Problems in predicted HIRLAM T_{2m} in winter, spring and summer

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1 Introduction

One long-lasting problem in HIRLAM has been the poor quality of the predicted 2-metre temperature (T_{2m}). The problem was detected several years ago and some improvements have been achieved since HIRLAM-2 and HIRLAM-4 systems. But, there is still room for improvement as will be demonstrated in this write-up, which describes recent T_{2m} problems in the operational RCR system (HIRLAM version 6.2.1) at FMI.

In winter 2004, the predicted T_{2m} suffered from a considerable positive bias in high latitudes, e.g., in Scandinavia. The problem in spring was reversed with a negative bias dominating in northern Europe. In summer, a negative T_{2m} bias dominated over almost the whole model domain both in the daytime and at night. The T_{2m} problem seems to be of different type (and possibly of different origin) in different seasons.

2 T_{2m} in different seasons

In the following, the T_{2m} problem in different seasons will be presented.

2.1 Winter

Järvenoja (2004) reported on a wintertime T_{2m} problem in the RCR runs. This problem is highlighted in Fig. 1, which shows the geographical distribution of the T_{2m} bias on station basis in RCR (production name "V621") 48 h forecasts valid at night (00 UTC) in February 2004. In northern latitudes, in Scandinavia and northern Russia as well as in northern America, a considerable positive bias of up to 8-9°C dominates. A negative bias can be seen in central Europe as well as in northern Africa and in the Middle East.

The positive bias in northern Europe and Russia is unacceptably large. Järvenoja (2004) studied the problem more closely by trying to find dependence between the T_{2m} bias and the observed T_{2m}. It turned out that the model predicted T_{2m} has practically no bias in the temperature range between -5°C and +5°C in February 2004. At the observed temperatures below -5°C, the positive bias starts to grow when going to lower temperatures so that the bias reaches +13°C at -30°C (Järvenoja, 2004, Fig. 14). This means that most of the positive bias as seen in Fig.1 comes from cold cases.

Figure 2 depicts the cloud cover bias in the 48 h forecasts valid at 00 UTC in February. In calculations, the observed cloudiness (given in octas) is first converted to units of model cloudiness (fraction), and the bias is then plotted as fractions multiplied by 10. Figure 2 reveals that a positive bias dominates in high latitudes: in Scandinavia, Russia and northern America. This positive cloud bias coincides with the positive T_{2m} bias in Fig. 1. The excessive clouds can therefore be at least partly responsible for the positive T_{2m} bias by reducing the long-wave radiative cooling at the surface.

In spring 2004, several HIRLAM scientists tried to solve to the positive T_{2m} bias problem and a few cures for the problem were suggested. One suggested cure was a modified saturation table (ESAT) for water vapour. The table was modified so that liquid water was allowed to be present down to -23°C. This is expected to reduce downwelling long-wave radiation from clouds and also to result in a lesser cloud amount, and these effects would consequently lead to lower temperatures in cold cases.

The above mentioned modification was tested for a cold winter period of 26 December 2002 to 11 January 2003. The experiment with a modified ESAT table (C62) and the reference experiment (R62) were carried out with the HIRLAM 6.2 system. Figures 3 and 4 demonstrate systematic differences between C62 and R62 (C62-R62) for T_{2m} and cloud cover, respectively. As Fig. 3 shows, the modified version (C62) results in lower T_{2m} values, several degrees at most, in high latitudes, while hardly any differences are seen in central and southern Europe, in areas with mild temperatures. A closer examination (not shown) reveals that the ESAT modification alone is not enough to remove the large positive bias of high latitudes, but is a step to the right direction. The basic reason for the positive T_{2m} bias might, however, be deficiencies in parameterization of the stable boundary layer (with inversions). Figure 4 demonstrates that the modified experiment (C62) results in a lesser cloud cover than the reference run (R62) over almost the whole model domain, most in high latitudes.

2.2 Spring

The complicated T_{2m} bias structure in spring is demonstrated in Fig. 5, showing the daytime (12 UTC) bias in 48 h forecasts, for April 2004. The winter-type positive bias prevails in high latitudes, in northern America and northern Russia. There is still snow cover in these areas and temperature hardly rises above zero. In Scandinavia, Estonia and Russia east and southeast of Finland, there is a negative T_{2m} bias of a few degrees. In western and central Europe, the bias is close to zero or slightly positive.

Figure 6 depicts the cloud cover bias in 48 h forecasts valid at 12 UTC for April 2004. A clear positive bias is seen in high latitudes, with the largest bias, about 0.5 expressed in fractions, over Finland. In central and southern Europe the bias is close to zero or slightly negative. The negative T_{2m} bias in Scandinavia coincides with the positive cloud cover bias. This feature has been seen also in previous operational HIRLAM systems at FMI. The problem was very serious in spring 2000 and 2001 with the largest T_{2m} forecast errors being as much as -15 ... -20°C. Introduction of the ISBA surface scheme was expected to almost remove the negative T_{2m} bias as the test runs prior acceptance into the HIRLAM reference system suggested (Järvenoja, 2002a, 2002b).

Figure 7 shows the T_{2m} bias at 00 UTC for April 2004. The nighttime bias much resembles that of the daytime, but some differences can be seen in Finland and in Russia east of Finland around 60°N. The negative daytime bias is replaced by a positive nighttime bias. This means that the diurnal cycle in the predicted T_{2m} is damped, which is an indication of excessive cloud amount and is in agreement with the positive cloud cover bias in Fig. 6.

Figure 8 demonstrates the T_{2m} bias as a function of the observed T_{2m} in 36 h forecasts valid at 12 UTC, for April 2004 in Scandinavia and northern Russia. There is a very narrow temperature interval, from -2°C to +2°C, where the T_{2m} bias is close to zero. At temperatures below -2°C, a winter-type positive bias appears, with the bias reaching +4°C at the observed temperature of -10°C. At temperatures above +2°C, a negative T_{2m} bias is present, reaching -2°C at the observed temperature of +8°C, and is then about -3°C at temperatures above +10°C. This is in agreement with the values seen in the T_{2m} bias map of Fig. 5.

The negative springtime T_{2m} bias problem is prominent (and annoying) in Finland. Versatile measurements carried out at Sodankylä observatory (67°22' N, 26°37' E) provide data that can be used for studying and understanding model problems, such as the T_{2m} bias problem.

Figure 9 shows the predicted hourly T_{2m} (upper panel) and RH_{2m} (relative 2-metre humidity, lower panel) values together with the corresponding observed values at Sodankylä for the period 12 April 00 UTC to 15 April 00 UTC, 2004. Observed values are indicated with solid lines and model predicted values from several cycles, starting at 00 and 12 UTC with dotted lines. Figure 9 (upper panel) clearly shows the nature of the T_{2m} problem. There is under-prediction of 3-4°C during the daytime and over-prediction of 6-7°C at night, which result in a hugely damped diurnal cycle in the predicted T_{2m}. The behaviour of the predicted RH_{2m} is very dubious: RH_{2m} stays between 90 and 100% all the time, while there is clear diurnal cycle in the observed RH_{2m}, with 90% at night and 40% during the daytime.

Explanation for the T_{2m} and RH_{2m} problem can be found in Fig. 10, which shows the model fluxes of global radiation (upper panel), latent heat (LH, middle) and sensible heat (SH, lower) together with corresponding measured fluxes at Sodankylä for the period 12 to 15 April 2004. The model and observed global radiation fluxes (upper panel) are in a rather good agreement, with the model values being only slightly smaller during the daytime. A clear model problem can be seen in the LH flux (middle). The model overestimates the LH flux by several times, with the model flux being about 200 W/m^2 during the daytime while the observed LH flux is only 50 W/m^2 at maximum. It is obvious that the high low-level humidity (RH_{2m} in Fig. 9) and the overestimated cloud cover are generated by excessive evaporation (i.e., LH flux). A reversed problem can be seen in the SH flux. The model underestimates the SH flux, with the model flux being only 50 W/m^2, while the measured flux exceeds 200 W/m^2.

Behaviour of the LH and SH fluxes clearly reveals a model problem: the net radiative flux at the surface is incorrectly partitioned between LH and SH fluxes. There is work going on at the moment to reduce the excessive springtime evaporation in northern latitudes. Evaporation in spring (April) is rather small in Nordic latitudes because soil is still frozen, snow can be still present, there is no or very little grass on the ground and there are no leaves on the deciduous trees yet. An *ad hoc* modification to reduce the springtime evaporation by a factor of 1/3 was done in the FMI operational HIRLAM (4.6.2 version) in spring 2001, and that clearly improved the predicted T_{2m}.

2.3 Summer

The T_{2m} bias in the RCR system was very serious in summer 2004. The month of July is shown as an example (other months show a similar problem) and Fig. 11 demonstrates the T_{2m} bias on station basis in 48 h forecasts valid at 12 UTC. A negative bias of several degrees dominates over almost the whole model domain, except in Spain. This type of problem has not been seen in the operational HIRLAM implementations before (since introduction of observation verification in 1995).

The reason for the negative summertime T_{2m} bias cannot be found in the cloud cover bias, which is small and mainly negative in large parts of the model domain (not shown). The winter and spring T_{2m} bias could be related to the cloud cover bias, but not the summer T_{2m} bias. Therefore, one could think that the parameter "total cloud cover" represents a different thing in winter/spring and in summer. In summer, most of the clouds are of convective origin, whereas in winter/spring the clouds are mainly of stratiform type.

Figure 12 shows the T_{2m} bias dependence on the observed T_{2m}. It can be seen that the predicted T_{2m} is practically unbiased only in a narrow temperature interval around 10°C. At temperatures above 15°C the negative T_{2m} bias linearly grows and reaches -5°C at 30°C. The daytime temperature in July in southern Finland (60°N) is normally about 21-22°C, which would mean a bias of about -3°C according to Fig. 12. This agrees well with the values shown in the geographical bias map in Fig. 11.

The basic reason for the negative summertime T_{2m} bias is not yet known. In preparation for the HIRLAM release 6.3.4, a group of HIRLAM scientists developed a set of model updates on top of version 6.3.3. These include modifications e.g., for turbulence (CBR) and for roughness length of heat and momentum. In addition, some code cleaning was done. Other differences compared to the RCR system (6.2.1) are e.g., the ESAT modification mentioned in connection with the C62 experiment (winter problem section), and radiation modifications of 6.2.4. This unofficial correction set was called "a First Aid Kit" (FAK), and it was tested for July 2004.

Figure 13 demonstrates the T_{2m} bias on station basis in 48 h FAK forecasts valid at 12 UTC, for July 2004. There is a remarkable difference between the FAK bias values and those of the operational RCR (Fig. 11). There is some negative bias left in southern Europe in the FAK forecasts and some positive bias is introduced in northern America. Bias is small elsewhere, with both positive and negative values present. In general, bias reduction compared to the RCR bias is prominent.

Finally, Fig. 14 shows the systematic difference in the total cloud cover between 48 h FAK and RCR (FAK-RCR) forecasts valid at 12 UTC, for July 2004. The cloud cover is smaller in FAK forecasts over almost the whole model domain, generally by 0.1-0.2 (expressed in fractions). This feature supports the higher T_{2m} values in FAK compared to those in RCR.

3 Summary

Bias problems in predicted HIRLAM T_{2m} in different seasons have been presented. A positive bias of several degrees dominates in high latitudes in winter. Bias is dependent on the observed temperature so that the largest bias values appear at low temperatures with inversions. Thus the problem is much related to the stable boundary layer. Also cloudiness plays some role. Introduction of modified ESAT tables helped to reduce the positive bias to some extent through a lesser cloud cover.

A negative daytime T_{2m} bias appears in high latitudes (e.g., Scandinavia) in spring, while a positive bias is seen at night at least in some areas (like Sodankylä). The diurnal cycle in the predicted T_{2m} is thus much damped. The reason for this kind of bias structure is due to surface fluxes: model overestimates the LH flux and underestimates the SH flux. The excessive evaporation results in too large cloud cover and too moist surface layer.

A negative T_{2m} bias dominates over almost the whole model domain in summer, both in the daytime and at night. This kind of problem has not been encountered before. The reason for the problem is not yet known, and further investigations might be therefore needed. The FAK modifications, however, seemed to help in the summer case.

References

Järvenoja, S., 2002a: ISBA tests in a Nordic area. Proceedings of the SRNWP/HIRLAM Workshop on Surface Processes, Turbulence and Mountain Effects, INM, Madrid 22-24 October 2001, 64-74.

Järvenoja, S., 2002b: ISBA tests in a Nordic area - an update *HIRLAM Newsletter*, **41**, 63-73.

Järvenoja, S., 2004: Towards the operational RCR system - results from pre-operational runs. *HIRLAM Newsletter*, **45**, 48-62.

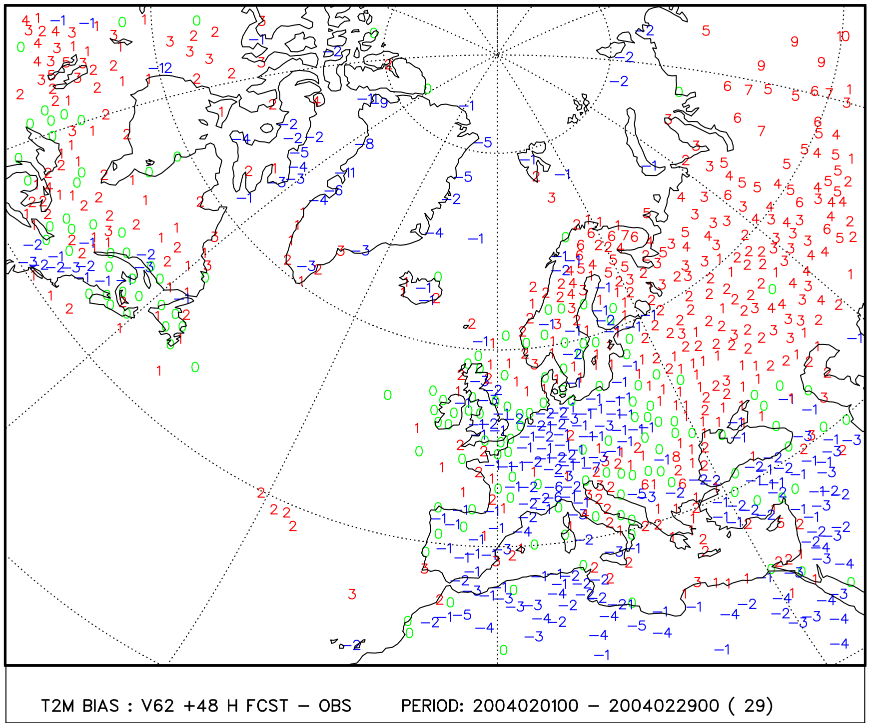

Figure 1: *T_{2m} bias (calculated against observations) in 48 h RCR forecasts valid at 00 UTC, for February 2004.*

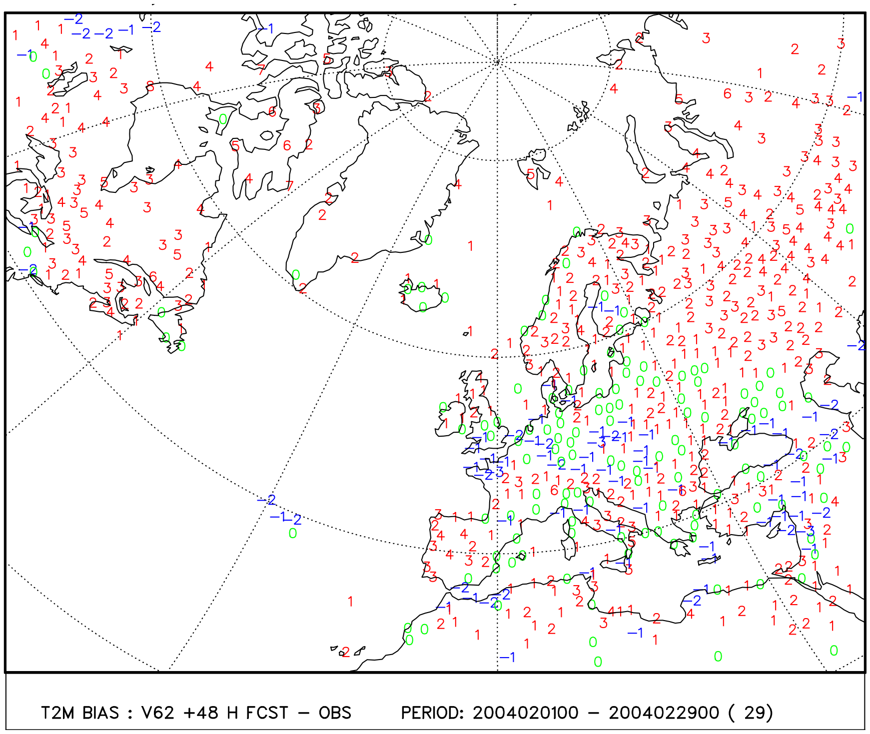

Figure 2: *Cloud cover bias (calculated against observations) in 48 h RCR forecasts valid at 00 UTC, for February 2004. Unit: fraction × 10.*

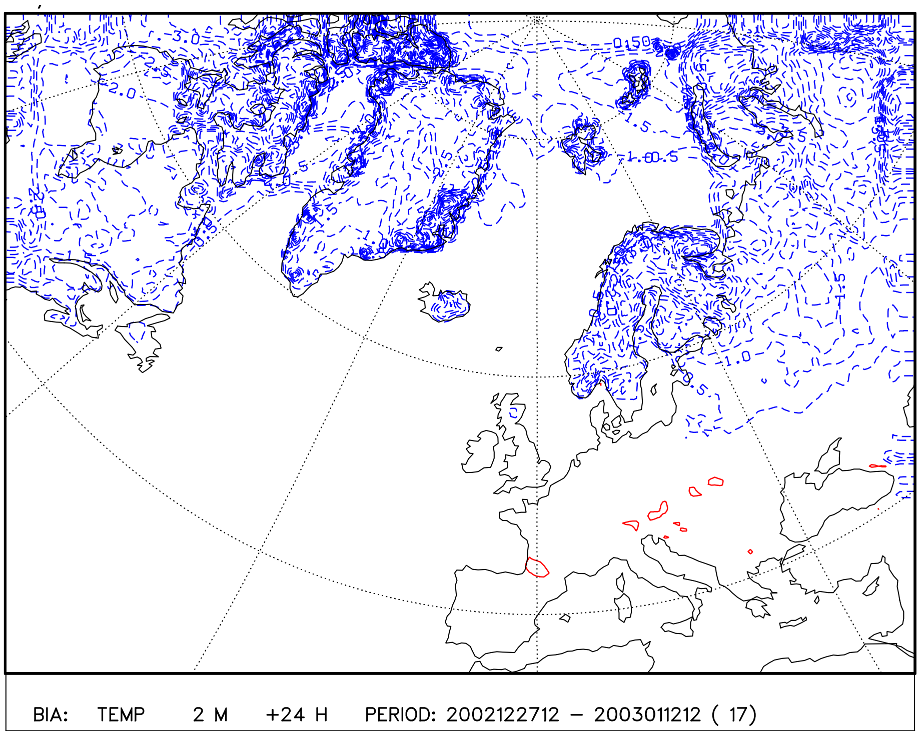

Figure 3: *Systematic difference in T_{2m} between C62 and R62 24 h forecasts for the period 26 December 2002 to 11 January 2003. Contour interval: 0.5° C. The zero isoline not plotted, negative values indicated with dashed lines.*

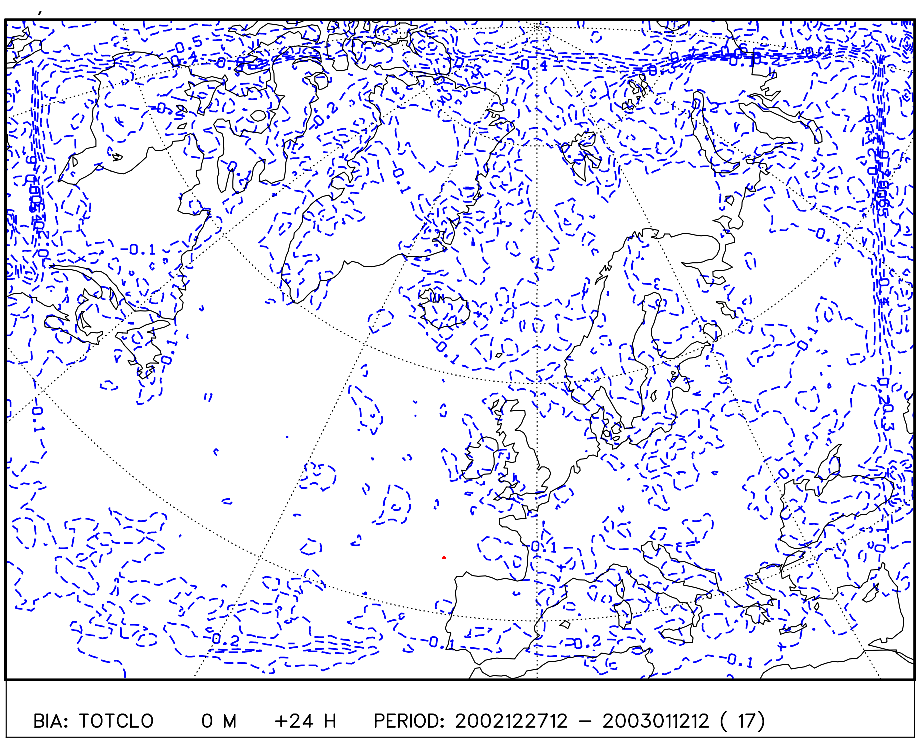

Figure 4: *Systematic difference in total cloud cover between C62 and R62 24 h forecasts for the period 26 December 2002 to 11 January 2003. Unit: fraction; contour interval: 0.1. The zero isoline not plotted, negative values indicated with dashed lines.*

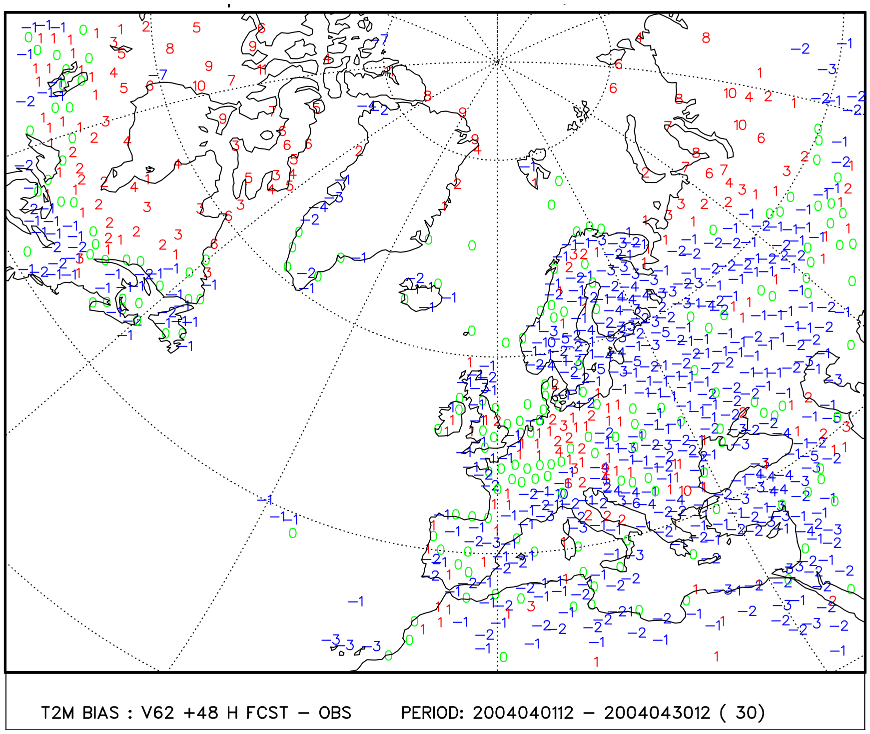

Figure 5: *T_{2m} bias (calculated against observations) in 48 h RCR forecasts valid at 12 UTC, for April 2004.*

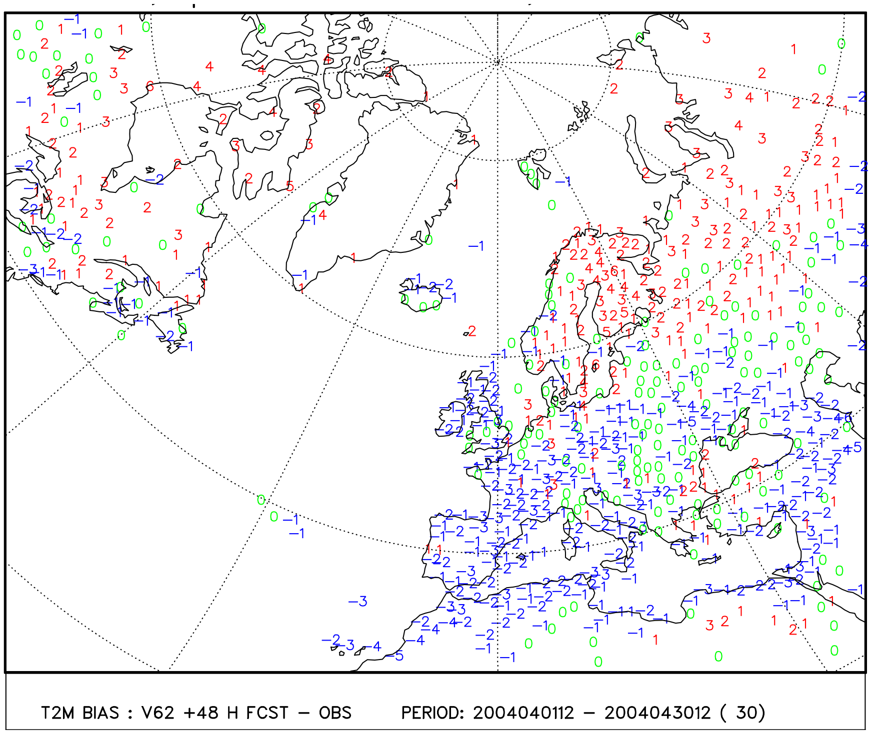

Figure 6: *Cloud cover bias (calculated against observations) in 48 h RCR forecasts valid at 12 UTC, for April 2004. Unit: fraction × 10.*

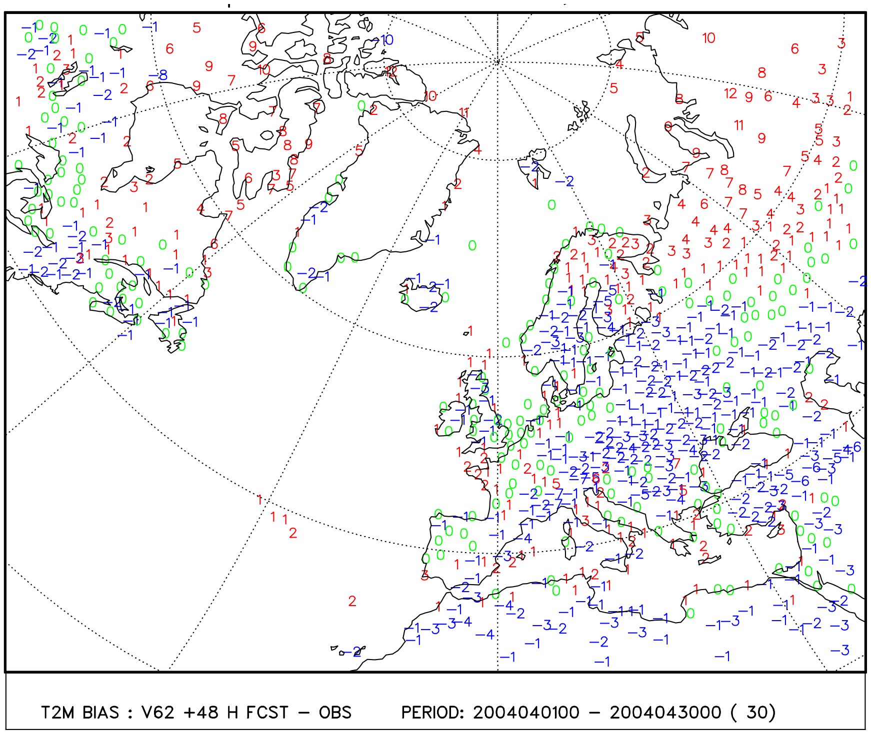

Figure 7: *T_{2m} bias (calculated against observations) in 48 h RCR forecasts valid at 00 UTC, for April 2004.*

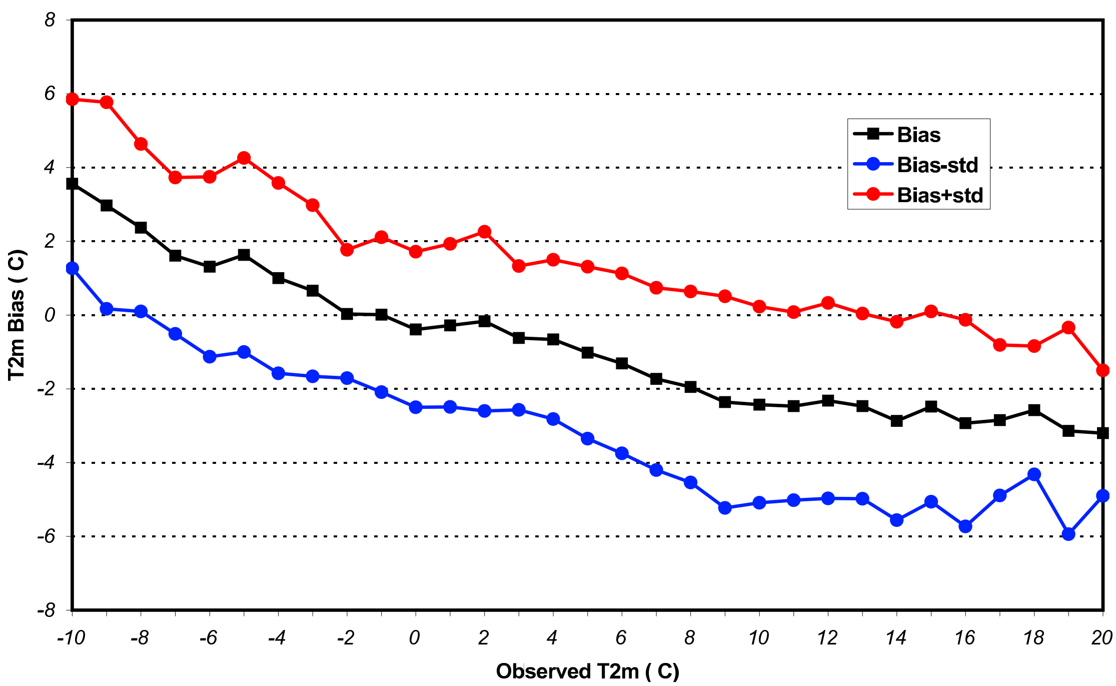

Figure 8: *T_{2m} bias in HIRLAM RCR 36 h forecasts valid at 12 UTC, as a function of the observed T_{2m}, for April 2004 in Scandinavia and northern Russia. Bias is indicated with squares, and bias ± one standard deviation with circles.*

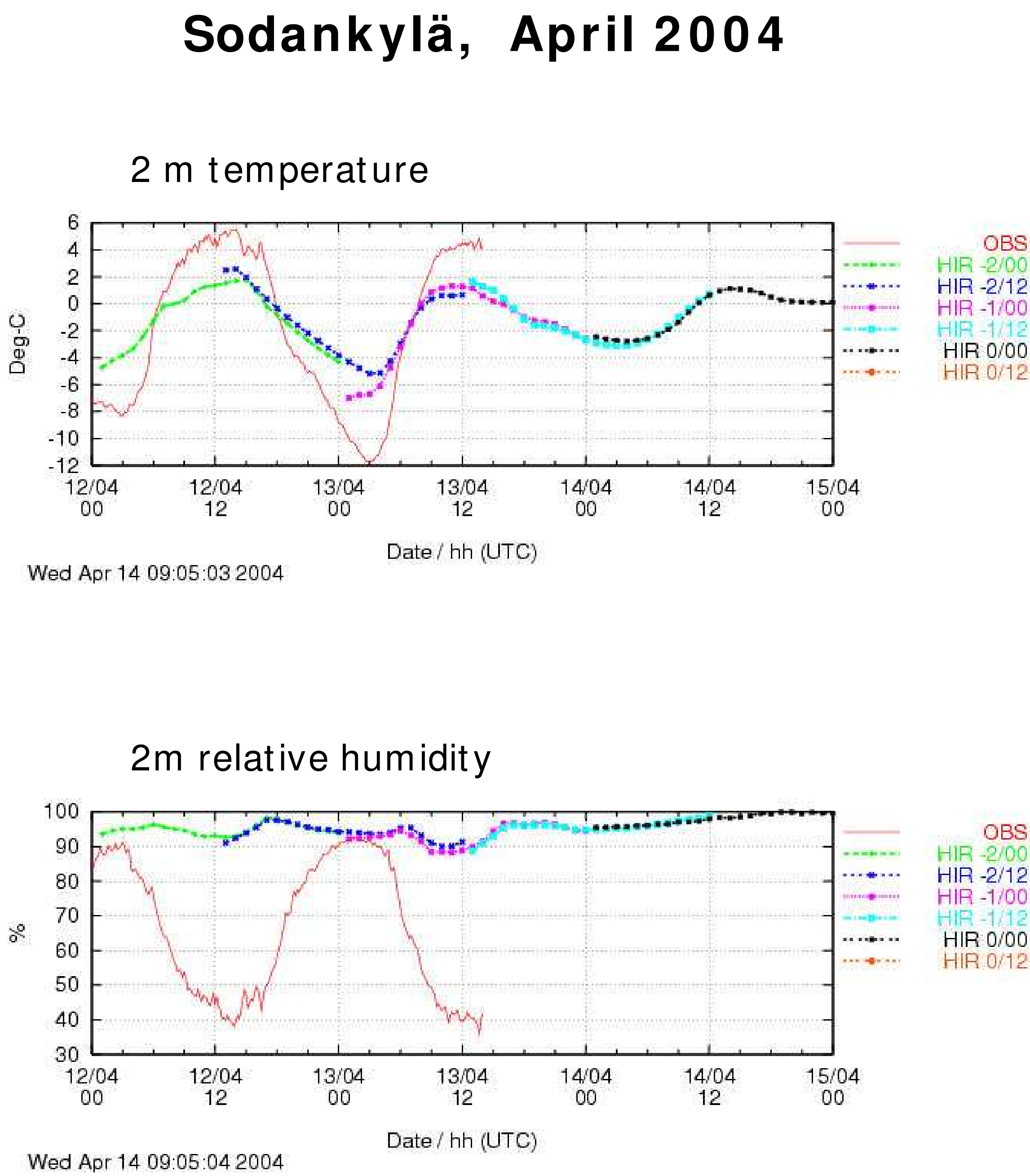

Figure 9: *Comparison of predicted HIRLAM T_{2m} (upper panel) and RH_{2m} (lower panel) against observations at Sodankylä for the period 12-15 April 2004. Solid lines indicate observed values. Dotted lines represent predicted values from different HIRLAM assimilation cycles, starting from 00 and 12 UTC.*

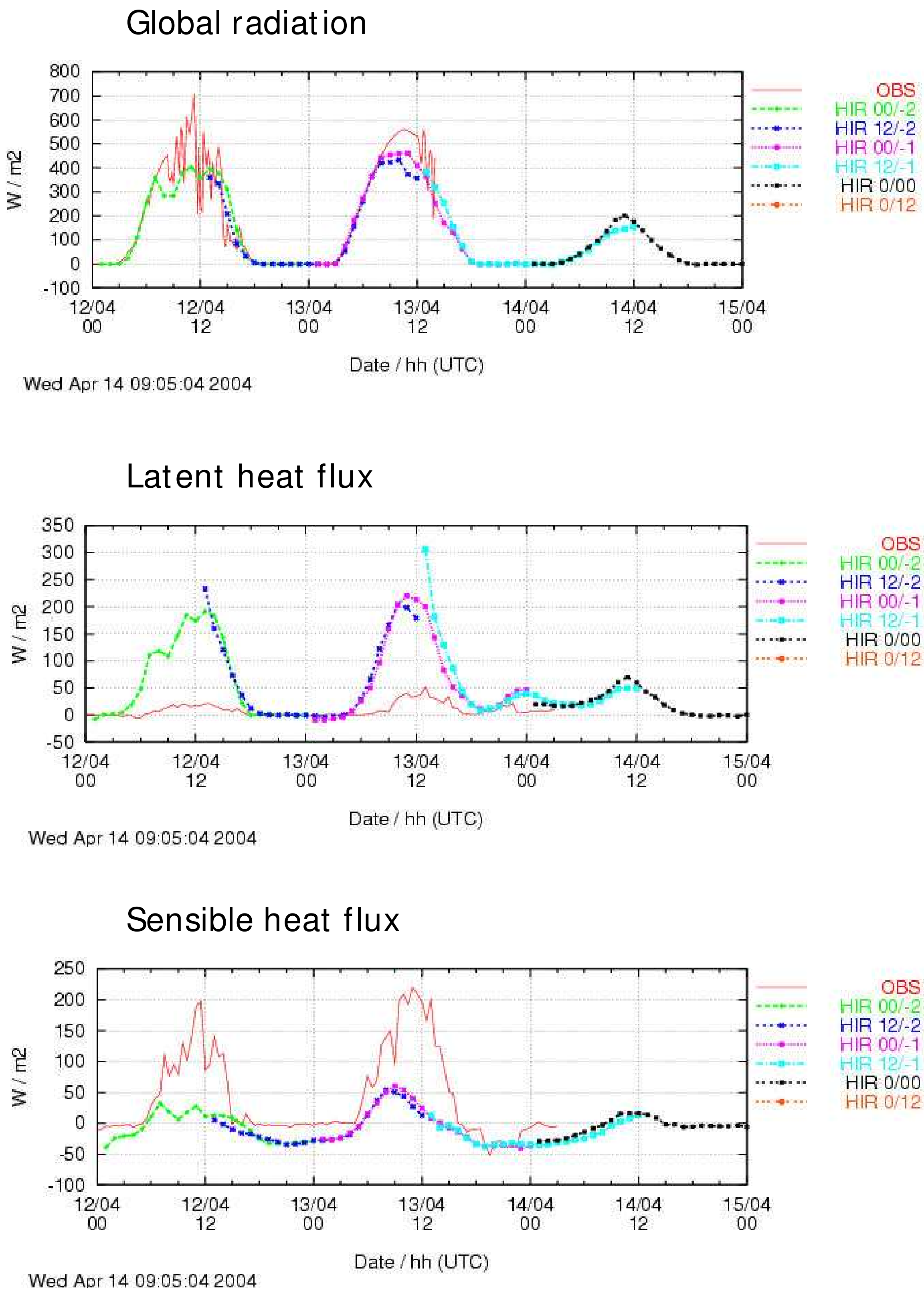

Figure 10: *Comparison of model fluxes of global radiation (upper panel), latent heat (middle panel) and sensible heat (lower panel) against Sodankylä mast measurements for the period 12-15 April 2004. Solid lines indicate measured values. Dotted lines represent predicted values from different HIRLAM assimilation cycles, starting from 00 and 12 UTC.*

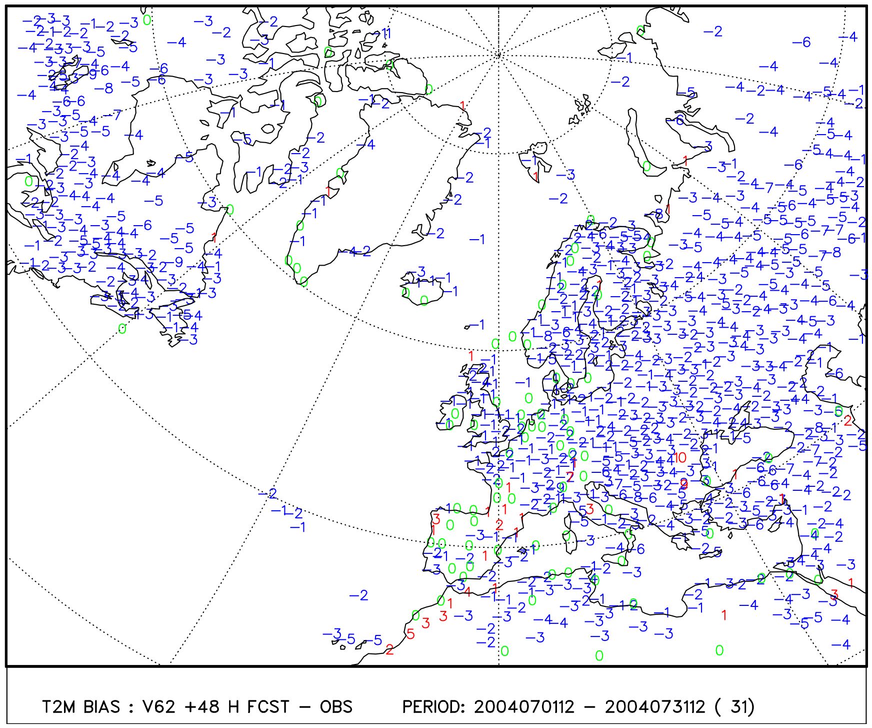

Figure 11: *T_{2m} bias (calculated against observations) in 48 h RCR forecasts valid at 12 UTC, for July 2004.*

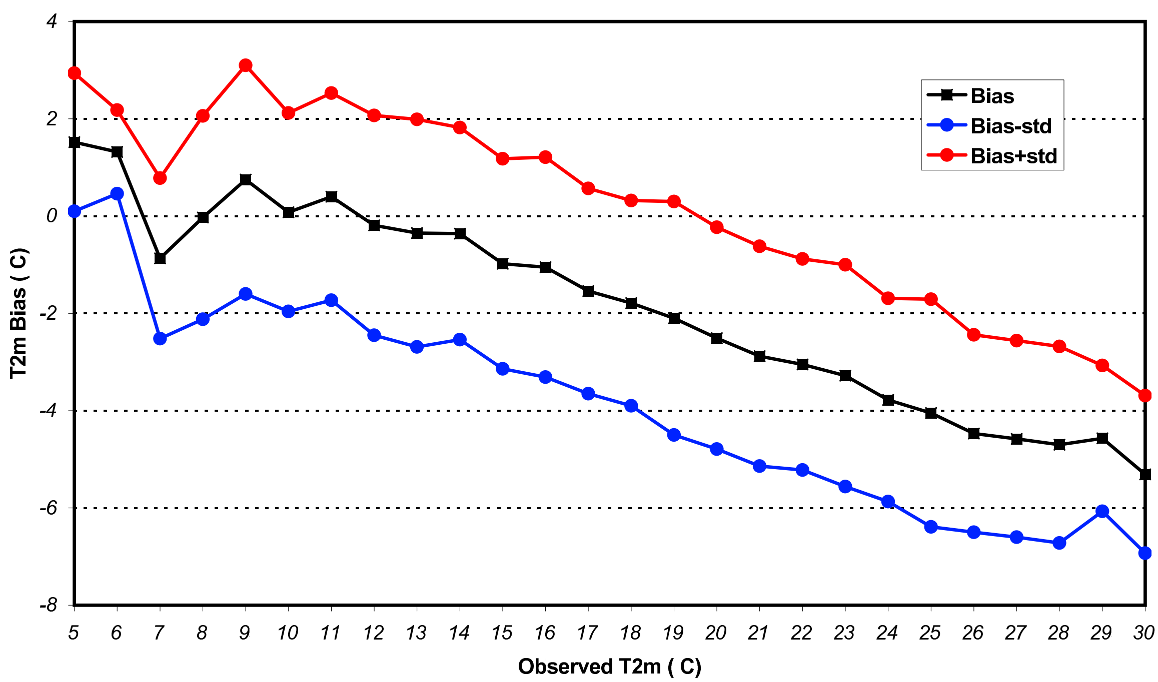

Figure 12: *T_{2m} bias in HIRLAM RCR 36 h forecasts valid at 12 UTC, as a function of the observed T_{2m}, for July 2004 in Scandinavia and northern Russia. Bias is indicated with squares, and bias ± one standard deviation with circles.*

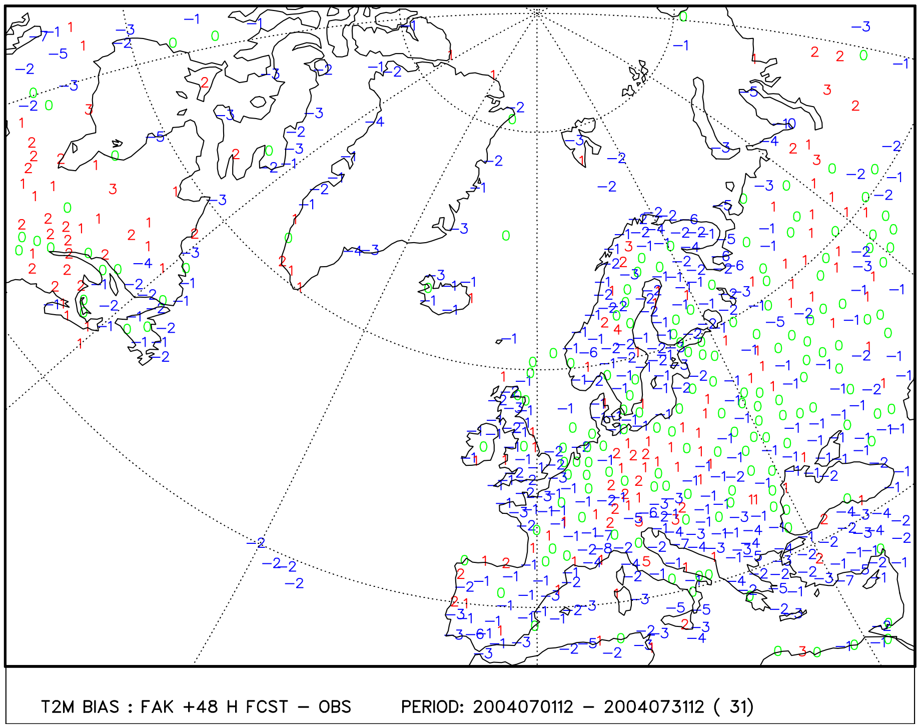

Figure 13: *T_{2m} bias (calculated against observations) in 48 h experimental FAK forecasts valid at 12 UTC, for July 2004.*

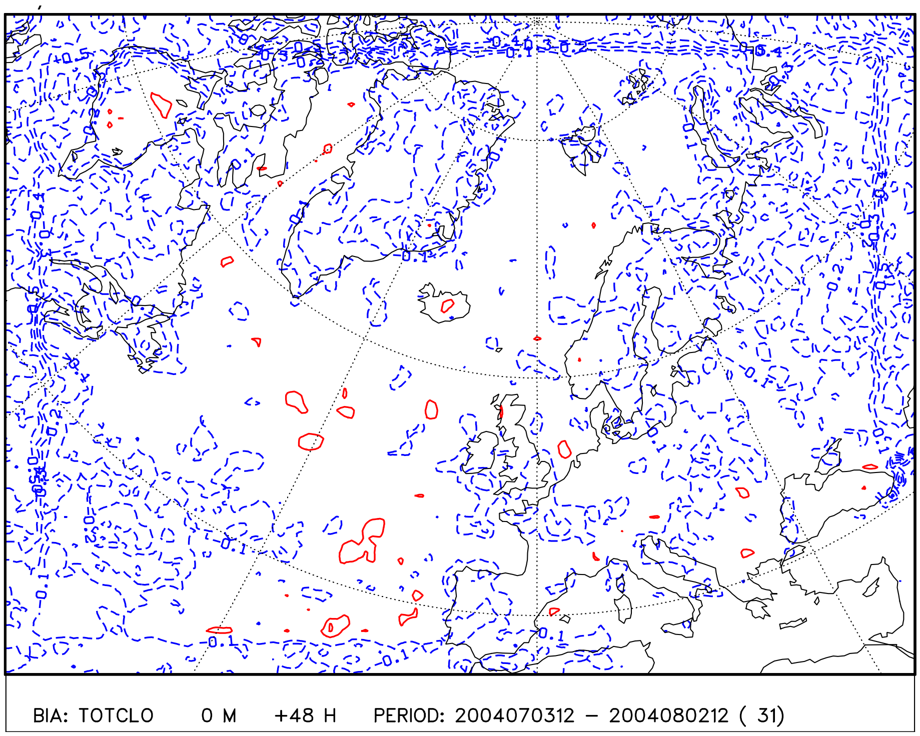

Figure 14: *Systematic difference in total cloud cover between FAK and RCR (RCR interpolated into the FAK grid) 48 h forecasts valid at 12 UTC, for July 2004. Unit: fraction; contour interval: 0.1. The zero isoline not plotted, negative values indicated with dashed lines.*