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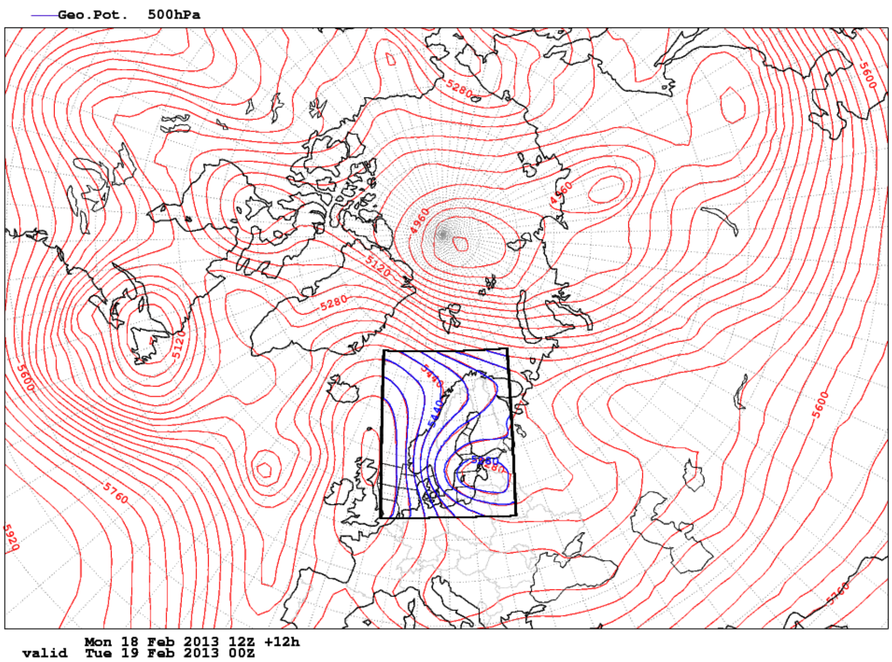
A Comparison Of Two Large Scale Blending Methods

J_k and LSMIXBC

Per Dahlgren



Front:
Map with geopotential isolines at 500hPa. Red lines show a +12h ECMWF forecast valid at Feb 19 2013, blue lines are from an AROME +12h forecast valid at the same time.

MetCoOp

Meteorological Co-operation on Operational NWP (Numerical Weather Prediction)

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A Comparison Of Two Large Scale Blending Methods

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Summary

This report describes and evaluates two methods of mixing the large scale features from a global model, providing the lateral boundaries, into the initial state of a regional model. The host model is the global model from ECMWF and the regional model is the HARMONIE AROME model used in the MetCoOp project. The first method, LSMIXBC, combines the large scale spectral components from the first boundary file with the small scale components from AROME into a modified field used as first guess in the 3DVAR analysis. The second method adds a penalty term, J_k, to the cost function in 3DVAR that measures the distance between the model state and the large scales from the host model.

Error covariance matrices for J_k were computed from differences between +24h and +48h operational ECMWF forecasts, valid at the same time (i.e., by the so-called NMC method), sampled from 8 weeks spread out over the year 2011. The J_k information was truncated at wave number $k^*=20$ to make sure only the largest scales were penalised, and the weighting of the J_k term was adjusted so that the analysis could adjust to the large scales as well as observations.

Three forecast experiments were conducted over a windy period from Dec 18 2011 to Jan 5 2012: one with LSMIXBC, one with J_k and finally a reference with no blending at all. Verification results showed that LSMIXBC improved forecasts up to +24h compared to reference. The results from the experiment with J_k showed that it only occasionally improved the forecasts compared to the reference, but not on average and not better than LSMIXBC.

Sammanfattning

I denna rapport beskrivs och utvärderas två metoder för att mixa in det storskaliga flödet från ECMWF (randvärdesmodell) i AROMEs initialtillstånd. Den första metoden, LSMIXBC, kombinerar de storskaliga spektrala komponenterna från ECMWF med de småskaliga dito från AROME och bildar ett modifierat fält som sedan används som första gissning i 3DVAR. Den andra metoden lägger till en term, J_k, till kostfunktionen i 3DVAR som straffar avståndet mellan modelltillståndet och de stora skalorna från ECMWF.

Felkovarianserna för J_k beräknades från skillnader mellan +24h och +48h ECMWF prognoser gällande vid samma tid, NMC metoden. Skillnadsfält togs fram från 8 veckor, jämnt fördelade över året 2011. Informationen i J_k termen trunkerades vid vågtal $k^*=20$ för att säkerställa att endast de stora skalorna anpassas till ECMWF i analysen. Vidare justerades viktkoefficienterna i J_k så att analysen kan anpassas till observationerna och J_k samtidigt.

Tre prognosexperiment utfördes för perioden 18:e Dec 2011 till 5:e Jan 2012. Ett experiment med LSMIXBC, ett med J_k och slutligen en referens utan storskalig mixning. Verifikationerna visade att LSMIXBC gav positiva resultat jämfört med referensen upp till 24h prognoslängd. Experimentet med J_k visade sig i vissa fall kunna prestera bättre än referensen men inte bättre än LSMIXBC.

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1 Background

Numerical Weather Prediction (NWP) on a regional domain requires a coupling system that provides lateral boundary information during the time integration step. The coupling system is often a global NWP model run on a coarser grid mesh than the regional model. Global models are generally better at representing large scale features, e.g. Rossby waves with a length scale of 10^3 km, which is essential to get the position of the synoptic high- and low pressure systems right. Blending, or large scale mixing, refers to the methodology of introducing the large scale features of the host model into the initial condition of a regional model. If the host model information is provided in spectral space, i.e. as Fourier series, the large scales can separated out by selecting only small wave numbers from the spectrum. This report will describe and evaluate two blending methods implemented in the HARMONIE system.

2 Aim

The MetCoOp project is developing an operational technical infrastructure where the HARMONIE AROME model will be run with the ECMWF model as the coupling system. The experiments presented here are done with the purpose of selecting which blending method to use in the pre-operational daily runs.

3 Model geometry and configuration

The HARMONIE experiments presented in this report are run with AROME physics and are based on *code version cy37h1*. The model domain has 750 grid points in the east-west direction (NLON=750) and 960 grid points in the north-south direction (NLAT=960). In the MetCoOp project, this model domain is called *hires2* as it is the second one used in the project for daily runs and experimental tests. The distance between grid points is 2.5 km and there are 65 levels in the vertical with the model top at 10hPa. The geographical coverage of the domain is shown in figure 1.

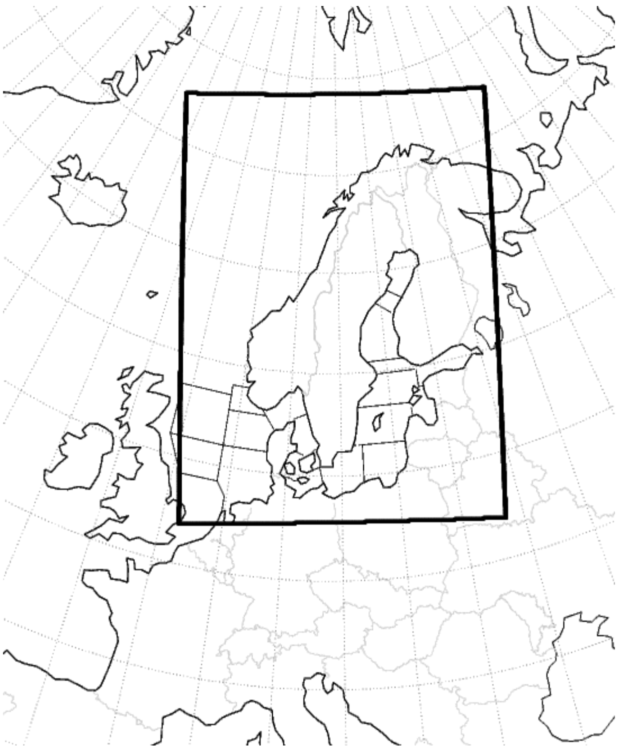

Figure 1 Model domain, called hires2.

4 Description Of Blending Methods

We have selected two ways of performing the large scale blending that will be described in this section. The initial condition for the upper air variables is determined with a 3DVAR analysis where the +6h forecast from the previous cycle is used as a first guess for the analysis. The following notations will be used throughout this report:

$x_b =$ First guess, i.e. the +6h forecast from the previous cycle

$x_{ls} =$ Large scale information from the coupling system, i.e. the first boundary file.

Variables in spectral space are denoted $\hat{x}$.

4.1 LSMIXBC

This method modifies the first guess, $\hat{x}_b$, before doing the 3DVAR analysis. The large scales from the coupling system are combined with the small scales from the first guess:

$$\hat{x}_b^{mixed}(m,n,lev) = w_{BC}\,\hat{x}_{ls}(m,n,lev) + (1-w_{BC})\,\hat{x}_b(m,n,lev) \qquad (1)$$

where (m,n) are wave-numbers, *lev* is vertical level and w_{BC} a weighting function for the boundary condition (BC) fields. Each wave-number pair (m,n) is linked to a total wave-number k^* by:

$$k^* = \sqrt{M_{max}N_{max}\left[\left(\frac{m}{M_{max}}\right)^2 + \left(\frac{n}{N_{max}}\right)^2\right]} \qquad (2)$$

The weighting function in equation 1 consists of a horizontal and vertical part:

$$w_{BC} = w_h w_v \qquad (3)$$

w_h depends on a cut-off wave-number that is computed by dividing the regional model resolution in degrees, R_{own}, with the host model resolution in degrees, R_{ls}

$$k_C^* = \sqrt{M_{max}N_{max}}\,\frac{R_{own}}{R_{ls}} \qquad (4)$$

w_h is then set according to:

$$w_h = \begin{cases} 1, & k^* \le 0.9\,k_C^* \\ \frac{1.1k_C^* - k^*}{0.2k_C^*}, & 0.9k_C^* < k^* \le 1.1k_C^* \\ 0, & k^* > 1.1k_C^* \end{cases} \qquad (5)$$

The vertical weight is calculated by using the A and B coefficients that define the vertical hybrid coordinates, η

$$\eta_{lev} = \frac{A_{lev}}{p_0} + B_{lev} \tag{6}$$

where p_0 is a reference pressure set to 100000Pa. w_v is then defined:

$$w_v = 1 - \eta^{E_v} \qquad E_v = 2 \tag{7}$$

With the A and B coefficients from the model configuration that was used for the experiments presented later, the vertical weight is as shown:

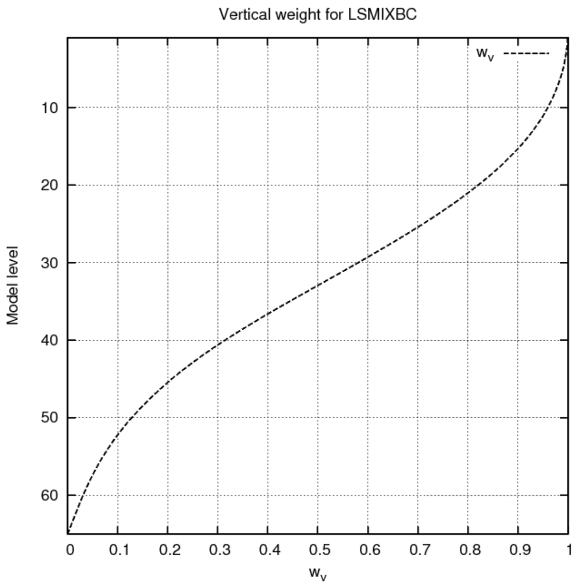

Figure 2 The vertical weight used in LSMIXBC. Model level on y-axis and vertical weight on x-axis..

The reason why the vertical weights go gradually to zero near the ground is that the orography of the host model can be very different from the orography of the fine scale model over complex terrain. Surface pressure is therefore also believed to be better represented in the fine scale model and is not mixed at all.

4.2 J_k

The upper air analysis is determined by minimizing a cost-function

$$J(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}\left(y - H(x)\right)^T R^{-1}(y - H(x)) \qquad (8)$$

where x is the model state vector (for vorticity, divergence, temperature, specific humidity and surface pressure):

$$x = \begin{pmatrix} \zeta \\ \eta \\ T \\ q \\ \ln p_s \end{pmatrix} \qquad (9)$$

and y observations, $H(x)$ is the model state interpolated to the observation locations. B is a matrix that describes the errors of x_b and R is a matrix that describes the errors of the observations y.

If we now introduce the host model x_{ls} as an extra source of information and assume that the errors of x_{ls} are uncorrelated to both x_b and observations, then an extra term, J_k, can be added to the cost-function that measures the distance between the model state and the host model x_{ls}

$$J(x) = J_b + J_o + (x - x_{ls})^T V^{-1}(x - x_{ls}) \qquad (10)$$

where $J_b + J_o$ is the cost-function presented in equation 8 and V is a matrix that describes the errors of x_{ls}. The J_k implementation in HARMONIE furthermore assumes the matrix V to be diagonal, thus cross-covariances and spatial error structures in x_{ls} are not described.

4.2.1 Error covariances

The error covariances in the V matrix were calculated by computing differences between +24h and +48h ECMWF forecasts valid at the same time. Forecast differences valid at 00UTC and 12UTC were calculated from the operational ECMWF model forecasts for 2011 and data was extracted from the MARS archives for 2 weeks in each of the months January, April, July and October.

Before calculating the differences, the extracted ECMWF forecasts need to be interpolated from the global spherical harmonic representation to the limited area geometry (see figure 1) which is in Lambert map projection and spectral fields are represented with bi-Fourier series with an extension zone to ensure periodic variations. The interpolation was done with the HARMONIE boundary interpolation software, *gl*. Data is normally also interpolated to the regional model grid point resolution, in our case from 16km (ECMWF) to 2.5km (AROME), but in this case the original horizontal resolution was maintained. The extra wave numbers that will be added to the ECMWF data to achieve 2.5km horizontal resolution does not contain any useful information for the statistical computations. Thus, ECMWF forecasts were interpolated to the AROME geometry, covering the same domain as *hires2* (figure 1), but with the original horizontal resolution maintained.

Forecast differences were calculated after the interpolations. The difference files could then be used by the same software, *festat*, normally used for calculating the background error covariances. Since the implementation of J_k assumes a diagonal error matrix, the cross covariance and balance operator calculations in *festat* were switched off making the calculations significantly less costly.

After processing forecast differences with *festat*, we get an estimate of the error variance spectra for the variables in x_{ls}, i.e. vorticity, divergence, temperature, specific humidity and surface pressure. These variances are the contents of the V matrix in the J_k implementation in HARMONIE AROME. In figure 3, the error variances of vorticity are shown for x_{ls} together with the corresponding background errors.

Comparing the statistics in figure 3, the ECMWF statistics have a much narrower spectrum than AROME due to the difference in resolution. AROME also has a lot of activity on scales not resolved by ECMWF, e.g. at wave-number 100 on model level 30 (lower left plot in figure 3). Note that the statistics from AROME and ECMWF are of the same order of magnitude up to about wave number 30 and that the ECMWF statistics thereafter decrease rapidly.

There is a peak in the ECMWF statistics (full lines) around wave-number 70. This may be due to some error in the interpolation of the ECMWF data to the AROME geometry covering the *hires2* area, figure 1. The extension zone is usually set to 11 grid points, and the number of grid points, plus the extension zone, need to be equal to $5^b3^d2^e$, where b, d, and e are arbitrary positive integers. When interpolating the ECMWF forecasts, the extension zone was set to 21 grid points in the north-south direction and 20 grid points in the east-west direction to fulfil that relation. This may have caused some problems in the interpolation software and has not yet been investigated further.

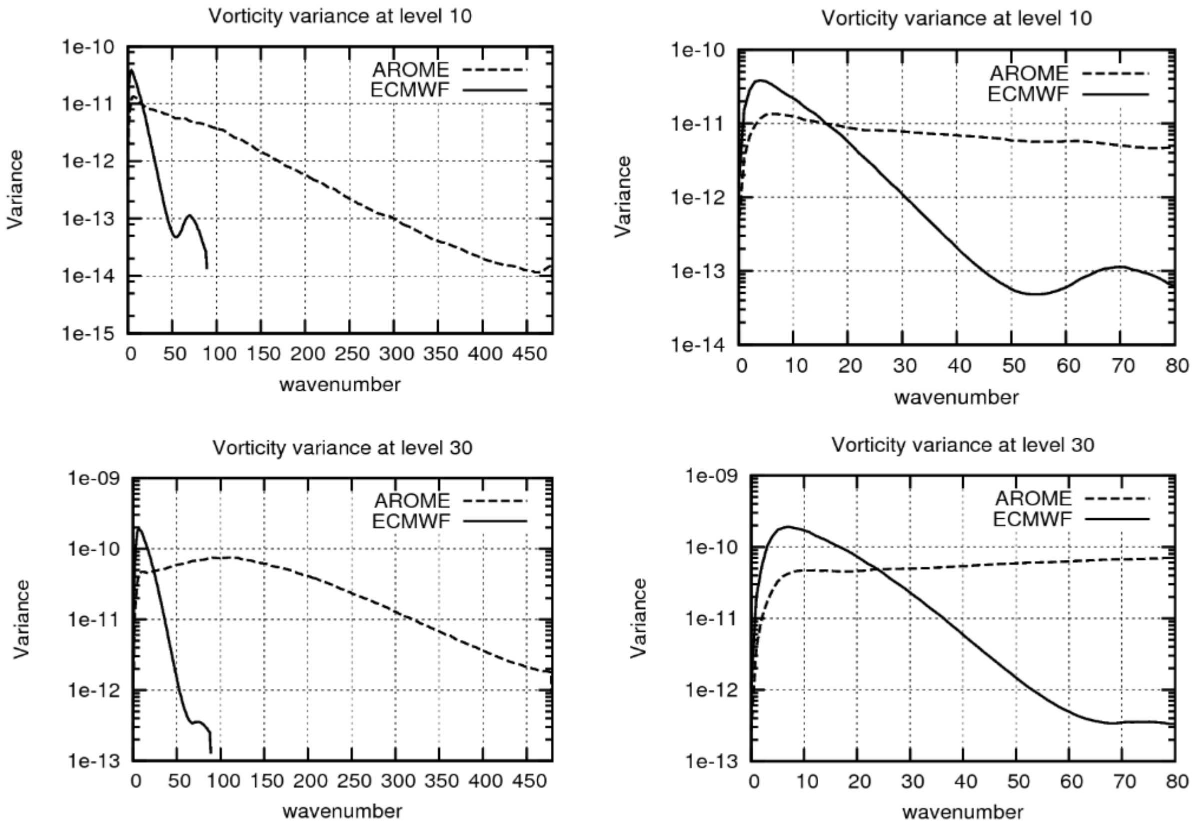

Figure 3 Vorticity error variances on model levels10 (~200hPa) and 30 (~400hPa).Dotted lines:AROME, full lines: ECMWF. X-axis shows the total wave number k^* and the units on the y-axis are [s^{-2}].

4.2.2 Specific humidity

The J_k code was first implemented by Meteo-France to be tested in ALADIN, i.e. the physics package suitable for grid point resolutions around 10km, *Guidard and Fischer 2008 [1]*. In the ALADIN code, all model state variables are in spectral space and the J_k code was originally designed to do all calculations in spectral space. In the AROME model specific humidity is in grid point space and therefore code modifications were necessary. The use of specific humidity in the J_k code was deactivated. This is not an appropriate long term solution, but was suitable for a first impact study such as this one.

4.2.3 Truncation and tuning

All J_k information, including surface pressure, was switched off on the 5 lowest model levels. The J_k term was also truncated at wave-number $k^*=20$ to make sure only large scales are penalised in the analysis. There is a separate scaling factor for each variable in x_{ls} that can be used to adjust the weight given to the J_k information in the analysis. Tuning the weights for this experiment was an ad hoc procedure where one data-assimilation case was run several times and the cost-function behaviour studied. The scaling coefficients for vorticity, divergence and temperature in J_k were tuned so that the cost-function values for J_k and J_o decreased to approximately 50 percent of the initial value. An example of the cost-function behaviour with the chosen scaling factors is shown in figure 4. The number in the upper right corner of the individual plots shows the ratio between the cost-function value at the last iteration and the initial value, e.g. $\frac{J_k^{last\ iter}}{J_k^{first\ iter}}$.

With the chosen settings we can make the analysis fit to both observations and the ECMWF forecast on large scales.

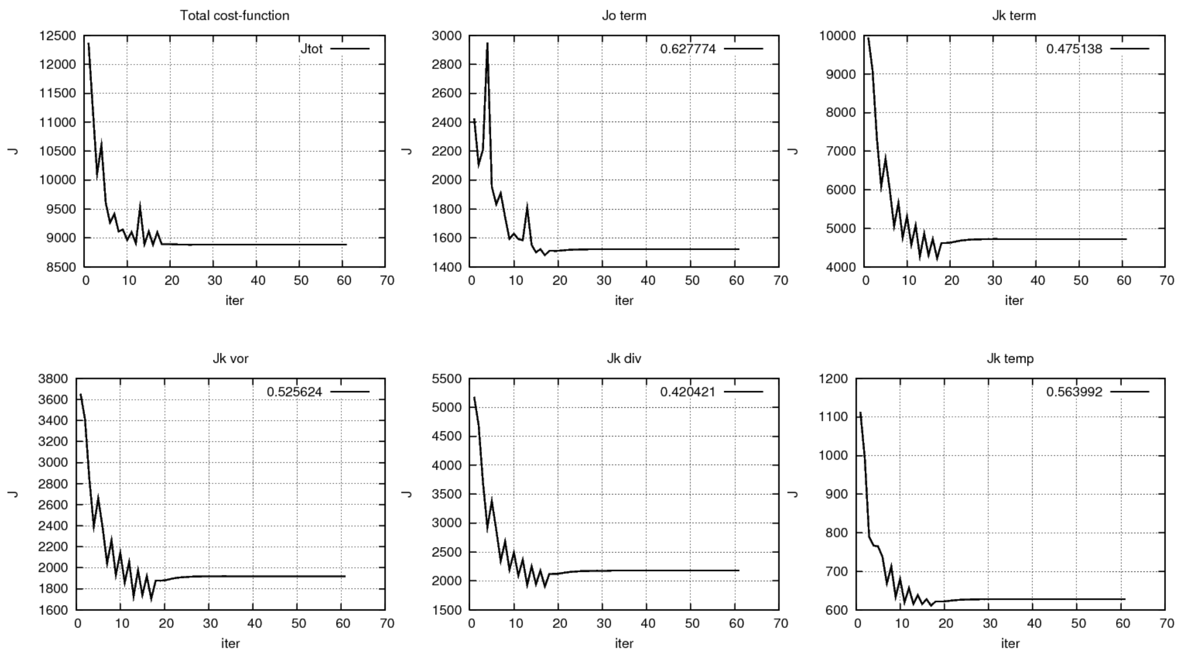

Figure 4 Cost-function behavior for one analysis on Dec 22, 2011 at 00UTC.
Upper left plot: total cost-function, i.e. $J_b+J_o+J_k$.
Middle plot, upper row: the J_o*-term showing the fit towards observations.*
Upper right plot: the J_k*-term showing the fit towards the large scales from ECMWF.*
Low row: the three individual part of J_k*, i.e.* $J_k=J_k^{vor}+J_k^{div}+J_k^{temp}$.

An extension zone of 11 grid points is used to create cyclic fields needed for a spectral bi-Fourier representation. If the extension zone is too small, information from an observation close to a lateral boundary can be reflected over to the other side of the domain via the background errors (that are represented in spectral space). This is solved by not using observations close to the lateral boundaries, a safety zone is declared using a parameter "redzone" in HARMONIE. Studies of increments created by J_k also revealed such *wrap around effects*, see *Dahlgren 2012 [2]*. In HAROMIE these effects can be avoided by setting the J_k information to zero close to the boundaries, the side effect being that the geographical coverage of the J_k information will be reduced. After some consideration it was decided that it would be preferable to maintain the geographical coverage of J_k despite the wrap around effects.

5 Results

The experiment period chosen was a windy period from Dec 18 2011 to Jan 5 2012. For more information about the period see METCOOP MEMO 01/2012 chapter 3.5 [3]. This period was suggested to be appropriate for this study due to the rapid movement of the weather coming into the boundaries of the local area model. The experiments were run with a 6 hour assimilation cycle and a 3DVAR analysis with conventional observations. At 00 and 12UTC the model was run for forecast times up to +48h. At 06 and 18UTC the forecast time was +6 hour. Forecasts were evaluated by computing mean and RMS errors using SYNOP and radiosonde observations. Three sets of assimilation experiments were carried out:

- **AM_Hires2T** – reference, no blending performed
- **mc2_37h1_jk** – blending with J_k
- **mc2_37h1_lsmixbc** – blending with LSMIXBC

For most surface parameters the results were neutral, i.e. no noticeable differences in terms of RMS errors could be seen. For mean sea level pressure (MSLP), however, a clear degradation of forecasts up to +24h was seen when J_k had been actively used, red curve in figure 5. LSMIXBC on the other hand, improved forecasts, green curve in figure 5.

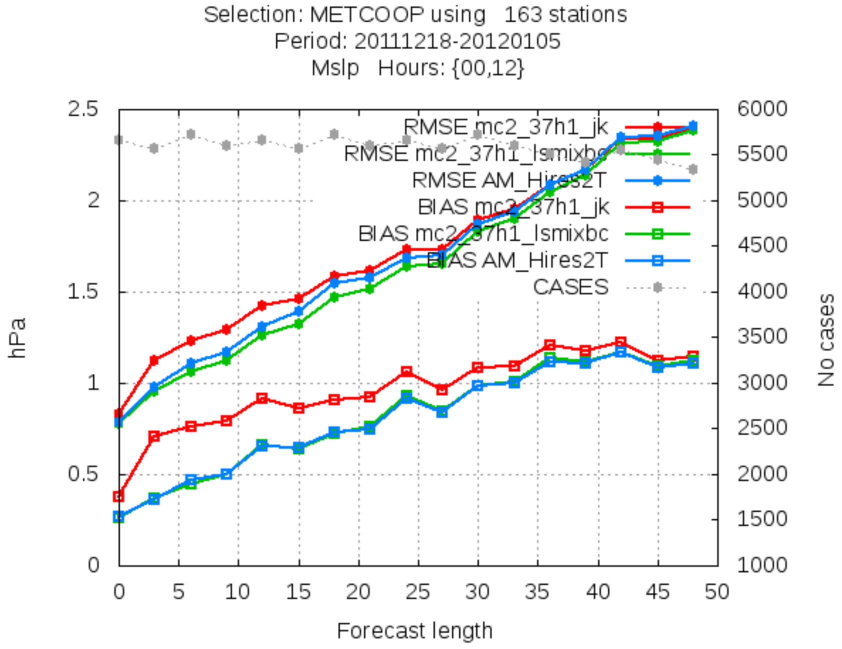

Figure 5 RMS and mean errors of MSLP forecasts compared to observations.

The upper air parameters, verified against radiosondes, showed differences in RMS errors up to +24h. For temperature and wind speed, the LSMIXBC experiment gives better results than the J_k experiment and the reference run in most cases, see WebgraF verification on the web [4]. Figure 6 shows RMS and mean errors of +12h forecasts as vertical profiles. It shows that J_k in some cases performs better than 3DVAR alone (i.e. no blending) in terms of RMS errors, but not better than LSMIXBC.

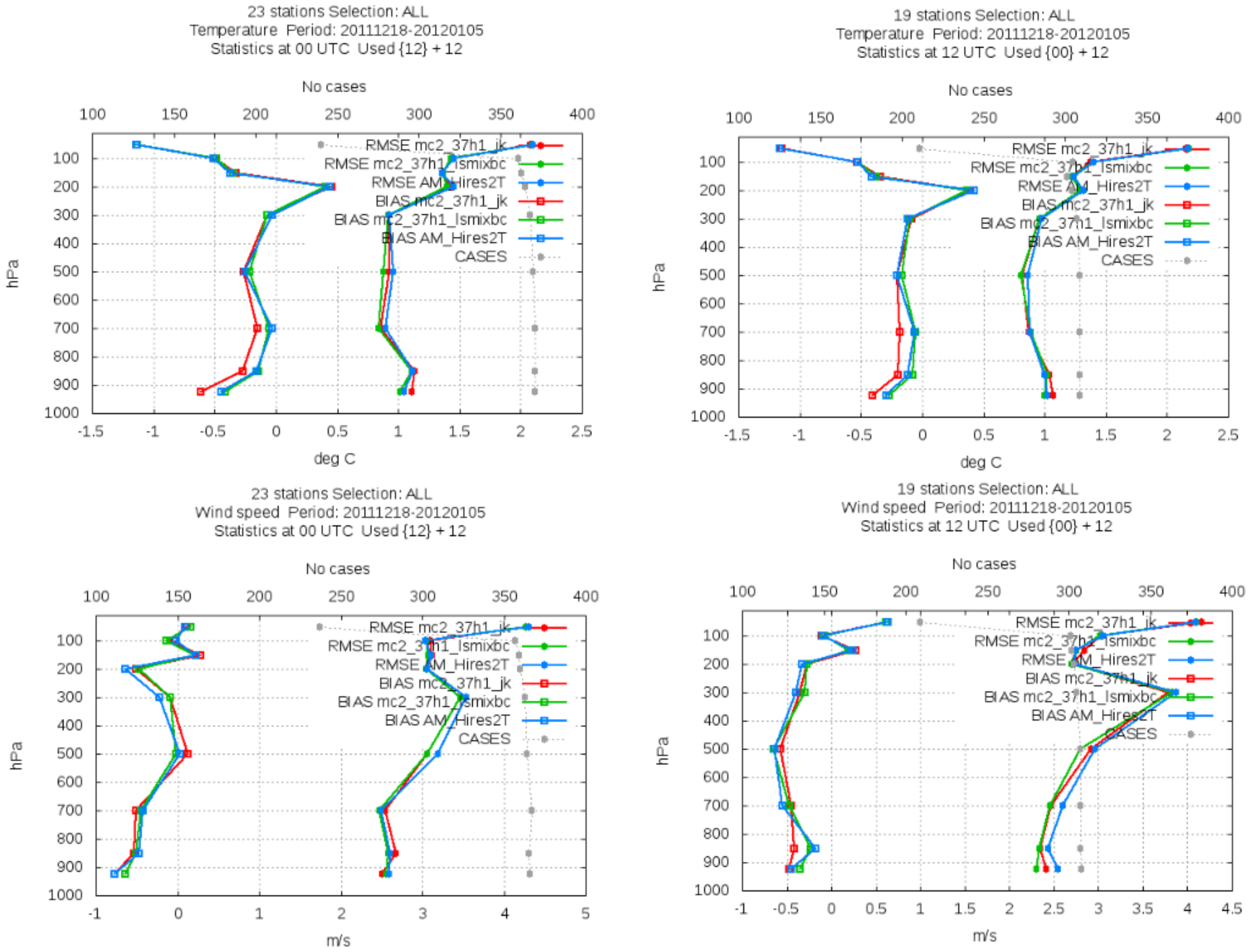

Figure 6 Root mean square (RMS) and mean errors of +12h forecasts compared to radiosonde data. Upper plots show errors of temperature valid at 00 and 12UTC respectively. Lower plots show the same statistics for wind speed.

6 Conclusions

The problem of mixing the large scale from the host model into the analysis of a regional model has been addressed here. Two methods of performing the mixing, LSMIXBC and J_k, have been described and tested. For the scope of the MetCoOp project, the conclusion is that large scale mixing improves forecasts, and should be performed using LSMIXBC.

7 References

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[4] WebgraF verification on the web (access from SMHI and met.no only) http://metcoop.met.no/verif/JK_LSMIXBC_3DVAR_export

8 Figures and tables

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