HIRLAM T2m problems

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1 Introduction

The HIRLAM T2m has been a problem in winter for quite some time. January 2001 again showed a period where the KNMI HIRLAM performed poorly with respect to the T2m. This period led to the formation of a task force at KNMI that tried to tackle the problem of the T2m in HIRLAM.

To resolve the T2m problem we followed two different roads. First we tried to reproduce the temperature problem at ECMWF with the current reference HIRLAM. After this reproduction of the problem we wanted to try different possible solutions (adjusting the evaporation in winter, turbulence scheme, climate package, etc.). However, the reproduction of the error at ECMWF proved to be more difficult than expected, causing us to perform additional experiments with different HIRLAM versions.

In the second approach, which we called the quick fix, we adjusted the distribution of the available energy between the sensible and latent heating in favour of the sensible heating. For the testing of this adjustment we set up two parallel experiments on a high resolution (11 km). This adjustment has been tested for the month of February 2001.

January 2001 was an average winter month in the Netherlands. The second decade was colder than average with temperatures below 0° on most days. The problems in HIRLAM started to show up on January 11 (see figure 1), a clear day (in the observations, but not in the model). The model showed the known problem of erroneous clouds at model level 30, which made the erroneous drop in temperature even stranger.

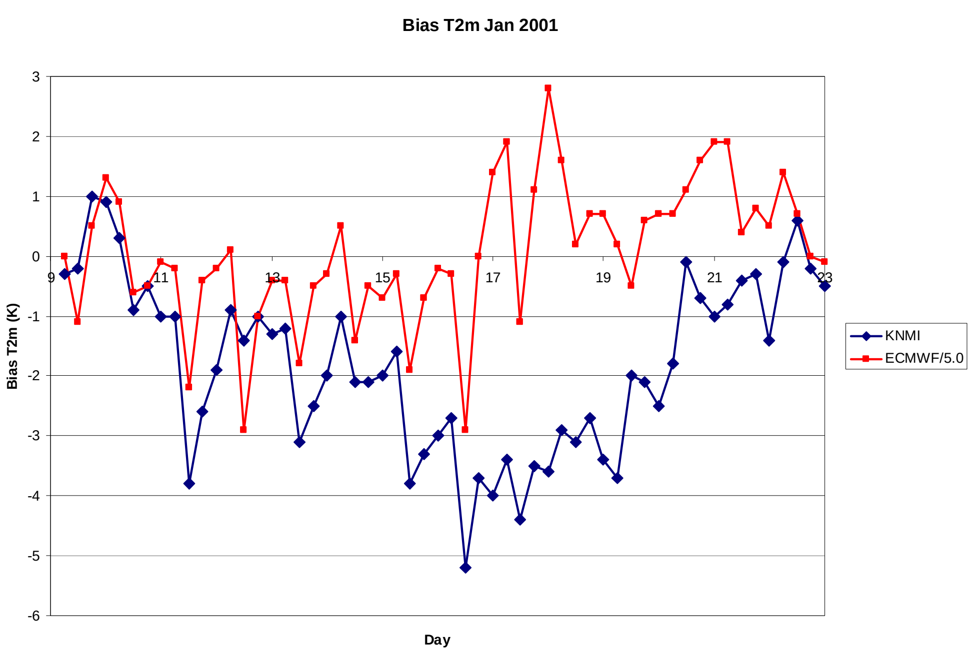

Figure 1: *The bias in T2m in the KNMI HIRLAM run and a rerun with HIRLAM version 5.0. This verification was made against the Nt+ stations (Netherlands and surroundings).*

After January 11, the temperature bias first decreased but around January 15, the bias again increased and stayed large (-3°C or lower) until January 19. At some stage the temperature bias was larger than 10° in some places, making HIRLAM incredible for the forecasters.

2 Experiments with different HIRLAM versions

To enable us to tackle the problem with the large T2m bias we first tried to reproduce the large bias with HIRLAM at ECMWF. As a beta version of mini-SMS became available around the time we performed these experiments, we ran an experiment with HIRLAM version 5.0 under mini-SMS. Figure 1 shows that the negative bias does not show up in this experiment. So somewhere between version 4.3.4 and version 5.0 something has changed that prevents the temperature from dropping far below the observed values.

Experiments with HIRLAM version 5.0 with changes in physics (Holtslag vertical diffusion instead of CBR, old RADIA instead of new version) did not reproduce the large negative bias. Also DFI could not be the problem as HIRLAM version 4.3.4 (NMI) as well as the experimental 11 km XHIRLAM (version 4.6.3, with DFI) both showed the negative bias. The bias was slightly smaller in XHIRLAM.

To reproduce the negative temperature bias we therefore had to leave mini-SMS (only supports versions higher than 4.9.1) and HIRLAM version 5.0 and move back to HIRLAM 4.6.3. The model runs at ECMWF with this version showed a T2m bias very similar to the KNMI bias in figure 1. Version 4.8.0 also showed a large negative bias that was only marginally smaller than the bias in version 4.6.3. The largest differences therefore occurred between the runs with HIRLAM 4.8 and 5.0 (which in fact is equal to version 4.9.1). The solution to this particular problem therefore is one of the changes in the HIRLAM system between versions 4.8 and 4.9.1.

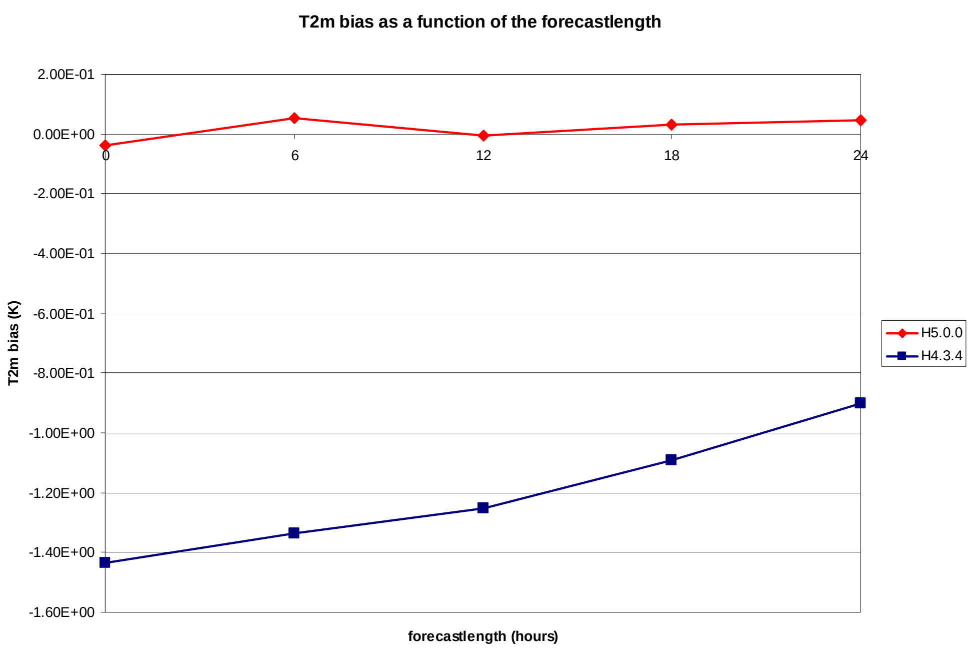

Figure 2: *The bias in T2m in the KNMI HIRLAM run and a rerun with HIRLAM version 5.0 as a function of forecastlength. This verification was made against the Nt+ stations (Netherlands and surroundings).*

A clue to the change that caused the reproduction problem (and at least a partial solution to the T2m problem) can be found in figure 2. This figure shows the bias as a function of the forecastlength in the KNMI HIRLAM run and the experiment at ECMWF with version 5.0. The negative bias in T2m is decreasing with increasing forecastlength at KNMI while the bias stays close to zero in the ECMWF run. This means that the T2m is lower at a certain time in each subsequent forecast than at the same verification time in the previous forecast. The error therefore does not grow with increasing forecast time, but rather with additional analysis/initialization.

The main change between version 4.8.0 (that still showed the problem) and version 5.0 is the adjusted initialization of cloud water. It probably is this change that can explain the behaviour of the different HIRLAM versions. In the versions before 4.9.1 the cloud water showed a spinup problem. After the first time step a large part of the cloud water was lost and the cloud cover reduced considerably with this loss of cloud water. After a couple of hours (1-3) the cloud cover usually was at the same level as before the analysis and initialization. The reduced cloud cover in the hours just after the initialization causes the surface to lose heat due to the negative longwave radiation balance, causing the increasing negative bias in the KNMI run. However, the increasing negative bias can also be found during the day time when the radiation balance is dominated by the shortwave radiation and is positive. How can this be in keeping with the decreasing cloud cover? This effect probably is caused by the evaporation of the moisture that 'rains' out in the first time step. This evaporation reduces the energy available for sensible heating almost to zero. All energy is put into the evaporation and the air temperature does not increase.

3 Adjustment of the fluxes

The last comment of the previous section brings us to the second problem we found on a number of occasions during winter and spring. This problem is an excessive evaporation during fair weather, causing the surface to put too much energy in evaporation. This leaves very little energy for sensible heating which also causes a negative bias in T2m, especially around noon (also visible in the daily cycle in figure 1). Consequently, the boundary layer is too thin, cool and moist, which may be at least partly responsible for the formation of cloud water at the lowest model levels.

This problem surfaces mainly in winter and spring and may be caused by the conditions under which the parameterizations of the surface fluxes are derived. As these fluxes are largest in summer it is logical that the dependence of the evaporation on the level of soil moisture is derived from observations in this season. However, a large part of the evaporation is caused by the vegetation in this season. This vegetation is not active below certain temperatures and e.g. foilage trees cannot evaporate moisture in winter and early spring due to the absence of leaves that have fallen off in autumn. All these factors cause a different dependence of surface evaporation than currently incorporated in HIRLAM.

A second problem is the very thick first soil layer, causing the moisture buffer capacity to be large. As the evaporation is quite small in winter, it takes a long time to diminish the amount of soil moisture to a level that causes a reasonable balance between the latent and sensible heat fluxes. This first soil layer also does not include effects of surface drying due to the sinking of the water into the surface. This usually leaves the first few millimeters of the surface quite dry after a day without rain or fog, reducing the potential evaporation capacity of the surface. The third problem is the vertical diffusion of water in the soil. This must describe the transport of water through the soil by roots of plants and trees, but this transport does not take place in winter. Therefore it is erroneous in this season and should be shut off.

To overcome these problems we introduced a 'quick fix' into a parallel high resolution (11 km) HIRLAM run. This quick fix causes a small reduction in the available surface moisture below a temperature of about 10°. This reduction increases with decreasing temperature, taking the reduced activity of vegetation at low temperatures into account. As the evaporation capacity is a strongly non-linear function of the available surface moisture (to the power 8, probably to incorporate the large latent heat flux directly after a precipitation event) a small reduction leads to a large reduction in the evaporation capacity. Equation 1 is the equation that is used for the adjustment of the available soil moisture in SLFLUXO.f.

$$zwet = 0.01 + 0.5\left(1.8 + \frac{0.2(zts - 281)}{\sqrt{3 + (zts - 281)^2}}\right), \tag{1}$$

where zts is the surface temperature and $zwet$ the proportional factor we include in the evaporation capacity. For temperatures below 12°C this equation reduces the amount of soil moisture available for evaporation with a smooth function that reaches and stays at a minimum value of 0.8 below about 2°C. As the potential evaporation is a function of the available soil moisture to the power 8, the evaporation is reduced considerably for temperatures below 10°C. This 'quick fix' does not include the non linear effect of the relatively low leaf area index in spring (crops that are small or just have been sown, no leaves on trees) and will therefore still produce a too large evaporation in spring when temperatures reach above about 10°C. However if this effect has to be taken into account in a good and physical way it should not only depend on the temperature but also on the Leaf Area Index.

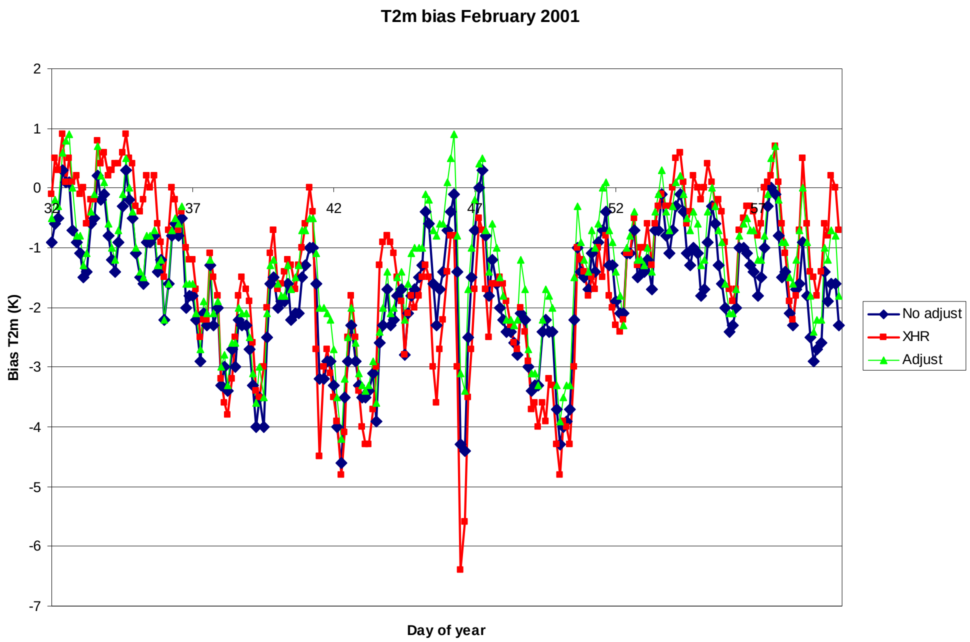

Figure 3: *The bias in T2m in the KNMI XHIRLAM run and two parallel high resolution runs. This verification was made against the Nt+ stations (Netherlands and surroundings).*

Figure 3 shows the results of the runs with high resolution (11 km) HIRLAMs version 4.3.4 without and with adjustment and version 4.6.3 (semi operational version) that also runs without the adjustment. The negative temperature bias clearly also occurred in February 2001. This bias again was larger than 3°C on a large number of days and the largest bias occurred in XHR (version 4.6.3, with DFI). This figure also shows that the negative bias is reduced by about 0.5°C on average due to the adjustment. The bias is not reduced more and increasing in time as the model domains are small and the advection of the operational HIRLAM temperature problems into the high resolution domain is large. Therefore this adjustment has to be tested in e.g. HIRLAM version 4.6.3 on a larger scale to see if it reduces the temperature problems, if this reduction in negative bias is sustained in the model and if the correction does not shoot through into a positive bias (overcorrection).

4 Conclusions

Experiments with different HIRLAM versions have shown us that one of the causes of the negative T2m bias is the spinup problem of cloud water. Consecutive forecasts show a increasing negative bias, caused by the reduction in cloud cover, the larger negative longwave radiation balance and problably also the too large evaporation of the cloud water that has rained out in the first time step. In HIRLAM 4.9.1 this problem is reduced considerably.

The quick fix that consisted of reducing the amount of soil moisture available for evaporation below a certain temperature reduced the negative bias by about 0.5° on average. This reduction was not larger due to the advection of too cold air from the operational HIRLAM at the boundaries.

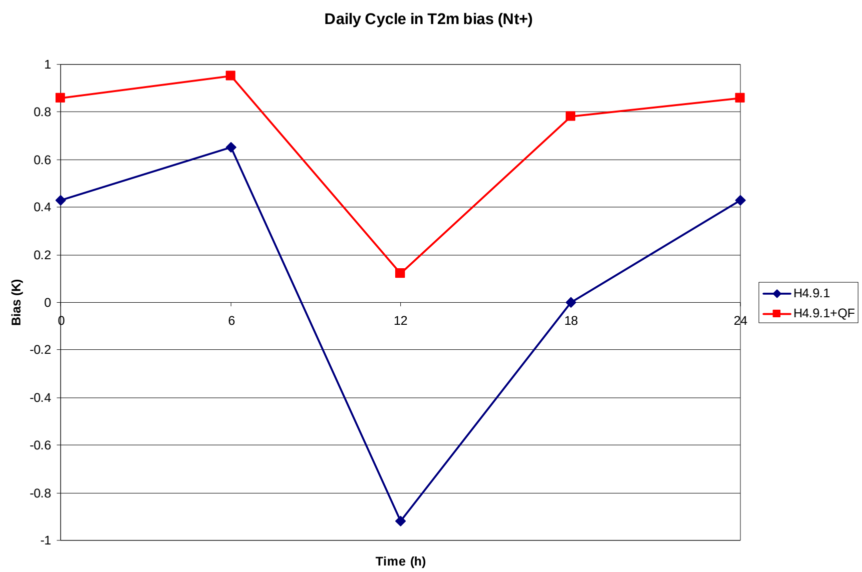

Figure 4: *The daily cycle of the bias in T2m in the ECMWF HIRLAM 4.9.1 run with and without the quick fix on the . This verification was made against the Nt+ stations (Netherlands and surroundings).*

HIRLAM version 5.0 does not have the large negative T2m bias anymore. However, we are still left with a daily cycle in the bias in winter. During the night it is positive on average while during the day-time it is negative. This problem is caused by the erroneous clouds at the lowest two model levels in combination with the too small sensible heat fluxes (too large evaporation) at low temperatures. The low clouds cause too little cooling during the night and too little warming during the day.

Further tests over a larger area have been carried out to see if the quick fix can reduce the T2m bias more when it is included in a larger domain. The results are presented above in figure 4. It clearly shows the reduction of the daily cycle in the bias from about 1.6°C in the reference 4.9.1 run to about 0.8°C in the run with the quick fix. However we also see that the average temperature is higher in the run with the quick fix, increasing the bias to about 0.6°C. A definite answer to the problem of the T2m bias and bias cycle probably cannot be given before the solution of the low cloud problem.