Development and operational application of a short-range ensemble prediction system based on the ALADIN limited area model

Edit HÁGEL

Theses of the PhD dissertation

Eötvös Loránd University, Faculty of Science

Ph.D. School for Earth Sciences, Geography-Meteorology Program

School leader: Prof. Dr. Miklós Monostori, doctor of HAS

Program leader: Prof. Dr. Gyula Gábris, doctor of HAS

Thesis advisors:

Dr. András Horányi

Assoc. Prof. Dr. István Matyasovszky

Hungarian Meteorological Service

Numerical Modelling and Climate Dynamics Division

2009

Introduction, main goals of the work

Over the past 50 years the use of numerical weather prediction (NWP) models has become an indispensable part of weather forecasting. NWP is based on the solution of a set of partial differential equations (the so-called primitive equations). These equations are nonlinear and are impossible to solve analytically. Because of nonlinearity, the solution is highly dependent on the accuracy of the initial conditions (ICs). To improve the quality of the initial conditions, different techniques are being developed in the field of data assimilation. However, one has to keep in mind that an exact description of the initial state is not achievable due to the limited number of the observations, their uneven spread around the globe, the inevitable observation errors and the errors in the data assimilation techniques and the models themselves. As a result, there will always remain some uncertainty in the initial conditions of NWP models.

By perturbing the initial state of an NWP model it is possible to take into account the impact of the errors in the initial conditions. The model is integrated from these different ICs forming an *ensemble* of forecasts. The spread of the ensemble provides valuable information on the predictability of the atmospheric state and on the probability of different weather events. In this way not only the future state of the atmosphere can be forecasted, but the uncertainty related to this forecast can be predicted as well. Since its first operational application in 1992, global ensemble forecasting has become a widely used technique by many meteorological services around the world. In the last couple of years intensive research has started to apply the ensemble method in short-range limited area forecasting as well.

Motivated by the promising results of the above mentioned studies, research started at the Hungarian Meteorological Service with the final aim to establish an operational short-range limited area ensemble prediction system (LAMEPS) and to see how it can improve the predictions of the existing global systems. It was decided to start the experiments with the dynamical downscaling of global ensemble forecasts. Two possible choices were considered: the downscaling of ARPEGE ensemble forecasts (see below in more detail) and the downscaling of ECMWF EPS members (for further information on ECMWF EPS downscaling see [9]).

The aim of the PhD work was the development, investigation and finally the operational application of a short-range limited area ensemble prediction system based on the ALADIN model, using global ARPEGE ensemble forecasts as initial and lateral boundary conditions. The work presented in the thesis had three main parts: (i) sensitivity studies with global singular vectors with respect to their optimization area and optimization time, (ii) experiments with limited area singular vectors, and (iii) the development and (quasi-) operational application of a LAMEPS based on the dynamical downscaling of the global PEARP (Prévision d'Ensemble ARPege, the operational ARPEGE EPS) system.

Applied methods

One possible way to create an ensemble prediction system (EPS) is the use of the singular vector (SV) method in order to perturb the initial conditions of the model ([1]). The aim of the singular vector approach is to find the fastest growing perturbations to a given initial state that have the maximal growth during a given time interval (the *optimization time*), over a specific area (the *optimization area*) and based on the predefined norm. The singular vector technique is an operationally applied method to generate the initial condition perturbations for EPS systems, mainly on global scales.

As a first step of the PhD work sensitivity studies were performed in order to see whether or not it was possible to optimize the existing ARPEGE based global ensemble system (PEARP, formerly PEACE) for the Central European area by changing the *optimization domain* and *optimization time* used for the global singular vector computations. With this purpose several different optimization areas and times were defined and tested through case studies and longer test periods ([4], [6], [8], [2] and [5]). Global ensemble forecasts were made with the ARPEGE model and were downscaled with the ALADIN model. The impact of using these targeted singular vectors was carefully examined.

Based on the results of the sensitivity studies it is believed that the computation of local perturbations is needed in the limited area model for properly addressing the small-scale initial uncertainties of the atmosphere, which are not present in the global model. Therefore, as a second step, I have started the work in the field of singular vectors computed with the ALADIN limited area model ([3]).

Meanwhile, in parallel with the above mentioned research activities, a short-range limited area ensemble system - based on the ALADIN model - was developed and put into operations, in order to gain experience not only from case studies and test periods, but on a day-to-day, real-time basis ([7]). At present, the only operationally feasible solution is the direct dynamical downscaling of the PEARP members, therefore this method is used. The system has been running on a daily basis in quasi-operational status since February, 2008 and it is going to be developed and improved continuously, using results of the ongoing researches.

Results

The most important results of my PhD research can be summarized as follows.

General result for limited area ensemble predictions systems (discussed in *Chapter 3* of the thesis):

1. I have shown for our limited area ensemble system that it is very important to use not only different initial conditions, but also different lateral boundary conditions for each ensemble member in order to maintain the difference between the members and to have sufficient spread, which - on average - would increase and not decrease during the forecast interval.

Results of the sensitivity experiments with global singular vectors (*Chapter 3* in the thesis):

2. Analysing the verification results of the sensitivity experiments (case studies and longer test periods), I have shown that the proper choice of

the optimization area used for the global singular vector computations can increase the spread of the ensemble and can improve the quality of the probabilistic forecasts for the area of our interest (Central Europe and particularly Hungary).

3. I have also shown that changing the optimization time of the global singular vectors from 12 hours (as used in the operational global PEARP system) to 24 hours, the spread of the ensemble can be further increased and the skill of the forecasts can be improved (for the Central European area).

4. I have compared the verification results of the global and the limited area ensemble systems in order to see whether the limited area model could improve the predictions of the global model. I have shown that it is very difficult to achieve significant overall improvements by simply downscaling the forecasts of the global system with the limited area model. However, I have also noted that due to the so-called double penalty problem the results of this comparison should be interpreted with care.

Results of the experiments with limited area singular vectors (presented in *Chapter 5*):

5. I have performed experiments with limited area singular vectors computed with the ALADIN model. Singular vectors were computed with 22 km and 44 km horizontal resolution and 12 hours and 24 hours as optimization time. I have found that the resolution used for the SV computation did not have a strong impact on the structure, but on the singular values. In case of higher resolution the singular values were larger.

6. The difference in the optimization time had the effect of changing the location of the SVs both at initial and final time. I have also found that singular vectors computed with 24 hours optimization time cover a considerably larger area at final time than the 12 hours SVs.

Results of the quasi-operational system (discussed in *Chapter 4*):

7. Analysing the verification results of the test periods and the quasi-operational LAMEPS I have shown that the spread-skill relationship and the skill of the ensemble system are better for higher levels and worse for lower levels. The reason of this is related to the characteristics of the perturbations that are applied in the PEARP system.

Conclusions

Based on the results of the PhD thesis, the following conclusions can be drawn. With the proper choice of the singular vector optimization area and optimization time (to be used in the global system) it is possible to improve the spread-skill relationship and the skill of the forecasts for the area of our interest (Central Europe, particularly Hungary). Further improvement was expected from downscaling the global forecasts with the limited area ALADIN model, however, it was found to be difficult to achieve significant overall improvements. For that reason it is believed that local perturbations are needed in the limited area model to have better representation of the small-scale initial uncertainties.

Analysing the verification scores of the quasi-operational system I have found that better results can be obtained for higher levels. This behaviour suggests that in the future surface perturbations need to be included in our system.

References

[1] R. Buizza, J. Tribbia, F. Molteni, and T. Palmer. Computation of optimal unstable structures for a numerical weather prediction model. *Tellus*, 45A:388–407, 1993.

[2] E. Hágel. Latest results of the LAMEPS experiments. *ALADIN Newsletter*, 27:105–113, 2005.

[3] E. Hágel. Singular vector experiments at the Hungarian Meteorological Service. *ALADIN Newsletter*, 33:52–59, 2008.

[4] E. Hágel and A. Horányi. The development of a limited area ensemble prediction system at the Hungarian Meteorological Service: sensitivity experiments using global singular vectors, preliminary results. *Időjárás*, 110(3-4):229–252, 2006.

[5] E. Hágel and A. Horányi. Sensitivity experiments of global singular vectors at the Hungarian Meteorological Service. *ALADIN Newsletter*, 29:50–57, 2006.

[6] E. Hágel and A. Horányi. The ARPEGE/ALADIN limited area ensemble prediction system: the impact of global targeted singular vectors. *Meteorologische Zeitschrift*, 16(6):653–663, 2007.

[7] E. Hágel and M. Mile. The limited area ensemble prediction system of the Hungarian Meteorological Service. *ALADIN Newsletter*, 35, 2009. To appear.

[8] E. Hágel and G. Szépszó. Preliminary results of lameps experiments at the Hungarian Meteorological Service. *ALADIN Newsletter*, 26:44–52, 2004.

[9] B. Szintai and I. Ihász. The dynamical downscaling of ECMWF EPS products with the ALADIN mesoscale limited area model: Preliminary evaluation. *Időjárás*, 110(3-4):253–277, 2006.