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Observability of planetary waves and their predictability in the ECMWF H500 forecasts

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Abstract. The problem of a hard contradiction between limited possibilities of meteorological observations and uncontrolled complication of the present-day weather forecasting models, and its consequences for the planetary wave predictability are considered with examples from the ECMWF short- and medium-range H500 forecasts for the Northern Hemisphere. A supposition is voiced that this problem adds difficulties to the weekly predictability limit overcoming.

1 Introduction

To depict well nonlinear interactions between waves of different scales modelers complicate weather forecasting models more and more. So, the maximal zonal wave number is about 3000 in the present-day ECMWF model, i.e. planetary waves with lengths of a few tens of km are taken into explicit consideration. Such large model complication generates a difficulty with initialization of shortest atmospheric waves in model runs. The aim of this paper is to find where is a boundary between observable and unobservable waves in the H500 fields of the Northern Hemisphere, and to clear up the character of the predictability loss of both kinds of these waves in the ECMWF medium-range forecasts.

2 A spectral consideration of the planetary wave observability

Let consider a relationship between a known set of imperfect observations of the Northern Hemisphere H500 field and an unknown set of the spherical harmonic coefficients of this field

$$H500_s(t,\theta_s,\lambda_s)=\sum_{m=0}^{M}\sum_{n=m}^{N}P_n^m(\cos\theta_s)e^{im\lambda_s}x_n^m(t)+\varepsilon(t,\theta_s,\lambda_s)$$
$$\rightarrow \boldsymbol{y}(\boldsymbol{t})=\mathbf{A}(\theta_s,\lambda_s)\boldsymbol{x}(\boldsymbol{t})+\boldsymbol{\varepsilon}(\boldsymbol{t})$$
$$s=1,...,S;m=0,1,...,M;n=m...,N;n-m=2k,k=0,1,...,K \qquad (1)$$

where $\boldsymbol{\varepsilon}=0$, $\mathbf{R}=\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}'=\sigma^2\mathbf{I}$. Taking in mind the least-square solution of Eq. (1)

$$\boldsymbol{x}(\boldsymbol{t})=(\mathbf{A}'\mathbf{R}^{-1}\mathbf{A})^{-1}\mathbf{A}'\mathbf{R}^{-1}\boldsymbol{y}(\boldsymbol{t})=(\mathbf{A}'\mathbf{A})^{-1}\mathbf{A}'\boldsymbol{y}(\boldsymbol{t}), \qquad (2)$$

one can assume our ability to watch waves in H500 fields is determined by the eigen value spectrum of the problem

$$(\mathbf{A}'\mathbf{A})\boldsymbol{\varphi_i}=\lambda_i\boldsymbol{\varphi_i}, i=1,2,...,\mathbf{I} \qquad (3)$$

If $\lambda_i>1$, errors of observations decrease in Eq. (2), and so the spherical harmonics collinear to the eigen vector $\boldsymbol{\varphi_i}$ represent waves that are observable; if $\lambda_i<1$, observation errors increase, i.e. the respective waves are unobservable. At the first time such an eigen value spectrum has been computed by Kazandjan and Sonechkin (1982). It is shown in Fig. 1. One can see $\lambda_i\leq 1$ for $i=126\div 136$, i.e. the boundary between observable and unobservable waves is near $m=8$, and this boundary shifts to $m=\sim 12$ if radiosonde wind observations (with geostrophic assumption) are assimilated.

The matrix **A** corresponding to the present-day satellite data is almost orthogonal, and so $\mathbf{A}'\mathbf{A}\approx\mathbf{I}$ because these data cover almost all Earth's surface. To assimilate these data Sonechkin (1973), Ghil et al. (1981), Le Dimet and Talagrand (1986), and Lorenc (1986), basing on the conception of the so-called Kalman filter, have proposed to use recurrent procedures like

$$\boldsymbol{x}(\boldsymbol{t})=\boldsymbol{x}(\boldsymbol{t})+(\mathbf{A}_t'\mathbf{R}_t^{-1}\mathbf{A}_t+\mathbf{Q}_t^{-1})^{-1}\mathbf{A}_t'\mathbf{R}_t^{-1}(\boldsymbol{y}(\boldsymbol{t})-\mathbf{A}_t\boldsymbol{x}(\boldsymbol{t})) \qquad (4)$$

where $\boldsymbol{x}(\boldsymbol{t})$ is a first guess of analysis taken from a very short-range forecast which is appointed at a very dense regular net of points, and so its covariation matrix **Q** is well conditioned. Thus, the observability problem seems to be settled at the first glance. But, it is not so in reality because the matrix

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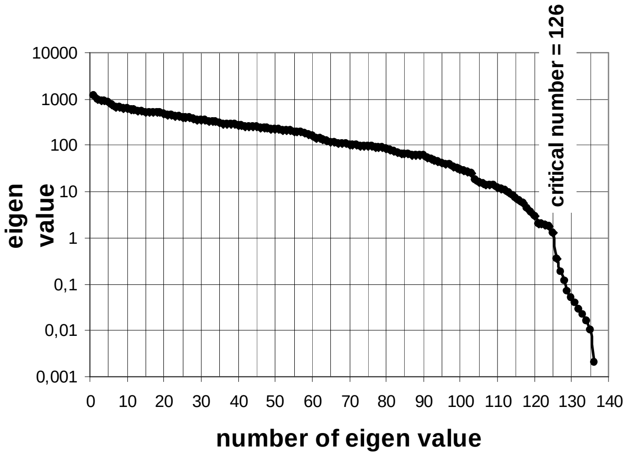

Figure 1. An example of the eigen value spectrum of the observability matrix $\mathbf{A}'\mathbf{A}$ with use the H500-data observed at 572 radiosonde stations of the Northern Hemisphere, and with taking into consideration 136 spherical harmonics (a rhomboidal spherical harmonics truncation with maximal wave numbers $M=8$, $N=22$).

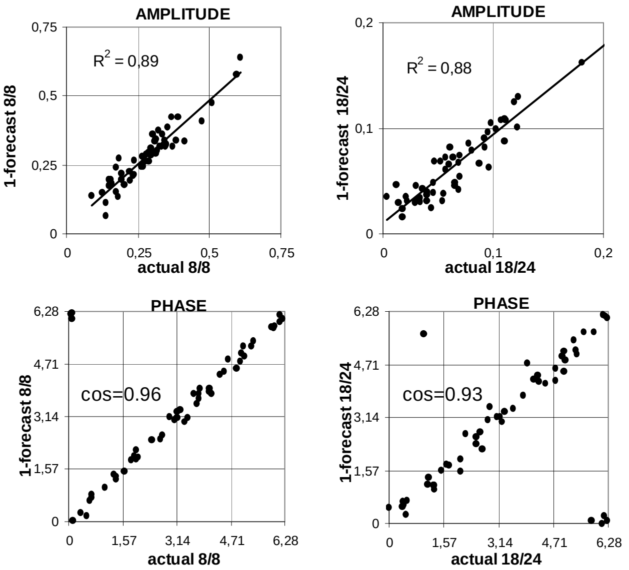

Figure 2. Examples of the relationships between actual and forecasted (1-day lead time) amplitudes and phases of the observable ($m=8$, $n=8$) and unobservable ($m=18$, $n=24$) waves in H500-flields of the Northern Hemisphere. Squared correlation between actual and forecasted amplitudes, and mean values of the cosine of the actual and forecasted phase differences are indicated as quantitative measures of the 1-day forecast skill.

$\mathbf{A}'\mathbf{R}^{-1}\mathbf{A}$ is ill conditioned or even singular by the reason of high horizontal correlation of satellite data errors. As a result, the first guess can dominate the analysis Eq. (4). To overcome this difficulty the author of this paper have proposed "to bleach" the satellite data before their assimilation. It can be done, for example, by expanding of the full satellite data set on the spherical harmonics, and consequent reconstructing this set taking into account the spherical harmonic coefficients corresponding to smaller-scale waves only. Unfortunately, it turned out to be impossible to realize this idea in the USSR.

It is currently accepted in the present-day Western studies (see Liu and Rabier, 2003 and many other publications) to neglect these satellite data error correlations, i.e. to assume $\mathbf{A}_t'\mathbf{R}_t^{-1}\mathbf{A}_t=\sigma^{-2}\mathbf{A}_t'\mathbf{A}_t=\sigma^{-2}\mathbf{I}$ even if the density of satellite data is very high, and the vector $\boldsymbol{x}(t)$ is of very high dimension (of the order 10^3–10^4). But such acceptance overestimates the satellite data weight in Eq. (4). Several methods (producing one "super-observation" from many neighbouring satellite data, thinning satellite data etc.) have been proposed (see Dando et al., 2007 for a review) to compensate for the inadequacy of the assumption of uncorrelated satellite data errors. The main disadvantage of these methods consists in a loss of smaller-scale details of the meteorological fields under analysis. For example, Dando et al. (2007) have chosen the thinning to distances between 100 and 150 km to produce analyses most appropriate for short-range forecasts. These optimal distances are 2–3 times more than the horizontal resolution of the Met Office NWP system used in the Dando et al. (2007) research. It means the waves shorter than 100–150 km (corresponding zonal wave number $m \geq 100$) remained to be unobservable. Moreover, the authors indicated further work is needed to develop the thinning methods into a viable operational alternative. One can conclude a limit of the planetary wave observability is really inherent to the present-day NWF systems, and so the initiation for the unobservable shortest waves actually comes from the first guess of the assimilation procedure.

3 Effects of the unobservable wave initiation on the wave predictability

Thus, the present-day comprehensive weather forecasting models are integrated without a part of real initial data in fact. Under this condition even short-range forecasts of the unobservable waves themselves must be spurious. Besides, one can suppose that the penetration of the considerable errors of such forecasts onto the long waves (via Lorenz's upscale propagation of forecasting errors) can imply a premature predictability loss in the extended weather forecasts.

In order to check is it so in fact, 1–6 day H500 forecasts of ECMWF were considered as these are presented at $2.5^\circ \times 2.5^\circ$ grid points for the Northern Hemisphere during March–August 2009. It was found that 1-day forecasts of unobservable waves are quite successful: correlations between actual and forecasted wave amplitudes, and cosines of differences between wave phases were found to be $\sim$0.90 (example for $m=18$, $n=24$ given in Fig. 2), i.e. practically the same that were found for the observable waves (example for $m=8$, $n=8$ given in Fig. 2). But the skill of the unobservable wave forecasts decreases very fast for longer lead times although such skill continues to be rather high (correlations of amplitudes 0.6–0.9, and cosines of differences between phases 0.5–0.9 even for the 6 day lead time) for observable waves (see Supplemental Information: www.adv-sci-res.net/4/5/2010/asr-4-5-2010-supplement.pdf).

4 Conclusion, speculation, and recommendation

In spite of incessant improvements of the weather forecasting models the predictability limit position remains to be almost invariable during the latest decade. Many meteorologists believe defects in parametrizations of heterogeneous processes, especially those connected with the moisture transformations in the atmosphere, are the main reasons of such regrettable state of the weather forecasting art, and so further efforts must be applied to complicate the model physics. In turn, such physical complication needs to increase the forecasting model spectral resolution. As a result, and in spite of essential improvement of the world system of meteorological observations, another source of the weather forecast unpredictability becomes to be important anew that is connected with upscale propagation of errors in the meteorological field initiation.

Indeed, direct computations of the eigen value spectrum of the observability matrix for the radiosonde net, and character of the predictability loss of the planetary waves of different spatial scales in the ECMWF short- and medium-range H500 forecasts for the Northern Hemisphere reveal that the present-day assimilation systems are not capable to watch the shortest planetary waves represented in the ECMWF forecasting system explicitly.

Certainly, it would be necessary to re-examine this conclusion directly comparing characteristics of unobservable waves just before (in the 6-h forecasts used as the first guess) and just after each assimilation time step in the ECMWF assimilating/forecasting system because our comparison with use 24-h forecasts instead of the 6-h ones is not quite correct.

One can speculate spurious variations of the unobservable planetary waves, if these really exist, are capable to accelerate the predictability loss of the synoptic scale waves doing the present-day weekly predictability limit hard to overcome.

A possible method to assimilate the full set of satellite data that are dense everywhere on the Earth, and so to settle the unobservability problem, consists in a preliminary "bleaching" of these data by means of their band-pass filtering.

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References

Dando, M. L., Thorpe, A. J., and Eyre, J. R.: The optimal density of atmospheric sounder observations in the Met Office NWP system, Q. J. Roy. Meteor. Soc., 133, 1933–1944, 2007.

Ghil, M., Cohn, S. E., Tavantzis, J., Bube, K., and Isaacson, E.: Applications of estimation theory to numerical weather prediction, in: Dynamic meteorology: Data assimilation methods, edited by: Bengtsson, L., Ghil, M., and Kaellen, E., Springer-Verlag, New York, 139–184, 1981.

Kazandjan, G. P. and Sonechkin, D. M.: An outline of the spectral objective analysis of aerologic observations. Trudy Gidrometeorologitcheskogo Nauchno-issledovatelskogo Centra SSSR, 243, 85–101, 1982 (in Russian).

Le Dimet, F. X. and Talagrand, O.: Variational algorithms for analysis and assimilation of meteorological observations: Theoretical aspects, Tellus, 38A, 97–110, 1986.

Lorenc, A. C.: Analysis methods for numerical weather prediction, Q. J. Roy. Meteor. Soc., 112, 1177–1194, 1986.

Liu, Z. and Rabier, F.: The potential of high-density observations for numerical weather prediction. A study with simulated observations, Q. J. Roy. Meteor. Soc., 129, 3012–3035, 2003.

Sonechkin, D. M.: Grounds for four-dimensional (continuous) assimilation of meteorological observation based on a dynamic-stochastic approach, Meteorologiya i Gidrologiya, 4, 13–19, 1973 (in Russian).