Testing of the MC2 boundary treatment in HIRLAM

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1 Introduction

Pre-operational tests with an ISBA-based HIRLAM system started at FMI in summer 2002. Experiences from these pre-operational tests are reported in another write-up in this newsletter (Järvenoja, 2003). One problem experienced during the pre-operational tests was the frequent crashes with the 0.18° resolution/40-level model. This problem was shortly presented at the HIRLAM-5 Workshop in Dublin in October 2002. In one of the working groups of the workshop, lateral boundary conditions were discussed, and the boundary treatment of the Canadian MC2 model was introduced. There were suggestions that the crashes experienced at FMI might be due to the boundary treatment. McDonald (2003) implemented the MC2 boundary treatment into the HIRLAM forecast model soon after the workshop, carried out a basic test and documented the MC2 boundary treatment within HIRLAM.

This write-up first describes the boundary problem experienced at FMI and then reports the results from 2-week parallel tests using the HIRLAM and MC2 boundary treatment.

2 Boundary problem

The pre-operational test runs at FMI with the HIRLAM 5.1.4 system in summer and autumn 2002 suffered from crashes. The crashes were frequent with the 0.18°resolution/40-level model, but the 0.3° model also crashed about once a week.

One crash case was debugged carefully. The problem was located at the eastern boundary, over the Caucasus mountains east of the Black Sea. In the 0.18° resolution, the Caucasus mountains are now higher and steeper than in the then operational ATA suite with the 0.4° resolution. The reason for the crash was traced back to the STRACO scheme. Temperature at level 33 in the 40-level model exceeds 373 K (100°C !) after 52 hours' integration. The water vapor saturation pressure table is limited to 100°C, which means that the water vapor saturation pressure for temperatures above 100°C is sought outside the table. Water vapor saturation pressure and consequently, temperature becomes NaN (not a number) and horizontal diffusion then spreads this value everywhere resulting in the crash.

It was found that there were symptoms of this problem already before the actual crash. Temperature at level 33 at the eastern boundary point oscillated between 290 and 350 K for several hours before the crash. This unrealistic temperature is due to excessive precipitation and latent heat release over high/steep orography. However, the boundary relaxation resets the temperature to a reasonable value of the boundary dataset at every time step after the physics, thus preventing the blow-up. The boundary relaxation also resets the humidity (q) at the boundary to the value of the boundary dataset. This means that new moisture is being made available for STRACO to release more precipitation and latent heat. At some stage the surrounding grid points will be also affected so that the temperature finally exceeds 373 K and the crash occurs.

The pre-operational test suite with a horizontal resolution of 0.3° and with 40 levels crashed on 12 October 2002 in the 18 UTC cycle. The MC2 boundary treatment was used for this case, and it helped: there was no blow-up. This proves that the MC2 boundary treatment helps to prevent crashes.

3 Parallel tests with different boundary treatment

The calculations in the HIRLAM reference model are carried out in the following order: dynamics, physics, horizontal diffusion and boundary relaxation. In the MC2 model the order is different. After the dynamics, the the boundary relaxation is carried out. Then comes the physics and after the physics, the physics tendencies are relaxed in the boundary zone. The same weights as in the actual boundary relaxation are used, and the tendencies are relaxed towards zero at the boundary. This is an additional step compared to HIRLAM. Finally, horizontal diffusion is carried out.

Parallel test runs have been carried out using the present HIRLAM reference boundary treatment and the MC2 boundary treatment. The runs have been conducted on IBM at CSC using the HIRLAM 5.1.4 system. Three parallel experiments are as follows:

- ATC : reference HIRLAM boundary treatment
- ABC : MC2 boundary treatment adopted to HIRLAM, tendency of cloud water relaxed
- ABW : as ABC, but tendency of cloud water not relaxed

The common features for the three experiments are:

- Domain: Area corresponding to the FMI operational suite (ATX) with a 0.3° horizontal resolution
- 256 × 186 grid points; 40 levels in the vertical
- Semi-Lagrangian advection, time step 6 min
- Each suite with its own data assimilation (3D-Var, 6 h cycling)
- ISBA surface scheme with the related surface analysis package
- Lateral boundary conditions: ECMWF frames as received operationally
- 48 h forecasts from 00 UTC analyses only
- Period: 10-27 January 2003

In the parallel tests using the MC2 boundary treatment, two alternatives for treatment of cloud water were used, relaxing (experiment ABC) and not relaxing (ABW) the cloud water tendencies due to physics in the boundary zone.

4 Results from parallel tests

In the following, some results from the parallel tests are presented.

The observation verification scores for the parallel experiments are almost identical for surface parameters as well as for upper air parameters, and are therefore not shown. The similarity of the scores is supported by Figs. 1 and 2, which show the systematic differences, over the 2-week period, between ABC and ATC (ABC-ATC) 48 h forecasts for mean-sea-level pressure (p_{msl}) and 2-metre temperature (T_{2m}), respectively. Systematic differences in p_{msl} are small, with the largest differences in the boundary zone in areas of high orography: over the Caucasus mountains (+2 hPa) and in northern Africa (+2 hPa). Differences in the inner area are still smaller: -0.5 hPa north of Scandinavia and +0.5 hPa north of Iceland and north of Faroe Islands. Systematic differences in T_{2m} are also mainly limited to the boundary zone: over the Caucasus mountains and in the northern boundary. Differences in upper air parameters such as temperature, geopotential height and relative humidity are small as well: for example, $\pm 1°$C in temperature and ± 10 m in geopotential height, mainly in the boundary zone (not shown). It can be concluded that the impact of different boundary treatment on basic surface and upper air variables is small and is mainly concentrated in the boundary zone.

Figure 3 shows the accumulated 48 h stratiform precipitation, averaged over the 2-week period for the ATC experiment. Maximum values of the order 10 mm can be seen in southern Norway, elsewhere values are smaller. There is little or no stratiform precipitation close to boundaries. Figure 4 demonstrates the systematic difference in the accumulated 48 h stratiform precipitation between experiments ABC and ATC (ABC-ATC). Differences are small. Experiment ABC gives slightly less (0.1-0.5 mm) stratiform precipitation than ATC in the inner area and also at the western boundary (40°N). On the contrary, at the eastern boundary, east of the Mediterranean experiment ABC gives 1.5 mm more stratiform precipitation in two spots. As a whole, the impact of different boundary treatment on stratiform precipitation is rather small.

Figures 5 and 6 show the accumulated 48 h convective precipitation, averaged over the 2-week period for experiments ATC and ABC, respectively. These figures show that winter-time convection is active only over the Atlantic and in southern Europe, especially over mountains. A special feature in the convective precipitation pattern of experiment ATC (Fig. 5) is large values ("frames" with a width of a few grid points) in the boundary zone at the western and southern boundary and also at the eastern boundary over high orography. Extremely high, unrealistic values are seen in northern Africa and east of the Mediterranean. The large precipitation amounts in the boundary zone are absent in experiment ABC (Fig. 6), elsewhere the pattern is similar to that of ATC in Fig. 5. The difference in accumulated 48 h convective precipitation between experiments ABC and ATC (ABC-ATC) is demonstrated in Fig. 7. Small differences (± 2 mm) can be seen scattered over the Atlantic, but huge differences are seen at the boundaries, especially in northern Africa (-100 mm in 48 hours on average) and east of the Mediterranean (-190 mm). Thus the MC2 boundary treatment much reduces, or almost removes, the convective precipitation in the boundary zone.

Finally, Fig. 8, showing the difference in the predicted (48 h) total cloud cover between experiments ABC and ATC (ABC-ATC), demonstrates that the MC2 boundary treatment much reduces the total cloud cover in the boundary zone and, in fact, almost removes the clouds at the boundary. Differences are very small in the inner area.

Another experiment, ABW, with the MC2 boundary treatment was also carried out. This differs from ABC in one aspect: the physics tendency of cloud water is not relaxed towards zero in the boundary zone. The results from this experiment are very similar to those of ABC. Figure 9 demonstrates the systematic difference in the accumulated 48 h convective precipitation between ABW and ABC (ABW-ABC) for the 2-week period. The differences are of the same order as between ABC and ATC, but there are no differences in the boundary zone. Figure 10 shows the systematic difference in the total cloud cover. There are small differences in the inner area of the model domain, but there is a larger cloud fraction in experiment ABW at the western, northern and eastern boundary zone. This larger cloud fraction appears in bands along the boundary, covering a couple of grid points in the inner part of the boundary zone.

The results presented in this section indicate that the impact of the MC2 boundary treatment is mainly limited to the boundary zone. Furthermore, this impact is significant only on convective precipitation and total cloud cover, which are both much reduced compared to values from runs using the reference HIRLAM boundary treatment.

5 Case study

The parallel tests presented in the previous section were carried out for a winter period, when the convective activity is less intense over the continental areas. An example of a crash case with excessive convective precipitation in the boundary zone is presented in this section. The case is from 14 August 2002 at 06 UTC. The test run with a 0.18°/40-level model using the HIRLAM reference boundary treatment crashed in this case, as did a later re-run with 0.3°/40-level system (ATC). The crash with the ATC system occurred just after 30 hours' integration. There was, however, no crash in the run with the ABC system. Figures 11 and 12 demonstrate the accumulated 30 h convective precipitation for ATC and ABC runs, respectively. Large convective precipitation amounts can be seen at the western, southern and eastern boundaries for experiment ATC (Fig. 11). This case is favorable for convection in the area of the Black Sea: there is a cyclone with hot and humid air in that region. It is no wonder that largest amounts of convective precipitation, as much as 1193 mm in 30 h, are over the Caucasus mountains east of the Black Sea. This unrealistically large amount of precipitation leads to a huge release of latent heat, which soon after 30 hours' integration results in a crash. Figure 12, demonstrating the accumulated 30 h convetive precipitation for ABC, clearly shows the impact of the MC2 boundary treatment: precipitation in the boundary zone is much reduced with the maximum amount being more realistic, 55 mm in 30 h, over the Caucasus mountains. Consequently, much less latent heat is released, and the blow-up in the model is avoided.

6 Summary

The MC2 boundary treatment has been tested in HIRLAM. The impact of the MC2 treatment is mainly small, and can be seen in the boundary zone. The impact on basic variables is small. Larger impact can be seen in convective precipitation and total cloud cover. The convective precipitation is much reduced in the boundary zone, and so is also the cloud cover. The reduced convective precipitation makes the model more stable and model crashes can be avoided, even in higher resolution with steeper mountains.

References

Järvenoja, S., 2003: Experiences from pre-operational HIRLAM 5.1.4 tests at FMI. *HIRLAM Newsletter*, **43**, (in this issue).

McDonald, A., 2003: MC2 boundary treatment in HIRLAM. *HIRLAM Newsletter*, **43**, (in this issue).

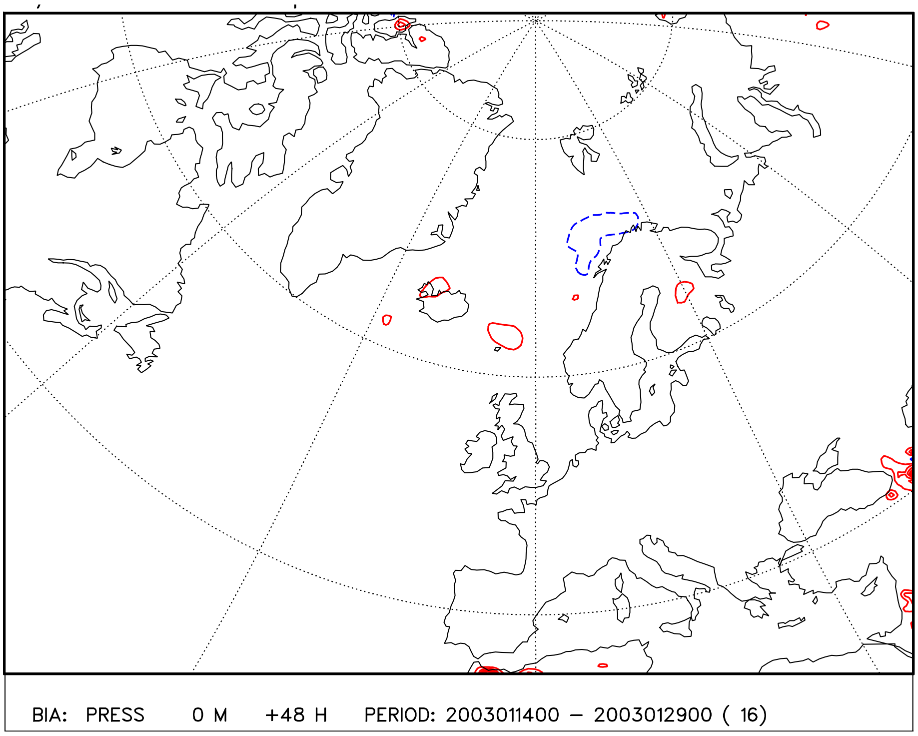

Figure 1: *Systematic difference in 48 h p_{msl} forecasts between ABC and ATC experiments (ABC-ATC), for the period 12-27 January 2003. Contour interval: 0.5 hPa. The zero isoline not plotted, negative values indicated with dashed lines.*

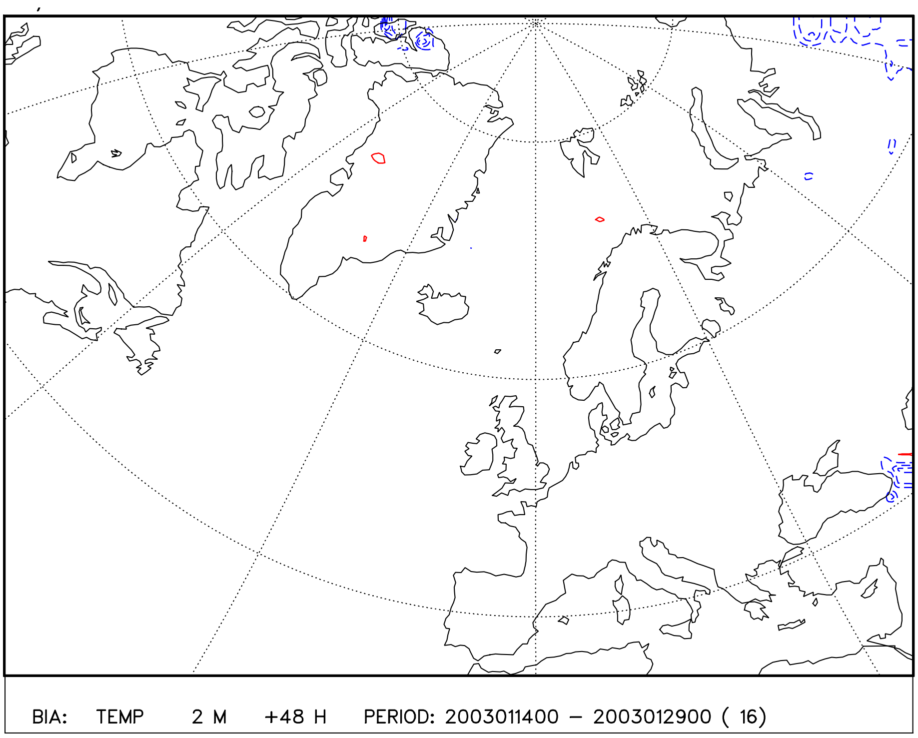

Figure 2: *Systematic difference in 48 h T_{2m} forecasts between ABC and ATC experiments (ABC-ATC), for the period 12-27 January 2003. Contour interval: 1° C. The zero isoline not plotted, negative values indicated with dashed lines.*

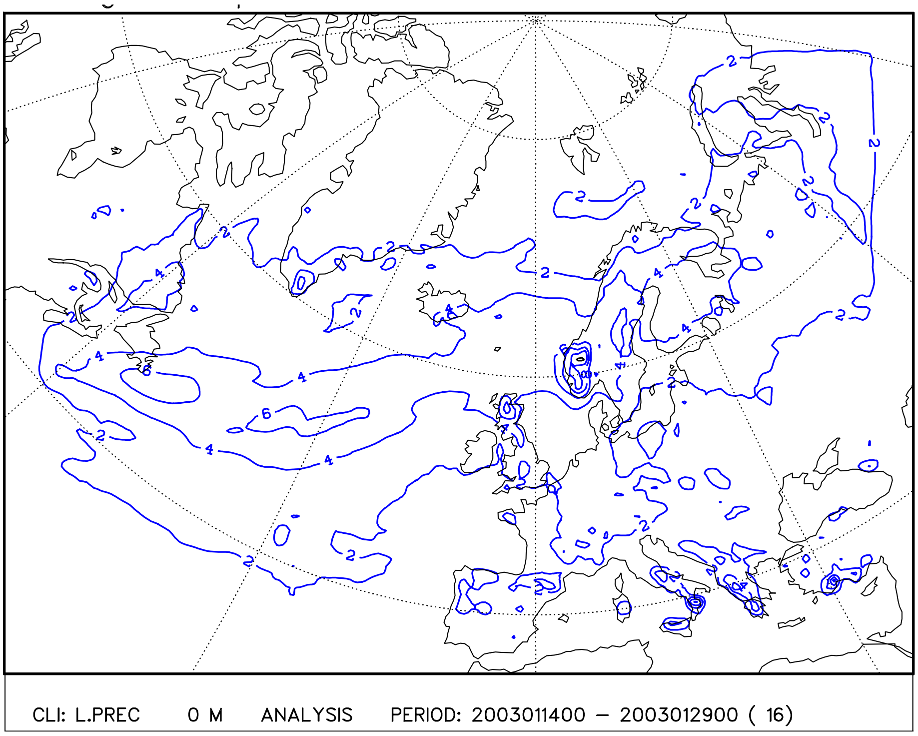

Figure 3: *Average 48 h accumulated stratiform precipitation for experiment ATC, for the period 12-27 January 2003. Contour interval: 2 mm.*

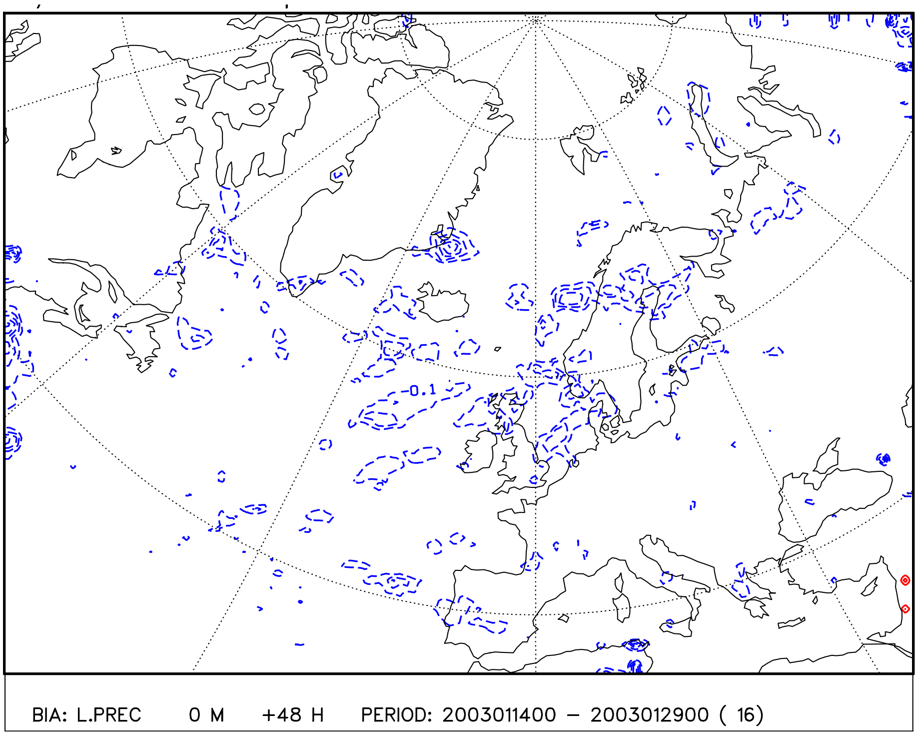

Figure 4: *Systematic difference in 48 h accumulated stratiform precipitation between ABC and ATC experiments (ABC-ATC), for the period 12-27 January 2003. Contour interval: 0.1 mm. The zero isoline not plotted, negative values indicated with dashed lines.*

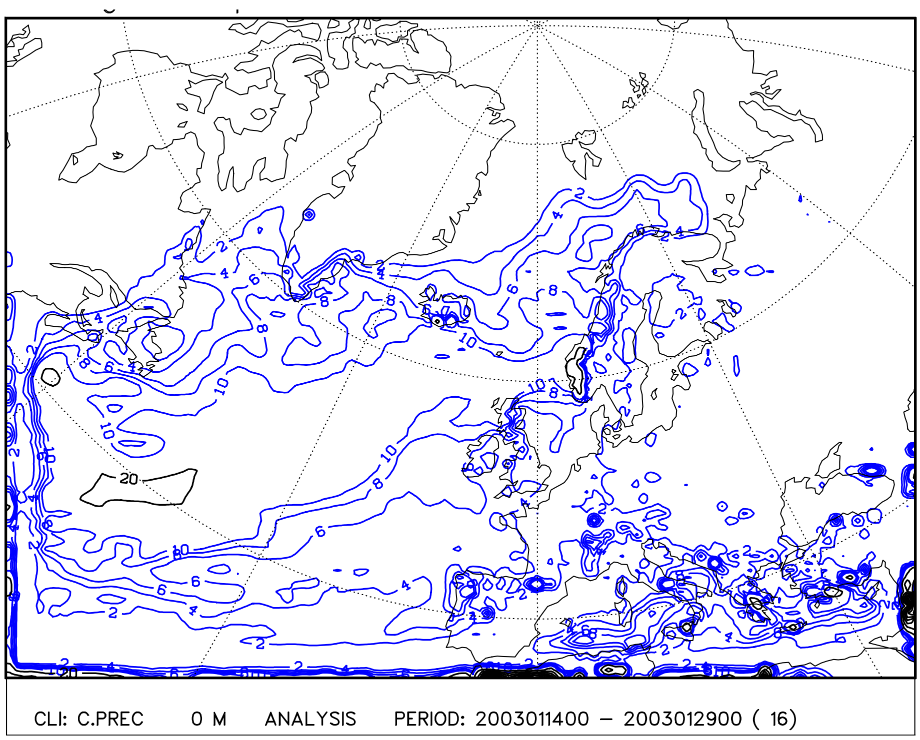

Figure 5: *Average 48 h accumulated convective precipitation for experiment ATC, for the period 12-27 January 2003. Contour interval: 2 mm for values 2-10 mm; 20 mm for values of 20 mm or more.*

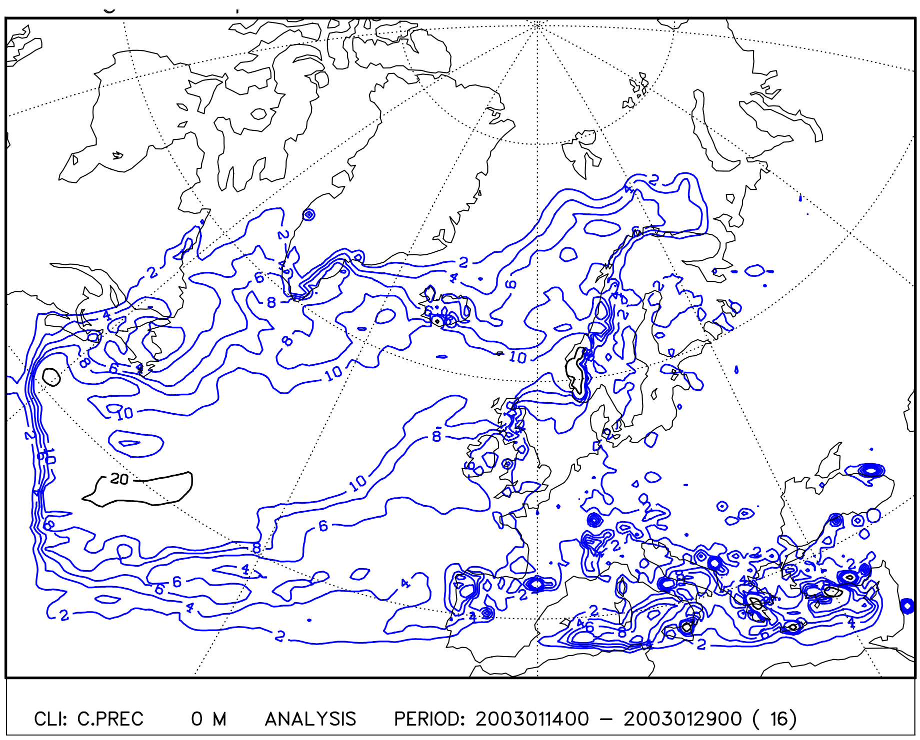

Figure 6: *Average 48 h accumulated convective precipitation for experiment ABC, for the period 12-27 January 2003. Contour interval: 2 mm for values 2-10 mm; 20 mm for values of 20 mm or more.*

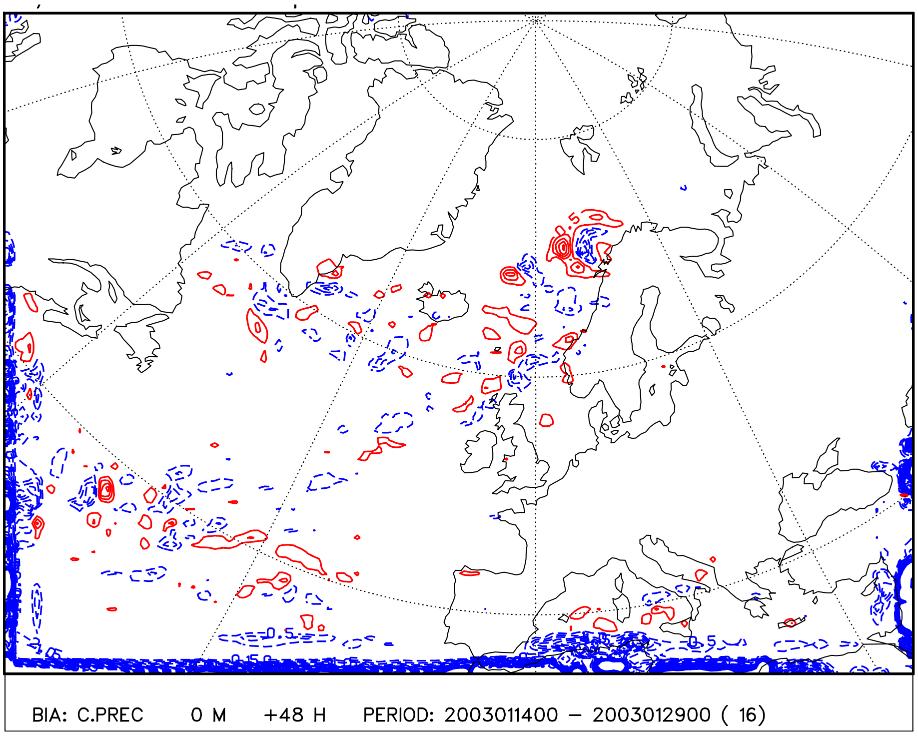

Figure 7: *Systematic difference in 48 h accumulated convective precipitation between ABC and ATC experiments (ABC-ATC), for the period 12-27 January 2003. Contour interval: 0.5 mm. The zero isoline not plotted, negative values indicated with dashed lines.*

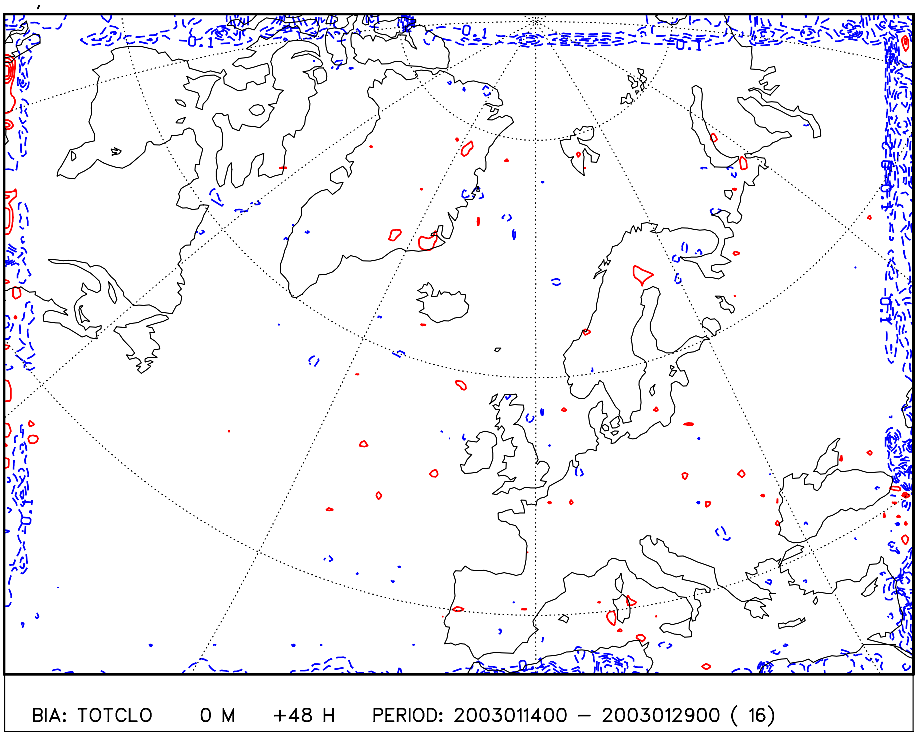

Figure 8: *Systematic difference in 48 h total cloud cover between ABC and ATC experiments (ABC-ATC), for the period 12-27 January 2003. Contour interval: 0.1. The zero isoline not plotted, negative values indicated with dashed lines.*

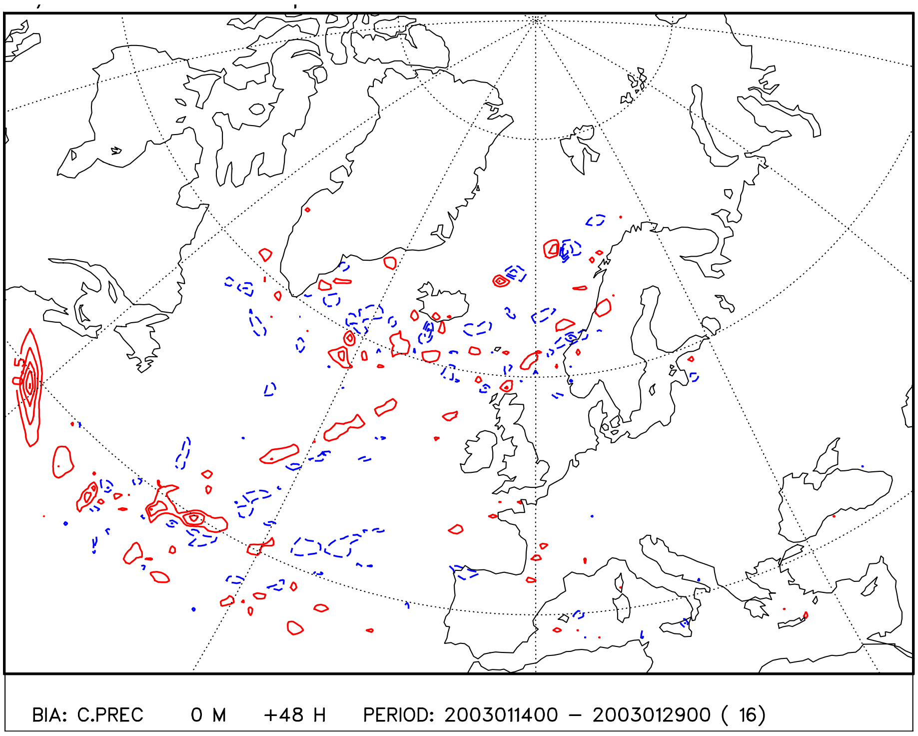

Figure 9: *Systematic difference in 48 h accumulated convective precipitation between ABW and ABC experiments (ABW-ABC), for the period 12-27 January 2003. Contour interval: 0.5 mm. The zero isoline not plotted, negative values indicated with dashed lines.*

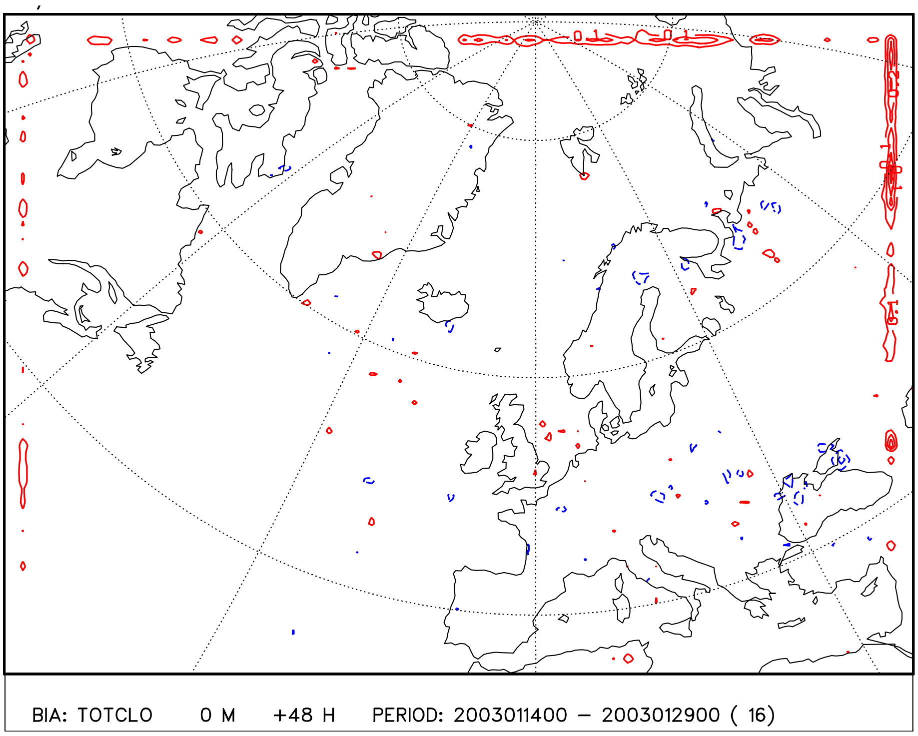

Figure 10: *Systematic difference in 48 h total cloud cover between ABW and ABC experiments (ABW-ABC), for the period 12-27 January 2003. Contour interval: 0.1. The zero isoline not plotted, negative values indicated with dashed lines.*

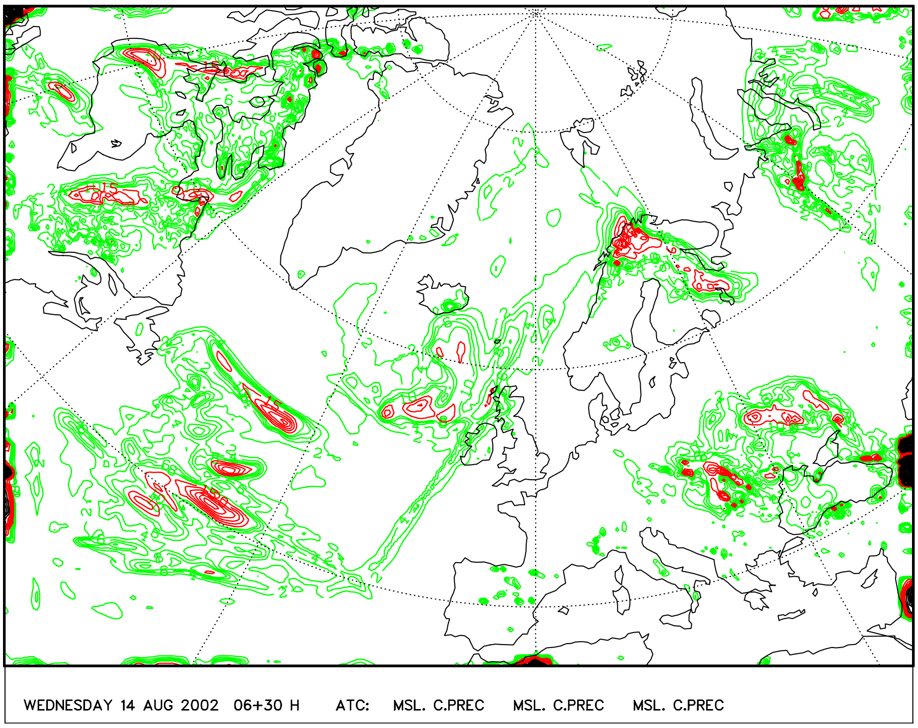

Figure 11: *Accumulated 30 h convective precipitation for experiment ATC, starting from the 06 UTC analysis, 14 August 2002. Contour interval: 2 mm for values 2-20 mm (light grey), 5 mm for values 25-35 mm (darker grey) and 10 mm for values of 40 mm or more (black).*

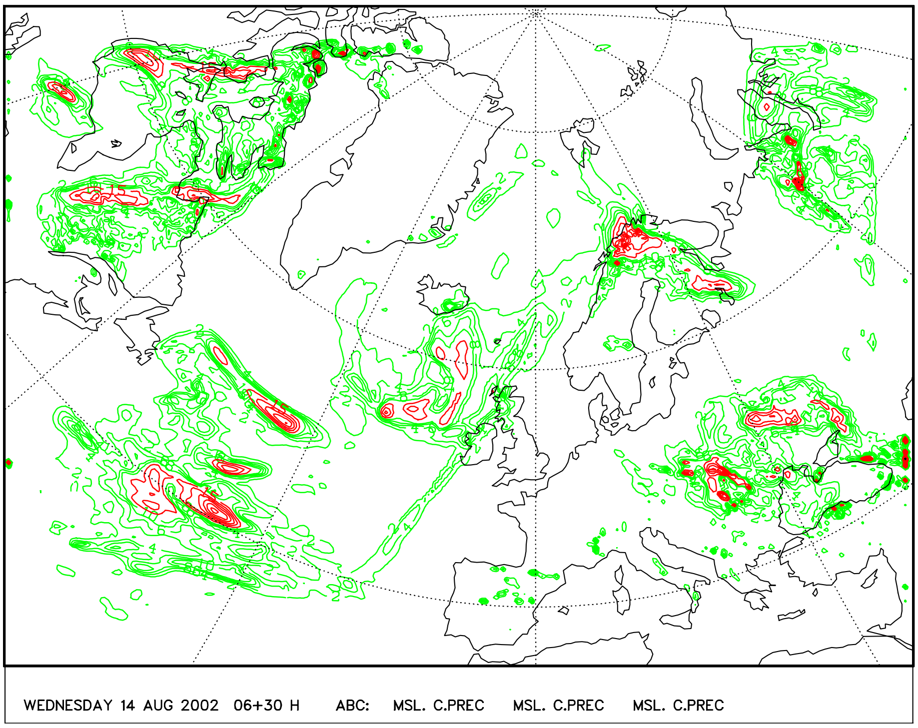

Figure 12: *Accumulated 30 h convective precipitation for experiment ABC, starting from the 06 UTC analysis, 14 August 2002. Contour interval: 2 mm for values 2-20 mm (light grey), 5 mm for values 25-35 mm (darker grey) and 10 mm for values of 40 mm or more (black).*