The Central European limited area ensemble forecasting system: ALADIN-LAEF

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SUMMARY

The Central European Limited Area Ensemble Forecasting system ALADIN-LAEF has been developed in frame of the international cooperation ALADIN/LACE, and been put into pre-operational since March 2007. The main feature of the pre-operational ALADIN-LAEF is dynamical downscaling of the ECMWF EPS. In February of 2009, ALADIN-LAEF has been upgraded. In the new ALADIN-LAEF, several methods for dealing with the forecast uncertainties are developed, and implemented on ALADIN-LAEF for improving the forecast quality. Those are: 1) Perturbations to initial conditions are calculated by blending the large scale perturbation generated by ECMWF Singular Vector and the small scale perturbation generated by ALADIN-Breeding; 2) multi-physics scheme are applied for model perturbation; 3) NCSB (non-Cycling Surface Breeding) technique is for perturbations to initial surface conditions.

The new ALADIN-LAEF and the proposed methods blending, multi-physics scheme and NCBB are described in this paper. Investigation on the performance of the new design of ALADIN-LAEF has been carried out. Comparison with the pre-operational LAEF (dynamical downscaling of ECMWF EPS) and detailed verification of the new design of LAEF have been done for a two-month period in June/July/August 2007. High resolution deterministic ALADIN forecast has been taken as the reference in the verification, in particular, for the skill scores. Results show that LAEF with new strategies for representing uncertainties in the forecast performs much better and are more skillful that the pre-operational LAEF.

KEY WORDS: Ensemble Prediction System, Limited Area Model, Probabilistic forecast

1. INTRODUCTION

During the recent years, Limited Area Model Ensemble Prediction System (LAMEPS) has become more important as a scientific tool for improving prediction of high impact weather, especially the meso-scale short-range probabilistic prediction, for identifying model error sources and developing methods for reducing the weather forecast errors. Several LAMEPS systems have been developed. Various approaches are employed for dealing with the uncertainties related with the limited area numerical forecast. There are mainly four sources of uncertainty, which should be adequately tackled in a LAMEPS system:

a) Uncertainties due to observational errors and data assimilation method.

   To quantify the uncertainties, some methods are used for generating the perturbation to the initial conditions (IC). Breeding vectors (Toth and Kalnay, 1993) is used by SREPS at NCEP (Hamill and Colucci 1997; Stensrud *et al.*, 1999; Du and Tracton 2001; Du *et al.*, 2003), similar Breeding method is also applied at CMA (Gong *et al*., 2008). Chengdu Regional Meteorological Center (CRMC) of CMA , proposed a method for initial perturbation using Different Physical Mode Method (DPMM) for dealing with the initial uncertainties on different scales (Chen *et al.* 2005, Feng *et al.* 2006). Another very popular way for the perturbation to IC is the dynamical downscaling of global EPS. The regional version of MORGREPS (Bowler *et al.*, 2008) downscales dynamically its global counterpart EPS based on the ETKF method

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(Wang *et al.*, 2003). The IC perturbation of NORLAMEPS (Frogner *et al.*, 2006) is provided from a version of the ECMWF EPS with dry targeted SV over northwestern Europe. In similar way, the REPS at MSC (Li *et al.,* 2007) applies the perturbation from the MSC global EPS with moist targeted SV. COSMO-LEPS (Molenti *et al.*, 2001; Marsigli *et al.*, 2008) has applied a strategy of representative members to downscale the ECMWF EPS, in which the representative members are chosen from clusters of ECMWF EPS members. Other initial perturbation methods are used, such as, employing analysis from different forecast center, like multi-analysis SREPS at INM (Garcia-Moya *et al.*, 2007), PEPS at DWD (Denhard) and University of Washington (Eckel and Mass, 2005). There is also approach like random initial condition perturbation (Du *et al.*, 1997, Stensrud *et al.*, 2000). Research studies on ETKF/ET, forced SV in the LAM context have been investigated by Wang et al.,(2006), Bolwler et al. (2008), and Barkmeijer et al.(2008).

b) Uncertainties due to errors in lateral boundary conditions (LBC) related to coupling with its global counterpart.

Most of the LAMEPS systems are coupled with global EPS for having the quantification of uncertainties in LBC. The SREPS at INM and PEPS at DWD obtain the LBC perturbation by using deterministic global forecast form different NWP centers.

c) Uncertainties arising from description of surface condition and corresponding physical process in model.

There are only few LAMEPS systems which take into account the surface uncertainties, especially the initial surface conditions. Applying different tunning parameters in the model surface schemes is used in COSMOS-DE-EPS at DWD (DWD, Gebhardt and Teise, personal comunication). NCEP is using the different surface analyses and models for perturbing the surface moisture in its SREPS system.

d) Uncertainties caused by approximation in model formulation and physical parameterization.

Multi-physics, multi-model, perturbing the tunning parameters in the physical parameterizations and stochastic physics are the popular methods for representing model uncertainties in the all LAMEPS system, for example, multi-model methods in SREPS at NCEP, SREPS at INM, PEPS at DWD; multi-physics in SREPS at NCEP, COSMO-SREPS and DPMM at CRMC (Cheng-Du, China). In REPS at MSC, model physics uncertainties are partly accounted by stochastically perturbing the parameters in the parameterization schemes. The perturbations are obtained from first order Markov processes. In MORGREPS, two stochastic-physics are included to represent the model uncertainties: the ‘random parameters’ and the ‘stochastic convective vorticity’ scheme.

At ZAMG (**Z**entral**A**nstalt für **M**eteorologie und **G**eodynamik), the Central European Limited Area Ensemble Forecasting system LAEF has been developed in frame of the international cooperation LACE (**L**imited **A**rea modelling **C**entral **E**urope), and been put into pre-operational since March 2007. The main feature of LAEF is dynamically downscaling of ECMWF EPS (Buzzia and Palmer 1995, Molteni *et al* 1996, Buzzia *et al* 2007) with LAM model ALADIN (Aire Limitée Adaptation dynamique Développement InterNational). The first 16 perturbed ECMWF members provide LAEF with the initial condition perturbations and lateral boundary perturbations. The model uncertainty and the surface uncertainty were not taken into account in the pre-operational LAEF.

As mentioned before, the perturbed IC and LBC in most operational LAMEPS are provided directly (downscaling) by a global EPS system. There are studies on LAM ETKF and SVin early stage. Some studies have shown, most of the LAMEPS system has similar performance as its global counterpart. How to introduce the LAM native perturbation taken the consistency problem into account, how to perturb the initial surface condition etc is of great interests of LAMEPS research.

This paper describes a new design of LAEF which takes all the uncertainties mentioned above into account. For dealing with the initial uncertainties, a blending method is proposed for combining large scale perturbation from the ECMWF SV and the small scale perturbation from the LAM native breeding vector. The Blending method takes the advantage of the ECMWF SV perturbation, which is computed for the future uncertainties; and the advantage of breeding vector, which is account for the uncertainties in the past (Talagrand 2007). On the other side, it is make the more consistent between the treatment of perturbations in the global and regional EPS system. A new idea for the initial surface perturbation NCSB (Non-Cycling Surface Breeding) is implemented in LAEF too. This is using the perturbed atmospheric forcing to generate the perturbation to the initial surface condition like soil moisture and so on. As the most other LAMEPS system, multi-physics and coupling with

ECMWF EPS members are used for dealing with the uncertainties to model and LBC. The benefit from the introduction of the quantification of all the uncertainties mentioned the above and the performance of the new design of LAEF are investigated in this study.

The paper is organised as follows. In Section 2 ALADIN-LAEF configuration is introduced. Perturbation methods, blending for initial condition, multi-physics for model uncertainty and NCSB for the surface initial conditions are described in section 3. Section 4 presents the results of a two-month verification and comparison of LAEF. A summary and conclusions are given in section 5.

2. ALADIN-LAEF SYSTEM CONFIGURATION

The key element of a LAMEPS system is the limited area model. LAEF uses high resolution LAM ALADIN-Austria as the model system. ALADIN-Austria is the ALADIN configuration running at ZAMG operationally (Wang *et.al*., 2006). ALADIN is a hydrostatic, spectral LAM model. It includes a hybrid vertical co-ordinates; spectral method with bi-periodic extension of the domain using elliptical truncation of double-Fourier series; two-time level semi-Lagrangian advection scheme; semi-implicit time-stepping; fourth order horizontal diffusion; Davies-Kalberg type relaxation and digital filter initialisation (DFI). A brief description on ALADIN model physics will be given in section 3.2.

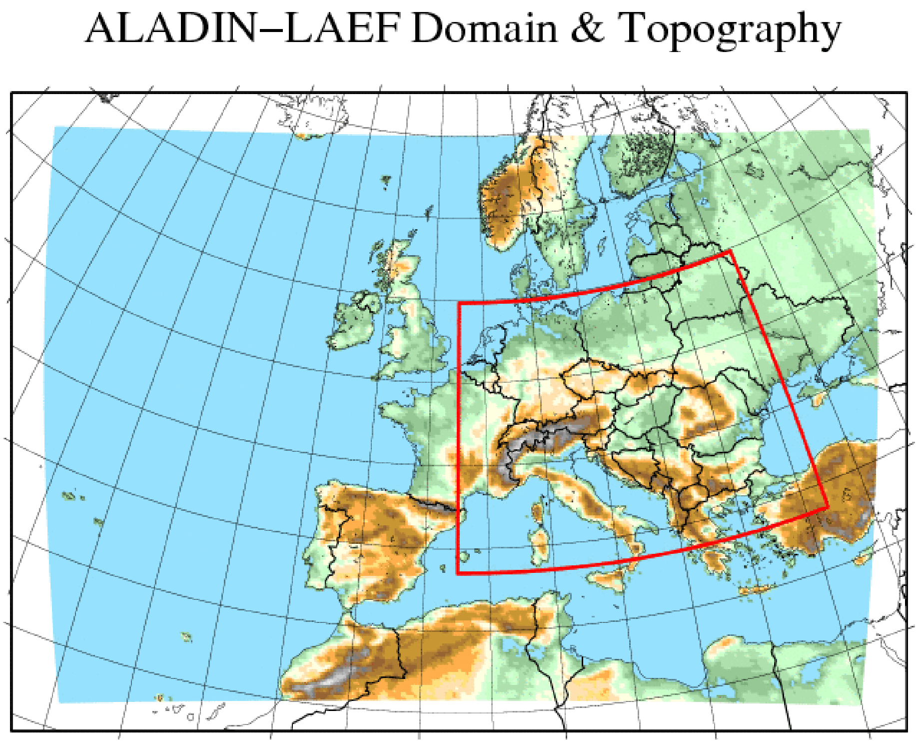

Figure 1. ALADIN-LAEF domain and model topography. The inner limited-area domain in red is the ALADIN-LAEF verification domain, which covers Central Europe and is with a resolution of 0.15 x 0.15 degree.

The ALADIN-LAEF integration domain covers whole Europe and large part of Atlantic, shown in Figure 1. This is based on the fact that the development of many weather systems in the Atlantic is very important for the forecast over Central Europe on one side, on the other side the domain is chosen big enough, so that the impact of the LBC is not strong and direct on the Central European region.

ALADIN-LAEF is run at a resolution of 18 km in horizontal and 37 levels in vertical. The LAEF forecast is to 60 h ahead and twice per day at 00UTC and 12UTC. LAEF is constructed with 18 members, of which 16 members are perturbed and LBC perturbations are provided by the first 16 ECWMF EPS members. The other 2 LAEF members take LBC from ECMWF EPS control member and ECMWF deterministic forecast respectively.

3. PERTURBATIONS

3.1. Initial condition perturbation: Blending global SV and LAM bred vector

It is very crucial to quantifying the initial perturbation for a skilful LAMEPS. A lot of studies have been done on IC generation methods for global model. However there are very limited studies on methods of LAM native initial perturbation generation. NCEP/SREPS (Du 2003) uses Breeding to generating LAM initiall perturbation. Few experiments on LAM SV (Bajmkert 2008) and LAM ETKF/ET (Wang 2007) are still in very early stage. Most of the LAMEPS system just nest a LAM ensemble within a global ensemble.

In LAMEPS context, two requirements for generating IC perturbation have to be taken into account. Firstly, the IC perturbations should be effective immediately from the initial time. This means that they should focus on quantifying the uncertainties in the analysis (Bowler 2008). Secondly, the LAM native IC perturbation should keep consistent with initial LBC perturbations, in other words, the LAM IC generation method will generate initial boundary values that should be somewhat consistent with global EPS BCs, if LAMEPS couples with a driving global EPS for tackling the BC perturbation. It is very likely, that a system, for example, coupling LAM Breeding perturbation within a global SV, will lead to spurious gravity wave generation at the lateral boundaries. It is not clear at all that this ill-posed set-up would produce a superior system to running a LAMEPS off its global counterpart, which is essential requiremnet of a LAMEPS. Meshing a LAM ETKF/ET within a global ETKF/ET (Sahar 2008, Du 2008), LAM Breeding within a global Breeding (Du 2008) or LAM SV within a global SV. are probably good way to avoid spurious gravity wave generation at the lateral boundaries (Bishop, personal coomuication).

For LAEF, the practically and operationally available global EPS system are ECMWF and PEARP/ARPEGE which are using the SV technique to produce the initial perturbation. On one side, LAM SV is still in a very early stage for experiment, and on the other side, SVs are not for use very close to initial time, as LAMEPS needs, but optimized for some forecast time (using very crude analysis error estimates), this makes some sense for the ECMWF whose charge is to make medium range forecasts, but it is less clear for LAMEPS, and may not be suitable for short range ensemble (Bowler 2008). And moreover, computation of SV is quite expensive.

The simplicity, cost-efficiency , and the success of the application of breeding at NCEP encourage us to explore the use of Breeding for LAEF, In order to ameliorate the aforementioned the inconsistency problem of coupling with ECMWFEPS, a new idea Blending for generation of LAM native perturbation has been proposed. The idea is using ALADIN blending technique (Brozkova *et al.* 2001), a digital filter and spectral analysis method, to combine the large-scale uncertainty generated by SV with ECMWF model with the small-scale uncertainty generated by Breeding with ALADIN model. The new perturbation has the feature that its large-scale part of the perturbation is the ECMWF SV one, and the mesoscale part is the LAEF Breeding one.

It is expected that the new perturbation, i). can somehow reduce the inconsistency between the different perturbation method used in global ensemble system which determine the perturbation at the boundaries and the initial analysis perturbation method used in limited area ensemble prediction system, This is based on the fact that the large scale part of the new perturbation is consistent with its global counterpart. ii). small-scale uncertainty in analysis will be more detailed and accurate described, due to the higher resolution and more balanced orographic/surface forcing of LAM breeding cycle, this should be closer to the reality than the interpolation of lower resolution of global model analysis. Buizza et al. (2005) has found the advantage of breeding in short range and small scale forecast. Furthermore, iii). The future uncertainty generated by SV and the uncertainty in the history generated by Breeding are all represented in this blended analysis. As discussed by Toth and Kanaly (1997), Ehrendorfer (1997) and Buizza et al. (2005), the Breeding attempts to give the best estimate of the actual errors in the initial analysis based on the past information of the flow, whereas the SV contain future information of possible forecast error.

In following, the methods which are applied for the breeding and blending in LAEF will be briefly described.

3.1.1. LAEF Breeding

Breeding (breeding of growing vectors) is designed to simulate how the growing errors are “bred” and maintained in a conventional analysis cycle through the successive use of short range forecasts. The bred vectors should thus provide a good estimate of possible growing error in the analysis (Toth and Kalnay 1993, 1997). The set up of Breeding consists the following steps: i) beginning with an introduction of an arbitrary perturbation on to control analysis, this should be done only once; ii) integrating the model with control analysis and the perturbaed IC; iii) building the difference between the two forecasts at fixed time interval (6h or 12h); iv) scaling down the forecast difference in amplitude to the size of the perturbation; v) adding the rescaled difference to the new control analysis. The steps ii) to v) is then repeated, and the perturbations are being bred that grow along the forecast trajectory.

In LAEF Breeding, the perturbed initial conditions were generated in sets of positive and negative pairs around a control analysis. Our implementation of the breeding method has the features: *a)* clod 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)* eight pairs, *f)* constant rescaling S , which is computed by:

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

where C is a tuning constant less than 1. N is the total grid number, T_{850}^{p} and T_{850}^{n} are the positive and negative short-term temperature forecasts near the 850hPa of the pair (J. Du, 2006, personal communication).

3.1.2. Blending large scale perturbation from SVs and small scale perturbation from LAEF Bred modes

The idea of blending is to combine large scale features resolved by global model perturbed analysis (in our case ECMWF EPS members generated by SVs) with the small scale features provided by LAM perturbed analysis (here are the initial states by LAEF pure Breeding). The hypothesis is that the short-wave part of the spectrum of LAEF pure breeding contains more reliable information for the mesoscale uncertainty than the short-wave part of corresponding interpolated ECMWF perturbed analysis which does not resolve these scales.

Blending technique developed by Brožková et al. (2001) is a spectral technique with standard Dolph-Chebyshev digital filter. Such a technique is very suitable especially for the spectral models, like ALADIN, where the model variables are defined by the spectral coefficients of their Fourier expansion. Then the combination of the wave numbers over the selected part of spectrum by using digital filter defines the new blended state. Moreover, in the spectral model an elegant trick can be used to mimic the spectral truncation simply by decreasing spectral resolution of the fields while the grid-point resolution is kept unchanged.

The whole blending procedure consists of several consequent steps. But the main principle is to apply a digital filter on both ECMWF SV and ALADIN Breeding perturbed initial states on the original ALADIN grid but at a lower spectral resolution. The difference between those filtered files, already at the ALADIN full spectral resolution, represents a large scale increment which should be added to the original ALADIN file. The combination (blending) of both spectra shall be performed in the transition zone. It is considered that the model error in the large scales is given by the smallest scale the driving model can analyse rather than those that it can predict. On the other hand, the LAM forecast is governing the mesoscale part of the spectrum, thus their relation can be used as a first empirical estimate of the blending cut truncation. In digital filtering, the spectral coefficients are progressively dumped and not strictly forced to zero values, hence a shock in the transition zone can be easily avoided.

The detailed description of digital filter technique for NWP can be found in Lynch and Huang (1992). The symbolic equation of Blending can summarize after Radmila et al. (2006),

$$IC_{blend(m)} = A_{bred(m)} + \left\{ \left(\overline{A}_{sv(m)}^{DF} \right)_{LOW} - \left(\overline{A}_{bred(m)}^{DF} \right)_{LOW} \right\}_{HIGH} \qquad (2)$$

Where IC_{blend} denotes initial condition after blending, A_{sv} stands for perturbed analysis generated by ECMWF SV, and A_{bred} for ALADIN breeding. *LOW* means the cut-off truncation, and *HIGH* is the ALADIN original spectral resolution. *m* is the m^{th} member of the ensemble. The digital filtering *DF* is applied at spectral resolution *LOW* in order to remove small scale noise or to obtain a clean long wave state. The final result IC_{blend} is performed at ALADIN spectral resolution *HIGH*.

The details on the mathematical background of digital filter used in blending, the technical implementation of Blending in LAEF, and the tunings on the split of the large scale and small scale part can be found in Bellus (2008 LACE report).

3.2. Model perturbation: multi-physics

Imperfection and simplification in model formulation, in particular in model physics, is one of the main error sources for uncertainties of forecast. Addressing those uncertainties is necessary for a skillful LAMEPS. In ALADIN-LAEF, the multi-physics approach is introduced for dealing with the uncertainties due to model errors. Different ALADIN physics configurations, and different variations of certain parameterizations are included in the ALADIN-LAEF, which are summarized in Table 1. The physical processes mainly addressed by these configurations and variations are large scale and sub-grid scale precipitation, radiation, turbulent transport and diffusion processes.

Tabel 1: Summary of ALADIN-LAEF Multi-Physics.

mem #	configuration	Cloud-physics	deep convection	radiation	turbulent transport	shallow convection	mixing length &entrainment rate
M 1	ALADIN-25	Kessler	BGMC	RG	Louis81	JFG03	Setting_0
M 2	ALADIN-25	Kessler	BGCP	RG	Louis81	JFG03	Setting_1
M 3	HARMONIE	Sunqunist	STRACO	Savijarvi90	CBR+S90	JFG03	---
M 4	ALARO+3MT	Alaro	3MT	JFG05	JFG06	JFG03	---
M 5	ALADIN-32	Lopez	BGMC	ECMWF	Louis81	KFB	Setting_0
M 6	ALADIN-32	Lopez	BGCP	ECMWF	Louis81	KFB	Setting_1
M 7	ALARO	Alaro	BG_MCON	JFG05	JFG06	JFG03	---
M 8	ALARO	Alaro	BG_MCON	JFG05	JFG06	JFG03	---
M 9	ALADIN-32	Lopez	BG_MCON	ECMWF	CBR+B81	KFB	Setting_0
M 10	ALADIN-32	Lopez	BG_CAPE	ECMWF	CBR+B81	KFB	Setting_1
M 11	ALADIN-32	Lopez	BG_MCON	ECMWF	CBR+S90	KFB	Setting_0
M 12	ALADIN-32	Lopez	BG_CAPE	ECMWF	CBR+S90	KFB	Setting_1
M 13	ALADIN-32	Lopez	BG_MCON	ECMWF	CBR+S90	JFG03	Setting_0
M 14	ALADIN-32	Lopez	BG_CAPE	ECMWF	CBR+S90	JFG03	Setting_1
M 15	ALARO+3MT	Alaro+XR	3MT	JFG05	JFG06	JFG03	---
M 16	ALARO+3MT	Alaro+XR1	3MT	JFG05	JFG06	JFG03	---
M 0	ALARO	Alaro	BG_MCON	JFG05	JFG06	JFG03	---
M 99	ALADIN-32	Lopez	BG_MCON	ECMWF	Louis81	KFB	Setting_0

In the following the main characteristics of each configuration are described. At first, a basic or reference physics setting for the ALADIN model is described, later the main differences of the other configurations with respect to this basic configuration are listed.

Configuration 1: *ALADIN-25*

This ALADIN physics setup can be seen as a reference or basic setting. Several physical parameterizations are employed in ALADIN (Gerard 2000). The main features of those physical parameterizations are briefly summarized as,

- ✓ Cloudiness and large-scale precipitation:
  A diagnostic scheme, where resolved cloudiness and cloud water content are determined as a function of humidity and temperature, is employed. The precipitation flux is computed from the condensation rates with the assumption that any supersaturation is converted to precipitation instantaneously. Evaporation, melting and freezing of precipitation are taken in to account by applying a revised Kessler (1969) scheme.
- ✓ Deep convection:
  The muss-flux-type scheme of Bougeault (1985) is applied in ALADIN. Several refinements and modifications have been developed, mainly addressing the dependency of the Kuo-type closure on horizontal resolution, following the ideas of Bougeault and Geleyn (1989), the treatment of the vertical transport of horizontal momentum and the entrainment rate, see Geleyn (2003).
- ✓ Radiation:
  The radiation scheme within this configuration is based on Geleyn and Hollingworth (1979) and Ritter and Geleyn (1992) with some simplification made in order to be able to compute the interactions between soil, clouds and radiation at each time step.
- ✓ Turbulent transport and planetary boundary layer:
  The computation of turbulent fluxes of heat, water vapour and momentum are designed on the basis of Louis (1979) and Louis et al. (1981), whereas parametrization of shallow convection follows Geleyn (1987). Several modification addressing the exchange coefficient and mixing length are proposed by Geleyn (2003).
- ✓ Mountain drag:
  The linear gravity wave drag contribution is based on the ideas of Boer et al. (1984). The form drag contribution follows Lott and Miller (1997). Some other effects of unresolved features due to topography have been taken into account by Geleyn (2003).
- ✓ Soil processes:
  ISBA (Interactions Soil Biosphere Atmosphere) scheme (Noilhan and Planton 1989; Giard and Bazile 2000) is used in ALADIN. There are 6 prognostic variables used: surface temperature, deep soil temperature, surface reservoir water content, deep reservoir water content, interception reservoir water content and snow cover water content.

Configuration 2: *ALARO*

Setting 2, *ALARO*, is the operational physics setup in ALADIN-AUSTRIA. It is a new ALADIN physical package developed within the ALADIN and RC LACE (Regional Cooperation for Limited Area Forecasting over Central Europe) cooperation. The main modifications with respect to *ALADIN-25* are in large-scale precipitation, turbulent transport and radiation.

- — Cloudiness and large scale precipitation (*Alaro*)
  Alaro is a prognostic type parameterization for resolved cloudiness and precipitation (Catry *et al*., 2007). There are 5 prognostic quantities in the scheme: cloud water, cloud ice, rain, snow and water vapour. The computation of condensates entering the microphysics depends on the existence of cloudiness, which is diagnosed using a modified Xu-Randall formulation (Xu and Randall, 1996). There is an alternative option implemented to use a Smith-typed (Smith, 1990) formulation, but for this configuration the Xu-Randall option was chosen.
  A statistical approach is applied for sedimentation, where instead of fixed fall velocities, probabilities are used to describe the downward transfer of precipitating species. The physical processes, auto-conversion, evaporation, sublimation, melting, freezing and the Wegener-Bergeron-Findeisen process are taken into account in the Alaro scheme. The existence of graupel and the resulting effect on the fall speed is simulated in a diagnostic way. A detailed description can be found in Geleyn et al. (2008).
  In order to prevent the occurrence of negative values for the humidity and water phases contents, a correction is applied when negative values occur. This correction is done by additional condensation of water vapour or pumping of water vapour from layers below. A cascading approach is used, whereas model humidity variables and temperature are updated after each parameterization call (Gerard, 2007).
- — Turbulent transport (*JFG06*)

The TKE scheme has been revised in order to make it (pseudo-)prognostic, following Geleyn et al. (2006). The turbulent kinetic energy is a prognostic variable, whereas the exchange coefficient is determined in a diagnostic way.

- Radiation (*JFG05*)

  Compared to the radiation scheme in the basic configuration, there three major modifications have been introduced: A new saturation cloud model was developed in order to improve the cloud optical properties in solar and thermal band, making them dependent on cloud water and cloud ice (Masek, 2007). Further, a simplified version of the Voigt-line-broadening effect was implemented (Geleyn *et al*., 2005a); and a new statistical model for the interpolation coefficient for the net exchange rate computations was introduced following Geleyn et al. (2005b).

The schemes for deep convection, soil processes and mountain drag as depicted for the basic configuration remain mainly unchanged.

Configuration 3: *ALARO+3MT*

Configuration *ALARO+3MT* includes parameterization *Alaro* and a new parameterization scheme 3MT (Modular Multiscale Microphysic and Transport, Gerard 2007; Gerard and Geleyn 2005; Piriou *et al*. 2007), which is being developed mainly for handling the transition from parameterization of sub-grid convection at coarse horizontal resolutions to explicit computation of convection at cloud resolving resolutions for horizontal model resolutions between 7 km and 2km. *ALARO+3MT* represents a package of parameterizations for deep convection, resolved condensation and microphysics which is able to deliver physically consistent results for all model resolution. The convective parameterization acts with a prognostic mass-flux scheme.

In *ALARO*, the different parameterizations are called within a cascade, where the model variables for the water phases and temperature are updated after each parameterization call yielding the initial state for the following call. This cascade includes: turbulent diffusion; resolved condensation; convective updraught; generation of precipitation through auto-conversion; evaporation; sedimentation and associated processes of collection and melting; downdraught computation. The computations of updraught and downdraught are followed by Gerard (2007).

Updraught: There is no precipitation generated during the updraught computation, but generated condensates are detrained and finally added to the resolved condensates which are finally passed to the microphysical part. This allows a common handling for all condensates, no matter whether they are resolved or sub-grid origin. Triggering of the convective updraught is based on buoyancy and moisture convergence. There are prognostic variables used for updraught vertical velocity and the updraught area fraction.

Downdraught: The computation of the moist downdraught is performed after the microphysical call and is based on the heat sink resulting from precipitation through melting and evaporation and vertical temperature advection. For triggering the downdraught the existence of negative buoyancy is needed. There are prognostic variables used for downdraught vertical velocity and downdraught area fraction.

In the LAEF multi-physics design, 3 variations of configuration *ALARO+3MT* are used. As already mentioned in *ALARO* configuration, the physical package allows to use 2 different options for the computation of the resolved part of condensation and evaporation processes. Variation 1 *Alaro,* uses the Smith based option, for variation 2 *Alaro+XR,* the Xu-Randall typed computation was activated. In Variation 3 *Alaro+XR1,* the Xu-Randall option is activated together with an option affecting the protection of convective condensate produced during the updraught computation.

Configuration 4: *ALADIN-32*

ALADIN-32 is the current operational ALADIN setup at Météo-France. The large-scale cloudiness and precipitation scheme is a prognostic one proposed by Lopez (2002). The main differences to the reference configuration *ALADIN-25* are:

- Cloudiness and large-scale precipitation (*Lopez*)

Cloud water, cloud ice, rain and snow are the prognostic variables in the scheme (Lopez 2002). The computation of condensation and evaporation processes of resolved condensates is following the ideas of Smith (1990), auto-conversion is determined following Kessler (1969). Beside the parameterization of evaporation of precipitating species there are three types of collection processes taken into account: Accretion, aggregation and riming. For sedimentation a semi-Lagrangian approach is used with constant fall velocities for rain and snow.

— Radiation (*ECMWF*)

ECMWF radiation scheme is used in *ALADIN-32*, which is RRTM for the long wave and the scheme of Morcrette (1991) for the short wave.

— Turbulent transport (*CBR*)

A prognostic TKE scheme (Cuxart *et al*., 2000) is used for calculation of turbulence transport. In LAEF multi-physics implementation, *CBR* scheme is combined with two options (*CBR+B81* and *CBR+S90)* for modeling the cloud in the boundary layer, the PDF cloud scheme of Bougeault (1981) or the one of Smith (1990).

Moreover, shallow convection can be parameterized in configuration *ALADIN-32* by two different schemes (KFB*,* Bechtold *et. al*., 2002; and *JFG03*, Geleyn 2003). Those are designed as variations in the LAEF multi-physics too.

Configuration 5: *HARMONIE*

Thanks to HARMONIE (Hirlam ALADIN Regional/Meso-scale Operational NWP in Europe), it makes HIRLAM physics packages possible within frame of ARPEGE/ALADIN/AROME dynamics. The combination of ALADIN dynamics with HIRLAM physics is as one option in the ALADIN-LAEF multi-physics. The main features of this physics package are:

— HIRLAM radiation scheme (*Savijarvi*)

HIRLAM radiation scheme is developed by Savijarvi (1990) and described in Sass et al. (1994) and Wyser et al. (1999). It considers only two radiation bands, shortwave and longwave, therefore it is a quite cheap radiation scheme, and can be activated at every time step.

— HIRLAM vertical diffusion scheme (*CBR*)

The CBR scheme (Cuxart *et al*., 2000) with adjustments to the length scale (Lenderink and Holtslag, 2004) is used for the vertical diffusion. It makes use of the prognostic Turbulent Kinetic Energy (TKE) and a diagnostic length scale to determine the eddy diffusion coefficient.

— HIRLAM convection and condensation scheme (*STRACO*)

STRACO (Soft Transition Condensation) puts emphasis on the gradual transitions from convective to stratiform regimes. It is a modified Kuo-type convection scheme (Kuo, 1974). The microphysics and precipitation processes are based on the work of Sundqvist (1993).

Two different settings of some empirical and adjustable parameters for calculation of mixing length, entrainment rate and cloud base are included in the configuration *ALADIN-25* and configuration *ALADIN-32*. The values of those parameters are estimated/chosen by ALADIN physics experts (personal communication Bazile, Geleyn) in the way so that the ALADIN model keeps the same quality in the forecast.

3.3. Initial Surface condition perturbation: Non-Cycling Surface Breeding (NCSB)

Perturbing initial surface conditions, such as soil moisture, should have a beneficial impact on the skill of short-range probabilistic forecast of surface weather parameters (Sutton *et al.*, 2006). Up to now the generation of initial perturbations presented in this paper is restricted to free atmosphere variables (e.g. temperature, specific humidity). In the following a strategy, how to generate perturbations of the surface variables, e.g. *soil moisture content* and *surface temperature,* NCSB (Non-Cycling Surface Breeding) is briefly introduced. More detailed description and discussion on NCSB are given in a companion paper (Wang *et al.*, 2008)

The idea behind the NCSB is to perturb the initial surface conditions by employing short range forecasts driven by perturbed free atmospheric forcing and the breeding method. Similar as Breeding, the simulation of the fast growing “errors of the day” (Kalnay 2003) on the surface state is started by introducing perturbations in free atmosphere. The perturbation is not randomly seeded. The LAM model is then integrated for 6 or 12 hours from the perturbed free atmospheric initial conditions, together with perturbed LBCs and model physics. The 6 or 12 hour surface forecasts are subtracted from the corresponding new surface analysis, and the difference is scaled down, and then added to the corresponding new surface analysis. The process is started every time new. It should noted that the the free atmosphere perturbation is independent to the native LAM initial perturbation. This is to avoiding the drifting problem if (personal communication Radmila 2007)

In the implementation of NCSB in ALADIN-LAEF, the 16 perturbed free atmospheric initial conditions are downscaling of the first 16 initial perturbation of ECMWF EPS. LBC perturbations are obtained also form the forecasts of corresponding ECMWF EPS members. The aforementioned multi-physics approach is applied for quantification of model uncertainty. ARPEGE surface analysis is used instead of the ECMWF surface analysis. This is due to differences in the surface physical parameterization between the ECMWF-model and ARPEGE/ALADIN. It is problematic to use the surface variables of ECMWF in ALADIN coupling-files. By replacing the surface from ECMWF with the surface from ARPEGE surface analysis this problems can be ameliorated.

4. TECHNICAL IMPLEMENTATION

The presented methods for generating the initial perturbation (breeding, blending, NCSB) and the multi-physics approach, to account for the uncertainties of the model formulation, are all introduced in ALADIN-LAEF. For the LBC perturbation, a 12h time lagged coupling with ECMWF EPS forecast is applied in ALADIN-LAEF. It is considered for operational purposes. LAMEPS should be available as earlier as possible. The technical implementation of the new ALADIN-LAEF is schematically described in Figure 2.

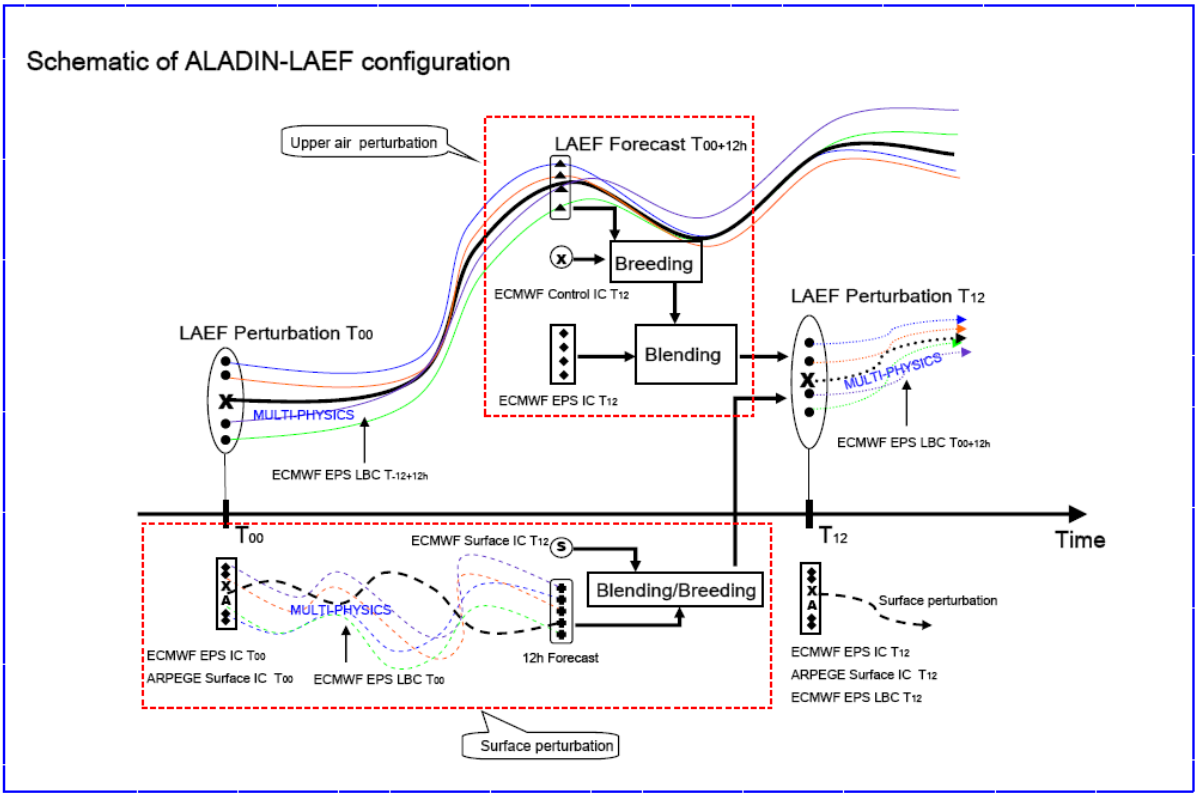

Figure 2. Schematic description of ALADIN-LAEF.

Each day two ALADIN-LAEF runs are performed, with initial time at 00 UTC and 12 UTC.

As for the 12UTC run, the 12h forecasts of ALADIN-LAEF started at 00UTC ***LAEF Forecast T_{00+12h}***, which is computed with LAEF Perturbation **T_{00}**, multi-physics, and time lagged ECMWF LBC ***ECMWF-EPS-LBC $T_{-12+12h}$***., together with the ECMWF control analysis valid at 12UTC ***ECMWF Control IC T_{12}***, ALADIN breeding is performed for the generation of the meso-scale part of the perturbation. The ALADIN breeding perturbation is then mixed with the ECMWF initial perturbations generated by SV. This is the Blending. The results of the blending is as the new upper air perturbation for the ALADIN-LAEF at 12 UTC. This is the part of upper air perturbation showed in the Fig.

The generation of initial surface perturbation for 12UTC run is ALADIN integration started with the 00 UTC ECMWF upper air perturbation from ECMWF EPS members and the ARPEGE surface. The corresponding LBC from ECMWF 00 UTC run and multi-physics are used for the integration. 12h ALADIN surface forecasts of this additional ensemble run provide the new surface conditions at 12 UTC, which is used for breeding with the ECMWF surface analysis valid at 12UTC. Again the breeding results are used as the new initial surface perturbation at 12UTC.

With the new upper air perturbation by blending and initial surface perturbation from NCSB, the new LAEF perturbation at T_{12} are built. ALAADIN model starts for the 12UTC run with multi-physics and the time lagged ECMWF LBCs.

After the LAEF main forecast, the preparation for the next cycle begins, the 12h ALADIN-LAEF forecast is prepared for the 00UTC breeding cycle,. Another cycle independent 12h ALADIN forecast with ECMWF EPS member is prepared for the initial surface perturbation.

5. RESULTS

In this study the performance of the new design of ALADIN-LAEF (referred to as BBSM, Breeding-Blending-Surface perturbation-Multiphysics) and the pre-operational ALADIN-LAEF (referred to as DOWN) are accessed for a 2-month period (June 20 to Aug. 20 2007). The ALADIN-LAEF were initialized at 00UTC and run for 54 h. ECMWF analysis is used for verification of ALALDIN-LAEF forecast of upper air weather variables, both analysis and forecast are interpolated on a common regular 0.15 x 0.15 grid. Observation is applied for the verification of surface weather variables. The verification of the surface weather variables is performed at the observation location. Forecast values is interpolated to the observation site for those smoothly varying field, such as 2m temperature, 10m wind speed and surface pressure. For precipitation, which is with strong spatial gradients, the observation is matched to the nearest grid point.

The verification is performed over a limited-area inner domain, which is over Central Europe and with resolution of 0.15 x 0.15 degree, shown in Fig. 1.

A set of standard ensemble and probabilistic forecast verification methods are applied to evaluate the performance of those two ALADIN-LAEF configurations, BBSM and OPER. They are ensemble spread/ ensemble root-mean square error, Talagrand diagram or Rank histogram, Continuous Ranked Probability Score (CRPS), Continuous Ranked Probability Skill Score (CRPSS), outlier statistics, Area under Relative Operating Characteristic curve (AROC), Reliability diagram. The detailed description of those verification scores is not given here, they can be found, e.g. in Anderson (1996), Hamill and Colucci (1996), Talagrand et al. (1999), Mason (1982), Jolliffe and Stephenson (2003), Stanski et al. (1989) and Wilks (2006). Those verification scores measure the quality of probabilistic forecast of scalar quantities.

5.1 Verification of upper air weather variables

Verification of upper air weather variables (temperature, geopotential height, wind speed and relative humidity) has been carried on different pressure levels, e.g. 500 hPa and 850hPa. Similar results have been observed for different levels. In this paper we will focus on verification of the forecast of temperature at 850 hPa (T850), geopotential height (Z850), wind speed (V850) and relative humidity (RH850).

The discrepancy between the ensemble spread and the error of the ensemble mean is a measure of the statistical reliability. The magnitude of ensemble spread should be correspond with the magnitude of r.m.s. error of ensemble mean. A large difference between the error of ensemble mean and ensemble spread is an indication of statistical inconsistency (Buizza et al 2005). Fig. 3 shows r.m.s. error of ensemble mean and ensemble spread of forecast of T850, Z850 V850 and RH850 for BBSM and DOWN.

For temperature, wind speed and relative humidity, larger perturbation growth (spread) and smaller r.m.s. error, therefore small discrepancy between r.m.s. error and spread can be noticed with BBSM, which performs clearly better than DOWN. For geopotential, the ensemble spread slightly overestimates the r.m.s. error for BBSM, while the growth of ensemble spread is quite close to the r.m.s. error of forecast of DOWN.

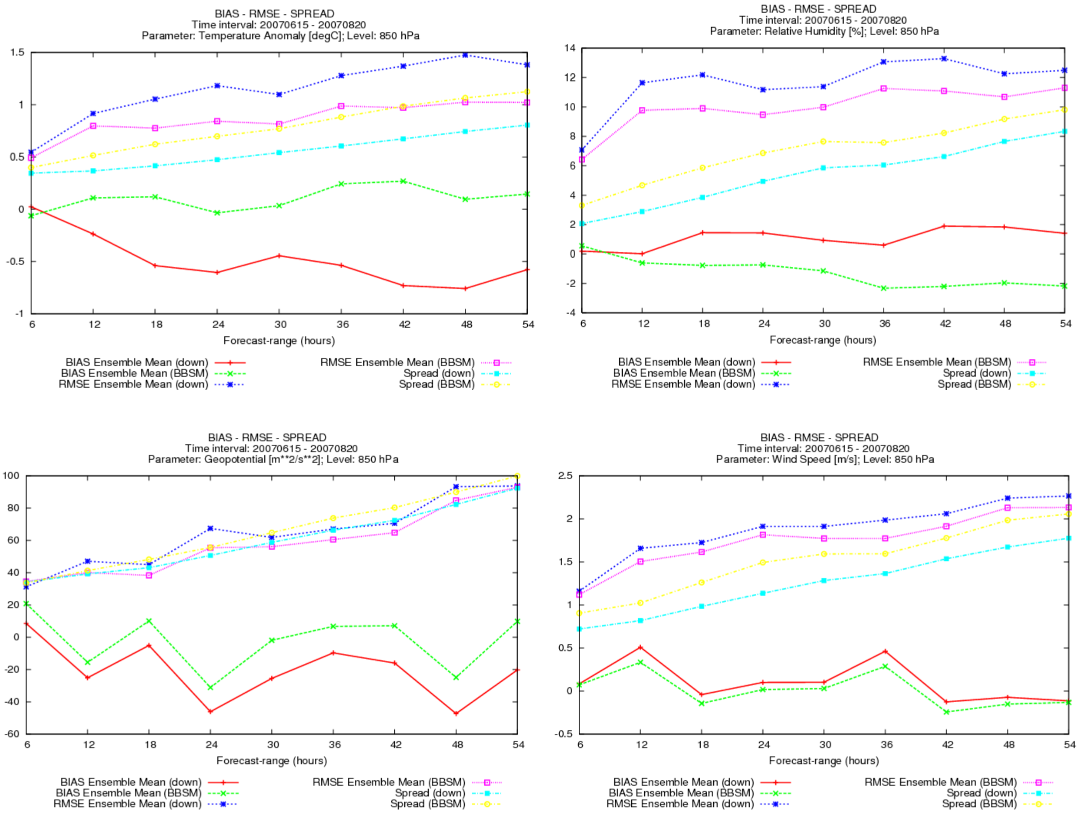

Figure 3. r.m.s. error of the ensemble mean (solid lines) and ensemble spread (dotted lines) of DOWN (circles) and BBSM (crosses) for a) Z850; b) T850; c) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

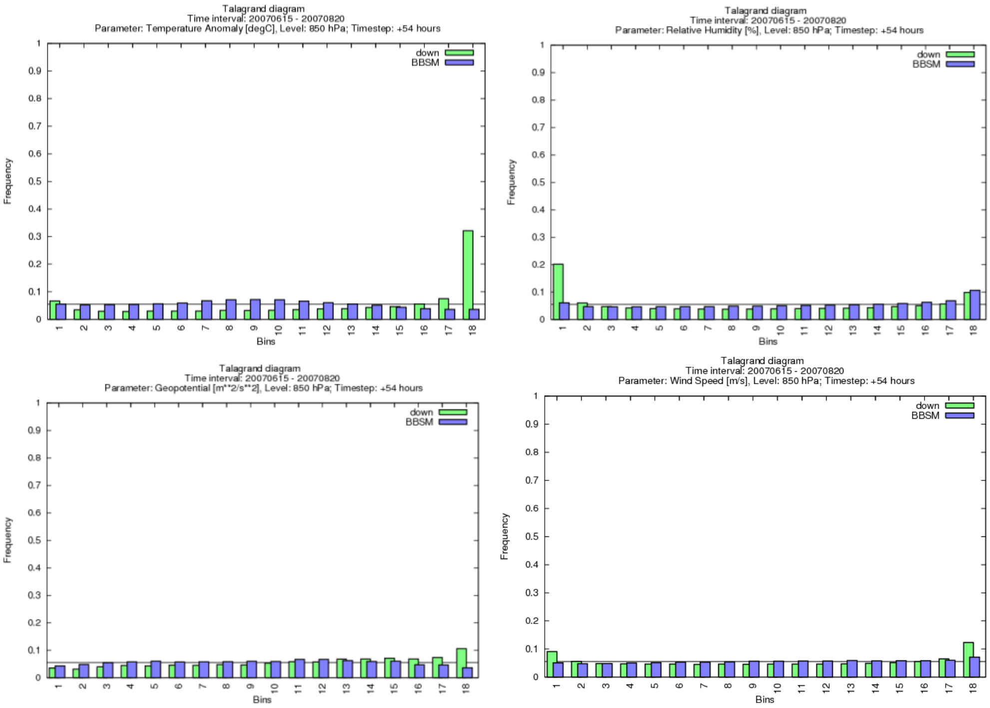

Figure 4. Talagrand diagram of DOWN (green) and BBSM (blue) for forecast at a lead time of +54h of a) Z850; b) T850; c) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

Talagrand diagram is applied to evaluate the ability of an ensemble system to reflect the observed frequency distribution, it describes the characteristic of ensemble spread and bias (Talagrand *et al.* 1997). A perfect ensemble system has a flat rank histogram. The reference rank uniformity is equal to $1/(n_{ens}+1)$, where n_{ens} is the ensemble size. Figure 4 shows the Talagrand diagrams for Z850, T850, RH850 and V850 at forecast lead time +54h for BBSM and DOWN. The cold and moist bias in the DOWN forecast (T850 and RH850), under-dispersion in V850 and under-forecasting bias in Z850 have been improved by BBSM, the relative flatness of the rank histogram for all the variables of BBSM is the indication that observation can be predicted within the BBSM forecast. A slight over-dispersion in Z850 of BBSM is found, which is consistent with the result in Figure 3.

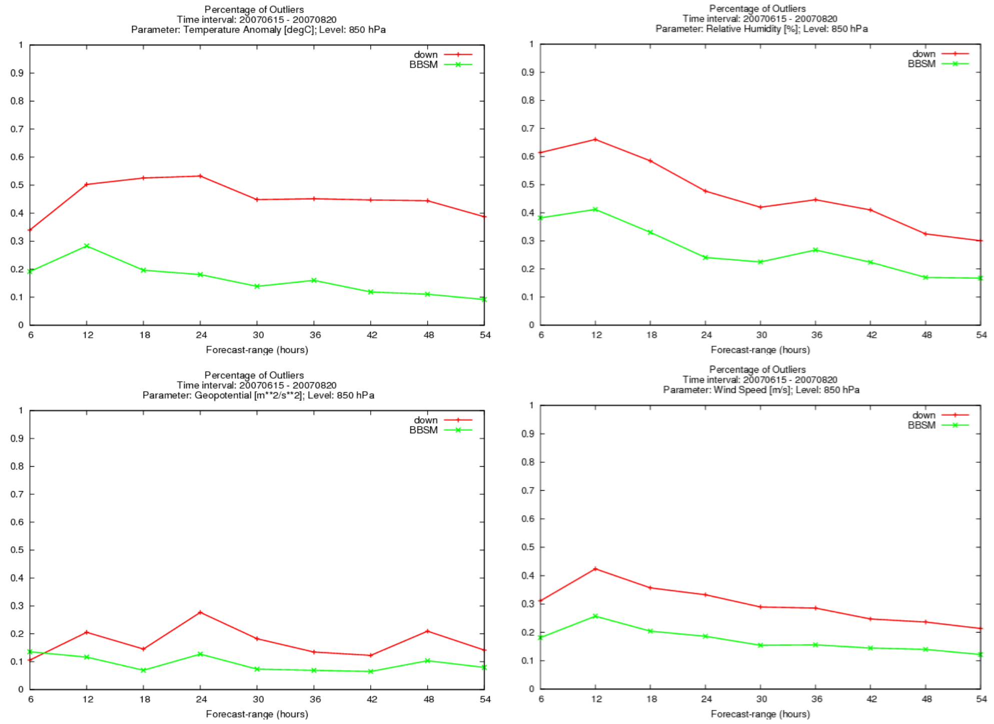

Figure 5. Percentage of outliers of DOWN (circles) and BBSM (crosses) of a) Z850; b) T850; c) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

As another measure of statistical reliability is the percentage of outlier. This is the statistics of the number of cases when the verifying analysis at any grid point lies outside the whole ensemble. A more reliable system should have a score closer to zero. It is evident that BBSM has less outlier than DOWN for all the weather variables (Figure 5).

A comprehensive appreciation of forecast quality considering statistical reliability and resolution is given by reliability diagram, this is a graphical description of the resolution and reliability of a EPS by plotting the frequency of forecast probabilities against the related verification frequency. For a perfect reliable EPS, the forecast and the verification probabilities should be matched each other (the diagonal line in the diagram). Figure 6 presents the reliability diagram for the weather variables T850, V850 and RH850 of DOWN and BBSM, valid at forecast lead time +54h. The thresholds used in the diagram are temperature anomaly > 0°C, wind speed > 10m/s and relative humidity > 40%. Same as in the Talagrand diagram, cold bias or under forecasting in the temperature forecast, moist bias or over forecasting in the relative humidity are found with DOWN forecast. BBSM forecast gives a good resolution and calibration for T850 and RH850. Slightly better performance is shown for V850 with BBSM.

Figure 7 shows the CRPS of Z850, T850, V850 and RH850 for both BBSM and DOWN. The CRPS is the generalized form of the discrete ranked probability score, simulating the mean over all possible thresholds. As noted by Hersbach (2000), CRPS is analogous to an integrated form of Brier score, which can be decomposed into reliability, resolution and uncertainty. The CRPS has a negative orientation, and it rewards concentration of probability around the step function located at the observed value. A perfect CRPS score is zero, as with the Brier Score. The clear feature presented in Figure 7 is the out-performance of BBSM to DOWN.

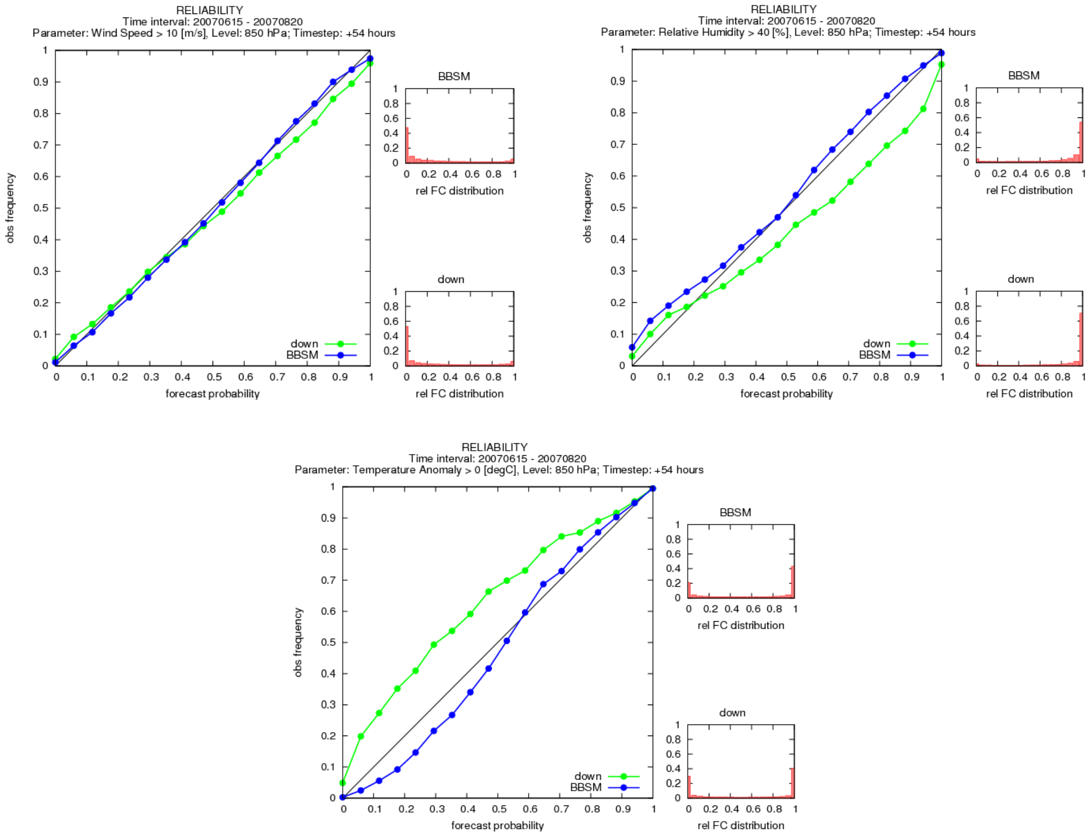

Figure 6. Reliability diagram of DOWN (circles) and BBSM (crosses) for forecast at a lead time of +54h of a) T850; b) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20. The threshold for T850 is temperature anomaly > 0^{o} C; for V850 is > 10 m/s and for RH850 is > 40%.

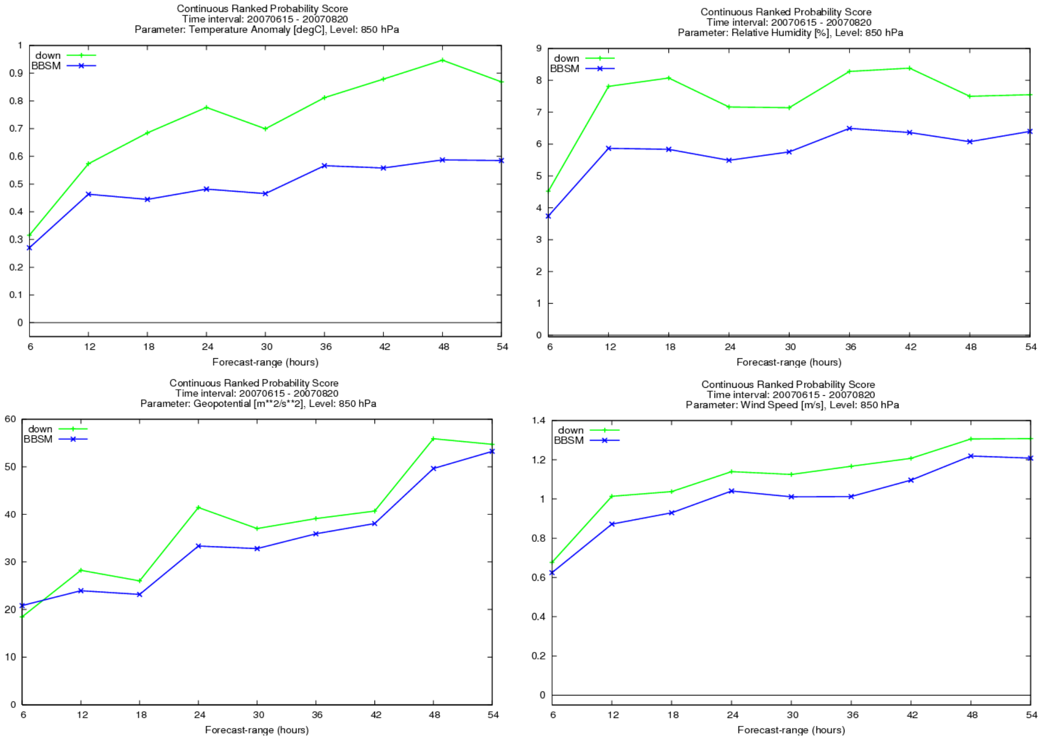

Figure 7. Continuous ranked probability scores of DOWN (circles) and BBSM (crosses) of a) Z850; b) T850; c) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

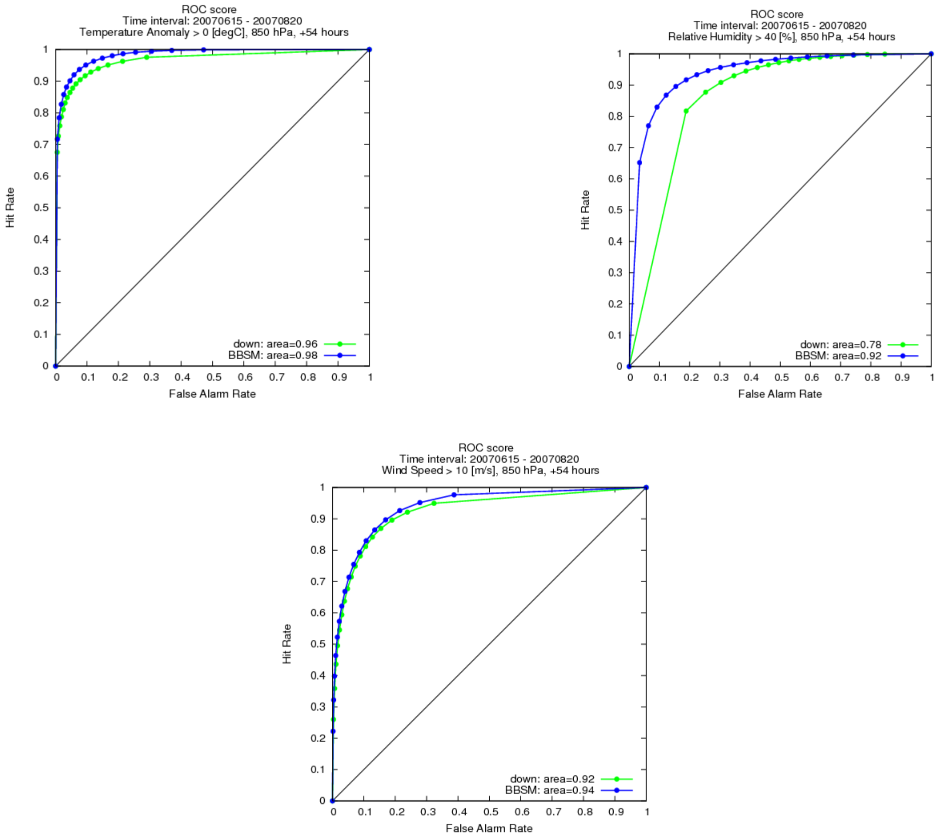

Figure 8. Area under the relative DOWNating characteristics of DOWN (circles) and BBSM (crosses) of a) T850; b) RH850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

The AROC score measures the statistical discrimination capability of an ensemble system. It gives information quite similar to the resolution part of the Brier skill score, and can be applied to access more directly the inherent value of a prediction system (the score is with skill larger than 0.5, the best is 1). Again, as for the other scores, the AROC score shown in Figure 8 indicates the superiority obtained by BBSM to DOWN.

5.2 Verification of surface weather variables

Since the main product of ALADIN-LAEF concerns the short-range forecast of surface weather variabless, the verification is focused on 2 meter temperature (T2m), 10 meter Wind (W10m), 12h accumulated rainfall (RR) and mean sea level pressure (MSLP). Similar statistical scores to those in subsection 5.1 have been used to evaluate the forecast quality. Verification of the forecasts from DOWN and BBSM for the months of June - August 2007 are shown in Figures 9-15.

a. *The ensemble spread and r.m.s. error of ensemble mean*

Figure 9 shows the time evolution of ensemble spread and r.m.s. error of ensemble mean of T2m, W10m, RR and MSLP for BBSM and DOWN. Overall, the spread of BBSM forecast for those surface variables are larger than the DOWN forecast; and the r.m.s. error of the ensemble mean of BBSM are smaller than DOWN. The smaller discrepancy between ensemble spread and r.m.s. error of ensemble mean of BBSM implies the superiority of BBSM to DOWN concerning the reliability of the ensemble system. Quite clear improvement can be observed for the rainfall and near surface temperature forecast, whereas the improvement on the r.m.s. error of wind is almost invisible. It seems that the employment of NCBB, which is mainly concerns the soil moisture and soil temperature, doesn't brings clear benefits for the wind forecast.

It is noted that the gain on statistical consistency for the surface variable from BBSM is not so competitive as for the upper air variables. The surface forecast of BBSM and DOWN are still strong under-dispersive, e.g. the growth of ensemble perturbation can not match the error of the ensemble mean; the magnitudes of the initial perturbation are much smaller than the level of estimated initial errors of the system. Similar features are seen at all the lead time. The growth of spread are determined by two factors, the initial perturbation and model perturbation. It is obviously that the lack of the model perturbation in related physical processes in the surface and small surface perturbation at initial time are the reasons.

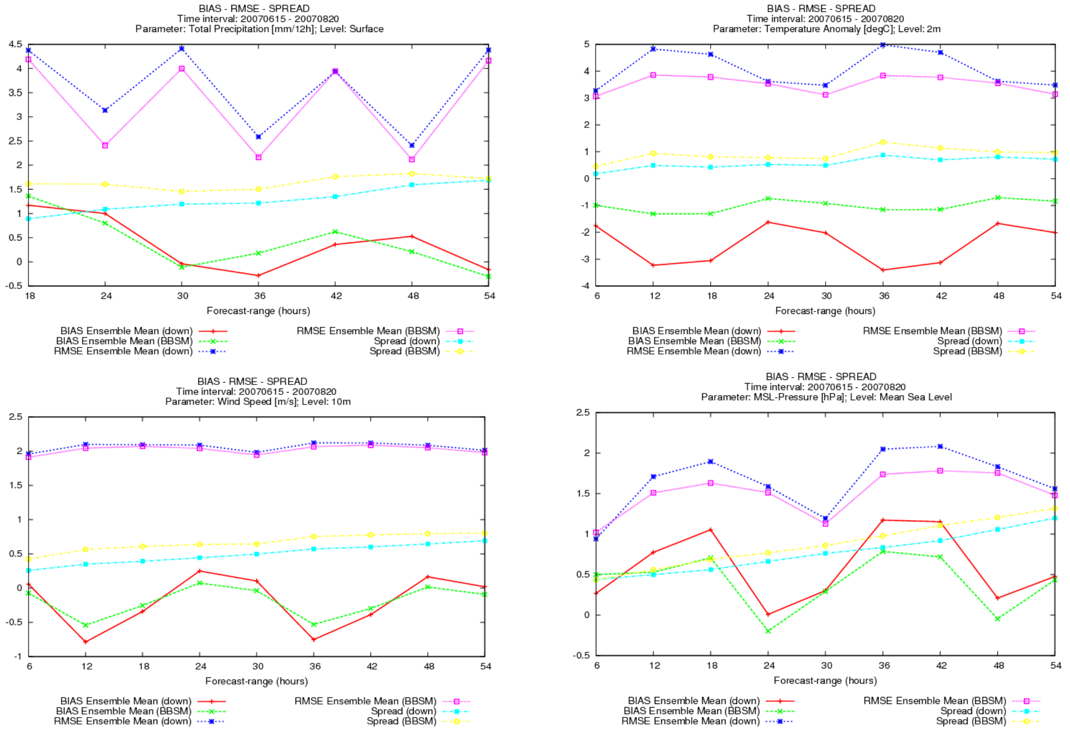

Figure 9. r.m.s. error of the ensemble mean (solid lines) and ensemble spread (dotted lines) of DOWN (circles) and BBSM (crosses) for a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

b. *The Talagrand diagram*

The reliability of BBSM and DOWN is evaluated in Figure 10 in term of Talagrand diagram for the forecast of T2m, RR, W10m and MSLP, valid at lead time +54h. BBSM removes the bias in DOWN, in particular, in the forecast of T2m and MSLP (Figs. 10a, 10d), and increases the spread of rainfall forecast in DOWN, shown in Figure 10b. Concerning the wind forecast, small improvement on spread is found in BBSM wind forecast (Figure 10c). Despite the better performance of BBSM in spread, both ALADIN-LAEF configurations are strongly underdispersed. This is quite different to the result for the upper air variables shown in Figure 3. This probably because of the lack of surface physics perturbation in the systems and too small initial perturbations in the surface, as seen from Figure 9.

c. *The outlier statistics*

Figure 11 shows the outlier statistics of the forecast from BBSM and DOWN. The differences between the BBSM and DOWN in the outlier statistics is quite significant for all the weather variables, the BBSM forecast is clearly more reliable than the DOWN forecast. This is consistent with the results in Figure 9.

d. *The reliability diagram*

Figure 12 shows the reliability diagrams for T2m, W10m, RR and MSLP from the ALADIN-LAEF configurations BBSM and DOWN, the forecast is valid at lead time 54h. The verifying events are chosen for temperature anomaly > 0^{o}C, wind speed > 4 m/s, mean sea level pressure > 1015 hPa and rain fall > 10mm/12h.

Result from Fig. 12a for the reliability diagram of T2m indicates that the strong cold bias in the DOWN forecast is removed by BBSM. The forecast of BBSM is more reliable and has better resolution than DOWN. This positive effect of BBSM is due to the use of NCBB, the initial surface perturbation in ALADIN-LAEF. The poor reliability of DOWN is caused by a cold bias in the forecast, this is known as a problem in the surface coupling between

ALADIN and ECMWF. The use of NCSB is to remove the bias by applying ARPEGE analysis. A verification of a winter month 2008/2009 gives the proof of this conclusion. (Not shown)

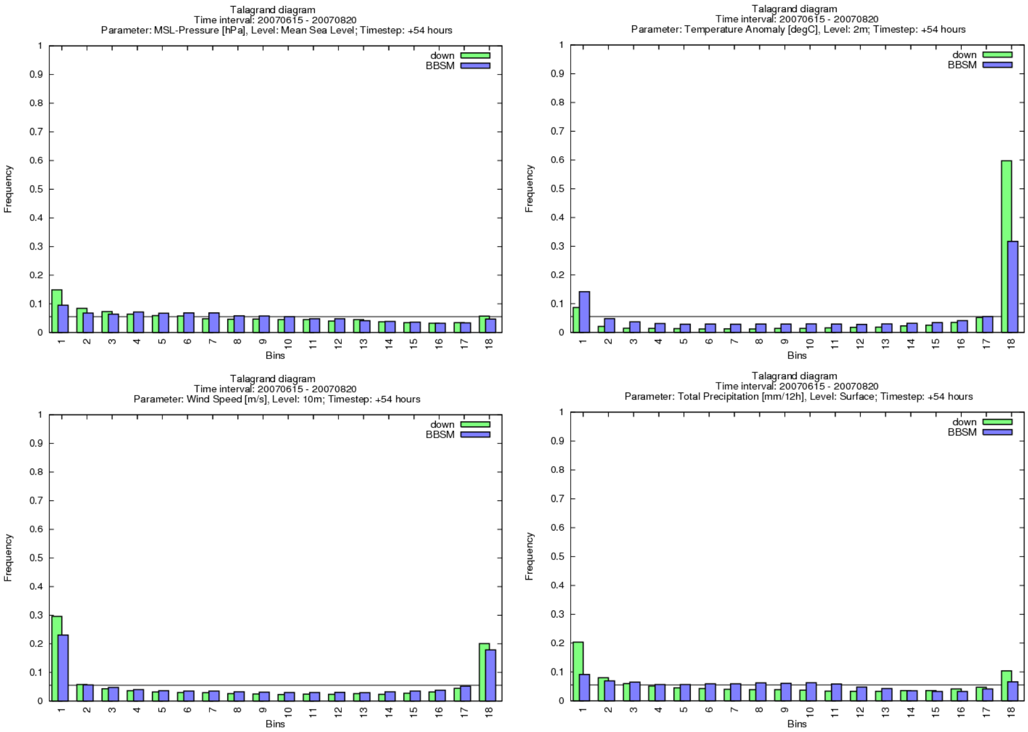

Figure 10. Talagrand diagram of DOWN (green) and BBSM (blue) for forecast at a lead time of +54h of a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

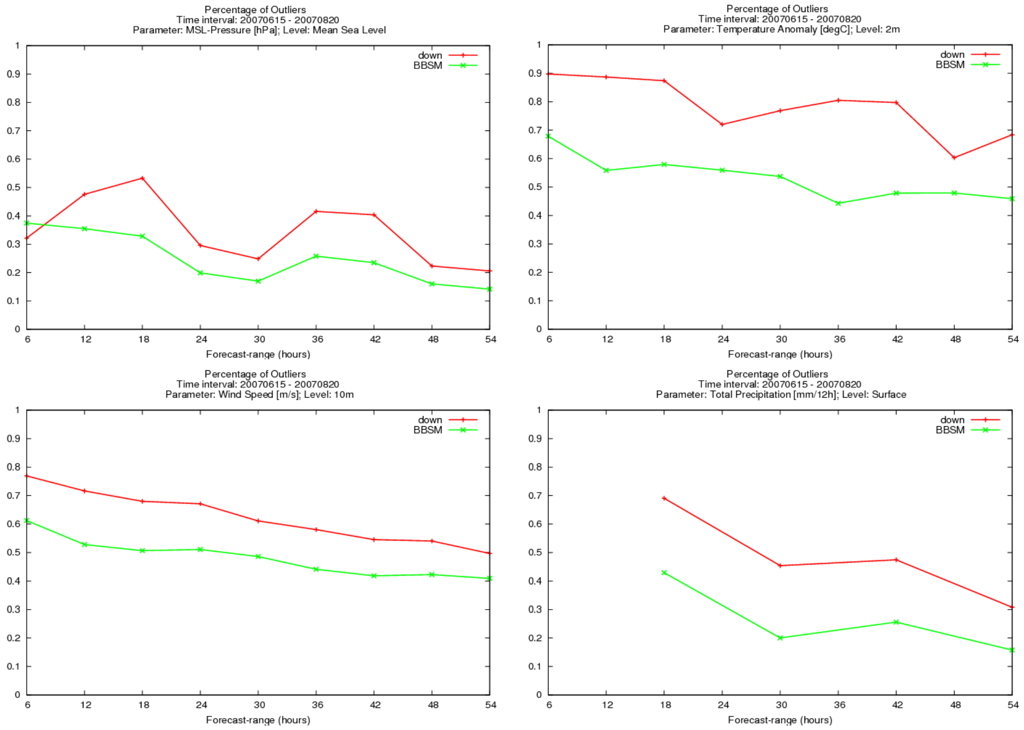

Figure 11. Percentage of outliers of DOWN (dashed) and BBSM (solid) of a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

Fig. 12b shows the verification of 12h accumulated rainfall forecast at lead time 54h of the event larger than 10m/12h. The reliability curve of BBSM is closer to diagonal than DOWN. Same as the T2m forecast (Fig. 12a), the rainfall forecast of BBSM is more reliable, and has better resolution than DOWN. This means the combination of the IC perturbations, in particular the LAM native IC perturbation, with the multi-physics scheme is quite beneficial to the probabilistic skill of the precipitation forecast.

It can be also noted that BBSM brings some improvement on wind and MSLP, shown in Fig. 12c and 12d, but those are not so remarkable as T2m and RR.

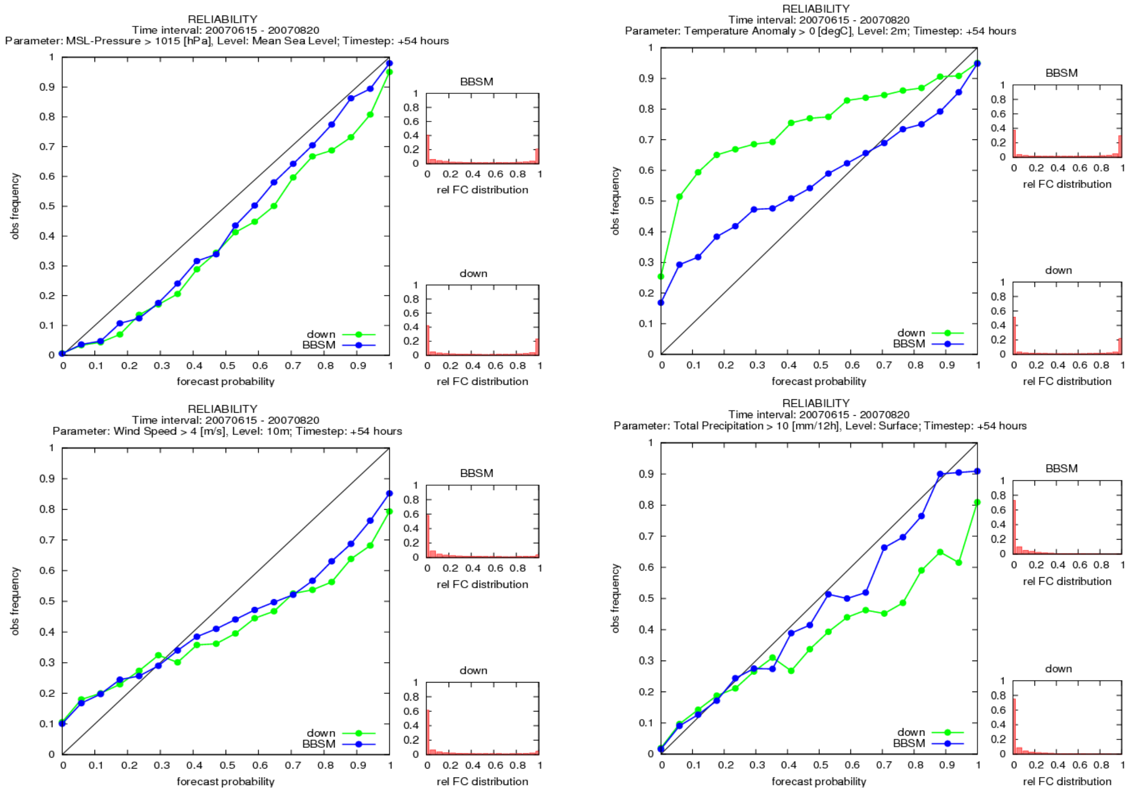

Figure 12. Reliability diagrams and sharpness of DOWN (circles) and BBSM (crosses) for forecast of a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

e. *CRPS and CRPSS*

The skills of BBSM and DOWN forecast are verified with CRPS and CRPSS, which is one of a proper measure of overall ensemble forecast performance. Similar to Brier skill score, CRPSS measures the skill relative to the reference forecast, it is skill score by normalizing CRPS by the skill of reference forecast. CRPSS is positively oriented, it is equal to 1 for a perfect system and it is null for the system which has the same performance as the reference system. A negative values means that the ensemble system is under-perform to the reference system. In our verification, the high resolution deterministic forecast of ALADIN-AUSTRIA, which is operationally run at ZAMG with 9.6 km horizontal resolution and 60 levels in vertical (Wang et al. 2007), is used as the reference forecast in the CRPSS computation, this is because we do believe that the ALADIN-LAEF should be at least more skillful than the ALADIN-AUSTRIA forecast. If it were not the case, then it would be difficult to justify the operational use of ALADIN-LAEF.

Figure 13 and 14 show the CRPS and CRPSS for the T2m, RR, W10m and MSLP, respectively. Obviously for all the surface weather variables, BBSM has better reliability and resolution than DOWN in terms of CRPS, and is more skillful than DOWN in terms of CRPSS. Except the T2m forecast of DOWN, each forecast of BBSM and DOWN has higher skill than the reference, the forecast of ALADIN-AUSTRIA. The no-skill in T2m of OPER is due to the different surface parameterization scheme used in ALADIN and ECMWF model, this inconsistency, in particular in the soil moisture and soil temperature, on the surface coupling between ALADIN model with the

ECMWF, which introduces the strong cold bias in the 2m temperature forecast (not shown). The removal this cold bias by BBSM is the use of ARPEGE surface analysis in the NCSB.

f. *AROC*

The AROC scores of T2m, W10m, RR and MSLP are shown in Figure 15 respectively, which are calculated by averaging the ROC area for 3-4 climatologically equally likely events. As was the case for upper air variables, the better discrimination characteristics are obtained by BBSM for the surface variables. As noted by Buzzia (2005), the AROC score provides a measure of the statistical discrimination capacity of the ensemble system, which is more directly related to the inherent value of a forecasting system. The improvement on the quality of discrimination of ALADIN-LAEF by BBSM is probably because of the introduction of multi-phsysics scheme into ALADIN-LAEF.

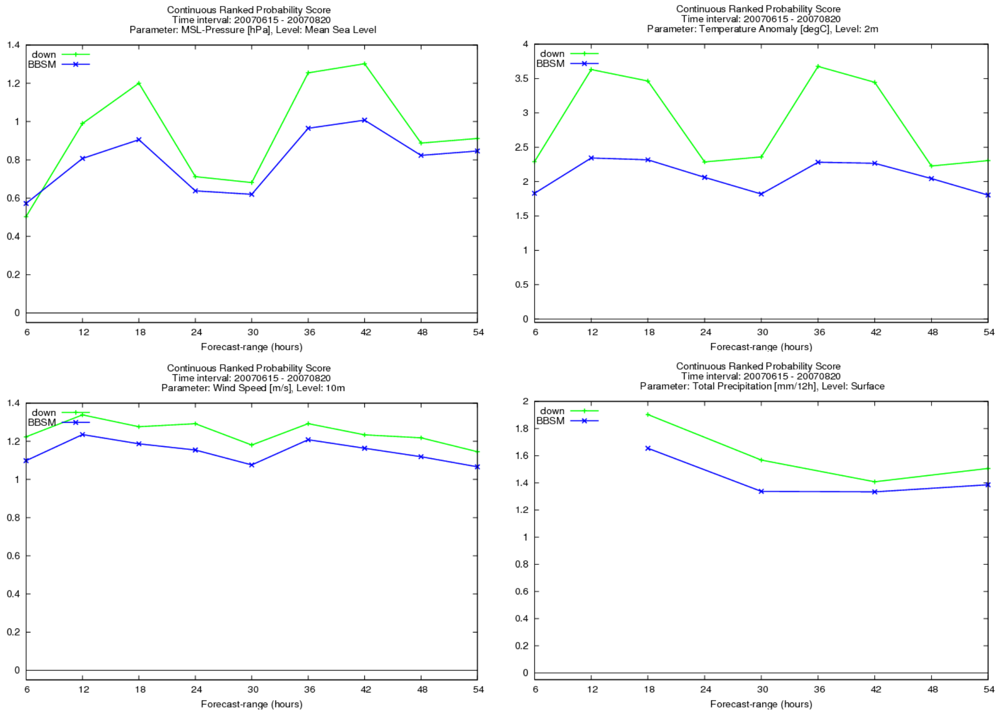

Figure 13. Continuous ranked probability score of DOWN (circles) and BBSM (crosses) for forecast of a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

6. SUMMARY AND CONCLUSIONS

In this paper we have described the new design of the central European limited area ensemble forecasting system ALADIN-LAEF. Blending and NCSB methods have been applied for the generation of initial perturbation and generation of initial surface perturbation, respectively. The multi-physics scheme has been introduced for representing model-related uncertainty. Blending is an appropriate method for IC perturbation for a LAMEPS. It combines the global large scale perturbation and the LAM small scale perturbation. This make the LAM initial perturbation more consistent to its global coupling model. NCBB is a new strategy for generating the initial surface perturbation, in particular those crucial parameters like soil moisture and soil temperature. It uses LAM short range forecast driven by ECMWF global EPS for generating the LAM initial surface perturbation. The multi-physics scheme is effective way for tackling the uncertainty related the model error.

ALADIN-LAEF with Blending, NCBB and multi-physics scheme has been implemented at ECMWF, and running operationally since 1 Feb. 2009.

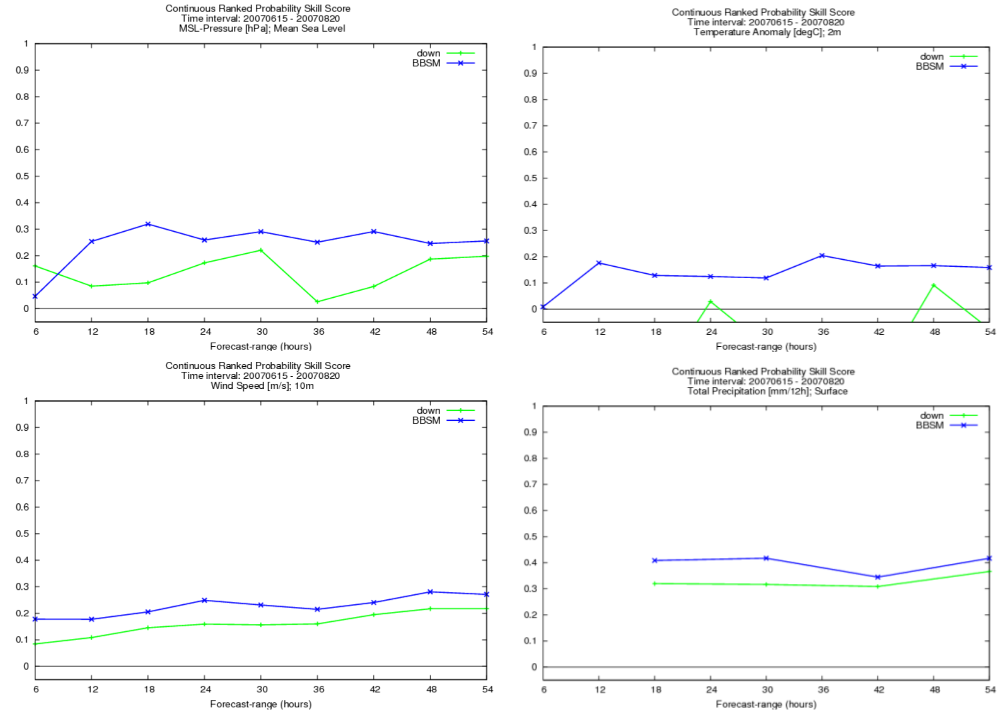

Figure 14. Continous ranked probability skill score of DOWN (circles) and BBSM (crosses) for forecast of a) T2m; b) RR; c) W10m and d) MSLP, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

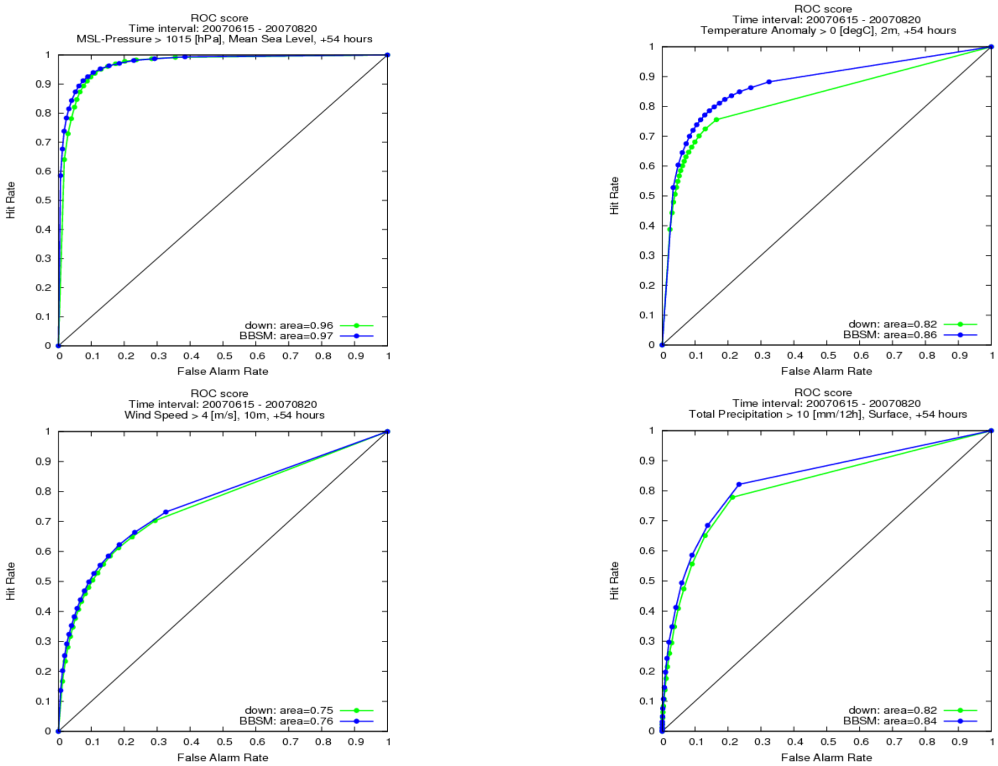

Figure 15. Area under the relative operating characteristics of DOWN (circles) and BBSM (crosses) of a) T2m; b) RR; c) W10m and d) MSLP,, averaged over the verification domain (see Fig. 1) and over the verification period from 2007/06/15 to 2007/08/20.

The new design of ALADIN-LAEF (BBSM) has been comparatively verified against the pre-operational ALAIN-LAEF (DOWN) over more than 2 months from 2007/06/15 to 2007/08/20. The verification has been carried out by comprehensive EPS verification scores considering the statistical reliability, resolution and discrimination. Overall, the results are quite encouraging:

- Very clear superior performance for the upper air weather variable is shown by BBSM. When the performance measured using spread/rms error, in terms of reliability , resolution and skill of the system.
- Remarkable benefits are achieved for the surface weather variables with BBSM. More skill, better resolution.

Unreliability and under-dispersion still remain in the forecast of ALADIN-LAEF surface weather variables, such as 2m temperature and 10 m wind forecast. The reasons are inadequate representation of uncertainties in the initial surface condition and lack of quantification of uncertainties related to the model surface physics.

In the next future, more efforts will be put on improving the unreliability and under-dispersion problems in ALADIN-LAEF forecast of surface weather variables. Works will be focused on better representation of uncertainties related to the model surface physics, for example, introduction of stochastic surface physics in the ALADIN; tests of different strategies in the NCSB for generating initial surface perturbation. Optimization of multi-physics scheme and use of ETKF/ET instead of breeding for small scale perturbation in the blending technique will be also carried out.

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