GEOFISICA INTERNACIONAL

REVISTA DE LA UNION GEOFISICA MEXICANA. AUSPICIADA POR EL INSTITUTO DE GEOFISICA DE LA UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

México, D.F., 1o. de enero de 1976

ON THE DOMINATING PROCESSES IN THE FORMATION AND MAINTENANCE OF LONG–TERM ATMOSPHERIC FLUCTUATIONS

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RESUMEN

Utilizando datos reales, se obtiene un modelo espectral no-adiabático modificado con la ayuda de métodos estadísticos para simular en la forma más aproximada las fluctuaciones no regulares. Dicho modelo se aplica para reproducir las ondas atmosféricas más largas. Los resultados se usan para estimar el papel de los factores dinámicos y el efecto del calor del océano en los cambios geopotenciales no-periódicos de escalas planetarias para los periodos de tres días a un mes, con el objeto de estimar los tiempos característicos del efecto de los factores no-lineales y lineales sobre la evolución de la circulación hemisférica, así como para estudiar métodos de parametrización de los movimientos de escala de sub-rejilla. Se analizan un modelo turbulento de la interacción con un mecanismo no lineal de viscosidad turbulenta y un modelo de atmósfera-océano para la predicción meteorológica a largo plazo, en ausencia de datos iniciales en el océano.

ABSTRACT

Using real data an spectral nondiabatic model modificated with the help of statistic methods for the most accurate simulation of non-regular fluctuations, is obtained. The model is applied to reproduce the longest atmospheric waves, the results are used to estimate the role of dynamic factors and heat ocean effect in nonperiodic geopotential changes of planetary scales for the periods of three days to a month, to estimate the characteristic times of the effect of nonlinear and linear factors on the hemispherical circulation evolution and to study parameterization methods of subgrid scale motion. A turbulent model with a nonlinear mechanism of turbulent viscosity and a model of atmosphere-ocean interaction for long-range meteorological forecasting, in the absence of initial data in the oceans, are discussed.

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INTRODUCTION

Diagnostic calculations of atmospheric energetics (Wiin-Nielsen, 1967) and numerical simulation of general atmospheric circulation by sophisticated hydrodynamical models (Smagorinsky, 1970) contributed much to the study of quasi-stationary large-scale processes. However, the study of non-stationary fluctuations, especially non-regular, with spans, in particular, from 3 to 30 days, is restricted by "incompleteness" of real observations for the corresponding diagnostic calculations of energy balance components, and the study of non-stationary non-regular fluctuations employing long-term integrations of sophisticated general atmospheric circulation models is hampered by a predictability problem at its present state.

It is necessary to know physical processes, which dominate for the given prediction spans and, first of all, which generate perturbations, for a construction of the long-range weather prediction theory – the theory of non-regular perturbations with prolonged periods. One of the main questions is the following: whether thermal ocean forcing generates or destroys the largest non-regular perturbations in the atmosphere.

AN ESTIMATE OF THE ROLE OF DYNAMIC FACTORS AND HEAT OCEAN FORCING IN NON–REGULAR GEOPOTENTIAL TENDENCIES OF THE LARGEST SCALE.

In spite of the above mentioned restrictions, an attempt is made to answer the questions of whether the ocean heat fluxes generate or destroy the largest-scale non-regular perturbations in the atmosphere, as well as some other questions, important for determining the right direction in the construction of long-range weather prediction models. At present it is possible to carry out this attempt, in particular, employing the spectral diabatic model (Kurbatkin 1972, 1974) (Kurbatkin and Sinyaev, 1972), which includes simple mechanisms of heating and dissipation and is modified with the use of statistical methods for the most accurate simulation of non-regular fluctuations of the longest atmospheric waves:

$$\frac{\partial \Delta\psi}{\partial t} = -\mathcal{J}(\widetilde{\psi}, \Delta\psi'') - \mathcal{J}(\psi'', \Delta\widetilde{\psi} + f\alpha^2) - \mathcal{J}(\psi'', \Delta\psi'') - \nabla(f\nabla\chi'') + \widetilde{\mathcal{J}(\psi'', \Delta\psi'')} + F''_{\Omega},$$

$$\frac{\partial \Phi''_p}{\partial t} = -\mathcal{J}(\widetilde{\psi}, \Phi''_p) - \mathcal{J}(\psi'', \widetilde{\Phi}_p) - \mathcal{J}(\psi'', \Phi''_p) - \sigma(p)\omega'' + \widetilde{\mathcal{J}(\psi'', \Phi''_p)} + F''_T ,$$

$$\omega''_p = -\Delta x'', \quad \Delta\Phi'' = \nabla(f\nabla\psi''), \quad T'' = -\frac{p}{R}\Phi''_p,$$

where

$$F''_\Omega = \mu_\Omega \frac{\Delta^2\psi''}{\alpha^2} + \frac{\partial}{\partial p} K(p) \frac{\partial}{\partial p}\Delta\psi'', \quad F''_T = \mu_\Omega \frac{\Delta\Phi''_p}{\alpha^2} - \nu(P)\Phi''_p;$$

with $\quad p=0: \quad \omega''=0, \quad K(P)\frac{\partial}{\partial p}\Delta\psi''=0, \qquad (1)$

with $\quad p=p_0: \quad$

$$\omega'' = \frac{p_0 g\alpha^2}{RT}\left[\frac{1}{g}\left(\frac{\partial\Phi''}{\partial t} + \mathcal{J}(\widetilde{\psi}, \Phi'') + \mathcal{J}(\psi'', \widetilde{\Phi}) + \right.\right.$$

$$\left.\left. + \mathcal{J}(\psi'', \Phi'') - \widetilde{\mathcal{J}(\psi'', \Phi'')}\right) - \mathcal{J}(\psi'', \xi)\right],$$

$$K(p)\frac{\partial}{\partial p}\Delta\psi'' = -K_0\,\Delta\psi'',$$

$$\nu(p)\Phi''_p = \text{э}\,\nu_{0\,\text{sea}}\,\Phi''_p + (1-\text{э})\nu_{0\,\text{gr.}}\,\Phi''_p,$$

$\text{э}=1$ over the sea and $\text{э}=0$ over the ground.

Here: $(\widetilde{\ \ })$ is the climatic (periodic) part of the corresponding function or non-linear term, which is calculated by an averaging over several years in one and the same calendar day; $(\ \ )''$ are non-regular (transient) fluctuations, i.e. a deviation from a climatic value of the corresponding function or term.

The spectral method of spherical harmonics is used in all the calculations of this model:

$$\Phi(\theta,\lambda,p,t)=\sum_{m=-\mu}^{\mu}\ \sum_{n=\varphi(m)}^{N+\varphi(m)} \Phi_n^m(p,t)Y_n^m(\theta,\lambda),$$

$$Y_n^m(\theta,\lambda)=P_n^m(\theta)\,e^{im\lambda},\qquad \varphi(0)=2,\qquad \varphi(m\neq 0)=|m|$$

Climatic parts of the corresponding functions and non-linear terms are calculated only for 15 harmonics: $m=0,\ 1,\ 2$; $n=\varphi(m),\ \varphi(m)+2,\ \ldots,\ \varphi(m)+8$, by the statistic method with the utilization of the hemispherical geopotential information for the Decembers, 1964-68, with a day interval, on 8 vertical levels: 1000, 850, 700, 500, 300, 200, 100 and 50 mb, *after filtering fluctuations with 2-day periods from the fields*. The coefficients μ_Ω, $K(p)$, K_0, $\nu(p)$ $\nu_{0\ sea}$ and $\nu_{0\ gr.}$ are calculated in the result of the inverse problem solution, and are optimal for the transient fluctuations of the first 15 harmonics. The numerical coefficient values are given in Table 1. 81 harmonics are used in all these calculations in every factor of the non-linear terms: $m=0,\ 1,\ 2,\ldots 8$, $n=\varphi(m)$, $\varphi(m)+2,\ldots,$ $(m)+16$, i.e. including the waves of the mean-cyclonic scale.

Now system (1) in a spectral form allows us to integrate it over time with a time step $\Delta t=1$ day for the first 15 harmonics. Therefore, while integrating over time, we can substitute the real fields Φ'' with a one-day interval in the right-hand sides of the equations, and then 81 harmonics are involved in non-linear terms of the right-hand sides on every time step, i.e. "full" dynamics is involved for the calculation of time deviations of the first 15 harmonics.

Notice that in the case of such integration relative errors remain less than 1 (absolute errors are less than real variability) during 5 days on

1 000 mb, during 6 days on 850 mb and on 500-100 mb level during 9 days- a maximum period during which a calculation series consisting of 100 examples was carried out. Numerical values of average relative errors are given in Table 2. We will also note that the terms F''_T and F''_Ω improve the predictions, reducing average relative errors by 4 to 8 percent during the whole integration period up to 9 days. Hence, the contribution of the terms F''_T and F''_Ω, remain approximately 8 to 5 times smaller than that of the dynamic terms during the whole integration period.

The time integration procedure, when the real fields Φ'' with a day interval are substituted in the right-hand sides, is equivalent to the averaging of the model equations with the time interval, which is equal to the integration interval, and the procedure allows us to calculate non-regular geopotential tendencies taking place during several days for the longest waves.

If these many-day tendencies also will be prescribed as real from observations, i.e. right and left-hand sides of system (1) will be calculated on real data, then such diagnostic calculations allow us to estimate the role of dynamics, heating and dissipation in the generation of slow non-regular fluctuation of the longest waves.

We will present this problem symbolically in the following way:

$$\int_0^{j\Delta t} \frac{\partial \Phi''^{\,m}_{\,n}(P)dt}{\partial t} = \alpha^m_{jn}(p)\int_0^{j\Delta t} (\mathcal{J}'')^m_n \, dt + \beta^m_{jn}(p)\int_0^{j\Delta t} (F''_T)^m_n \, dt + \gamma^m_{jn}(p)\int_0^{j\Delta t} (F''_\Omega)^m_n \, dt \; , \quad (2)$$

$m = 0, 1, 2; \quad n = \varphi(m) \; , \quad \varphi(m)+2, \ldots, \quad \varphi(m)+8 \; ;$

$P = 1\,000, 850, 700, 500, 300, 200, 100$ and 50 mb

$j = 1, 2, 3, \ldots$

The first term on the right-hand side of (2) gives a contribution of "full" dynamics in non-regular geopotential tendencies of the largest-scale waves; the second term, of heating; and the third one, of dissipation.

The parameters $\alpha^{m}_{jn}(p)$, $\beta^{m}_{jn}(p)$ and $\gamma^{m}_{jn}(p)$ are introduced artificially as indicators of the generating mechanisms. They will be defined from the inverse problem by the least square method.

First, we will analyse the dependence of the j -day geopotential tendencies on dynamic terms. For this purpose we will prescribe $\beta^{m}_{jn}(p) = \gamma^{m}_{jn}(p) \equiv 0$ and calculate $\alpha^{m}_{jn}(P)$.

Numerical values of the parameters α^{m}_{jn} for $j = 1, 2, \ldots, 9$ for every harmonic on 1 000 mb averages for 100 cases are shown in Fig. 1 as continuous lines.

This analysis shows that the parameters $\alpha^{m}_{jn} \lesssim 1$, for non-regular geopotential tendencies for 1-3 days and the parameters α^{m}_{jn} decrease for geopotential tendencies for periods larger than 3 days ($j > 3$). This is apparently natural for them, as the role of diabatic processes must increase in the many-day geopotential tendencies.

It should be mentioned, however, that the rate of the α^{m}_{jn} decrease with the j increase will be dependent on the dynamic part of the model itself, and, therefore, the above rate can characterize its quality in comparison with other models.

Then we prescribe $\alpha^{m}_{jn}(p) \equiv 1$, $\gamma^{m}_{jn}(p) \equiv 0$ and calculate $\beta^{m}_{jn}(p)$. Numerical values of the parameters β^{m}_{jn} for $j = 1, 2, \ldots, 9$ are given in Fig. 1 by the dashed lines.

Weighted-mean values (for 15 harmonics) of the parameters $\beta^{m}_{1n}(p)$ must be about +1, since the physical coefficients in F''_T have been optimized for this case. However, it appeared that the values of the parameters β^{0}_{1n} (for zonal harmonics of the function F''_T) differ considerably from +1. First of all, this fact indicates that the weight of the zonal part from F''_T is less than that of a non-zonal one, when optimization of the physical coefficients in F''_T is carried out. Apparently, the zonal part of the heating F''_T in a given model must be less than that of F''_T for m = 1 and 2.

The behaviour of the parameters β^{0}_{jn} also differs from β^{1}_{jn} and β^{2}_{jn} when j increases. We will discuss the latter which are more interesting and important. Preservation of almost constant values of $\beta^{m}_{jn} \approx +1$ for all $j = 1, 2, \ldots 9$ is characteristic for them. It might mean that there is a persistent correlation between F''_T and $\frac{\partial \Phi''}{\partial t}$ when j increases, i.e. it might indicate a possible role of generating or maintaining the heating.

But this characteristic result may appear to be a consequence of persistent correlation between F''_T and non-linear advective terms, ($\mathcal{J}''$), i.e. it may express a quasi-stationary nature of the heating mechanisms given here. Thus, an additional investigation is required.

We will prescribe $\alpha^{m}_{jn}(p) = \gamma^{m}_{jn}(p) \equiv 0$ and calculate $\beta^{m}_{jn}(p)$ once more. This result is shown in Fig. 1 by the dotted lines. It turned out that the correlation between F''_T and $\frac{\partial \Phi''}{\partial t}$ not only decreases considerably in absolute magnitude but also changes its sign. The negative values β^{m}_{jn} are preserved for all $j = 1, 2, \ldots, 9$. That means that the mechanisms F_T'' in the hydrodynamical diabatic model (1) up to the 9-day tendencies must compensate only partially dynamic processes in order to describe correctly the anomalies of geopotential tendencies for the longest-scale waves.

The heat ocean fluxes, described in the model by the boundary condition at $p = p_0$: are the main heat sources in F_T'' at 1 000 mb level:

$$\nu(p)\Phi_p'' = \ni \nu_{0\,sea}\ \Phi_p'' + (1 - \ni)\nu_{0\,gr.}\ \Phi_p'',$$

$\ni = 1$ over the sea and $\ni = 0$ over the ground, therefore with the help of the given analysis we can formulate the following conclusion concerning the role of the ocean: the change of the parameter sign before F_T'' when the dynamics, ($\mathcal{J}''$), is rejected, means that the ocean fluxes are necessary to compensate, to some extend, dynamic processes, and therefore they are not able to generate or maintain atmospheric perturbations of the largest scale, they must rather destroy these perturbations.

Note that non-regular longest perturbations can obtain energy from available potential energy of zonally averaged air temperature distribution, from available potential and kinetic energies of the climatic non-zonal perturbations.

The above mentioned observational data set ensured by the statistics of the analysis of the formation mechanisms from one day up to 9-day geopotential tendencies. In this analysis the non-linear model equations were averaged, and thus relatively quick processes were filtered. Thus, the 9-day averaging, filtered fluctuations with the 5-day periods and suppressed fluctuations with the 9-day periods by 50 percent more.

The role of the dynamic processes may be gradually relaxed, and the role of the heat fluxes may be intensified with further increase (more than 9 days as many) of integration interval of eq. (2). And beginning with some integration intervals the largest scale long-term perturbations can be generated or maintained by the heat ocean fluxes. Then beginning with some j the sign of the parameter –indicators at F_T'' would not be changed with rejection of the dynamics, i.e. dotted lines would have passed into the domain of positive values with further increase of j .

This analysis has been carried out on the basis of the fields of five 3-month intervals of real data during September-November, 1969 to 1973, though only on 6 levels: 1 000, 500, 300, 100, 30 and 10 mb, and without filtering the fluctuations with the 2-day periods.

A six level spectral diabatic model has been carried out similarly to (1). Numerical values of the coefficients μ_Ω , $K(p)$, K_0 , $\nu(p)$, $\nu_{0\ sea}$, $\nu_{0\ gr.}$ calculated for the model are given in Table 3. Series of integration, each up to 31 days, have been carried out according to scheme (2). The parameters calculated for 1 000 mb are given in Fig. 2 only for $j = 1, 2, \ldots, 17$ as their asymptotic behaviour is observed within these intervals of the change of j. It is shown in Fig. 2:

α^m_{jn} at $\beta^m_{jn}(p) = \gamma^m_{jn}(p) \equiv 0$ by continuous lines,

β^m_{jn} at $\alpha^m_{jn}(p) \equiv 1,\ \gamma^m_{jn}(p) \equiv 0$ by dashed lines,

β^m_{jn} at $\alpha^m_{jn}(p) = \gamma^m_{jn}(p) \equiv 0$ by dotted lines.

Before these calculations are discussed we note that with increase of j the parameters α^m_{jn} at $\beta^m_{jn}(p) = \gamma^m_{jn}(p) \equiv 0$ more rapidly decrease in Fig. 2 than those in Fig. 1 for the same values of j. Perhaps that shows insufficiently high qualities of the 6-level model with its rough resolution in the lower troposphere. That is why one should be very careful with respect to the estimations obtained by the 6-level model.

However, we can say that the basic character of the changes of the parameters β^m_{jn} at F''_T depending on j is preserved to some extend in this analysis: the absence of the significant decreases or increases of the parameters $\beta_{jn}^{m} \approx +1$ at $\alpha_{jn}^{m}(p) \equiv 1$, $\gamma_{jn}^{m}(p) \equiv 0$ and the negative values of the parameters β_{jn}^{m} which are obtained at $\alpha_{jn}^{m}(p) = \gamma_{jn}^{m}(p) \equiv 0$ (with rejection of the dynamics).

Besides, it is seen from the given analysis that the parameters β_{jn}^{m} at $\alpha_{jn}^{m}(p) = \gamma_{jn}^{m}(p) \equiv 0$ (dotted lines) with the increase of j tend to some negative, small in absolute magnitude (much smaller than 1) asymptotic values for some harmonics and to 0 for the others, the parameters remaining in the negative domain, instead of possible passages through the zero values to the domain of positive values β_{jn}^{m}

Thus, the analysis hasn't changed the above obtained estimation of the ocean heat effect even at considerable integration periods (up to 31 days), and this is equivalent to considerable time averaging of the model equations.

AN ESTIMATION OF THE CHARACTERISTIC TIMES OF THE EFFECT OF NON-LINEAR AND LINEAR FACTORS ON THE EVOLUTION OF THE HEMISPHERICAL CIRCULATION.

If heat ocean effect only compensates dynamic terms by filtering the wide enough part of the time spectrum of the largest scale atmospheric perturbations, this would mean that by construction of the long-range weather prediction model of averaged meteorological fields one can never rely on the cardinal solution of the problem.

However, wave generation may not be the dominating process for some prediction periods. That is why long-range prediction models of time averaged characteristics, which do not require incorporation of sophisticated physical mechanisms for the description of small and rapid processes, would be possible, if they have as well other advantages in comparison with the models of detailed prediction. Here we mean those advantages, which could result in more accurate prediction of time averaged weather characteristics.

Thus, even at considerably averagings of model equation the ocean heat effect only partially compensates the dynamic terms. Then dynamics should be taken into account in the long-range meteorological prediction models.

But the structure of dynamic (advective) terms themselves could be considerably simplified at a gradual amplification of the model equation averaging. Thus, beginning with some considerable averaging, the non-linear terms of the system (1),

$$\mathcal{J}(\psi'', \Delta\psi'') - \overline{\mathcal{J}(\psi'', \Delta\psi'')}\,, \quad \mathcal{J}(\psi'', \Phi''_p) - \overline{\mathcal{J}(\psi'', \Phi''_p)}\,\cdot$$

$$\mathcal{J}(\psi'', \Phi'') - \overline{\mathcal{J}(\psi'', \Phi'')}$$

could become much smaller than the linear terms, linearized, it is necessary to underline, with respect to the mean climatic fields which are the functions of time and of all the space coordinates. In this case the largest-scale and slow evolving processes would be approximately described by simple equations:

$$\frac{\partial \overline{\Delta\psi''}}{\partial t} + \mathcal{J}(\overline{\psi''}, \Delta\widetilde{\psi} + f a^2) + \mathcal{J}(\widetilde{\psi}, \Delta\overline{\psi''}) + \nabla(f \nabla \overline{\chi''}) = \overline{F''_\Omega},$$

$$\frac{\partial \overline{\Phi''_p}}{\partial t} + \mathcal{J}(\overline{\psi''}, \widetilde{\Phi}_p) + \mathcal{J}(\widetilde{\psi}, \overline{\Phi''_p}) + \sigma(p)\,\overline{\omega''} = \overline{F''_T}\,. \qquad (3)$$

$$\overline{\omega''_p} = -\Delta\overline{\chi''}, \quad \Delta\overline{\Phi''} = \nabla(f \nabla \overline{\psi''}), \quad \overline{T''} = -\frac{p}{R}\overline{\Phi''_p},$$

with $p = 0$: $\quad \overline{\omega''} = 0,$

$$\text{with } p=p_0: \ \overline{\omega''} = \frac{p_0\, g a^2}{RT}\left[\frac{1}{g}\left(\frac{\partial \overline{\Phi''}}{\partial t} + J(\overline{\psi''}, \tilde{\Phi}) - J(\tilde{\psi}, \overline{\Phi''})\right) - J(\overline{\psi''}, \xi)\right],$$

$(\overline{\quad})$ is the time filter. Satisfaction of the approximate relation $\overline{(\tilde{\ })} \approx (\tilde{\ })$ is supposed here.

Equations (3) are linear with "climatic sources" excluded from them. Therefore, truncation errors would be reduced to a minimum in calculating the advective terms.

But are non-linear factors relaxed with the model equation integrating over large periods, i.e. with the equation averaged within large intervals? Are they relaxed in natural way without any parameterization?

Only non-linear or linear terms are left in system (1) for the analysis of this question. Real data is substituted in only non-linear or linear terms and the system is solved with respect to one-day geopotential tendencies $\left(\frac{\partial \Phi}{\partial t}\right)''$, for which it is necessary to invert a three-dimentional linear elliptic operator. It allows us to calculate contribution of the non-linear factors $\left(\frac{\partial \Phi}{\partial t}\right)''_{non\text{-}lin}$ (or only the linear factors $\left(\frac{\partial \Phi}{\partial t}\right)''_{lin}$) in daily geopotential tendencies. Calculations were carried out according to real data for 5 month periods, December 1964-1968, at 8 levels after 2-days fluctuations had been filtered from these geopotential fields. Then the daily tendencies $\left(\frac{\partial \Phi}{\partial t}\right)''_{non\text{-}lin}$ and $\left(\frac{\partial \Phi}{\partial t}\right)''_{lin}$, calculated for every day were averaged by 100 days (cases) and the following relations were taken

$$N_n^m = -\frac{\overline{\left[\left(\left(\frac{\partial\Phi}{\partial t}\right)''_{non\text{-}lin}\right)^2\right]_n^m}}{\overline{\left[\left(\left(\frac{\partial\Phi}{\partial t}\right)''_{lin}\right)^2\right]_n^m}},$$

where the operator $\overline{(\ )} = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} (\ ) \sin\theta\, d\theta\, d\lambda$.

Similar calculations have been successively carried out for 2-day, 3-day . . . ., 9-day geopotential tendencies. Calculation of j-day geopotential tendencies is equivalent to j-day averaging of model equations. Therefore, such characteristics allow us to judge about the relations between linear and non-linear dynamic factors not only in the equation integrated for different periods, but also about the character of this relation depending on time averaging of the model equations.

Calculations gave the characteristic values N_n^m within the limits 1.3 - 1.5. They remain approximately constant for different averagings except the values N_n^m for the harmonics with the numbers (m,m), for which they considerably diminish with increase of averaging. Moreover, even some increase of the relation N_n^m is observed in smoothing increase for many significant harmonics. This fact indicates a weakening of the role of the transfer of non-regular fluctuations by zonal stream in increasing the averaging of these waves, thus indicating losses of mobility of waves, this losses being due to dynamic adiabatic factors (including topographic effect).

Thus, all the largest scale harmonics practically appear to be "non-linear" in different averagings. All the facts show that characteristic times of the effects of non-linear and linear factors on planetary circulation evolution are approximately equal.

A similar result was obtained employing the 6-level model based on real data during five 3-month intervals, September-November, 1969-1973, and for averagings with a larger time interval up to 15-day. The presence of almost regular 15-day climatic fluctuations gives resonance effect in these calculations with further averaging increase of model equations. The effect is sufficiently strong at the upper stratosphere levels, but also noticeable at 500 mb level. Therefore, climatic fields and "climatic sources" were taken stationary: they were averaged during 3-month intervals from September 1 till November 31, besides usual averaging during 5 years for every calendar day, and all the calculations were carried out for successively increasing averagings up to those with 31-day intervals. Approximation of dynamic advective factors by linear terms, linearized with respect to stationary climatic fields, proved to be rather worse than in the above cases, but persistent, monotonic, without essential deviations for all the considered intervals of averagings.

AN ATTEMPT TO STUDY AND PARAMETERIZE THE SUB–GRID PROCESSES FOR THE DEVELOPMENT OF LONG–RANGE METEOROLOGICAL PREDICTION MODELS.

It was determined, that there was no natural damping of nonlinear terms in considerable time averagings of model equations.

Let a long-range predicting model be non-linear. Then what can we say about possibility of the development of a non-linear model of long-range prediction of averaged fields? First of all, it is necessary to deduce equations for averaged fields, then the formulated question is reduced either to discussion of possible development of general theory of closing of hydrodynamic atmospheric equations or, at least, to discussion of possibility of parameterization of sub-grid large-scale cyclonic perturbation effect.

It is necessary to penetrate somewhat deeper in the physical nature of non-stationary atmospheric processes, advisable in wider frequency range, before passing to such discussion. Now we can discuss only some auxiliary analysis, numerical experiments and suggestions concerning the formulated question.

Let us calculate the contribution to geopotential changes of those parts of non-linear terms, which are responsible for prolonged effects due to the quicker sub-grid perturbations in low-frequency fluctuations in the prediction model. This can be easily done without excluding regular climatic fluctuations and corresponding to them "sources" in model equations, and with some approximation of the $\overline{(\ \ )} + \overline{\overline{(\ \ )}} \approx \overline{(\ \ )}$ type. It is enough to compare with what accuracy time averaged equations (variant 1) and the equations from the time averaged fields (variant 2) are satisfied, if real data is substituted in the right and the left-hand sides of both variants. Diagnostic relative errors of geopotential daily tendencies averaged by 100 examples for the 15 first spherical harmonics on adiabatic 8-level model are given in Table 4 for 3 averaging types:

$$\left((f)_{K3}\right)_3 = \frac{1}{4}(f_{K-1})_3 + \frac{2}{4}(f)_{K3} + \frac{1}{4}(f_{K+1})_3 ,$$

$$\left(\left((f)_{K3}\right)_3\right)_3 = \frac{1}{4}\left((f_{K-1})_3\right)_3 + \frac{2}{4}\left((f)_{K3}\right)_3 + \frac{1}{4}\left((f)_{K3}\right)_3 ,$$

$$\left[\left[(f)_{K3}\right]_5\right]_5 = \frac{1}{5}\sum_{l=K-2}^{K+2}\left[(f)_{l3}\right]_5 , \qquad (4)$$

where $(f)_{K3} = \frac{1}{4} f_{K-1} + \frac{2}{4} f_K + \frac{1}{4} f_{K+1}$, $\left[(f)_{K3}\right] = \frac{1}{5}\sum_{l=K-2}^{K+2}(f)_{l3}$;

f_K is the function value in the time point K. The filter $[f]_5$ is equivalent to symbolic notation of the operation $\int_0^{5\Delta t} f dt$ in symbolic eq.(2). In some cases we will also make use of the above notation of arbitrary time filter: $\overline{(\ \ )}$.

Each of the averagings (4) transfers the fluctuations into a sub-grid domain with frequencies restricted from the two sides: from one side - by 3-day periods, and by the effect of the filter given. It is seen from Table 4 that sub-grid perturbation effect increases with filter intensification and it changes the mean error at the lower atmospheric level by 0.12 with the strongest of the considered filters. Note that the presence in the model of non-linear terms, which provide long-term effects from sub-grid perturbations, i.e. terms

$$\overline{J(\psi, \Delta\psi)} - J(\overline{\psi}, \overline{\Delta\psi}), \quad \overline{J(\psi, \Phi_p)} - J(\overline{\psi}, \overline{\Phi_p}),$$

$$\overline{J(\psi, \Phi)} - J(\overline{\psi}, \overline{\Phi}), \tag{5}$$

always makes the error still worse in slow fluctuation description (note that slow regular and non-regular fluctuations in given calculations, as opposed to the above only non-regular fluctuations, e.g., according to formula (2).

The dynamic terms calculated for the averaged fields as well as for non-averaged fields, cannot define in many cases the sign of daily tendencies correctly. So there are distortions of amplitudes in both variants and the terms due to the quicker perturbations (5), taken into account, distort the amplitudes of slow perturbations even more. Hence, the parameters β^m_n artificially introduced before these terms are generating or supporting an indicator of quicker fluctuations

$$\frac{\partial \overline{\Phi^m_n}}{\partial t} = (J_{\overline{\Phi}})^m_n + \beta^m_n \left\{ \overline{J_\Phi} - J_{\overline{\Phi}} \right\}^m_n ,$$

would not change their signs rejecting dynamic terms $J_{\overline{\Phi}}$ calculated from the averaged fields.

Thus, the sub-grid fluctuations considered here actively support slow planetary perturbations in the atmosphere, at least, with respect to the dynamics calculated on averaged fields, i.e. dynamics without a sub-grid fluctuation effect. At the same time sub-grid fluctuations must "shatter the atmosphere". It means that there should be compensating processes in the atmosphere.

From the above analysis (see paragraph 1) we know that in the evolution of the largest scale perturbations with frequences which are considered here as sub-grid (e.g. with the filter $\left[\left[(f)_3\right]_5\right]_5$ - from perturbations with 3-day periods to 75 percent of perturbations with 12-day periods) dynamic processes are generated with respect to non-adiabatic heating processes. But it does not mean that dynamic processes must be generated for all the scales and frequences. So it would be interesting to study whether generated diabatic processes are active within the periods shorter than 3 days.

It is very important to carry out the statistical analysis of the atmosphere, which would determine the generating and supporting processes in each range of nonstationary and, especially nonregular atmospheric changes, unlike destructive and passive processes. Such classification does not follow directly from extensive studies of atmospheric energetics. Moreover, it is little known from diagnostic energetic analysis of physical processes, connected with non-stationary non-regular atmospheric perturbations except, perhaps, the cyclonic waves. However, the results of studying nonstationary processes within the wide range of scales and frequencies could help to study the parameterization of sub-grid processes in long-range weather prediction problems.

In fact, the solution of the inverse problems in meteorology as the method of coefficient optimization in postulated mechanisms of heating and dissipation in the development of weather prediction models for different time ranges, has attracted the attention of scientists in our country and abroad. This method (Kurbatkin, 1972, 1974) (Kurbatkin and Sinyaev, 1972) assumes the possibility of parameterization of the smaller and quicker perturbations with respect to the appearance of the largest-scale atmosphere (or, generally, of the large-scale atmosphere). This method does not require direct information of sub-grid processes. Therefore it is important to underline that utilization of this method is physically proved for parameterization on those subgrid processes, which are passive according to a given classification. The development of parameterization methods of subgrid processes, which in their range could be generated according to statistics, is a much more difficult problem. It must be solved by the direct method on the basis of the detailed information about sub-grid processes with sufficiently fine resolution in space and time.

However, this condition is not obligatory. One can calculate an optimized coefficient of the mechanism of heating and dissipation from the solution of the inverse problem, without paying attention to the suggested classification of sub-grid processes, otherwise, the prediction model will be more inflexible and therefore less accurate.

However, let us return our attention to the analysis of the obtained calculations. We will illustrate the process of parameterization of "subgrid" perturbations by "climatic sources" and simple diffusion mechanisms of heating and simple diffusion mechanisms of heating and dissipation. Diagnostic relative errors, averaged by 100 examples, of one-day, . . ., five-day geopotential tendencies of 15 longest spherical harmonics are shown in Tables 5, 7, 9, 11, 13, 15. They are calculated by variant 2 using averaged fields. The results are shown only for 2 types of the filters:

$$\left(\left((f)_3\right)_3\right)_3 \quad \text{and} \quad \left[\left[(f)_3\right]_5\right]_5$$

Tables 5, 7, 9, 11, 13, 15 successively illustrate the contribution of the following factors: 1) dynamics calculated from filtered fields; and then contribution of 2) "climatic sources" and 3) mechanisms of heating and dissipation, both optimized by averaged fields (by the two above filters). For comparison Tables 6, 8, 10, 12, 14 and 16 show the estimation of the contribution in averaged geopotential tendencies of 1) dynamics, preliminarily calculated by non-averaged fields and then time averaged; and contribution of 2) "climatic sources" and 3) mechanisms of heating and dissipation, both optimized by non-averaged fields and then time averaged.

This comparison shows that the filtered prediction model for averaged fields, without including all physical processes affecting the given predicting phenomenon, can give more accurate predictions than a similar model for non-averaged fields at the expense of some statistical improvement of balancing the dynamics and physical processes. But such filtered model will have limited accuracy, and further physical enrichment of this model will not improve predictions unlike a similar one but a non-filtered model, whose accuracy considerably increases at the expense of heating and dissipation.

Tables 6, 8, 10, 12, 14, 16 show diagnostic errors for the averaged geopotential tendencies of variant 1 of model (1). They can be interpreted as errors of variant 2 of model (1) the problem of "full" parameterization of sub-grid processes excluded from explicit description by variant 2 of model (1) by the corresponding filters $\left(\left(\left(\ \right)_3\right)_3\right)_3$ and $\left[\left[\left(\ \right)_3\right]_5\right]_5$ being solved. The errors are bad, therefore, in the class of models described by equations (1) and within the above definition of sub-grid processes, even successful solution of parameterization problem, apparently, would not give an answer to the question of the possibility of the construction of long-range weather prediction model with averaged fields for periods of a month. It is also known that there is not a single model of the most sophisticated modern detailed hydrodynamic ones, able to claculate predictions of anomalies averaged for periods of a month. The sources of remaining errors of diagnostic estimations of averaged geopotential tendencies calculated by averaged fields (similar to variant 2), are: 1) the sub-grid perturbations which are parameterized by "climatic sources" and by the used mechanisms F" mainly describing a quasi-stationary part of sub-grid fluctuation (Kurbatkin, Sinyaev and Yantsen, 1976),2) the quicker modes, generalized by the model persistently in time integration.

Let us introduce additionally in the equation of model (1) the term with the lagging argument $h(t-t_\tau)\dfrac{\partial\Phi(t-t_\tau)}{\partial t}$

$$\left|\frac{\partial\Phi^m_n(p)}{\partial t}\right| = \left[(\mathcal{J}'')^m_n + (F'')^m_n\right]_t + h^m_{jn}(p)\left(\frac{\partial\Phi''^m_n}{\partial t}\right)_{t-t_\tau = t-j\Delta t} \qquad (6)$$

Here the equations of model (1) were taken as resolved with respect to $\dfrac{\partial\Phi''^m_n(p)}{\partial t}$ and a notation similar to (2) was used. The coefficients $h^m_{jn}(p)$ were calculated statistically employing the least square method. The coefficients are shown in Fig. 4 for p=1 000, 500 and 50mb for harmonics: m =0, n=2; m=0, n=4; m=1, n=3; m = 1, n = 5; m=2, n=4; m=2, n=6; for j=0, 1,2. . . , 9; Δt =1 day for the instantaneous fields and the fields averaged by the filters $(\ )_3$ and $((\ )_3)_3$, respectively.

Non-zero values of the calculated coefficients h^m_{jn}, somewhat increasing by absolute magnitude with amplification of averaging, confirm the validity of the above mentioned sources of the left errors. In fact, the additional term is added to correct frequencies statistically. A precisely detected minima of the values of the coefficients h^m_{jn} as the functions of the index j and displacements of these minima towards the increase of j while amplification of time averagings of geopotential fields may be explained by the following fact: the sub-grid eddy transfer of momentum and heat fluxes, considered at a given moment, is not defined by the largest-scale stream at the same moment. When establishing new planetary circulations, sub-grid eddies reach a new state of interaction with slow-varying planetary circulation only for several days. By means of the calculations the time of delay equal to $t_\tau/\Delta t$ was defined, depending on an harmonic and the averaging: for 1 000mb level –in limits from 2 to 4 days; on 50mb level from 2 to 7 days (Fig. 4).

The integral surfaces, which are the most approximated to "inertia prediction" on each isobaric surface, will be the solution of equation (6). Therefore, the numerical experiments with $h \frac{\partial \Phi}{\partial t}$ which have been carried out, first of all, for the effects of sub-grid processes, would give an additional information about some features of their nature. One should seek the solution of the parameterization problem of the sub-grid processes as the development of mechanisms of macro-turbulent exchange of momentum and heat fluxes, which are assumed to be non-linear, with an alternating sign.

Large gradients of the fields predicted are inevitably lost; and in any averaging of meteorological fields, the energy of important unstable formations of the largest-scale processes, is lost. Hence the mechanisms of non-linear turbulent exchange must be capable not only of destroying "old" perturbations in the atmosphere, but also of supporting or intensifying some generated waves selectively.

An investigation was started in this direction, making use of the following barotropic eddy equation (Kurbatkin, Eykher and Krupchatnikov 1975 :

$$\frac{\partial \Delta \psi}{\partial t} + J_{\Omega} = \widetilde{F} + F''(t - t_{\tau}) \qquad (7)$$

where $\widetilde{F}(\theta,\lambda,t)$ is "the climatic source", $F''(t-t_{\tau})$ is the deviation from the climatic value of the term F , taken at the time $t-t_{\tau}$ (for the support of "inertia" effect due to the sub-grid processes), where the term F is equal to

$$F = (a \sin\theta)^{-1} \left[\frac{\partial F_{\theta}}{\partial \lambda} - \frac{\partial (F_{\lambda} \sin \theta)}{\partial \theta} \right] .$$

$$F_\lambda = (a \sin\theta)^{-1} \frac{\partial}{\partial\lambda}(K_{MH} D_T) + a^{-1} \frac{\partial}{\partial\theta}(K_{MH} D_S) \text{ ,}$$

$$F_\theta = (a \sin\theta)^{-1} \frac{\partial}{\partial\lambda}(K_{MH} D_S) - a^{-1} \frac{\partial}{\partial\theta}(K_{MH} D_T) \text{ ,}$$

$$D_T = (a \sin\theta)^{-1}\left[\frac{\partial u}{\partial\lambda} - \frac{\partial}{\partial\theta}(v \sin\theta)\right] \qquad (8)$$

$$D_S = (a \sin\theta)^{-1}\left[\frac{\partial v}{\partial\lambda} - \frac{\partial}{\partial\theta}(u \sin\theta)\right]$$

$$D = (D_T^2 + D_S^2)^{\frac{1}{2}} \text{ ,}$$

$$K_{MH} = a^2(\Delta\lambda)^2\left[\mu_0 \sin^2\theta + \mu_1 \sin^3\theta\, D + \mu_2 \sin^4\theta\, D^2\right]$$

A linear mechanism of the horizontal turbulent viscosity

$$F'' = \left(\mu_\Omega / a^2\right) \Delta^2 \psi'' \text{ .}$$

Was also considered for comparison. The inverse problem of simultaneous determination of the parameters μ_0 , μ_1 and- μ_2 was solved by the least-squares method. In this connection the real hemispherical geopotential fields at the level of 500mb with the time interval $\Delta t = 1$ day, $\Delta\theta = 5°$, $\Delta\lambda = 10°$, from December 1-25, were used.

An spectral method of spherical harmonics was used for the solution of this problem. The stream function ψ was calculated by the linear balance equation. In order to decrease to some extend approximation errors, the expansion coefficients F_n^m of the righthand side (8) of equation (7) were calculated by the formula

$$F_n^m = \frac{1}{a^2} \int_0^{2\pi} \int_0^{\frac{\pi}{2}} K_{MH} \left[D_S \left(\Delta Y_n^{*m} - \frac{2}{\sin^2 \theta} \frac{\partial^2 Y_n^{*m}}{\partial \lambda^2} \right) + 2D_T \frac{1}{\sin \theta} \frac{\partial^2 Y_n^{*m}}{\partial \theta \partial \lambda} \right] \sin \theta d\theta d\lambda \, . \quad Y_n^{*m} = P_n^m(\theta) e^{-im\lambda}$$

obtained as the result of double integration of the right-hand side (8) of equation (7) by parts, taking into consideration that D_T and F_λ are even functions relative to the equator, and ψ , D_S and F_θ are odd functions.

All the calculations were carried out for 81 spherical harmonics: m=0,1, . . ., 8; n = $\varphi(m)$, $\varphi(m)+2, \ldots$, $\varphi(m)+16$; $\varphi(0)=2$, $\varphi(m \neq 0) = |m|$. The calculated parameters μ_0 , μ_1 and μ_2 . optimized by 81 harmonics, and the mean square errors δ for the non-linear mechanism are given below:

$\mu_0 = 2.7 \times 10^5 \ m^2/sec$, $\mu_1 = -3.4 \times 10^9 \ m^2$

$\mu_2 = 0.8 \times 10^{13} \ m^2 \ sec^2$

$$\delta = 1-0.6 \times 10^{-2} ,$$

for the linear mechanism:

$\mu_\Omega = 0{\cdot}9 \times 10^5 \ m^2/sec$

$\delta = 1 - 0{\cdot}2 \times 10^{-2}$;

where

$$\delta = \left[\frac{\sum_K \overline{(L''-F'')^2}}{\sum_K \overline{(L'')^2}} \right]^{\frac{1}{2}}$$

$$L'' = \frac{\partial}{\partial t}\Delta\psi + J_{\Omega} - F \,, \qquad (\ )'' = \sum_m \sum_n (\ )''^m_n \cdot Y^m_n \,,$$

$$\overline{(\ )} = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} (\ ) \sin\theta d\theta d\lambda \,,$$

$\sum_K$ is a summation by 25 days.

Fig. 5 shows for December, 1967 (as an example) the following energetic characteristics as the time functions:

$-\overline{\psi L''}$ above, continuous lines;

$-\overline{\psi F''}$ (increased by 100 times) below,

for the non-linear mechanism, a dashed line,
for the linear mechanism, a dashed-dotted line .

Similar calculations were carried out on real geopotential fields after averaging the time filter $(((f)_3)_3)_3$. Calculated parameter values and similar to the above estimations for the filtered fields are given below:

$\mu_0 = 1\cdot 8 \times 10^5 m^2/sec$, $\mu_1 = -1\cdot 76 \times 10^{10} m^2$,

$\mu_2 = 0\cdot 56 \times 10^{15} m^2/sec$, $\delta = 1 - 0\cdot 0\,1$;

for the linear mechanism:

$\mu_{\Omega} = 1.2 \times 10^5 m^2/sec$

$\delta = 1 - 0.25 \times 10^{-2}$

The energetic characteristics for this case are shown in Fig. 6 (the notation is similar to that of Fig. 5).

We will make two remarks: 1) the magnitude of the error $\delta = 1 - 0.01$ means that the term F'' is of about 10 percent of the weight of the dynamic term $\mathcal{J}_\Omega - \widetilde{\mathrm{F}}$ in equation (7); 2) namely the energetic characteristics averaged over the hemisphere (Fig. 5, 6) distinguish profitably the enough ability of the non-linear mechanism with an alternating sign (8) to characterize non-stationary nature of macroturbulence of the free atmosphere in comparison with the linear mechanism $\mu_\Omega \nabla^4 \psi''$, with the consideration of which the equation of energy has the form

$$\overline{-\psi''\left[\frac{\partial \nabla^2 \psi''}{\partial t} + \left(\mathcal{J}_\Omega - \mathrm{F}''\right)\right]} = \frac{\sum_K \overline{\nabla^4 \psi''\left[\frac{\partial \nabla^2 \psi''}{\partial t} + \left(\mathcal{J}_\Omega - \widetilde{\mathrm{F}}\right)\right]}}{\sum_K \overline{(\nabla^4 \psi'')^2}} \overline{(-\psi'' \nabla^4 \psi'')}$$

or approximately

$$\overline{-\psi'' \cdot \frac{\partial \nabla^2 \psi''}{\partial t}} = \frac{\sum_K \overline{\nabla^4 \psi'' \cdot \left(\mathcal{J}_\Omega - \widetilde{\mathrm{F}}\right)}}{\sum_K \overline{(\nabla^4 \psi'')^2}} (-\psi'' \cdot \nabla^4 \psi'') \cdot$$

where $\dfrac{\sum_K \overline{\nabla^4 \psi''\left(\mathcal{J}_\Omega - \widetilde{\mathrm{F}}\right)}}{\sum_K \overline{(\nabla^4 \psi'')^2}} \approx \mu_\Omega$. In Figs. 5 and 6 a dotted-dashed

line shows weak correlation between $\overline{\left(-\psi'' \dfrac{\partial \nabla^2 \psi''}{\partial t}\right)}$ and

$(-\psi'' \cdot \Delta^4 \psi'')$, and also considerable variability in time of the first magnitude and constancy in time of the second.

The long-range prediction model of atmospheric circulations must include mechanisms of atmosphere and ocean interaction. But even the slowest and largest scale atmospheric perturbations are not waves, just thermically caused by the oceans. This means, that any model of long-range prediction of atmospheric circulation must be capable of simulating the effects of baroclinic development, it must therefore include advective terms and be non-linear; integration over time will be prolonged, multistage. If the ocean in the same range of horizontal scales and frequences plays a passive role in the generation of atmospheric perturbations , then the atmospheric part of the long-range meteorological prediction model should be thoroughly developed, and one can try to add the ocean effect to the meteorological prediction model by simple mechanisms of interaction.

Frequent and complete information about real atmospheric processes with the ocean initial data being absent, allows us to follow with some additional assumptions the changes of the winter layer of the seasonal thermocline from the beginning of autumn (its formation with the highest temperature of the ocean surfaces in a minimally thin quasi-homogeneous layer) to the end of winter (when it is practically destroyed). Among the additional assumptions there is the suggestion that in the beginning of autumn the oceans have the parameters equal to their mean many-year values. Overcoming all the difficulties in modelling changes of the ocean quasihomogeneous layer during winter half a year, using known frequent and complete atmospheric data for the past years, we can obtain a possibility of having initial parameters of the ocean for prediction at any moment of the current winter half a year. These initial parameters of the ocean may depend on "pre-history" of atmospheric processes development when autumn begins.

The following mechanisms for computing the anomalies of ocean heat flux have been prepared:

$$q_0'' = \nu_{0\,sea} \left[h \frac{\partial T_0''}{\partial t} - \widetilde{\left(h \frac{\partial T_0}{\partial t} \right)} \right]$$

$$\frac{\partial h}{\partial t} \sim \frac{\alpha}{(T_0 - T_H)} \left[H \frac{\partial T_0''}{\partial t} - q_0'' / \nu_{0\,sea} \right]$$

where h(t) is the lower boundary of an ocean quasihomogeneous layer:

H is the lower boundary of an active ocean layer; H and T_H are constants; $\left(\frac{\partial T_0''}{\partial t}\right)_{sea} = \left(\frac{\partial T_0''}{\partial t}\right)_{atm.}$; $(\widetilde{\ })$ is the mean value for many years; and $(\ )''$ is the deviation from "climate".

As the function h(t) cannot be defined at any arbitrary moment of time, integration over time for the ocean should be carried out from the beginning of autumn in order to have a possibility of predicting atmospheric largest scale processes at any moment. Therefore, h(t) will depend on "pre-history", while calculating prediction examples during winter half of a year.

Perhaps, this would not lead to completely successful long-range prediction but to a better understanding of prolonged anomalies. It is therefore a scientific aspect of the analyses on long-range prediction, as well as, on the parameterization of the mechanisms, including mechanisms of heating, dissipation, "inertia" and "pre-history", which are of physical but not of calculating nature.

Now it should be noticed, that in the methods given above the computation of the optimal values of external coefficients of the prediction model are based only on real data and on the model equations (1). Therefore, the developed prediction model will still contain errors of different nature, the consideration of which is completely omitted. We mean the errors induced by the defects of spectral structure of initial data and model defects due to energy redistribution. And these errors will appear only on process of time integration of model equations. They can also be minimized by additional diffusive mechanisms. Optimal coefficients of the additional mechanisms in a general case may depend on prediction spans, and therefore, the models optimized for different spans may differ.

It should be underlined that the estimation of the role of heat ocean effect on atmospheric circulations was obtained under the assumption of the absence of ocean temperature anomalies. In the calculations the temperature of the ocean surface always remained normal. Later on one of the primary problems must be revision of similar analysis with given real anomalies of ocean surface temperature. But, the final result indica-

Table 2.

Mean relative errors of calculation of geopotential tendencies for 15 spherical harmonics for 1, 2, . . ., 9 days.

Levels	days								
mb	1	2	3	4	5	6	7	8	9
50	0.78	0.79	0.81	0.84	0.87	0.91	0.95	0.99	1.02
100	0.72	0.72	0.73	0.75	0.78	0.81	0.86	0.90	0.94
200	0.66	0.66	0.67	0.70	0.73	0.77	0.82	0.86	0.91
300	0.61	0.61	0.62	0.64	0.68	0.71	0.75	0.79	0.84
500	0.60	0.60	0.62	0.65	0.70	0.74	0.78	0.83	0.88
700	0.65	0.66	0.68	0.72	0.77	0.82	0.88	0.94	1.01
850	0.69	0.71	0.74	0.79	0.85	0.92	0.99	1.07	1.15
1000	0.75	0.77	0.81	0.86	0.93	1.00	1.08	1.15	1.22

Table 3.

Calculated values of coefficients in dissipation and heating mechanisms for the 6–level spectral model

$$\mu_{\Omega} = 4 \times 10^5 \, m^2 \, sec^{-1}$$

$$K = 0 \cdot 72 \times 10^{-4} \text{ tons } m^{-1} \, sec^{-3}$$

Levels (mb)	10^{-4} tons^2 m^{-2} sec^{-5} K(P)	10^{-6} sec^{-1} ν(P)
20	1.52	11.0
65	3.14	–11.0
200	7.2	–0.04
400	- 10.0	0.29
750	–28.0	ν_0 of the sea 1.90 ν_0 of the ground 0.98

this problem), and under the condition that atmospheric anomalies do not affect the formation of essential ocean anomalies during some time.

Investigation on construction of such hydrodynamic model will explain the conditions under which the knowledge of an almost normal atmosphere will be enough to predict ocean anomalies, important for atmospheric circulation.

To obtain real initial data of oceans for this problem is quite possible as the data must be essentially averaged by time.

Finally, note that prediction of atmospheric anomalies on the appeared ocean anomalies should not be a question of scientific aspect of investigations on development the hydrodynamic theory of long-range weather prediction. There exist some questions in the weather prediction problem where the use of empiric relations does not mean weakness and imperfection of the hydrodynamic theory but, on the contrary, is a consequence of true statements of a problem, and is dictated by objective conditions, e.g. by "incompleteness" of real initial data.

Table 1.

Calculated values of coefficients in dissipation and heating mechanisms for the 8–level spectral model

$$\mu_\Omega = 1.12 \times 10^5 \ m^2 sec^{-1}$$

$$K_0 = 1.35 \times 10^{-4} \ tons\ m^{-1}\ sec^{-3}$$

Levels (mb)	10^{-4} tons^2 m^{-2} sec^{-5} K(p)	10^{-6} sec^{-1} ν(p)
75	0.26	1.34
150	0.31	0.45
250	−3.49	0.48
400	10.2	−0.71
600	25.7	0.07
775	36.6	1.17
925	22.5	ν_0 of the sea 2.62 ν_0 of the ground 1.56

ting the role of the ocean which destroys planetary non-stationary non-regular atmospheric waves, seems unchangeable.

In fact, this result means that the oceans warm the colder air masses and cool the warmer. If it were on the contrary and real anomalies of ocean surface temperature were absent from the calculations, the coefficient $\nu_{0\,sea}$ in the mechanism F_T'' would be negative, but the parameters β_{jn}^{m} would not change their sign, with dynamic rejection.

Ocean heat effect on non-stationary non-regular atmospheric waves of the largest scale plays a passive role, but this is not always the case.

It is believed that the anomalies of the ocean heat effect dictates the prolonged anomalies of planetary atmospheric circulation once in several years in extreme years.(Adem, 1973; Bjerknes, 1962; Blinova, 1970; Kats, 1973; Marchuk, 1974; Monin, 1969; Namias, 1974; Sawyer, 1965). An statistical estimation, maintaining or destroying the role of the ocean according to scheme (2) would not detect such a case. It would not detect it even using real ocean anomalies and a considerably long integration.

If successive integration of equations (2) would be carried out for different time spans till 3 months and even till one year, the average estimation with respect to many cases would show only a passive role of ocean heat effect on the atmosphere.

Scheme (2) will be able to show a generating or a supporting role of large ocean anomalies by preserving the sign β_{jn}^{m} with dynamic rejection. The tendency of changes of atmospheric circulation due to ocean anomalies will appear only after the exclusion of those dominant non-regular fluctuations of atmospheric circulation, which are assumed not to be maintained but destroyed by the oceans. By means of considerable averagings of meteorological fields but not of model equations, it is possible to exclude the above non-regular fluctuations. Though it is equivalent to an artificial simplification of atmospheric dynamics in a long-range prediction model, it is possible in models of ocean anomaly prediction using real initial data in oceans under the condition of averaged atmospheric anomalies (thus the quicker processes are excluded in

Table 4

Mean relative errors of one-day geopotential tendencies.

$$\frac{\partial \Phi}{\partial t} = \mathcal{J}$$

Filters	$((f)_3)_3$		$(((f)_3)_3)_3$		$\left[\left[(f)_3\right]_5\right]_5$	
Levels (mb)	$\overline{\mathcal{J}}_{\Phi}$	$\mathcal{J}_{\overline{\Phi}}$	$\overline{\mathcal{J}}_{\Phi}$	$\mathcal{J}_{\overline{\Phi}}$	$\overline{\mathcal{J}}_{\Phi}$	$\mathcal{J}_{\overline{\Phi}}$
50	1.18	1.14	1.25	1.20	1.72	1.67
100	0.99	0.94	1.04	0.97	1.39	1.27
200	0.88	0.87	0.92	0.91	1.14	1.13
300	0.83	0.84	0.88	0.88	1.08	1.07
500	0.96	0.96	1.05	1.03	1.30	1.30
700	1.25	1.23	1.35	1.32	1.80	1.74
850	1.53	1.48	1.67	1.61	2.30	2.18
1000	1.78	1.73	1.96	1.89	2.67	2.55

MEAN RELATIVE ERRORS

FILTER $(((f)_3)_3)_3$

Table 5

$$\frac{\partial \overline{\Phi}}{\partial t} = \overline{J}_{\Phi}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.20	1.23	1.28	1.34	1.43
100	0.97	0.98	1.01	1.06	1.12
200	0.91	0.93	0.96	1.00	1.06
300	0.88	0.90	0.92	0.96	1.02
500	1.03	1.06	1.10	1.16	1.25
700	1.32	1.37	1.44	1.54	1.66
850	1.61	1.67	1.78	1.92	2.10
1000	1.89	1.96	2.09	2.26	2.48

Table 6.

$$\frac{\partial \overline{\Phi}}{\partial t} \quad \overline{J}_{\Phi}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.25	1.28	1.34	1.41	1.49
100	1.04	1.06	1.10	1.15	1.22
200	0.92	0.94	0.98	1.03	1.09
300	0.88	0.90	0.93	0.98	1.04
500	1.03	1.06	1.11	1.18	1.26
700	1.35	1.40	1.48	1.58	1.71
850	1.67	1.74	1.85	2.00	2.19
1000	1.96	2.04	2.17	2.35	2.58

MEAN RELATIVE ERRORS

FILTER $(((f)_3)_3)_3$

Table 7.

$$\frac{\partial \overline{\Phi}}{\partial t} = \mathcal{J}_{\overline{\Phi}} + \widetilde{F}_{\overline{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	0.82	0.83	0.85	0.88	0.91
100	0.76	0.77	0.78	0.80	0.84
200	0.74	0.75	0.76	0.79	0.83
300	0.70	0.71	0.73	0.75	0.78
500	0.72	0.73	0.76	0.78	0.82
700	0.79	0.80	0.83	0.86	0.91
850	0.85	0.87	0.90	0.95	1.01
1000	0.94	0.96	0.99	1.04	1.11

Table 8.

$$\frac{\partial \overline{\Phi}}{\partial t} = \overline{(\mathcal{J}_{\Phi} + \widetilde{F}_{\Phi})}$$

mb \ $j\Delta t$	1	2	3	4	5
50	0.84	0.85	0.86	0.89	0.92
100	0.78	0.78	0.80	0.83	0.86
200	0.72	0.74	0.76	0.79	0.82
300	0.68	0.69	0.71	0.74	0.77
500	0.69	0.71	0.73	0.76	0.80
700	0.77	0.79	0.82	0.86	0.90
850	0.84	0.86	0.90	0.95	1.01
1000	0.92	0.94	0.98	1.03	1.09

MEAN RELATIVE ERRORS

FILTER $(((f)_3)_3)_3$

Table 9.

$$\frac{\partial \overline{\Phi}}{\partial t} = \mathcal{J}_{\overline{\Phi}} + \widetilde{F}_{\overline{\Phi}} + F''_{\overline{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	0.83	0.84	0.86	0.89	0.92
100	0.75	0.75	0.76	0.78	0.82
200	0.71	0.72	0.74	0.77	0.80
300	0.67	0.68	0.69	0.71	0.74
500	0.68	0.69	0.70	0.73	0.77
700	0.74	0.76	0.78	0.81	0.85
850	0.80	0.82	0.85	0.89	0.95
1000	0.86	0.88	0.91	0.96	1.02

Table 10.

$$\frac{\partial \overline{\Phi}}{\partial t} = \overline{\left(\mathcal{J}_{\Phi} + \widetilde{F}_{\Phi} + F''_{\Phi}\right)}$$

mb \ $j\Delta t$	1	2	3	4	5
50	0.84	0.85	0.87	0.90	0.93
100	0.77	0.78	0.80	0.82	0.85
200	0.70	0.71	0.74	0.76	0.80
300	0.65	0.66	0.67	0.70	0.73
500	0.63	0.64	0.66	0.69	0.73
700	0.69	0.70	0.73	0.76	0.80
850	0.75	0.77	0.80	0.85	0.90
1000	0.82	0.84	0.87	0.91	0.97

MEAN RELATIVE ERRORS

FILTER $\left[\left[(\mathcal{S})_3\right]_5\right]_5$

Table 11.

$$\frac{\partial \overline{\Phi}}{\partial t} = \mathcal{J}_{\overline{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.67	1.69	1.71	1.73	1.76
100	1.27	1.27	1.28	1.30	1.32
200	1.13	1.14	1.15	1.17	1.21
300	1.07	1.07	1.08	1.11	1.14
500	1.30	1.30	1.32	1.36	1.42
700	1.74	1.76	1.80	1.86	1.95
850	2.18	2.21	2.27	2.38	2.52
1000	2.55	2.59	2.68	2.80	2.98

Table 12.

$$\frac{\partial \overline{\Phi}}{\partial t} = \overline{\mathcal{J}_{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.72	1.74	1.77	1.80	1.84
100	1.39	1.40	1.41	1.44	1.47
200	1.14	1.14	1.16	1.18	1.22
300	1.08	1.08	1.10	1.12	1.16
500	1.30	1.30	1.32	1.36	1.42
700	1.80	1.81	1.85	1.91	2.01
850	2.30	2.33	2.40	2.50	2.64
1000	2.67	2.72	2.80	2.94	3.12

MEAN RELATIVE ERRORS

FILTER $\left[\left[(f)_3\right]_5\right]_5$

Table 13

$$\frac{\partial\overline{\Phi}}{\partial t} = \overline{\mathcal{J}_{\Phi}} + \overline{\widetilde{F}_{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.08	1.08	1.09	1.09	1.09
100	0.95	0.95	0.96	0.96	0.98
200	0.87	0.87	0.87	0.88	0.90
300	0.81	0.81	0.81	0.82	0.84
500	0.86	0.86	0.87	0.88	0.91
700	0.96	0.97	0.98	1.00	1.04
850	1.07	1.08	1.10	1.13	1.18
1000	1.16	1.17	1.19	1.23	1.28

Table 14.

$$\frac{\partial\overline{\Phi}}{\partial t} = \overline{\left(\mathcal{J}_{\Phi} + \widetilde{F}_{\Phi}\right)}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.05	1.06	1.07	1.07	1.08
100	1.00	0.99	0.99	0.99	1.00
200	0.84	0.84	0.84	0.84	0.86
300	0.76	0.76	0.76	0.77	0.79
500	0.80	0.80	0.80	0.82	0.84
700	0.91	0.92	0.93	0.95	0.98
850	1.02	1.03	1.05	1.08	1.12
1000	1.10	1.10	1.12	1.16	1.20

MEAN RELATIVE ERRORS

FILTER $\left[\left[(f)_3\right]_5\right]_5$

Table 15.

$$\frac{\partial\overline{\Phi}}{\partial t} = \overline{\mathcal{J}_{\Phi}} + \overline{\widetilde{F}_{\Phi}} + \overline{F''_{\Phi}}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.07	1.07	1.08	1.08	1.08
100	0.91	0.91	0.92	0.92	0.94
200	0.83	0.83	0.83	0.84	0.86
300	0.76	0.76	0.76	0.77	0.79
500	0.79	0.79	0.80	0.82	0.84
700	0.90	0.91	0.92	0.95	0.98
850	1.02	1.02	1.04	1.07	1.12
1000	1.06	1.07	1.09	1.12	1.17

Table 16.

$$\frac{\partial\overline{\Phi}}{\partial t} = \overline{\left(\mathcal{J}_{\Phi} + \widetilde{F}_{\Phi} + F''_{\Phi}\right)}$$

mb \ $j\Delta t$	1	2	3	4	5
50	1.07	1.07	1.08	1.09	1.10
100	0.98	0.98	0.97	0.97	0.98
200	0.81	0.81	0.81	0.81	0.83
300	0.71	0.71	0.71	0.72	0.73
500	0.71	0.71	0.72	0.73	0.76
700	0.80	0.81	0.82	0.84	0.87
850	0.90	0.91	0.93	0.96	1.00
1000	0.96	0.97	0.98	1.02	1.06

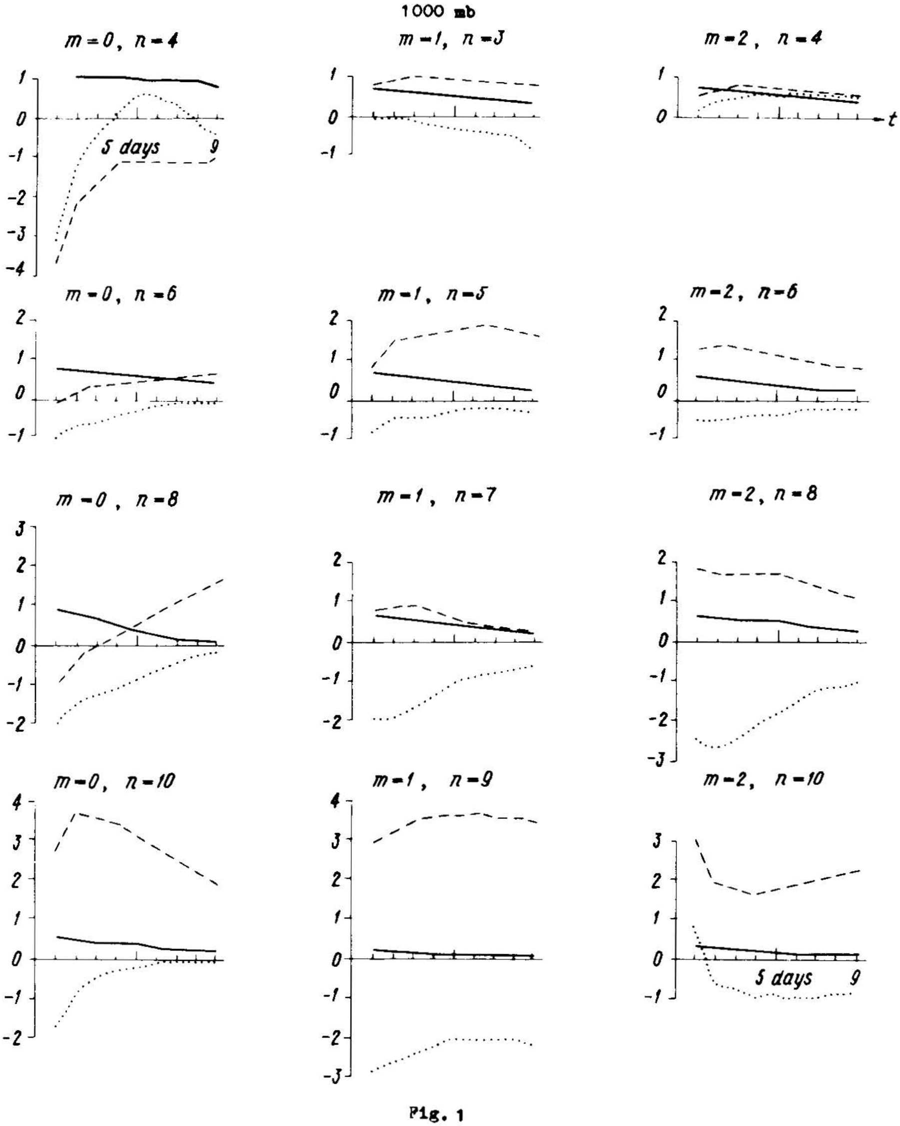

Fig. 1

Fig. 1 The estimation of correlative relation by 8-level spectral model at 1 000 mb. level: The continuous line is the geopotential change $\frac{\partial \Phi''}{\partial t}$ for different spans with the dynamical factors ($\mathcal{J}''$); the dashed line, $\frac{\partial \Phi}{\partial t}$ and $\mathcal{J}''$ with mechanisms of heating F_T''; the dotted line, $\frac{\partial \Phi}{\partial t}$ with F_T'' with the rejection ($\mathcal{J}''$).

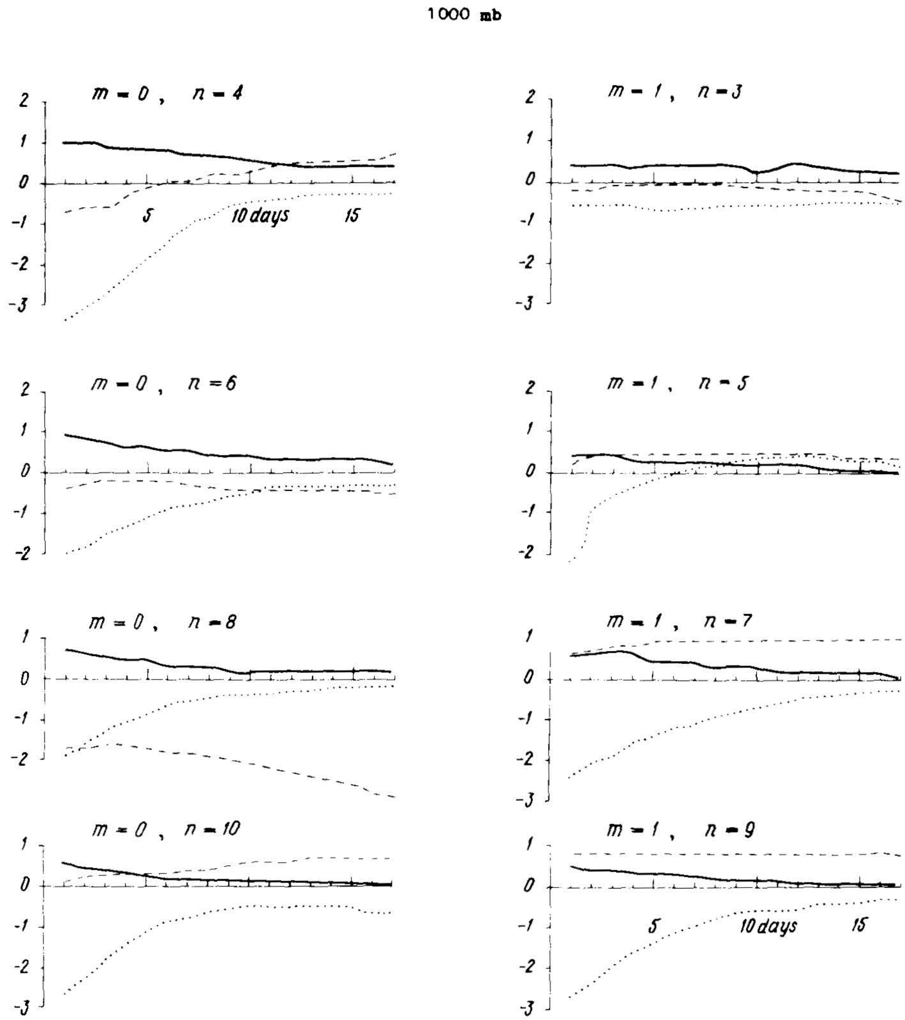

Fig. 2

Fig. 2. The estimation of correlative relation by 6-level spectral model at 1 000 mb. level: the continuous line is the geopotential change $\frac{\partial \Phi''}{\partial t}$ for different periods with the dynamical factors ($\mathcal{J}''$) ; the dashed line, $\frac{\partial \Phi''}{\partial t}$ and $\mathcal{J}''$ with mechanisms of heating F''_T : the dotted line $\frac{\partial \Phi''}{\partial t}$ with F''_T with the rejection $\mathcal{J}''$.

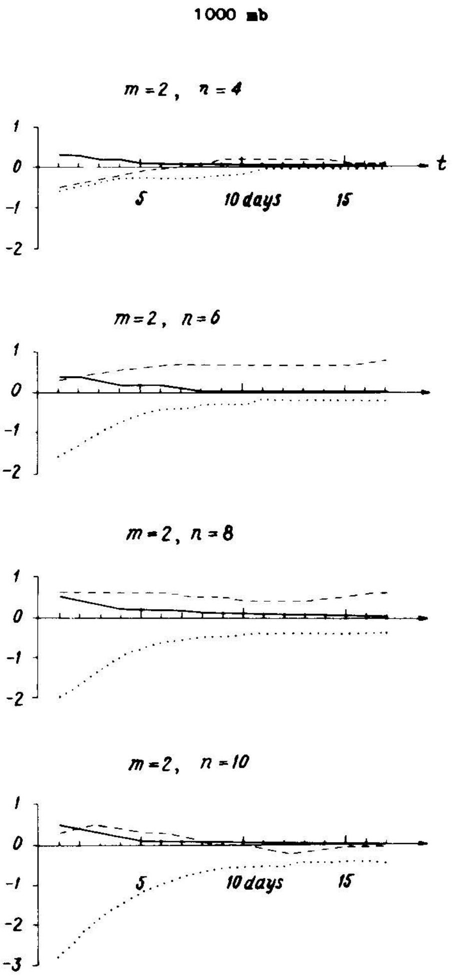

Fig. 3

Fig. 3. See Fig. 2, only for the harmonics m =2, n =4; m=4, n =6; m =2, n =8; m= 2 , n=10.

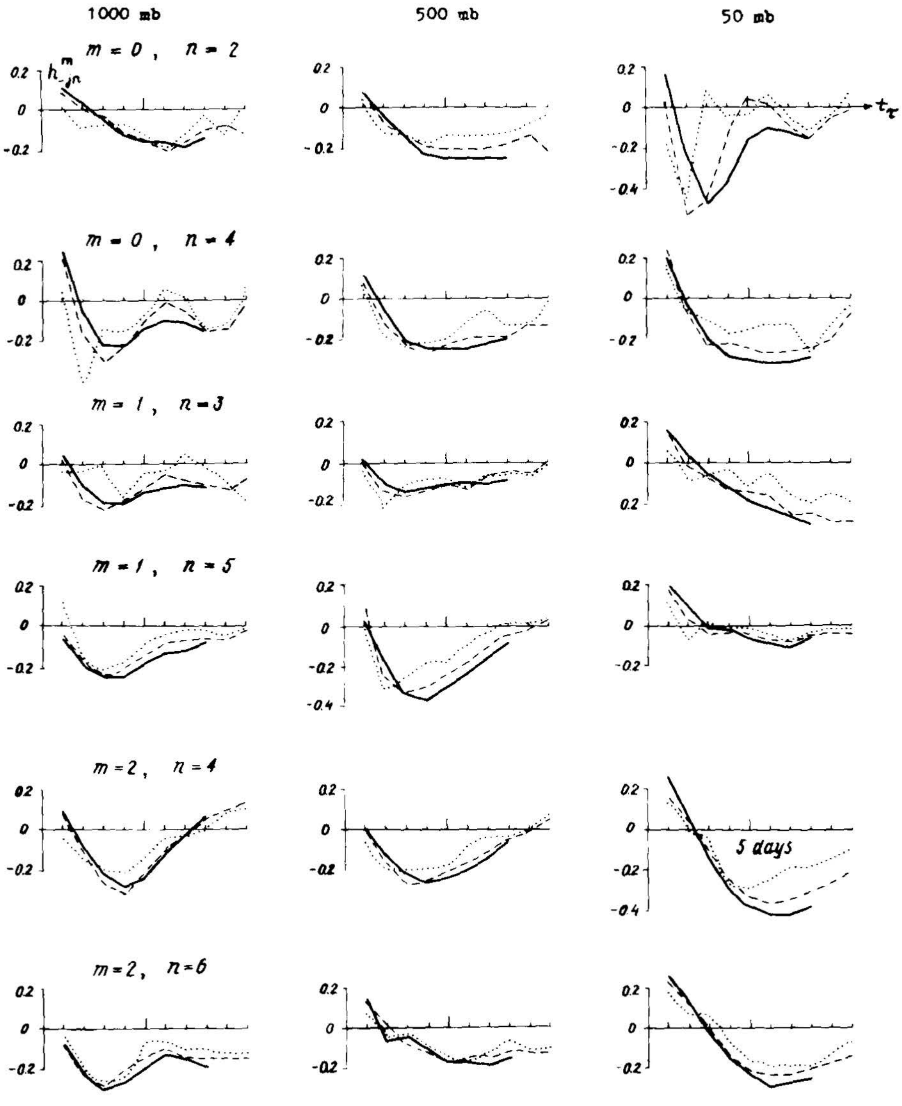

Fig. 4

Fig. 4. The factors h^m_{-jn} from the term $h(t-t_\tau)\frac{\partial\Phi(t-t_\tau)}{\partial t}$ as functions of the lagging argument $j\Delta t$ for 6 harmonics, calculated: 1) on momentary fields (dots), 2) on the averaged fields with the time filter $(f)_3$ (dashed lines), 3) on the averaged fields with the time filter $((f)_3)_3$ (continuous line) p =1 000 mb, 500 mb, 50 mb.

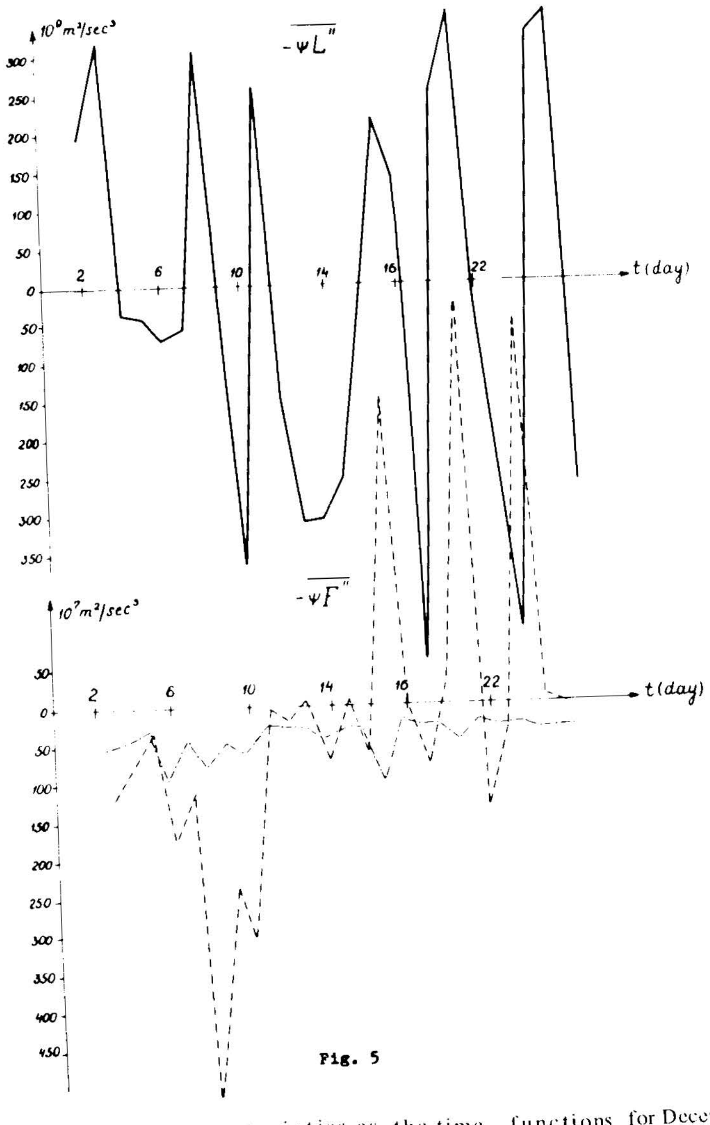

Fig. 5 Energetic characteristics as the time functions for December 1967. $-\overline{\psi L''}$ (above, a continuous line). $-\overline{\psi F''}$ (below) for the non-linear mechanism (a dashed line), for the linear mechanism (a dotted-dashed line).

Energetic characteristics as well as optimized coefficients of the mechanism F″, are calculated on momentary fields.

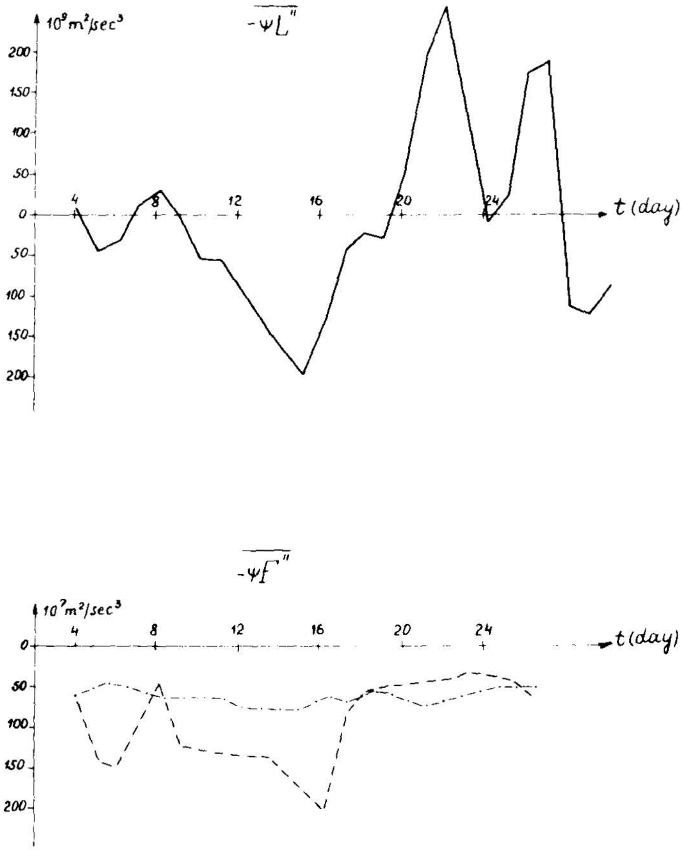

Fig. 6

Fig. 6. See Fig. 5, only energetic characteristics are calculated on the averaged fields by the filter $(((f)_3)_3)_3$

BIBLIOGRAPHY

ADEM, J. 1973. Ocean effects on weather and climate, *Geofísica Internacional*, 13 No. 1: 1-71.

BJERKNES, J., 1962. Synoptic survey of the interaction of sea and atmosphere in the North Atlantic, *Geofysiske Publikasdoner*, 24: 115-145. Norvegica.

BLINOVA, E. N. 1970. large-scale processes and numerical simulation of general atmospheric circulation and long-term weather prediction, *Meteorologiya i gidrologiya*, pp. 3-15.

KURBATKIN, G. P., 1972. Ultralong atmospheric waves and long-range forecasting, *Tellus*, 24: 499-513.

KURBATKIN, G. P. AND V. N. SINYAEV, 1972. Diagnostic estimations of turbulent friction and macro-scale "external" heat effect on general circulation of the atmosphere, *Izv. Fizika atmosphery i okeana*, 8: 1246-1252.

KURBATKIN, G. P., 1974. Hydrodynamic long-range prediction model with *a priori* mean climatic constraints and excessive degrees of freedom Proceedings of Symposium 17-22 September, Novosibirsk, 1973, part 1, pp. 34-50.

KURBATKIN, G. P., V. N. SINYAEV AND A. G. YANTSEN, 1976. Diagnostic investigations of planetary atmospheric waves on the basis of a spectral prediction model, *Izv. Fisika atmosphery i okeana*, 12, No. 3.

KURBATKIN, G. P., M. SH. EYKHER AND V. N. KRUPCHATNIKOV, 1975. The study of the sensibility of the general atmospheric circulation model to some mechanism of non-linear viscosity. The GARP programme on numerical experimentation, report No. 9: 6-22.

KATS, A. L. 1973. The unusual summer of 1972, Leningrad, Gidrometeoizdat, 58 pp.

MARCHUK, G. I. 1974. Numerical solution of problems of the atmosphere and ocean dynamics, Leningrad, Gidrometeoizdat, 303 pp.

MONIN, A. S., 1969. Weather prediction as the problem of physics, Moskva, Nauka, 184 pp.

NAMIAS, J. 1974. Longevity of coupled air-sea-continent system, *Monthly Weather Review*, 102: 638-648.

SMAGORINSKY, J., 1970. Numerical simulation of the global atmosphere, in *The global circulation of atmosphere. Royal-Meteorological Society*, 257.

SAWYER, J. S., 1965. Notes on the possible physical causes of long-term weather anomalies, WMO Technical Note, No. 66: 227-248.

WIIN NIELSEN, A., 1967. On the annual variation and spectral distribution of atmospheric energy, *Tellus*, 19: 540-559.