Testing the modifications aimed to reduce noise in the semi-Lagrangian scheme

Kalle Eerola
Finnish Meteorological Institute

1 Background

There has been discussion that HIRLAM produces noisy fields and in extreme cases even crashes, especially when using high resolution (an example of one type of noise problem is given by Eerola (2004)). McDonald (2002) looked at the behavior of HIRLAM in one case, where DMI had a crash with maximum wind speed 323 m/s when running on a high resolution ($0.1^\circ \times 0.1^\circ$). He suggested the following three modifications in the semi-Lagrangian scheme to avoid the "crash" and reduce noise:

1. Linear interpolation of vertical velocity from half to full levels instead of cubic interpolation in the semi-Lagrangian scheme
2. "Extrapolation along the trajectories" in finding the departure point. For discussion about finding the departure point see, McDonald (1999)
3. A modified discretization in the temperature equations of the semi-Lagrangian scheme using the Tanguay-Ritchie method

All these modifications together succeeded in this case best to reduce noise, as judged by human eye and measured by the square root of vertical velocity integrated over the domain. This is a commonly used method of measuring the noise level. In addition he suggested using smoothed (filtered) orography. This affects especially in the precipitation fields, eliminating the "grid point storms".

James Hamilton (personal communication) tested these modifications in a longer period test using late-summer/early-autumn situation. He found improvements in the verifications scores against observations. Especially the temperature bias at 250 hPa and 850 hPa was reduced.

The above-mentioned study and tests suggest that these modifications reduce the noise and improve the verification scores. So it is worth implementing them into the reference system. The problem was that the modifications were originally developed and tested in an earlier Hirlam environment (HIRLAM 5.0). Therefore the changes had to be merged to the latest Hirlam 6.3.3 beta-release. At the same time other changes, especially related to OpenMP optimization, were done to the corresponding routines CALPQR.f, SLDYN.f and SLDYNM.f. Merging was done by careful hand-work. In this connection it was decided to run another two-week period using winter conditions. This note describes results from that experiment.

2 Design of the experiment

The testing was done using the HIRLAM 6.3.3 environment with minimal changes. Test period was from 1 Feb 2004 00UTC to 15 Feb 2004 00UTC. The verification scores were computed for the period 3 Feb 2004 00UTC ... 15 Feb 2004, letting the two first days be the warming-up phase. Long +48 h forecasts were run twice a day from 00 and 12 UTC analysis. Otherwise the Hirlam 6.3.3 beta-release was unmodified. The resolution was the default 0.2° and the integration domain the RCR domain with 438×336 grid points and 40 levels. Analysed boundaries were used as lateral boundary conditions.

The experiment RAI is the unmodified HIRLAM 6.3.3 system, while in the experiment RAB the suggested modifications to the semi-Lagrangian scheme have been done. Note that HIRLAM 6.3.3 by default uses filtered orography. So this requirement is fullfilled in both experiments.

3 Results

In this section we look at the verification scores against observations at the EWGLAM stations. The emphasis will be on the upper-air scores and surface pressure, because our problem concerns mainly dynamics. Remember also that the HIRLAM 6.3.3 physics is assumed to contain unsolved problems. In all cases observation verification scores have been calculated from forecasts starting at 00 UTC and 12 UTC analyses. Especially when considering the upper air scores, we should mainly look at the +12, +24, +36 and +48 hour forecasts, because the other forecast lengths refer to hours, when much less sounding data are available.

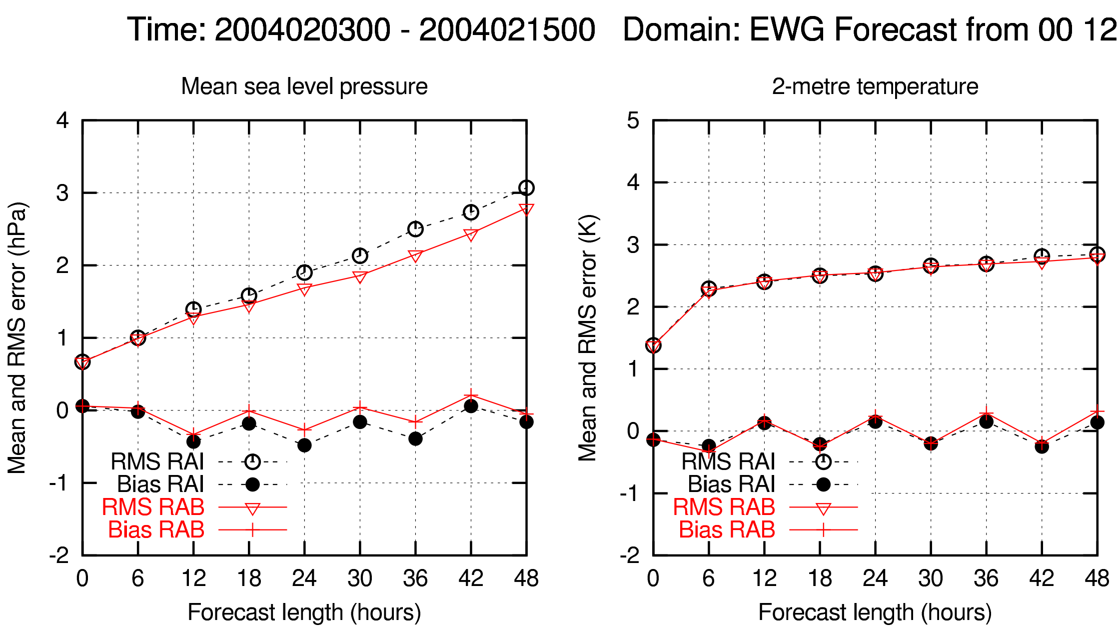

Figure 1: *Observation verification scores of surface variables for the EWGLAM stations.*

Looking at the mean sea level pressure scores in Figure 1 it is evident that both rms and bias scores are better in the RAB experiment compared to the unmodified RAI experiment.

The improvement is much larger than expected, because the main effect was supposed to be the reduction of noise.

The scores for 850 hPa level are shown in Figure 2. We see that temperature bias at main observation hours (+12, +24, +36 and +48 hour forecasts) is almost the same but rms error for temperature is reduced, especially at the longer forecast lengths. Wind speed bias is marginally increased in the RAB experiment, but on the other hand rms error is reduced at +12, +24, +36 and +48 hour forecasts. The same conclusions apply also to the 500 hPa level (not shown). At 250 hPa level (Figure 3) we see a clearly reduction in wind speed bias values (being almost zero in RAB experiment at +12, +24, +36 and +48 hour forecasts). The reduction can also be seen in the wind speed rms values. A small increase in temperature bias values can be seen, but again rms values are slightly reduced.

Another way of verifying the forecasts is to investigate the geographical distribution of forecast errors. In this case the errors are computed against (initialized) analysis. Normally such statistics are presented on constant pressure levels, but in this case the verification is done directly on model levels to minimize the effect of vertical interpolation.

Figure 4 shows the rms error of +48 hour temperature forecasts on model level 29 (around 830 hPa) computed against initialized analysis for the RAI (upper panel) and for the RAB (lower panel) experiment. We see a reduction in rms error almost everywhere when compared RAB to RAI experiment. Especially, the large error in the Arctic Sea north of Scandinavia is reduced, but improvements can be seen almost everywhere. A good sign is that the error is reduced on the European continent, where the analysis is supposed to be good because of good sounding network. Note also that the error structure in the RAB experiment seems to miss the smallest scale, i.e. being smoother. This could be due to the reduction in noise in the forecasts. The signal from the wind verification is very similar (not shown).

When going upper in to the atmosphere, the situation is slightly different. Figure 5 shows the same rms error on level 10 (around 210 hPa) for RAI (upper panel) and for RAB (lower panel). The RAB experiment gives larger rms values in an area from the British Isles towards Iceland, but the error in RAB is smaller over the continent. The area of larger error in RAB is mainly over the sea, where the observational network is sparser. The results for winds are very similar to those of temperature (not shown).

The standard measure for noise in the Hirlam model is the absolute value of surface pressure tendency averaged over the integration domain. To see if the suggested modifications really reduce the noise, we randomly selected one forecast and averaged the absolute pressure tendency from +42 hour forecast to +48 hour forecast. The averaged values were 0.894Pa/3hrs and 0.880Pa/3hrs in RAI and RAB experiment, respectively. So at least in this case the modifications reduced the absolute pressure tendency, i.e. noise.

4 Discussion and summary

This note described results from the experiments that have been done to test the modifications in the semi-Lagrangian scheme. The aim of these modifications is to reduce noise and prevent "grid point storms" in the Hirlam forecast model, especially when running on higher resolution. These modifications were already tested by James Hamilton (personal communication) in late-summer/early autumn situation. The present tests were done in winter conditions.

James Hamilton found, in verifying the forecasts against observations using the EWGLAM station list, improvements mainly in the 850 hPa and 250 hPa temperature bias, which was reduced in both cases. In the present study the improvements could mainly be seen in the rms values of temperature and wind speed and to a smaller agree also in the bias. The stronger and more active mid-winter circulation compared to the early autumn, may explain the difference.

Looking at the rms errors of temperature and wind in the field verification scores there were improvements in RAB over RAI in the lower atmosphere all over the integration area. In upper atmosphere larger rms errors were received in the modified RAB system over parts of the Atlantic Ocean, but improvements were found over the European continent. There was small scale structure detectable in the rms fields. Normally these fields look rather smooth. There can be at least two reasons to this.

First of all, it suggests that the individual fields are rather noisy. And indeed, when looking at individual forecasts there is "noise" left in the both experiments. "Noise" means here that fields do not look like smooth as we are used to, when running on coarser resolution. Secondly, the number of cases, when computing the rms scores, is rather small, because only forecasts based on 00 UTC analysis were included in the computation of field verification scores and the length of the test period was only two weeks.

All the statistics shown here and by Hamilton indicate that the suggested modifications have a positive effect on the forecasts. In particular, larger than expected improvements in winter-time verification scores were found, in addition to the reduction of noise.

References

Eerola, K., 2004: Monitoring the RCR system: first impressions and findings. *Hirlam Newsletter*, **45**, 72–79.

McDonald, A., 1999: An examination of alternative extrapolations to find the departure point position in a "Two-Time-Level" Semi-Lagrangian integration. *Mon. Wea. Rev.*, **127**, 1985–1993.

McDonald, A., 2002: Changes to the HIRLAM needed for finer grids? *Hirlam Newsletter*, **42**, 9–17.

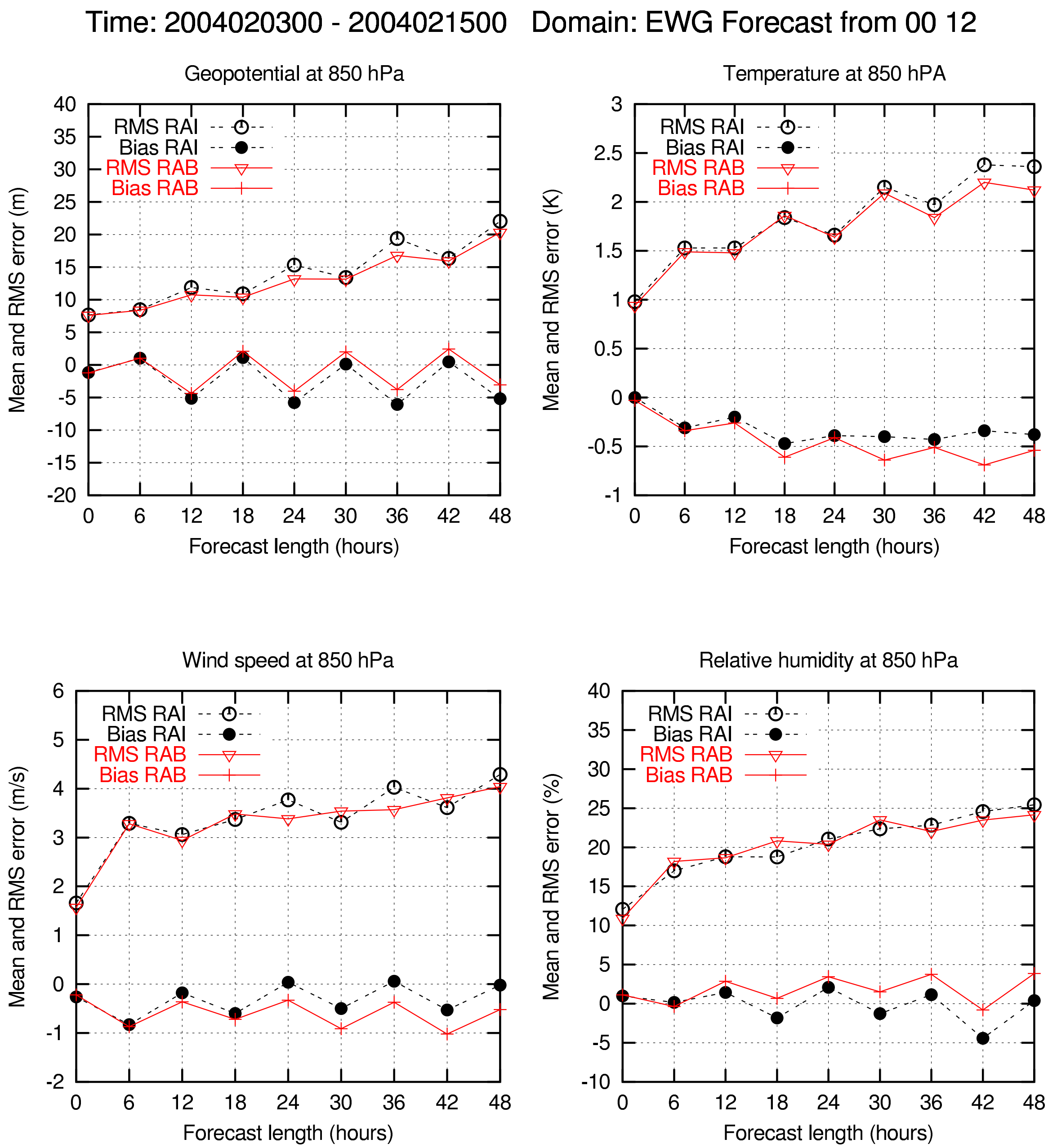

Figure 2: *Observation verification scores of upper air variables for the level 850 hPa and for the EWGLAM stations.*

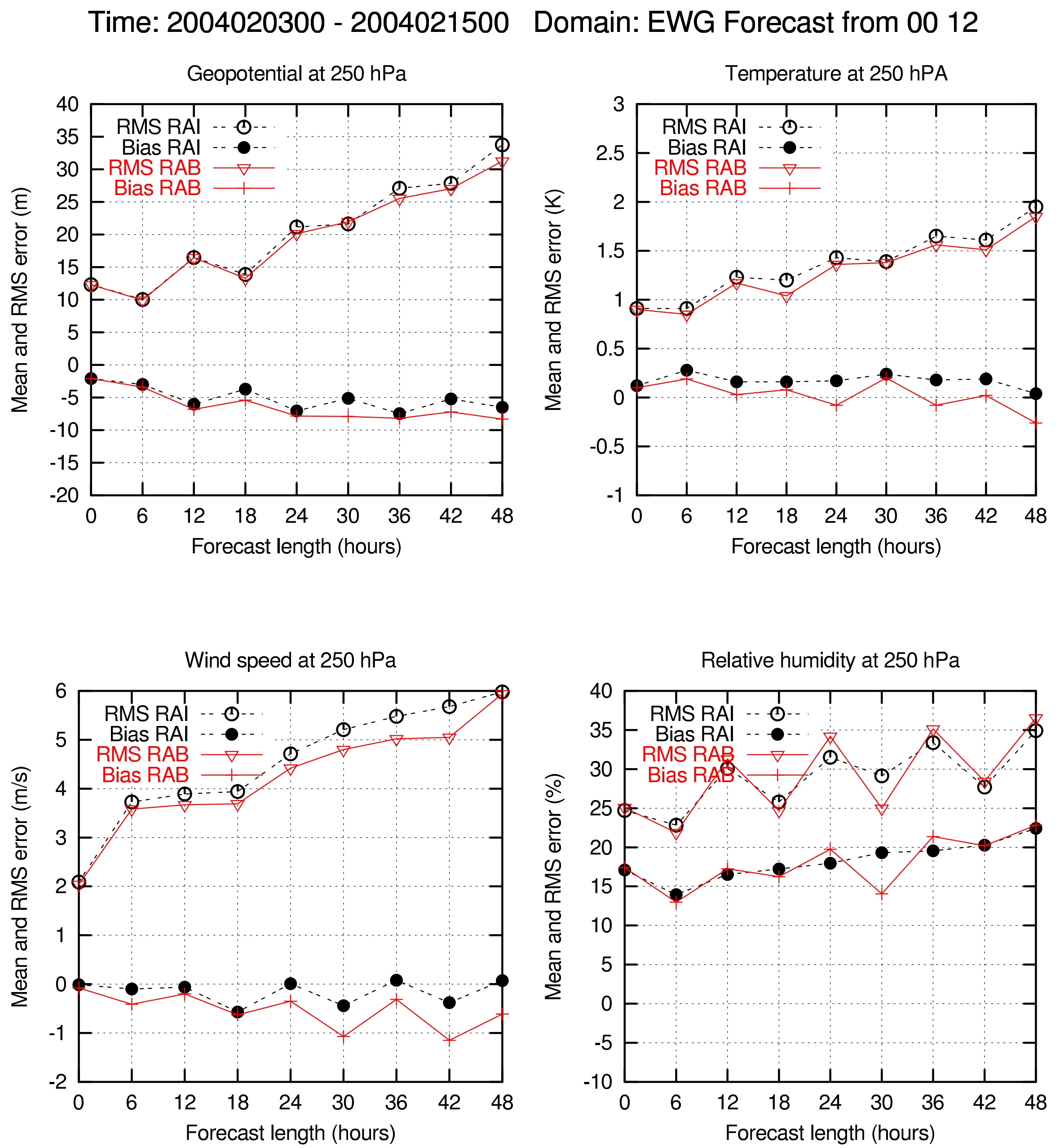

Figure 3: *Observation verification scores of upper air variables for the level 250 hPa and for the EWGLAM stations.*

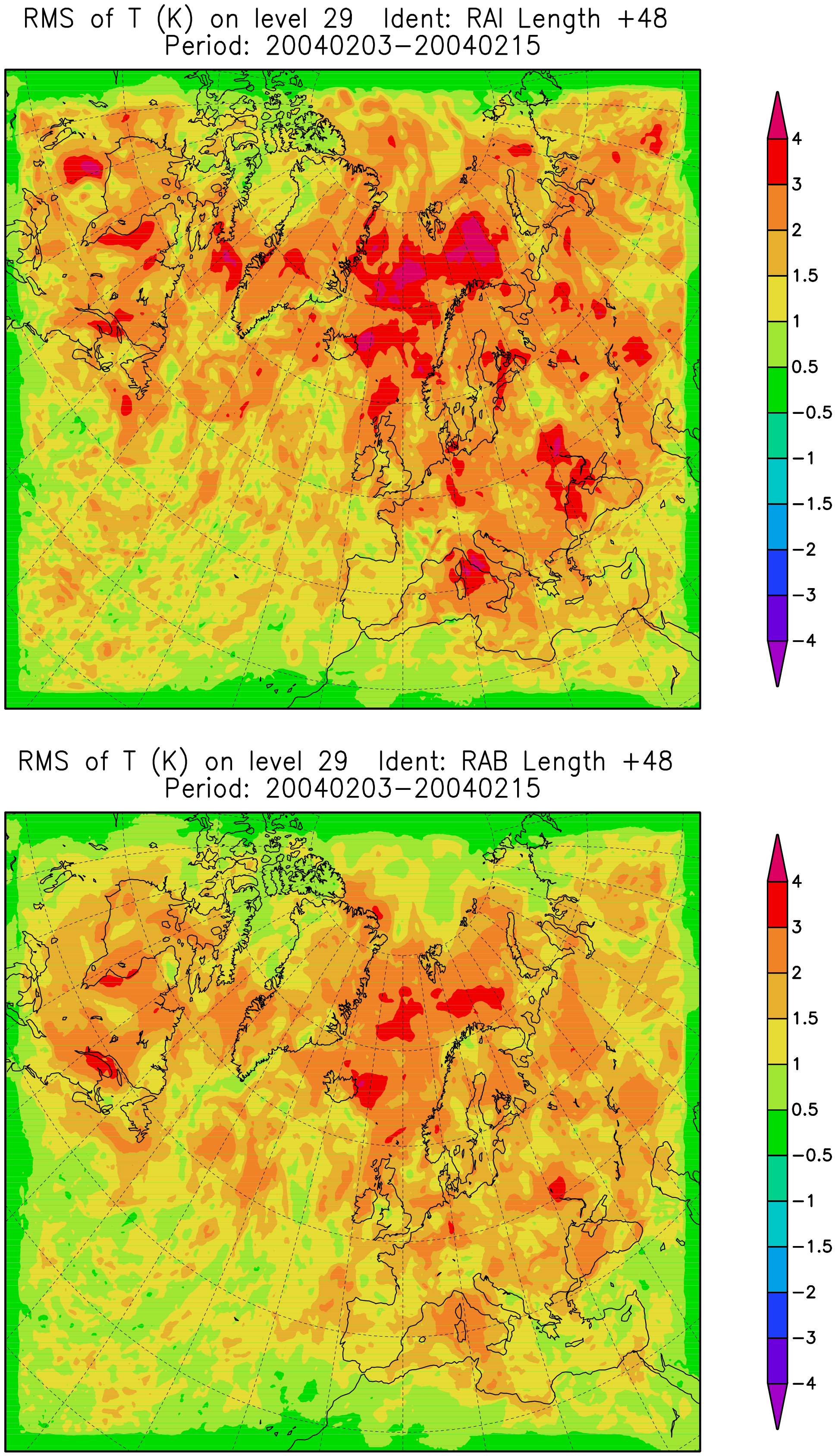

Figure 4: *Rms error of +48 hour temperature forecasts against initialized analysis on model level 29, from experiment RAI (upper panel) and from RAB (lower panel).*

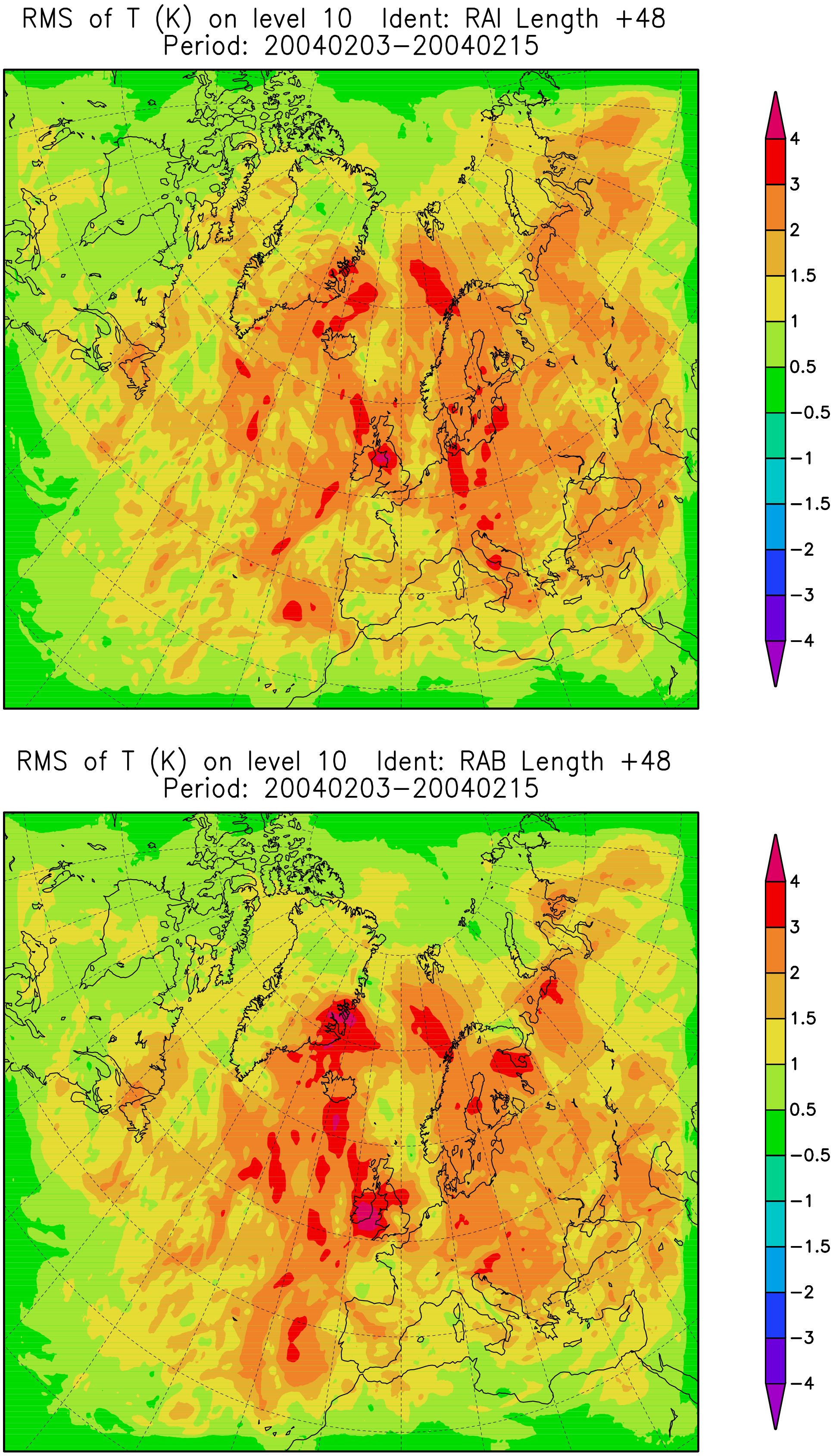

Figure 5: *Rms error of +48 hour temperature forecasts against initialized analysis on model level 10, from experiment RAI (upper panel) and from RAB (lower panel).*