A polar night temperature problem over Greenland

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Introduction

During winter season 2007-2008 a severe negative surface temperature bias developed over parts of Greenland in the operational weather prediction models operated at the Danish Meteorological Institute. The problem occurred mainly in the southern and western parts of Greenland for periods of time extending from days to weeks. Other operational models such as the operational global model from the European Centre for Medium Range Weather Forecasts (ECMWF) also suffered from a negative bias in forecasted 2m temperatures for Greenland.

It is well known that accurate surface temperature prediction in polar regions is difficult during the polar night due to sparse observations to analyse. The lack of sunshine implies a risk for developing a wrong surface energy balance which may persist for long periods of time. As consequence there is a risk of building up a significant surface temperature bias.

A brief diagnosis of the problem seen in the HIRLAM models is given in section 2. Model changes which were successfully tested in parallel daily runs at DMI are described in section 3. The impact of the proposed changes is documented in section 4. Finally, a brief discussion and conclusions are provided in section 5.

Diagnosed problem for operational models covering Greenland

The operational models at DMI involving Greenland (see http://www.dmi.dk/eng/index/research and development/dmi-hirlam-2.htm) comprise a high resolution model named Q05 (0.05°, 40 vertical levels) and a lower resolution model named T15 (0.15°, 40 vertical levels) extending towards east to cover also the European continent. The current operational HIRLAM version (DMI-HIRLAM) contain a number of differences from the so-called reference HIRLAM system (RCR) operated at the Finnish Meteorological Institute.

As regarding physical parameterizations (surface scheme, turbulence, condensation, clouds and radiation) the differences are considered of relatively minor importance for the conclusions of the present study. This hypothesis is consistent with the fact that the RCR reference system suffered from the same problem as that seen in the DMI operational models.

The severe temperature bias which could be up to around 20° occurred in some valleys and fiords of the southern and western Greenland. The problem were clearly most pronounced in situations with a weak geostrophic wind. A radiosonde in southern Greenland indicated that the severe bias was mainly occurring at the surface and very close to it (e.g. at 2m height). Already at a height of the lowest model level (about 30 m) the temperature bias is much reduced. This is a strong indication that the surface energy balance has developed a wrong distribution of energy fluxes. Since the problem is mainly pronounced during periods with weak geostrophic winds and hence probably small
sensible- and latent heat fluxes it is to be expected that the radiative surface fluxes and ground heat fluxes are unrealistic. It has been confirmed that the special situation of an approximate 'pure radiative balance' occurred in some areas. This means that the ground heat flux became unimportant in the surface energy budget where the surface temperature adjusted to produce a Planck greybody radiation equal to the longwave downwelling radiation from the atmosphere. It is questionable whether such conditions occur in reality since ground conduction may be considered non-negligible in many situations.

The tentative conclusion is then made that the ground heat flux of the surface scheme (the ISBA scheme) is sometimes much too weak. One may speculate that the force-restore method used is not treating well the long time scales of the polar night, but is suited to describe better a diurnal cycle. A modification to improve on this likely deficiency is suggested in section 3.

A part of the problem with a 2m temperature bias might be linked to limitations in the diagnostic formulas to describe the 2m temperature in a very stable boundary layer. The current diagnostic formulas [Geleyn, 1988] approach linear profiles in these situations. In reality, at least for non-stationary conditions, the temperature profile between the surface and the lowest model layer may be non-linear as indicated in Fig.1. This figure illustrates that a linear profile might be an underestimation of the 2m temperature if radiative cooling is a dominating process for transient conditions. A tentative and revised formulation of 2m temperature which tends to avoid the linear profiles provided by the previous formula while respecting the original formula when approaching neutral conditions are given in section 3.

Fig.2 indicates that during February 2008 the radiative input to the ground is far from constant in time. The figure shows observed versus modelled LW downward radiation at a position near the ice edge in the western part of Greenland. This non-stationarity in radiative fluxes must be expected due to varying advections aloft and due to associated varying cloudiness.

Fig.2 also indicates the presence of some deficiency of the radiation scheme since the best fit linear regression is not according to the ideal diagonal. This deficiency could be partly a result of a non-perfect cloud cover in the model. Provided that the measured downcoming longwave flux is reliable the figure indicates that the model underestimates downward longwave radiation at low temperatures by a magnitude of order 10 W/m² on average. The amount of underestimation obviously depends on the actual bias in cloud cover occurring during a given period. This underestimation of downward radiation flux seems to contribute the negative bias developing in the model.
The modified diagnostic equation is given by (4) and (5). It is noted that these equations are correctly reproducing the lowest model level temperature when the height \( z \) approaches \( z_n \). Also the original formulation is reproduced near neutral conditions.

3 Alleviation of the diagnosed problem

Based on the diagnosis of the previous section some formulas are described below. The new formulas have been suggested in order to alleviate the temperature bias problems.

Currently only the heat conduction in the ground and the diagnostic formulation of 2m-temperature have been treated. Possible corrections to the radiation scheme and/or cloud cover formulation have not yet been tested.

The modified treatment of surface temperature prediction is done via a modified prediction equation for the second (deep soil) temperature \( T_d \) of the surface scheme. The unmodified force-restore equation is given in (1) while the new formulation is written in (2)

\[
\frac{\partial T_d}{\partial t} = \frac{T_s - T_d}{\tau_s}
\]

\[
\frac{\partial T_d}{\partial t} = \frac{T_s - T_d}{\tau_s} + \frac{T_{clim} - T_d}{\tau_d}
\]

In (1) and (2) \( \tau_s \) and \( \tau_d \) are time scales of 24 hours and 120 hours respectively. \( T_s \) is the surface temperature, \( T_d \) is the deep soil temperature and \( T_{clim} \) is a climatic temperature which is available from the model’s climate generation system.

The original diagnostic temperature formula is given by (3)

\[
\theta(z) - \theta_s = (\theta_n - \theta_s) \cdot F_{int}(z/z_n, Ri)
\]

The modified diagnostic equation is given by (4) and (5). It is noted that these equations are correctly reproducing the lowest model level temperature when the height \( z \) approaches \( z_n \). Also the original formulation is reproduced near neutral conditions.

Figure 2: Observed versus modelled LW downward radiation in the RCR reference HIRLAM in January-February 2008 at a measuring position close to the ice edge in western Greenland
\[
\theta(z) - \theta_n = (\theta_n - \theta_s) \cdot (F_{\text{int}})_{\text{mod}} \tag{4}
\]

\[
(F_{\text{int}})_{\text{mod}} = F_{\text{int}} \cdot \left( 1 + \frac{R_i}{R_i + 1} \right)^\beta \frac{\psi}{F_{\text{int}}} - 1 \tag{5}
\]

where \( \beta = 1 \) and

\[
\psi = 0.5 \cdot \left( 1 + e^{-1 \exp\left(\frac{z}{z_n}\right)} \right)
\]

\( F_{\text{int}} \) is the original formula for obtaining 2m temperature [Geleyn, 1988] and \((F_{\text{int}})_{\text{mod}}\) is the modified interpolation formula. \( z \) is vertical height (m) and \( z_n \) is the height of the lowest model level.

### 4 Impact of proposed changes

The modifications to the surface scheme and to the 2m temperature diagnosis have been tested in daily runs during late winter and spring 2008 in both models Q05 (high resolution model) and T15 (3 times lower resolution). To be more precise the model Q05 was upgraded operationally already in February 2008 due to satisfactory results of preliminary tests.

In the present report the results for Greenland synoptic stations in February and April (bias and standard deviation) are shown for the operational model T15 (not upgraded) to be compared with a test version T1T with the described modifications. The figures (3 and 4) show that a clear improvement in bias and standard deviation occurs in T1T as a result of the modifications. The model change was introduced in T1T in mid February which is clearly visible in the relevant figure.

Interestingly the improvements do not entirely disappear in April (fig. 4) in spite of the test for European stations when there is a pronounced diurnal cycle in the flux solar radiation. Results for other months (not shown) are quite similar in behaviour.

Figure 3: Bias and standard deviation of 2m temperature for Greenland stations using operational model T15 on large area (blue curves) and a comparable test model T1T (red curves) in February and April 2008.
Interestingly the improvements do not entirely disappear in April (fig.4) in spite of the test for European stations when there is a pronounced diurnal cycle in the flux solar radiation. Results for other months (not shown) are quite similar in behaviour.

5 Discussion and conclusions

The diagnosed severe temperature bias over parts of Greenland for extensive periods during winter 2007-08 required modifications to be implemented in the operational HIRLAM system at DMI.

It remains to be understood why the surface analysis scheme does not do a better job to prevent the development of such bias. It is desirable to improve the surface analysis procedure to be more robust in the sense that developments of a pronounced temperature bias is avoided.

The temperature bias in the eastern part of Greenland was on the average much smaller than the level mentioned in the present report. Presumably stronger winds associated with stronger pressure gradients and possibly more cloudy skies are valid explanations to this behaviour.

Although the modifications in the surface scheme and in the formula for diagnosing 2m temperature are preliminary, and more testing, tuning and further refinements could be done, the results presented here indicate that both bias and standard deviation are improved in the operational HIRLAM models used at DMI. It is relevant to notice the verification results for EWGLAM stations in April 2008 which indicate that the diurnal cycle over Europe has not been degraded by the proposed changes.

The indication that the model longwave downwelling radiation is underestimated at very low temperatures gives a hint that a modification of the radiation scheme alleviating this problem is worthwhile pursuing. This idea is supported by the fact that 2m temperature still has some remaining negative bias on average after the proposed modifications currently tested. At the same time the role of cloud, e.g. a possible underprediction, should be investigated. Due to the sparse traditional observations in the polar regions it seems quite vital in the future to make optimal use of existing operational satellite data in order to analyse temperature, humidity and cloud cover as input to the model since this will be a key source for reducing errors in radiative input to the surface energy balance.
References

Acknowledgments
Thanks to Sander Tijm (KNMI) for contributing with radiation measurements and corresponding results for the reference HIRLAM version (RCR).