Implementation of AMSU-A usage over sea-ice in DMI-HIRLAM

J. Grove-Rasmussen and B. Amstrup
E-mail: jgr@dmi.dk and bja@dmi.dk
Danish Meteorological Institute
Lyngbyvej 100, DK-2100 Copenhagen, Denmark

Abstract

The DMI-HIRLAM[1] 3D-VAR[2] data assimilation and forecasting system has been modified to use ATOVS[3] AMSU-A radiance data over sea-ice from NOAA[4]15 and NOAA16 in addition to the operationally used data over oceans. Preparations have also been made for use of data over land. The extended use of data requires calculation of new bias statistics for each surface type, and determination of proper error covariance matrices.

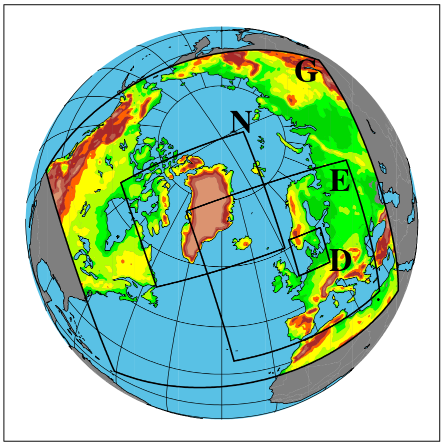
The implementation of changes is in this study tested for observations over sea-ice, and the impact is found to be neutral to slight positive over 9 days in January 2005.

DMI-HIRLAM

The model system used for this experiment is the previous operational local DMI version of the HIRLAM (Sass et al., 2002; Amstrup et al., 2003; Amstrup, 2004). The model system with 3D-VAR data-assimilation is regional (Gustafsson et al., 2001; Lindskog et al., 2001) and nested with four different regions (see figure 1 for an illustration and table of the position and resolution for the various models). The largest model area (DMI-HIRLAM-G) has lateral boundaries from ECMWF[5], whereas the inner models have lateral boundaries from their surrounding HIRLAM model. The DMI-HIRLAM analysis and forecasting system consists of the 3 dimensional variational data analysis system with an assimilation window of 3 hours, and a forecast model with 40 levels reaching the 10 hPa pressure level - above this a climatological model is applied for data needed in the radiative transfer model. The HIRLAM partners are Denmark, Finland, Iceland, Ireland, Netherlands, Norway, Spain and Sweden.

In the DMI-HIRLAM 3D-VAR system the following observation types (and observation quantities) are used: SYNOP (pressure), DRIBU (pressure), SHIP (pressure), TEMP (temperature, wind and specific humidity), PILOT (wind), AIREP (temperature and wind), NOAA15

[1]HIgh Resolution Limited Area Model
[2]3 dimensional variational
[3]Advanced TIROS (Television Infrared Observation Satellite) Operational Vertical Sounder
[4]National Oceanic and Atmospheric Administration
[5]European Centre for Medium-Range Weather Forecasts



Model Identification	G	N	E	D
grid points (mlon)	202	194	272	182
grid points (mlat)	190	210	282	170
No. of vertical levels	40	40	40	40
horizontal resolution	0.45°	0.15°	0.15°	0.05°
time step (dynamics)	120 s	50 s	50 s	18 s
time step (physics)	360 s	300 s	300 s	216 s

Figure 1: The previous operational DMI-HIRLAM regions, geographical coverage and resolution specifications.

and NOAA16 AMSU-A data (brightness temperature) (Amstrup, 2003; Schyberg et al., 2003), QuikScat data (surface wind) and Meteosat-8 AMV[6] (wind).

AMSU-A data used in this study are received through either the two local DMI receiver stations in Kangerlussuaq/Sdr. Strømfjord (Greenland) and at Smidsbjerg (Denmark), or through EARS[7]. At present the EARS consist of 14 receiver stations (of which Kangerlussuaq is one) giving good coverage to the DMI-HIRLAM regions, see figure 2.

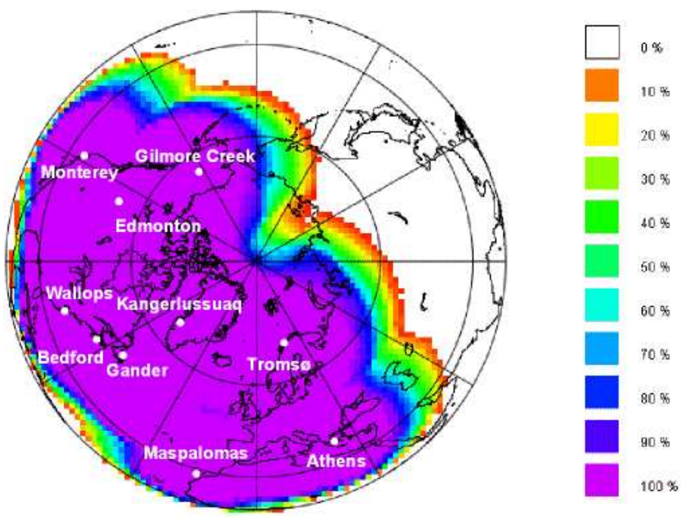


Figure 2: Percentage of observed data at a specific position being retransmitted through EARS with an early 10 station configuration. From `http://www.eumetsat.de/en/dps/atovs.html`.

The EARS has a structure which makes addition of further stations easy, and new stations (and products) are being discussed.

[6] Atmospheric Motion Vectors

[7] EUMETSAT ATOVS/Advanced Retransmission Service

Data flow

Data are received via HRPT[8] and pre-processed through the AAPP[9] to level 1c which is geolocated and calibrated to radiances and brightness temperatures. The level 1c data are received either via local equipment or via EARS, and is encoded into BUFR[10] for the use in the DMI assimilation system.

Forward model and emissivity

The forward model presently used operationally at DMI to calculate model derived brightness temperatures for ATOVS data is RTTOV7[11] (Saunders et al., 1999) developed in the Numerical Weather Prediction SAF[12] project setup by EUMETSAT. As DMI-HIRLAM reach 10 hPa the radiative transfer equation integration is using a climatological model above this height. Experiments are made with the most recent version RTTOV8 (B. Amstrup, these proceedings).

Each observation is categorized to be over either ocean, sea-ice or land based on the HIRLAM masking. In this experiment observations over land and sea-ice are assigned constant values of emissivity, respectively $\varepsilon_{\text{land}} = 0.95$ and $\varepsilon_{\text{sea-ice}} = 0.85$. These values are assigned based on previous works (e.g. (Hewison and English, 1999; Andersen, 1998; Mätzler, 1994)), but should be handled with great care as the emissivity value changes with e.g. sea-ice type/age and land surface humidity. Only data over ocean and sea-ice are used in this experiment.

A cloud clearing based on the total cloud liquid water content is made based on AMSU-A channel 1 and 2. Data are subsequently thinned to 0.9° for NOAA15 and NOAA16 data separately to match the model resolution.

Bias correction and error statistics

For bias-correction a Harris-Kelly (Harris and Kelly, 2001) scheme with 7 predictors from the background model (model first guess) is used: **1)** a constant displacement, **2)** thickness between 1000 hPa and 300 hPa, **3)** thickness between 200 hPa and 50 hPa, **4)** the surface temperature, **5)** the integrated water vapor content per area from the surface up to the top of the atmosphere, **6)** the square of the observation zenith angle and **7)** the observation zenith angle. The examination that was done for NOAA16 data (Schyberg et al., 2003) showed that the scatter of the difference between observed and modeled brightness temperature varied significantly as a function of latitude. Accordingly, there are separate bias-correction coefficients for three latitude bands: **1)** up to 45°N, **2)** between 45°N and 65°N, and **3)** north of 65°N.

The bias estimation scheme has been applied for the three surface types simultaneously giving a set of predictor coefficients for each satellite (NOAA15 and NOAA16), surface type and latitude band. A time-span of four months (June to September 2003) has been used. The coefficients have been determined for both the experiment values of emissivity and an additional test with $\varepsilon_{\text{sea-ice}} = 0.90$ to test the system sensitivity. The change in emissivity only resulted in minor changes of the coefficients. Due to lack of data the bias can not be determined for sea-ice in the southern most latitude bin.

The observation error covariance matrix has been chosen diagonal with the same values for NOAA15 and NOAA16. The values for channels 1-3 ("surface channels") are so large that

[8] High-Rate Picture Transmission
[9] ATOVS and AVHRR Processing Package, provided by EUMETSAT
[10] Binary Universal Form for Representation, defined by World Meteorological Organization.
[11] Radiative Transfer model for TOVS, release 7
[12] Satellite Application Facility

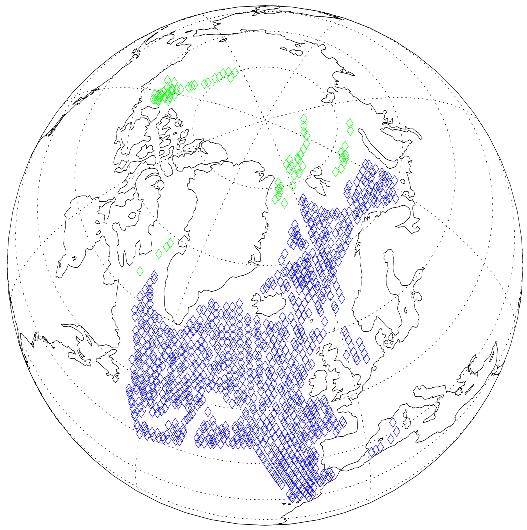


Figure 3: The ATOVS AMSU-A data assimilated for January 8th 2005, 15:00 UTC. Blue diamonds are over ocean and green over sea-ice.

effectively only channels 4-10 are used. Over sea-ice furthermore channels 4-6 are given low weight due to strong surface contamination (see table 1) as the weighting function of these channels include the surface microwave emission.

Table 1: The values in the diagonal of the observation error covariance matrix. All off-diagonal elements are 0.

channel	1	2	3	4	5	6	7	8	9	10
error - ocean (K^2)	900	900	900	90	0.35	0.35	0.35	0.35	0.70	1.40
error - sea-ice (K^2)	900	900	900	900	900	900	90	1.40	0.70	1.40

When including data over land the bias predictor 2 (thickness between 1000 hPa and 300 hPa) might need modification as the land surface often rise above the 1000 hPa level in mountainous regions and over the Greenland ice shelf.

Results

An assimilation experiment has been made in the DMI-HIRLAM system to evaluate the impact of the added sea-ice data (land data is still in early testing and not included).

Figure 3 shows the amount of data after removal of data over land and with high total cloud liquid water, and thinning for January 8th 2005, 15:00 UTC. A total of 1027 observations are used, with 951 over the ocean and the remaining 76 over sea-ice.

Figure 4 shows results from observation verification using an EWGLAM[13] station list for an OSE[14] experiment for a 9 day period (1st to 9th) in January 2005. The rms-scores are

[13] European Working Group on Limited Area Model
[14] Observing System Experiment

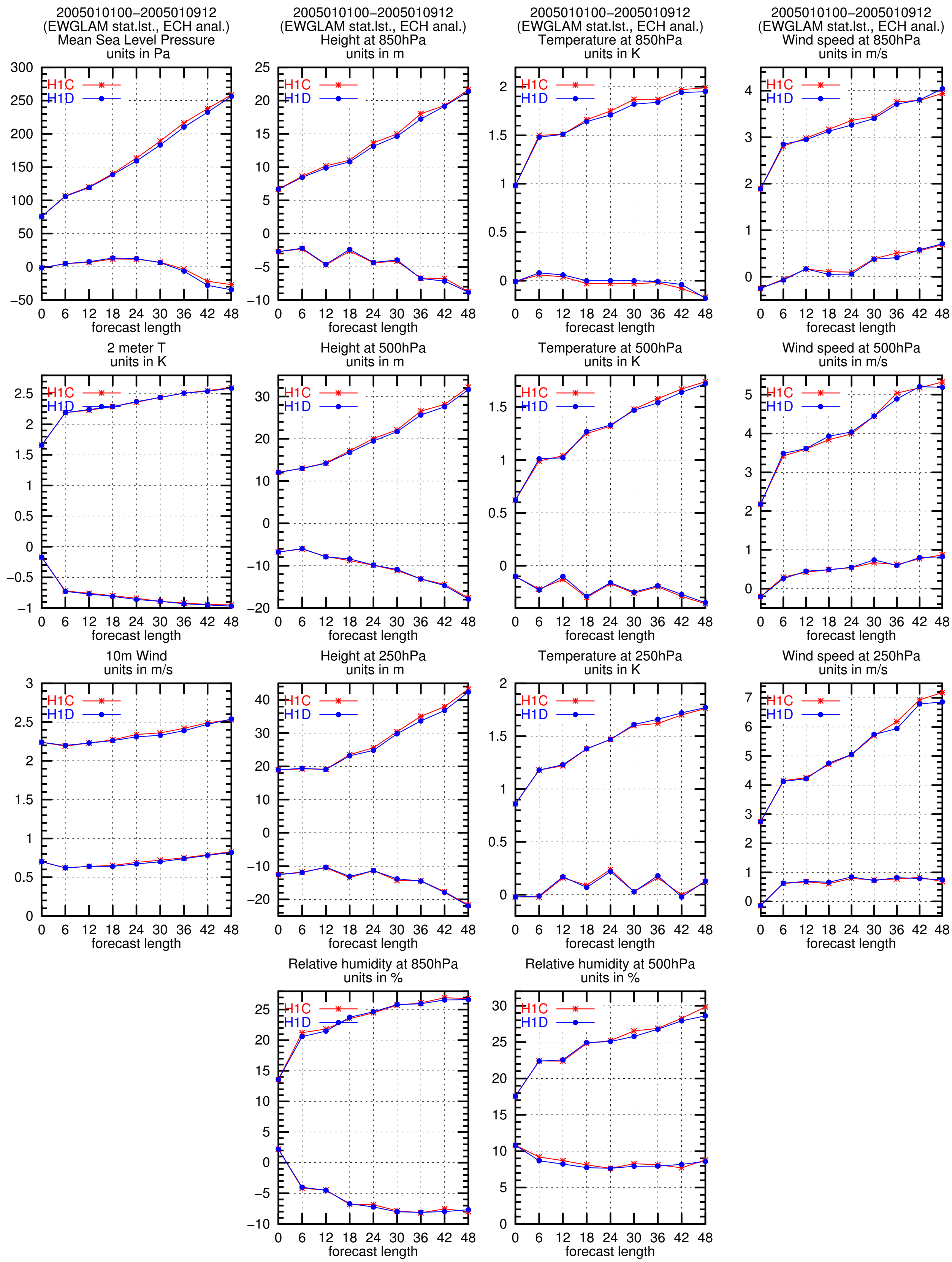


Figure 4: Observation verification (bias and rms, EWGLAM station list) results for January 2005 of surface parameters and geopotential height, temperature and wind for pressure levels specified in the plot. The OSE experiment was done with the DMI-HIRLAM-E model (see figure 1). The upper curves are rms and lower curves bias, red without ATOVS over sea-ice and blue with ATOVS over sea-ice.

slightly better for most variables for the run including AMSU-A data over sea-ice implying a neutral to slight positive impact. The positive impacts are observed in the MSLP[15] and the 850 hPa parameters (geopotential height, temperature and wind speed), whereas most of the other parameters have neutral to very slight positive impact. Most remarkable is it that MSLP has been improved, even though the additional data are channels peaking high in the atmosphere.

Conclusion and future work

The observation assimilation experiment using additional sea-ice data show a neutral to slight positive impact, which we expect to increase by recalculating the bias statistics to cover more winter season and modify the cloud clearing algorithm, as the one used is found to be unreliable over land and sea-ice.

The assimilation system is stable for variation of the emissivities, but still some work needs to be done for the optimal emissivity values to be determined. Optimally the emissivity should be determined based on AMSU-A window channels, or with the emissivity being a free parameter. Only a weak dependency on emissivity is expected as all the channels with weighting function reaching the ground are given very low weight (see Table 1). In the sea-ice region emissivities from the OSI[16] SAF might prove better than a fixed value.

The temporal variation of the bias predictors is in general rather small, but a large constant displacement is derived for data over sea-ice and land, especially for the lower channels.

The land surface mask is to be refined to contain only land and no border zone (the zone off the coast line) as it is at present, where some sea-ice and ocean is included. This reduce the amount of data available as all border zones with fractional land and ice should be ignored. However the observations over land becomes a more homogeneous sample. Where land rises high (mountainous regions and e.g. the Greenland ice shelf) data should be rejected or used with a further reduced channel selection.

By using observations over sea-ice extra information is gained especially in the Greenland area. As the amount of this data type data is depending on season, a further stable positive impact is expected when using data over land.

The vertical extension of DMI-HIRLAM is presently 10 hPa with climatology above this level. It is considered to test the method by shifting the top upwards or alternatively use actual data from the ECMWF in this region of the atmosphere. That there is positive impact on MSLP when using data high up in the atmosphere could have the implication that shifting the model top upwards and hence gain access to more channels might have a positive impact on the 850 hPa level, or even higher levels. We should also prepare for NOAA18 and AMSU-B/MHS[17] and the high resolution infrared sounders.

Acknowledgments

This work is partly financed through a EUMETSAT research fellowship on ATOVS AMSU assimilation in regional NWPs.

---

[15] Mean Sea Level Pressure
[16] Ocean and Sea Ice
[17] Microwave Humidity Sounder

References

Amstrup, B. (2003). Impact of NOAA16 and NOAA17 ATOVS AMSU-A radiance data in the DMI-HIRLAM 3D-VAR analysis and forecast system - January and February 2003. Scientific Report 03-06, Danish Meteorological Institute. `http://www.dmi.dk/f+u/publikation/vidrap/2003/Sr03-06.pdf`.

Amstrup, B. (2004). Impact of NOAA16 and NOAA16 ATOVS AMSU-A radiance data in the DMI-HIRLAM 3D-VAR data assimilation system - november and december 2003. *Hirlam Newsletter*, 45:235–247.

Amstrup, B., Mogensen, K. S., Nielsen, N. W., Huess, V., and Nielsen, J. W. (2003). Results from DMI-HIRLAM pre-operational tests prior to the upgrade in December 2002. Technical Report 03-20, Danish Meteorological Institute. `http://www.dmi.dk/f+u/publikation/tekrap/2003/Tr03-20.pdf`.

Andersen, S. (1998). Monthly artic sea ice signatures for use in passive microwave algorithms. Technical Report 98-18, Danish Meteorological Institute.

Gustafsson, N., Berre, L., Hörnquist, S., Huang, X.-Y., Lindskog, M., Navascués, B., Mogensen, K. S., and Thorsteinsson, S. (2001). Three-dimensional variational data assimilation for a limited area model. Part I: General formulation and the background error constraint. *Tellus*, 53A:425–446.

Harris, B. and Kelly, G. (2001). A satellite radiance-bias correction scheme for data assimilation. *Q.J.R. Meteorol. Soc.*, 127:1453–1468.

Hewison, T. and English, S. (1999). Airborne retrievals of snow and ice surface emissivity at millimeter wavelengths. *IEEE Trans. on Geoscience and Remote Sensing*, 37(4):1871–1879.

Lindskog, M., Gustafsson, N., Navascués, B., Mogensen, K. S., Huang, X.-Y., Yang, X., Andræ, U., Berre, L., Thorsteinsson, S., and Rantakokko, J. (2001). Three-dimensional variational data assimilation for a limited area model. Part II: Observation handling and assimilation experiments. *Tellus*, 53A:447–468.

Mätzler, C. (1994). Passive microwave signatures of landscapes in winter. *Meteorol. Atmos. Phys.*, 54:241–260.

Sass, B. H., Nielsen, N. W., Jørgensen, J. U., Amstrup, B., Kmit, M., and Mogensen, K. S. (2002). The operational DMI-HIRLAM system - 2002 version. Technical Report 02-5, Danish Meteorological Institute. `http://www.dmi.dk/f+u/publikation/tekrap/2002/Tr02-05.pdf`.

Saunders, R., Matricardi, M., and Brunel, P. (1999). An inproved fast radiative transfer model for assimilation of satellite radiance observations. *Q.J.R. Meteorol. Soc.*, 125:1407–1425.

Schyberg, H., Landelius, T., Thorsteinsson, S., Tveter, F., Vignes, O., Amstrup, B., Gustafsson, N., Järvinen, H., and Lindskog, M. (2003). Assimilation of ATOVS data in the HIRLAM 3D-VAR system. Technical Report 60, HIRLAM. `http://hirlam.knmi.nl/open/publications/TechReports/TR60.pdf`.