ALADIN Limited Area Ensemble Forecasting (LAEF)

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1. Introduction

Scientific and computational limitations prevent us from constructing a perfect NWP model of real systems. Small errors in the initial condition, in the boundary conditions, in the model, e.g. physics and dynamics, can grow exponentially and eventually render a forecast useless. For dealing with those uncertainties, we have implemented an experimental ALADIN regional EPS system LAEF (Limited Area Ensemble Forecasting). Works have been focused on the initial condition perturbation, on the impact of the uncertainty on the lateral boundary conditions. ALADIN dynamical downscaling of ARPEGE global EPS system PEARP, and ALADIN multi-physics downscaling have been also investigated.

2. The ALADIN LAEF configuration

The ALADIN model used for the ensemble forecasting is run in hydrostatic mode, with 16 km horizontal resolution, and 31 levels in the vertical. The model domain covers the area 25°W – 35°E, 32°N – 58°N, which includes Europe and a large part of the North Atlantic (Fig. 1).

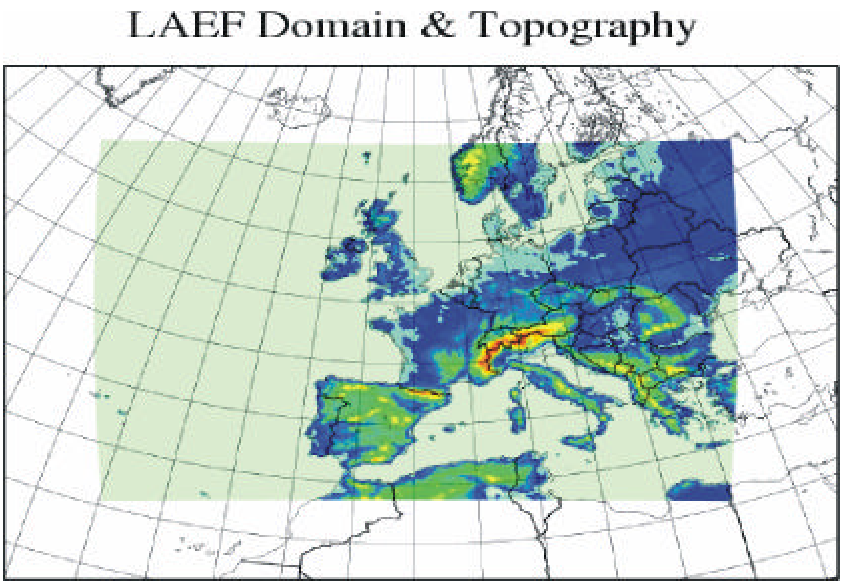

Figure 1 : ALADIN LAEF Domain and model topography.

3. Experiments

Several experiments with LAEF have been carried out:

• ***Initial condition (IC) perturbation:***

The Breeding method (Toth and Kalnay 1993, 1997) is used for constructing the initial perturbed conditions for LAEF. By Breeding (breeding of growing vectors), the perturbed initial conditions were generated in sets of positive and negative pairs around a control analysis. The method consists of the following steps: (i) either starting with random perturbations, short-term forecasts are made for both members of a pair, this is so-called cold start; or starting with forecasts which are valid at the specified the starting time, e.g. 48h forecast and 24h forecast from two days before and one day before, this is the warm start (ii) building the difference between the perturbed forecast and control forecast (one-side perturbation) or the difference between the two forecasts of the pair (two-side perturbation) (iii) the difference is scaled down, and added/substracted on the control analysis. The perturbations are then centered around the control analysis, creating the positive and negative perturbation. This method is repeated for the remaining sets of pairs. Short-term forecasts are then generated for each ensemble member, and the breeding method (aforementioned steps) is repeated at the next breeding cycle.

Our implementation of the breeding method has the following features: *a)* lukewarm start, *b)* 12 hour cycle, *c)* two-side and centering around the control analysis, *d)* wind, temperature, moisture and surface pressure are perturbed at each level and model grid-point, *e)* 5 pairs, *f)* constant rescaling S, which is computed by:

$$S = C / \Delta P, \quad \Delta P = \sqrt{\sum_{1}^{N} \left[T_{850}^{p} - T_{850}^{n}\right]^{2} / N} \tag{1}$$

where C is a tuning constant around 1. N denotes the total grid number, T_{850}^{p} and T_{850}^{n} are the positive and negative short-term temperature forecasts near 850hPa of the pair.

In the experiment, the breeding cycle with 24h and 12h have been conducted, different tuning of the rescaling factor $C = 1.2, C = 0.4$ and $C = 0.2$ have been investigated.

Another method, ETKF (Ensemble Transform Kalman Filter, Bishop et al 2001) has been also implemented in LAEF for constructing the initial perturbation. The ETKF analysis perturbations are achieved by postmultiplying the short-term ensemble forecast perturbations by a transformation matrix. This transformation matrix is obtained by solving the error covariance update equation (Eq. 2) for an optimal assimilation scheme within the ensemble subspace.

$$P^{a} = P^{f} - P^{f} H^{T} (HP^{f} H^{T} + R)^{-1} HP^{f} \tag{2}$$

Where P^{a} is the analysis error covariance matrix and P^{f} the forecast error covariance. The matrix H is the linear observation operator which maps model variables to observed variables and the matrix R is the observation error covariance matrix. More details can be found in Wang and Bishop (2003).

For ETKF experiments, we used the fixed observation network, approx 120 observation stations on three levels 850hPa, 500hPa and 250hPa. The interpolated ARPEGE analysis of wind and temperature as the observation, 12h cycle, 11 members. Same as in Breeding method, wind, temperature, moisture and surface pressure are perturbed at each level and grid-point. One-side forecast perturbation generation is applied. Since the ETKF analysis perturbation is not centered around the analysis, we applied a spherical simplex transformation (Wang and Bishop 2004) for preserving the P^{a} and the perturbation is around the analysis.

If the number of ensemble perturbations is much smaller than the number of directions to which the forecast error variance projects, as in our case with 11 members, the total analysis error variance will be significantly underestimated because of the lack of contribution from important parts of the error space. To ameliorate this problem, we tested two methods for inflating the perturbation. The first one, proposed by Wang and Bishop (2003), is the innovation inflation technique, the second is a similar one as in the breeding.

Similar to ETKF, we have also implemented the ET (Ensemble Technique, Bishop and Toth 1999) for generating the initial perturbation. The ET method has been proposed originally for the target observation studies. The formulation of ET for constructing initial perturbation can been found in Wei et al. (2006). The practical implementation of ET in LAEF is: 11 members, wind and temperature on 6 levels in model space are used for computing the transformation matrix, which are near the standard pressure levels. A spherical simplex transformation is also used for preserving the P^{a} and the perturbation is around the analysis. A combination of ET and breeding for rescaling the forecast perturbation is implemented too.

• ***Lateral boundary condition (LBC) perturbation***:

Tests have been carried out with LAEF breeding configuration coupled with the ARPEGE control LBC and with the perturbed LBC from ARPEGE SV EPS.

• ***Uncertainties in the model physics***:

ALADIN dynamical adaptation of ARPEGE SV EPS members with and without multi-physics has been worked out. 11 combinations of different physics parameterizations and tunings in ALADIN were chosen for dealing with the uncertainty in the model physics, they are: Bougeault-type scheme of deep convection Boguault convection scheme, the modified Kain-Fritsch deep convection scheme, moisture convergence and CAPE closure, Kessler-type scheme for large scale precipitation, Lopez microphysics scheme, tuning of the mixing length, entrainment rate, and the computation of the cloud base.

4. Results

To investigate the uncertainties in ALADIN, we have chosen the strong storm case Lothar (20-28 Dec. 1999) for all tests. In the following, we will focus on the spread of the LAEF experiments.

4.1 Breeding (evolution of initial perturbation)

Fig. 2 shows the evolution of the initial perturbation during the Breeding experiment. The spread in terms of Geopotential increases during the development of the storm and decreases afterwards.

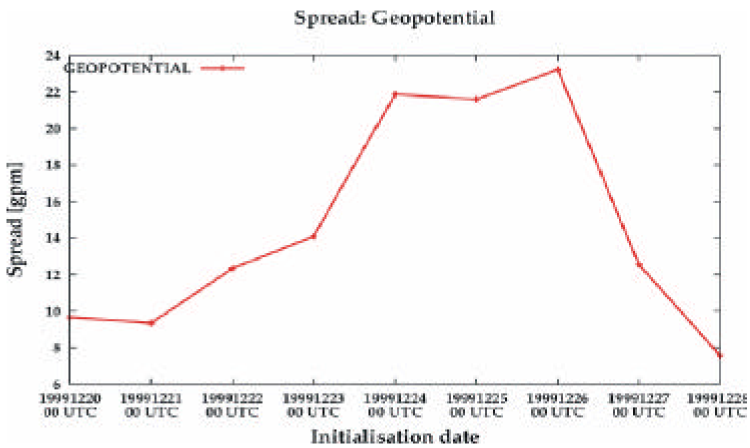

Figure 2: Spread of Geopotential at initialisation date.

4.2 24 hour vs. 12 hour breeding cycle, scaling factor

Fig .3 compares the spread of geopotential, kinetic energy and temperature as a function of forecast time for different pressure levels. The thick lines denote the spread with 24h breeding cycle, the thin lines the ones with 12h cycle. In case of 24h breeding cycle and scaling factor 1.2, the spread is much larger than with 12h cycle and scaling factor 0.4. During integration their differences decrease due to the constant LBC, but still remain larger.

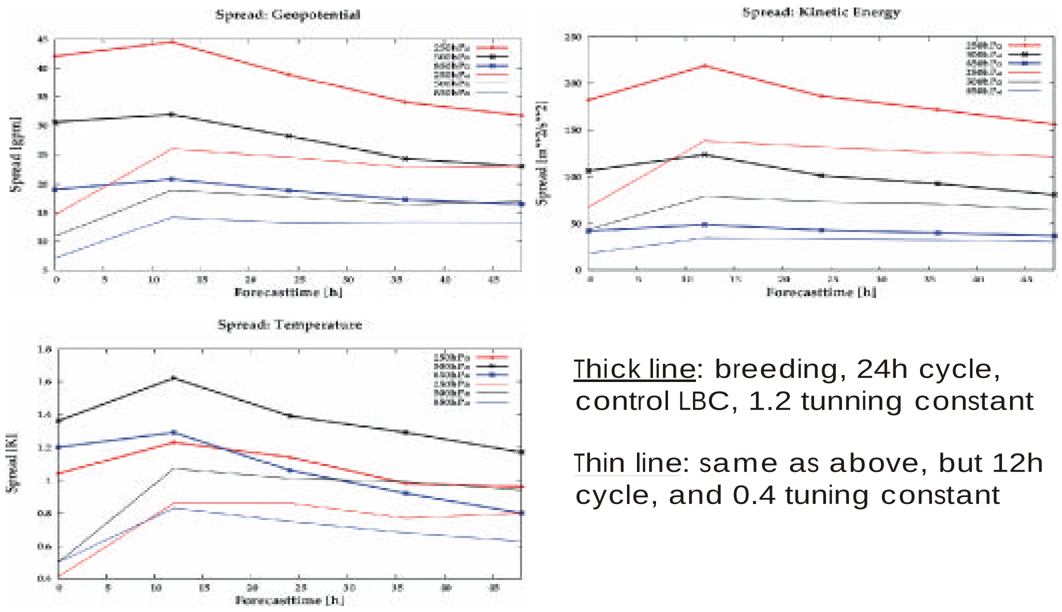

Fig. 3: Spread of Geopotential, Kinetic Energy and Temperature at selected levels (250hPa, 500hPa, 850hPa) using 24h – breeding cycle with scaling factor = 1.2 (thick lines) and 12h – breeding cycle with scaling factor = 0.4 (thin lines).

4.2 Impact of the LBC

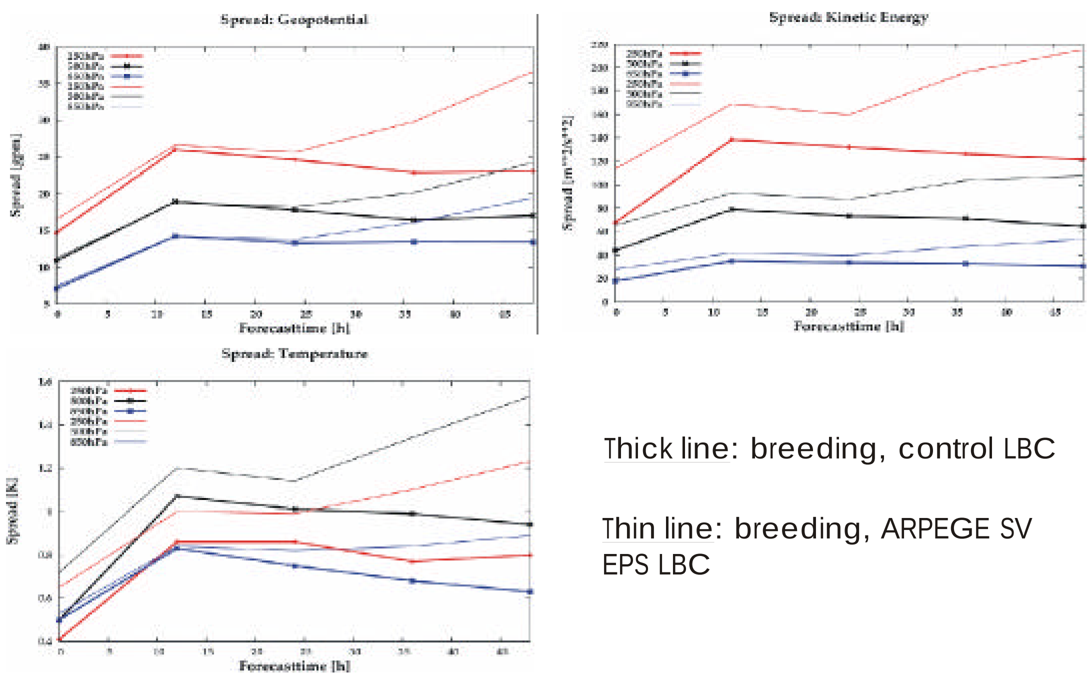

Fig. 4: Spread of Geopotential, Kinetic Energy and Temperature at selected levels (250hPa, 500hPa, 850hPa) with constant LBC (thick lines) and LBCs from Arpege SV EPS members (thin lines).

Concerning the impact of LBCs, the importance of perturbed LBCs are especially relevant for the integration period +24 to +48 hours (Fig. 4). Regarding geopotential the spread does not differ much between constant LBC and EPS LBCs up to +24 hours, but rapidly increase afterwards. This effect is reflected by the spread of kinetic energy and temperature, although slightly less pronounced.

4.3 Downscaling vs. global EPS

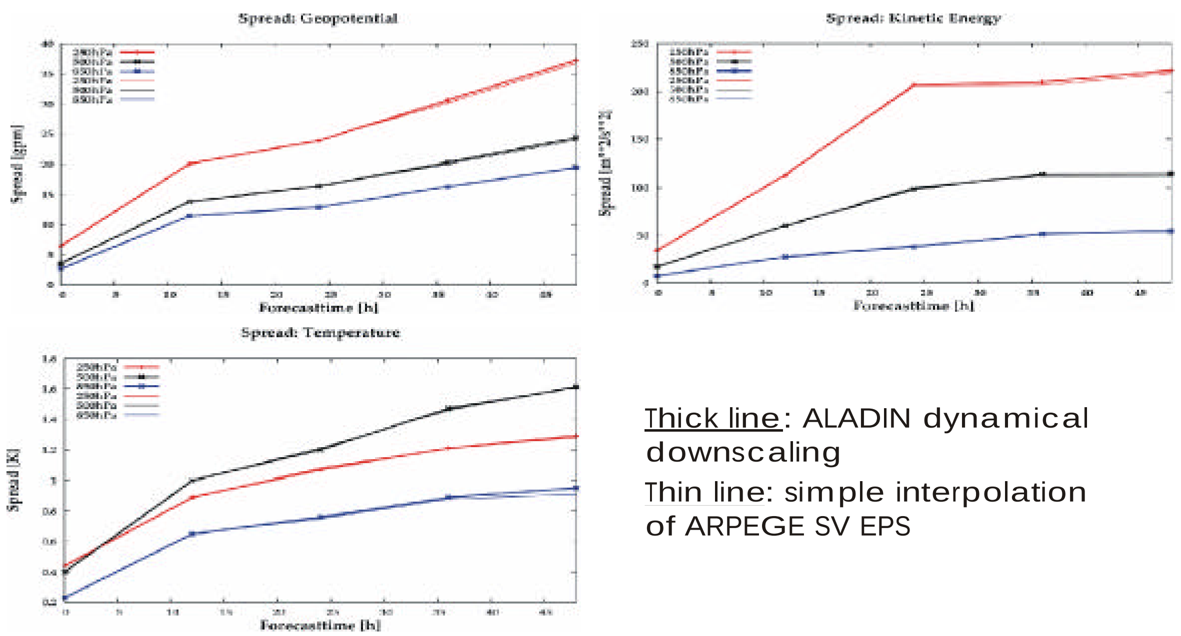

Fig. 5: Spread of Geopotential, Kinetic Energy and Temperature at selected levels (250hPa, 500hPa, 850hPa) gained by Aladin dynamical downscaling (thick lines) and by simple interpolation of Arpege SV EPS (thin lines).

Comparing the spread of Aladin dynamical downscaling and simple interpolation of the Arpege SV EPS members, their differences are marginal. Both methods produce similar spread at initialisation time and during the integration (Fig. 5).

4.4 ALADIN dynamical downscaling vs. breeding

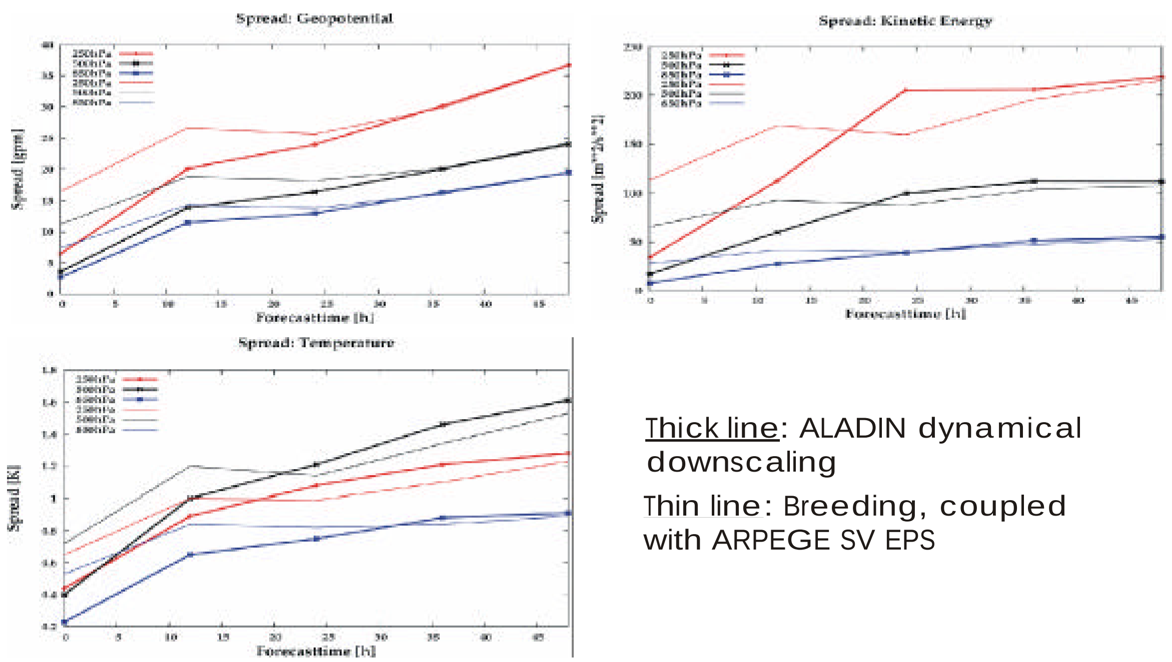

Fig. 6: Spread of Geopotential, Kinetic Energy and Temperature at selected levels (250hPa, 500hPa, 850hPa) gained by Aladin dynamical downscaling (thick lines) and by breeding method, coupled with Arpege SV EPS (thin lines).

Comparing dynamical downscaling and the breeding method, the differences in terms of spread are significant during the first 24 hours (Fig. 6). This is mainly due to reduced perturbation of the Arpege EPS members at initialisation time. From +24h to +48h integration, both methods converge as the members of the breeding method are coupled with Arpege SV EPS members.

5. Conclusion

We have carried out several experiments with the LAEF system, the focus was put on different aspects of the limited area model forecast uncertainties, like initial condition perturbation, impact of the LBC on the performance of the LAM-EPS, and the mulitphysics for investigation of the uncertainty in the model physics.
All the experiments have been done with the strong storm case Lothar (20-28, Dec. 1999). The results can be summarized as follows:

1. LAM-IC perturbation with breeding + LBC perturbation shows certain potential/skill for the short range forecast within 24h.
2. Breeding needs larger IC perturbation, the bred vector maybe reflects part of the covariance structure contained in P^a, e.g, only the uncertainty in first guess.
3. LBC perturbation is very important, especially for keeping the spread growing after 12 hours.
4. ALADIN dynamical downscaling of ARPEGE EPS members with multi-physics option does not outperform the simple ALADIN dynamical downscaling of ARPEGE EPS.
5. Strong bias needs to be corrected.

Concerning the use of ETKF, we found that the initial perturbation, especially by ETKF, is too small. One reason is that 10 EPS members are insufficient for the number of directions to which the forecast error variance projects.
One solution is the inflation technique, which makes short term ensemble spread consistent with short term differences between forecast and observation. Following Wang & Bishop (2003), the main contribution of inflation comes from the first random perturbation! We have to find a way to inflate the perturbation by the rule:
Ensemble variance + observation error variance = variance {forecast - observation}

Acknowledgements

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