Id: 7890
Au: Trosnikov, Igor.
Ti: Prognostic experiments for prediction of Low-Frequency components of the atmospheric circulation.
Fo: Anais da Academia Brasileira de Ciencias; 68(1):59-65, 1996.
Re: Two series of prognostic experiments were conducted with a barotropic model. In one of them, the model was used for the calculation of long time series of streamfunction fields. These data were used for creating ensembles of the initial conditions and for the estimation of a forcing. The second series of the prognostic experiments were conducted with real data. The experiments were aimed at evaluating the prognostic ability of the barotropic model for long time period integration, and studying the influence of the lagged average forecast (LAF) technique on prediction errors. The experiments have shown that using LAF technique makes better the prediction skill of the model, and the predicted linear trend of time evolution of the atmospheric circulation has a positive skill beyond 10 days.
Lo: INPE-6775-PRE/2785.

Academia Brasileira de Ciências

Regional Conference on Global Change

MCMXVI

Vol. 68, Supl. 1, 1996

Prognostic Experiments for Prediction of Low-Frequency Components of the Atmospheric Circulation

IGOR TROSNIKOV

INPE-CPTEC – Rodovia Presidente Dutra, km 40, 12643-00 Cachoeira Paulista, SP
(igor@cptec.inpe.br)

Manuscript received on March, 1996; accepted for publication on October 30, 1996

ABSTRACT

Two series of prognostic experiments were conducted with a barotropic model. In one of them, the model was used for the calculation of long time series of streamfunction fields. These data were used for creating ensembles of the initial conditions and for the estimation of a forcing. The second series of the prognostic experiments were conducted with real data. The experiments were aimed at evaluating the prognostic ability of the barotropic model for long time period integration, and studying the influence of the lagged average forecast (LAF) technique on prediction errors. The experiments have shown that using LAF technique makes better the prediction skill of the model, and the predicted linear trend of time evolution of the atmospheric circulation has a positive skill beyond 10 days.

Key words: Atmosphere, climate, barotropic, low-frequency, prediction.

1. INTRODUCTION

The short-term climatic variations, which are determined by the deviation of atmospheric circulation elements from climatic mean, have life spans of weeks to months. They exceed the average life span of synoptic processes, which is of the order of three to five days. This behavior of climatic system is due to the fact that large-scale atmospheric circulation has multiple regimes, each of which has a characteristic spatial pattern and mean time of duration larger than the life span of the cyclones. The climate is the result of averaging all over these regimes. Nonlinearity and instability of the atmospheric processes do not allow to predict the short-term climatic variations with all details, however the low-frequency components of the atmospheric circulation may be estimated by dynamical methods.

This report contains the results of numerical experiments with a barotropic model of the atmosphere. The experiments were performed to study the possibility of forecasting beyond the predictability limit, estimating of the influence of the baroclinic forcing on a forecast skill, and estimating the linear trend of a time evolution of the atmospheric circulation. Finally the geometrical interpretation of the climate system evolution during two weeks in a phase space is presented.

2. BAROTROPIC MODEL

The model is governed by the barotropic form of the equation for the conservation of potential vorticity on the sphere

$$\frac{\partial \zeta}{\partial t} = [\zeta + f, \psi] - \sigma \zeta + F,$$

where the following notation is used

ζ	vorticity,
ψ	streamfunction,
$f = 2\Omega \sin\varphi$	Coriolis parameter,

σ linear damping with a characteristic time $\sigma^{-1} = 10$ days,

$\bar{F}$ forcing,

$$[A,B] = \frac{1}{a^2 \cos\varphi}\left(\frac{\partial A}{\partial \lambda}\frac{\partial B}{\partial \varphi} - \frac{\partial A}{\partial \varphi}\frac{\partial B}{\partial \lambda}\right)$$ is the Jacobian,

a radius of the earth,

Ω its angular velocity,

λ longitude,

φ latitude,

t time.

The spectral method is used for the numerical integration of the model. The vorticity equation is spectrally transformed with rhomboidal wavenumber M on the sphere:

$$\psi(\lambda, \mu, t) = \sum_{m}^{M} \sum_{n=|m|}^{|m|+M} \psi_{m,n}(t)\, Y_{m,n}(\lambda, \mu),$$

where $Y_{m,n} = P_n^m(\mu)e^{im\lambda}$, $P_n^m(\mu)$ are the associated Legendre functions, and $\mu = \sin\varphi$. Substituting the spectral expansions into the vorticity equation, we finally obtain a set of ordinary differential equations for the expansion coefficients

$$-\frac{n(n+1)}{a^2}\frac{\partial \psi_{m,n}}{\partial t} = -\frac{2\Omega}{a^2} im\, \psi_{m,n} +$$

$$+ J_{m,n} + \sigma \frac{n(n+1)}{a^2} \psi_{m,n} + F_{m,n},$$

where $F_{m,n}$ and $J_{m,n}$ are the expansion coefficients for the forcing and Jacobian. The transform method for calculation Jacobian coefficient is used (Orszag, 1970). Computer code of the barotropic model includes the basic subroutines of the general circulation model, which is used at CPTEC (Center for Weather Forecasting and Climate Prediction) for weather prediction and numerical modeling.

3. FORCING

A major concern in developing barotropic models is the incorporation the effects of baroclinic motions. In our model these effects are included by means of the baroclinic forcing, which is calculated by two methods. For the first method, a forcing is calculated as the remainder term of the barotropic equation, after substituting streamfunction for its known values:

$$\bar{F} = \frac{\zeta^{k+1} - \zeta^k}{\Delta t} - [\zeta^k + f, \psi^k] + \sigma\zeta^k,$$

where Δt is the time step equal one day, ζ^k, ψ^k are the known values of vorticity and streamfunction for the time t_k.

For the second method, a forcing $\bar{F}$ is calculated as a baroclinic forcing in the model with two layers (Lorenz, 1960).

$$\bar{F} = [\nabla^2\tau, \tau] + \sigma\nabla^2\tau,$$

where

$$\tau = \frac{1}{2}(\psi_1 - \psi_2), \quad \psi_1 = \frac{1}{p}\int_0^p \psi dp',$$

$$\psi_2 = \frac{1}{p_0 - p}\int_p^{p_0} \psi dp',$$

$$\nabla^2\tau = \frac{1}{a^2}\left(\frac{1}{\cos\varphi}\frac{\partial}{\partial\varphi}\cos\varphi\frac{\partial\tau}{\partial\varphi} + \frac{1}{\cos^2\varphi}\frac{\partial^2\tau}{\partial\lambda^2}\right).$$

4. NUMERICAL EXPERIMENTS

A rhomboidal-truncated spectral representation of the fields with total wavenumber M=21 (R21) and LAF (Lagged Average Forecast) technique (Hoffman, and Kalnay, 1983) have been used for the prognostic experiments.

First of all, the model run for the calculating time series of the streamfunctions at 500 hPa. The integration started from real data valid at 15 December 1982 with the forcing which was calculated by the second method for the same date. The calculated streamfunctions of 41, 42, 43, and 43 days were used as the initial conditions for the four members of the forecast ensemble. The forecast period included 15 days from 44 to 58. The forecast forcing was calculated from the previous forecast period streamfunctions. The forecast period streamfunctions also were used for the forcing. Such forcing will be named the "exact" forcing. Hereafter we will use the scaled streamfunction

$$\Psi = \frac{f_0}{g}\psi ,$$

where f_0 is the Coriolis parameter at latitude of 5°, g is the gravity acceleration. Ψ has the dimension of length (m).

The errors of an analysis were simulated by adding to the initial condition field the same field shifted by 180° and scaled for 10 m. As a measure of the prediction skill of the model, root mean square error $\mathrm{RMSE} = (\overline{(\Psi_o - \Psi_p)^2})^{1/2}$ is used. The overbar indicates a spatial mean. The subscript o refers to the observed value and subscript p refers to the predicted value. The ensemble RMSE are shown in Figure 1. Members of ensemble are marked by open circles and black circles are persistence forecast. The squares indicate the ensemble mean forecast. The ensemble mean forecast is calculated as

$$\Psi_e(t,t_0) = \frac{1}{N}\sum_{k=0}^{N-1}\Psi(t, t_0 - k\Delta t),$$

where $\Psi(t, t_0)$ is a forecast from t_0 to t, N is the number of members of the ensemble. It should be pointed out that LAF-forecast is better than member forecasts. Figure 2 shows the RMSE for the three ensemble mean forecasts: 1) without forcing (cross), 2) with forcing (square) and 3) with "exact" forcing (open circle) and persistence forecast (black circle). The forcing was calculated by the first method.

The second set of the prognostic experiments has been carried out with real data from the CPTEC prognostic data base. The data from 7 to 25 March 1995 were used. RMSE for this forecasts shown in Figure 3. While all members of the forecast ensemble have RMSE larger than the persistent forecast, the ensemble mean forecast has less RMSE after 6 days.

It's very difficult to obtain a good detailed forecast with a barotropic model. We suggest that forecast of low-frequency barotropic components of the circulation would be better. For example, a linear trend of the streamfunction in every point is

$$\Psi_{LT}(\lambda,\varphi,t) = A(\lambda,\varphi)t + B(\lambda,\varphi).$$

The coefficients A and B are computed by the least mean squares method. Figures 4a and 4b show the observed and predicted tendency (A). The correlation of the observed and predicted trend

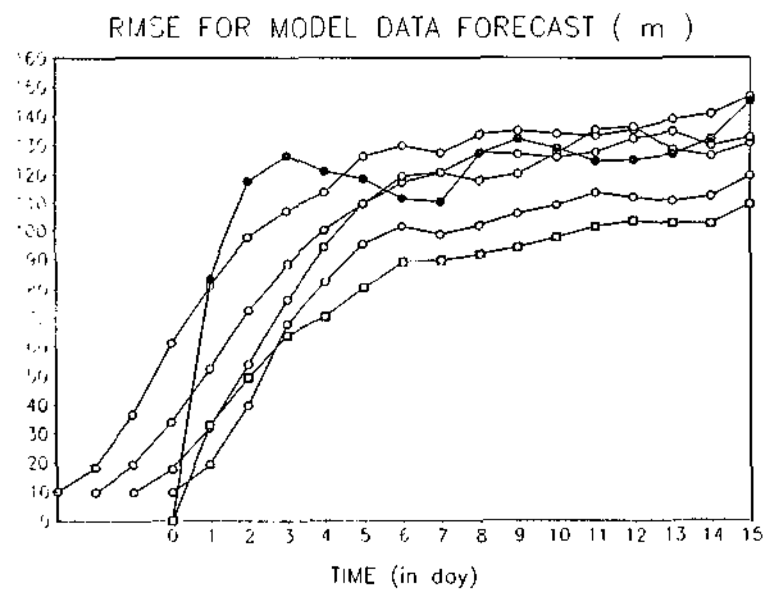

Fig. 1 — Root mean square (rms) errors (in m) of the ensemble forecast. The members of the ensemble marked open cicles, the black cicles are the persistence forecast. The squares indicate the ensemble mean forecast.

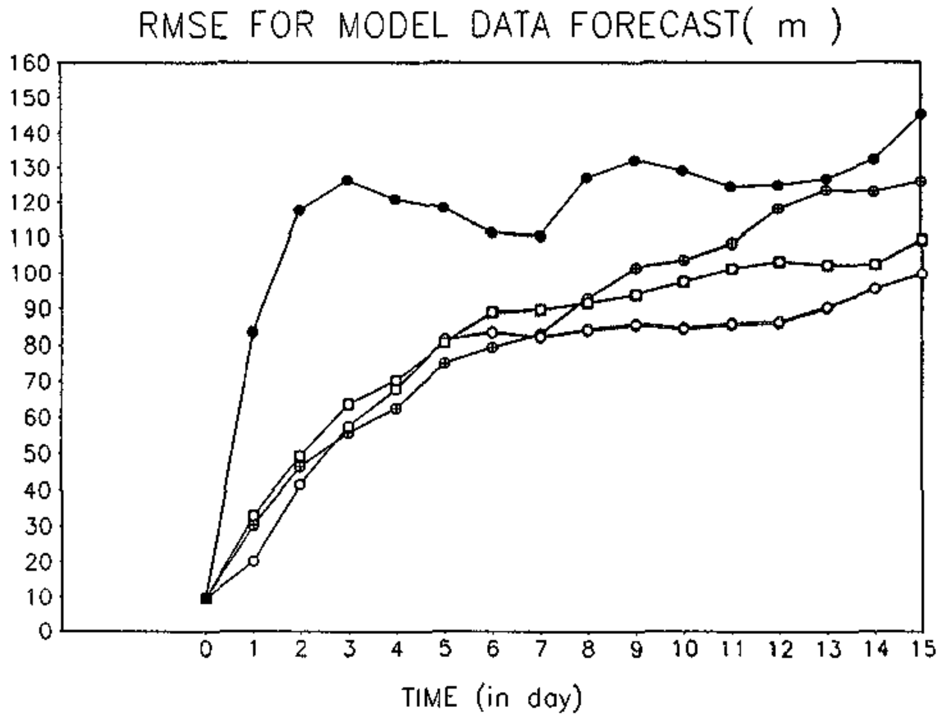

Fig. 2 — The forecast sets: without forcing (cross), with forcing (square) and with "exact" forcing (open cicle). The persistence forecast are marked by the black circles.

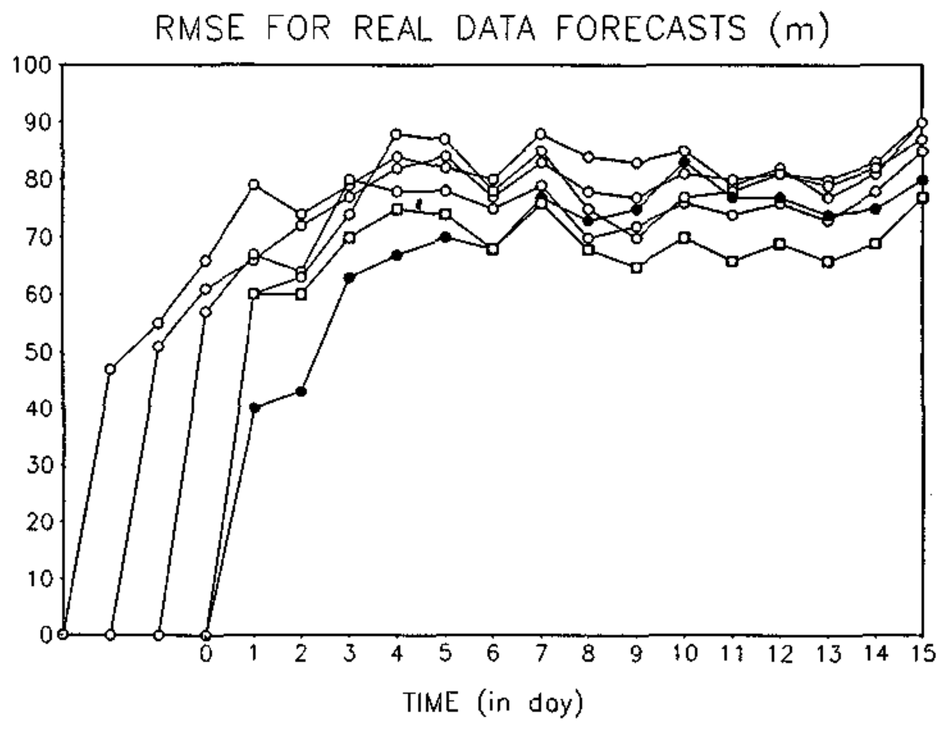

Fig. 3 — The root mean square (rms) errors (in m) of the ensemble forecast with the real data.

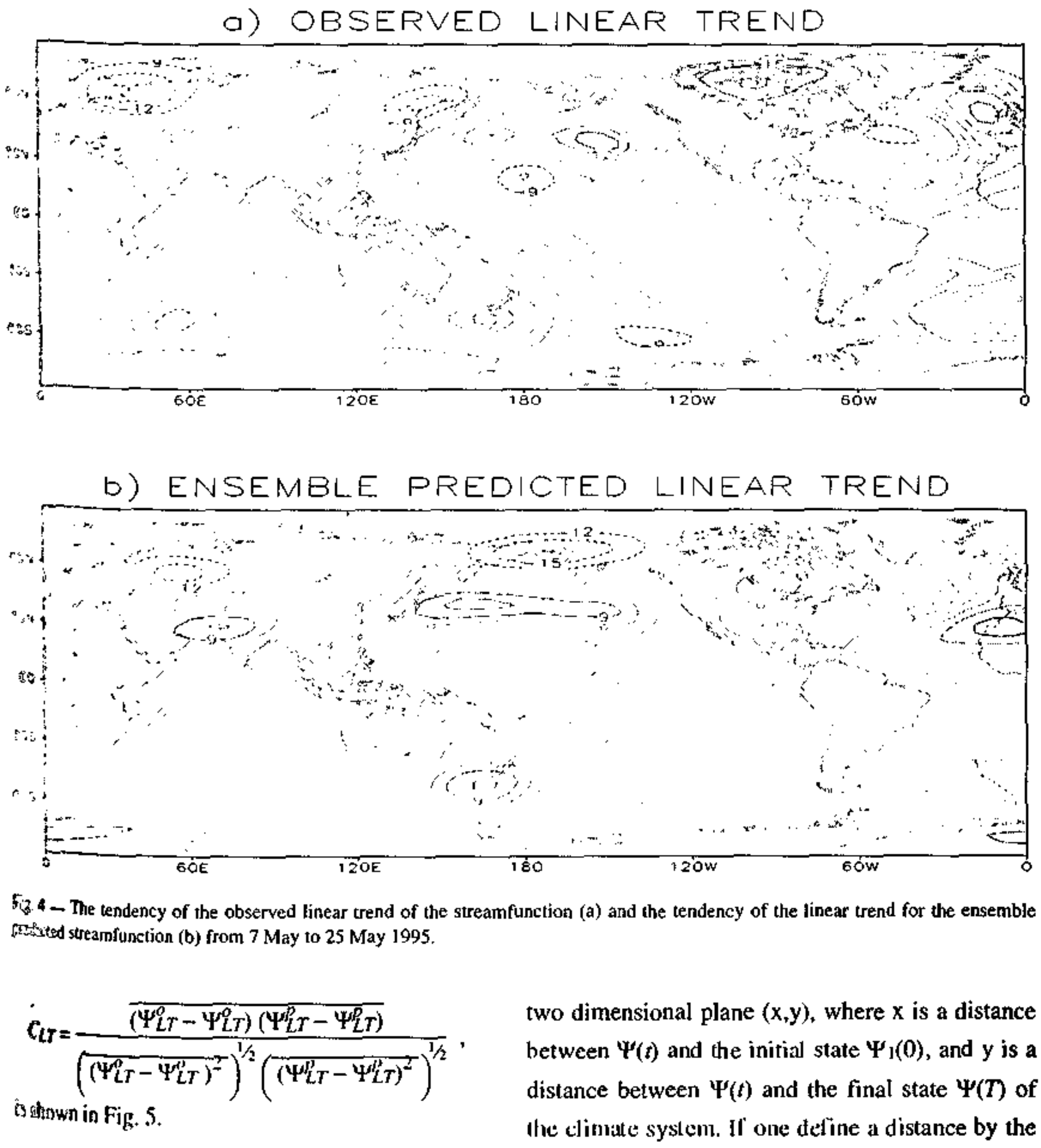

Fig. 4 — The tendency of the observed linear trend of the streamfunction (a) and the tendency of the linear trend for the ensemble predicted streamfunction (b) from 7 May to 25 May 1995.

$$C_{LT} = \frac{\overline{(\Psi^{o}_{LT} - \overline{\Psi^{o}_{LT}})\,(\Psi^{p}_{LT} - \overline{\Psi^{p}_{LT}})}}{\left(\overline{(\Psi^{o}_{LT} - \overline{\Psi^{o}_{LT}})^{2}}\right)^{1/2}\left(\overline{(\Psi^{p}_{LT} - \overline{\Psi^{p}_{LT}})^{2}}\right)^{1/2}},$$

is shown in Fig. 5.

5. TIME EVOLUTION OF CLIMATE SYSTEM IN PHASE SPACE

A phase space of the climate system is very multidimensional. Therefore to represent trajectory of the climate system in a phase space it is necessary to map one in small dimensional subspace. There are many ways to do it. Let us represent a state of the climate system $\Psi(t)$ how a point of the spectral coefficient space and map the time evolution during the time period from t = 0 to t = T in two dimensional plane (x,y), where x is a distance between $\Psi(t)$ and the initial state $\Psi_1(0)$, and y is a distance between $\Psi(t)$ and the final state $\Psi(T)$ of the climate system. If one define a distance by the energy norm

$$\|\Psi\| = \left(\sum_{m,n} \frac{n(n+1)}{a^2}\,\Psi_{m,n}\,\Psi^{*}_{m,n}\right)^{1/2},$$

where * is complex conjugation, then

$$x = \|\Psi(t) - \Psi(0)\| \quad \text{and} \quad y = \|\Psi(t) - \Psi(T)\|.$$

Figure 6 shows different trajectories in (x,y) plane. The x-crosses indicate observed positions of the climate system on the trajectory during 19 days. The black squares, diamonds and triangles

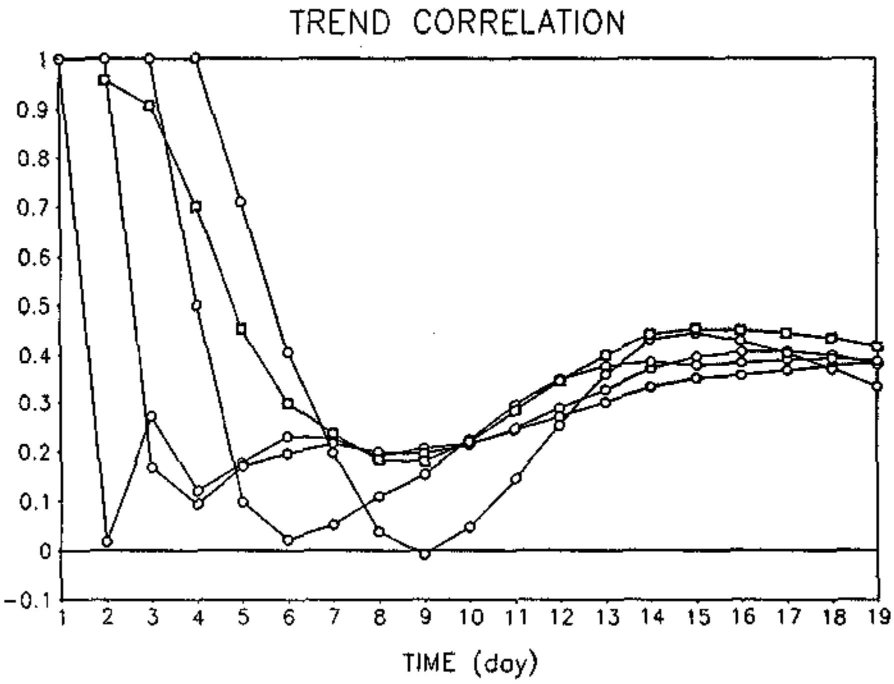

Fig. 5 — The correlation of the observed and predicted trends. The ensemble members are marked by the cross and the ensemble forecast is marked by the square.

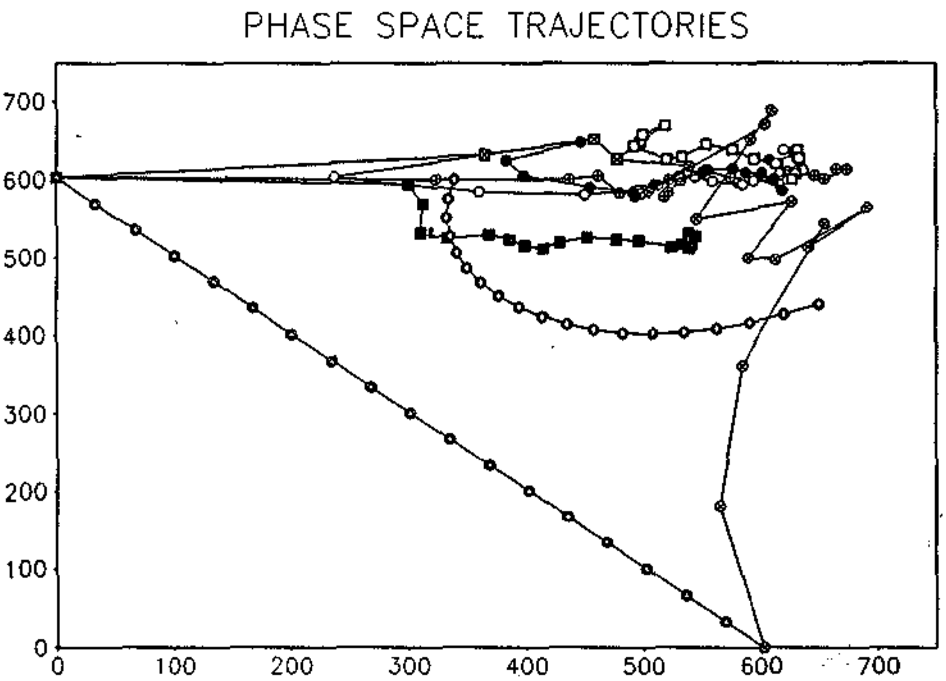

Fig. 6 — The projection of the trajectory of the climate system on a plane, where x is a distance between the current state of the system and its initial state; y is a distance between the current state and its end state; (x) - the observed trajectory, (+, O, ●, ❑) - the trajectories of the ensemble forecast members, (Δ) - the proection of the geodesic between the initial and end states, (✧) - the trajectory of the linear trend.

indicate the ensemble mean forecast, the linear trend and the geodesic between $\Psi(0)$ and $\Psi(T)$, respectively. All others markers show the ensemble members. It should be pointed out that the linear trend and the ensemble mean forecast are closer to the final state of the system.

6. CONCLUSIONS

Two series of the prognostic experiments were conducted with the barotropic model. In one of them, the model was used for the calculation of the long time series of the streamfunction fields. These data were used for creating initial condition ensemble and for the estimation of a forcing. The second series of the prognostic experiments were conducted with the real data. The aim of the numerical experiments was made in order to estimate possibility the prediction of low-frequency components of the atmospheric circulation beyond the predictability limit for the short-term climatic variations. The experiments have shown that using LAF technique makes better the prediction skill of the model, and the predicted linear trend of time evolution of the atmospheric circulation has a prognostic information beyond 10 days.

7. ACKNOWLEDGEMENT

This research has been sponsored by CNPq (Brazil).

REFERENCES

ORSZAG, S. A., (1970), Transform method for calculation of vector-coupled sums: Application to the spectral form of the vorticity equation. *J. Atmos. Sci.*, **27:** 890-895.

LORENZ, E., (1960), Maximum simplification of the dynamic equations. *Tellus*, **12:** 243-254.

HOFFMAN, R., E. KALNAY, (1983), Lagged average forecasting, an alternative to Monte Carlo forecasting. *Tellus*, **35A**, 100-118.