IOMASA deliverable 2.4
Impact of Humidity Assimilation in the Arctic

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1 Introduction

The IOMASA work at SMHI has concerned data assimilation of remote sensing data as well the use of sea ice cover in the HIRLAM boundary layer scheme, both over the Arctic region. The data assimilation work has been focused on humidity information from AMSU-B, a microwave sensor at 183 GHz.

Humidity information is given through a retrieval of Total Water Vapor, TWV. The goal has been to compare the assimilation of the TWV retrieval and to assimilate the radiances directly. If direct assimilation is to be utilized, several very difficult problems must be solved. During the course of this work we have worked with direct assimilation of AMSU-B radiances over sea and taken the experiences from that work as an outline for how it should be done over ice. This report is on the impact of TWV retrieval assimilation.

2 Experiment Setup

The model domain used for the assimilation experiment is shown i figure 1. It is a grid-point model with a horizontal resolution of 33km and 40 levels in the vertical with the model top at 10hPa. Our experiment is based on the same version of the HIRLAM code that is presently used for operational forecasting at SMHI, version 6.3.5. The general features of the forecast model is:

- Semi-Lagrangian semi-implicit time-stepping.
- Rasch-Kristjansson scheme for stratiform condensation.
- Kain-Fritsch scheme for convective processes.
- Turbulence scheme is CBR
- ISBA, a surface analysis and physics scheme.

In the experiments we have used a 6 hour assimilation cycle and the model is integrated up to +48 hours. The analysis is a 3 dimensional variational scheme, 3DVAR, with a ± 3 hour observation window. Observations are divided into hourly slots and compared to a first guess field valid at the appropriate time. That is, for a ± 3 hour observation window, 6 first guess fields are used. This technique is called FGAT, First Guess at the Appropriate Time.

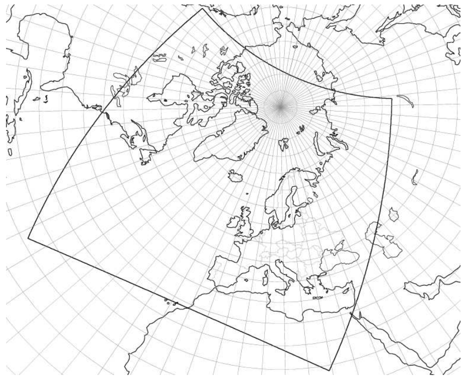

Figure 1: *The HIRLAM domain used for the experiments*

The period chosen for the experiment is January 2005 and we ran the model through the whole month two times:

Experiment name	Conventional observations	ATOVS data	TWV retrievals
REF	Yes	Yes, AMSU-A over sea	No
EXP	Yes	Yes, AMSU-A over sea	Yes

From here on, the experiments will be referred to as REF and EXP.

3 Impact Study

How the TWV observations are distributed to SMHI and preprocessed is already described in IOMASA deliverable 2.3, so that will be skipped in this report.

First of all, it is interesting to see what the $(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$ departures looked like for January 2005. $\mathbf{y}$ is the observation, $\mathbf{x}_b$ the NWP model first guess and $\mathbf{H}$ is RTTOV7. A large sample of $(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$ deparures should ideally have a Gussian distribution. The statistics in figure 2 shows no disturbing features, in fact it looks very Gaussian which is just what we want.

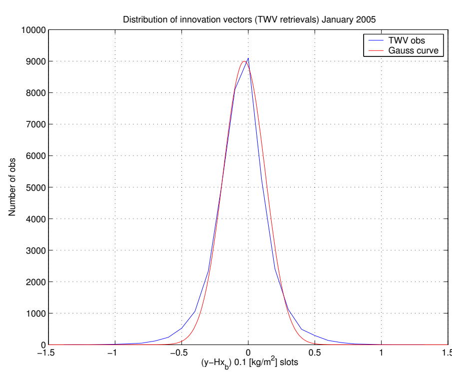

Figure 2: *Distribution of* $(\boldsymbol{y} - \boldsymbol{Hx}_b)$ *statistics for January 2005*

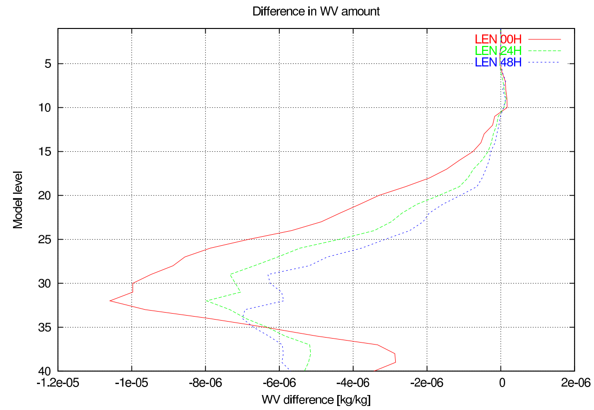

Figure 3: *Mean difference between REF and EXP (wv amount) for three different forecast lengths*

3.1 Model Impact

Before comparing the results with observations we will first study the effects in the model, i.e the differences between REF and EXP. To do that, monthly mean fields have been calculated and compared between the experiments. Since it is moisture data that has been assimilated we first look at the effect on the moisture field. Figure 3 shows water vapor profiles, the mean difference between REF and EXP, for three forecast lengths; +00, +24H and +48H. It shows that the difference is generally larger for short forecast lengths. It also shows that we have the biggest difference at model level 30, which is around 850hPa. The curves are also negative which indicates that the WV observations has generally increased the water vapor amount in the model (the curves show REF-EXP).

In figure 5 (appendix) the WV difference is plotted as a map. The changes in the model are concentrated around the Arctic area, the new information has not spread much to other parts of the domain. Other WV related fields are also plotted in the appendix, cloudiness in figure 6 and precipitation in figure 7. It seems like the increased WV amount has increased the cloudiness, whereas the precipitation has not changed much. The changes in the moisture field has also changed the 2m temperature.

3.2 Verification Against Observations

The standard verification package at SMHI uses a station list defined by EWGLAM, the European Working Group for Limited Area Models, the so-called EWGLAM list. Those stations are black in figure 4 and it is clear that they are not very suitable to verify against. Therefore, some stations in the Arctic region was chosen, the red dots in figure 4. *It should now be kept in mind that it is only 5 stations, which is very few, that the verifications are based on.*

First of all, the 2m temperature has a reduced bias and RMSE in EXP, figure 9. It seems like the MSLP and geopotential is a bit better as well. The

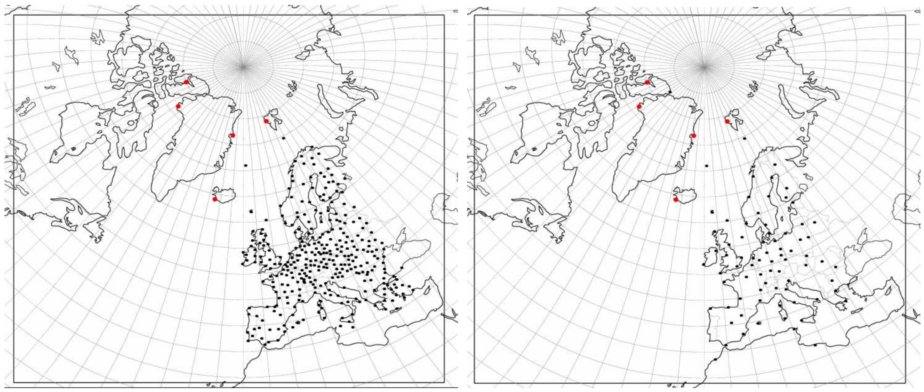

Figure 4: Stations used for verifications are shown in red. Black are the stations in the EWGLAM list. Left: synops. Right: temps

changes in cloudiness has probably given the temperature improvements that, in turn, has improved MSLP and geopotential.
As far as the cloud observations are concerned, it is even more risky to draw conclusions. This is because the experiment is run during the polar night and most of the observations are manual. The uncertainties in the moisture observations are also big when it is very cold. If we look at the 48h profiles of bias and RMSE in figure 9, it seems like EXP has a larger RH than REF (larger bias). That is consistent with the increased WV amount seen in e.g figure 3. It is however difficult to say whether is it is better or not.

3.3 Summary of Model Impact

Retrievals of Total Water Vapor, TWV, has been provided to SMHI from DTU, Danish Technical University, and was assimilated into the HIRLAM model analysis during January 2005. The main changes in the model remained in the Arctic region. The main conclusions, from looking at differences between the experiments and comparing against observations, were:

- The TWV retrievals increased the WV amount and cloudiness in the model.
- This, in turn, led to a warmer model which scored a bit better on temperature, MSLP and geopotential.

4 Discussion of Results

Are the results presented here an improvement? First of all, if we look again at the 2m temperature errors is figure 9 we can see that they are very high, around 7 degrees RMSE. A typical value over e.g Sweden in winter is 1-3 degrees. We may therefore suspect that we have some kind or error in the model physics over the Arctic. In fact, an error in the surface scheme ISBA over ice has been found. The ice thickness is considered to be infinite! This, in turn, leads to a zero heat flow through the ice and up into the atmosphere with a too cold model as the result. A correction for this was implemented into the HIRLAM code after these experiments were made. When it was introduced into the SMHI operational suite an immediate warming of several degrees was noticed in the Arctic.

It is difficult to determine the quality of the information in an observation. If it is introduced into a model with a strong biases it is even more difficult. At this point it is therefore hard to say what the quality of the TWV retrievals actually were to the model. In this experiment, they have acted as a bias reducer for the model by providing more wv, clouds and therefore a warming, which is just what the model needed. It is, however, better to solve such problems by correcting the physics.

For the future, it would be interesting to correct the physics in the Arctic as much as possible and rerun this experiment. The most interesting thing, however, would be to compare with the other approach: direct radiance assimilation.

A Difference Between Monthly Means, Water Vapor

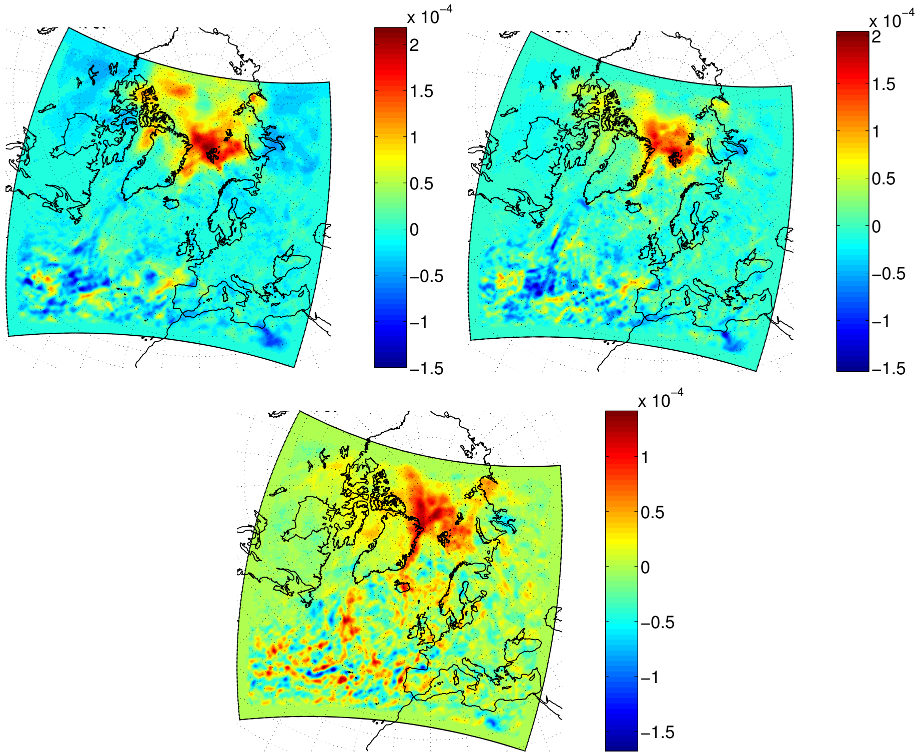

Figure 5: Difference between EXP and and REF, at model level 30 for different forecast lengths, 00H (upper left),+24H (upper right), +48H (bottom).

B Difference Between Monthly Means, Cloudiness

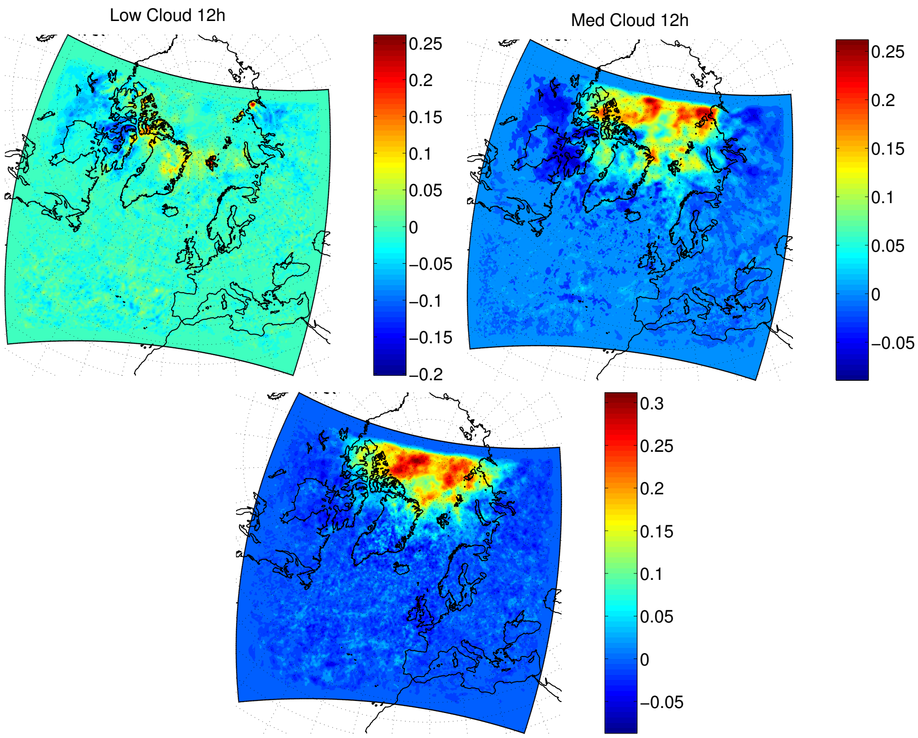

Figure 6: Difference in cloudiness between EXP and and REF for different cloud heights, Low (upper left),medium (upper right), high (bottom)

C Difference Between Monthly Means, Precipitation

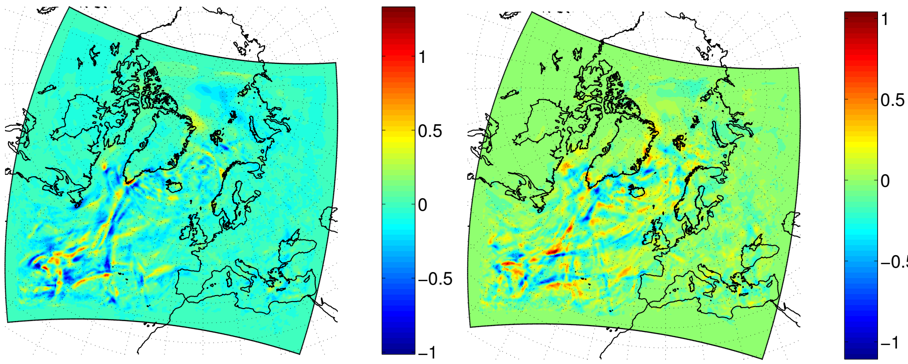

Figure 7: Difference between REF and EXP for total precipitation $[kg/m^2]$. Left: 00-24H. Right: 24-48H

D Difference Between Monthly Means, 2m Temperature

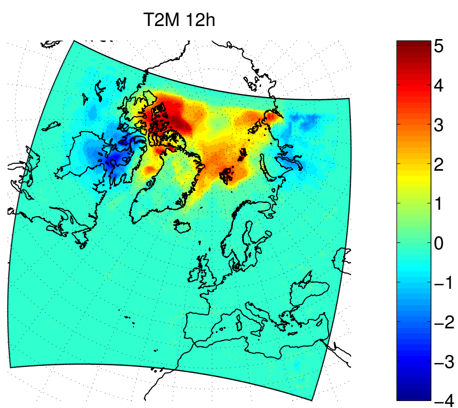

Figure 8: Difference between REF and EXP 12h forecasts for T2m

E Verification Against Observations

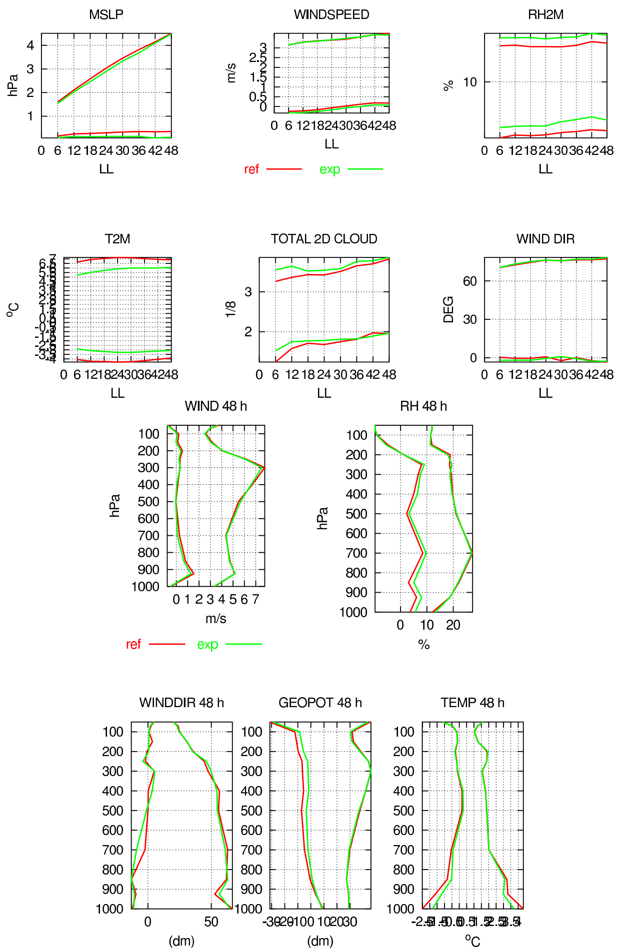

Figure 9: RMSE and mean errors