VARIOUS APPLICATIONS OF THE BLENDING BY DIGITAL FILTER TECHNIQUE IN THE ALADIN NUMERICAL WEATHER PREDICTION SYSTEM

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The blending by digital filter is a technique allowing for the obtaining of a more exact initial state for the integration of the limited area numerical weather prediction system, by a combination of large scale information coming from the driving model with small scale features resolved by the high resolution model. The basic idea of the blending is briefly explained and its possible applications to the ALADIN numerical weather prediction system are presented. The standard usage is in the (pseudo) data assimilation cycle, documented by a case study and example in advanced specific application. The innovative approach exploits the blending in the limited area ensemble forecasting.

Použitie techniky tzv. blendingu pomocou digitálneho filtra umožňuje získať počiatočný stav na integráciu numerického predpovedného modelu, ktorý presnejšie zodpovedá reálnemu stavu atmosféry. Procedúra spočíva v kombinácii mezoškálových informácií modelu s vysokým rozlíšením a javov synoptickej mierky pochádzajúcich z riadiaceho modelu. V práci je vysvetlená základná idea blendingu a jeho použitie v numerickom predpovednom systéme ALADIN. Štandardnú aplikáciu v pseudo-asimilačnom cykle ilustruje prípadová štúdia a jeden príklad využitia v špeciálnej konfigurácii. Inovatívne je použitie blendingu v tzv. ensemblových predpovediach.

Key words: numerical weather prediction, blending, digital filter initialization, ensemble forecasting, ALADIN model

INTRODUCTION

Nowadays, the numerical weather prediction (NWP) is defined as an initial value problem (Daley, 1991). In other words, the success of the numerical weather forecast is determined by the quality and the accuracy in the description of the present state of the atmosphere. That represents the initial state, from which an integration of the model equations according to the laws of physics is carried forward in time to obtain the atmospheric state in the future - the forecast. Usually, the present state of the atmosphere is estimated from the available observations. To cover the data void areas, these measurements are further combined with other information, so called background or guess. The guess can be for example the climatology, or more often a short model forecast. Then, the initial state for the numerical integration is a best possible combination of the observations and the background. However, to maintain the technological link for obtaining, processing, quality control and archiving the observations is a rather difficult task. Therefore, especially for the limited area models applied over smaller domains, the dynamical downscaling of the driving model initial state via more-or-less sophisticated interpolation methods is often used. In the ALADIN NWP system this approach is called the dynamical adaptation mode. The known drawback of such a procedure is that the resulting initial fields are rather smooth with respect to the higher resolution surface forcing of the coupled model, irrespective of the quality of the interpolation technique (Giard, 2001). This leads to the so-called spin-up in the first hours of the forecast, well seen for example on the precipitation fields. Consequently, sometimes the older forecast valid at a certain time is better than the newest one, even if the latter is based on more recent observations.

An alternative approach to obtain the initial state consistent both with the large scale information analysed by the driving model and small scale features forecasted by the limited area model is their combination (blending). Such a technique is very suitable especially for the spectral models, where the model variables are defined by the spectral coefficients of their Fourier expansion. Then simply the combination of the wave numbers, preferably over the selected part of spectra, defines the new (blended) state. As the observations are not directly used here – their information enters through the analysis of the driving model - the blending might be considered as the pseudo data assimilation. The so called explicit blending technique has been tested in the ALADIN/LACE system coupled to the ARPEGE global model (G. Radnóti, personal communication) and later in ALADIN/HUNGARY (Tóth, 2003 and Alexandru et al., 2004). Here the weighted linear combination of the spectral coefficients of the driving model analysis and the coupled model forecast formed the new initial state for the high resolution model integration. The spectral interval for the wave number mixing was empirically a-priori predefined. After such rather brutal mixing in the spectral space the balance in the initial state had to be restored by some initialization. A more natural implicit alternative to determine the scale selection is by the means of digital filter (DF) (Lynch and Huang, 1992 and Lynch et al., 1997). The properties of digital filter are used to select the desired part of spectra from the driving model and to combine it with other part of the spectra of mesoscale model. Here the spectral transition is smoother than with explicit blending mentioned above, thanks to the intrinsic model and filter properties. The blending by digital filter technique was developed and tested in RC LACE centre in Prague (Brožková et al., 2001) and this was the tool used in the presented work.

The following section briefly describes the ALADIN NWP system. The second one deals with the core of the presented work - the blending by digital filter. First the principles of the technique are explained. Then its various applications in the ALADIN model are shown: the case study with the classical blending cycle, more advanced usage in dedicated ALADIN configuration, and the most innovative approach - the utilization in the ensemble forecasting. Finally, some conclusions and perspectives are drawn.

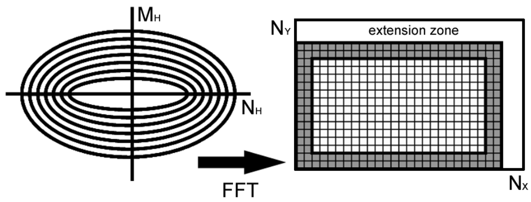
THE ALADIN NUMERICAL WEATHER PREDICTION SYSTEM

Only a brief scientific description of the ALADIN system necessary for understanding the terminology used in the presented work is given here without further references. Horányi et al. (1996) or Bubnová et al. (1995) can be consulted for general details. The implementation of ALADIN at SHMU is described in Derková (2005).

ALADIN is a spectral limited area model designed for dynamical adaptation at the limit of the hydrostatic approximation. It was developed in the frame of the international cooperation of 15 Euro-Mediterranean countries as the limited area version of its counterpart - the French global model ARPEGE. The ALADIN domain is typically a rectangle with the equidistant horizontal resolution in the x and y directions, using the tangent Lambert conformal projection. The spectral representation of the model fields uses the bi-Fourier expansion with the elliptical truncation. The computational domain is made biperiodic by adding an artificial extension zone (Figure 1). The transformation between the spectral and grid-point space is performed via Fast Fourier Transforms (FFT).

The irregular eta-hybrid coordinate, which is terrain following near the surface and approaches to the p-system close to model top, defines the vertical levels distribution. The model prognostic variables are temperature, zonal and meridional wind components, specific humidity and surface pressure. Many other derived parameters (e.g. cloudiness, precipitation, wind gusts, radiative fluxes) can be diagnosed from the physical parameterizations of the sub-grid scale processes.

Figure 1. Schematic illustration of the elliptical spectral space and its transformation into the plane geometry using Fast Fourier Transforms. N_H and M_H are the maximum wave numbers in zonal and meridional directions, N_X and N_Y their corresponing number of grid points. Grey area represents the coupling zone.



The information about the phenomena outside the model domain is passed through the boundaries using the lateral boundary conditions (LBC). These come from the driving model (in the ALADIN case this is usually the ARPEGE global model) via so called coupling procedure. In the coupling zone (grey area in Figure 1) the solution X of the driving model is combined with the solution of the limited area model according to the equation (1):

$$X = (1 - \alpha) * X_{ALADIN} + \alpha * X_{ARPEGE}\,, \qquad (1)$$

where α are the relaxation coefficients ranging from 1 at the outer boundary to 0 at the central zone. As already mentioned, in the dynamical adaptation mode the initial conditions for the model integration are obtained by the interpolation of the analysis of the driving model into the target grid. A sophisticated algorithm is applied, allowing for example to change the geometry including the horizontal and vertical resolution, or to preserve the vertical structure of the planetary boundary layer when interpolating to higher resolution orography. However, despite the quality of the method, the resulting initial state is rather smooth, containing basically the synoptic scale features recognised by the host model. Moreover, the interpolation often brings some imbalances to the initial state of the local model, causing temporal oscillations of the variables at the beginning of integration. Therefore an initialization procedure has to be applied to filter out these unrealistic high-frequency modes and to balance the fields.

In the ALADIN system the initialization by non-recursive Dolph-Chebyshev digital filter is used (Lynch and Huang, 1992 and Lynch et al., 1997). This consists of two short integrations of the model for a time span (integration length) T_s. The first integration starts from the time t=0 adiabatically backward, the second one from $t = -T_s/2$ diabatically forward. The model values at each model grid point (in fact each spectral coefficient) and each time step are multiplied by weights varying with time so as to yield the desired filtering. The main tuning parameters (see Lynch et al., 1997) are the stop-band edge τ_s (frequencies shorter than τ_s are severely damped) and the time span T_s. As the time-step length is determined by model resolution and model dynamics, in practice one adjusts the number of time-steps during DF integrations to get the required filter response. The output of each integration is valid in the middle of T_s, as illustrated in Figure 2. Here the A denotes the original (downscaled) analysis and I the new filtered initial state from which the forecast can be computed.

The effect of digital filter initialization is illustrated in Figure 3. The time evolution of the surface pressure for one randomly selected grid point is shown at every time step. The black solid line with obvious noisy oscillation shows the case when digital filter initialization (DFI) was not applied. The grey dashed line represents the model run with DFI, which is much smoother. Both curves tend to converge with time to the same values.

Although DF is in fact the time filter, it acts like a space filter as well, because usually high frequencies are associated with horizontally short waves. Thus, apart from initialization, the properties of the digital filtering can be used for the scale selection in the blending by digital filter technique.

BLENDING BY DIGITAL FILTER

The basic principles of the blending by digital filter technique

As already explained, the idea of blending is to combine the large scale features analyzed by the global model with mesoscale features forecast by the high resolution model. The hypothesis behind this considers that these mesoscale features obtained by a short-range forecast of the high resolution model are closer to reality thanks to a better balance with the orographic/surface forcing. In the global model analysis this short wave part of spectra is a result of pure mathematical interpolations. A schematic illustration of the discussed spectral ranges is in Figure 4. The small wave numbers represent the large scale part of the spectra to be obtained from the global model, high wave numbers (i.e. the short waves) represent the small scales to be better captured by the high resolution model. In the transition zone the blending (combination) of both spectra shall be performed. The difficulty might be to determine that transition zone. Here one considers 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. The short range forecast of the limited area model is governing the mesoscale part of the spectra. Thus their relation defines the first empirical estimate of the blending cut truncation. A properly tuned digital filter can filter the model state so as to keep only the waves larger than this blending truncation. As in the digital filtering the spectral coefficients are progressively damped and not "brutally" forced to 0 values, the possible shock in the transition zone can be easily avoided. Moreover, in the spectral model an elegant trick can be used to mimic the blending spectral truncation: only the spectral resolution is decreased while the grid-point resolution is kept the same. Further, an inspiration from the incremental algorithms used in data assimilation can be applied: if one computes the large scale increment between the driving model analysis and the LAM model forecast, this increment will be used to correct the high resolution model guess.

Figure 2. Schematic illustration of filtering procedure. The black dashed line represents adiabatic backward integration, black solid line the diabatic forward one. Both steps are filtered. After Lynch et al., 1997.

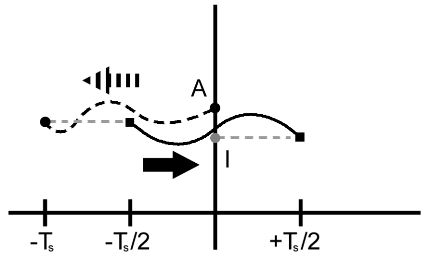


Figure 3. Time evolution of the surface pressure for randomly selected grid point. The run with DFI is in grey dashed and without DFI in black solid line.

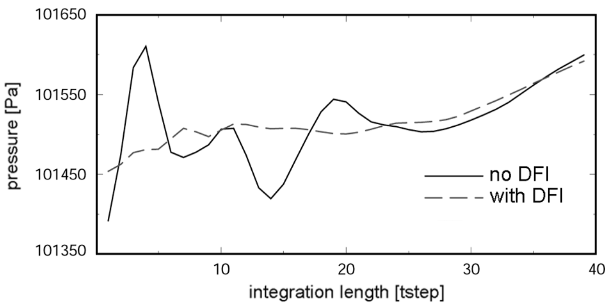
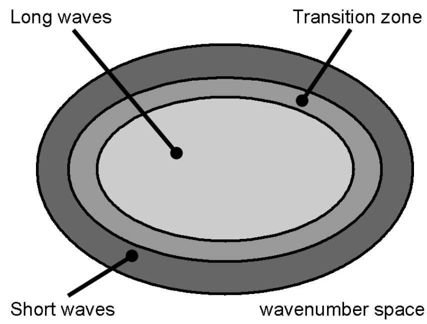


Figure 4. Schematic illustration of the elliptical spectral zones for the blending.



Thus the blending by digital filter equation in the notation of ARPEGE/ALADIN system can be written as:

$$\mathbf{I} = \mathbf{G}^{ALD} + (\mathbf{A}^{ARP}{}_{\mathrm{LOW}}' - \mathbf{G}^{ALD}{}_{\mathrm{LOW}}')_{\mathrm{HIGH}}, \qquad (2)$$

where I denotes the new blended initial state, $\mathbf{A}^{ARP}$ is the ARPEGE global model analysis and $\mathbf{G}^{ALD}$ is the ALADIN guess (the short range forecast). Subscript $_{\mathrm{LOW}}$ represents the lower blending spectral resolution and subscript $_{\mathrm{HIGH}}$ the full spectral resolution. The prime stays for the filtered state.

The new blended initial state **I** is then an input for the 6h forecast to obtain the new guess for the next step in the assimilation cycle, as sketched in Figure 5. The same procedure is applied to obtain the initial state for the longer operational forecast. It has to be mentioned that the treatment of surface fields is not tackled within this work.

The positive effect of blending is demonstrated in Figure 6. It shows the field of the total cloudiness as seen in the model initial state for one randomly chosen case of testing the procedure in ALADIN/SHMU system described below. The upper panel displays the initial state obtained via standard dynamical adaptation mode, the bottom panel is the initial state obtained with blending. The map has to be interpreted as a satellite picture, i.e. white colours represent clouds. The verifying satellite picture is in the middle. One can see that the standard initial state is rather smooth, while the blended one depicts many features observed in reality (e.g. above France, Ukraine and Belarus).

The tuning

There are several tuning parameters available in the setup of the blending by digital filter procedure. Their first empirical estimation is driven by already mentioned idea that the scale selection is determined by the scales the driving model can analyze rather than those it can resolve. Therefore one has to consider the resolution of ARPEGE analysis with respect to the resolution of ALADIN forecast. Then, following Giard (2001) as an example for the current setup of ALADIN/SHMU model (as specified in Table 1), one has to compute:

- T^{fa}_{ARP} – an average resolution (more precisely its corresponding spectral truncation) of ARPEGE forecast over the target domain. It can be estimated from the actual ARPEGE truncation T^{f}_{ARP} (T358) multiplied by the average map factor over the domain (map factor *m* can vary from *1/c* to *c*, where *c* is the actual ARPEGE stretching – c=2.4):

$$T^{fa}_{ARP} = T^{f}_{ARP} * m = 358 * 2.26 \cong 809$$

- T^{a}_{ARP} – the mean resolution of the ARPEGE analysis, as a geometric mean between T^{fa}_{ARP} and resolution of ARPEGE analysis T^{m}_{ARP}. That is currently the four-dimensional variational data assimilation in the unstretched grid with triangular truncation T147 (dx ~100 km):

$$T^{a}_{ARP} = \sqrt{T^{fa}_{ARP} * T^{m}_{ARP}} = \sqrt{809*147} \cong 347$$

- T^{f}_{ALD} – an ARPEGE-equivalent truncation for ALADIN, i.e. the truncation ARPEGE would have with ALADIN full resolution and corresponding grid (denominator is 3 for quadratic and 2 for linear grid), where *L* is the Earth perimeter and *dx* is the horizontal model resolution:

$$T^{f}_{ALD} = L/3 * dx = 40000/(3*9) \cong 1481$$

Figure 5. Schematic illustration of the blending pseudo-assimilation cycle.

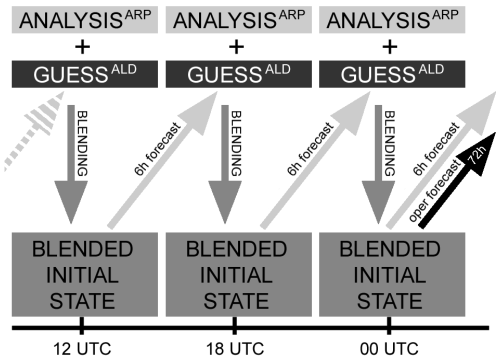
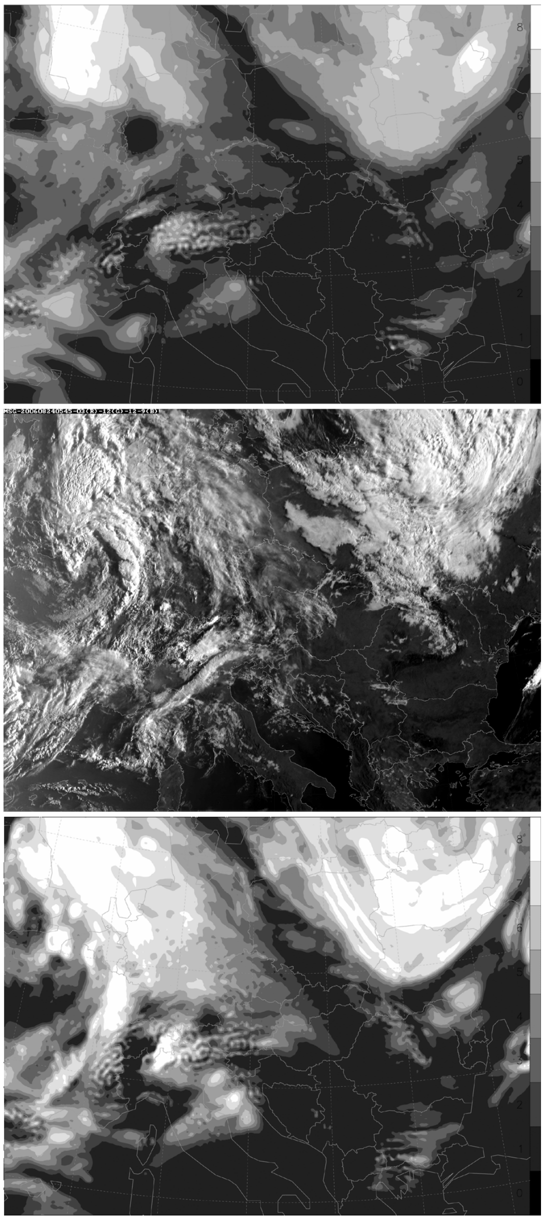


Figure 6. Total cloudiness in the initial model state in octets (the operational model - top, the blended initial state - bottom) and the verifying satellite picture - middle.



- T^{c}_{ALD} – an ARPEGE-equivalent low (blending cut) truncation for ALADIN:

$$T^{c}_{ALD} = \sqrt[3]{T^{a^2}_{ARP} * T^{f}_{ALD}} = \sqrt[3]{347^2 * 1481} \cong 563$$

- r_b – the blending ratio, which should be larger than the coupling ratio r_c :

$$r_b = \frac{T^{f}_{ALD}}{T^{c}_{ALD}} = 2.63, \qquad r_c = \frac{T^{f}_{ALD}}{T^{fa}_{ARP}} = 1.83$$

In ALADIN/SHMU, the maximum zonal and meridional wave numbers are $N_H = 106$, $M_H = 95$ respectively. The blending spectral truncation (with maximum wave numbers N_B , M_B) has to follow:

$$\sqrt{N_B{}^2 + M_B{}^2} * r_b \cong \sqrt{N_H{}^2 + M_H{}^2} \qquad \text{and}$$

$$\frac{N_B}{M_B} \cong \frac{N_H}{M_H} \cong \frac{N_X}{N_Y} \ ,$$

where N_X and N_Y are the number of grid points in the zonal and meridional directions respectively (Fig. 1). Then:

$\boldsymbol{N_B} = N_H/r_b = 106/2.63 \cong \mathbf{40}$

$\boldsymbol{M_B} = M_H/r_b = 95/2.63 \cong \mathbf{36}$.

Now we can verify that the blending ratio computed from the elliptical truncation corresponds to the theory:

$$r_{b\_elliptic} = \frac{\sqrt{N_H{}^2 + M_H{}^2}}{\sqrt{N_B{}^2 + M_B{}^2}} = \frac{\sqrt{106^2 + 95^2}}{\sqrt{40^2 + 36^2}} = 2.645,$$

that is sufficiently close to $r_b = 2.63$.

The same blending ratio is applied to modify the time step of the digital filter. In ALADIN/SHMU $TSTEP = 400$s, therefore $TSTEP_B = 400*2.63 = 1052$. For convenience reasons - to have the exact number of time steps within the used 3h coupling interval - we chose rather $TSTEP_B = 1080$s. Half number of DF time steps (*NSTDFI*) is connected with the time-span T_s (the DF integration length) as:

$$T_s = 2*NSTDFI * TSTEP_B \, .$$

According to Lynch et al. (1997), with the setup of the Dolph-Chebychev filter as applied in ALADIN the relationship between the time span and stop band edge TAUS, with required damping factor r=0.05, is:

$$T_s \geq \left(\frac{1}{\pi} \cosh^{-1} \frac{1}{r} \right) * TAUS$$

$$NSTDFI * TSTEP_B \geq 0.693 * TAUS \, .$$

The stop band edge *TAUS* has to correspond to the ARPEGE DF setup, i.e. $TAUS = 5$h, therefore the number of time steps in blending by DF for ALADIN/SHMU is $NSTDFI = 6$.

A case study using a classical blending cycle

The classical pseudo assimilation blending cycle with the tuning as described above has been implemented in the ALADIN system running at SHMU. To validate its performance, a few case studies were conducted. The presented case on 03/09/2006 is characterised by the precipitation observed in the morning hours that were not predicted by the operational run - hence the idea to check the possibility of improving the forecast via a better initial state. A 24h (i.e. 4 updates) of the blending cycle was run, starting from the operational guess. Then the 3days forecast was launched, with the initial state provided by that blending. The lateral boundary data and whole model setup was otherwise the same as in the operational suite, which was used as a reference.

First, the spectra of the model variables for the input and output fields was checked. As an example, the kinetic energy averaged over the whole domain for model levels number 10 (~11 km), 20 (~4.3 km) and 37 (model bottom, ~17 m) is plotted in Figure 7. The black line is the spectra of the ARPEGE analysis interpolated to full ALADIN resolution, the grey one is the ALADIN guess and the grey dotted line represents the blended state. One can see that blending acts as expected – the grey dotted line lays between the black and grey ones, i.e. that blended state is a mixture of the ARPEGE and ALADIN ones. In the upper atmosphere (represented by the 10th model level), where the large-scale phenomena are dominant, all three curves almost coincide. There is not much information for the higher wave numbers in the ALADIN data at those levels (note, that for ARPEGE this part of the spectra is a result of pure interpolation). Towards the troposphere the ALADIN spectrum starts to dominate in the meso-scales (wave numbers between 20–50), the same is observed in the blended state. In the large scale part of spectra the blended state gets closer to the ARPEGE analysis (not very well seen on the log-log plot). Close to the model surface the ALADIN clearly determines the spectra and the ARPEGE part is almost negligible.

As already stated, the experiment was focused on the precipitation forecast. The hourly precipitation values predicted by the operational model starting on 03/09/2006 00 UTC for +6 hours are plotted in Figure 8 at the top. The same field but with the forecast initialized by the blended state is at the bottom. The verifying analysis as measured by the radar and automatic station network of SHMU is displayed in the middle of the picture. One can see that the light precipitation observed in the western part of Slovakia is not forecasted by the operational model at all. With blending there are the precipitation patterns predicted, although not exactly in the correct place and with the correct amounts. (Note that the rain forecast by blending in Bohemia was really observed but not visualized, since the system uses only Slovak radar and automatic weather station data.) Such a positive effect of blending is remarkable only within the first hours of the forecasts, usually up to 6–12h. After that period the two forecast converge (not shown). However it is considered that a more realistic beginning of the numerical forecast gives more confidence to the human forecasters to the model performance.

Figure 7. The kinetic energy spectra for selected model levels for ARPEGE analysis (black line), ALADIN guess (grey line) and the final blended state (grey dots).

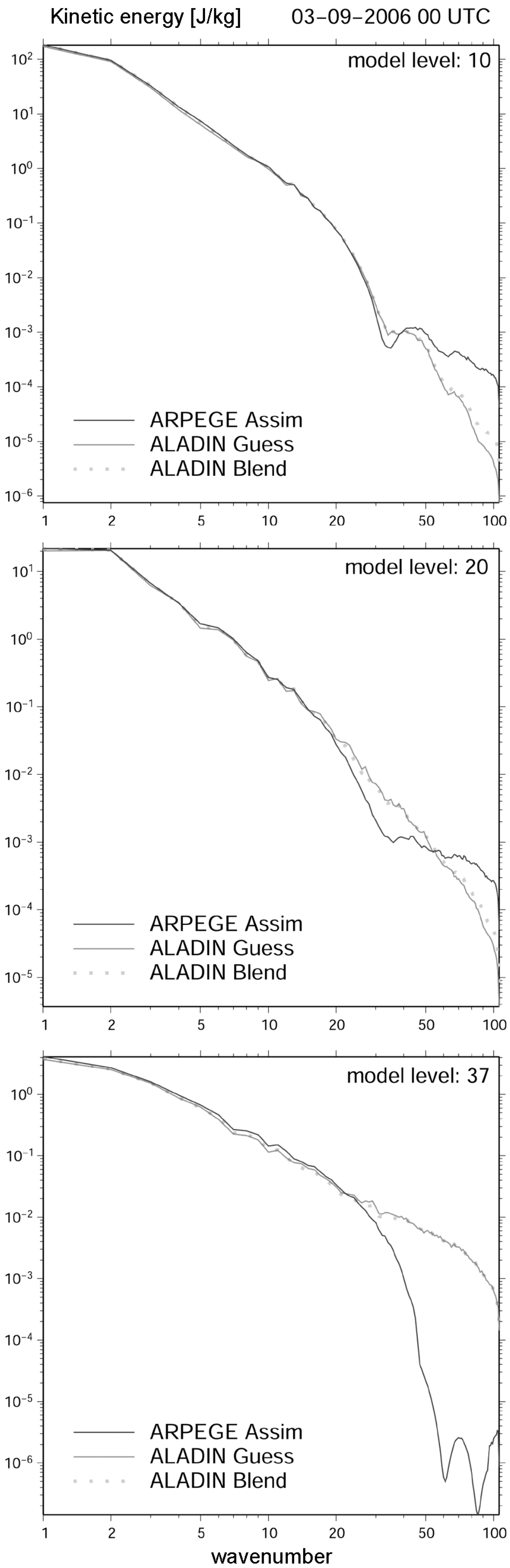
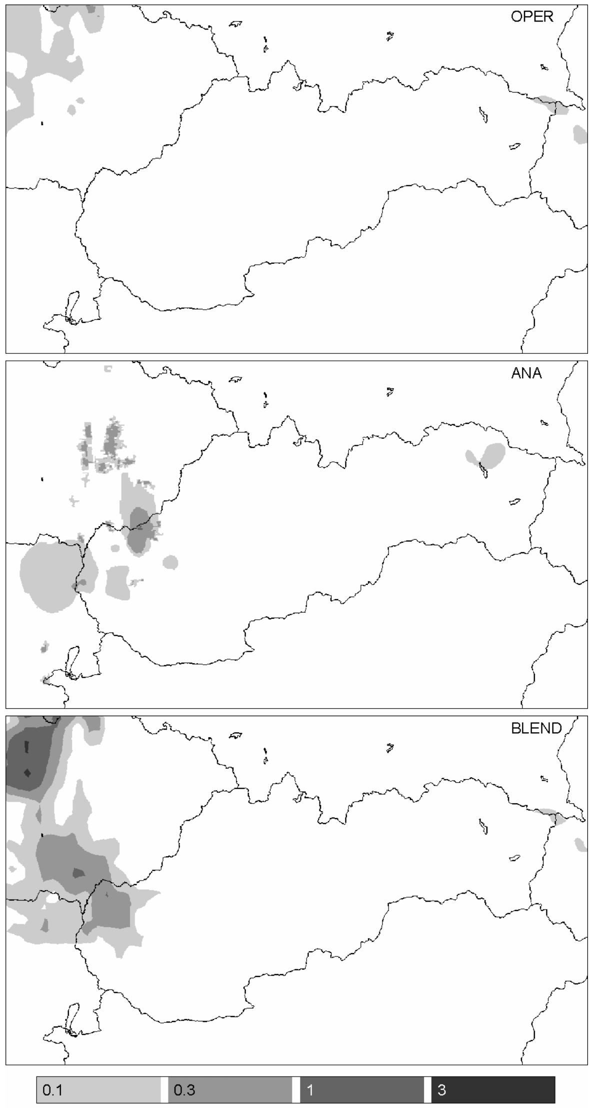


Figure 8. Hourly cumulated precipitation for +6h forecasted by the operational model (top) and by the model initialized with blending (bottom). Veryfying analysis based on radar and automatic stations measurements (Slovak territory only) is in the middle.

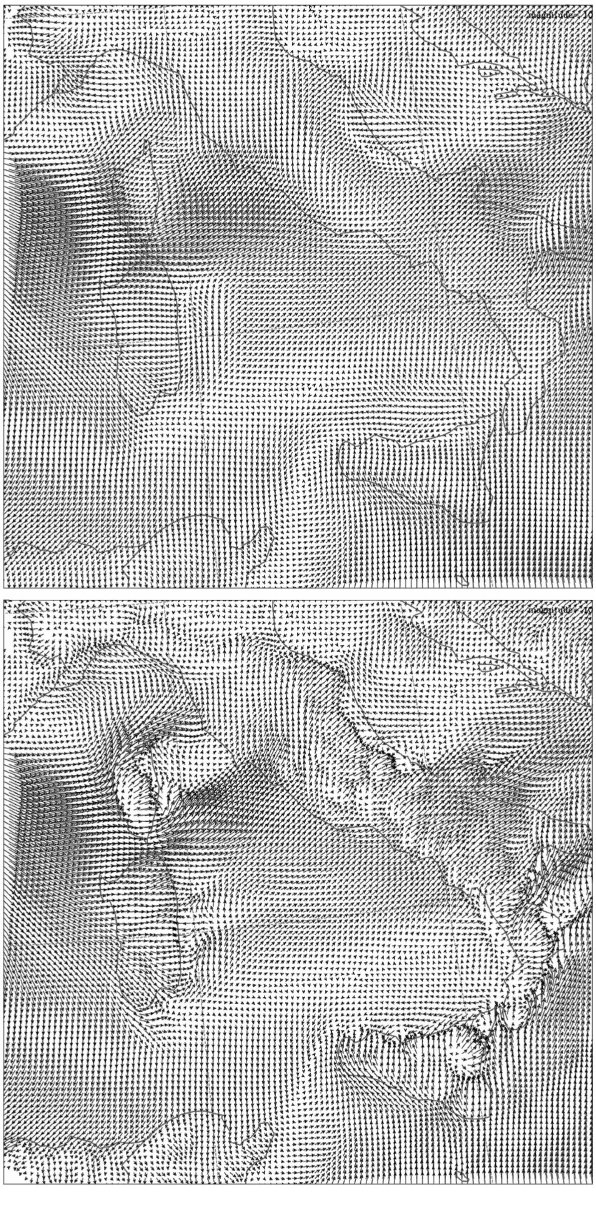


The presented case study was the first very preliminary result of the implementation of the blending procedure at SHMU. Further validation and possible tuning of the system are planned, including additional diagnostics, more case studies and the parallel suites, as well as the treatment of the surface fields and possible initialization with incremental digital filter, before considering switching the blending by digital filter into ALADIN/SHMU operational suite.

Application in ALADIN/MFSTEP

Another illustration of the usefulness of the blending by DF technique is given by example coming from the work performed few years ago at the Czech Hydrometeorological Institute in Prague. Here they use the blending by DF operationally since June 2001 for the ALADIN system, and as such was used in ALADIN/MFSTEP as well.

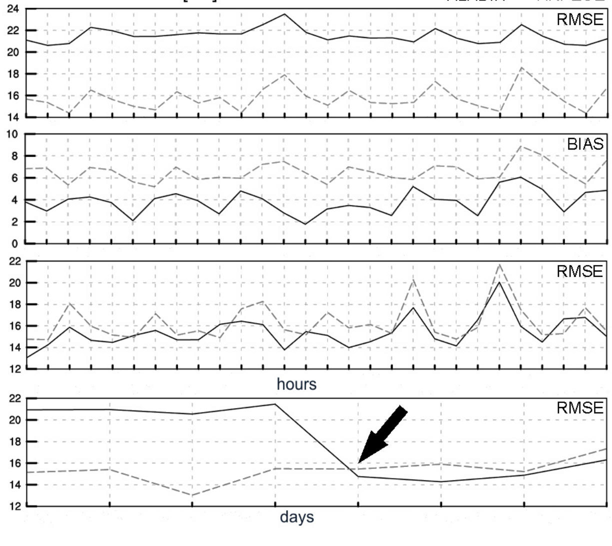
Figure 9. The 10m wind field - the initial state downscaled from the ARPEGE analysis (top) and produced by blending by digital filter (bottom).



MFSTEP is the acronym of the international project funded by the 5th EU Framework Program - Mediterranean Forecasting System: Towards Environmental Prediction. The Project aims at the further development of an operational forecasting system for the Mediterranean (http://www.ignv.bo.it/mfstep). Among its work packages one deals with the atmospheric forcing, where the near-surface parameters forecast by the atmospheric models serve as the upper boundary condition of the numerical oceanographic models. For such a purpose, a dedicated version of the ALADIN system (named ALADIN/MFSTEP) has been installed at the Czech Hydrometeorological Institute. Further model improvements were carried out in order to improve the near-surface fluxes (Brožková et al., 2006). The need to provide oceanographers with the high-resolution data both in space and time and both in the assimilation and the prediction modes led to the usage of the blending by digital filter procedure. Its profit for the coastal modelling is illustrated in Figure 9. The initial state of the 10m wind field coming directly from the driving model ARPEGE is plotted on the top panel. The initial state based on the blending by the DF assimilation procedure is on the bottom panel. Here the structure of the wind field matches much better the shape of the coast and other local orographic features, like the flow in the straights and around the islands of Corsica, Sardinia and Sicily, and also on the lee side of the Apennine peninsula.

Figure 10 demonstrates another problem that had to be solved in ALADIN/MFSTEP. In practice, the lateral boundary data coming from ARPEGE are created in Météo-France, Toulouse, with the resolution corresponding to the average ARPEGE resolution over the MFSTEP domain (29 km). These files are transferred to Prague and interpolated into the target computational resolution (9.5 km). The telecommunication constraints forced us to use a rather large telecommunication ratio, i.e. the ratio between the spectral truncations of the so-called telecom resolution and the target computational resolution. These non-optimal relations between the blending, computational and telecom truncations (see Table 1) caused incorrect RMSE scores of the mean sea level pressure of the analysis (upper panel). There was nothing suspicious detected on BIAS (second from the top), the scores of the +6h forecast were good as well (third from the top). The problem was corrected by the application of the initialization procedure in the assimilation cycle (Figure 5), which is normally not needed in standard applications with more optimal resolution ratios. This illustrates the importance of the proper tuning of all parameters associated with the blending procedure.

Figure 10. The scores of the mean sea level pressure: RMSE of the analysis (top), BIAS of the analysis (second from the top) and RMSE of guess (third from the top). At the bottom there is again RMSE of the analysis but focused on the date when the incremental digital filter was applied in the assimilation cycle.



Application in the limited area ensemble forecasting

The application of the blending by DF technique in the limited area ensemble forecasting (LAEF) is a completely new idea. In the LAEF setup, as applied at the Zentralanstalt für Meteorologie und Geodynamik (ZAMG) in Vienna, the breeding[1] method is used to generate perturbed initial conditions for the limited area ensemble prediction. The downscaled outputs of the global model ARPEGE ensemble system named PEARP (where perturbations are based on the singular vectors[2]) are used for the lateral boundaries. Therefore, the LAEF boundary data are inconsistent with the LAEF initial state, as different techniques were used for their production. The initial state created as a combination of the small scale uncertainties coming from the LAM model and the large scale perturbations of the driving model shall be more consistent with the boundary conditions downscaled from the global model ensemble forecasts (Y. Wang, personal communication). For this purpose - to mix both initial states - the blending by digital filter, as schematically illustrated in Figure 11, was installed at ZAMG (Belluš, 2006). Table 1 summarizes the setup and tuning of the system.

Figure 12 shows the kinetic energy (KE) spectra at the 20th model level computed over the whole domain for one particular experiment and one randomly chosen member of the ensemble. The black line represents the ARPEGE singular vector member. The spectra of the ALADIN breeding member plotted in grey demonstrates that there is additional high resolution information present, as there are higher KE values for wave numbers roughly between 10 and 60. The final blended state (grey dots) matches the ARPEGE spectra for the large scales (black arrow), and for the short waves (i.e. higher wave numbers) converges towards ALADIN (grey arrow), as expected. The transition between these two parts of spectra remains smooth and continuous. Similar behaviour is found for other levels and other members of the ensemble (not shown).

The correct behaviour of the blending procedure is also documented on the maps of the temperature perturbations at 850 hPa. In Figure 13 the top picture shows the ALADIN initial state from breeding, and the middle picture the ARPEGE singular vector based one. The final blended state (bottom) contains the features from both input files, as requested. Thus it can be concluded that such blended initial state will be more consistent with the boundary data downscaled from singular vector based PEARP members, while posing the high resolution details generated by the breeding. Further refinement of the tuning parameters is likely to provide even more satisfying results.

[1] *Breeding is a technique which simulates the effect of uncertainty in observations by rescaling the nonlinear perturbations that comes from the forecasts pairs based on perturbed initial conditions. Five pairs (10 members) and one control run form the LAEF breeding ensemble.*

[2] *Singular vectors technique simulates the uncertainty in the initial conditions by identifying the regions that are the most sensitive to initial perturbations by computing the eigenvalues and eigenvectors of the system. PEARP ensemble consists of one control run and ten perturbed members.*

Figure 11. Schematic illustration of the application of blending by DF in ensemble forecasting. A_{BR} denotes ALADIN breeding initial state, A_{SV} ARPEGE singular vectors. (ee927 is model configuration used here to perform the changes in spectral resolution)

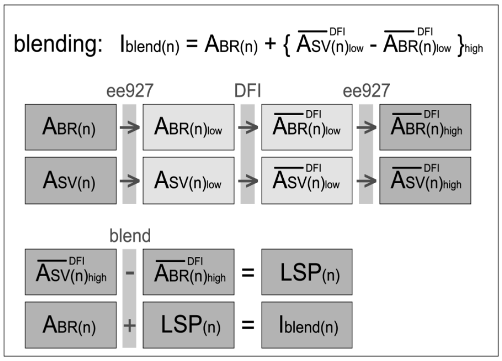


Figure 12. Kinetic energy spectra at the 20th model level for randomly selected ensemble members, where ARP SV is ARPEGE singular vector analysis, ALD BR is ALADIN breeding analysis and ALD blend is final blended initial state.

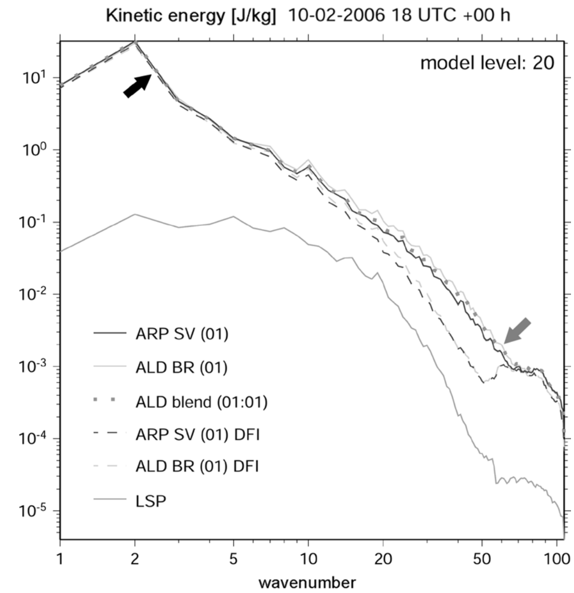
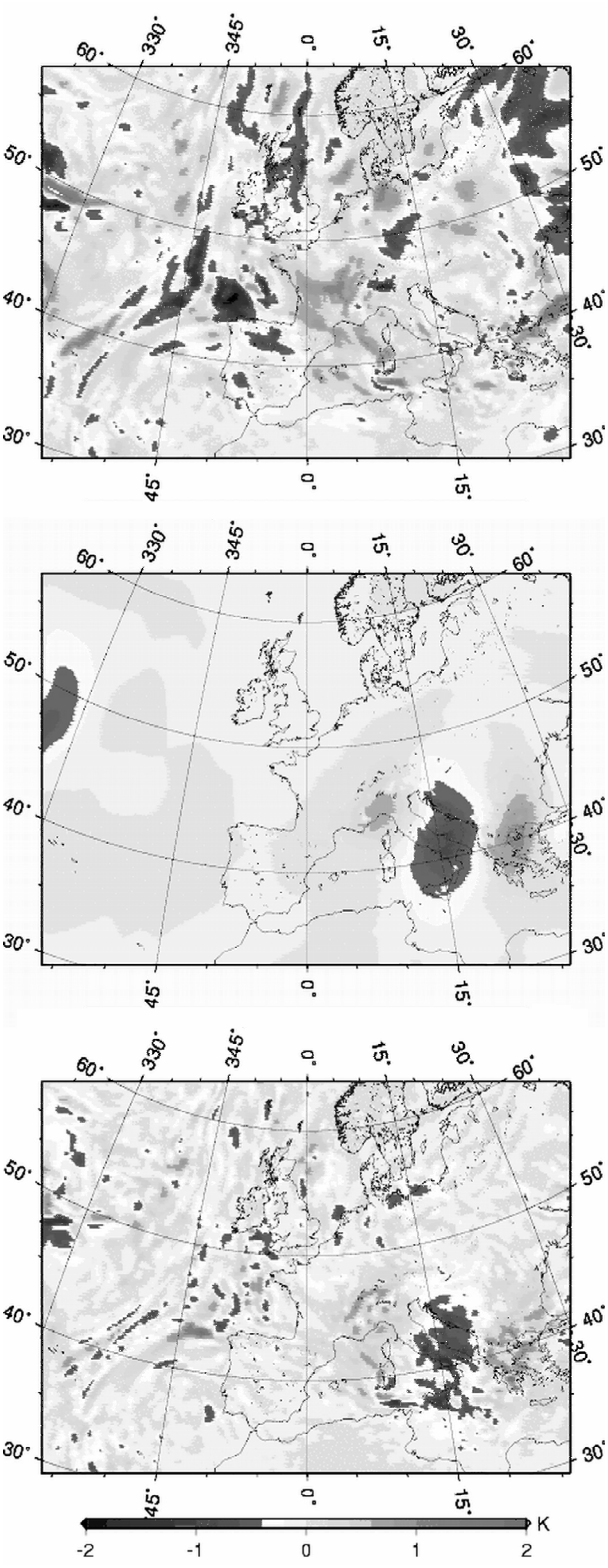


Table 1. Setup of various ALADIN systems referenced in the text.

	ALADIN/SHMU	ALADIN/MFSTEP	ALADIN/LAEF
horizontal resolution	9.0 km	9.5 km	18 km
high res. spectral truncation	106 x 95	299 x 159 (linear grid)	107 x 74
number of grid points	320 x 288	600 x 320	324 x 225
telecom horizontal resolution	20.7 km	29 km	18 km
telecom spectral truncation	49 x 44	71 x 39	107 x 74
blending spectral truncation	40 x 36	65 x 35	56 x 39
blending ratio	2.63	4.58	1.92
vertical levels	37	37	31
operational time step	400 s	400 s	600 s
blending time step	1080 s	1800 s	1200 s
number of DFI steps	6	5	6

Figure 13. The temperature perturbations at 850 hPa for one randomly selected member of the ensemble. The ALADIN perturbations generated by breeding (top), the ARPEGE ones from singular vectors (middle) and their combination via blending by digital filter (bottom).



CONCLUSIONS AND PERSPECTIVES

The blending by digital filter is a powerful semi-empirical technique that enables obtaining a more realistic initial state including the small-scale features for the integration of the high-resolution limited area model. Among its advantages belong the use of the technical procedures already developed and well adapted for the ALADIN system, with tuning parameters available for optimal behaviour. Also, its possible applications are various, as documented in the presented work.

The necessary tools for the utilization of the blending by DF technique were successfully installed on two independent computer platforms with different environments at the ZAMG and SHMU institutes. At ZAMG, the blending is used to obtain the initial state for the limited area ensemble forecast more consistent with the lateral boundary data, as they are produced by different techniques. After the necessary tuning the application aims to participate at the WMO/WRRP Beijing 2008 Olympics Mesoscale Ensemble Prediction Research and Demonstration Project. At SHMU, the blending has been applied in its original design - in the pseudo-assimilation cycle. Only a few case studies have been performed up to now. More detailed validation including the parallel suite is planned, with the aim of final application into the ALADIN/SHMU operational suite.

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