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WHAT ARE THE ADDED-VALUES OF LAMEPS?

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1. INTRODUCTION

Over recent years Limited Area Model Ensemble Prediction System (LAMEPS) has become more important as a scientific tool for improving prediction of high impact weather. Remarkable progresses on mesoscale predictability have been made and several LAMEPSs have been developed. A number of studies on quantification of the impact of uncertainties in initial conditions, in model, in lateral boundary conditions and in surface conditions have been carried out. Few studies on comprehensive comparisons between LAMEPS and global EPS have been documented, and no clear overall out-performance of regional EPS to global EPS has been demonstrated. Some comparisons for case studies, verification for certain weather parameters, for selected forecast range have been performed in the last years (Chessa et al. 2004; Frogner et al. 2006; Magarssi 2008; Bowler et al. 2008). Hamill (2008) summarized the potential of some LAMEPSs. In this paper, we will put our efforts on evaluation of LAMEPS. More specifically, attention focuses on addressing the question:

- What are the added-values of LAMEPS to global EPS?

Model and analysis related errors contribute to the eventual loss of predictive skill. Ensemble forecasting method has proved to be a successful way for handling those errors in the model. A high resolution deterministic LAM, on the other side, is still a necessary for the weather forecast. The question is then very naturally raised:

- Is LAMEPS adding value to its existing high resolution deterministic Limited Area Model (LAM) forecast?

Those are the natural and essential questions to a LAMEPS. If the performance of LAMEPS were inferior to the global EPS and the higher resolution deterministic LAM forecast available operationally at the Met-service, then it would be very difficult to justify its high development cost and extra computational expense.

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At ZAMG (ZentralAnstalt für Meteorologie und Geodynamik), a LAMEPS ALADIN-LAEF (Wang et al. 2011) has been developed in frame of the international cooperation ALADIN/LACE. In ALADIN-LAEF, the initial condition uncertainties is addressed by using a Blending method which is based on the idea to combine the large scale perturbation from the ECMWF EPS and the small scale perturbation from the ALADIN breeding vector. To simulate the error in the surface initial conditions, a strategy NCSB (Non-Cycling Surface Breeding, Wang et al. 2010) is implemented in ALADIN-LAEF. This is using the perturbed atmospheric forcing to generate the perturbation to the surface initial condition like soil moisture and so on. As in many other LAMEPSs, multi-physics schemes and coupling with ECMWF-EPS members are used for dealing with the model and LBC uncertainties.

In this paper, ALADIN-LAEF was used to assess the added-values of LAMEPS to global EPS over a two months summer period, in our work the ECMWF-EPS was chosen for the comparison since ECMWF-EPS is often acknowledged as the best in the world (Park et al. 2008; Froude 2010), and operationally available at ZAMG.

Further, ALADIN-LAEF forecast was verified with the higher resolution operational LAM forecast ALADIN-AUSTRIA (Wang et al. 2006) at ZAMG to demonstrate the benefits of a LAMEPS to higher resolution deterministic operational LAM.

2. EXPERIMENT DESIGN

To investigate the more added values of LAMEPS to global EPS, we have compared the performance of ALADIN-LAEF (16 members) with ECMWF EPS (50 members). Table 1 details the configuration used in the comparison between ALADIN-LAEF and ECMWF-EPS.

Another experiment has been set up to verify the performance of ALADIN-LAEF against the higher resolution deterministic operational forecast. This issue is addressed by comparing the performance of LAEF with a time-lagged EPS based on the ALADIN-AUSTRIA forecast. This time-lagged EPS is constructed by using the most recent ALADIN-AUSTRIA forecasts, which is illustrated in Table 2. Those forecasts started at the initial time and 6, 12, 18 and 24 hours earlier. Further, in the experiment the ensemble mean/median of ALADIN-LAEF forecast have been compared with ALADIN-AUSTRIA forecast, and the ALADIN-LAEF forecast has been assessed using probabilistic skill score, e.g. CRPSS, in which the ALADIN-AUSTRIA forecast is taken as the reference. Table 3 gives an overview of ALADIN-LAEF and ALADIN-AUSTRIA in the experiment.

Table 1: Summary of the configuration of ALADIN-LAEF and ECMWF-EPS

	ALADIN-LAEF	**ECMWF-EPS**
Resolution	18km; 37 Levels	T_L399; 62 Levels
Ens. size	16	50
Model	ALADIN	ECMWF-IFS

Tabel 2: Time lagged EPS of ALADIN-AUSTRIA

00 UTC:	00	06	12	18	24	30	36	42	48	54	60	66	72
06 UTC:		00	06	12	18	24	30	36	42	48	54	60	66
12 UTC:			00	06	12	18	24	30	36	42	48	54	60
18 UTC:				00	06	12	18	24	30	36	42	48	54
00 UTC:					00	06	12	18	24	30	36	42	48

Table 3: Summary of the configuration of ALADIN-LAEF and ALADIN-AUSTRIA

	ALADIN-LAEF	**ALADIN-AUSTRIA**
Resolution	18km;37Levels	9.6km;60 Levels
Ensemble size	16 members	5 members (time lagged)
Deterministic Forecast	Ensemble mean	deterministic

2.1 *ALADIN-LAEF*

The core of ALADIN-LAEF is based on the operational limited area model ALADIN-AUSTRIA run at ZAMG with a horizontal resolution of 18 km and 37 vertical levels. ALADIN-AUSTRIA is a hydrostatic spectral model with a hybrid vertical coordinate. Wang et al. (2006) gives details about the governing equations, physical parametrization and numerical algorithms in ALADIN-AUSTRIA.

ALADIN-LAEF consists of 16 perturbed members and one unperturbed control forecast. The initial condition (IC) perturbations are generated by ALADIN Blending method and lateral boundary condition (LBC) perturbations are provided by the first 16 ECWMF-EPS members (Buizza and Palmer 1995; Molteni *et al.,* 1996; Leutbecher and Palmer 2008). The ALADIN-LAEF control forecast obtains IC and LBC from the ECMWF EPS control forecast.

We apply different ALADIN physics configurations in ALADIN-LAEF for dealing with the uncertainties due to model errors. The physical processes mainly addressed by these configurations are cloud physics, deep convection, radiation, turbulent transport and diffusion processes (Wang et al. 2011). Variations of the mixing length and the entrainment rate in the deep convection scheme are also introduced in ALADIN-LAEF.

a. Atmospheric initial condition perturbations in ALADIN-LAEF: Blending

A detailed description of the Blending in ALADIN-LAEF was given by Wang et al (2011). This is based on the idea to combine the 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 (Singual Vector) perturbation, which is computed for the future uncertainties (Buizza and Palmer 1995; Molteni *et al.,* 1996) and the advantage of breeding vector, which accounts for the uncertainties from the past (Descamps and Talagrand 2007); on the other side, it minimizes the risk of inconsistency due to the different treatment of perturbations in the global and regional EPS system.

Blending is a spectral technique using a standard digital filter (in our case a non-recursive low-pass Dolph-Chebyshev digital filter). The core principle is to apply a digital filter to the perturbed initial states from the ECMWF SVs and ALADIN-Breeding on the original ALADIN grid but at a lower spectral resolution. This resolution is defined by the blending ratio, which depends on the scales that can be analyzed by the driving model rather than on the ones it can predict. The difference between those filtered fields represents a large-scale increment. This increment contains almost pure low-frequency perturbation information, which is then added to the original high-frequency signal of the perturbed high-resolution LAM analysis (i.e. to the ALADIN-Breeding analysis). The combination (blending) of both spectra is performed in the transition zone. The detailed description and discussion of Blending, in particular the technical implementation in ALADIN-LAEF, are given in Derkova and Bellus (2007).

b. Surface initial conditions perturbation in ALADIN-LAEF

Surface initial perturbations are introduced in ALADIN-LAEF by applying NCSB (Wang et al. 2010). It uses short-range surface forecasts driven by a perturbed atmosphere and a pseudo-Breeding method. As with Breeding, the simulation of growing error is started by introducing perturbations in the atmosphere. The perturbed atmosphere is not random, but downscaled from a global EPS. The regional model is then integrated up to 6 or 12 hours with the perturbed initial atmospheric conditions and LBCs, but the same initial surface state. The difference between the 6- or 12-hour surface forecasts and the corresponding new surface analyses is rescaled, and then added to the corresponding new surface analysis. This pseudo-breeding run is restarted every time with a new perturbation of the atmosphere obtained from the global EPS. This non-cycling feature ensures that the initial surface perturbations in LAMEPS are only driven by the atmospheric perturbations from the global EPS. In a cycling mode, in which the impact of the short-range LAM forecast is put into the initial surface conditions continuously, model drifting problems will be very probably introduced after several months.

2.2 *ECMWF-EPS*

Since 1992, the ECMWF EPS has been run operationally, and applied several updates. In our experiment the ECMWF EPS forecast in 2007 included one control forecast started from unperturbed analysis and 50 perturbed members integrated twice a day up to 15 days. The resolution of ECMWF-EPS was $T_L399L62$ (spectral triangular T399 with 62 vertical levels, ca. 50 km resolution) for days 0-10 and $T_L255L62$ (spectral triangular T255, ca. 80-km resolution) for the days 10–15.

Initial conditions are perturbed using a combination of initial-time and evolved singular vectors (Buizza and Palmer 1995) computed at T42L62 resolution, with 48-h optimization time interval and a total-energy norm. Singular vectors are computed to maximize the final time norm over different areas (Barkmeijer et al. 1999), combined and scaled to have initial amplitude comparable to an estimate of the analysis error. Model uncertainties due to physical parameterizations are simulated using a stochastic scheme (Buizza et al. 1999). The ensemble control analysis is obtained by interpolating the $T_L799L91$ analysis to the ensemble $T_L399L62$ resolution.

2.3 *Higher resolution deterministic LAM forecast*

The operational LAM system ALADIN-AUSTRIA at ZAMG has been used for comparison with ALADIN-LAEF. It is with 9.6 km horizontal resolution, 60 levels in vertical, hydrostatic etc. (see Wang et al. 2006 for more details). ALADIN-AUSTRIA runs 4 times per day at 00, 06, 12 an 18 UTC. Its products as deterministic NWP forecasts are provided to the forecasters and to end-users at ZAMG. The main characteristics of the model are as follows:

• 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).

• Kessler-type scheme for large scale precipitation; Geleyn's scheme of shallow convection and simple radiation; Bougeault-type scheme of deep convection; Boer-type scheme of gravity wave drag; force-restore method for soil temperature and water; vertical exchange calculation taking into account a planetary boundary layer and a surface layer based on the Louis scheme.

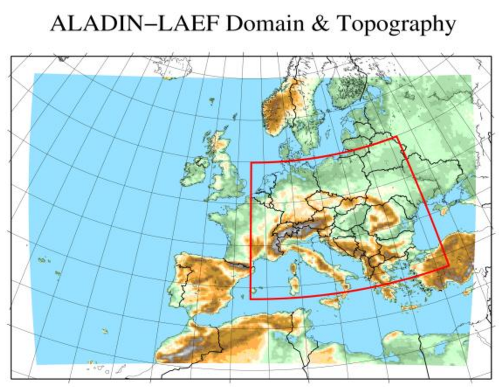


Figure 1. ALADIN-LAEF domain and model topography. The inner limited-area domain in red depicts the verification domain, which covers Central Europe.

3. RESULTS

In this study the performance of ALADIN-LAEF, ECMWF-EPS and the deterministic forecasts of ALADIN-AUSTRIA are compared for a 2-month period (June-August 2007). The ALADIN-LAEF runs started at 00UTC and run for 54 h. ECMWF analysis is used for verification of the forecasts of upper air weather variables, both analysis and forecast are interpolated to a common regular 0.15 x 0.15 degree latitude/longitude grid. Observations are used for the verification of surface weather variables. The surface verification is performed at the observation location. Forecast values are interpolated to the observation site for smoothly varying fields, such as 2m temperature, 10m wind speed and surface pressure. For precipitation, which has strong spatial gradients, the observation is matched to the nearest grid point. The verification is performed for a limited area of the forecast domain over Central Europe, as shown in Fig. 1. In the verification domain 1219 synop-stations were used in this study.

A set of standard ensemble and probabilistic forecast verification methods is applied to evaluate the performance of ALADIN-LAEF and ECMWF-EPS. The scores considered are ensemble spread, ensemble root-mean square error, The Talagrand diagram or Rank histogram, Continuous Ranked Probability Score, Continuous Ranked Probability Skill Score, outlier statistics, Relative Operating Characteristic curve, the Area under ROC and Reliability diagram. A detailed description of those verification scores can be found, e.g. in Wilks (2006).

To verify the performance of the ensemble mean/median of ALADIN-LAEF and the deterministic forecast of ALADIN-AUSTRIA, the scores, e.g. Hit Rate, False Rate Alarme, Equitable Threat Score, Accuracy score, Threat Score and Correlation Coeficient etc. are used.

3.1 *Evaluation: ALADIN-LAEF and ECMWF-EPS*

Verification of upper air weather variables have been carried out on temperature at 850 hPa (T850), geopotential height (Z850), wind speed (V850) and relative humidity (RH850).

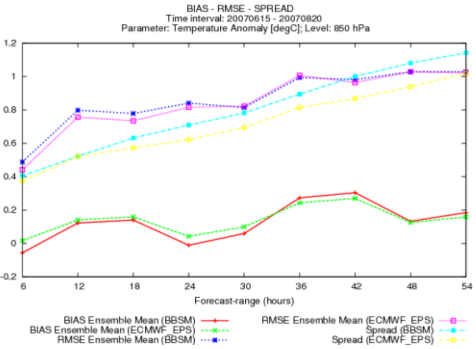
The discrepancy between the ensemble spread and the error of the ensemble mean is a measure of the statistical reliability. The magnitude of ensemble spread should correspond to the magnitude of RMSE of the ensemble mean. Fig. 2 shows RMSE and Bias of ensemble mean, and ensemble spread of T850, Z850, V850 and RH850 for ALADIN-LAEF and ECMWF-EPS.

For temperature, wind speed and relative humidity ALADIN-LAEF shows increased spread and slightly increased RMSE compared to ECMWF-EPS, a smaller discrepancy between RMSE and spread can be noticed for LAEF forecast on temperature and wind. This indicates that LAEF is statistically more consistent than ECMWF EPS forecast. For geopotential, the LAEF ensemble spread is similar to ECMWF-EPS forecast but with less RMSE, the LAEF forecast is clearly over dispersive for geopotential. Forecast bias of the ensemble mean of LAEF tends to not be improved, rather more stronger than ECMWF-EPS, which might be related to the model physics in the ALADIN-LAEF.

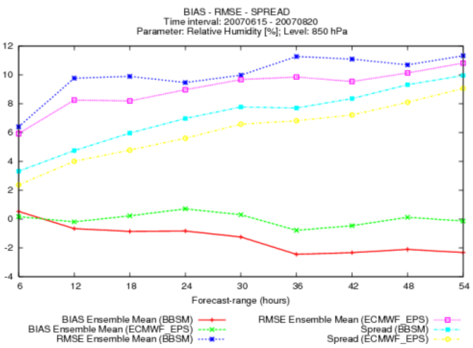
In general the LAEF forecast performed quite similar to ECMWF-EPS forecast, with increased spread, but the slightly increased RMSE and Bias on the other side, which is not desired.

Figure 3 shows the CRPS of Z850, T850, V850 and RH850 for LAEF and ECMWF-EPS. The ECMWF-EPS performs clearly better than LAEF except for geopotential. The ECMWF-EPS forecast in the atmosphere is more reliable than LAEF except for Z850.

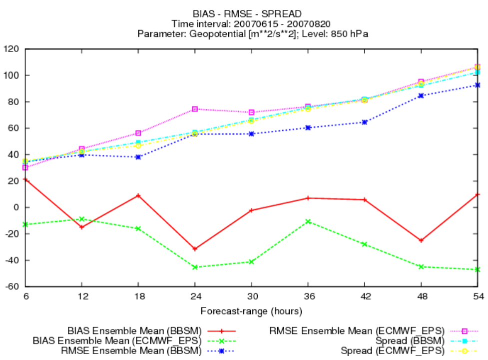
a) T850



b) RH850



c) Z850



d) V850

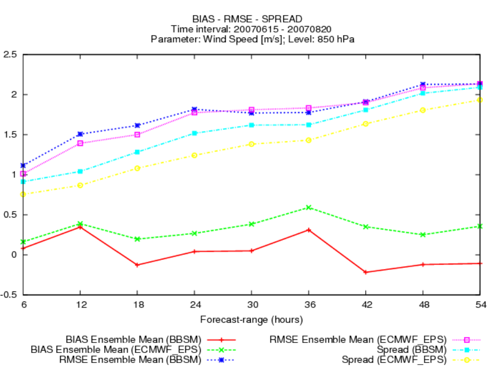
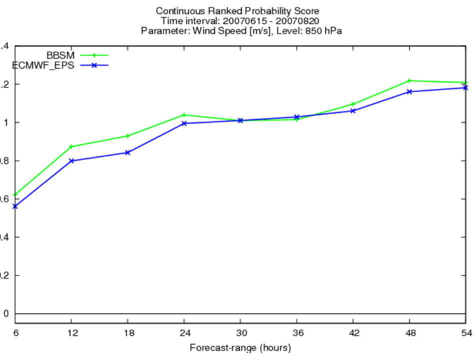
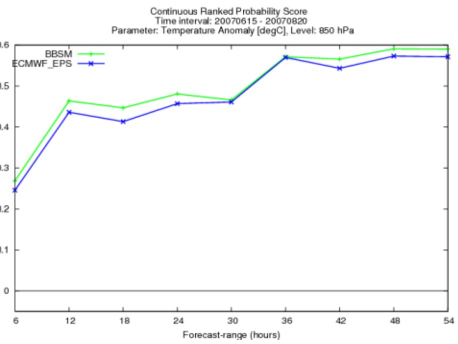


Figure 2. Bias, RMSE of the ensemble mean and ensemble spread of ALADIN-LAEF and ECMWF-EPS for a) T850; b) RH850; c) Z850 and d) V850, averaged over the verification domain (see Fig. 1) and over the verification period from 15 June 2007 to 20 August 2007.

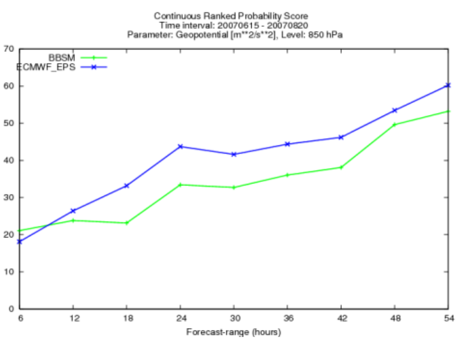
a) V850



b) T850



c) Z850



d) RH850

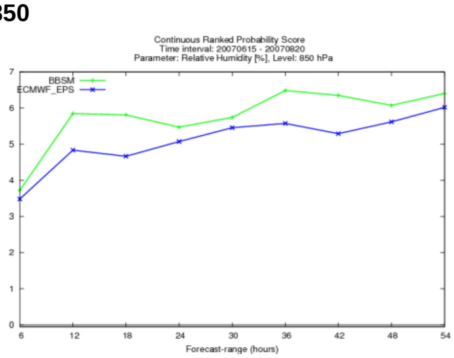
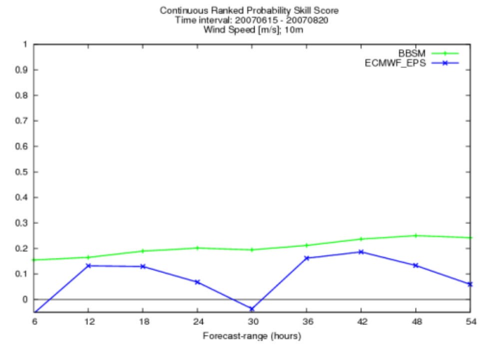
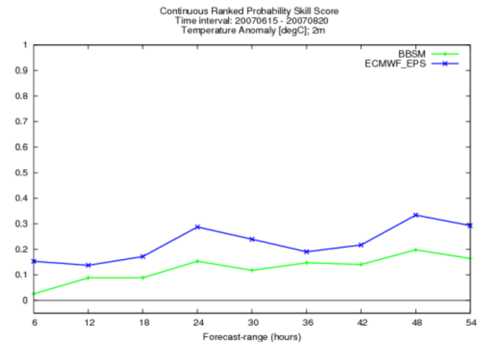


Figure 3. Comparison of CRPS of a) V850 ; b) T850; c) Z850 and d) RH850 between ALADIN-LAEF (in green, BBSM) and ECMWF EPS (in blue, ECMWF_EPS).

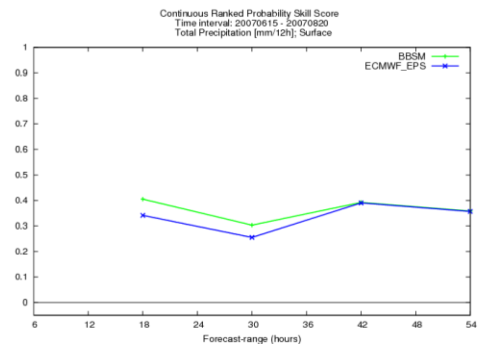
a) W10m



b) T2m



c) PREC



d) MSLP

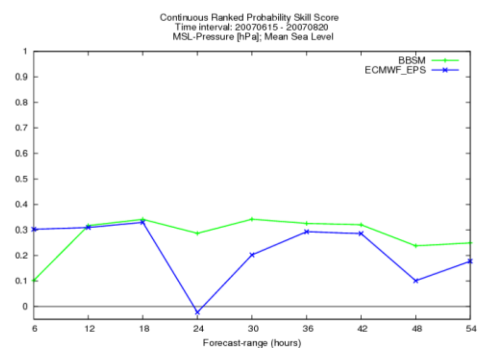
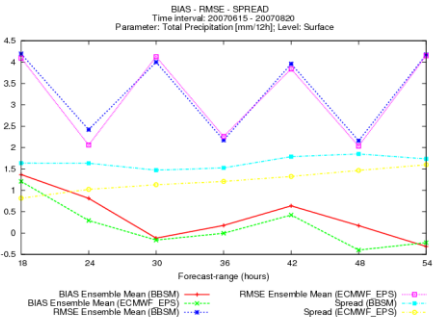
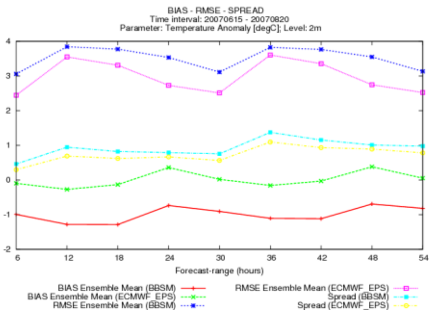


Figure 4. Comparison of CRPSS of a) 10m wind; b) 2m temperature; c) 12h accumulated precipitation and d) mean sea level pressure between ALADIN-LAEF (in green) and ECMWF EPS (in blue); averaged CRPSS statistics over central Europe and a two-month summer period.

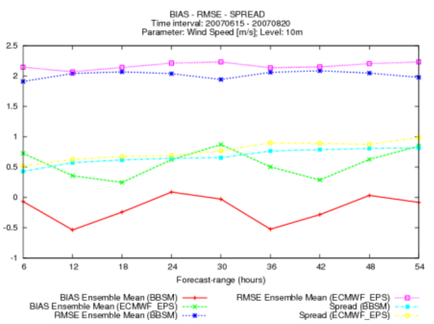
a) PREC



b) T2m



c) W10m



d) MSLP

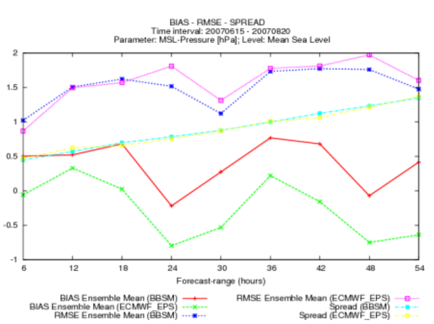


Figure 5. Bias, RMSE of the ensemble mean and ensemble spread of ALADIN-LAEF and ECMWF-EPS for a) PREC; b) T2m; c) W10m and d) MSLP.

Verification of surface weather variables is focused on 2 meter temperature (T2m), 10 meter Wind (W10m), 12h accumulated rainfall (PREC) and mean sea level pressure (MSLP). In Figure 4 Continuous Ranked Probability Skill Scores (CRPSS) of those surface variables of ALADIN-LAEF and ECMWF EPS are shown. It is evident that most of the variables, wind, mean sea level pressure and rainfall forecast of ALADIN-LAEF is more skillful than ECMWF EPS. The 2m temperature is an exception, the ECMWF-EPS is much better than ALADIN-LAEF. The reason we found that there is a strong cold bias in the ALADIN-LAEF T2m forecast (Fig. 5), which results in a large RMSE error. This is largely due to the different surface parameterization schemes used in ALADIN and ECMWF model. This inconsistency, in particular in the soil moisture and soil temperature (surface coupling between ALADIN with the ECMWF), introduces a strong cold bias in the 2m temperature as shown in Fig. 5. For the other variables the RMSE, Bias of ensemble mean and ensemble spread depicts the similar results as in Fig. 4.

3.2 *Evaluation: ALADIN-LAEF and ALADIN-AUSTRIA*

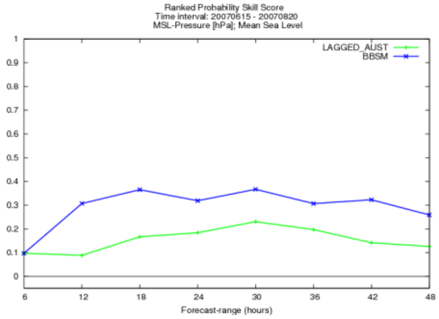
Three experiments have been conducted for investigating the performance of LAEF against the higher resolution LAM forecast to demonstrate the added values of LAEF, i) comparing ALADIN-LAEF with a time lagged EPS based on the high resolution deterministic forecast; ii) using the high resolution deterministic forecast as the reference in the probabilistic statistical skill score to learn if the LAEF forecast has a skill to the reference or not (results please refer to Fig. 4); and iii) verifying the LAEF ensemble mean with ALADIN-Austria in the deterministic way.

The comparison of ALADIN-LAEF (17 members; 18km resolution) with the time lagged ensemble of ALADIN-AUSTRIA (5 members; 9.6km resolution) is shown in Figure 6. The CRPSS of ALADIN-LAEF is clearly superior of the time lagged ALADIN-AUSTRIA ensemble. Figure 7 presents the Equitable threat score (ETS) of 12h accumulated precipitation forecast of ALADIN-LAEF ensemble mean/median and of ALADIN-AUSTRIA. More skill with ALADIN-LAEF can be observed than the forecast of ALADIN-AUSTRIA, the ensemble median performs the best.

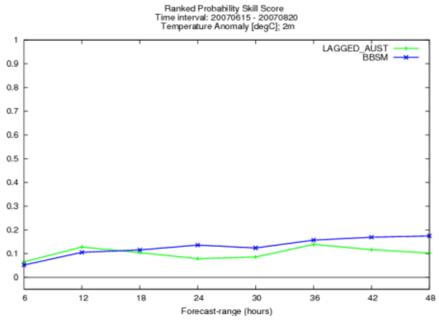
4. CONCLUSIONS

To investigate the added-values of LAMEPS, in particular those to the global EPS and high resolution deterministic LAM forecast, we compared the performance of ALADIN-LAEF with ECMWF-EPS and the operational higher resolution LAM forecasts at ZAMG ALADIN-AUSTRIA over a two months summer period in 2007. Results are evaluated by using a set of standard verification scores.

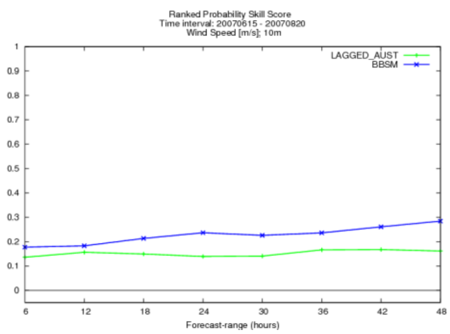
a) Mean Sea Level Pressure



b) 2m Temperature



c) 10m Wind



d) 12h accumulated precipitation

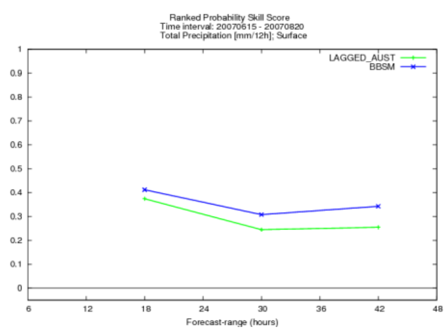


Figure 6. Comparison of CRPSS of a) mean sea level pressure; b) 2m Temperature; c) 10m Wind and d) 12h accumulated rainfall forecast between ALADIN-LAEF (in blue, BBSM), the time lagged ensemble of ALADIN-AUSTRIA (in blue).

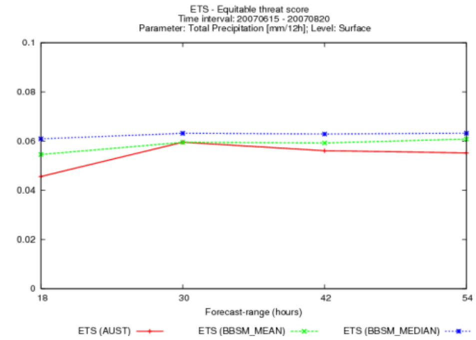


Figure 7. Comparison of ETS of 12h accumulated rainfall forecast between ALADIN-LAEF ensemble mean (in green), ensemble median (in blue) and ALADIN-AUSTRIA (in red); averaged ETS statistics over central Europe and a two-month summer period.

The main conclusions of this study are summarized in following:

1. LAEF is more skillful than ECMWF EPS on surface parameters, except T 2m. The reason is the different/inconsistent surface physical schemes used in ALADIN and ECMWF-IFS.
2. In general the LAEF forecast of upper air parameters performed quite similar to ECMWF-EPS forecast, no clear advantage found for LAEF upper air parameters.
3. LAEF is outperform to the time lagged ALADIN-AUSTRIA with higher resolution.
4. LAEF Ensemble mean is better than ALADIN with higher resolution, except 2m Temperature.

In the time of writing, ECMWF has recently upgraded its system with higher resolution and has introduced the EDA SVINI, this upgrade has improved the ECMWF-EPS forecast mainly in extra-tropic and for the upper air level parameter. The possible impact of those upgrades on the performance of ALADIN-LAEF, in particular, its more added-values to ECMWF-EPS will be investigated in the next future.

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