ECMWF Feature article

from Newsletter Number 126 – Winter 2010/11

METEOROLOGY

Use of the ECMWF EPS for ALADIN-LAEF

www.ecmwf.int/en/about/news-centre/media-resources

doi:10.21957/d9j1nx7p

This article appeared in the Meteorology section of ECMWF Newsletter No. 126 – Winter 2010/11, pp. 18–22.

Use of the ECMWF EPS for ALADIN-LAEF

Yong Wang, Martin Bellus, Geert Smet, Florian Weidle

The chaotic and highly non-linear nature of the atmosphere means that small errors in initial conditions or in the model itself can grow rapidly and become large over time, even in a matter of hours. Most NWP centres have applied the ensemble prediction technique as the dynamical way of accounting for the forecast uncertainty. The optimal design of an ensemble prediction system (EPS) strongly depends on the quantification of uncertainties due to errors in initial conditions, model formulation and physical parametrizations. Compared to global EPSs, additional challenges posed for a skilful LAMEPS (limited area model ensemble prediction system) include, for example, the problem of quantifying the uncertainties due to errors in lateral boundary conditions.

In recent years, several LAMEPSs have been developed and run operationally in the Member States. All of them uses dynamical downscaling of the ECMWF EPS for generating atmospheric initial condition perturbations, though hardly any use methods for perturbing the initial state of the land surface. Here are some examples of the use of the ECMWF EPS.

- The perturbations for the LAMEPS at the Norwegian Meteorological Institute are provided from a version of the ECMWF EPS with dry targeted Singular Vectors (SVs) over northwestern Europe.
- COSMO-LEPS (Consortium for Small scale Modelling Limited-area Ensemble Prediction System) follows a strategy of using representative members to downscale the ECMWF EPS; the representative members are chosen from clusters of ECMWF EPS forecasts.
- The experimental multi-model system called GLAMEPS (Grand LAMEPS) being developed by HIRLAM and ALADIN institutes employs the downscaling of the ECMWF EPS.

At ZAMG (ZentralAnstalt für Meteorologie und Geodynamik), the Central European regional ensemble system ALADIN-LAEF (Limited Area Ensemble Forecasting) has been developed – see *Wang et al.* (2011) for more information. This initiative has been part of the LACE (Limited Area Modelling in Central Europe) international project. ALADIN-LAEF has run quasi-operationally since 2007 and now employs the following.

- Blending method for dealing with the atmospheric initial condition perturbations, which combines the large-scale forecast uncertainty predicted by a global EPS with the small-scale perturbations resolved by a limited area model (LAM).
- Non-Cycling Surface Breeding (NCSB) technique for generating initial surface condition perturbations.

Also different ALADIN physics configurations are used for dealing with the uncertainties due to model errors.

We verified the performance of ALADIN-LAEF over a two summer months during the MAP (Mesoscale Alpine Project) D-PHASE Operations Period in 2007 (*Rotach et al.*, 2009). The results show that ALADIN-LAEF compares favourably with the ECMWF EPS for most surface weather parameters (*Wang*, 2010).

In this article we briefly describe the use of ECMWF EPS perturbations in the Blending and NCSB techniques for the quantification of ALADIN-LAEF atmospheric initial and surface condition perturbations. We also present some verification results. Since the main products of ALADIN-LAEF are the forecasts of surface weather variables, we focus on the verification of variables such as precipitation, 2-metre temperature and 10-metre wind.

AFFILIATIONS
Yong Wang, **Florian Weidle**: Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria
Martin Bellus: Slovak Hydro-meteorological Institute, Bratislava, Slovakia
Geert Smet: The Royal Meteorological Institute of Belgium, Brussels, Belgium

 doi:10.21957/d9j1nx7p

Configuration of ALADIN-LAEF

The core of ALADIN-LAEF is based on the operational limited-area model run at ZAMG with a horizontal resolution of 18 km and 37 vertical levels (see *Wang et al.*, 2006 for details about the governing equations, physical parametrization and numerical algorithms). Figure 1 shows the ALADIN-LAEF integration domain which covers much of Europe and a large part of the Atlantic.

There are 17 ensemble members in ALADIN-LAEF, of which the first 16 members are perturbed. Their lateral boundary condition (LBC) perturbations are provided by the first 16 members of the ECWMF EPS (*Leutbecher & Palmer*, 2008). The 17th ALADIN-LAEF member contains ICs (initial conditions) and LBCs from the ECMWF EPS control forecast.

Blending method

For perturbing atmospheric initial conditions in a LAMEPS, there are at least three key requirements:

- The LAM perturbations should be consistent with the perturbation coming through the lateral boundary.
- The scale of the perturbation should be in accordance with the scales of variability resolved by the model.
- The IC perturbations should be effective immediately from the initial time.

The dynamical downscaling of ensembles from a global model for generating atmospheric initial perturbations, which is used in most operational LAMEPSs, is incapable of meeting the second and third of these requirements. An alternative is the Breeding technique that, when applied to LAMEPS, creates the perturbations including, in principle, all scales resolved by the LAM. It has been successfully implemented in the SREF (Short Range Ensemble Forecasting) system at NCEP (National Centers for Environmental Prediction) for atmospheric initial perturbations while the ensemble of LBCs required for SREP is obtained from the global ET (Ensemble Transform) ensemble.

For ALADIN-LAEF the natural choice for the LBC perturbations are those from ECMWF EPS forecasts. This is not only because of the similarity in model physics in the ECMWF EPS and ALADIN, but also the quality of ECMWF EPS forecasts and their operational availability at ZAMG.

The atmospheric initial perturbations for the ECMWF EPS are generated using the Singular Vector (SV) technique (*Buizza & Palmer*, 1995). This is an appropriate method for medium-range forecasting, but it is still unclear whether it is appropriate for use in LAMEPS. Research on LAM SVs is in a very early stage; the design of the SVs is surely not optimal for a short-range ensemble, which has to quantify the uncertainties in the analysis. Furthermore, the SV technique is computationally expensive.

To make use of ECMWF EPS perturbations, we use Blending for generating atmospheric initial perturbations for the ALADIN-LAEF. Blending combines the large-scale uncertainty generated by the ECMWF SVs with the small-scale uncertainty generated by Breeding with the ALADIN model (ALADIN-Breeding). A combined perturbation has the feature that its large-scale part is from ECMWF SVs, and the small-scale part is from ALADIN-Breeding.

Figure 1 ALADIN-LAEF domain and model topography. The inner area bounded in red is the domain used for verification.

We believe that the new perturbations meet the three key requirements for LAMEPS IC perturbations. Through ALADIN-Breeding the perturbations provided by Blending attempt to give the best estimate of the actual errors in the initial analysis based on the past information about the flow, whereas the SVs contain future information of possible forecast error. On the large scale, the atmospheric initial perturbations are now consistent with the LBC perturbations, with both of them being based on the ECMWF SV perturbations. The small-scale uncertainty in the analysis is more detailed and accurate due to the higher resolution and more balanced orographic/surface forcing of the ALADIN-Breeding. This should be a better representation of the uncertainties than interpolated large-scale perturbations from the global model.

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 *Bellus et al.* (2011).

In the implementation of Blending, the ALADIN-Breeding perturbations are generated in sets of positive and negative pairs around a control analysis. The ALADIN-Breeding has the following features: (a) cold start, (b) 12-hour cycle, (c) two-sided and centred around the control analysis, (d) wind components, temperature, moisture and surface pressure perturbed at each level and model grid-point, and (e) no regional variation in rescaling.

Evaluation of Blending

To evaluate the Blending, comparisons with downscaling and ALADIN-Breeding have been carried out – the set-up of the comparison is described in Table 1. Note that in the experiment we did not apply the land surface perturbations and the multi-physics for the model perturbations in ALADIN-LAEF. This makes it possible to have a clean comparison between Blending, Downscaling and Breeding.

Experiment	Upper-air initial perturbation
Downscaling	Downscaling of ECMWF EPS
Breeding	ALADIN-Breeding
Blending	Blending ECMWF EPS with ALADIN-Breeding

Table 1 Description of experiments ‘Downscaling’, ‘Breeding’ and ‘Blending’ used to evaluate the Blending technique. ALADIN-LAEF is configured with initial perturbations generated by using downscaling, Breeding and Blending. The same lateral boundary perturbations from the ECMWF EPS forecast and the same land surface analysis from ECMWF EPS control are applied in those experiments. No multi-physics is in use in the experiments.

The ALADIN-LAEF forecasts started at 00 UTC and run for 54 hours. Observations are used for the verification of surface weather variables. The verification is performed at the observation location so we interpolated forecast values to the observation site for smoothly varying fields, such as 2-metre temperature, 10-metre wind speed and surface pressure. For precipitation, which has strong spatial gradients, the observation is matched to the nearest grid point. No observation uncertainties were taken into account in the verification. The verification is performed for a limited area of the forecast domain over Central Europe (see Figure 1) for which 1,219 SYNOP stations were used in this study.

Figures 2 and 3 show the comparison of Blending, downscaling and ALADIN-Breeding for ALADIN-LAEF 2-metre temperature and 12-hours accumulated precipitation forecasts for a two-month period. Regarding the probabilistic score measured by the CRPS (Continuous Rank Probability Score), the benefit of using Blending is quite clear, particularly in the first 24 hours of the forecast; the positive impact of Blending can also be seen in the growth of ensemble spread, which is larger for Blending than the spread for downscaling and ALADIN-Breeding. Downscaling underperforms in the first 24 hours. This demonstrates that downscaling of ECMWF SV perturbations is not optimally designed for the early forecast range. We notice that Blending does not improve the RMSE (Root Mean Square Error) of ensemble mean of the 2-metre temperature.

In the later forecast period downscaling performs the same as Blending; this is obviously due to the impact of the LBC perturbations. Blending has the same large-scale perturbations as in downscaling, which are consistent with the LBC perturbations. ALADIN-Breeding initializes a larger spread in the early hours, but the growth of perturbations is slower than Blending and downscaling. The generation of perturbations

 doi:10.21957/d9j1nx7p

by ALADIN-Breeding conflicts somehow with the LBC perturbations from the ECMWF SVs – this impact becomes clear after 30 hours into the forecast.

From Figure 2b we see that the introduction of Blending has little impact on improving the bias of the 2-metre temperature forecast. It is remarkable that there is a strong cold bias in the ALADIN-LAEF temperature forecast and a large error in the surface initial conditions. This is largely due to the different surface parametrization schemes used in the ALADIN and ECMWF models. It is this inconsistency, in particular in the soil moisture and soil temperature, that introduces a strong cold bias in the 2-metre temperature. The deficiency can be reduced to some extent if the model surface from ECMWF is replaced by the one from the ARPEGE surface analysis.

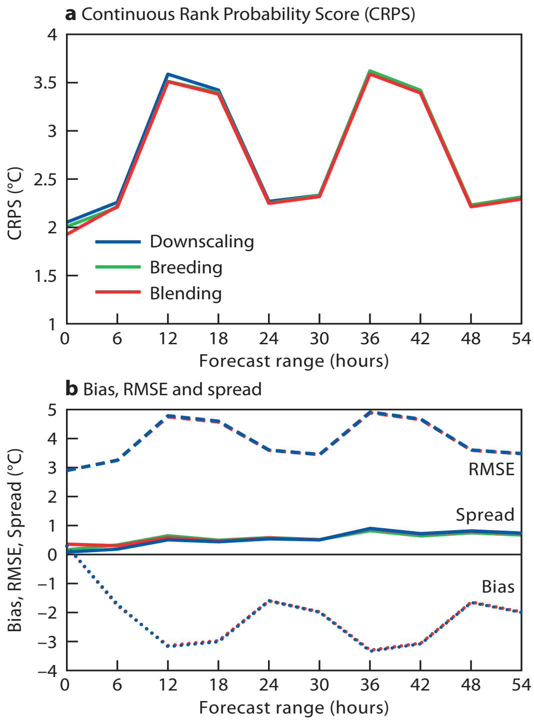

Figure 2 Verification of 2-metre temperature forecasts from ALADIN-LAEF for experiments 'Downscaling', 'Breeding' and 'Blending' using (a) Continuous Rank Probability Score and (b) Bias, RMSE of the ensemble mean and ensemble spread. Scores are averaged over the verification domain (see Figure 1) for the period from 20 June to 20 August 2007.

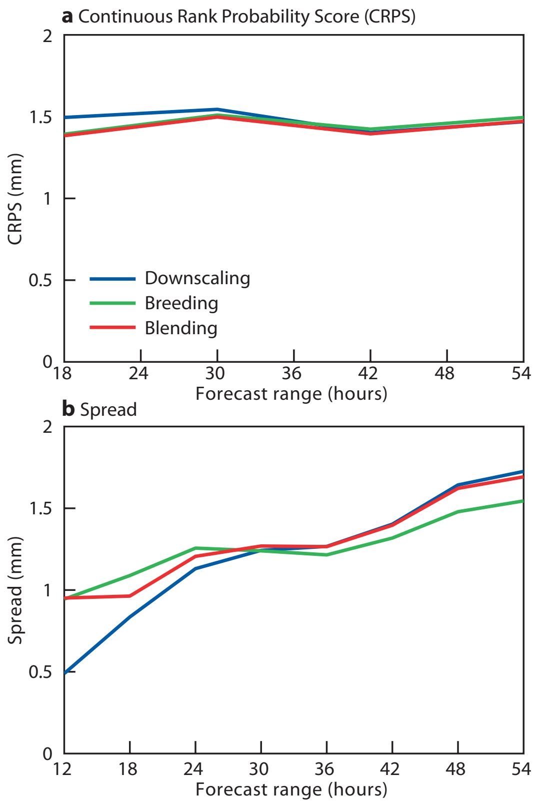

Figure 3 Verification of 12-hour accumulated precipitation forecasts from ALADIN-LAEF for experiments 'Downscaling', 'Breeding' and 'Blending' using (a) Continuous Rank Probability Score and (b) ensemble spread. Scores are averaged over the verification domain (see Figure 1) for the period from 20 June to 20 August 2007.

Non-Cycling Surface Breeding (NCSB)

Initial surface perturbations are introduced in ALADIN-LAEF by applying NCSB (*Wang et al.*, 2010; *Smet*, 2009). 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 atmospheric initial 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 surface initial 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 surface initial conditions continuously, model-drifting problems will be very probably introduced after several months.

Implementation of NCSB

In the implementation of NCSB in ALADIN-LAEF, the perturbed atmospheric initial conditions are downscaled from the first 16 initial perturbations of the ECMWF EPS. Also LBC perturbations are obtained from the forecasts of the corresponding ECMWF EPS members. The multi-physics approach is applied for the quantification of model uncertainty. When coupling ALADIN with ECMWF, the different land surface parametrizations in the ECMWF model and ARPEGE/ALADIN cause inconsistencies (e.g. in terms of the cold bias in the forecast). This deficiency can be reduced to some extent if the model surface analysis from ECMWF is replaced by the one from the ARPEGE surface analysis.

The use of ECMWF EPS perturbation for generating surface initial perturbations in ALADIN-LAEF valid at time t can be summarized as follows.

- IC perturbations valid at time t-12 h from the ECMWF EPS are downscaled to ALADIN-LAEF.
- The corresponding ECMWF EPS forecasts are used to provide the LBC perturbations of ALADIN-LAEF.
- The ECMWF surface is replaced with the ARPEGE surface in the initial conditions at time t-12 h.

After ECMWF EPS perturbations are prepared for NCSB, ALADIN-LAEF members are started at time t-12 h and are then integrated up to 12 hours with the multi-physics option. The resulting 12-hour ALADIN-LAEF surface forecasts, valid at time t, are considered as perturbed surface conditions; these are similar to those using Breeding.

Performance of NCSB

We now consider the performance of NCSB. The experiments carried out make a comparison between ALADIN-LAEF with and without NCSB. All the experiments have the same upper-air initial perturbations (downscaling of ECMWF EPS), lateral boundary perturbations (coupling with ECMWF EPS), model perturbations (multi-physics) and surface analysis (ARPEGE).

The superior performance of using NCSB can be seen in Figure 4. This shows the verification in terms of CRPS, outlier statistics, and the ratio between RMSE of the ensemble mean and ensemble spread for 2-metre temperature and 10-metre wind forecasts from ALADIN-LAEF with and without NCSB. The outperformance of NCSB is more evident in the early forecast range up to 24 hours. A small but positive impact on reliability and resolution from the CRPS score are obtained for NCSB 2-metre temperature forecasts. Fewer outliers and better ratio between the error of ensemble mean and ensemble spread of the NCSB 2-metre temperature and 10-metre wind forecasts are an indication of improved statistical consistency with NCSB.

It is noted that the CRPS of surface weather variables does not increase significantly with the forecast lead-time as it does for the upper-air weather variables. This indicates the difficulty the ALADIN model has in predicting the surface weather variables in the short range with high skill.

Conclusions and future developments

The use of ECMWF EPS perturbations in ALADIN-LAEF can be summarized as follows:

- ECMWF EPS large-scale perturbations are combined with small-scale perturbations from ALADIN-Breeding by using Blending for the atmospheric initial perturbations in ALADIN-LAEF.
- ECMWF EPS initial perturbations are used to drive ALADIN-LAEF surface initial perturbations by using the NCSB technique.
- ECMWF EPS forecasts provide the LBC perturbations for ALADIN-LAEF.

doi:10.21957/d9j1nx7p

Verification has shown the benefits of use of ECMWF EPS perturbations in ALADIN-LAEF with Blending and NCSB, with the impact being particularly remarkable in the 24-hour forecast. These benefits are due to (a) the introduction of surface initial perturbations driven by the ECMWF EPS atmospheric perturbations in NCSB, and (b) the sound large-scale perturbations from the ECMWF EPS and the consistency between the IC and LBC perturbations.

Future work will focus on better representation of uncertainties related to the model surface physics (e.g. introduction of stochastic surface physics in the ALADIN-LAEF). Experiments on the use of ETKF/ET (Ensemble Transform Kalman Filter/Ensemble Transform) instead of breeding for generating the small-scale perturbation in Blending will also be carried out.

Whilst conducting the experiments presented in this work, two main upgrades to the ECMWF EPS have been implemented. One is the increase of horizontal resolution from T399L62 to T699L62 and the other is the introduction of EDA – the ensemble of data assimilations (*Buizza et al.*, 2010; *Isaksen et al.*, 2010). We have put much effort into the technical adaptation of ALADIN-LAEF to take account of those changes to the ECMWF EPS. Consequently, some statements made earlier concerning the nature of the SVs in the Blending method are no longer valid as a result of the introduction of EDA. It is conceivable that the benefit of the blended perturbation technique is potentially reduced, as the EDA perturbations should adequately represent initial uncertainty from the initial time in contrast to using SVs. The possible impact of those upgrades on the performance of ALADIN-LAEF, particularly its ability to add value to the ECMWF EPS, will be investigated in the near future.

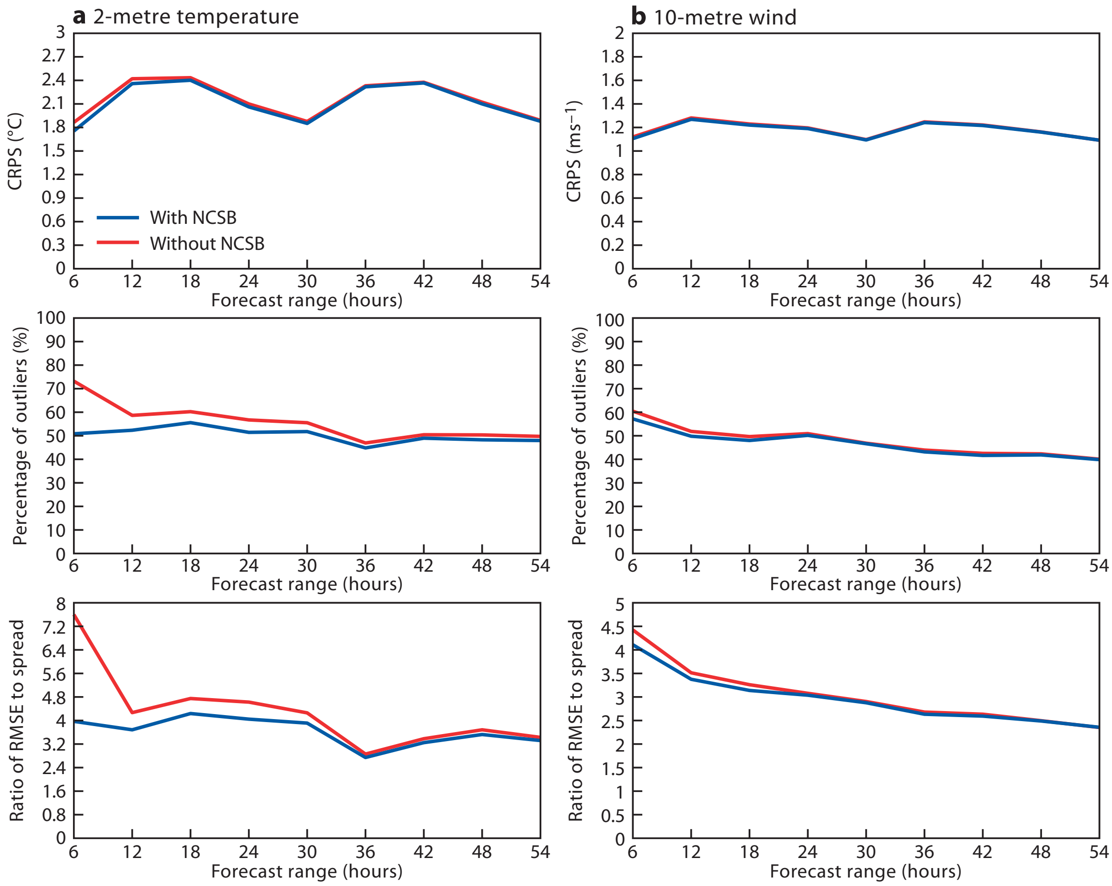

Figure 4 Verification of (a) 2-metre temperature forecasts and (b) 10-metre wind forecasts from ALADIN-LAEF for experiments ‘With NCSB’ and ‘Without NCSB’ using Continuous Rank Probability Score (left), percentage of outliers (centre) and ratio between RMSE and ensemble spread (right). Scores are averaged over the verification domain (see Figure 1) for the period from 20 June to 20 July 2007.

Further reading

Bellus, **M.**, **Y. Wang**, **J.F. Geleyn** & **W. Tian**, 2011: A new method for initial perturbation generation in LAMEPS: Blending. *In preparation for Mon. Wea. Rev.* Available from the authors on request.

Buizza, **R.** & **T.N. Palmer**, 1995: The singular vector structure of the atmospheric general circulation. *J. Atmos. Sci.*, **52,** 1434–1456.

Buizza, **R.**, **M. Leutbecher**, **L. Isaksen** & **J. Haseler**, 2010: Combined use of EDA- and SV-based perturbations in the EPS. *ECMWF Newsletter* **No. 123,** 22–28.

Isaksen, **L.**, **J. Haseler**, **R. Buizza** & **M. Leutbecher**, 2010: The new ensemble of data assimilations. *ECMWF Newsletter* **No. 123,** 17–21.

Leutbecher, **M.** & **T.N. Palmer**, 2008: Ensemble forecasting. *J. Comput. Phys.*, **227,** 3515–3539.

Rotach, **M.W.** & **Co-authors**, 2009: MAP D-PHASE real time demonstration of weather forecast quality in the Alpine region. *Bull. Am. Meteorol. Soc.*, **90,** 1321–1336.

Smet, **G.**, 2009: Surface perturbation in LAEF, 31 p. *Available online*: http://www.rclace.eu/?page=40

Wang, **Y.**, **T. Haiden** & **A. Kann**, 2006: The operational Limited Area Modelling system at ZAMG: ALADIN-AUSTRIA. *Österreichische Beiträge zu Meteorologie und Geophysik*, **37,** ISSN 1016–6254

Wang, **Y.**, **A. Kann**, **M. Bellus**, **J. Pailleux** & **C. Wittmann**, 2010: A strategy for perturbing surface initial conditions in LAMEPS. *Atmos. Sci. Lett.*, **11,** 108–113, DOI: 10.1002/asl.260.

Wang, **Y.**, 2010: Evaluation of the added value of LAMEPS. 32nd EWGLAM and 17th SRNWP Meetings, 4–7 October 2010, Exeter. http://srnwp.met.hu/Annual_Meetings/2010/download/wednesday/predictability/laef_exeter.pdf

Wang, **Y.**, **M. Bellus**, **C. Wittmann**, **M. Steinheimer**, **F. Weidle**, **A. Kann**, **S. Ivatek-Sahdan**, **W. Tian**, **X. Ma**, **S. Tascu** & **E. Bazile**, 2011: The Central European limited-area ensemble forecasting system: ALADIN-LAEF. *Q. J. R. Meteorol. Soc.*, **137,** 000–000. DOI:10.1002/qj.751.

 doi:10.21957/d9j1nx7p