges and in 1947 defended his Candidate's dissertation on this subject.

N. V. Petrenko manifested great interest in investigations in the field of aviation meteorology, to which he turned with greater dedication beginning in 1953, when he received a transfer to the aviation meteorology section. Between 1957 and 1977 Nikolay Vladimirovich headed this section.

Meteorologists are very familiar with his studies on the conditions for the formation of fogs, on the prediction of fogs and visibility in them, on jet streams, on prediction of the maximum wind aloft, on conditions for flight in the upper troposphere and lower stratosphere. N. V. Petrenko took an active part in the creation of our country's first RUKOVODSTVO PO KRATKOSROCHNYM PROGNOZAM POGODY (Manual on Short-Range Weathering Forecasting). He is the author of many sections in the first (1955) and second (1964) editions of this manual and also of a number of methodological aids for weathermen.

He generalized the principal results of his scientific investigations in his Doctor's dissertation, defended in 1970.

A distinguishing characteristic of N. V. Petrenko is great interest in the development of studies in the field of aviation meteorology not only at the USSR Hydrometeorological Center, but also at other institutes of the USSR Hydrometeorological Service with which he established contacts. He held consultations and shared his experience and knowledge.

N. V. Petrenko was widely known to the meteorologists of foreign countries as a scientist making a substantial contribution to international cooperation in the field of aviation meteorology. He invested much strength and energy in the development of regulations pertaining to aviation meteorology by means of direct participation in the work of many sessions of the WMO Commission on Aviation Meteorology, aerial navigation conferences of the ICAO and the sessions of regional associations of the WMO. Over the course of many years N. V. Petrenko was a member of different working groups. A substantial contribution to international cooperation was the WMO note "Fogs and Deterioration of Visibility at an Airport," prepared for press by N. V. Petrenko, published in 1980 by the WMO Secretariat.

N. V. Petrenko wrote about 60 published studies. He is co-author of the monograph TUMANY (Fogs) and the book METEOROLOGICHESKIYE USLOVIYA POLETOV SVERKHZVUKOVYKH SAMOLETOV (Meteorological Conditions for Flights of Supersonic Aircraft). Being one of the authors of the monograph TUMANY, in 1963 N. V. Petrenko received the Voyeykov Prize.

The productive and reproachless work activity of N. V. Petrenko earned a series of awards, including the medal "For Illustrious Work," the medal "For Illustrious Work in Commemoration of the 100th Anniversary of the Birth of V. I. Lenin," the medal "Work Veteran," and others. He is a "Distinguished Worker of the Hydrometeorological Service" and his name has been entered on the Honor Roll of the USSR Hydrometeorological Center.

Even now, being on a merited rest, N. V. Petrenko continues cooperation with the aviation meteorology section. He is always ready to come to assistance and generously shares his rich experience and knowledge.

In congratulating Nikolay Vladimirovich on his noteworthy birthday, with all our hearts we wish him good health, good spirits, a long life and successful creative cooperation with his colleagues and friends.

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OFFICIAL AWARDS TO SOVIET HYDROMETEOROLOGISTS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 p 116

[Unsigned article]

[Text] The following workers of the State Committee on Hydrometeorology and Environmental Monitoring have been presented awards for active participation in preparations for and support of the trial flight of the Il-18D aircraft to Antarctica:

Order of the October Revolution

Korilov Nikolay Aleksandrovich -- head of the 25th Soviet Antarctic Expedition (SAE) of the Arctic and Antarctic Scientific Research Institute;

Order of the Red Banner of Labor

Tolstikov Yevgeniy Ivanovich -- Deputy Chairman of the USSR State Committee on Hydrometeorology and Environmental Monitoring;

Order of Friendship of Peoples

Ivanov Gennadiy Nikolayevich -- head of the construction detachment of the 24th SAE;

Order "Emblem of Honor"

Burkov Nikolay Aleksandrovich -- tractor driver of the construction detachment of the 24th SAE;

Yefremenko Vladimir Nikolayevich -- director of the operations group of the Arctic and Antarctic Scientific Research Institute;

Samodurov Leonid Ivanovich -- electric-gas welder of the construction detachment of the 24th SAE;

Medal "For Illustrious Work"

Varagushin Yuriy Vasil'yevich -- chief meteorologist of the Administration for the Meteorological Support of Aviation of the State Committee on Hydrometeorology and Environmental Monitoring;

[Note: As is customary in such lists of awards, the last name is given first.]

Maretskiy Nikolay Viktorovich -- chief engineer of the Marine, Arctic and Antarctic Administration of the State Committee on Hydrometeorology and Environmental Monitoring;

Mironov Aleksey Alekseyevich -- engineer of the 24th SAE;

Moryakin Leonid Sergeyevich -- metalworker-assembler of the construction detachment of the 24th SAE;

Smirnov Viktor Alekseyevich -- meteorological engineer of the 24th SAE;

Medal "For Distinction in Work"

Vorob'yev Nikolay Aleksandrovich -- tractor driver of the construction detachment of the 24th SAE;

Martynov Viktor Vladimirovich -- senior engineer of the Arctic and Antarctic Communications Unit of the Main Radiometeorological Center;

Mishin Valeriy Nikolayevich -- weatherman-engineer of the 24th SAE;

Obryadin Leonid Pavlovich -- head of the communications center of the Moscow Main Aerometeorological Center.

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The Honorary Diploma of the Presidium RSFSR Supreme Soviet was awarded by a decree of the Presidium RSFSR Supreme Soviet to the Moscow Hydrometeorological Technical School for successes attained in the training of qualified specialists for the national economy.

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The title "Meritorious Worker in Science of the RSFSR" was awarded by a decree of the Presidium RSFSR Supreme Soviet to Doctor of Physical and Mathematical Sciences Shabo Aslanovich Musayelyan for services in scientific activity and the training of scientific personnel.

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 116-118

[Article by G. L. Lukshis-Lukshaytis, I. F. Gertman and Yu. G. Slatinskiy]

[Text] An anniversary session of the Scientific Council, dedicated to the 40th anniversary of the Central Aerological Observatory, was held on 30 May.

The First Deputy Chairman of the USSR State Committee on Hydrometeorology and Environmental Monitoring, Yu. S. Sedunov, appeared and gave a welcoming address to observatory personnel. He noted the successes achieved by the Central Aerological Observatory in the field of investigations of the free atmosphere during the 40 years of its existence.

The reports given at the session presented the principal scientific results obtained at the Central Aerological Observatory during recent years.

A report by I. P. Mazin, entitled "Investigations of the Central Aerological Observatory in the Field of Cloud Physics," examined the ways work is developing in the field of cloud physics at the Central Aerological Observatory. Six directions can be defined: measurement instruments and methods, field investigations, laboratory studies, applied investigations, studies in the field of theory and numerical modeling. In conclusion the author enumerates the problems on whose solution the greatest efforts must be concentrated in the coming decade.

A report by N. Z. Pinus, entitled "Investigation of Free-Air Turbulence," gave the results primarily of experimental investigations of turbulence in the troposphere and in the lower stratosphere. The report gave quantitative estimates of fluctuations of the wind velocity components and temperature fluctuations in the clear sky and in clouds, the rates of dissipation of turbulent energy into heat and the rate of evening-out of the fluctuating temperature field, and the intensities and structure of the horizontal and vertical turbulent heat flows. Also considered are the laws of energy distribution in a wide range of space and time scales of the turbulence spectrum.

A report by Yu. V. Mel'nichuk, entitled "On the Status and Prospects of Development of Radiosonde Observations of the Atmosphere," gave the history of development at the Central Aerological Observatory of methods for the use of radar in measuring the meteorological parameters of the atmosphere, study of the dynamic structure of clouds and the use of meteorological radar in measuring the quantity of precipitation in an area. The prospects for the further development of meteorological radar are set forth.

A report by Yu. A. Seregin, entitled "Results of Work on Artificial Modification of Clouds and Fogs," gave a detailed examination of the present status and paths of development of artificial methods for the modification of atmospheric processes. The author cited the results of the effectiveness of modification of hail processes for the protection of agricultural crops in an area of Moldavia. Also examined were the results of laboratory and theoretical investigations associated with the search for new reagents for cloud modification.

G. A. Kokin, in a report entitled "Some Problems in the Physics of the Upper Atmosphere," noted that a new and very productive stage in the activity of the Central Aerological Observatory was related to rocket investigations of the upper atmosphere, begun on the initiative of G. I. Golyshev in 1949 in a specially organized section. As a result, the world's first meteorological rocket MR-1 was launched in October 1951. Then G. A. Kokin discussed the technical means for sounding, the development of the network of rocket sounding stations and the results of investigations of the upper atmosphere. The present-day status of meteorology of the stratomesosphere was reviewed.

A solution of the problem of the relationship between processes in the troposphere and in the high layers of the atmosphere in the light of recently accumulated data is now acquiring special importance not only for understanding the climate of the troposphere, but also for solution of the problem of long-range and superlong-range weather forecasting.

A report by G. P. Trifonov noted advances in radiosonde observations of the atmosphere and the contribution which has been made by studies carried out at the Central Aerological Observatory. Some prospects for further studies were also mentioned.

V. D. Reshetov gave a concise review of investigations of the patterns of variability of meteorological elements in intervals from several hours or days to several months under the influence of atmospheric and cosmophysical factors. These studies are part of the investigations of the patterns of atmospheric circulation.

A review of the principal scientific results of investigation of the atmosphere with the use of lasers, obtained at the Central Aerological Observatory, was presented by O. K. Kostko. He presented data on the optical properties and the spatial-temporal distribution of stratospheric aerosol. The author analyzed the principal attainments in creation of remote laser apparatus for determination of the meteorological parameters of the atmosphere (wind velocity and direction, humidity, temperature). Also examined are the results of use of laser methods in problems involved in the monitoring of atmospheric contaminations and contamination of water bodies. The most promising directions in further investigations in study of the atmosphere by optical methods were determined.

A report by V. K. Babarykin, entitled "Flying Meteorological Observatories," examined the present status of the scientific equipment on flying laboratories of the Flight Scientific Research Center and the prospects for the use of aircraft investigations of different problems which can be solved in the observatory.

An All-Union Conference of Users of Oceanographic Information was held at Obninsk during the period 19-22 May. Participating in the conference were representatives of 23 institutes of the State Committee on Hydrometeorology, Ukrainian Academy of Sciences, USSR Fisheries Ministry and other departments.

A total of 22 reports were presented. They dealt with a broad range of problems related to the creation of banks of oceanographic data and support of the national economy of the country with observational data, the results of computations and manuals on the regime of the seas and oceans.

In opening the conference, V. I. Lamanov, head of the Oceanographic Data Center, noted that in the Tenth Five-Year Plan the oceanographic institutes of the country have carried out much work in the field of collection, processing and use of oceanographic information. In particular, at the Oceanographic Data Center work has continued on creation of files of oceanographic information (data banks) on long-lasting technical carriers. Much attention has also been devoted to the development of means for the automated processing of oceanographic data.

It was noted in the report that depending on the departmental affiliation and specialization of different institutes the makeup and volume of data entering into the basic bank can be extremely different. However, structurally each data bank must be formed with adherence to some technical-economic and scientific-organizational principles which are common for all, in particular, adequacy of data, universality, unity of structure, optimum volume, technical stability, economy and internal consistency. All the information collected at the scientific research institutes or Administrations of the Hydrometeorological Service and registered on a technical carrier constitutes the basic data bank. This basic bank in turn is divided into disciplinary banks arranged by types of observations, Depending on the observation method, design of the instruments, methods for transmitting data, etc., the disciplinary banks can contain measurement data both for one parameter or for a whole group of parameters. In addition to the disciplinary banks, it is possible to create special banks for individual major projects, such as GATE, FGGE, SISM, etc.

In the reports and addresses of participants in the conference it was noted that the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center and a number of other institutes are carrying out much work for the processing of punched tapes of historical deep-water information from Sea Administrations of the Hydrometeorological Service on a "Minsk-32" electronic computer. During 1979 alone about 0.4 million horizons were punched in the field, both current and past deep-water information. Work has begun on creation of a complex bank of oceanographic data under the "Razrezy" [Sections] program and a technique was developed for the registry of deep-water oceanographic information from punched cards onto the YeS computer magnetic tape. The archives of algorithms and programs is constantly being supplemented. Only recently more than 70 programs for the processing of oceanographic information were sent to users.

The speakers touched on a broad range of matters relating of the methodological and technical support of work on the creation of branch and regional data banks. In particular, Ye. D. Vyazilov and N. Z. Yemel'yanova (All-Union Scientific Research Hydrometeorological Institute-World Data Center) told about the creation of an automated catalogue of oceanographic data and grid square files of abyssal bathometric observations. Ye. V. Kopayev (Institute of Oceanology) discussed some problems in the technology involved in creating banks with observational data on currents. He reported on the development of mathematical support of the system making it possible to accomplish recording on magnetic tape and statistical processing of current observations using BPV current meters.

V. R. Fedorenko and A. Ye. Rogachev (Cybernetics Institute Ukrainian Academy of Sciences) told about a new system for the processing of oceanographic data which makes possible an analysis of the most diverse data registered on the technical carrier in accordance with the data formats developed at the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center.

I. F. Gertman (Sevastopol' Division of the State Oceanographic Institute) reported on the results of work on creation of a regional bank of abyssal oceanographic data for the Black Sea and the Sea of Azov using an M-222 electronic computer. The mathematical support of the bank was used in carrying out investigations under the "Shel'f" (Shelf) project and in other work. Virtually without any modifications it can be used for creating a data bank for any other region with a data volume not greater than 0.3 million oceanographic stations.

The conferees devoted much attention to the problem of routine use of the accumulated data and its dissemination to users in the most convenient form. In particular, A. A. Rybnikov (State Oceanographic Institute) reported on plans for the use of oceanographic information during 1981-1985. K. P. Vasil'yev (USSR Hydrometeorological Center) presented a detailed discussion of the requirements on the processing of oceanographic information for predicting some elements of the hydrometeorological regime of the sea. V. P. Kut'ko (All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center) told about the preparation of climatological handbooks for the world ocean and I. M. Ovchinnikov (Southern Division Institute of Oceanology) told about the prospects for the use of the Mediterranean Sea data bank in preparing a monograph on the hydrological regime of this region.

A resolution issued by the conference gave a formulation of a number of specific proposals for the further development of work related to the local formation of regional banks of abyssal hydrological information. In particular, it was deemed extremely desirable that in every way possible there be an acceleration of the accumulation of masses of data on internal and marginal seas, and also the creation of specialized data banks in accordance with a plan coordinated with all the organizations receiving and using hydrometeorological information. It was recommended that information on new data processing systems, conferences and seminars which have been held, etc., be regularly published in the Information Bulletin of the Oceanographic Data Center. It was decided that conferences of users of oceanographic data be held annually.

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 pp 118-120

[Article by B. I. Silkin]

[Text] As reported in SCIENCE NEWS, Vol 116, No 15, p 244, 1979, during the last decade there have been more and more cases of a high content of sulfur dioxide and nitrogen oxides in the atmosphere, leading to increased acidity of the falling precipitation. It has been established that this is an anthropogenic phenomenon related primarily to the combustion of fossil fuel. Such cases were particularly frequent in Scandinavia and the remaining part of Northwestern Europe. However, now such a phenomenon is frequently being observed also in the territory of the United States.

For example, in the Adirondacks, in northern New York, famed for its untouched environment, there has been mass death of fish in numerous lakes and damage to cultivated field crops caused by the acidity of precipitation. The mean pH level in the water in Adirondack lakes, which in the 1930's was 6.5, has now fallen to 4.8; more than 90 of them have become completely without fish.

W. M. Lewis and M. S. Grant, scientific specialists at the University of Colorado in Boulder, speaking at a conference of the National Commission on Water Quality, reported that now there have been cases of the "displacement of this problem" into the western regions of the United States, affected later by industrialization. They mentioned cases of highly acidic precipitation in the region of the continental divide of North America. Measurements in the Indian Peaks reservation (Colorado) which lasted four years indicated that the acidity of the precipitation has increased almost sevenfold there.

It is important that for the time being the sources of such contaminations cannot be discovered. With the appearance of stacks of a great height the products of combustion of coal at electric power stations can enter into ever-higher layers of the atmosphere and are being transported to ever-greater distances.

In a special statement made by an assistant to the head of the United States Environmental Protection Agency for scientific matters, S. G. Gage, it is stated that the measures now adopted will be able to bring the existing situation under control. For example, the intensified monitoring of industrial discharge of sulfur dioxide which has now been established should reduce it by 80-90% in several years. However, the transport of this type of atmospheric contaminants for extremely great distances makes the acidity of precipitation an international problem and requires thorough and universal study.

A federal program for evaluating the problem of acidity of precipitation, work to be carried out over a 10-year period, was initiated by government order in the United States beginning with 1 January 1980. The following are the primary problems defined: 1) study of the status of numerous lakes in the northern part of Minnesota and Michigan which have already been affected by acidity; 2) investigation of the dependence of crop yield on the acidity of precipitation; 3) determination of specific lakes in the territory of the United States especially vulnerable to such contamination and the formulation of measures for preventing their contamination; 4) collection of data on the processes of transport of acidic contaminating agents, their behavior and reactions of sulfur dioxide and nitrogen oxides transpiring in the atmosphere.

For these purposes two networks of special stations are being organized and cooperation is being established with the similar global network created by the WMO.

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As reported in SCIENCE, Vol 208, p 281, 1980, and in NEW SCIENTIST, Vol 86, No 1207, p 394, 1980, the hypothesis that during a period of maximum spot-forming activity on the sun, having a cycle of 11 years, its temperature increases, has still remained undemonstrated during the several decades which have elapsed since its formulation, although it is supported by the tendency for onset of a "good" year in the years of the solar maximum.

It was impossible to validate the correctness of such a hypothesis exclusively by surface observations because the variations of energy radiated by the sun do not exceed 1% and the variable state of the earth's atmosphere easily absorbs and conceals these variations.

Now the first substantial confirmation of such a hypothesis has been obtained in the course of an experiment carried out with the artificial earth satellite "NIMBUS-7" by a group of specialists headed by J. R. Hickey. The data obtained from a high-response radiometer carried aboard this satellite clearly show that between 1976, when there was a solar activity minimum, and 1978 there was an increase in the quantity of energy released by the sun, attaining at least 0.5%.

These data coincide well with the readings of instruments launched on rockets in the period between 1976 and 1978. Thus, the assertion that during the period of the solar activity maximum (the latter was reached early in 1980) the quantity of thermal energy released by the sun increases by not less than a half-percent in comparison with its minimum can be considered valid.

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As reported in NEW SCIENTIST, Vol 87, No 1208, p 6, 1980, Doctor K. Henson, a scientific specialist at NOAA, has stated that the catastrophic eruption of Mount St. Helens in Washington state caused considerable interference in climatological investigations. The ejected solid particles and gases, entering into the atmosphere, are a hindrance to the work being carried out extensively on all continents for measuring the influence exerted by the combustion of fossil fuels on weather and climate.

Hypotheses have been advanced that the anthropogenic effect on the atmosphere, especially its contamination resulting from the consumption of petroleum and coal, should cause a so-called greenhouse effect -- a general warming on a global scale. Now the volcanic products to a considerable degree have masked the observable meteorological effects.

Data are available indicating that in the past large eruptions of volcanoes, in which a considerable volume of solid particles and gases entered the atmosphere and propagated over the planet, led to a small cooling of the air in its surface layer and warming in the stratosphere.

If the ejecta of St. Helens volcano reaches great altitudes in the stratosphere, Henson postulates that the cooling which will be caused in the surface layer will mask any warming which may be associated with the entry of carbon dioxide from industrial sources into the atmosphere.

OBITUARY OF IVAN VARFOLOMEYEVICH KRAVCHENKO (1912-1980)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 12, Dec 80 p 120

[Article by a group of comrades]

[Text] The Soviet weather service has experienced a severe loss: Ivan Varfolomeyevich died on 10 October 1980 in his 69th year of life after a severe prolonged illness. He was deputy head of the Administration for Hydrometeorological Support of the National Economy of the USSR State Committee on Meteorology and Environmental Monitoring, an engineer-colonel in the reserves.

I. V. Kravchenko was born on 27 January 1912 in Kiyevskaya Oblast. After successfully graduating in 1936 from the Moscow Hydrometeorological Institute, he began work in the field of specialization of meteorological engineer at the Main Meteorological Station of the Air Force, where he served more than 30 years, including more than 13 years in the post of head of the Main Aviation Meteorological Center of the Air Force.

I. V. Kravchenko particularly manifested high qualifications of a specialist in the field of aviation meteorology, consistency and clarity in his work during the years of the Great Fatherland War when with his direct participation meteorological support was successfully given to the military operations of the Soviet Air Force. Ivan Varfolomeyevich directly supplied meteorological information to such universally known operations as the trans-polar flights of Soviet aircraft, the Teheran and Yalta conferences and combat actions in the war with Japan.

For his successful support of these operations I. V. Kravchenko was awarded the Order of the Red Banner, Order of the Fatherland War (Second Degree), three orders of the Red Star and many medals.

I. V. Kravchenko loved his field of specialization greatly and willingly transmitted his knowledge to young specialists. He wrote the book LETCHIKU O METEOROLOGII (Meteorology for the Flier); it has appeared in three editions and has become a reference manual for airmen and aviation meteorologists.

In 1965 I. V. Kravchenko retired, but did not abandon his favorite work and continued with his field of specialization at the Main Administration of the Hydrometeorological Service of the USSR Council of Ministers, where he devoted the last 14 years of his life to the hydrometeorological support of the national economy of our country.

During these years he carried out much work for improving the meteorological support of fuel and power, as well as transportation enterprises, agriculture, forestry, communal management and the population. I. V. Kravchenko devoted much attention to problems relating to the testing and introduction of new and improved methods for weather forecasting, the development of which is being carried out at scientific research institutes and weather bureaus.

Being energetic, an outstanding lover of work and highly principled, Ivan Varfolcmeyevich remained a modest and simple person. All those who worked for many years with Ivan Varfolomeyevich will always remember him as a thourough-going Communist, a demanding administrator, an honest, impartial, direct and very sincere man.

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