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ANTHROPOGENIC CHANGES IN GLOBAL CLIMATE

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[Text]

Abstract: The article discusses the problem of impending anthropogenic changes in global climate. It is concluded that the climatic conditions of the end of the 20th century and especially the first half of the 21st century will substantially differ from those of today under the influence of an increase in the content of carbon dioxide in the earth's atmosphere.

The hypothesis that under the influence of economic activity there can be a change in global climatic conditions was already expressed in the 1930's [33]. The first scientific conferences on this problem were held in the USSR in 1961 [11] and in 1962 [12].

During the period 1975-1980 there was a series of international and national conferences at which there was discussion of the anthropogenic change in modern climate. Among these conferences was the First World Conference on the Climate Problem (Geneva, 1979), a series of Soviet-American scientific symposia, the All-Union Conference on Anthropogenic Change in Climate (Leningrad, 1980) and many others. During recent years materials and conclusions from a series of scientific conferences have been published, as well as the reports of different scientific organizations on the problem of anthropogenic change in climate [10, 30, 34-36, 39, 41 and others]. In these publications the opinion is expressed that there can be a major change in global climate in the near future and because of this the task of evaluating the anthropogenic change in climate is acquiring great practical importance.

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Natural climatic changes. Anthropogenic changes in global climate are developing against the background of its natural fluctuations, whose temporal changes fall in the range from a few years to a time period commensurable with the duration of the earth's existence. In a study of modern climatic changes it is possible to limit the examination to an analysis of the fluctuations over the period of a century.

A spectral analysis of time series of different meteorological elements, including the mean air temperature of the northern hemisphere, does not reveal a distinct periodicty of the natural changes in climate [8, 14 and others]. However, there are a considerable number of investigations whose authors feel that the natural fluctuations of climate have a more or less cyclic character [16, 24, 26 and others].

These studies point out the existence of cyclic fluctuations of climate with a duration of 1500-2000 years, 300-500 years, 60-120 years (secular cycle) and less than a hundred years (intrasecular fluctuations). By the term "cyclicity" is meant fluctuations whose periods and amplitudes can vary in definite, but rather broad limits. In a number of studies information on climatic cycles was used in predicting natural changes in climate [16 and others].

The physical mechanism of modern natural climatic changes is governed to a considerable degree by the attenuation of solar radiation penetrating into the troposphere by stratospheric aerosol, whose mass is determined by the regime of explosive volcanic eruptions [4, 18, 42, 44, 52]. There is basis for assuming, in particular, that repeated coolings in Europe, accompanied by an increase in ice content in the northern part of the Atlantic Ocean, for the most part are attributable to a decrease in atmospheric transparency after group explosive volcanic eruptions. Warmings occur with an increase in transparency in an epoch with a lessening of volcanic activity. Such transparency changes are easily traced using data on fluctuations in conductivity of Greenland ice during the last 250 years [42]; these are associated with the fallout of the products of volcanic eruptions.

A number of studies give a discussion of the problem of the influence of solar activity on modern changes in climate. Such an influence can be associated with changes in the concentration of stratospheric ozone [23]. However, there is no reliable empirical confirmation of the influence of solar activity on climate [25, 54, 55].

Astronomical factors -- fluctuations of parameters of the earth's orbit -- exert no influence on modern climatic changes because they involve time scales of thousands and tens of thousands of years.

The amplitude of natural climatic changes which can occur in the course of the next decades is small. Thus, in particular, it is extremely improbable that there will be a deviation from the norm for the mean global temperature averaged for five-year intervals greater than 0.25° at the earth's surface under the influence of natural factors [29]. In this connection an anthropogenic warming, changing the mean global temperature not more than tenths of a degree, can be appreciably intensified (or compensated) by natural climatic changes. Greater anthropogenic changes in climate, associated with fluctuations in mean global temperature by several degrees, will considerably exceed the natural climatic changes and will be decisive for the climatic conditions of the future.

Anthropogenic factors in climatic change. According to estimates available at the present time, an increase in the content of atmospheric carbon dioxide is the principal factor exerting an influence on climate and is a virtually inevitable consequence of the development of world electric power production.

A prediction of the consumption of fossil fuel is an important factor on which the prediction of the atmospheric CO_2 content in the coming decades is dependent. With the availability of such a prediction the computation of the distribution of anthropogenic carbon dioxide among the principal reservoirs, that is, among the atmosphere, ocean and biomass, is carried out by solution of a system of equations describing the global cycling of carbon. The principal parameters entering into these equations have been considerably refined during recent years as a result of new experimental investigations, and in particular, by data from monitoring of the content of atmospheric CO_2, which has been carried out since 1958 [30, 67]. The results of monitoring indicate a continuous increase in the CO_2 concentration in both the northern and southern hemispheres. The mean annual concentration increased from 315 $million^{-1}$ in 1958 to 336 $million^{-1}$ in 1978. An analysis of data from measurements made sporadically in the 19th century gave a concentration of about 290 $million^{-1}$ for the middle of the century [30, 33].

Numerous computations [27, 31, 32, 58, 61] of the CO_2 distribution as a result of exchange processes occurring between the atmosphere, ocean and biomass predict for the coming century an increase in the fraction of anthropogenic carbon dioxide remaining in the atmosphere. This fraction should be not less than 60% in 2025. Thus, with retention of the present-day rates of energy development (4.5% annually, see [39]) and under the condition that coal, petroleum and gas in 2025 will constitute 56% of all the energy resources used (which corresponds to the most probable prediction of the development of energy [59]), the carbon dioxide content in the atmosphere in this case in 2000 will be 380 $million^{-1}$, in 2025 -- 520 $million^{-1}$ and in 2050 -- 750 $million^{-1}$.

The probable error in these evaluations under the condition that the industrial effluent is precisely known is about 20%. The results of computations by different authors relating to temporal changes in CO_2 content in the atmosphere up to 2100 with identical rates of industrial effluent agree with one another in approximately this same range.

The greenhouse effect, caused by doubling of the CO_2 concentration in the atmosphere, should, as indicated below, result in an increase in mean temperature at the earth's surface by 2-3°C. The scale of these changes will considerably exceed the changes in the thermal regime on the earth under the influence of other anthropogenic factors.

In principle, all the gases having absorption bands in the IR spectral region can make a contribution to the greenhouse effect.

Estimates of the direct influence of changes in the content of minor gas components on the radiation fluxes and on the temperature of different layers of the troposphere and stratosphere were made for the most part using models of radiational-convective equilibrium with various additional assumptions [29, 60, 63 and others]. In such models it is possible to determine the change in air temperature caused only by the direct influence of minor gas components on the radiation fluxes. A warming in the lower troposphere with a doubling of the present-day content of CH_4 and N_2O and an unmodified relative humidity will amount to 0.4-0.6°; there will be approximately the same warming of the troposphere with a 20-fold increase in its content of freons. A decrease in the content of ozone in the stratosphere by 30% will result in an increase in the temperature of the lower troposphere by several tenths of a degree [56].

As is well known [1, 47], minor gas components in the atmosphere actively participate in many photochemical reactions with other gaseous and aerosol compounds. The rate of these reactions is dependent on temperature and the fluxes of ultraviolet radiation in different layers of the atmosphere. A substantial warming of the troposphere and cooling of the stratosphere with an increase in the CO_2 concentration will exert a substantial influence on the intensity of photochemical transformations and on the content of minor gas components, whereas the latter in turn will change the radiation and temperature fluxes. The first attempts at model investigations of this effect indicated that its influence on the temperature increase caused by an increase in CO_2 is small [17].

The atmosphere contains a considerable quantity of anthropogenic aerosol, most of which is concentrated in the troposphere over industrially well-developed countries. There are contradictory opinions concerning whether the global content of aerosol in the troposphere will cease or continue to grow as a result of economic activity [21, 60]. Taking these estimates into account, the preliminary conclusion can be drawn that there is no adequate basis for expecting a considerable increase in the quantity of anthropogenic aerosol, especially since at the present time intensive work is being carried out for purifying the air of populated regions against contamination.

The results of different investigations [21, 60] also lead to the conclusion that the possible relatively small anthropogenic increase in aerosol content in the troposphere will not result in any considerable climatic effect because on a global scale it is possible to expect compensation of the effects of heating and cooling due to the absorption and reflection of radiation by aerosol.

The quantity of aerosol of anthropogenic origin in the stratosphere evidently is small in comparison with the mean natural level arising as a result of volcanic activity.

According to estimates, the background aerosol forming in the stratosphere during a period of low volcanic activity (for the most part as a result of oxidation of OCS gas -- carbonyl sulfide -- entering from the troposphere) will reduce the global temperature of the earth's surface by not more than 0.1°C [2, 62]. Preliminary investigations of the OCS balance in the atmosphere reveal that it is determined to a considerable degree by anthropogenic sources. The possible increase in the background concentration of atmospheric OCS during the first half of the next century will lead to a global decrease in temperature of the earth's surface by not more than 0.1-0.3°.

Estimates of the influence of development of stratospheric aviation and transport space vehicles on background stratospheric aerosol content and climate reveal that this effect will be insignificant [4, 21]. Thus, the probable increase in the content of anthropogenic aerosol in the atmosphere will not lead to climatic effects comparable with the effect of the increase in atmospheric CO_2 content.

The very same applies to anthropogenic changes in the state of the earth's surface. At the present time these factors are changing the mean global temperature by not more than 0.1°C [5]. The direct heating of the atmosphere inevitable with the use of any form of energy can be of definite importance for the climate of the future. However, computations reveal that the influence of this factor will be manifested in the more remote future and that during the next 70-100 years it cannot be comparable with the influence of an increase in the CO_2 concentration [40].

Response of climate to changes in climate-forming factors. It is usually assumed that changes in global climate can be regarded as the sum of definite factors and random changes transpiring under the influence of phenomena external relative to the climatic system, which are a result of instability of the climatic system itself [4, 5].

Among the most general characteristics of the determined component of changes in global climate is a dependence of mean air temperature at the earth's surface on changes in the climate-forming factors exerting an influence on the earth's energy balance.

As a measure of the response of climate it is customary to use estimates of changes in the global or local climatic characteristics with a stipulated change in climate-forming factors.

Estimates of the response of the global thermal regime to an additional heat influx or to a change in the atmospheric CO_2 content were obtained first in simple models of the theory of climate [4, 5 and others]. Then they were confirmed and made specific by computations using models of general circulation of the atmosphere [47-49, 64, 65], and also empirical estimates based on data from study of the annual variation of meteorological elements, on data on modern changes in climate and on changes in the climate of the past [5, 22, 50 and others].

The computations in [64], agreeing with empirical estimates in [5, 22, 37], reveal that changes in the global cloud cover, accompanying changes in the thermal regime, exert little influence on the response of global climate, although this problem will require further investigations.

According to [35], which gives a review of the results of computations for five general circulation models, the change in the mean global air surface temperature with a doubling of atmospheric CO_2 content is 3 ± 1.5°C. The incomplete coincidence of existing estimates of this parameter is attributable to the presence of different simplifying assumptions in all models of the theory of climate.

The computations in [48, 65] have indicated an appreciable role of allowance for the seasonal variation of meteorological elements in models of the theory of climate. Accordingly, the computations of response in [48, 57, 65] are the most reliable. There seasonal variation is taken into account and this value falls in the range 2.0-3.3°C. The empirical estimates in [5, 22, 50] do not contradict the theoretical estimates.

The conclusions cited above concerning the response of the global thermal regime to external factors are correct for stationary or quasistationary climatic changes. Computations of climatic changes for several decades must include allowance for thermal inertia of the climatic system.

This inertia is related primarily to the heat capacity of the upper quasihomogeneous layer of the ocean and to processes of interaction between this layer and the deeper layers [19, 38, 43]. Estimates of this inertia obtained by means of models of the theory of climate, taking into account the upper quasihomogeneous layer of the ocean [43] and by means of an analysis of empirical data on the modern changes in climate [5, 52], satisfactorily agree with one another and give a lag time in changes in mean annual air surface temperature of about 10 years. With allowance for interaction between the quasihomogeneous layer and the deeper layers this time can be increased [38], but this problem requires more detailed study.

Models of the theory of climate make it possible to study the patterns of change in the zonal and seasonal characteristics of the thermal regime and the moisture cycle with an increase in atmospheric CO_2 content, but because of the approximate nature of the models the accuracy of these conclusions is less than the accuracy of computations of the response of the global mean annual thermal regime.

Quantitative information on local climatic changes, accompanying changes in climate of a global scale, can be obtained using models of general circulation of the atmosphere but also by a statistical analysis of empirical data on changes in climate during the period of instrumental meteorological observations [7, 9, 13, 45, 66 and others].

These estimates can be used as materials characterizing the changes in climatic conditions with a relatively small increase in the content of atmospheric CO_2 if the changes in mean annual air surface temperature in the northern hemisphere do not exceed 0.5°C.

Empirical information on climatic conditions for a higher atmospheric CO_2 content can also be obtained by the use of paleoclimatic data [5-7 and others].

In investigations of evolution of the chemical composition of the atmosphere it was found that in the Neogene (3-22 million years ago) the atmosphere contained a quantity of carbon dioxide exceeding the present-day level by a factor of 2-4 [5, 6]. The use of data on climate of the Neogene for computations of the thermal regime and the moistening regime with high CO_2 concentrations gave results close to the results of computations using models of general circulation of the atmosphere [5-7].

Computations using models and empirical estimates show that the greatest changes in surface temperature will be in the polar regions where they can attain 8-10°C with a doubling of the atmospheric CO_2 content [5-7, 49, 65].

Anthropogenic climatic changes. Since 1972, first in Soviet investigations, and then in the studies of foreign authors, a number of computations of impending anthropogenic changes in climate were published [3-5, 7, 10, 20, 29, 40]. These computations were based primarily on an estimate of climatic changes under the influence of an increase in the atmospheric CO_2 content. In some of the investigations in this cycle of studies in determining the climatic conditions of the future the authors employed models of the theory of climate, whereas in other studies this was accomplished using empirical data on the patterns of change of climate in the modern epoch and in the geological past. A fact worth noting is that the results of these computations in most cases agree well with one another.

Evaluations of the climatic change caused only by the increase in the concentration of carbon dioxide must be considered minimum. In addition, it is improbable that the influence of other factors will increase the anticipated changes in the mean global air temperature by more than a factor of 1 1/2.

On the basis of computed data from models of the theory of climate and empirical models, with allowance for the data cited above on the increase in atmospheric CO_2 content, it is possible to obtain the estimates of the anthropogenic change in mean global temperature cited below for the earth's surface in comparison with the temperature at the beginning of the 20th century.

Years	2000	2025	2050
Change in mean temperature, °C	0.9	1.8	2.8

The changes in mean air temperature at different latitudes are not identical. As noted above, they increase with an increase in latitude. The nature of this dependence can be seen from data (see below) which give the changes in the mean latitudinal temperatures corresponding to an increase in mean global temperature by 1°C.

Latitude, degrees	0	20	40	60	30
Change in mean annual temperature, °C	0.5	0.6	1.0	1.7	3.0

In the middle and especially in the high latitudes the temperature changes substantially in the annual variation, attaining a maximum in winter and a minimum in summer.

It can be concluded from the data in these tables, based on materials in [5, 49], that sea polar ice in the near future must be transformed from perennial to one-year ice. The problem of the regime of sea ice under conditions of development of a global warming has been discussed in a number of studies [5, 47, 53 and others]. Taking into account the materials of these investigations and data from the tables cited above it can be concluded that arctic perennial sea polar ice will be destroyed prior to 2050 and possibly even before 2025.

Data on the impending change in air temperature over the territory of the USSR were obtained by empirical methods: for the late 20th century -- on the basis of the patterns of modern climatic changes [9], for the 21st century -- on the basis of paleoclimatic analogues [7]. Taking into account more precise geochronological data, the latter can probably be considered as characterizing the climatic conditions of 2025-2050 [6].

In this epoch the mean air temperature in the summer months in the territory of the USSR will increase by several degrees in the northern regions and by about 1° in the southern regions. During the winter months there will be a more considerable change in climate [7].

It follows from materials on the moistening regime over the territory of the USSR in the future [5, 7, 9] that in the late 20th century in the central regions of the European USSR and in the northern part of Kazakhstan there will be some decrease in the precipitation totals, most significant during the winter. During the second quarter of the 21st century in the northern part of the European USSR and in Western Siberia the quantity of precipitation will increase considerably; in the central regions the precipitation total will also increase, although less significantly; in a number of southern regions the quantity of precipitation may decrease.

The annual sums of runoff in this territory will increase considerably in the north, somewhat increase in the central regions and decrease in the southern regions.

Conclusions concerning the moistening regime in the future [7] can be checked in part on the basis of materials from an investigation based on model computations of the theory of climate [49]. A comparison of the results of these independent studies reveals that they give similar conclusions with respect to changes in the moistening regime for warming conditions [6].

Reliability of information on climatic conditions of the future. In an analysis of the reliability of available data on the climatic conditions of the future it must be taken into account that these materials are based on two fundamentally different types of initial data. One of these is evaluations of economic activity in the future and the second is computations of the influence of this activity on climate.

The need for taking economic data into account in computations of anthropogenic changes of climate gives these computations a conditional character, making them sharply different from such types of forecast as a weather forecast. Thus, in particular, evaluations of climatic conditions of the future should differ appreciably for different scenarios of energy development.

However, computations of the climate of the future retain the quality of a forecast of events which will occur under the mentioned conditions of economic development. The degree of conditionality of such a forecast will increase for the more remote future.

A source of error in computations of climate is the approximate nature of existing methods for determining climatic change with stipulated values of changes in external climate-forming factors. Since all models of the theory of climate used in these computations have limited accuracy, the possibility of comparing the conclusions of model computations with the results of use of independent empirical models, based on a generalization of data on modern changes in climate or on the climatic conditions of the geological past, is assuming a great importance.

In those cases when similar conclusions are obtained by several (not less than two) independent methods these conclusions must be considered quite reliable.

Conclusions. 1. It follows from modern investigations of anthropogenic changes of climate that the climatic conditions of the end of the 20th and the first half of the 21st centuries will to an ever-greater degree be dependent on economic activity. The most significant influence on global climate will be exerted by an increase in the concentration of carbon dioxide in the atmosphere, which by the middle of the 21st century will more than double in comparison with the present-day level. The increase in the CO_2 concentration will lead to an increase in the mean global air temperature at the earth's surface by not less than 2-3°C. In the high latitudes the temperature increase will be several times greater, which will result in a partial or complete destruction of perennial sea polar ice in the northern hemisphere. A change in the thermal regime will exert a substantial influence on the conditions of moistening of the continents, in individual regions of which the quantity of precipitation will increase, whereas in others (for the most part in the zone of unstable moistening) it will decrease.

2. On the basis of data from long-term meteorological observations it can be concluded that during the modern epoch, under the influence of natural climatic factors, the mean air temperature at the earth's surface will change by not more than several tenths of a degree. Accordingly, in the 21st century the natural fluctuations of climate will be appreciably less than the anthropogenic changes.

3. In order to ensure the needs of the national economy with data on the climatic conditions of the future it must be taken into account that these conditions, as a result of the influence of economic activity, will differ substantially from the modern level.

Such an allowance is particularly necessary in the long-range planning of economic activity and in the planning of long-operating objects. These include, in particular, a complex of structures ensuring the interzonal shifting of runoff.

4. The problem of optimum methods for using available information on the climatic conditions of the future requires special study.

It is necessary to develop a strategy for the use of these data in solving various practical problems, taking into account the limited accuracy and detail of now-existing evaluations of climate of the future.

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INDIRECT COMPUTATION OF CHARACTERISTICS OF THE PREVAILING WIND

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 18 Nov 80) pp 15-18

[Article by F. F. Bryukhan', Moscow Division, All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center]

[Abstract] In problems related to evaluations of the transport of atmospheric impurities and contaminants it is common to use the characteristics of the prevailing wind. These characteristics (direction, frequency of recurrence and velocity) are also important in the planning of air flights since allowance for these makes possible a considerable reduction in flight time. Computations of the prevailing wind are also important in climatology because they graphically characterize the regime of air currents. The method outlined in the manual METODY KLIMATOLOGICHESKOY OBRABOTKI METEOROLOGICHESKIKH NABLYUDENIY (Methods for Climatological Processing of Meteorological Observations), Leningrad, Gidrometeoizdat, 1957 is usually used in the computation of these characteristics. However, this generally employed method, requiring a knowledge of the wind roses, is quite approximate. For example, the frequencies of recurrence computed by that method can exceed 100%. In addition, in the case of a small number of observations such computations do not make it possible to smooth the actual wind roses. An extremely convenient computation method based on use of a circular form of the two-dimensional normal law was developed by the author in two earlier studies: TRUDY III VSESOYUZNOGO SIMPOZIUMA PO PRIMENENIYU STATISTICHESKIKH METODOV V METEOROLOGII, 1978 and TRUDY VNIIGMI-MTsD, No 65, 1979. However, that method is correct only in those cases when there is one prevailing direction and when the ellipticity parameter is close to unity. Here the author develops the method still further, presenting an improved method for indirect computations of characteristics of the prevailing wind, using as a point of departure an elliptical form of the two-dimensional normal law. Such computations make it possible to discriminate several prevailing directions. The computations presented here reveal a good correspondence between the computed and actual characteristics. When there is one prevailing direction and a weak ellipticity the computations can be made using a circular law. Figures 1, tables 1; references 6: 5 Russian, 1 Western.

INVESTIGATION OF THE ENERGY CYCLE IN THE USSR HYDROMETEOROLOGICAL CENTER MODEL OF GENERAL CIRCULATION OF THE ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 25 Nov 80) pp 19-25

[Article by A. Ye. Nikitin, USSR Hydrometeorological Scientific Research Center]

[Text]

Abstract: A study was made of the Lorenz energy cycle reproducible by a four-level hemispherical model of general circulation of the atmosphere developed at the USSR Hydrometeorological Center for January conditions. The results characterize the properties of the model and its correspondence to the real atmosphere. The author has demonstrated the relationship between some energy characteristics and macroscale circulation processes.

At the present time the most complete evaluation of the intensity of general circulation of the atmosphere is possible from the point of view of an analysis of atmospheric energy in the understanding proposed by Lorenz [3, 7]. Because of this energy is one of the most important criteria for evaluation of the adequacy of global and hemispherical hydrodynamic models of general circulation of the atmosphere to processes in the real atmosphere. In this article we give the results of an analysis of the energy cycle of a four-level hemispherical model of general circulation of the atmosphere developed at the USSR Hydrometeorological Center. The number of points at each level is 32 x 18 (along a circle of latitude and meridian respectively). The model was described in detail in [5].

Method and data. In the selected experiment the initial data applied to November (Basic Data Set archives). The integration was carried out under fixed January circulation conditions (ocean temperature, albedo, cloud cover, short-wave radiation). When computing the energy characteristics use was made of data on geopotential, temperature and wind at the levels 125, 375, 625 and 875 gPa, as well as on vertical velocity at the intermediate levels and surface pressure from the first to the 98th day of the experiment. We computed the values of the zonal and eddy components of the available potential and kinetic energy (AZ, AE, KZ, KE) and the rate of transformation of one type of energy to another, specifically: C_A -- rate of transition of AZ into AE, C_E-AE into KE, C_K-KE into KZ and C_Z-AZ into KZ. The generation of available potential energy and the dissipation of kinetic energy were computed from the equations for the balance of the corresponding energy components. The method for computing the energy characteristics was described in [6,8]. The derivatives were approximated by central differences and at the boundaries by directed differences. The boundary conditions corresponded to the boundary conditions of the model. The eddy components of energy were represented in the form of the sum of eddies of a synoptic scale (period less than seven days) and the energy of quasistationary disturbances (period seven or more days). The cited results relate to the period from the 30th to the 95th days of the experiment, that is, the period of intensive "acceleration" of the model.

Notations employed:

AZ, AE -- zonal and eddy available potential energy,
KZ, KE -- zonal and eddy kinetic energy,
A_T, K_T -- available potential and kinetic energy of moving eddies of a synoptic scale,
A_S, K_S -- available potential and kinetic energy of quasistationary disturbances,
C_Z, C_E -- rate of transition of AZ into KZ and AE into KE,
C_T, C_S -- rate of transition of AE into KE in moving and quasistationary eddies,
C_A, C_K -- rate of transition of AZ into AE, KE into KZ,
G_Z, G_E -- rate of generation of AZ, AE,
D_Z, D_E -- rate of dissipation of KZ, KE,
V -- wind velocity,
ω -- vertical velocity,
T -- temperature,
p_S -- surface pressure,
X -- averaging of X for the hemisphere,
[X] -- averaging of X along a circle of latitude,
X^* -- deviation of the latitudinal X value from the mean.

Results. Figure 1 shows curves of the temporal variation of available potential and kinetic energy (a), rate of transformation of available potential energy into kinetic energy (b) and standard energy diagrams (c) (obtained by Oort [8] on the basis of real data for the northern hemisphere (c_1), in the described experiment (c_2), in the old model of the GFDL model and in the GISS model [14] -- (c_3 and c_4)).

In the variation of the zonal energy components it is easy to see an increase in AZ and KZ to the 50th-60th days of the experiment. In the variation of the eddy components, especially in the change in the energy of the quasistationary eddies and eddies of a synoptic scale, there is no definite trend beginning on the 30th day. At the same time, the changes in eddy energy were somewhat smoothed in comparison with the period from the 55th through the 95th days, which is evidence of an understating of the pressure and temperature gradients along the circles of latitude. These facts indicate that the restructuring of the model to winter conditions is completed only by the 50th-60th days. After the 60th day the zonal and eddy energy are in antiphase. During the entire experiment the ratio of KE to KZ is approximately 0.5-0.6, decreasing to 0.4 only by the 90th-95th days. It is interesting to note that the preliminary analysis of the temporal variation KE/KZ, and especially AE/AZ, indicates the existence of a quasiperiodicity in the variation of these characteristics. The period of variations was close to two weeks. Since the KE/KZ and AE/AZ ratios can be interpreted as some analogue of the index of zonal circulation, it can be stated that in the model there is reflection of the known fact of two-week periodic variations of the index.

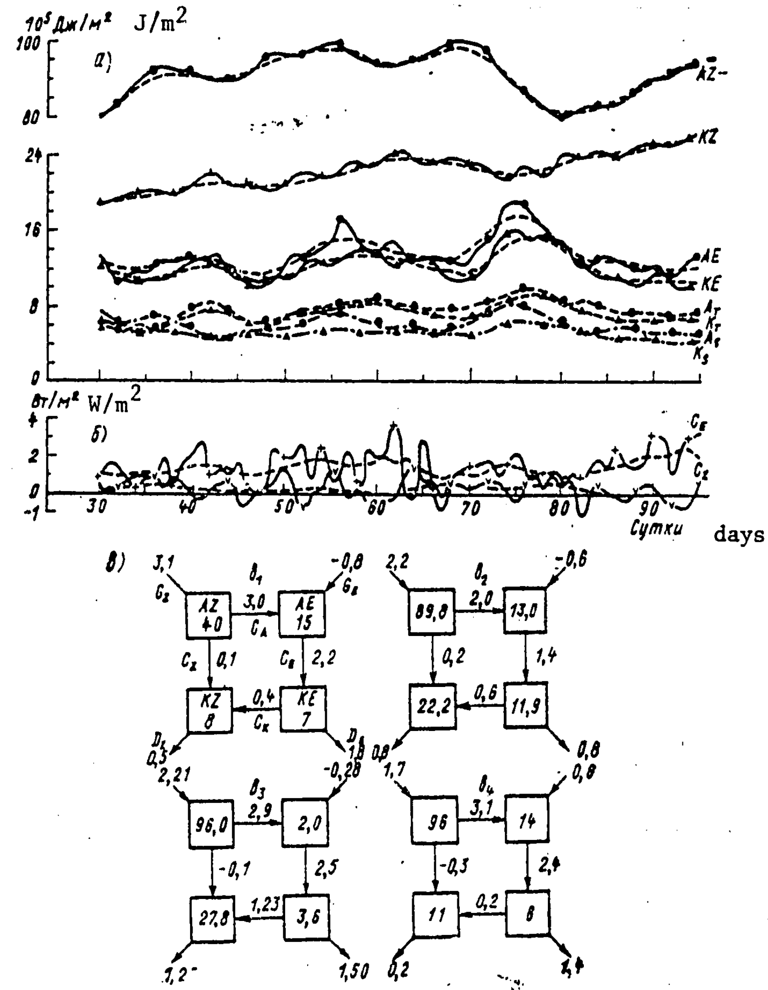

Fig. 1. Integral energy characteristics of model. a) temporal variation of AZ, KZ, AE, KE, A_T, K_T, A_S and K_S; b) temporal variation of C_Z and C_E (the dashed curve gives the seven-day moving mean values of the energy characteristics); c) diagrams of the energy cycle; c_1) real atmosphere [7], c_2) in described experiment; c_3) in GFDL model [13]; c_4) in GISS model [14].

The energy of the moving eddies of a synoptic scale is more significant than the energy of the quasistationary eddies and on the average is about 60% of the eddy energy. This agrees with the results of empirical investigations [12, 16]. It must be noted that the averaging period in our case is considerably shorter (7 days instead of 30). Thus it can be assumed that the energy reserves in the eddies of a synoptic scale are exaggerated due to an understating of the energy of stationary eddies, that is, the synoptic disturbances in the model are more active than similar formations in the real atmosphere.

The rate of transition of the available potential energy into kinetic energy C_E and C_Z does not reveal a definite trend in its secondary variation, that is, these characteristics are adapted to winter circulation conditions stipulated in the model more rapidly than the values of the available potential and kinetic energy. An important fact is that these transitions are in antiphase (this is especially conspicuous on the curves of the 7-day moving means C_E and C_Z); accordingly, the model has a tendency to conserve the full energy, compensating its changes with a change in the intensity of the transitions. The transitions between available potential and kinetic energies of moving (C_T) and quasistationary (C_S) eddies are also in antiphase, that is, the increase in the intensity of cyclonic activity is accompanied by a decrease in the intensity of quasistationary eddies and vice versa. In this case the decisive role is played by energy exchange in the system of moving eddies. From the 35th through the 90th days it is about 80% of the eddy transition C_E. A predominance of C_S over C_T is observed only at the beginning of the experiment (up to the 35th day). At the end -- about the 90th day -- the ratio of C_S to C_E is approximately 0.5, which is attributable to an attenuation of cyclonic activity when there is a strong activation of zonal flow.

Now we will examine the energy diagrams shown in Fig. 1c.

The zonal energy components are exaggerated in comparison with the real data, but the eddy components agree with them quite well. The values of the transitions C_A and C_E, as well as the dissipations of eddy kinetic energy D_E (the residual term in the equation for the balance of eddy kinetic energy), are somewhat understated. Nevertheless, on the whole the energy cycle reflects the processes existing in the real atmosphere and agrees satisfactorily with the energy in other models [13-15].

Figure 2 shows the meridional sections of zonal kinetic and available potential energy and also the transitions C_Z and C_E, determined during the period from the 60th through the 70th days (this period is characterized by active synoptic processes). As a comparison we give some characteristics obtained for the real atmosphere by Oort and Rasmusson [10]. The distribution of the cited characteristics agrees well with the real data but some differences should be noted.

The jet stream is displaced poleward by approximately 10° and its intensity is somewhat exaggerated. There is also an exaggeration of the KE values, especially in the lower troposphere. We note a KE maximum near the equator at altitudes of about 7 km. It is evidently related to fluctuations at the equatorial boundary. The distribution of AZ and AE, interpreted as the contribution of this latitude zone and layer to the total available potential energy, shows that in the model at the present levels near the equator there is a rather significant understating of the horizontal temperature in the pole-equator direction, whereas near the pole it is exaggerated. The AE maximum in the latitude zone 20-40°N at the lower level indicates a great activity of meridional processes on the periphery of subtropical anticyclones. Judging from the C_Z distribution, the Hadley cell in the model is narrowed and its intensity is exaggerated. The Ferrel cell, on the other hand, is "drawn out" along the meridian. These differences are attributable not only to the characteristics of the model, but also to different periods for averaging of the cited results.

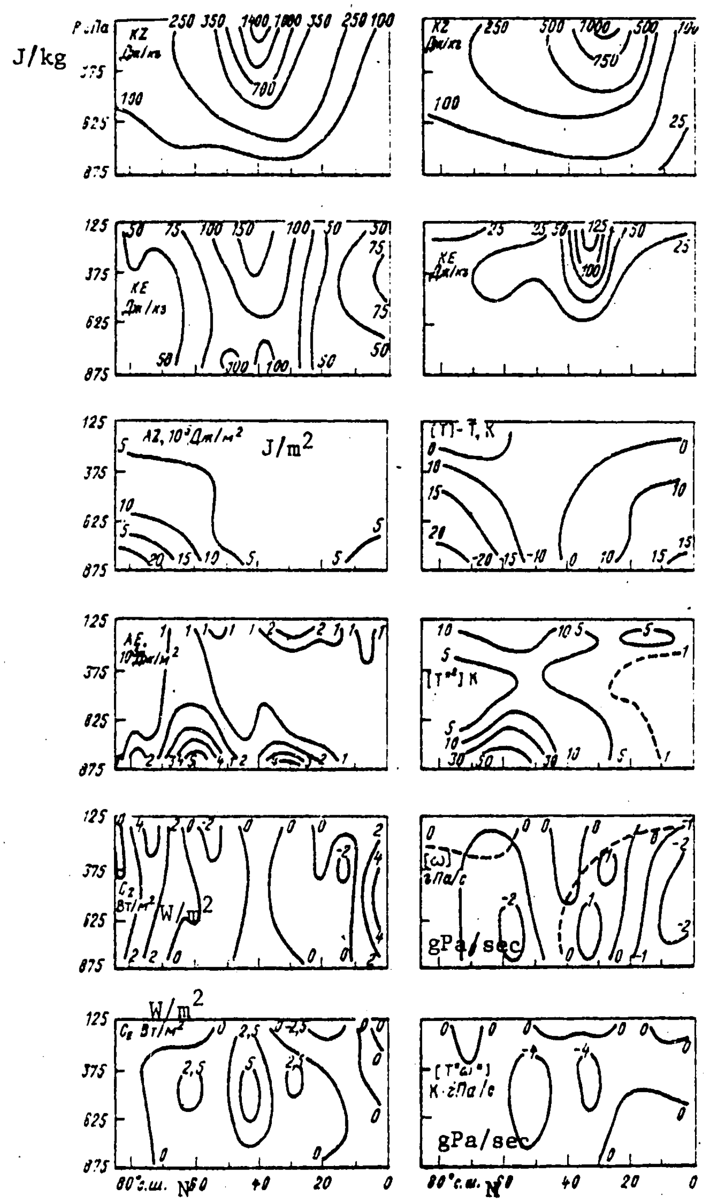

Fig. 2. Meridional sections of energy characteristics of model averaged during the period from the 60th through the 70th days (at left) and characteristics of real atmosphere for January [10] (at right).

Despite the cited differences, it should be noted that the zonal structure of the model in general is close to the structure of the fields in the real atmosphere.

For a deeper understanding of the energetics of general circulation it is of interest to examine not only the zonal, but also the latitudinal-longitudinal distribution of energy characteristics for the hemisphere.

A joint analysis of the thermopressure fields and the KE and C_E fields indicates that eddy kinetic energy is closely related to the pressure field. Its maximum values are localized within the leading parts of the cyclones, which agrees with the analysis of kinetic energy of cyclones in [4] and in zones of convergence of flows in the rear parts of cyclones in the presence of a blocking anticyclone or with lowering of a trough into the subtropical latitudes. The minimum KE values are noted in the low and high latitudes and middle-latitude low-gradient fields. In many situations cyclonic formations are displaced in the direction of the KE maxima.

The maximum positive C_E values are associated with regions of heat advection where the heated air experiences ascending movement in virtually the entire thickness of the atmosphere, and in addition, in zones of advection of cold in the system of a blocking anticyclone. In cold troughs the process has a dual character. In the rear part of the trough the cold air subsides, leading to a transition of the eddy available potential energy into kinetic energy. This process has a considerably lesser vertical extent than the ascending movement of air during the advection of heat, and therefore the C_E maxima in the cold troughs are less clearly expressed. On the other hand, in the leading part of the trough the relatively less cold, and accordingly, less dense air rises in the region of convergence over the colder air, leading to the transformation of eddy kinetic energy into available potential energy.

The results presented above make it possible to draw some conclusions relating, first of all, to the properties of the described model itself, second, to the correspondence of the model to the real atmosphere, and third, to the relationship between the energy characteristics and macroscale atmospheric processes.

1. The transitions between the zonal and eddy components of available potential and kinetic energy are in antiphase, that is, the model has a tendency to conserve the total energy.

2. The temperature gradients in the pole-equator direction are somewhat distorted in the high and low latitudes, which is manifested graphically in the meridional sections of available potential energy.

3. The eddy formations of a synoptic scale are more active than the similar eddies in the real atmosphere.

4. The "wall" at the equator increases the eddy kinetic energy in the middle tropopsphere.

5. The integral energy characteristics of the model agree satisfactorily with the characteristics of the real atmosphere, that is, the energy of the model in general corresponds to the real atmosphere.

6. Moving eddies of a synoptic scale carry the greater part of the eddy energy (about 60%) and about 80% of the transformation of eddy available potential energy into eddy kinetic energy occurs in them.

7. The interaction between the zonal components of energy is related for the most part to the intensity of the Hadley and Ferrel cells, whereas the interaction between eddy formations is related to processes of a synoptic scale in the middle latitudes.

8. In the variations of the KE/KZ and AE/AZ parameters, in their physical essence closely related to the index of zonal circulation, there is a quasiperiodicity with the period of the variations being close to two weeks.

9. The maximum values of eddy kinetic energy are related to the leading parts of cyclones and zones of convergence of flows on the northern periphery of subtropical anticyclones, especially in the system of the blocking anticyclone.

10. The zones of maximum rates of transition of eddy available potential energy into kinetic energy are related to the advection of heat in cyclones and cold in anticyclones. The zones of maximum rates of transition of eddy kinetic energy into available potential energy are related to the advection of cold in cyclonic systems.

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VERTICAL CIRCULATION IN THE HIGH-ALTITUDE FRONTAL ZONE OVER WESTERN SIBERIA AND KRASNOYARSKIY KRAY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 5 Nov 80) pp 26-31

[Article by L. I. Vinogradova and N. P. Shakina, candidate of physical and mathematical sciences, Krasnoyarsk Weather Bureau and USSR Hydrometeorological Scientific Research Center]

[Text]

Abstract: The authors made an isentropic analysis of the intensive high-altitude frontal zone (HAFZ) over Western Siberia and Krasnoyarskiy Kray. It is shown that on the cold side of the region of entry into the HAFZ the air descends from the tropopause and from the stratosphere, whereas on the side of the warm air there are ascending movements. In addition to this main thermally direct circulation cell, on the cold side of the entry region there was a local thermally inverse frontogenetic circulation. In the delta region the direction of the vertical circulations is the opposite: the main circulation cell is frontogenetic and imparts a katafrontal character to the front.

Processes of frontogenesis and frontolysis are three dimensional both at the lower levels and in the upper troposphere and form regions of well-expressed vertical movements affecting thick air layers. The nature of the vertical circulation (thermally direct with ascent on the side of the warm air or thermally inverse with ascent on the side of the cold air) is determined by the direction of evolution of the frontal zone [5, 8]: thus, with intensification of the latter there is a thermally direct circulation. Computations on the basis of real data presented in [6, 10, 11] and relating to intensive frontal zones over the territory of North America show that in the process of upper tropospheric frontogenesis there is a subsidence of the tropopause and the stratospheric air situated over it to tropospheric altitudes. Such systems of movements in high-altitude frontal zones, described in the late 1950's, at one time were a subject of discussion (see [2, 3]); they still cannot be regarded as adequately investigated.

This article gives an isentropic analysis of an extensive and intensive high-altitude frontal zone situated over the territory of Western Siberia and Krasnoyarskiy Kray. Such an analysis has not yet been made in this geographical region.

Another feature of the case is that both the "input" and the "delta" of the frontal zone were situated within the limits of the mentioned region.

The synoptic situation during the analysis period (30 December 1978-1 January 1979) was characterized by the presence of a deep cyclone over the Arctic. The input of the high-altitude frontal zone (HAFZ) was situated to the east of the Ural Range, whereas the the delta was over the Yenisey. During the studied period at the earth's surface there was a displacement of the deep cyclone, arising after the wave disturbance had crossed over the Urals. The Arctic front, on which this cyclone had developed, by the end of the period had passed across the entire Krasnoyarskiy Kray, bringing with it an abrupt cooling (by 25-30°C). The zone of this front is traced in the entire troposphere up to the tropopause.

In the analysis we made use of data from 40 radiosonde stations for five basic observation times. Since outside the boundary layer the isentropic surfaces, that is, the surfaces of equal potential temperature, can with an adequate degree of accuracy be regarded as material surfaces, analysis of their topography has a number of advantages in the study of high-altitude frontal zones.

In addition to potential temperature θ, as a tracer it is convenient to use still another conservative characteristic of a material particle, Ertel potential vorticity, being an invariant of the system of so-called full (primitive) equations,

$$q = -(\zeta + l)\frac{\partial \theta}{\partial p}.$$

Here $\zeta = \partial v/\partial x - \partial u/\partial y$ is the relative vorticity, l is the Coriolis parameter. The isolines q = const on the isentropic surfaces represent (on the assumption of adiabaticity) material lines. Ertel vorticity has a significantly (by an order of magnitude) different value in the troposphere and stratosphere; taking this into account, it is possible to distinguish tropospheric air (with a characteristic value $q \approx 5 \cdot 10^{-6}$ K/(sec·gPa) from stratospheric air (for which $q \approx (30\text{-}60) \cdot 10^{-6}$K/(sec·gPa)).

The interpolation of the wind velocity components at the surface θ = const was accomplished using a cubic spline function of altitude [1], after the altitude of the surface θ = const was computed by linear interpolation between the isobaric surfaces.

Maps of the topography of the isentropic surfaces (9 maps for each observation time) with plotted p, u, v, q values give some idea concerning the structure of the thermal field and the location of the frontal zones. These maps also show the velocities of vertical movements ω in gPa/12 hours, computed with use of the properties of conservancy of temperature and potential vorticity.

An example of a map of the isentropic surface 300 K is shown as Fig. 1. In the northwestern part of the region the mentioned surface lies above the isobaric surface 300 gPa; here $q = (20\text{-}45) \cdot 10^{-6}$K/(sec·gPa). In a southeasterly direction the pressure at the isentropic surface increases sharply; it slopes steeply downward; in this case q decreases to typically tropospheric values. It is necessary to discriminate boundary values q by means of which it would be possible to distinguish stratospheric air and the air of the tropopause layer from tropospheric air.

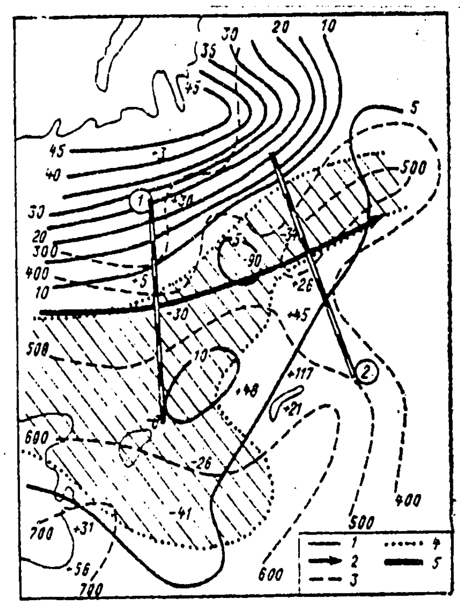

Fig. 1. Map of isentropic surface 300 K for 1500 hours on 30 December 1978. 1) isolines of potential vorticity each $5\cdot10^{-6}$K/(sec·gPa), 2) jet stream; 3) isobars each 100 gPa; 4) isolines $\omega = 0$; 5) lines of vertical sections; the ω values are given at individual points in gPa/12 hours. The region of ascending movements is shaded.

We recall that Ertel potential vorticity in general increases from south to north: on the mean meridional section, constructed using Petterssen's data, at latitude 60° values $q \geqslant 10\cdot10^{-6}$ K/(sec·gPa) are noted beginning at the level 500 gPa, whereas at latitude 35° the isoline $q = 10\cdot10^{-6}$K/(sec·gPa) runs at the altitude of the surface 300-350 gPa [6, 9]. Accordingly, the mentioned q value, which under conditions, for example in the United States, must be considered essentially substratospheric, and possibly also stratospheric [6, 12], in our case is instead more characteristic for the upper troposphere even in the warm air; however, in a cold air mass the layer of an inversion-type tropopause is characterized by considerably higher potential vorticity values. We therefore should consider values $q > (25\text{-}30)\cdot10^{-6}$K/(sec·gPa) to relate to the stratosphere, $q = (20\text{-}25)\cdot10^{-6}$K/(sec·gPa) are characteristic for the tropopause layer, and $q = (10\text{-}20)\cdot10^{-6}$K(sec·gPa) are characteristic for stable layers under the tropopause and in the upper troposphere.

Three-dimensional sections reveal the detailed picture of the structure of movements in the HAFZ input and delta. They were constructed in the following directions: in the input region -- along the normal to the HAFZ (section 1 in Fig. 1), through the stations Salekhard - Khanty-Mansiysk - Omsk - Pavlodar - Balkhash, and at the end of the period, in addition, along the normal to the surface front, through Salekhard - Aleksandrovskoye - Kolpashevo - Krasnoyarsk - Nizhneudinsk - Irkutsk, and also in the delta region (section 2 in Fig. 1) -- through Turukhansk - Podkamennuyu Tungusku - Yeniseysk - Krasnoyarsk - Abakan - Kyzyl.

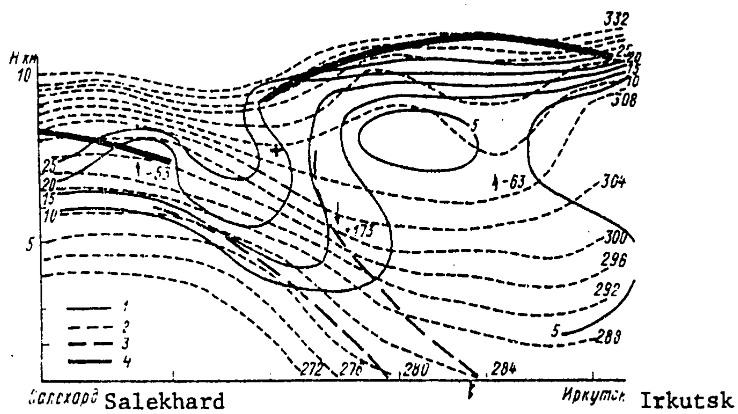

Fig. 2. Vertical section through input region of HAFZ (Salekhard - Aleksandrovskoye - Kolpashevo - Krasnoyarsk - Nizhneudinsk - Irkutsk) for 0300 hours on 1 January 1979. 1) isolines of potential vorticity in 10^{-6}K/(sec•gPa); 2) isolines for each 4 K; 3) frontal zone boundary; 4) tropopause; the cross denotes the jet stream axis, the arrows denote the direction of vertical movements, indicated in gPa/12 hours.

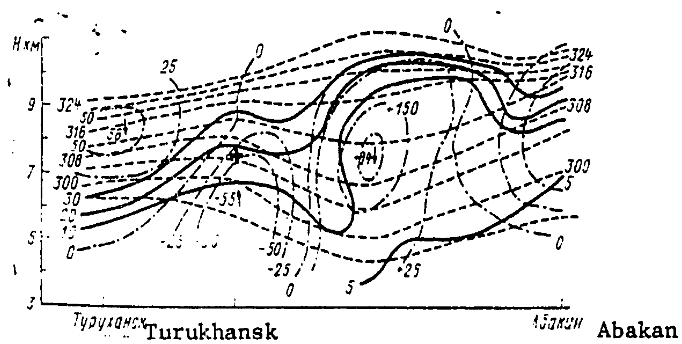

Fig. 3. Vertical section through region of HAFZ delta (section 2 in Fig. 1) for 1500 hours on 30 December 1978. The notations are the same as in Fig. 2.

The section through the input region (Fig. 2) clearly shows the tropospheric frontal zone, the descending movements in it and the ascending movements to the right in the warm air mass and also in a less extensive region in the cold air mass. The jet stream axis is situated in the descent zone. It can be seen how the isolines of high q values outline a descending "tongue" of air in the frontal zone. This pattern was a result of the evolution which can be observed in the sections at the preceding observation times (along section 1 in Fig. 1). For example, in the section for 1500 hours on 30 December the tongue of stratospheric air is still relatively little developed so that the isoline $q = 20 \cdot 10^{-6}$ bends only to the level 6.5 km. We note the well-developed ascending branch of circulation in the warm air at this time:

the vertical velocities attain -127 gPa/12 hours (at this time the maximum of descent is 50 gPa/12 hours). Both branches jointly create a frontolytic effect, straightening out the curved isentropic surfaces in the main part of the HAFZ to the right of the jet stream axis. At this time there is already noted a second, less intensive circulatory cell on the cold side of the front; it includes the same descending branch in the frontal zone and slight ascent (to -30 gPa/12 hours) in the direction of the cold air mass. The circulation here is obviously thermally inverse and frontogenetic (this cell can be seen clearly in Fig. 2, its left part, where ascending movements attain -53 gPa/12 hours). Later there is a narrowing of the tongue of descending air; at 0300 hours on 1 January in section 1 the isoline $q = 20 \cdot 10^{-6}$ already reaches an altitude of 4 km. The subsiding stratospheric air is localized well in the frontal zone so that the section at this observation time is similar to that shown in Fig. 2, differing, however, in having a considerably greater intensity of the ascending branch of circulation in the warm air (maximum value -238 gPa/12 hours). Weak ascent on the cold side persists.

The results obtained for the input of the HAFZ agree with those described earlier in [6, 10, 11]. The differences involve a greater intensity of the ascending branches of circulation in comparison with that found in the cited studies, especially in the warm air; on the other hand, the descent of stratospheric air was found to be more intense in [6, 10, 11]. The existence of stable deep regions of ascending movements evidently plays the role of a forcing factor for processes of cloud and precipitation formation before and over the surface cold front.

In our case on the warm side of the front during the entire time we observed the volume of the warmest air (in the neighborhood of Pavlodar in the section in Fig. 2), to the south of which in the middle and upper troposphere the temperatures drop rapidly. It is possible that the presence of such an inversion of the horizontal temperature gradient also caused the development of such intensive ascent. The warm air in this part of the section appeared as a result of occlusion of a cyclone moving over these regions earlier.

Now we will proceed to a discussion of the results obtained for the HAFZ delta. Insofar as we know, in the scientific literature there are no descriptions of vertical circulations in this part of the HAFZ, computed on the basis of real data; on the basis of theoretical considerations [5, 7, 8] it is possible to expect a thermally inverse frontogenetic circulation which would develop primarily as a compensatory circulation relative to the frontolytic effect of the horizontal movements. Such a direction of circulation in the delta is actually observed (see Fig. 1): the warm air descends to the right of the jet stream axis, whereas on the axis of the jet stream and to the left of it there is ascent. The velocities of vertical movements here, in general, are less than in the input. A more detailed picture can be seen in the vertical sections, in particular in the section for 1500 hours on 30 December, shown in Fig. 3. All the branches of vertical circulations here have a direction opposite of those in Fig. 2. Instead of the tongue of air penetrating to tropospheric altitudes with large q, observed in all sections in the input region, here it is possible to see only a rather considerable bending of the q isolines. The sections at successive observation times passing through the delta region show that the reverse movement of the region with large q occurs very rapidly. The ascent of relatively cold air from the lower-lying layers, maximum at an altitude of about 6 km at 1500 hours on 30 December and 8 km at 1500 hours on 31 December has the following result: the horizontal contrasts of temperatures in the HAFZ virtually do not change during the course of a day. The descending branch of the circulation on the warm side of the HAFZ warrants attention: here subsidence is observed at all isentropic surfaces below 324 K, that is, from the tropopause and at least to an altitude of 4.7 km (the altitude of the surface 296 K at Yeniseysk); thus, the front in the middle and upper troposphere assumes the character of a katafront, which is characteristic for the late stages in the development of frontal discontinuities. This leads to an increase in the horizontal temperature gradients not only in the frontal zone, but also in the right part of the section -- over Krasnoyarsk and Abakan. We will also note the following circumstance: the maximum wind velocities are observed in the region occupied by ascending movements and the line of change in the sign of vertical movements ($\omega = 0$) divides the zone of maximum slope of the isentropic surfaces approximately in half.

Thus, the employed method for isentropic analysis made it possible to examine the structure of vertical circulations in the input and delta of the HAFZ with the same degree of detail as is allowed by the spatial and temporal resolution of the employed data. We will enumerate the principal conclusions from this study.

1. The phenomenon of subsidence of air from the tropopause layer and from the stratosphere on the cold side of the region of input into the HAFZ in the case of intensive horizontal frontogenesis. The penetration of air with high values of Ertel potential vorticity to tropospheric levels was observed as a stable process over a considerable territory. On the side of the warm mass there were extremely significant ascending movements vertically occupying a great part of the troposphere. The principal circulation cell, including the mentioned ascending and descending branches, is thermally direct and in the central part of the frontal zone -- on the jet stream axis and to the right of it -- creates a frontolytic effect.

2. On the cold periphery of the HAFZ input there is a region of weaker ascending movements taking in a thinner layer; these movements, together with the principal descending branch in the frontal zone, form a local thermally inverse frontogenetic circulation increasing the temperature contrasts on the periphery of the HAFZ.

3. The vertical circulations in the region of the HAFZ delta in the studied case have a direction which is the reverse of the direction in the input. Specifically in the region of maximum horizontal temperature gradients there are ascending movements taking in the jet stream axis. As a result of these ascending movements air with high potential vorticity values, subsiding earlier from the tropopause layer and from the lower stratosphere, is expelled from tropospheric levels, in this case in an upward direction. Together with intensive descending movements in the thick air layer on the warm side of the frontal zone these ascending movements create a cell of frontogenetic, thermally reverse circulation, imparting the character of a katafront to the frontal discontinuity. At the same time, on the cold side of the HAFZ there is a weak thermally direct circulation.

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NUMERICAL MODEL OF POLLUTANT TRANSPORT IN THE ATMOSPHERIC BOUNDARY LAYER

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[Text]

Abstract: The article examines a joint model of the dynamics of atmospheric processes and the transport of pollutants in the atmospheric boundary layer. The authors describe a method for parameterization of interaction between the pollutants and the earth's surface and a numerical scheme for solution of the transfer equation based on the method of splitting with respect to physical processes. Examples of the numerical experiments are given.

In connection with the intensive development of man's economic activity there is much interest in the problem of evaluating the influence of the results of this activity on the environment. With an increase in the scales of economic activity the quantity of energy produced is increasing, as is the quantity of discharge of heat and pollutants into the atmosphere. The released pollutants experience different transformations and are propagated for great distances, causing environmental contamination. The propagation of pollutants in the atmosphere is essentially determined by the wind field. In this connection, when formulating mathematical models the need arises for a joint solution of problems in atmospheric dynamics and the transformation of pollutants. A number of investigations have been carried out in this direction during recent years and a detailed review of these has been given in [1-3, 10, 14].

In this article we examine a method for parameterization of the interaction of pollutants with the underlying surface and a numerical method for solving transfer equations. In describing atmospheric dynamics we use the numerical model of the boundary layer given in [12, 13]. The interaction between the atmosphere and the underlying surface is taken into account using a surface layer model.

We will begin exposition of formulation of the problem with a description of a model of atmospheric dynamics. We will examine a spatial nonstationary numerical model of the boundary layer over orographically and thermally nonuniform surfaces [12, 13]. As in [13], we will formally divide the atmosphere into two layers: the surface layer and the layer situated above it. The surface layer will be parameterized in such a way that its influence is taken into account by means of boundary conditions.

The initial system of equations will be written in the following form:

$$\frac{\partial u'}{\partial t} + \operatorname{div} \vec{u} u = -\frac{\partial \pi'}{\partial x} + l v' + \lambda \delta_x \vartheta' + \tilde{\Delta} u, \tag{1}$$

$$\frac{\partial v'}{\partial t} + \operatorname{div} \vec{u} v = -\frac{\partial \pi'}{\partial y} - l u' + \lambda \delta_y \vartheta' + \tilde{\Delta} v, \tag{2}$$

$$\frac{\partial \pi'}{\partial z} = \lambda \vartheta', \tag{3}$$

$$\frac{\partial \vartheta'}{\partial t} + \operatorname{div} \vec{u} \vartheta' + S w' = -u'(S\delta_x + \Theta_x) - v'(S\delta_y + \Theta_y) + \tilde{\Delta}\vartheta', \tag{4}$$

$$\frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y} + \frac{\partial w'}{\partial z} = 0, \tag{5}$$

$$\frac{\partial q'}{\partial t} + \operatorname{div} \vec{u} q' = -u' Q_x - v' Q_y + \tilde{\Delta} q', \tag{6}$$

$$\tilde{\Delta}\varphi = \frac{\partial}{\partial x}\mu_{x\varphi}\frac{\partial \varphi}{\partial x} + \frac{\partial}{\partial y}\mu_{x\varphi}\frac{\partial \varphi}{\partial y} + \frac{\partial}{\partial z}\nu_\varphi\frac{\partial \varphi}{\partial z},$$

$$\operatorname{div} \vec{u}\varphi = \frac{\partial \varphi u}{\partial x} + \frac{\partial \varphi v}{\partial y} + \frac{\partial \varphi w}{\partial z} \quad (\varphi = u, v, \vartheta', q'). \tag{7}$$

Here t is time, x,y are curvilinear coordinates read along the earth's surface, u,v, w are the components of the velocity vector in the directions x,y,z respectively,

$$w = \tilde{w} - u'\delta_x - v'\delta_y,$$

where $\tilde{w}$ is vertical velocity in a Cartesian coordinate system; $\delta(x,y)$ is a function describing relief of the underlying surface;

$$\delta_x = \frac{\partial \delta}{\partial x}, \quad \delta_y = \frac{\partial \delta}{\partial y}$$

are the tangents of the slope of relief to the horizon; π is a value proportional to air pressure; ϑ', q' are the deviations of potential temperature and specific humidity from the background values;

$$\Theta_x = \frac{\partial \Theta}{\partial x}, \quad \Theta_y = \frac{\partial \Theta}{\partial y}$$

are the horizontal gradients of background potential temperature;

$$Q_x = \frac{\partial Q}{\partial x}, \quad Q_y = \frac{\partial Q}{\partial y}$$

are the horizontal gradients of background specific humidity; S is the stratification parameter; λ is the buoyancy parameter; l is the Coriolis parameter;

$$\mu_{x\varphi}, \ \mu_{y\varphi}, \ \nu_\varphi \ (\varphi = u, v, \vartheta', q')$$

are the coefficients of turbulent exchange in the directions x, y and z respectively.

The system of equations (1)-(7) was derived under the condition that the meteorological elements have the representations

$$u=U+u',\ v=V+v',\ w=W+w',\ \vartheta=\Theta+\vartheta',\ q=Q+q',\ \pi=\Pi+\pi', \tag{8}$$

where the capital letters denote the background values, assumed to be known functions of space coordinates and time, whereas the letters with a prime denote the deviations of the meteorological elements from the background values.

The interaction between an air mass and the earth's surface is taken into account using a model of the surface layer

$$\varkappa z\frac{\partial|\vec{V}|}{\partial z}=u_*\varphi_u(\xi),\ z\frac{\partial\psi}{\partial z}=\psi_*\varphi_\vartheta(\xi)\ (\psi=\vartheta,q,\ \psi_*=\vartheta_*,q_*), \tag{9}$$

$$\varkappa|\vec{V}|=u_*f_u(\xi,\xi_0),\quad \psi-\psi_0=\psi_*f_\vartheta(\xi,\xi_0),\quad \xi=\frac{z}{L},\quad \xi_0=\frac{z_0}{L}, \tag{10}$$

$$\nu_i=\frac{u_*\varkappa z}{\varphi_i(\xi)},\quad (\nu_i)_h=\frac{u_*\varkappa h}{\varphi_i(\xi_h)},\quad (i=u,\vartheta),\quad \xi_h=\frac{h}{L},\quad L=\frac{u_*^2}{\lambda\varkappa^2\vartheta_*}, \tag{11}$$

where $|\vec{V}|=(u^2+v^2)^{1/2}$ is the absolute value of the velocity vector; u_* is friction velocity; ϑ_*, q_* are the scales for potential temperature and specific humidity; $\varkappa$ is the Karman constant; z_0 is the roughness parameter; L is the length scale; ξ is dimensionless altitude; φ_i, f_i $(i = u, \vartheta)$ are continuous universal functions (a specific representation of these functions from [7] is used in the computations) h is the height of the surface layer. The subscript h denotes the values of the functions with z = h and the subscript 0 denotes the values at the roughness level. The roughness parameter is assumed to be stipulated over the land, whereas over the water surface it is determined in the course of the solution using the Chernok for- $(z_0 = 0.035\ u_*^2 g)$.

The temperature at the land surface ϑ_0 is determined from the heat balance equation

$$G_0-\rho c_p\left(\nu_0\frac{\partial\vartheta}{\partial z}\right)_0-\rho L_w\left(\nu_q\frac{\partial q}{\partial z}\right)_0=I_0(1-A)-F, \tag{12}$$

where

$$G_0=c_s\rho_s\left(k_s\frac{\partial T}{\partial z}\right)_0$$

is heat transfer through the soil surface, ρ_s, c_s, k_s, T are density, specific heat capacity, thermal conductivity coefficient and absolute soil temperature, ρ is air density, I_0 is short-wave solar radiation, A is albedo of the underlying surface, F is effective radiation. Equation (12) is solved jointly with the soil heat conductivity equation. Over the water the functions ϑ_0 and q_0 are assumed to be stipulated in the form

$$\vartheta_0=f_0(x,y,t),\quad q_0=0{,}622F_0(\vartheta_0)/p, \tag{13}$$

and over the land q_0 is determined using the formula

$$q_0 = 0.622\eta_0 F(\vartheta_0)/p, \tag{14}$$

where $f_0(x,y,t)$ is a known function, η_0 is the relative moisture content of the soil surface, E is the saturation elasticity of water vapor at the temperature ϑ_0, p is atmospheric pressure.

The system of equations (1)-(12) will be solved in the region

$$D = \{|x| \leq X, \quad |y| \leq Y, \quad h \leq z \leq H\}$$

with the following boundary-value and initial conditions:

$$u' = 0, \quad v' = 0, \quad \vartheta' = 0, \quad q' = 0 \qquad \text{with } t = 0 \tag{15}$$

$$u = U_\Phi, \quad v = V_\Phi, \quad \vartheta = \Theta_\Phi, \quad q = Q_\Phi \quad \text{with} \quad x = \pm X, \; y = \pm Y, \tag{16}$$

$$u' = 0, \quad v' = 0, \quad \vartheta' = 0, \quad q' = 0, \quad w = 0 \qquad \text{with } z = H, \tag{17}$$

$$\frac{\partial u}{\partial z} = a_u u, \quad \frac{\partial v}{\partial z} = a_u v, \quad \frac{\partial \vartheta'}{\partial z} = a_\vartheta (\vartheta - \vartheta_0),$$

$$\frac{\partial q'}{\partial z} = a_\vartheta (q - q_0), \quad w = 0 \qquad \text{with } z = h, \tag{18}$$

where a_j (j = u, v, ϑ) are functions characterizing interaction between the atmosphere and the underlying surface. With stipulated universal functions they are obtained from the surface layer equations [7].

The numerical method used for solution of the problem (1)-(18) was described in detail in [12, 13]. Its basis is the method of splitting with respect to physical processes [8].

In the modeling of the transport of pollutants in the atmospheric boundary layer the initial equations are the semiempirical equations of turbulent diffusion. Atmospheric pollutants constitute a multicomponent medium and different components interact with the atmosphere and with one another. As a result of chemical reactions there can be appearance of new substances not present in the substances initially ejected by the sources. We will assume that the pollutant consists of $n (n \geq 1)$ different components and we will denote by $\vec{c} = \{c_t\}$, $\vec{C} = \{C_i\}$ $(i = \overline{1, n})$ the volumetric concentrations of the impurities and the background values of the concentrations of pollutants, and by $\vec{F}_s = \{F_{is}(\vec{x}, t)\}$ $(t = \overline{1,n}, \; \vec{x} = (x,y,z))$ -- the sources of pollutants. Then the model of transport of pollutants can be described by the following system of equations:

$$\frac{\partial \vec{s}}{\partial t} + u \frac{\partial \vec{s}}{\partial x} + v \frac{\partial \vec{s}}{\partial y} + (w - \tilde{w}_s) \frac{\partial \vec{s}}{\partial z} + B\vec{s} = \tilde{\Delta} \vec{s} + \vec{F}_s(\vec{x}, t), \tag{19}$$

where

$$\tilde{\Delta} \vec{s} = \frac{\partial}{\partial x} \mu_{xs} \frac{\partial \vec{s}}{\partial x} + \frac{\partial}{\partial y} \mu_{ys} \frac{\partial \vec{s}}{\partial y} + \frac{\partial}{\partial z} \nu_s \frac{\partial \vec{s}}{\partial z},$$

$$\vec{s} = \vec{c} - \vec{C}, \quad \vec{s} = \{s_i\} \; (i = \overline{1, n})$$

are the deviations of the concentrations of pollutant from their background values, μ_{xs}, μ_{ys}, μ_{zs} are the coefficients of turbulent diffusion in the directions x, y, z respectively, $\tilde{\omega}_s = \mathrm{diag}\{\tilde{\omega}_{is}\}$ $(i = \overline{1,n})$ is a diagonal matrix whose elements are equal to the velocities of gravitational settling of substances (it is assumed that each substance has its own rate of precipitation),

$$B_{ij}(\vec{x},t) = 0 \quad (i,j = \overline{1,n},\ i \neq j),$$

is a matrix operator describing the interaction of different substances with one another and their local changes. In a general case the matrix elements B(x,t) can be dependent on the values of the fields of meteorological elements and on the concentrations of pollutants. If $B_{ij}(\vec{x},t) = 0$ $(i,j = \overline{1,n},\ i \neq j)$, the pollutants do not interact with one another, but if $B(\vec{x},t) = 0$, the pollutants will be called passive. We also note that the sources can not only eject pollutants, but also absorb them.

In evaluating the effect of pollutants on a specific physiographic region it is of practical interest to evaluate the contamination of individual sectors of the ground surface differing with respect to physical properties (water bodies, forests, soil, etc.). Accordingly, one of the parameters which must be determined is the quantity of pollutants entering from the atmosphere onto a specific sector of the underlying surface. It is known that the distribution of pollutants, especially in the lower layers of the atmosphere, is essentially dependent on stratification, wind velocity and other characteristics of the surface layer [1, 2, 14]. Accordingly, the interaction of pollutants with the underlying surface will be taken into account in parameterized form.

We will write the equation for the balance of pollutants at the roughness level [12]. Assuming that each of the components of the pollutants interacts with the ground surface independently of the others, we obtain

$$\nu_s \frac{\partial c_i}{\partial z} + \tilde{\omega}_{si} c_i = \beta_{si} c_i - f_{si}(x,y,t) \quad (i = \overline{1,n}), \tag{20}$$

where β_{si} $(i = \overline{1,n})$ are values having the dimensionality of velocity and characterizing the interaction of pollutants with the underlying surface. It is easy to see that the condition $\beta_{si} = 0$ corresponds to reflection of pollutants from the ground surface, $\beta_{H_{si}} = \infty$ is the total "absorption" of the pollutants, $0 < \beta_{si} < \infty$ is an intermediate situation of partial reflection and absorption. If the pollutants interact with one another, in the right-hand side of (20) in place of $\beta_{si}c_i$ there will be expressions of the type

$$\sum_{k=1}^{n} \beta_{sik} c_k,$$

where β_{sik} $(i,k = \overline{1,n})$ are coefficients determining the regime of interaction of different substances. The functions $f_{si}(x,y,t)$ $(i = \overline{1,n})$ in (20) describe the sources of impurities at the roughness level. In most cases the functions describing the local transformations of pollutants and the distributions of sources have a subgrid scale and therefore it is desirable that they be smoothed first taking into account the parameters of the grid region and the properties of the underlying surface. This smoothing procedure is natural for a discrete model, which in essence makes it possible to compute the characteristics of fields averaged by grid region units.

We will assume that in the surface layer there is an analogy between the distributions of pollutants and potential temperature [11]. In such a case for the parameterization of the transport of pollutants in the surface layer it is possible to derive formulas similar to (9)-(11). Taking this assumption into account and as a convenience in exposition omitting the subscript denoting the form of substance, from (10) for the scale of the pollutant c_* we obtain the following expression:

$$c_* = \frac{c_h - c_0}{f_\vartheta(\zeta_h, \zeta_0)} \quad \left(\zeta_h = \frac{h}{L}\right). \qquad (21)$$

Substituting (21) into (10) and differentiating the derived expression for z, and then assuming z = h, we obtain

$$h\frac{\partial c}{\partial z} = \frac{\varphi_\vartheta(\zeta_h)}{f_\vartheta(\zeta_h, \zeta_0)}(c - c_0). \qquad (22)$$

Taking (11) into account, equation (22) can be written in the form

$$\nu_s \frac{\partial c}{\partial z}\Big|_{z=h} = a_\vartheta (c_h - c_0). \qquad (23)$$

where

$$a_\vartheta = \frac{|\vec{V}|\varkappa^2}{f_u(\zeta_h, \zeta_0) f_\vartheta(\zeta_h, \zeta_0)}.$$

Equation (23) can be used as the lower boundary-value condition vertically with z = h for equation (19). We note that in formula (23) for the time being there are no terms containing the functions β_s and $\tilde{\omega}_s$ from (20).

Now we will write an equation of type (23) in a more general form which contains the functions β_s and $\tilde{\omega}_s$ and at the same time the relative position of the height of the source of pollutant d and the height of the surface layer h is taken into account. We will examine two different cases.

a) The source is situated above the surface layer, that is, $d \geqslant h$. Assuming a constancy of the fluxes of pollutants in the surface layer

$$\left(\nu_s \frac{\partial c}{\partial z}\Big|_{z=z_0} = \nu_s \frac{\partial c}{\partial z}\Big|_{z=h}\right)$$

and using formulas (20) and (23), we obtain

$$\frac{\partial c}{\partial z}\Big|_{z=h} = \frac{a_\vartheta(\tilde{\beta} c_h - f_s)}{(\tilde{\beta} + a_\vartheta \nu_{sh})} \quad (\tilde{\beta} = \beta_s - \tilde{\omega}). \qquad (24)$$

b) The source is situated below the height of the surface layer, that is, $d \leqslant h$.

Writing formula (23) for the height z = d, we obtain

$$\frac{\partial c}{\partial z}\Big|_{z=d} = a_\vartheta (c_d - c_0).$$

Taking into account that

$$\nu_s \frac{\partial c}{\partial z}\Big|_{z=z_0} = \nu_s \frac{\partial c}{\partial z}\Big|_{z=d} = \nu_s \frac{\partial c}{\partial z}\Big|_{z=h}$$

and using equations (20) and (23), we arrive at the expression

$$\left.\frac{\partial c}{\partial z}\right|_{z=h} = (\tilde{\beta} c_h - f_s)\left(\tilde{\beta}\frac{\nu_{sh}}{\nu_{sd}} + a_\theta \nu_{sh}\right)^{-1} a_\theta , \qquad (25)$$

where ν_{sh} and ν_{sd} are the coefficients of turbulent diffusion for a pollutant at the altitudes z = h and z = d respectively. The values of the functions ν_{sd} and ν_{sh} can be obtained using the equation

$$\nu(z) = \frac{\varkappa u_* z}{\varphi_\theta(\xi)}, \qquad (26)$$

where $\varphi_\theta(\xi)$ is a continuous function dependent on stratification. In order to make computations use is made of the function $\varphi(\xi)$ in the following form [7]:

$$\alpha(0)\varphi_\theta(\xi) = \begin{cases} \gamma_{1\theta}(\xi')\left(\frac{\xi'}{\xi}\right)^{1/3} & \text{when } \xi' H < \xi < \xi' \\ \gamma_{1\theta}(\xi) & \text{when } \xi' \leq \xi \leq 0 \\ 1 + \beta_\theta \xi & \text{when } 0 \leq \xi \leq \xi'' \\ \left(\frac{1}{\xi''} + \beta_\theta\right)\xi & \text{when } \xi'' \leq \xi \leq \xi'' H, \end{cases} \qquad (27)$$

where $\gamma_{1\theta}(\xi) = (1 - \gamma_\theta \xi)^{-1/2}$, $\alpha(0) = 1{,}35$, $\xi' \approx -8{,}21$, $\beta_\theta = 6{,}34$,

$$\xi'' = 1, \quad \xi = \frac{z}{L}.$$

Formulas (25) and (26) were derived under conditions of stationarity and horizontal uniformity. Since the diurnal or annual variation is being considered, it can be postulated that the quasistationarity condition is satisfied. If d > h and the dimensions of the cloud of diffusing pollutant are much greater than the intervals of the grid region in horizontal variables, it makes sense to assume a horizontal uniformity within the limits of one elementary unit of the grid region. If d < h, it is also possible to consider the plane sources to be locally uniform, for example, the residential sections of a city, dust-covered sectors of the earth's surface, etc.

The remaining boundary-value conditions for concentrations of pollutants are stipulated in the following form:

$$\nu\frac{\partial s}{\partial z} = 0 \text{ with } z = H, \qquad (28)$$

$$c = C_{back} \text{ with } x = \pm X,\ y = \pm Y, \qquad (29)$$

$$c = C_{back} \text{ with } t = 0, \qquad (30)$$

where C_{back} is the background value of the pollutant concentration. In the absence of information on the background values at the lateral boundaries we will use the condition

$$\mu s \frac{\partial s}{\partial n} = 0,$$

where n is the external normal to the boundary of the region.

A serious problem at the present time is the method for stipulating the diffusion coefficients in horizontal directions. Some methods for describing transverse diffusion are given in [1, 4, 6, 16]. For example, in [1, 6] for computing the transverse coefficient for diffusion of a pollutant from a point source use is made of the formula

$$\mu_{ys} = u\,(k_0 + r\,\sigma_0^2), \qquad (31)$$

where σ_0^2 is the dispersion of disturbances of wind direction, averaged over a quite great time interval, r is the distance from the source, k_0 is a parameter determined from the characteristics of the surface layer, u is wind velocity. In (31) it is postulated that the direction of the x-axis coincides with the direction of the velocity vector. We are interested in the distribution of the concentrations of pollutant averaged by grid region units. For the modeling of smaller-scale processes use is made of a special method, such as in [17]. Since the wind direction can vary at each point in the grid and the sources can be distributed over the entire region, with the use of formula (31) we will limit ourselves, adhering to [6], to a stipulation of some mean σ_0 value. For this same reason we will also assume that $\mu_{y_s} = \mu_{x_s}$. When the region containing the pollutant assumes sufficiently great dimensions vertically it is necessary to take into account the influence of the vertical shear of the velocity vector on turbulent diffusion. The author of [16], for an Ekman boundary layer with a constant turbulence coefficient, obtained an expression taking into account the additional increase in the coefficient of transverse diffusion,

$$\mu_{ys} = 0{,}214\,\frac{u_g^2}{l}, \qquad (32)$$

where u_g is the velocity of the geostrophic wind in the x direction.

In the numerical modeling of the propagation of pollutants additional requirements are imposed on the finite-difference approximations and on the methods for the solution of equation (19). Since in a physical sense the concentration is a nonnegative parameter, it is desirable to employ so-called "monotonic" schemes which make it possible to obtain nonnegative solutions. In order to develop a computation algorithm for the solution of equation (19) we will apply the method of splitting with respect to physical processes and in each small time interval $|t_j, t_{j+1}|$ $(j = 0, 1, \ldots)$ with the length Δt we will examine a scheme consisting of three stages:

1. Transport of pollutants along paths

$$\frac{\partial \vec{s}}{\partial t} + \frac{\partial u\vec{s}}{\partial x} + \frac{\partial v\vec{s}}{\partial y} + \frac{\partial w\vec{s}}{\partial z} = 0. \qquad (33)$$

2. Turbulent diffusion of pollutants

$$\frac{\partial \vec{s}}{\partial t} = \frac{\partial}{\partial x}\mu_{xs}\frac{\partial \vec{s}}{\partial x} + \frac{\partial}{\partial y}\mu_{ys}\frac{\partial \vec{s}}{\partial y} + \frac{\partial}{\partial z}\nu_s\frac{\partial \vec{s}}{\partial z}. \qquad (34)$$

3. Local transformations of pollutants and influence of sources

$$\frac{\partial \vec{s}}{\partial t} + B\vec{s} = \vec{F}_s. \qquad (35)$$

Such a representation of the model of transport of pollutants considerably simplifies its application when using an electronic computer. In the first two stages the equations are solved for each substance independently of the others and in the third there is a mutual adaptation and interaction of all the substances. Accordingly (35) can be regarded at each point in the integration range as a system of ordinary differential equations whose coefficients are parametrically dependent on space coordinates. The examination of all the interaction and transformation of pollutants of all processes in an individual stage makes it possible to carry out experiments with different variants of description of the operator B(x,t) and the vector of the function $\vec{F}_s(\vec{x},t)$ without changing the structure of the model as a whole.

The solution of each preceding stage at the time $t = t_{j+1}$ serves as an initial condition for the next stage at the moment in time $t = t_j$. The boundary-value conditions for equations (33) and (34) are obtained from the conditions (23)-(30).

The first stage is basic in the transport process and the most complex in its realization. There are several methods for solving equation (33). A review and comparative analysis of the most commonly used of these is given in [5, 15, 17-19]. Below we will describe an algorithm based on a modification of the scheme in [15]. This scheme has a law of conservation of the pollutant and has a second order of approximation with respect to space and time. In this scheme monotony is attained by the introduction, using a posteriori information, of a "monotonization" nonlinear operator of the divergent type which does not impair the order of approximation. The schemes for solution of a transfer equation with nonlinear monotonization were examined earlier in [19].

Using the method of splitting in space variables, we will write a finite-difference approximation of equation (33) in the direction of the x coordinate. The approximations are obtained in the y and z directions in a similar way.

As a simplification in the exposition we will examine the principal element of the scheme in the example of the one-dimensional equation

$$\frac{\partial s}{\partial t} + \frac{\partial us}{\partial x} = 0, \qquad (36)$$

derived from (33) by means of splitting in space variables. Adhering to [18], we will write for it a finite-difference approximation having monotonic properties. Selecting the orientation of the grid overlay in dependence on the sign of the u function, we obtain a scheme consisting of two expressions:

$$s_i^{j+1} = s_i^j - \sigma\Delta_{i-1/2}(su) - \frac{\alpha_1}{4}[\sigma(1-\sigma_2 u_{i+1/2})\Delta_{i+1/2}(us) -$$

$$-\sigma_1(1-\sigma_4 u_{i-3/2})\Delta_{i-3/2}(us) + (1-\sigma_2 u_{i-1/2})(\sigma_1-\sigma)\Delta_{i-1/2}(us)] +$$

$$+\frac{\alpha_2}{4}\Big\{\sigma R(\eta_{ij})[(1-\sigma_2 u_{i+1/2})\Delta_{i+1/2}(us) - (1-\sigma_3 u_{i-1/2})\Delta_{i-1/2}(us)] -$$

$$-\sigma_4 R(\eta_{ij-1})[(1-\sigma_2 u_{i-1/2})\Delta_{i-1/2}(us) -$$

$$-(1-\sigma_3 u_{i-3/2})\Delta_{i-3/2}(us)]\Big\}, \quad \text{если} \quad u \geq 0;$$

$$s_i^{j+1} = s_i^j - \sigma\Delta_{i+1/2}(su) - \frac{\alpha_1}{4}[\sigma(1-\sigma_5 u_{i+3/2})\Delta_{i+3/2}(us) -$$

$$-\sigma(1-\sigma_3 u_{i-1/2})\Delta_{i-1/2}(u_5) + (1-\sigma u_{i+1/2})(\sigma-\sigma_6)\Delta_{i+1/2}(us)] +$$

$$+\frac{\alpha_2}{4}\{\sigma_6 R(\eta_{ij})[(1-\sigma_5 u_{i+3/2})\Delta_{i+3/2}(us) - (1-\sigma_2 u_{i+1/2})\Delta_{i+1/2}(us)] -$$

$$-\sigma_4 R(\eta_{ij-1})[(1-\sigma_5 u_{i+1/2})\Delta_{i+1/2}(us) -$$

$$-(1-\sigma_2 u_{i-1/2})\Delta_{i-1/2}(us)]\}, \quad \text{если} \quad u < 0, \qquad (37)$$

where

$$\sigma = \frac{\Delta t}{\delta_i}, \quad \sigma_1 = \frac{\Delta t}{\delta_{i-1}}, \quad \sigma_2 = \frac{\Delta t}{\Delta x_{i+1}}, \quad \sigma_3 = \frac{\Delta t}{\Delta x_{i-1}}, \quad \sigma_4 = \frac{\Delta t}{\Delta x_{i-2}},$$

$$\sigma_5 = \frac{\Delta t}{\Delta x_{i+2}}, \quad \sigma_6 = \frac{\Delta t}{\delta_{i+1}}, \quad \Delta_{i-1/2}'(us) = (us)_i - (us)_{i-1},$$

$$\Delta_{i+1/2}(us) = (us)_{i+1} - (us)_i,$$

α_1, α_2 are nonnegative coefficients assuming the value 0 or 1.

Depending on the values of the coefficients α_1 and α_2 we obtain the following schemes: $\alpha_1 = 0$, $\alpha_2 = 0$ are schemes of directed differences of the first order of accuracy, $\alpha_1 = 1, \alpha_2 = 0$ is a nonmonotonic scheme of the second order of accuracy [19], $\alpha_1 = 1, \alpha_2 = 1$ is a monotonic scheme of the second order of accuracy.

Scheme (37) is stable if there is satisfaction of the condition

$$\sigma = \frac{|u|\Delta t}{\Delta x_i} \leq 1,$$

and the monotonic behavior conditions with $\alpha_1 = \alpha_2 = 1$ are determined by the inequality

$$0 \leq -\frac{s_i^{j+1} - s_i^j}{s_i^j - s_{i-1}^j} \leq 1 \qquad (38)$$

and by the choice of the function $R(\eta)$ in the form

$$R(\eta) = \frac{|\eta| - 1}{|\eta| + 1} \qquad (39)$$

for any η value stipulated at the points of intersection of the grid region by the expression $\eta_i = \Delta_{i+1/2}s/\Delta_{i-1/2}s$. With a specific numerical realization the grid function $R(\eta_i)$ can be determined by the expression

$$R(\eta_{ij}) = (|s_{i+1} - s_i| - |s_i - s_{i-1}|)/(|s_{i+1} - s_i| + |s_i - s_{i-1}|). \qquad (40)$$

If the denominator in (40) is equal to zero, then $R(\eta_i)$ also can be equated to zero.

We note that if the grid is nonuniform in space variables, the scheme (37) is of the first order of approximation. The turbulent exchange equation (39) is solved in the second stage by the method of splitting in space variables with the use of implicit approximations. In the third stage the system (35) is approximated in time at each point of the grid region with not less than a second order of accuracy. The structure of the approximation is determined by the method of stipulating the operator $B(\vec{x},t)$. Since the number of substances in solution of practical problems is not great, the accomplishment of the third stage is by means of modifications of standard algorithms for solution of systems of ordinary differential equations. The essence of the modifications is an allowance for the difference in the characteristic time scales of interaction of different substances.

Using the model described above, we carried out a series of numerical experiments for the purpose of studying the processes of propagation of pollutants in the atmospheric boundary layer. In all the computations the components of the velocity vector and some characteristics of the surface layer were obtained using a model of atmospheric dynamics with the following values of the input parameters:

$$H = 1750 \text{ m}, \; X = Y = 68 \text{ km}, \; h = 50 \text{ m}, \; \Delta x = \Delta y = 4 \text{ km}$$
$$\Delta z = 100 \text{ m, if } z \leqslant 200 \text{ m and } \Delta z = 150 \text{ m with } z \geqslant 200 \text{ m},$$
$$\lambda = 0.035 \text{ m}/(\text{sec}^2\cdot{}^\circ\text{C}), \; \ell = 10^{-4} \text{ sec}^{-1}, \; \mu_x = \mu_y = 2000 \text{ m}^2/\text{sec},$$
$$S = 3\cdot10^{-3}\,{}^\circ\text{C/m}, \; z_0 = 0.01, \; c_p = 0.24 \text{ cal/sec}, \; a_3 = 0.56.$$
$$b_3 = 0.08, \; U_{back} = -5 \text{ m/sec},$$
$$V_{back} = 0.$$

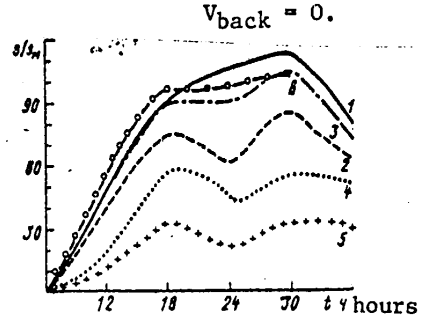

Fig. 1. Normalized value of maximum concentration of pollutant at level z = 50 m with and without allowance for parameterization. 1, 2, 3, 6 were obtained with allowance for the boundary conditions (24) with values $\beta_s = 10^{-6}$ m/sec, 0.5 m/sec, 10^{-3} m/sec, 10^{-3} m/sec respectively and the curves 4, 5 without allowance for parameterization (with $\beta_s = 0$ and $\beta_s = 0.5$). The curve 6 corresponds to a solution with the coefficient $\mu_y s$, computed using formula (31).

The moment in time t = 0 corresponds to 0600 LT. The coefficients of vertical turbulent exchange in the interval $h \leqslant z \leqslant H$ were stipulated in the form $\nu_i(z) = \nu_i(h)$ ($i = u, v, \vartheta, s$), and the coefficients of horizontal turbulence were assumed to be equal for all stubstances. The relative humidity and temperature over the water surface were stipulated using the Magnus formula.

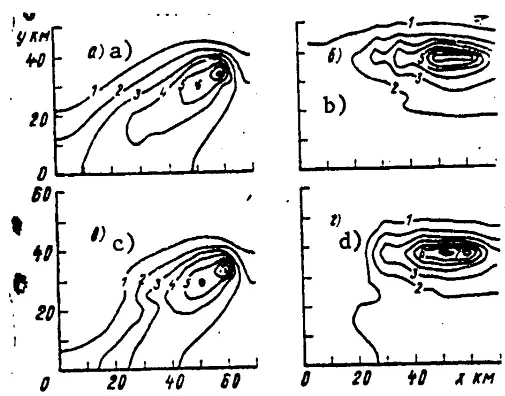

Fig. 2. Isolines of normalized concentration of pollutant at level z = 50 m in plane (x, y). a,b) solutions for time t = 12 hours with values $\beta_s = 10^{-5}$ m/sec and $\beta_s = 10^{-3}$ m/sec; c, d) same for t = 18 hours. The isolines at the center are the maximum values of the concentration 49.3, 93.1, 47.6 and 76.1 respectively.

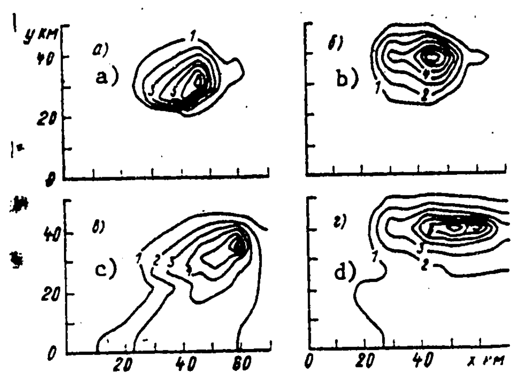

Fig. 3. Isolines of normalized concentration of pollutant with value β= 0.5 m/sec at level $z = z_0$ (a,b) and at altitude z = 50 m (c, d). a, c correspond to the moment in time t = 12 hours, b, d) time t = 18 hours. The isolines at the center correspond to maximum values of the concentration 1.4, 2.7, 42.4 and 76.8 respectively.

We will cite examples of propagation of a single-component passive pollutant from a continuously operative point source situated at an altitude z = 250 m at a point with the coordinates x = 56 km, y = 36 km. Integration in time was carried out in an interval equal to 24 hours. We recall that for a passive pollutant $B(\vec{x},t) = 0$. Figure 1 shows curves of the concentration of pollutant at an altitude z = h, normalized to a maximum value, in dependence on the parameter β_s and the method for stipulating the lower boundary condition vertically for equation (19).

The curves 1, 2, 3, 6 correspond to solutions with boundary conditions in parameterized form (25) and the curves 4, 5 correspond to conditions without parameterization. It follows from this figure that at an altitude z = h with all values of the β parameter the maximum value of the normalized concentration of the passive pollutant with parameterized allowance for the boundary condition is found to be larger than with stipulation of the conditions without parameterization. This can be attributed to the fact that the surface layer exerts a screening influence on the propagation of pollutants. It can be seen that this influence is essentially dependent on the turbulence characteristics in the surface layer. Curve 6 corresponds to solution of a problem with a transverse diffusion coefficient determined using formula (31).

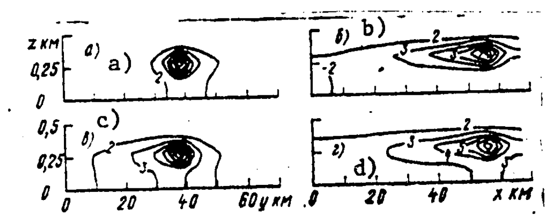

Fig. 4. Isolines of normalized concentration in planes x,z (a,c) and y,z (b, d) with $\beta_s = 10^{-6}$ m/sec, for times t = 24 hours (a,b) and t = 27 hours (c,d).

Such a method for stipulating horizontal turbulence does not lead to significant qualitative changes in the distribution of a pollutant in comparison with the distributions obtained with constant turbulence coefficients. This was evidently caused by the poor resolution of the numerical model in space variables, not making possible a detailed description of small-scale diffusion processes. At a distance of several hundred meters from the source the dependence of the solution on the method for stipulating the diffusion coefficients is significant. The results of computations cited in Fig. 1 also demonstrate the dependence of the distribution of a pollutant in the boundary layer on the β_s parameter. It was found that the β_s parameter need only be stipulated in the interval $10^{-5} \leqslant \beta_s \leqslant 1$. Beyond the limits of this interval the computed distributions of pollutants are slightly sensitive to changes in the β_s parameter; it can therefore be assumed that in the model the value $\beta_s = 1$ corresponds to the case of complete "absorption" of pollutants by the earth's surface and $\beta_s = 10^{-5}$ corresponds to complete "reflection."

Figures 2-4 show the two-dimensional sections of the fields of concentrations of pollutants, normalized to the maximum value, for different values of the β_s parameter at different moments in time. Figure 2 shows the fields of the normalized concentration at the altitude z = 50 m in the plane (x,y) for the moments in time t = 12 hours and t = 18 hours with different values of the β_s parameter, and in Fig. 3 we have shown the concentration with $\beta_s = 0.5$ m/sec at the level $z = z_0$ and z = 50 m.

Figure 4 shows vertical sections of the isolines of concentrations in the planes (x,z) and (y,z) for t = 24 hours and t = 27 hours with a value of the β_s parameter 10^{-6} m/sec. In all the figures 2-4 the isolines with the number 1 correspond to the minimum concentrations.

Constructively the realization of the model of transport of pollutants in the boundary layer was accomplished within the framework of a base model for study of the influence of the results of man's activity on the atmosphere. One of the aspects of this base model is discussed in [9]. The joint modeling of atmospheric dynamics and the transport of pollutants has a series of advantages because with such an approach it is possible to take into account the inverse influence of factors of anthropogenic origin on the atmosphere at local and global scales.

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CORRELATION BETWEEN THE ELECTRIFICATION OF THUNDERSTORM CLOUDS AND PRECIPITATION

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 12 Jun 80) pp 44-51

[Article by B. I. Zimin, candidate of physical and mathematical sciences, Central Aerological Observatory]

[Text]

Abstract: This is a review of field investigations of the thunderstorm process carried out during the last 30 years in different geographical regions of the earth. The author gives the results of 10 years of observations of thunderstorms in Moldavia and the Crimea carried out using radar, thunder recorder, lightning photorecorder and a pluviographic network. The results obtained by the author confirm the results obtained by other researchers on the primary role of precipitation in the mechanism of electrification of thunderstorm Cb and make it possible to establish a statistical dependence between the intensity of precipitation and the dimensions of thunderstorm cells, on the one hand, and the intensity of lightning discharges (frequency of lightning) on the other. The great number of measurements, especially accumulated in the temperate latitudes, gives basis for assuming that the electrification of thunderstorm Cb is related to the growth of solid particles in these clouds.

The mechanism of electrification of a thunderstorm cloud still remains one of the unsolved problems in cloud physics. Despite a great number of experimental and theoretical investigations in this field (see book by B. J. Mason [10], N. S. Shishkin [16], I. M. Imyanitov, et al. [5], V. M. Muchnik [12], J. A. Chalmers [15]), up to now there is no unanimous opinion concerning the principal reasons for the electrification of a thunderstorm cloud. However, most researchers feel that the principal mechanism of electrification of Cb is related to the formation of precipitation particles in a cloud and the gravitational separation of particles of different sizes.

Review of Studies

In the clarification of the principal processes of separation and accumulation of an electric charge in thunderstorm clouds an evaluation of the correlation between the electric and meteorological parameters of Cb can be of considerable assistance. In a number of studies attempts have been made to establish a correlation between the lightning activity of a cloud and the strength of the electric field in the atmosphere, on the one hand, and the vertical thickness of a cloud, precipitation and radar reflectivity, on the other [1, 7, 9, 11, 16, 30, 48, 57]. The results of these studies indicate the existence of a direct correlation between the electric and meteorological characteristics of a thunderstorm cloud.

The extremely detailed investigations of J. Kuettner, carried out in the 1940's in West Germany on the Zugspitze (elevation 3 km above sea level), indicated that in 93% of the cases of observations in thunderstorm clouds there was a predominance of solid precipitation elements. The central region of thunderstorm activity coincided with the region of most intensive precipitation [30].

During the last 30 years many new data have been obtained for different geographical regions confirming the reality of the assumption of the presence of a correlation between the electrification of a thunderstorm cloud and the precipitation formation process. Among these we should note the results of investigations by V. M. Muchnik in the Ukraine [12], S. Reynolds and M. Brook, and also P. Krehbiel, et al. in New Mexico in the United States [28, 29, 48], R. Kidder in South Africa [26], H. Larsen and E. Stansbury in Quebec, Canada [31], H. Hiser in Florida [24], G. Kinzer in Oklahoma [27], W. Sand, D. Musil and R. Schleusener in Colorado [50] and others [14, 25, 37, 46, 51, 55].

The results of investigations by the above-mentioned authors convincingly support the existence of an effective precipitation-forming mechanism of thunderstorm electrification. At least in the temperate latitudes it is possible to trace the correlation between the electrification of a thunderstorm cloud and the formation and growth of solid hydrometeors in Cb.

An example of extremely correct observations is the investigations of the localization of lightning carried out by Kidder [26], Krehbiel, et al. [28, 29]. In determining the coordinates of lightning discharges of the cloud-to-earth type Kidder used the base observation method employing cameras and cathode direction finders. The registry of lightning was accompanied by radar observations of clouds and precipitation. Circular-scan cameras were set up at the corners of a trapezium at a relative distance 25-40 km. The error in determining the bearing of lightning was ±0.5°. A comparison of the results of registry of lightning with maps of the radio echoes of clouds indicated that lightning was observed in the zone of heaviest precipitation and closer to the leading edge of the precipitation.

In order to localize the discharges of lightning and its individual strokes, the number of which in one lightning event could attain 6, Krehbiel, et al. investigated a thunderstorm over a polygon equipped with a radar and eight instruments for measuring electric field strength. It was established that the centers of the discharges were at altitudes 4.5-6 km (with a temperature -9 - -17°C) and coincided with the precipitation formation cells.

The correlation between lightning activity and the formation of solid hydrometeors is indicated, in particular, by the results of aircraft investigations made by D.Fittszheral'd [14], W. Sand, et al. [50] and E. Pybus [46], who registered the greatest electrical (lightning) activity during flight through cloud zones with maximum radar reflectivity, where the falling of graupel and hail was observed.

The results of measurements of the altitude of the upper boundary of the radio echo of clouds in Leningrad [8, 13], Dnepropetrovsk [12], New Mexico [48] and Florida [24] indicated that the peaks of thunderstorm clouds are in the region of negative temperatures (usually below -20°C), which also is evidence that the electrification of Cb in the temperate and subtropical latitudes is usually observed when solid particles of precipitation are present in the clouds.

On the basis of the correlation between lightning and the quantity of precipitation established by L. Battan in observations of thunderstorms in Arizona it was possible to estimate the quantity of precipitation corresponding to one lightning discharge ($3 \cdot 10^4$ tons of water per discharge) [18]. A similar estimate was made by G. Kinzer for thunderstorms in Oklahoma, according to which the mean mass of falling precipitation per one lightning discharge was $1.6 \cdot 10^4$ tons [27]. The correlation between the frequency of lightning and the intensity of precipitation during observations of thunderstorms was noted by N. S. Shishkin in Leningrad [16], E. Parczewski in Poland [45], V. M. Muchnik in the Ukraine and in the Valday [12].

N. S. Shishkin expressed in analytical form the correlation between the frequency of lightning and the intensity of precipitation and the correlation between the total number of lightning events and the quantity of precipitation falling from thunderstorm clouds [16].

J. Latham evaluated the role of precipitation formation in the electrification of thunderstorm clouds [32] and demonstrated that with an intensity of precipitation greater than 0.25 mm/min there can be a charge accumulation in convective clouds which is adequate for the development of thunderstorm phenomena.

B. J. Mason, on the basis of a critical analysis of the results of investigations of atmospheric electricity carried out primarily in Western Europe and the United States in 1950-1970 [6, 15, 17, 20-22, 30, 33-36, 38, 43, 44, 47, 49, 52], developed a scheme of electrification of a thunderstorm cloud when there is collision of cloud particles (crystals and droplets) with polarized charged grains of growing graupel [39]. According to this scheme, the strength of the electric field, beginning growth from a value 0.5 KV/m (in accordance with the fields measured in cumulus clouds not yielding rain), gradually, over the course of 400 sec, attains values 10 KV/m. Then in 120 sec it increases to 420 KV/m, after which the growth of the field is slowed down since the effect of the electrical forces on the charged particles and stray currents augments and counteracts an initial charging current. The increase in electric field strength ceases upon attaining 450 KV/m 9 minutes after the onset of falling of precipitation.

Since the mechanisms of induction charging are self-limiting and cannot generate macroscale fields with a strength more than 500 KV/m, Mason assumes that the initiation of lightning can occur in local regions of a cloud of lesser volume with a stronger field or with streamers, beginning from a coronal discharge at the surface of the precipitation particles [39].

According to the results of Mason's computations, the electric field strength attains 450 KV/m (after which there is a lightning discharge) with the intensity of precipitation attaining 0.6 mm/min. The separated charge in a cell with a radius of 1 km will be 12.5 Klux, in a cell with a radius of 2 km -- 50 Klux, in a cell with a radius of 5 km -- 312 Klux. Assuming that in the first case the lightning discharge neutralizes 10 of the 12.5 Klux of the separated charge, Mason finds that the field strength almost instantaneously decreases to 90 KV/m, and then begins to be restored. With a constant intensity of precipitation of 0.6 mm/min at the predischarge moment the field strength would be restored to 420 KV/m after 36 sec. If on the average for a size of the thunderstorm cell R = 2-3 km the lightning would neutralize 20 Klux, the field would decrease to 270 KV/m and would be restored to 420 KV/m after 20 sec. In a large cell R = 5 km a lightning discharge of 30 Klux would decrease the field to 405 KV/m and its restoration would require 5 sec. Thus, the intensity and frequency of the lightning discharges increase with an increase in the size of the thunderstorm cells.

According to V. M. Muchnik [12], the formation and separation of electric charges adequate for the development of lightning will occur only in the processes of growth of solid hydrometeors (graupel and hail).

Contradicting the opinion of a dominant role of precipitation in the electrification of a thunderstorm cloud, B. Vonnegut and C. Moore deny the correlation between thunderstorm phenomena and precipitation and assume, in agreement with G. Grenet [23], that the principal charge carriers are cloud droplets and the separation of electric charges occurs as a result of convective movements within the cloud [41, 53, 54]. On the basis of observations in New Mexico, the correctness of which has been questioned by B. J. Mason [39] and V. M. Muchnik [12], they concluded that precipitation is not the cause of lightning, but its consequence. The role of convection in this scheme essentially involves the transport and distribution of light ions on cloud droplets and the growth of precipitation particles occurs as a result of the electric coagulation of droplets.

The assertion of the adherents to the Grenet-Vonnegut scheme or the convective theory of a thunderstorm that precipitation is not mandatory for the generation of lightning contradicts numerous observations in different regions of the earth and seems poorly validated.

It should be noted that in this same New Mexico similar observations of thunderstorms, made by S. Reynolds, M. Brook and others, led to directly opposite conclusions [29, 48]. Nevertheless, the discussion initiated at the International Conference on Atmospheric Electricity in Montreux in 1963 [38, 41, 54, 56] between the adherents and opponents of the precipitation-forming mechanism of electrification of a thunderstorm cloud has not ended. It was renewed at the Fifth International Conference on Atmospheric Electricity in 1974 and is continuing on the pages of scientific journals [40, 42].

Some Results of Investigations of Thunderstorm Clouds in Moldavia and the Crimea

In the course of 10 years in Moldavia (from 1967) and in the Crimea (from 1968 to 1970) we carried out observations of thunderstorms from May through September with the use of radar stations, pluviographic network, thunderstorm recorders (lightning counters) and lightning photorecorder [2, 4]. Observations have shown that in both Moldavia and in the Crimea lightning was observed only from clouds the altitude of the upper boundary of whose radio echoes exceeded 6-7 km. With an increase in the altitude of the radio echo the number of lightning events increased [3]. These observational data agree with the results cited in [8, 12, 13, 48, 51].

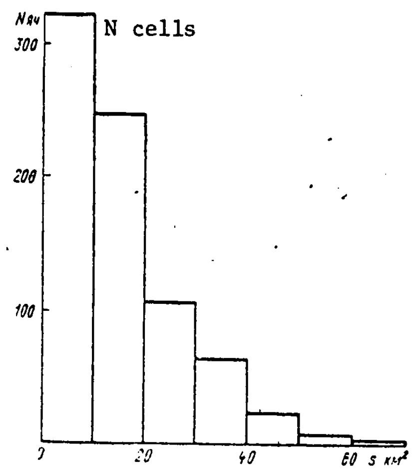

Fig. 1. Distribution of areas of thunderstorm cells.

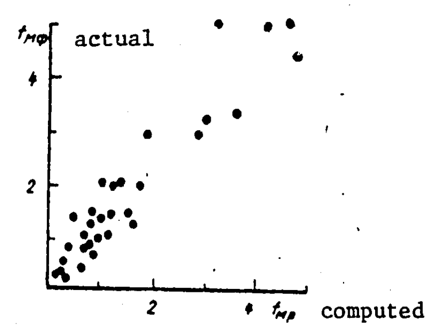

Fig. 2. Correlation between actual and computed frequencies of lightning (min^{-1}) from thunderstorm cells.

On the basis of observations in Moldavia data were obtained on the size, lifetime and lightning activity of thunderstorm cells. The thunderstorm cell was determined by the area bounded by closed radar reflectivity isolines, equal to 10^3 mm^6/m^3. The legitimacy of such a determination method was validated by our observations using a radar and a lightning photorecorder. These observations made it possible to localize a thunderstorm cell with an accuracy in azimuth of 1° [4].

Figure 1 shows a histogram of the frequencies of recurrence (with respect to the number of cases) of areas of thunderstorm cells on the basis of data from 775 cases of radar measurements in 194 Cb. The areas of the cells were determined from conical horizontal sections of clouds at the level of the altitude of the zero isotherm by planimetric measurements on sheets plotted from photographic images of zones of increased radar reflectivity. On the basis of the areas of the cells, approximated by circles, it was possible to determine their size (diameter).

The horizontal extent of the thunderstorm cells varied from 2 (weak thunderstorm) to 10 km (strong thunderstorm). The mean size of the cells was 5 km. The vertical extent of the cells, according to data from radar observations, exceeded 6 km and attained 14 km.

Thunderstorms in Moldavia have a predominantly frontal character and continue up to 6 hours or more. However, the life of individual cells usually did not exceed 1 hour and thunderstorm phenomena ceased 10-20 minutes prior to the ending of the falling of rain to the ground (the elevation of the hilly plain of central and northern Moldavia, where the observations were made, does not exceed 300-400 m above sea level). New cells most frequently were generated on the right flank in the direction of cloud movement. The number of thunderstorm cells attained 6. Unicellular thunderstorms generated 0.2-5 discharge(s)/minute, and multicellular thunderstorms generated up to 50 discharges/minute.

Our observations of precipitation from 500 Cb over an area up to 3,000 km^2 with a density of the pluviographic network of approximately 1 instrument per 30 km^2 indicated that in 90% of the cases thunderstorm phenomena were noted in those clouds from which rain fell with an intensity of more than 0.1 mm/min. The maximum intensity of precipitation from thunderstorm clouds usually did not exceed 3-4 mm/min.

Our investigation of the correlation between the rainfall intensity in the pluviographic network and the frequency of lightning from a thunderstorm cell, whose dimensions were determined by the radar method, indicates presence of a dependence in the form

$$f_{light} = \frac{H_{up} - H_{t = -20^\circ}}{H_{t = 0^\circ}} \frac{R}{R_0} \frac{\alpha (p - p_0)}{H_{low}},$$

where f_{light} is the frequency of lightning, min^{-1}; H_{up} is the altitude of the cloud radio echo, km; $H_{t = -20^\circ}$ is the altitude of the isotherm -20°C, km; $H_{t = 0^\circ}$ is the altitude of the zero isotherm, km; H_{low} is the altitude of the cloud base*; R is the radius of the thunderstorm cell, km; p is the intensity of precipitation, mm/min; α is a correction factor dependent on the period p of averaging; R_0 = 1 km; p_0 = 0.1 mm/min. With $H_{up} \leqslant H_{t = -20^\circ}$ and/or $p \leqslant p_0$ $f_{light} = 0$.

For finding α we constructed a graph of the correlation between the frequency of lightning observed from specific thunderstorm cells ($f_{light\ act}$), and the frequency of lightning computed using formula (1) on the assumption that $\alpha = 1$ ($f_{light\ comp}$) from 31 cases of simultaneous registry of precipitation, the number of lightning events from unicellular thunderstorm clouds and their radar parameters (see Fig. 2). The averaging interval for $f_{light\ act}$ was 15 minutes. During this same interval we selected the maximum p value registered by the pluviographic network. The least squares method gave $f_{light\ act} = 1.3 f_{light\ comp}$. Accordingly, $\alpha = 1.3$.

The falling of hail (diameter from 5 to 50 mm) was observed from thunderstorm Cb with an altitude of the upper boundary greater than 8 km, and as a rule was accompanied by showers. A comparison of the lightning activity of 22 hail and 23 thunderstorm clouds which we carried out in Moldavia indicated that on the average the lightning activity of hail clouds was greater than the lightning activity of those thunderstorm clouds from which the falling of hail was not noted. The greatest lightning activity was registered during the falling of hail. Our data on the increased lightning activity of hail clouds agree, in particular, with the results obtained by American researchers in Montana [19].

Thus, the results of observations of thunderstorms over a period of many years in Moldavia and the Crimea indicate a close correlation between the precipitation falling from Cb of a considerable vertical thickness and the lightning activity

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* The values $H_{t = -20^\circ}$, $H_{t = 0^\circ}$, H_{low} were determined from radiosonde data.

of Cb. These results confirm and supplement the results obtained by many other researchers in different geographical regions.

Summary

1. The formation and development of the thunderstorm process require not only the presence of a considerable vertical thickness of Cb, but also quite heavy precipitation from these clouds. Lightning will not occur in the absence of even one of the enumerated factors.

2. Usually the frequency of lightning for one thunderstorm cell does not exceed 5, but sometimes can attain 12 min^{-1}. The greater the linear dimensions and number of the thunderstorm cells, the more intense, as a rule, will be the thunderstorm phenomena.

3. There is a statistical dependence between the intensity of precipitation and the extent of the cells, on the one hand, and the frequency of lightning, on the other. This dependence is conveniently expressed by (1).

4. There is serious basis for the assumption that the mechanism of electrification of thunderstorm clouds, at least in the temperate latitudes, is closely associated with the processes of formation and growth of solid hydrometeors.

The author expresses appreciation to the engineers and technicians of the Moldavian and Crimean Antihail Expeditions for the assistance which they provided in obtaining the experimental data and is extremely appreciative to I. P. Mazin and S. M. Shmeter for useful advice and discussion of the results of the work.

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INFLUENCE OF HIGHLANDS IN THE ASIATIC TERRITORY OF THE USSR ON THE THICKNESS OF GLAZE AND RIME DEPOSITS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 5 Jan 80) pp 52-57

[Article by L. Ye. Lomilina, candidate of geographical sciences, All-Union Scientific Research Institute of Electric Power]

[Abstract] This article is devoted to a study of the influence of highlands on glaze and rime deposits in the Asiatic territory of the USSR. The study was limited to areas with elevations not greater than 600-700 m. These areas are located in the southern part of Western Siberia, in Kazakhstan and in Central Asia. This investigation is essentially a continuation of the author's earlier study in METEOROLOGIYA I GIDROLOGIYA, No 2, 1977. These studies make possible a quantitative evaluation of the influence of highlands on glaze and rime deposits over the entire lowland-hilly territory of the USSR. Six different varieties of relief were considered: 1) plain -- flat or dissected by river valleys, gullies or ravines with local relief not greater than 100 m; 2) windward slopes of highlands with local relief of more than 100 m; 3) leeward slopes of highlands with local relief not greater than 100 m; 4) the peaks of such highlands; 5) river valleys in regions of highlands with local relief of more than 100 m, open for a glaze-carrying flow; 6) river valleys in highlands not exposed to a glaze-carrying flow with local relief of more than 100 m. Emphasis is on plains, windward and leeward slopes. The observational data used in the study were collected over a period of 20-24 years at 40 meteorological stations. It was ascertained that glaze deposition is dependent on elevation, slope exposure relative to the prevailing wind and on synoptic-climatic conditions in the region. Expressions are derived which can be used in preparing maps of glaze loads and for determining possible glaze loads when planning electric power transmission lines. Figures 2, tables 2; references: 7 Russian.

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MODEL OF CIRCULATION OF A BAROCLINIC OCEAN UNDER INFLUENCE OF THE WIND AND HEAT FLOW FROM THE ATMOSPHERE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 16 Dec 80) pp 58-70

[Article by V. E. Ryabinin, USSR Hydrometeorological Scientific Research Center]

[Text]

Abstract: A two-layer model [11, 22, 24] is developed for the case of an ocean of finite depth and nonstationarity. The boundary value problem is determined using five different variants of boundary conditions at the eastern shoreline. The temperature and current velocity fields are computed on the basis of a stationary solution. The role of the wind and heat flow in the formation of oceanic circulations and the nature of the distribution of water masses is evaluated.

One of the fundamental problems in the theory of a baroclinic ocean is a determination of the role of the heat flow and wind in the generation of a stationary macroscale circulation and its principal components: oceanic circulations. The numerical modeling of the density field and currents in the world ocean (for example, see [2, 12, 14, 17, 18]) is a promising direction, but it continues to be held back by the limited capabilities of computers and the difficulties in stipulating correct and detailed boundary conditions. In this connection it is of interest to clarify the principal features of these fields using simple analytical models.

To a large extent this problem has already been solved by models of circulation caused by a nonuniform field of tangential wind stresses. Thus, at least qualitatively, the following criteria characteristic for the North Atlantic were reflected: deepening of the main thermocline in the middle latitudes and the western part of the ocean, zonal decrease in temperature from west to east in the subtropics and presence of a region of decreased temperature and thickness of the baroclinic layer along the northwestern shores of Africa, the correspondence of the total (from the surface to the bottom) discharge of the Gulf Stream to that computed from the wind field, and also some other effects. At the same time, all the precise solutions obtained in this way corresponded to a hydrostatically stable distribution of water density existing only with a heat inflow to the ocean in regions to the south of 32°N.

However, a negative heat flow exerts a considerable influence on ocean circulation and can serve as a factor in the formation of water masses [26]. In the opinion of A. S. Sarkisyan [14], the sign of vorticity of macroscale oceanic circulations is determined by the direction of the climatic flow of heat between the atmosphere and ocean. However, some authors ([7, 22]) feel that the role of the wind in the generation of ocean currents is still more important than the role of the heat flow.

Attempts at simultaneous allowance for the wind and heat flow of an arbitrary sign have been undertaken in a number of two-layer models. Among these those of the greatest interest are the so-called "generalized two-layer models of the type in [4-6, 11, 22, 24]. Precise solutions of a system of equations for the dynamics of a baroclinic ocean [11, 22, 24], whose vertical structure is characterized by the presence of a homogeneous layer at the surface, are known. The authors of [24] identify it with the region of 18° water, thus formally describing the density profile characteristic for the center of an anticyclonic circulation. An important property of these solutions was the existence of a region where the homogeneous layer disappears and the thermocline emerges at the surface. The corresponding advection of heat by geostrophic currents compensates the outflow in the northern part of the basin.

Among the shortcomings of the discussed models is the neglecting of heat advection by drift currents [11, 24], its inadequately precise computation in [22] (see below), and failure to take into account the influence of final ocean depth and water transport into the abyssal region. In addition, as will be demonstrated below, the choice of boundary conditions at the eastern shoreline, and especially the assumption of a constancy of thickness of the homogeneous layer there [22, 24], lead to results contradicting observational data.

We formulated a hydrodynamic model generalizing the models [11, 22, 24] for the cases of a finite depth of the ocean, nonstationarity and allowance for heat advection by drift currents. We found and examined its stationary solution for five different variants of boundary conditions on the eastern shoreline. The velocity components and temperature values were computed for fourteen levels.

Mathematical Model

The following parameterization of the vertical structure of the main thermocline is used: from the surface to a depth D there is a homogeneous layer (HL), below which the temperature falls to a constant value 3°C at the ocean floor.

The equations of motion are taken in a geostrophic approximation; in addition, in the upper layer the vertical shear of the current drift component is taken into account. We employ the hydrostatics expression, continuity equation and thermal conductivity equations, written for the deviations T of temperature from the bottom temperature:

$$T_t + uT_x + vT_y + wT' = \varkappa T''. \tag{1}$$

Here the subscripts x, y and the primes denote the derivatives along the coordinate axes, directed to the east, north and vertically downward, the subscript t denotes the time derivative; u, v and w are the velocity components along x, y and z, $\varkappa$ is the coefficient of vertical turbulent thermal conductivity.

The use of (1) is equivalent to the use of such an equation of state of sea water in which density is a linear function only of temperature. However, T can be regarded as some "equivalent" temperature, equally reflecting the effects of both temperature and salinity.

The following boundary conditions are stipulated at the ocean surface with z = ζ (ζ is the level):

$$w = 0, \quad \nu\rho_0 u' = -\tau^{(x)}, \quad \nu\rho_0 v' = -\tau^{(y)}, \quad \varkappa c_p \rho_0 T' = -Q, \tag{2}$$

where ν is the coefficient of turbulent viscosity, ρ_0 is mean water density, c_p is its heat capacity, $\tau^{(x)}$, $\tau^{(y)}$ are the components of the vector of wind shearing stress $\vec{\tau}$, Q is the heat flow into the ocean from the atmosphere.

At the ocean floor H(x, y) we use the condition of flow around relief

$$w = uH_x + vH_y \tag{3}$$

and the condition

$$T = 0. \tag{4}$$

If we limit ourselves to the case of an exponental distribution of water temperature in the thermocline.

$$T = T_0 \exp\,[-k\,(z-D)], \tag{5}$$

then using the equation of hydrostatics it is possible to represent the pressure disturbances relative to the hydrostatic disturbance in the form

$$P = N + \rho_0 \alpha_T g T_0 k^{-1} \exp[-k\,(z-D)], \tag{6}$$

where N is the barotropic component of the pressure disturbance, α_T is the coefficient of thermal expansion of sea water, g is the acceleration of free falling.

Substituting (6) into the geostrophic expressions, we find expressions for the horizontal components of the velocity vector. Then, vertically integrating the continuity equation, we determine the vertical velocity. For finding a precise solution of the thermal conductivity equation (1), we write expressions for u, v and w in terms of T_0, N, k and D and we use (5). In the derived equation in the form

$$\begin{gathered}[F_1+F_2\,(z-D)]\exp[-k\,(z-D)]+\\ +[F_3+F_4\,(z-D)]\exp[-2k\,(z-D)]=0,\\ F_i = F_i(x,\,y,\,t),\end{gathered} \tag{7}$$

we require that all F_i be equal to zero. This requirement is equivalent to the system of four equations

$$T_{0t} + T_0 k D_t + \rho_0^{-1} f^{-1} [I(N, T_0) + T_0 k I(N, D)] - w_D k T_0 -$$
$$- \gamma k^2 T_0 - \beta \alpha_T g f^{-2} T_0 (k^{-1} T_{0x} + T_0 D_x) = 0, \quad (8)$$
$$\rho_0 f^2 k_t + \beta k N_x + f I(N, k) = 0, \quad (9)$$
$$I(T_0, k) + T_0 k I(D, k) + \beta k f^{-1} (T_{0x} + k T_0 D_x) = 0, \quad (10)$$
$$k_x = 0, \quad (11)$$

where w_D is the vertical velocity at the lower boundary, HL, I is a Jacobian of two functions (x, y), f is the Coriolis parameter, $\beta = f_y$ is its derivative of y, assumed to be constant.

We will perform the following operations for determining w_D: we will represent P in the HL in the form

$$P = - \rho_0 g (\zeta + \alpha_T T_0 z)$$

and we will determine ζ, assuming a continuity of P with z = D:

$$\zeta = - \frac{N}{\rho_0 g} - \alpha_T T_0 (D + k^{-1}).$$

We introduce the total flows in the HL using the formulas

$$U = \int_{-\zeta}^{D} u dz, \quad V = \int_{-\zeta}^{D} v dz \quad (12)$$

and expressing them using the equations of motion through T_0, D, ζ and $\tau^{(x)}$, $\tau^{(y)}$ we find the vertical velocity w_D:

$$w_D = \frac{-\mathrm{rot}\left(\frac{\vec{\tau}}{f}\right)}{\rho_0} + \frac{\beta g D}{f^2} \left[\frac{N_x}{\rho_0 g} + \alpha_T \left(k^{-1} + \frac{D}{2}\right) T_{0x} + \alpha_T T_0 D_x \right] \quad (13)$$

In contrast to models of "wind" circulation [8, 16, 20, 21 and others], in the latter expression we retain all the terms on the right-hand side. Thus, the circulation of the main oceanic thermocline is related not only to the nonuniformity of the wind field over the oceans, but also to the features of its thermal regime: heat exchange with the atmosphere and advection by drift currents. These factors cause changes in the thickness and temperature of the HL, which is indicated by the integral heat balance equation

$$D T_{0t} + \frac{D}{\rho_0 f} I(N, T_0) - g \alpha_T f^{-1} D T_0 I(T_0, D + k^{-1}) = \quad (14)$$
$$= Q - \gamma k T_0 - \frac{1}{\rho_0 f} [\tau^{(y)} T_{0x} - \tau^{(x)} T_{0y}].$$

It follows from (9)-(11) that

$$k = \frac{c}{f}, \quad (15)$$

where c is an arbitrary constant.

Equations (8)-(14) are reduced to a closed system if w_D is excluded from them by means of (13) and with addition of the condition (3), expressed through the functions T_0, D and N.

We will write it in dimensionless variables:

$$f^2\Theta_t + \gamma f\Theta D_t - \vartheta\mu f J(N, \Theta) + \vartheta\mu\gamma\Theta J(N, D) - \varepsilon\Theta - \lambda w_E f\Theta - \qquad (16)$$

$$- \vartheta\Theta\left[f\Theta_x + \gamma\Theta D_x + \gamma f^{-1}D\left(\mu\tilde{\beta}N_x + f\Theta_x + \gamma\Theta D_x + \frac{1}{2}D\Theta_x\right)\right] = 0,$$

$$D\Theta_t + \mu\vartheta Df^{-1}J(N, \Theta) + \gamma\vartheta D\Theta\tilde{\beta}^{-1}f^{-1}J(D, \Theta) - \vartheta Df^{-1}\Theta\Theta_x +$$

$$+ \lambda\gamma^{-1}f^{-1}\left[\tau^{(y)}\Theta_x - \tau^{(x)}\Theta_y\right] + \varepsilon\gamma^{-1}f^{-1}\Theta - \gamma^{-1}\eta Q = 0, \qquad (17)$$

$$J\left(N, \frac{H}{f}\right) = \lambda w_E + \left[\Theta\left(1 + \gamma f^{-1}D + \frac{1}{2}\gamma^2 f^{-2}D^2\right)\right]_x \qquad (18)$$

In (16)-(18) the same notations have been retained for the dimensionless variables as for the dimensional variables. Only temperature $\theta = T/T_*$ (the asterisk denotes the scales of the variables) is denoted differently,

$$w_E = -\frac{1}{\rho_0}\,\mathrm{rot}\left(\frac{\vec{\tau}}{f}\right)$$

is the vertical velocity at the lower boundary of the Ekman boundary layer. We will expand the expressions for the dimensionless parameters: $\mu = (k^*H^*)^{-1}$ is the ratio of the characteristic values of thickness of the thermocline and ocean depth, $\vartheta = \beta\alpha_T T^* g t^*/f^{*2}Lk^*$, where L is the horizontal scale

$$\eta = k^*LQ^*\beta t^*/T^*f^*, \quad \lambda = \tau^*k^*t^*/f^*,$$
$$\varepsilon = k^{*2}\chi t^*$$

are parameters showing the extent to which the ocean temperature can change during the characteristic time for advection by geostrophic currents, heat flow from the atmosphere, wind effect and vertical turbulent exchange respectively, $\gamma^* = k^*D^*$ is the ratio of the scales of HL and thermocline thicknesses, $\tilde{\beta} = \beta L/f^*$ is the Rossby number.

In addition to the generally accepted values $H^* = 5\cdot10^5$ cm, $L = 5\cdot10^8$ cm, $f^* = 10^{-4}$ sec^{-1}, $\beta = 2\cdot10^{-13}$ cm$^{-1}\cdot$sec^{-1} $\rho_0 = 1$ g$\cdot$cm^{-3}, $g = 10^3$ cm$\cdot$sec^{-2}, $\alpha_T = 2\cdot10^{-4}$ $(^\circ C)^{-1}$ we assume $t^* = 1.57\cdot10^7$ sec (half-year), $\tau^* = 1$ dyne$\cdot$cm^{-2}, $Q^* = 4\cdot10^{-4}$ erg$\cdot$cm^{-2}sec^{-1}, $\chi = 1$ cm$^2\cdot$sec^{-1}, $T^* = 25^\circ$C. The characteristic thickness of the baroclinic layer of one kilometer is distributed equally between the thickness of the HL ($D^* = 5\cdot10^4$ cm) and the thickness of the thermocline ($k^* = 2\cdot10^{-5}$ cm^{-1}). It is found that $\mu = 0.1$, $\vartheta = 0.16$, $\eta = 0.0048$, $\lambda = \varepsilon = 0.0060$, $\gamma = 1$, $\tilde{\beta} = 1$.

Boundary Conditions and Method for Solving Equations in a Stationary Model

Several different investigations can be carried out on the basis of solution of the system of equations (16)-(17) with N = 0. For example, the authors of [24] studied the meridional distribution of zonally homogeneous water density for three cases: when 1) the full baroclinic flow at the eastern shore is equal to zero or when the boundary values D are stipulated, 2) constancy with depth, 3) linearly increasing. In [11] the condition w = 0 when z = D was added to the system (16)-(17) and the first condition in [24] was used. The additional equation led to a strong dependence of the results of computations on the χ parameter; the variant $\chi = 0$ was inadmissible. The two-parameter solution in [16] confirms that in the ocean there is a surface with a zero vertical velocity, but its depth was found to be considerably less than the depth of the inflection point on the density profile, being an analogue of the lower boundary of the HL. A superposition of conditions 1) and 2) in [24] was used in [22] in a study of the three-dimensional pattern of the density field.

As indicated by the brief discussion in [11, 22, 24], the boundary-value problem for system (16)-(17) was set only in [22], although the assumption of a constancy of D at the eastern shoreline cannot be regarded as completely valid. Moreover, as was demonstrated, for example, in [8, 23], in circulation of the ocean an important role is played by the compensation of discharges of baroclinic currents transpiring in the deep abyssal region. It can be taken into account using the system of equations (16)-(18), which must be supplemented by three boundary conditions for the functions θ, D and N.

The conditions of absence of total transport of mass and heat at the eastern shoreline [9] are most natural:

$$x = 1, \quad \int^{H} u\,dz = 0, \quad \int^{H} uT\,dz = 0. \qquad (19a,b)$$

They are frequently used in studying oceanic circulation of wind origin [9, 16]. Sometimes the condition for horizontal velocity is made more detailed: the integration domain is broken down vertically into parts, such as from the surface to the point z^* and from there to the bottom. By analogy with [20], showing that the assumption that the total flows normal to the shore are equal to zero within the limits of the baroclinic layer and below it (for example, see [13, 19]) is equivalent to an absence of exchange between them, it can be assumed that such increased detail leads to the absence of a coastal interaction of the layers lying above and below the point z^*. In this study we will examine several variants of choice of the point z^*. We will also discuss the "moment" condition proposed in [10] for "multiparametric" models. As a comparison with [22, 24] we will also use a third possibility: in addition to the conditions (19a,b) we will stipulate the thickness of the HL at the eastern shoreline to be constant. A summary of the conditions is given below.

Variants of Boundary Conditions With x = 1

A.	D = const,	19a, 19b	Analogue of variant in [22]
B.	U = 0	19a, 19b	$z^* = D$
C.	N = 0,	19a, 19b	$z^* = D + k^{-1}$
D.	N = 0, U,= 0	19a	$z_1^* \doteq D$, $z_2^* = D + k^{-1}$
E.	$\int^{H} uz\,dz = 0$,	19a, 19b	[10]

We will limit ourselves to an ocean of a constant depth. The wind stress and the heat flow are stipulated in the following form:

$$\tau^{(x)}/\tau^{*} = 0{,}19 + 0{,}81 \sin\left(\frac{\pi\varphi}{35} - \pi\right), \quad \tau^{(y)} = 0,$$

$$Q/Q^{*} = 2{,}6 \cos\left(\frac{\pi}{180}\sqrt{233\varphi + 639}\right), \tag{20}$$

where φ is in degrees. Formulas (20) were selected by the author in such a way that the wind stress is approximated by a curve in Fig. 2a from [7]; the w_E maximum in this case is obtained at 26°N and the heat flow changes sign at φ = 32°N and attains values Q^* and $-Q^*$ (scales) in the southern and northern parts of the computation region.

In solving the stationary problem in system (16)-(18) it is possible to proceed to new parameters. We will divide λ, ε, η by ϑ and use the notation

$$\tilde{\lambda} = \frac{\lambda}{\vartheta} = \delta\lambda_1, \quad \tilde{\varepsilon} = \frac{\varepsilon}{\vartheta} = \delta\varepsilon_1, \quad \tilde{\eta} = \frac{\eta}{\vartheta} = \delta\eta_1,$$

where δ is the characteristic value for $\tilde{\lambda}$, $\tilde{\varepsilon}$ and $\tilde{\eta}$. Since all the parameters were very close to one another, λ_1, ε_1 and η_1 are of the order of unity: with $\delta = 0.04$ $\lambda_1 = 1$, $\varepsilon_1 = 1$, $\eta_1 = 0.8$.

Integrating (18) for x, we find an expression for N and substitute it into (16), (17). The derived equations will be solved by means of expansion of the small parameter δ in a series of powers. It is easy to show that in the zero approximation θ_0, D_0, $N_0 = \theta_0$, D_0, $N_0(y)$ are determined by the boundary conditions at the eastern shoreline of the ocean. Hence follows the importance of a proper choice of the boundary conditions. In the first and final approximation we have:

$$\begin{gathered}\Theta_{1x}(A_1 B + \mu N_{0y}) + \gamma f^{-1}\Theta_0(A_2 B + \mu N_{0y}) D_{1x} = \\ = \lambda_1 \mu H^{-1} w_E(\gamma D_0 \Theta_0 - \tilde{\beta}^{-1} f^2 \Theta_{0y}) - \Theta_0(f^{-1}\varepsilon_1 + \lambda_1 w_E),\end{gathered} \tag{21}$$

$$\begin{gathered}\Theta_{1x} \gamma D_0 \left[\frac{\mu f^2}{\tilde{\beta} H}\Theta_{0y} A_1 + \mu N_{0y} + \Theta_0\left(1 + \frac{\gamma}{\tilde{\beta}} D_{0y}\right)\right] + \\ + \frac{\gamma}{f} D_0 \Theta_0 \Theta_{0y}\left(\mu A_2 - \frac{f}{\tilde{\beta}}\right) D_{1x} = \varepsilon_1 \Theta_0 - \eta_1 f Q - \\ \frac{\mu\lambda_1 f^2 w_E D_0 \gamma \Theta_{0y}}{\tilde{\beta} H} + f \cdot \mathrm{Adv},\end{gathered} \tag{22}$$

where

$$A_2 = 1 - \frac{\gamma f l_0}{f}, \quad A_1 = A_2 + \frac{\gamma^2 D_0^2}{2f^2}, \quad \mathrm{Adv} = -\frac{\lambda_1 \tau^{(x)}}{f}(\Theta_{\text{нов}})_y,$$

$$B = \frac{\mu}{\tilde{\beta} H}(f^2 \Theta_{0y} + \gamma f \Theta_0 D_{0y} - \gamma \tilde{\beta} D_0 \Theta_0). \tag{23}$$

The introduction of Adv requires clarifications. The transport of heat by drift currents is proportional to the integral of z for the product of current velocity and the meridional temperature gradient. In the case of temperature changing slightly with depth it is more convenient to use the total flows of the drift currents:

Table 1

Mean Latitudinal Water Temperatures in Atlantic Ocean at Different Depths* According to V. N. Stepanov [15] and According to Model Computations With Five Variants of Boundary Conditions

Depth, m	[15]	A	B	C	D	E	[15]	A	B	C	D	E
	10-20°N (14°N)**						20-30°N (26°N)					
800/750	6.4	-	-	-	-	-	8.6	-	-	-	-	-
1000	5.4	7.8	-	-	-	-	6.6	12.2	-	-	-	-
1500	4.5	3.1	-	-	-	-	5.2	4.4	4.7	-	5.1	-
2000	3.6	3.0	3.2	4.0	3.2	4.7	3.8	3.4	3.3	3.9	3.5	4.7
	30-40°N (35°N)						40-50°N (44°N)					
800/750	10.1	-	-	-	-	-	7.6	-	7.4	-	8.2	-
1000	8.0	-	-	-	-	-	6.6	-	5.7	-	6.2	-
1500	6.0	-	4.3	-	4.5	7.9	5.0	-	4.0	-	4.3	6.4
2000	3.8	-	3.4	3.0	3.5	4.5	3.4	-	3.4	3.0	3.4	4.2

* The dash in the table means that at least one condition is satisfied: a) the horizon is situated in the region of the homogeneous layer, b) the homogeneous layer emerged at the surface and the model is not valid, c) the thickness of the homogeneous layer is greater than the depth of the ocean (cases b and c are obtained only in variant "A").

** The temperatures according to computations were obtained for the latitudes indicated in parentheses.

no information is required on the coefficient of turbulent viscosity. Drift currents are concentrated in the surface region with a vertical scale of about a hundred meters. The water temperature in this region differs considerably from the mean temperature θ of a water layer with a thickness of about one kilometer. Moreover, whereas the temperature of the upper layer with a thickness of about a hundred meters drops off to the north, θ, being determined more by the thickness of the homogeneous layer than by other factors, frequently increases to the north. This means that the use of θ in (23) can lead to an error in the sign of heat transport by drift currents. It was assumed in the computations that $(\theta_{surf})_y = -1$. The noted effect was discovered for the first time in the numerical computations in [17], and evidently was not taken into account in [22].

The system (21)-(22) is a linear algebraic equation relative to $\overline{\theta_1}_x$ and $D^1{}_x$. Solving it using Cramer's rule, we obtain the values of the indicated derivatives and find the distribution of temperature and the thickness of the HL over the surface of the model ocean area. The three-dimensional fields T, P, u, v and w are determined from θ and D using (5), (6). The formulas for the velocity components were unwieldy and are not given in the article.

Analysis of Results of Model Computations

The variant "A" is an analogue of that used in [22]. The HL temperature field was found to be plausible in the eastern part of the ocean (with high x), where it decreased monotonically to the north. The rate of the meridional decrease in temperature was determined by the stipulated thickness of the HL at the eastern shoreline. With lesser thicknesses the dropoff was more rapid. A feature of this variant was the existence of a point on the eastern shoreline at which the principal determinant of system (21)-(22) changes sign. In the neighborhood of this point a heat balance is brought about due to a strong jet current, the position of whose axis is dependent on the D value at the eastern boundary. Here a first-order approximation is unsatisfactory. An optimum value of thickness of the HL at the eastern shoreline (750 m or 1.5 in dimensionless units) was obtained by trial and error. In [4, 5] V. F. Kozlov obtained results close to variant "A."

Since by "surface temperature" in this model we understand temperature of some layer, it is evident that with an increase in D the temperature should drop. This is seen clearly in computations for variant "B." Whereas the temperature of the HL is dependent for the most part on its thickness, the temperature below it agrees satisfactorily with the experimental data cited by V. N. Stepanov [15] (see table). The model shows a monotonic decrease in temperature with latitude at the eastern shore. In the western part of the ocean, which is warmer than the eastern part, there is a center of warm water with its center at 35°N (Fig. 1). The western boundary of the thermocline in the western part of the ocean drops down at these latitudes, whereas to the north of these latitudes the isotherms converge, simulating the emergence of the main thermocline at the ocean surface.

Below we will give a description of the main characteristics of the computed circulation.

Since the principal temperature changes and change in thickness of the HL in the model occur along the meridian, the circulation of the upper layers of the ocean and also the total transport of waters for the most part are zonal. Meridional circulation, "caused by turbulent exchange and the influence of the atmosphere," becomes comparable with the zonal circulation at depths of about 1 1/2 kilometer, which agrees with diagnostic computations made by V. A. Burkov in [2]. Circulation within the limits of the HL is anticyclonic (Fig. 2). From the southern boundary of the region to 17-20°N there are "branches of Trade Wind currents," whereas to the north the circulation is closed by easterly currents and their vorticity changes to cyclonic at a point corresponding to latitude 32°N, that is, specifically where the heat flow changes sign.

At depths of about 1.5 km the anticyclonic circulation of the upper layer is replaced by a weak circulation close to zonal, a circulation of a westerly direction; easterly flows are obtained only in the southern part of the basin to a latitude 10°N. At great depths the equatorial currents turn to the west and westerly transport becomes dominant. There is a weak meridional circulation of a northerly direction. Vertical movements in the model qualitatively agree well with the computations in [1]. In the central parts of the circulation there are descending currents, on the periphery -- ascending currents. Not only the wind, but the heat flow from the atmosphere is significant in their generation.

Variant "D" is, according to the results, very close to the preceding variant. In contrast to variant "B," at the horizons 1,750-2,000 m there is a change in the anticyclonic circulation to a cyclonic circulation, which at great depths dies out. The residual weak bottom circulation is directed to the east. The remaining features are the same as in variant "B."

Variant "C" is less close to reality than the others. The thickness of the HL is about 1.5-2 km and its meridional distribution in the western part of the ocean (minimum at 35°N) leads to a considerable decrease in mean temperature. The replacement of an anticyclonic circulation by a cyclonic circulation occurs at depths of about 2 km.

The combination of boundary conditions "E" best ensures the satisfaction of the precise nonflowthrough condition at the eastern shoreline (see Fig. 4). The pattern of the field of density and currents in this case is similar to variants "B" and "D", although it is possible to note a shifting of the region of warmer water to the south. For example, at a depth of 2,000 m a temperature maximum (5.7°C) was obtained at a latitude of 15°N. With an increase in depth the position of the maximum becomes more northerly (2,500 m -- 32°N, 3,000 m -- 38°N), which was caused by an increase in the Coriolis parameter with latitude and accordingly a lesser attenuation of temperature with depth in accordance with formulas (5) and (15). An anticyclonic circulation is well expressed to a depth of 750 m; then downward there is a zone of restructuring of circulation to cyclonic. The latter is established from a depth of 2,000 m and is replaced by a weak barotropic easterly circulation in the layer 3,000-4,000 m.

Influence of Heat Flow, Wind and Finite Depth on Distribution of Temperature and Oceanic Circulation

We will examine these effects on the basis of variants "B" and "D," since their results were closest to observational data.

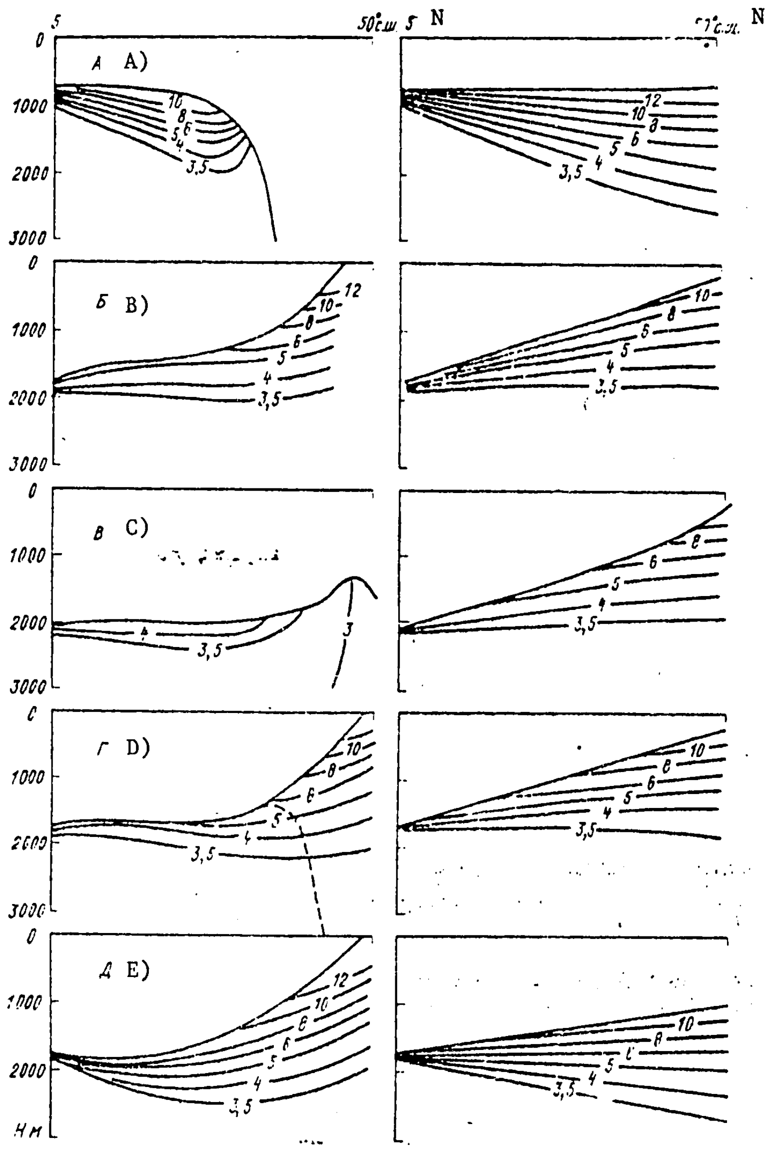

Fig. 1. Meridional sections of temperature along western (at left) and eastern (at right) shores of model ocean. The letters correspond to boundary condition variants. The lower boundary of the HL with allowance for convection is denoted by a dashed curve.

Computations show that a deepening of the thermocline and the center of warm water in the western part of the ocean are formed for the most part under the influence of the wind. In a case when the sign of Ekman velocity is replaced by the opposite sign the western part of the ocean was colder than the eastern part and the thermocline in the west was at much shallower depths (see Fig. 3). The HL emerged at the surface farther to the south than in a case with a real distribution of Ekman velocity. Here it must be added that the evaluation $w_E^* = \tau^*/\rho_0 f^* L$

considerably reduces the scale of Ekman velocity, which attains values 7 ($1.4\cdot10^{-4}$ $cm\cdot sec^{-1}$ in dimensional units) [13]. The influence of heat flow is less, primarily due to the smallness of the corresponding parameter. The effects of wind and turbulent exchange dampen the heat flow effect so that with a change in its sign there is no change in the direction of rotation of the circulation. In general, the wind and heat flow are distributed over the North Atlantic in such a way that their action together and separately leads to an anticyclonic circulation of the upper layer of waters. The heat flow first of all determines the latitude of emergence of the thermocline at the surface (D = 0). Since, in the opinion of the authors of [3, 7, 25], the line of emergence of D at the surface can coincide with the trajectory of the Gulf Stream, its deflection from the shore and further path are associated with the distribution of the heat flow. The influence of advection of heat by drift currents intensifies the action of the heat flow. Both these factors change sign at about 30°N; to the south of this latitude the heat is carried into the ocean, whereas to the north it is released.

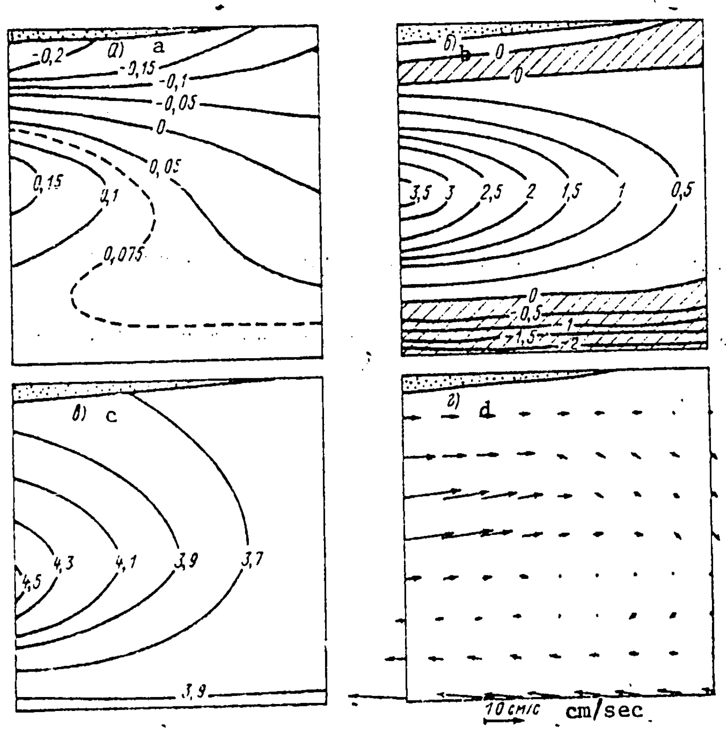

Fig. 2. Level (a), vertical velocity at the lower boundary of the HL (b), temperature at level 1,750 m (c) and currents at horizon 750 m (d) for variant "D" (in dimensionless units).

The model was very sensitive to ocean depth. With μ = 0 the mean thickness of the HL was about 2 km, but with μ = 0.1 -- about 1 km, that is, with a decrease in depth the thermocline is "pressed" toward the surface. It is evident that allowance for an inconstancy of ocean depth leads to a still greater dependence of the results of computations on the H value.

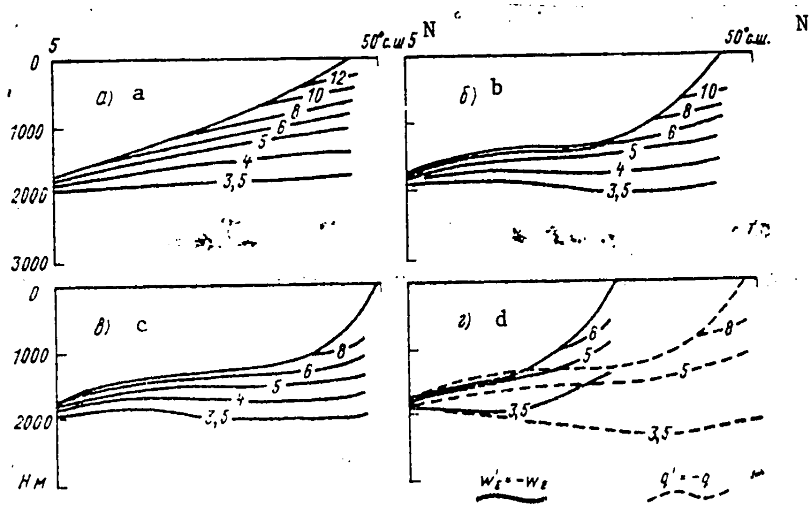

Fig. 3. Meridional sections of temperature along western shore of ocean in cases: a) nonallowance for wind, b) heat flow, c) drift advection of heat; d) changes in sign of heat flow and Ekman velocity.

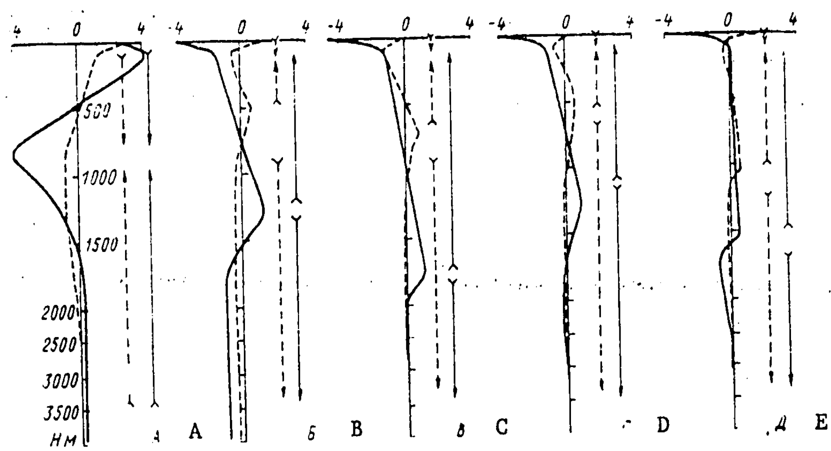

Fig. 4. Zonal velocities in eastern part of the ocean (cm/sec) at points corresponding to latitudes 14° (solid curve) and 41° (dashed curve) and corresponding directions of vertical compensation movements in coastal boundary layer (arrows).

According to the studies of Johnson [20, 21] the divergence of zonal velocity in the region of the east coast boundary layer is counteracted for the most part by vertical movements. If, on the basis of this hypothesis, the qualitative distribution of vertical velocity in the boundary layer is determined (see Fig. 4), for all variants of boundary conditions (except for "A") at 10-30°N there is an upwelling of waters from a depth of 1,000 m to the surface. The meridional component of wind stress in this case is not fundamentally necessary.

It is well known that in the regions where the ocean releases heat the stratification of its upper layer is unstable. The density convection arising in this case can attain great depths ensuring heat transfer to almost the entire water layer. The corresponding increase in the thermal conductivity coefficient was parameterized in the computations using the formula

$$\varkappa_{conv} = \varkappa[1 + p(|Q| - Q)],$$

where p was selected in such a way as to obtain the $\varkappa$ values characteristic for convection. The results indicated an increase in the thickness of the HL in the northwestern part of the ocean and the formation of a cold water mass in this region. In this case the thermocline emerges at the surface in the form of a rather narrow frontal zone. In cases when the increase in the coefficient of thermal conductivity to values characteristic during convection was not taken into account, the region of emergence of the thermocline at the surface was quite elongated and did not have a "frontal character," with no cold water mass being formed. Thus, allowance for convection is a necessary link in the modeling of the baroclinic layer in the ocean.

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UDC 556.(16:53)

SOME METHODOLOGICAL PROBLEMS IN APPLYING THE MAIN COMPONENTS METHOD IN STUDIES OF RIVER RUNOFF FIELDS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 30 Sep 80) pp 71-77

[Article by V. L. Sklyarenko, candidate of geographical sciences, Institute of Biology of Internal Waters]

[Abstract] The author examines a number of methodological problems involved in use of the main components method in an analysis of river runoff fields and its combination with some other procedures for the compression of data on multidimensional objects. By the term "analysis of river runoff fields" is meant the finding of base functions of runoff fields and the classification of rivers on the basis of the nature of variations of their runoff. Particular attention is devoted to the legitimacy of use of natural orthogonal functions of river runoff fields as criteria in the classification of rivers on the basis of the degree of harmony of variations of their runoff with time. It is shown that in a general case the use of these variables for solution of this classification problem is invalid. A new interpretation of extremal properties of the main components is given. Also dealt with is the classification of rivers on the basis of such criteria as the coefficients of correlation of rivers with one another and the Euclidean distances between rivers. The specific problems involved in application of the main components method to such data are discussed. The problem of what criteria to use in the classification of rivers and whether the main components method should be employed in such a case is dependent on the formulation of the problem, the volume of initial data and the capabilities of available computers. Almost everything dealt with in this article can be used in an analysis not only of river runoff fields, but also any other physical fields. References 7: 6 Russian, 1 Western.

UDC 556.(048+16)

EVALUATION OF PARAMETERS OF PROBABILITY DISTRIBUTIONS FOR RIVER RUNOFF

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 17 Nov 80) pp 78-86

[Article by A. V. Khristoforov, candidate of geographical sciences, Moscow State University]

[Abstract] The construction of joint confidence domains simultaneously for all parameters of the probability distribution for characteristic water discharges to the greatest degree reflects the real possibilities for extracting information from observational data for runoff and serves the purpose of hydrological computations. The application of the confidence evaluation approach makes it possible to obtain the maximum admissible values of the distribution parameters which do not contradict the observation series and accordingly can be taken into account in the computation of hydrological characteristics. For the case of a three-parameter gamma distribution the author proposes a method for constructing a joint confidence domain of the values of all three parameters: normal runoff, variation and asymmetry coefficients, taking into account the interrelationship of these parameters and the accuracy in their determination. Practical examples of application of this method are presented. Particular attention is devoted to the maximum admissible values for the ratio of the asymmetry and variation coefficients. The method of joint evaluation of the parameters of the probability distribution for runoff characteristics can serve as a useful supplement to the results and conclusions presented by A. V. Rozhdestvenskiy in the monograph OTSENKA TOCHNOSTI KRIVYKH RASPREDELENIYA GIDROLOGICHESKIKH KHARAKTERISTIK (Evaluation of the Accuracy of Curves of the Distribution of Hydrological Characteristics), Leningrad, Gidrometeoizdat, 1977. Tables 3; references: 13 Russian.

UDC 551.482.212.1

STATISTICAL CHARACTERISTICS OF RIVER BOTTOM RIDGED RELIEF

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 24 Nov 80) pp 87-91

[Article by D. I. Grinval'd, professor, V. I. Nikora and T. V. Boyko, Odessa Hydrometeorological Institute]

[Abstract] The hydraulic resistance of a channel is determined for the most part by bottom waves -- ridges of different size. But since the characteristics of these ridges vary randomly along the length of a river, sand waves of different scales are observed and the problem arises of determining the characteristic dimensions of the ridges: length and height, being representative characteristics of ridged relief in the investigated reach. Since solution of this problem will facilitate solution of the problem of hydraulic resistances of alluvial channels, the authors attempt to determine the dimensions of ridged relief by the correlation and spectral analysis method. A mathematical model of ridged bottom relief is proposed. This model was checked by computing the correlation functions and spectral densities of the longitudinal profiles of the bottom obtained by echo sounding for the Danube, Rioni and Turunchuk Rivers. On the basis of the nature of change in the correlation functions and the corresponding spectral densities it was possible to classify them with an indication of the difference between groups. It was found that the spectral density curves have clearly expressed peaks: in the region of large wave numbers the spectrum has the form of a power function; as a rule the exponent is equal to -3. Figures 2; references 7: 6 Russian, 1 Western.

UDC 556.535.6

COMPUTATION OF TURBIDITY PROFILE IN FLOW WITH TRANSPORTED SEDIMENTS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 14 Oct 80) pp 92-96

[Article by Ye. P. Anisimova, I. I. Ivlev and A. A. Speranskaya, candidates of physical and mathematical sciences, Moscow State University]

[Abstract] On the basis of data from field observations the authors define the conditions under which it is possible to apply diffusion theory for computing the vertical distribution of turbidity in a river of the lowland type with transported sediments. The measurements were made during summer in a linear river reach 255 m in length, with a width of about 20 m and a depth of about 1 m. The mean current velocity was measured with a small current meter, fluctuations of the longitudinal and vertical velocity components were determined with a thermohydrometer. The mean turbidity value and turbidity fluctuations were registered with a photoelectric turbidity meter. A synchronous record of velocity and turbidity fluctuations was obtained with a loop oscillograph. The turbulent fluxes of momentum were computed from records of the fluctuation parameters. The mean current velocity during the measurement period was 30 cm/sec. At the observation point the distribution of mean velocities across the river remained constant. The form of the vertical profile of mean velocity did not change in the investigated reach with transition from section to section along the flow. Samples were taken at these same horizons parallel with the turbidity measurements. Most of the particles in the stream were silt with a diameter 10^{-3} cm. The distribution of sediments remained constant in size at all horizons except for the thin layer near the bottom. The mean turbidity in the investigated flow was 40-60 mg/liter; the distribution did not change with transition from one section to the next. The turbulent viscosity coefficient and the coefficient of turbulent diffusion of the admixture were computed. It is shown that with allowance for the real relationship of these two coefficients it is possible to compute the mean turbidity profile in a natural plane open flow with transported sediment. Figures 4, tables 1; references 11: 10 Russian, 1 Western.

UDC 551.584.3/5:632.11:582.949.27

REGULATION OF PHYTOCLIMATE AS A MEANS FOR SUBSTANTIATING THE COMPONENTS FOR COMBINED SOWINGS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 30 Jul 80) pp 97-101

[Article by A. T. Ksendz and L. P. Savchuk, candidates of agricultural sciences, and V. N. Pokryshchenko, All-Union Scientific Research Institute of Volatile Oil Crops]

[Abstract] In the southern regions of the Ukrainian SSR great areas are occupied by heat-loving volatile oil crops. In the Crimea the greatest area is devoted to clary sage which yields a valuable volatile oil for perfumes and raw material for medicines. This is a biennial crop whose flower clusters are gathered only in the second year of growth. During the first year the flower clusters form only under definite weather conditions favorable for sage and when the fields are kept free of weeds. The irregularity in flowering and the great expenditures of manual labor in care of the crop and periodic damage to the sprouts by dust storms during the first year of growth make the cultivation of sage in clean cultivated fields unprofitable. The authors propose the "combined" cultivation of sage. Simultaneously with sage, in the first year there is cultivation of crops for green fodder or hay, which makes it possible to slow down the development of sage so that by autumn the "rosette" will have formed and strengthened and in the second year there will be a full yield of flower clusters. Accordingly, a field occupied by a combined crop gives an annual yield (in the first year a crop of green mass or hay, and in the second year a yield of sage flower clusters) and at lesser cost. The article gives the results of a study of the phytoclimate of such sown areas with sage being supplemented with winter rye, oats and winter bean-cereal mixtures. Such a cultivation method is recommended not only for combined sowings of different crops, but also for different varieties of the same crop and also for other combinations of plants for the purpose of increasing their productivity. Tables 2; references: 7 Russian.

UDC 551.551.8

INVESTIGATION OF HEAT FLOWS IN THE ATMOSPHERIC NEAR-WATER LAYER UNDER THE ATLANTIC TROPICAL EXPERIMENT PROGRAM

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 11 Dec 80) pp 102-109

[Article by Yu. A. Volkov, L. G. Yelagina and B. M. Koprov, Institute of Atmospheric Physics]

[Abstract] The principal objective of the Atlantic Tropical Experiment (GATE) was an investigation of the mechanisms for the accumulation and transformation of energy by the atmosphere and ocean and its transfer by movements of different scales. Using GATE data, the authors have formulated an improved model of circulation of the tropical atmosphere. Data were also collected for validating methods for the parameterization of microscale processes in model computations, that is, for finding their relationships to the macroscale characteristics of the atmosphere and ocean. The solution of these problems involved the implementation of special investigations for checking existing methods and developing new methods for determining vertical turbulent fluxes of heat, moisture and momentum. In addition, a study was made of the physical mechanisms for the formation of heat flows at the ocean surface and their difference from similar processes over the land. The most important result of the experimental program for investigating the heat flows was a quantitative determination of the heat balance at the ocean surface. It was found that the ocean assimilates about half the flux of solar energy intersecting its surface, which is appreciably greater than the evaluations made earlier. This emphasizes the role of the ocean as a heater in the global heat engine. The second half of the flux is returned to the atmosphere in approximately equal fractions in the form of effective radiation and the turbulent flux of latent heat. Another important result was the difference in the spectral composition of the turbulent fluxes of heat and moisture. The first are lower-frequency or greater in scale. This is a possible explanation of the difference in the heat and moisture exchange coefficients discovered in the TROPEKS, ATEKS and GATE experiments. The article gives details concerning the method for measuring turbulent fluxes, the characteristic values of the measured parameters, spectral characteristics, turbulent fluxes and their parameterization. By means of a comparison of the energy fluxes at the upper and lower boundaries of the atmosphere the authors evaluate the contributions of the atmosphere and ocean to the total meridional transfer of energy. Figures 5, tables 1; references 24: 14 Russian, 10 Western.

UDC 551.509.2:681.14

SOME APPLICATIONS OF THE 'WEATHERMAN-ELECTRONIC COMPUTER' DIALOGUE SYSTEM IN PROBLEMS OF ROUTINE DATA PROCESSING AND NUMERICAL WEATHER FORECASTING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 2 Dec 80) pp 110-114

[Article by A. A. Bagautdinov, V. P. Krysov, T. M. Pakhomova and P. Yu. Pushistov, candidate of physical and mathematical sciences, West Siberian Regional Hydrometeorological Center]

[Abstract] During recent years "weatherman-electronic computer" dialogue systems have come into extensive use. This article gives concise information on the dialogue system developed at the West Siberian Regional Hydrometeorological Center. In developing this system the following factors were taken into account: already available and projected apparatus; features of the system routinely employed in data processing and the models and schemes in use for numerical forecasting. The variant described here is based on a "Vesna" computer and a "Videoton-340" display (image field 200 x 150 mm, number of lines -- 16, number of symbols in line -- 80), as well as an appropriate mathematical support system. This mathematical support makes two operating regimes possible: output of information to the display screen with subsequent continued calculations in conformity to the main program; output of information to the display screen with subsequent input of information from the display. This variant is being used on an experimental basis with multiple checking of routine meteorological data for short-range numerical weather forecasting for the northern hemisphere and for a limited territory and in carrying out tests of a hydrodynamic-statistical model for local forecasting of the diurnal variation of meteorological elements at a point. The article gives a detailed description of the algorithms and some results of use of the dialogue system in these two problems. Figure 1 is a block diagram of the multiple checking program used in combination with the dialogue system; Figure 3 is a block diagram of the algorithm for the model for local forecasting in combination with the dialogue system. The execution of the program is illustrated in the example of specific observational situations. Reliable conclusions concerning the effectiveness of use of the dialogue system and the improvement in forecasts prepared with its use can be drawn only after one to three years of experimental use. Figures 3; references 8: 7 Russian, 1 Western.

UDC 551.(5+467):556.61(268.2)

EXPERIENCE IN SCIENTIFIC-OPERATIONAL HYDROMETEOROLOGICAL AND ICE DATA SUPPORT FOR WINTER VOYAGES IN THE ARCTIC

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 (manuscript received 21 Oct 80) pp 115-117

[Article by V. A. Voyevodin and A. I. Murzin, candidates of geographical sciences, Arctic and Antarctic Scientific Research Institute]

[Text]

Abstract: The article deals with the problems involved in the structure, organization, makeup, methods and special features of scientific-operational and hydrometeorological support for arctic navigation in the southwestern part of the Kara Sea and the Yenisey estuary during the winter season.

In accordance with the resolutions of the 25th CPSU Congress on measures for the lengthening of the navigation season on the Northern Sea Route, since 1978 there has been year-round navigation in the western region of the Arctic. This was preceded by the winter navigation of transport ships along the route Barents Sea-Dudinka (beginning in 1970) and the movement of ships during the winter-spring period to the Yamal Peninsula (Cape Kharasvey) with unloading on the shore ice (for the first time carried out in 1976). These voyages revealed the practical possibility of winter navigation on the mentioned routes of ships of the ice classes ULA and UL in the wake of powerful icebreakers.

In the 1960's navigation in the lower reaches of the Yenisey, the Yenisey estuary and the southwestern part of the Kara Sea on the average ended in late November. Beginning in 1970 the Murmansk Marine Shipping Administration began to carry out regular winter voyages, as a result of which in individual years the navigation season ended three or four months later than the average time, and in recent years it has become year-round [6]. From the stage of experimental voyages of individual ships the winter navigation has progressed to the stage of planned transport of cargo to Dudinka and the return transport of the production of the Noril'sk Combine, as well as the transport of cargo to a number of places in the southwestern part of the Kara Sea.

In order to support winter voyages, since 1970 there has been a scientific-operational group whose principal task has been supplying of ice and hydrometeorological data for winter navigation, study of the natural conditions for navigation and their influence on the passability of icebreakers and transport ships through the ice.

The scientific-operational support includes: preparation of meteorological forecasts with an advance time of 1-3 and 8-10 days, long-range ice forecasts of the thickness of ice with an advance time of 1-2 months, ice forecasts of the distribution of ice with an advance time of 1-10 days, forecasts of the compaction of ice with an advance time of 1-3 days, navigation advisories, formulation of forecasts of depths in limited sections of the route with an advance time of 1-3 days, and systematic collection, processing and analysis of data on the state of the ice cover and on level variations in limited sections of the route. In addition, the work program provides for every possible provision of information to the directors of sea operations and captains of ships on the actual hydrometeorological and ice conditions on navigation routes, organization and implementation of ice aerial reconnaissance and other generally adopted types of support [2-5].

The scientific-operational support of winter navigation has its specific features in comparison with the support of navigation in the summer navigation period. In particular, the support of winter navigation transpires against a background of deteriorating ice and hydrometeorological conditions, with the universal formation over great areas of ice which increases rapidly in thickness (as a result of which the compaction of ice occurs to all intents and purposes in the presence of winds of all directions), negative air temperatures to -55°C and under polar night conditions (extremely limited visibility).

The support of winter navigation occurs in the absence of sufficiently reliable and tested methods for the prediction of ice conditions in the sea section of the route (distribution of sea ice under the influence of dynamic and thermal factors, ice compaction, etc.). All this imposes increased requirements first of all on the organization of clear receipt and analysis of all types of operational information, including data on ice passability for icebreakers and transport ships.

a) Hydrometeorological and ice forecasts. Long-range ice forecasts of the thickness of ice in the southwestern part of the Kara Sea are prepared as a result of computations using theoretical and empirical dependences. The basis for these dependences is allowance for heat exchange of ice with the surrounding medium and also the influence of dynamic factors on the process of ice growth. The computations are made on an electronic computer of the "Minsk-320" type.

Forecasts of ice compaction occupy an extremely important place in the scientific-operational support of winter navigation conditions. The significance of prediction of this phenomenon is attributable to the fact that during winter more than 50% of the total extent of the navigation route is situated in compacted ice. At the same time, as indicated by the experience of winter navigation, when there is compaction even powerful modern icebreakers experience difficulty when operating in one-year ice. In addition, during winter, when there is ice compaction, there is an accompanying phenomenon of adhesion of pulverized ice and snow to the hulls of icebreakers, the formation of so-called "ice cushion." These factors considerably reduce the technical possibilities of icebreakers. This leads to a sharp increase in the necessary material expenditures on the convoying of ships.

For this reason the timely prediction of these phenomena favors an optimum choice of the route for the convoying of ships and a more rational organization of operation of the fleet.

The mechanism of formation of these phenomena is still inadequately studied, as a result of which the level of their prediction is low.

Meteorological forecasts are of great practical importance in supporting winter navigation. This type of forecasts, in addition to being of independent importance, is the basis for the preparation of different kinds of ice and hydrological forecasts. On the basis of a wind forecast (prediction of atmospheric pressure) it is possible to prepare forecasts of the distribution, compaction and thinning of the ice. The forecasting of air temperature is the main component of forecasts of ice thickness. The prediction of wind velocity and direction will be a basis for preparing forecasts of depths along limited sections of the navigation route (Turushinskiy sand bar and Sopochnaya Karga regions).

Forecasts of wind-induced level fluctuations in the Turushinskiy sand bar and Sopochnaya Karga regions make it possible to plan and organize the operation of the icebreaker fleet correctly, as well as the loading of transport ships at Dudinka.

b) Special features of the organization and implementation of ice aerial reconnaissance during the polar night. Ice aerial reconnaissance at the present time is the principal means for the collection of information on the state of the ice in arctic seas. During the period of support of winter navigation use is made of two methods for aerial reconnaissance: visual and instrumental.

The planning of aerial support is accomplished in such a way that observations by the indicated methods supplement and control one another, which in turn makes possible the most complete use of the positive properties of each method and compensation of their inadequacies.

The principal tasks of visual observations are:

-- nighttime and twilight determination of continuity, degree of compaction, hummocking, snow cover and other ice characteristics;
-- determination of the system of channels and leads, and also search for the optimum variant of navigation;
-- direct convoying (air patrols) of individual ships and groups of ships under complex ice conditions.

The instrumental observations have the purpose of:
-- mapping of the position of the boundaries of zones with different ice characteristics, in particular, the edges of inclusions of residual ice, and also shore ice;
-- determination of systems of major channels and leads;
-- determination of the nature of ice drift on the basis of data from successive surveys in polygons.

The operational detection of such an important characteristic of the state of ice as compression is still impossible by the instrumental method at the present time due to the low resolution of the radar station (50 m). This makes difficult a clear identification of zones of compaction and hummocking of ice. The processing of EFRU films (elektronnoye fotoregistriruyushcheye ustroystvo -- electronic photoregistry unit) to a definite degree will help in the detection of these zones. These films are obtained as a result of a radar survey. The detailed analysis of the film requires several hours, which considerably reduces the routine use of the collected information.

The implementation of a visual ice reconnaissance during winter involves a number of difficulties and specific features. This type of reconnaissance under polar night conditions is accomplished by means of lighting with the aircraft's landing lights, but sometimes only with illumination by the moon. Under such conditions an evaluation of the dynamic state of the ice cover is considerably complicated. Nevertheless, using a number of criteria (fresh traces of hummocking, layering, rate of ice closing in behind the ship's stern, etc.) the ice reconnaissance hydrologist gives a quite objective pattern of distribution of the force of compression of the ice in the investigated region.

It should be noted that in the support of winter navigation the greatest effect from visual aerial reconnaissance is given by air patrols over the convoy. It has been repeatedly noted that when escorting convoys when there is limited visibility the icebreakers frequently over a long time move parallel to the broad channels or leads, at some distance from them. In this case an air patrol considerably increases the rate of convoying of ships at nighttime, in this process making the maximum use of fresh cracks, channels and weak sectors of ice breccia which are hidden from the icebreaker by the darkness and steaming from the ice. As indicated by observational data, the rate of convoying of the ships in continuous, compacted ice increases by a factor of 6-7 when the convoy is being guided by an aircraft operating by the patrol method.

The air patrol method gives the greatest effect when there is compaction of the ice because ordinary compaction is a local phenomenon and upon discovering a zone of compaction the hydrologist almost always finds a way to bypass this zone.

c) Organization of navigation under polar night conditions. The organization of navigation during the polar night period is characterized by a number of special features:

-- the captains of the icebreakers ensuring the convoying of ships are required to adhere rigorously to the recommended navigation courses, clearly implement the instructions on the time for cessation of movement in expectation of an improvement in ice conditions and cessation of ice compaction and also at the proper time carry out the recommendations on the change in navigation course and maneuvering around zones of heavy ice and zones with intensive compression;

-- when issuing recommended navigation courses from aboard an ice reconnaissance aircraft it must be taken into account that under the specific conditions of the polar night different maneuvers and tactics of icebreakers and transport ships are extremely complicated;

-- the phenomenon of adhesion of an ice "cushion" to the icebreaker hull can create the effect of a sudden braking of the icebreaker, which is in the lead, up to its complete stoppage, which can result in an overriding or collision with the convoyed ship;

-- in the issuance of recommendations it must be taken into account that in sections of the path situated in the mouth regions of rivers the probability of ice adhesion is increased;
-- steaming of the surface, blizzards, and darkness of the polar night have the effect that it is not always possible to determine the character of movement of the convoyed ship.

The singular nature of operation of the fleet is also manifested during movement in shore ice, through a channel broken by an icebreaker. On the basis of available experience of winter voyages specialists have formulated definite optimum criteria for use of a channel during winter. In particular, the use of one channel is feasible over the course of 10-15 days and then due to pressure from below and shifts in the neighborhood of the channel brow and freezing together of the ice the advance of ships and icebreakers is made difficult. For this reason it is better to break a new channel through "virgin ice." During the period when the channel is being used each two or three days it must be "upgraded," that is, the icebreaker must pass through the channel at the mentioned interval.

The duration of use of a channel is dependent as well on its correct use. For example, movement must be accomplished along the axis of the channel and the route must be traversed with smooth turns (without abrupt changes in direction).

As a result of detachment of part of the shore ice under the influence of the wind and tides ice compaction is sometimes noted even in the neighborhood of a channel broken through the the shore ice. In this case it is recommended that a channel be broken through in another place. An important role in supporting the convoying of the ships through the channel is played by divers who in the course of ice morphometric investigations determine the character and degree of pressure from below in the region of the channels which are freezing together and the process of adhesion of ice to the icebreaker hull and provide other valuable information. The organization of navigation under polar night conditions provides for a multisided analysis of the unfavorable effect of natural factors on icebreakers and transport ships.

Despite the noted difficulties of a scientific-operational, hydrometeorological and ice data support system for winter navigation in the Arctic, this is important in the long run, having great importance in the national economy.

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CATALOGUE OF ICE ENCRUSTATIONS IN THE BAYKAL-AMUR RAILROAD ZONE, ISSUE I: ICE ENCRUSTATIONS OF THE UPPER PART OF THE CHARA RIVER BASIN (KATALOG NALEDEY ZONY BAM, VYPUSK I: NALEDY VERKHNEY CHASTI BASSEYNA R. CHARY), LENINGRAD, GIDROMETEOIZDAT, 1980

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 118-119

[Review by N. I. Tolstikhin, professor, meritorious worker in science and technology, doctor of geological and mineralogical sciences, and O. N. Tolstikhin, doctor of geological and mineralogical sciences]

[Abstract] One of the characteristic natural peculiarities of the Baykal-Amur Railroad zone is the formation of ice encrustations -- masses of layered ice forming in winter due to atmospheric, surface and ground water on the surface of rocks, soils, ice and also in large cavities in the earth's crust. This phenomenon is observed widely in the mountainous regions of Siberia, Northern Urals and in the Northeastern USSR. They constantly represent a problem for engineers and in the construction of transportation facilities, bridges, residential areas and industrial complexes. Ice encrustations greatly increase the costs of construction work and the use of transportation lines. On the other hand, agriculturalists have learned to use ice encrustations for increasing the productivity of meadow areas. As a result of interaction of many complex natural conditions ice encrustations provide much information on such matters as permafrost conditions in the regions where they occur, ground water resources, composition and formation of surface waters. The reviewed book covers all aspects of this subject. It covers an extensive territory in the upper part of the Chara River basin. Numerous maps, tables and photographs support the text. The book is based on the statistical processing and analysis of a broad spectrum of parameters predetermining the conditions for the occurrence of ice encrustations, their relationship to relief elements and absolute elevations, as well as the interrelationship of the geometrical parameters of ice encrustations. Expressions have been derived which can be used with a high degree of reliability to estimate the volumes of ice encrustations on the basis of the results of interpretation of aerial and space photographs and accordingly compute the natural resources of ground water, using the possibilities of remote research methods. This is only the first "catalogue," and it is hoped that others will follow. The book will be of exceptional value to specialists working in the zone of the Baykal-Amur Railroad and far beyond its limits.

FIFTIETH BIRTHDAY OF GEORGIY VADIMOVICH GRUZA

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 p 120

[Article by board members of the USSR State Committee on Hydrometeorology and Environmental Monitoring and All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center]

[Abstract] Professor Georgiy Vadimovich Gruza, doctor of physical and mathematical sciences, marked his 50th birthday on 19 August. His work in the field of general circulation of the atmosphere, stochastic and statistical forecasting methods, investigations of the statistical structure and variability of modern climate, is well known in the USSR and abroad. During 1957-1959, during the IGY period, G. V. Gruza participated in the Third Soviet Antarctic Expedition. Until 1970 being a specialist at the Central Asian Regional Scientific Research Hydrometeorological Institute, he directed work in the field of aerology, the creation of statistical short-range weather forecasting methods and the development of automated schemes for the prediction of temperature and precipitation in Central Asia. These investigations laid the beginning of the preparation of routine statistical forecasts of temperature and precipitation on electronic computers in Central Asia. The results of his investigations in the field of macroturbulence and the statistical structure of the pressure field in the northern hemisphere, published in a number of monographs, have considerably refined our ideas concerning processes in the atmosphere and are now in wide use. Since 1970 G. V. Gruza has worked at the All-Union Scientific Research Institute of Hydrometeorological Information-World Data Center at Obninsk. He organized the development of methods for the automated processing and storage of hydrometeorological data, created automated data recovery systems, carried out investigations of the statistical structure of modern climate and long-range weather forecasting with the use of the group analogues method, etc. Through energetic efforts and scientific innovations he created an automated system for the collection, processing and monitoring of meteorological data and a centralized system for the storage of aerological information arriving in communication channels. He laid a scientific basis for systems of hydrometeorological data banks and the centralized synoptic archives on magnetic tapes which he developed is used extensively by many researchers. Georgiy Vadimovich has published more than 110 studies, including monographs, study aids and reviews. Figures 1.

AWARDS AT THE USSR ALL-UNION EXHIBITION OF ACHIEVEMENTS IN THE NATIONAL ECONOMY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 120-123

[Article by M. M. Kuznetsova]

[Text] The Main Committee of the USSR Exhibition of Achievements in the National Economy has given additional awards to participants in the specialized exhibition "Agrometeorological Support of Agriculture in the Nonchernozem Zone" and the special exhibits "Winners of Socialist Competition" and "Artificial Modification of Meteorological Processes and Extinction of Forest Fires" presented in the "Hydrometeorological Service" Pavilion.

A First-Degree Diploma is awarded to:

-- The All-Union Scientific Research Institute of Agricultural Meteorology: for the development of a system for the agrometeorological support of agriculture in the Nonchernozem zone and creation of a complex of methods for quantitative evaluations of the state of sown crops and predictions of the yield of agricultural crops on a unified methodological basis of applied mathematical models of the productive process of these crops and the development of methods for prediction applicable to the peculiarities of crop cultivation on drained lands, which made possible a more effective, and in greater volume, servicing of agricultural production in meliorated lands.

-- The Murmansk Territorial Administration of Hydrometeorology and Environmental Monitoring: for the successful and timely supplying of hydrometeorological information concerning all unfavorable hydrometeorological conditions to all the principal branches of the national economy, Party and government agencies.

The administration successfully supported the fishing industry and thereby saved 28 ship-days of fishing time; the navigation of ships on recommended courses provided a saving of running time at sea of 92 ship-days.

The administration improved the system for the transmission of warnings concerning dangerous and especially dangerous phenomena, making it possible to reduce the time required for transmission to users by a factor of 10.

-- The Latvian Republic Administration of Hydrometeorology and Environmental Monitoring: for work on study of the hydrometeorological regime, hydrometeorological support of the national economy and monitoring the environment in the republic. The economic effect from support of the national economy was about 20 million rubles.

-- Transbaykalian Territorial Administration of Hydrometeorology and Environmental Monitoring: for attaining high indices in implementation of the plan for economic and social development and socialist obligations in 1979, for broadening and increasing the effectiveness and quality of hydrometeorological support of the national economy and population of the country.

A Second-Degree Diploma is awarded to:

-- The Estonian Agrometeorological Laboratory of the All-Union Scientific Research Institute of Agricultural Meteorology: for the developed method for computing the potential yield of agricultural crops, for formulating recommendations on the specific allowance for agrometeorological information in the programming of yields for planted and fallow earth, this making it possible to obtain additional production valued at 12 rubles more per 1 m^2 of hothouse area.

-- Northern Territorial Administration of Hydrometeorology and Environmental Monitoring: for formulating agrometeorological recommendations for the carrying out of top dressing of winter crops, preparation of the soil and seeds, prediction of the anticipated times of maturing of grain crops and mean oblast yield. The economic effect from use of the recommendations in agricultural production of Arkhangel'skaya and Vologodskaya Oblasts and the Komi ASSR during 1979 was more than 22 million rubles.

-- Lenino-Dachnoye Agrometeorological Station of the Central Volga Hydrometeorological Observatory: for routine agrometeorological support for crop cultivation in five regions of Moscow Oblast, the preparation and introduction of new forms and types of routine materials, the use of which in 1979 made it possible to obtain an economic effect of more than 1 million rubles.

-- Northwestern Territorial Administration of Hydrometeorology and Environmental Monitoring: for high-quality hydrometeorological support of vegetable production at five specialized production combines of Leningradskaya Oblast, the formulation, with allowance for agrometeorological conditions, of recommendations on the norms and times for the irrigation of fields, for recommendations on the use of frost warnings in the transplantation of seedlings on open ground, this making it possible to safeguard the seedlings and obtain additional vegetables valued at more than 300,000 rubles.

-- Kirovskaya Zonal Hydrometeorological Observatory of the Verkhne-Volzhskoye (Upper Volga) Territorial Administration of Hydrometeorology and Environmental Monitoring: for carrying out investigations of the hydrological regime of meliorated lands in Kirovskaya Oblast and timely warning of the catastrophic flood of 1979, making it possible to safeguard drainage systems, goods and equipment valued at about 7 million rubles.

-- Bryansk Agrometeorological Station of the Territorial Administration of Hydrometeorology and Environmental Monitoring of the Central Chernozem Oblasts: for high-quality hydrometeorological support of agriculture in Bryanskaya Oblast, direct participation in investigations for more precise determination of the agrometeorological parameters of conditions for the growth of new varieties of potatoes and rye, study of the microclimate of irrigated lands.

-- Scientific Research Weather Ship "Musson" of the Odessa Division of the State Oceanographic Institute: for attaining high indices in carrying out socialist obligations in 1979, overfulfilling the plan for expeditionary work by 15% and a saving of 77.3 tons of fuel. The economic effect from the use of recommendations on the navigation of ships was more than 200,000 rubles.

-- Scientific Research Ship "Mikhail Somov" of the Arctic and Antarctic Scientific Research Institute: for attaining high indices in the implementation of socialist competition and under complex conditions supporting the freight and transport operations of the 24th and 25th Soviet Antarctic Expeditions.

-- West Siberian Regional Scientific Research Institute: for high-quality support of the national economic organizations with hydrometeorological and specialized information on environmental monitoring; creation of new methods for predicting hydrometeorological elements and phenomena, preparation of aids, regime-reference and norm-setting publications for the national economy.

-- Ul'yanovsk Hydrometeorological Observatory of the Privolzhskoye (Volga Area) Territorial Administration of Hydrometeorology and Environmental Monitoring: for achieving high indices and implementing socialist obligations by the 110th anniversary of the birth of V. I. Lenin, as well as high-quality hydrometeorological support of agriculture in Ul'yanovskaya Oblast. The economic effect from the use of frost warnings during spring was 500,000 rubles, with an additional economic effect of more than 500,000 rubles from the use of information by "Ul'yanovskenergo," "Ul'yanovskavtodor" combine and "Volzhskoye Ob"yedineniye Ordena Lenina Rechnogo Parokhodstva" (Ul'yanovsk Electric Power, Ul'yanovsk Highway Enterprise, and Volga River Navigation Enterprise).

A Third-Degree Diploma is awarded to:

-- Lithuanian Agrometeorological Laboratory of the All-Union Scientific Research Institute of Agricultural Meteorology: for carrying out microclimatic investigations in the Southern Baltic Region, directed to the validation of the effectiveness of meliorative measures in this region and study of the influence of regional microclimate on the yields of agricultural crops for the purpose of their rational distribution.

-- Stende Hydrometeorological Station of the Latvian Republic Administration of Hydrometeorology and Environmental Monitoring: for supplying the Talsinskiy Agro-industrial Complex with timely frost warnings, recommendations on the times and norms for the irrigation of cultivated pastures, making it possible to obtain an economic effect of about 40,000 rubles per year.

A number of workers of the USSR State Committee on Hydrometeorology and Environmental Monitoring were awarded the Diploma of Honor and medals of the USSR All-Union Exhibition of Achievements in the National Economy.

A Diploma of Honor is awarded to:

I. G. Gringof, I. P. Fedoseyev (All-Union Scientific Research Institute of Agricultural Meteorology), A. A. Fokin (Central Design Bureau of Hydrometeorological Instrument Making), O. N. Vidyakina (Murmansk Administration of the Hydrometeorological Service), A. A. Pastors (Latvian Administration of the Hydrometeorological

Service), Ye. M. Chesnokova (Transbaykal Administration of the Hydrometeorological Service), N. M. Nefed'yeva (Ukrainian Aviation Meteorological Center), N. A. Barabanova (West Siberian Scientific Research Institute).

[Note: In the following listings the abbreviations used are as follows: AHMS = Administration of Hydrometeorology and Environmental Monitoring; MGO = Main Geophysical Observatory; SHI = State Hydrological Institute; AHD = antihail detachment; AUSRI AM = All-Union Scientific Research Institute of Agricultural Meteorology]

A Gold Medal is awarded to:

A. N. Polevoy (AUSRI AM), L. I. Borovaya (Murmansk AHMS); N. Ye. Zakharchenko (Latvian AHMS), G. V. Bespalova (Transbaykal AHMS).

A Silver Medal is awarded to:

Z. A. Shostak, A. G. Prosvirkina, V. F. Geogiyevskiy, L. S. Kel'chevskaya (AUSRI AM), S. V. Zavileyskiy (SHI), Ye. N. Romanova, D. D. Stalevich (MGO), Kh. G. Tooming (Estonian Agrometeorological Laboratory AUSRI AM), D. I. Berezin (Belorussian AHMS), V. I. Vorob'yeva (Northern AHMS), A. D. Bogachev, A. I. Dokuchayev, V. N. Chub (Central Design Bureau of Hydrometeorological Instrument Making), L. K. Konstantinov (Lenino-Dachnoye Agrometeorological Station of the Central Volga Hydrometeorological Observatory), L. P. Dugina, N. B. Moskaleva (State Committee on Hydrometeorology), S. P. Koznov and M. I. Degtyareva (Northwestern AHMS), Ye. V. Yermilova (Kirovskoye Zonal Hydrometeorological Observatory of the Upper Volga AHMS), T. F. Dubrovina (Bryansk Agrometeorological Station of the AHMS of the Central Chernozem Oblasts), N. A. Kozlitin (Murmansk AHMS), I. L. Lyul'ko (Latvian AHMS), M. Ye. Shkryum (Transbaykal AHMS), M. M. Danilyuk (Transcarpathian AHMS), M. M. Danilyuk (Transcarpathian Oblast Hydrometeorological Bureau of the Ukrainian AHMS), L. V. Belokurova (Ukrainian Aviation Meteorological Center), G. K. Volkorezova (Kolyma AHMS), A. N. Skornyakov (Scientific Research Weather Ship "Musson"), M. Ye. Mikhaylov (scientific research ship "Mikhail Somov"), M. A. Cherkesova (West Siberian Scientific Research Institute), L. Ye. Baranov (Ul'yanovo Hydrometeorological Observatory of the Volga AHMS), M. Ch. Zalikhanov (High-Mountain Geophysical Institute), G. L. Ayrapetyan (Armenian AHD), V. V. Spasibo (Moldavian AHD).

A Bronze Medal is awarded to:

V. G. Prikhot'ko, T. A. Goncharova, V. M. Pasov, A. D. Pasechnyuk, L. I. Polevaya, L. I. Yanshina, V. N. Matukhno, T. F. Serova, Ye. V. Abashina, A. D. Kleshchenko, V. F. Nikitin, A. A. Kryuchkov, Yu. A. Khvalenskiy, I. I. Vasyatkin, O. A. Bakarova (AUSRI AM), I. L. Kalyuzhnyy, V. P. Yemets (SHI), I. A. Beresneva, N. G. Goryshin, Ye. V. Orenburgskaya (MGO), A. I. Bagdonas, I. A. Ignatavichene (Lithuanian Agrometeorological Laboratory AUSRI AM), A. I. Strashnaya, A. G. Novikov, N. L. Sakharova (USSR Hydrometeorological Center), Kh. I. Myaetalu (Estonian Agrometeorological Laboratory AUSRI AM), O. T. Prokhorenko (Ural AHMS), V. M. Zhukovskiy, G. N. Spiridovich, L. Ye. Podymako (Belorussian AHMS), N. I. Kontsevich, G. A. Yelovikova (Northern AHMS), V. G. Naumov, A. A. Shulepov, Yu. F. Lanin (Central Design Bureau of Hydrometeorological Instrument Making), A. R. Balode (Stende Hydrometeorological Station of the Latvian AHMS), V. S. Shkreba, A. Ye. Prudnikova

(Lenino-Dachnoye Agrometeorological Station of the Central Volga Hydrometeorological Observatory), V. A. Kolgin (Central Volga Hydrometeorological Observatory), V. M. Baskakov, Yu. M. Felyshin, N. I. Tayurskaya, N. B. Sazhina, K. K. Smirnova (Northwestern AHMS), A. A. Sibiryakova (Kirov Zonal Hydrometeorological Observatory of the Upper Volga AHMS), T. I. Ivanova (Bryansk Agrometeorological Station of the AHMS of the Central Chernozem Oblasts), A. N. Dolinov, P. T. Morozov, Ye. I. Belentsova (Murmansk AHMS), D. V. Agalakova, N. G. Ul'yanets, A. N. Nizhnik (Latvian AHMS), T. N. Lysenko, N. P. Yakovleva, A. I. Golobkov (Transbaykal AHMS), V. V. Lashchenko, M. S. Sergeyeva (Ukrainian Biological Station), L. P. Ukhaneva (Cherkassy Oblast Hydrometeorological Bureau of the Ukrainian AHMS), M. N. Kashchavka (Mironovskaya Agrometeorological Station imeni V. F. Starchenko of the Ukrainian AHMS), A. N. Velichko (Oblast Zhitomirskoye Hydrometeorological Bureau of the Ukrainian AHMS), N. S. Shul'gin, A. M. Grishchenko (Kolyma AHMS), V. G. Gorozhankina, V. T. Proshin (Scientific Research Weather Ship "Musson"), M. Ya. Taskin, A. F. Zinger (Scientific Research Ship "Mikhail Somov"), V. S. Gromova, A. D. Drobyshev, T. Ye. Kovaleva (West Siberian Scientific Research Institute), A. K. Filaretov, L. N. Zapryagayeva, T. N. Mayskaya (Ul'yanovo Hydrometeorological Observatory of the Volga AHMS), M. T. Abshayev, A. S. Zhikharev (High-Mountain Geophysical Institute), M. S. Fayer, L. P. Manukyan (Armenian AHD), N. G. Shtul'man, N. B. Semenov (Northern Caucasus AHD), V. M. Murlin, N. I. Kizilov (Moldavian AHD), O. G. Sychenko (Oblast Hydrometeorological Bureau at Voroshilovgrad of the Ukrainian AHMS).

The total number of participants from the USSR State Committee on Hydrometeorology and Environmental Monitoring was 282. In addition to workers of the State Committee on Hydrometeorology and Environmental Monitoring, the Main Exhibition Committee of the USSR All-Union Exhibition of Achievements in the National Economy for the pavilion "Hydrometeorological Service" presented awards to other organizations taking a direct part in the work on a number of themes.

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 123-125

[Article by I. M. Shenderovich]

[Text] An international scientific and technical seminar on the theme "Means and Methods for Safeguarding Sensors and Measuring Instruments Against the Influence of the Environment" was held at the Institute of Meteorology and Hydrology in Bucharest during the period 8-13 December 1980. The seminar was attended by representatives of the Hydrometeorological Services of Hungary, German Democratic Republic, Romania, USSR and Czechoslovakia and the following reports were presented and discussed: "Protecting Hydrometeorological Instrumentation Against the Influence of Ambient Factors" (USSR), "Technical Means for Protecting Hydrometeorological Instrumentation Developed at the Scientific Research Institute of Instrument Making" (USSR) and "Design Improvement of Meteorological Instrumentation at Automated Mountain Meteorological Stations for the Purpose of Ensuring Performance Under Rime and Icing Conditions" (Romania).

The first report examined theoretical problems. It dealt with an analysis of the nature of the influence of ambient factors on the performance of hydrometeorological instrumentation (HMI), the principles for the classification of factors and methods for protecting HMI against the influence of these factors. The report also discusses the problems associated with carrying out of tests of HMI simulating the influence of external factors and the processing of the results of tests and the planning of an experiment. Particular attention was devoted to the need for creating control-checking equipment by means of which it would be possible to carry out many-sided laboratory tests of existing and newly created means for protecting HMI.

The second report gave the results of development work at the Scientific Research Institute of Instrument Making of the State Committee on Hydrometeorology and Environmental Monitoring in the field of creation of means for protecting HMI against the influence of ambient factors. In particular, it described the means for protecting HMI against the influence of changes in temperature, humidity, icing, snow and liquid precipitation. Most of the devices described in the report are protected by USSR Author's Certificates (patents) and this hydrometeorological equipment is in standard production.

The third report gave an analysis of the characteristics of an automatic meteorological station created in Romania and intended for use in mountainous regions and presented the results of improvement of meteorological sensors and developed for the purpose of ensuring their performance under conditions of icing, snow drifts and increased humidity.

In particular, for the installation of air temperature and humidity sensors it is proposed that use be made of a meteorological booth of a cylindrical configuration constructed of metal. The diameter of the cylinder is 100 cm. The booth has no bottom and in its upper part there is a gap for ventilation, protected against the entry of liquid and solid precipitation by a conical cover. Tests of this model of a booth, installed at three mountain stations, indicated that during the winter there are virtually no snow accumulations within the booth.

In order to prevent ice formation on the wind sensors, in the anemometer employed in the station there is a propeller-type wind sensor with flexible blades which in the case of high wind velocities are somewhat deformed. This ensures the destruction and casting-off of the ice crust from the propeller. In another variant of this anemometer the blades of the wind sensor are protected by rubber covers which prevent ice deposition on the propeller. Performance of the radio transmitter under conditions of increased humidity was ensured by its preliminary immersion in molten paraffin. The use of the measures enumerated above, as indicated by tests, made it possible to create stations with fault-free operation under mountainous conditions during winter for a period of eight months.

In discussion of the reports it was noted that it is timely to develop the theoretical aspects of creation of effective means for protecting HMI from the influence of ambient factors and there is a need for further work in this direction. It was also noted that at the present time there has been by no means a complete solution of the problem of protecting HMI against the influence of ambient factors, for the most part from icing and snow drifts. Most frequently this influence is manifested in the autonomous operation of meteorological sensors (unserviced) in mountainous regions and during winter. In addition, at the seminar there was a discussion of the problems related to checking of the constancy of the metrological characteristics of HMI in the case of use of different protective means. Information was given on some methods for contending with the icing of meteorological instruments on high towers in the CzSSR by means of electrical heating and protective housings from the GM-6 shipboard hydrometeorological station produced in the USSR.

A resolution passed at the seminar noted the timeliness of further development of the theoretical aspects of methods for protecting HMI against the influence of ambient factors and the need for creating new protective technical devices.

During the period of the seminar the Institute of Meteorology and Hydrology (Romania) organized a visit to three serviced meteorological stations situated in a mountainous region (Southern Carpathians, Brasov District). The purpose was to familiarize the seminar participants with the operation of stations under winter conditions.

In addition to the agenda, the seminar participants were familiarized with the design and plans for the introduction of an unserviced automatic hydrometeorological station developed in Romania and the design of a portable automatic hydrometeorological station developed in the Hungarian People's Republic.

As a result of introduction of the first station, plans have been laid for automating hydrometeorological observations in the mountainous regions of Romania and ensuring transmission of data to users. A zonal system for operation of the stations is used. A number of stations (8-12) are tied in to a zonal center (there should be 5-6 of the latter). In turn, the zonal centers are tied in to a common center located in Bucharest. The stations are connected to the zonal centers by telephone line or by radio channel. At each zonal center plans call for the use of electronic computers which will ensure calling of the appropriate station, interrogation of its sensors, selection of hydrometeorological information and its conversion into the WMO code and into physical parameters. The zonal centers have teletype communication with six prognostic centers and with the common center, at which two electronic computers are used, these being connected by telecommunications with other European countries and the WMO European center.

The station was developed so as to sit on the ground and has 100 inputs for the connection of sensors, of which 7 inputs are for evaluating the state of operation of the station itself, including checking of the power voltage. The power supply can be provided either from an a-c network or from storage batteries. In a standby regime (between measurement times) the station requires 30 mA. It operates for the most part by interrogation, but it has, in addition, a programming unit which ensures operation in accordance with a program. The station can be installed in a room or in a booth with the ambient air temperature from -40 to +50°C.

It is proposed that instruments of foreign and Romanian production be used as the meteorological sensors.

The station has undergone certification tests. Plans call for the construction of 70 stations during 1981-1984. During this same time it is proposed that the entire system be put into operation step-by-step.

The Am-10 Hungarian automatic meteorological station, whose standard production is planned for 1981, is intended for operation in different branches of the national economy (meteorological network, communal facilities, servicing of airports, expeditions, etc.) since the design of the station makes possible its use both in stationary and mobile modes.

The station measures meteorological parameters in the surface air layer (up to 9 m): air temperature and humidity, wind velocity and direction and atmospheric pressure. Up to eight sensors can be connected to the station.

The station includes a group of sensors and a commutator mounted on a support, a central unit and a cable with a length up to 250 m.

The central unit controls the operation of the entire station, converts frequency-pulsed signals arriving from the sensors and stores information until the next measurement. By command of the operator this information can be displayed or sent to the peripheral collection devices with subsequent transmission of data (print-out unit, teletype, puncher, etc.).

The AM-10 station is intended to operate with changes in ambient air temperature from -25 to +55°C.

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 125-126

[Article by B. I. Silkin]

[Abstract] Specialists at the United States Environmental Protection Agency have completed a series of studies of air quality in Alaska. It was found that in this little-developed state there has been a considerable deterioration of air quality as a result of anthropogenic influences. Most important is CO contamination in Fairbanks and Anchorage. With little industry, 96 and 85% of this contamination is generated by the automobile. The contamination is worst during the winter when the levels are the equal of the largest cities in the United States. Graphs constructed for both cities reveal a clear correlation between the CO content and the degree of air cooling. An equally important factor is the peculiarities of high-latitude meteorology. There the processes of nighttime cooling of the underlying surface are particularly intense, which leads to the appearance of an inversion in which the cold air masses lie below the warm masses. This prevents the scattering of accumulations of contaminating agents, which cannot penetrate above the inversion layer. Relatively small masses of the lower air layers subjected to contamination accumulate a considerable quantity of carbon monoxide. Under certain conditions the heat radiated by buildings and heated exhaust of vehicles can disrupt the inversion layer and favor the mixing of the contaminated atmosphere with its cleaner layers. At Fairbanks, however, even this is inadequate for disrupting such a layer at an altitude of 100 meters. It was concluded that with a decrease in air temperature the danger of its contamination with CO increases, but it has also been established that this is correct only to a definite level. The threshold or critical level of this correspondence sets in at about -18°C. Below this level the CO concentration has a tendency to remain constant.

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West Germany is about to return to the field of research and exploration in Antarctica. German scientists had worked on that continent in 1873, 1901, 1911 and 1938, as well as in 1975 when a West German research vessel studied krill and other marine organisms in the Antarctic Ocean. The site selected for the first Antarctic station is on the shores of the Weddell Sea. Up to 45 specialists will work there beginning in late 1981. From there treks will be made into the interior for up to a thousand kilometers. An Antarctic center has been established at Bremerhaven. The center will have a special scientific research ship adapted for expeditions to the high latitudes. Polar specialists will also be trained there.

OBITUARY OF PAVEL SAMOYLOVICH LINEYKIN (1910-1981)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 126-127

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

[Abstract] Professor Pavel Samoylovich Lineykin, doctor of physical and mathematical sciences, died on 2 May 1981 at an age of 72. It was in the 1950's that he wrote a series of papers which laid the beginning for a new long-range approach to study of macroscale circulation of the ocean and clarification of the mechanisms of formation of the main ocean thermocline. This direction is at present one of the most productive in theoretical oceanology. The results of the first stage in these investigations were generalized by P. S. Lineykin in a monograph entitled OSNOVNYYE VOPROSY DINAMICHESKOY TEORII BAROKLINNOGO SLOYA MORYA (Fundamental Problems in the Dynamic Theory of the Baroclinic Layer in the Sea) (1957), which became one of the classics of modern oceanology. The principles of the theory of the main thermocline laid by P. S. Lineykin and constituting his principal scientific heritage served and continue to serve as a basis for the solution of practical problems. In 1967, under the direction of P. S. Lineykin, specialists in the Laboratory of Marine Dynamics at the USSR Hydrometeorological Center developed investigations in the field of hydrodynamic modeling of macroscale and local processes in the ocean directed to the creation of specific computation and prognostic methods. In this direction substantial results were achieved, expressed in the formulation of practical methods for computing and predicting many elements of the sea regime. On the initiative of P. S. Lineykin it was possible to develop investigations of the interaction between the ocean and the atmosphere directed to improvement in methods for long-range weather forecasting. The final subjects on which he worked were: determination of the thickness of the baroclinic layer in the sea and further investigation of the main thermocline, including preparation of a large monograph on the theory of the thermocline.

MEMORIAL TO GRIGORIY IVANOVICH SHAMOV (1891-1956)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 8, Aug 81 pp 127-128

[Article by V. I. Aleksandrova, I. V. Bogolyubova, A. V. Karaushev, K. N. Lisitsyna, M. Ya. Prytkova, K. V. Razumikhina and Ye. S. Semenova]

[Abstract] Professor Grigoriy Ivanovich Shamov, doctor of technical sciences, was born on 12 February 1891; this is the 90th anniversary of his birth. An outstanding Soviet hydrologist, he was a specialist in the study of fluvial sediments and the silting of reservoirs. Beginning in 1937 and to the last days of his life (October 1956) Grigoriy Ivanovich worked at the State Hydrological Institute, heading the Sediments Laboratory. These were the years of his greatest creative activity. The monograph ZAILENIYE VODOKHRANILISHCH (Silting of Reservoirs) was published in 1939 and is widely known to specialists. For the first time it generalized Soviet and foreign materials on the silting of reservoirs, defined the laws of this process and provided a method for computing the silting of reservoirs. The Shamov method has still not lost its importance and is now included in the "Instructions on Computation of Silting of Reservoirs in Construction Planning." Shamov made a major contribution to hydrology in his studies of the runoff of river sediments. In 1949 he published the fundamental work STOK VZVESHENNYKH NANOSOV REK SSSR (Runoff of Suspended Sediments in the Rivers of the USSR); this was followed in 1951 by his work GRANULOMETRICHESKIY SOSTAV NANOSOV REK SSSR (Granulometric Composition of River Sediments in the USSR), and in 1954 by the study aid for colleges RECHNYYE NANOSY (River Sediments). This book, which is in essence a monograph on sediments, deals with the formation, regime and territorial distribution of the characteristics of the runoff of sediments and their granulometric composition, the problems involved in the method for measuring the discharges of sediments, determination of their grain size. Shamov described methods for computing movements of sediments in rivers and silting in reservoirs. The maps of turbidity and grain size constructed by G. I. Shamov have for more than a quarter-century served as a basis for planning work in the field of hydroengineering. His formulas for computing the movement of entrained sediments, due to their simplicity and reliability, are extensively used in engineering practice. G. I. Shamov formulated the fundamental principles for the distribution of the network of stations and posts for studying the runoff of river sediments. Although 25 years have passed since his death, the work of G. I. Shamov continues to exert an influence on Soviet hydrology.

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