Assimilating AMSU-A over Sea Ice in HIRLAM 3D-Var

Vibeke W. Thyness[1],
Leif Toudal Pedersen[2], Harald Schyberg[1], Frank T. Tveter[1]

[1]Norwegian Meteorological Institute (met.no)
Box 43 Blindern, N-0313 Oslo,
Norway
mail: vibeke.thyness@met.no

[2]Technical University of Denmark (DTU),
Building 348, Oersteds Plads, DK-2800 Lyngby,
Denmark

Abstract

In the IOMASA project, Norwegian Meteorological Institute (met.no) and partners develop methods for assimilating AMSU-A brightness temperatures above sea ice surfaces in HIRLAM 3D-Var. Methods that are currently developed at met.no for exploiting microwave soundings over ice surfaces are presented, with focus on estimating surface emissivities. As a first approach, typical emissivity values for First Year and Multi Year ice are used in combination with the ice concentration products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) to estimate the emissivity of each AMSU-A footprint. The calculated surface emissivities are given to the forward model RTTOV7.

Some preliminary results from impact studies with HIRLAM 3D-Var are also presented. With the current model setup, the AMSU-A observations contribute slightly positive to the forecast quality of the HIRLAM20 model at met.no.

Introduction

Norwegian Meteorological Institute (met.no) runs the Limited Area model HIRLAM on three different domains. The largest domain, 'HIRLAM20', has 0.2 degrees (~22 km.) horizontal resolution and 31 vertical layers; covering the North Atlantic and the Arctic, and extending from the surface up to 10 hPa. This model has its own 3D-Var assimilation system for observations (Schyberg et al. 2003). The lateral boundaries are frames produced by the ECMWF Global model. The three HIRLAM models supplement the global forecasts available twice a day from ECMWF, by providing higher resolution, and earlier available forecasts. They are therefore considered important tools for short range forecasts at met.no.

The scarcity of conventional observations over the Arctic makes observations from satellites, and in particular the microwave radiometry from the AMSU-A instrument, the main source of information for numerical weather prediction (NWP) in the region. Extensive data coverage over the entire HIRLAM20 domain is ensured by the EUMETSAT ATOVS Retransmission Service (EARS), which from June 2003 has redistributed ATOVS observations over the North-Atlantic and Arctic within 30 minutes after observation. Studies show that AMSU-A observations over open sea from EARS contribute positively to the final HIRLAM20 analysis (Vignes et al. 2005). AMSU-A (from EARS and local antenna) and QuikScat observations over open ocean are currently used by the operational assimilation system at met.no. Given the positive impact of assimilating AMSU-A observations over sea, good methods for exploiting observations from the large areas covered by sea ice are expected to further improve the forecast skill of the NWP models.

One of the main objects of met.no's work in the IOMASA (Integrated Observing and Modelling of the Arctic Sea Ice and Atmosphere) project is to develop methods to exploit observations made over sea-ice, in order to increase the number of observations available and thereby improve the quality of the initial state estimate of the HIRLAM20 analysis.

This work is divided into two main tasks: develop good methods for estimating the surface emissivity of sea-ice, and find optimal ways of using the microwave data in the HIRLAM20 model.

Surface emissivities of Sea Ice

Microwave radiances in wave bands with contribution from the surface are very sensitive to the surface emissivity, and the quality of the estimates relies on a good handling of the surface properties. Making a correct estimate of the microwave emissivities of the sea ice surface is therefore essential for optimal use of these observations in the data assimilation system.

The simplest way to handle this would be to apply suitable rejection criteria to prevent channels influenced by the surface from entering the assimilation system. The ideal solution would probably be to obtain the emissivities from a detailed model describing the evolution of the snow and ice layers and their properties. We have chosen an intermediate approach by letting the emissivity depend on daily retrievals of Multi Year and First Year sea ice concentrations.

a) Empirical determination of typical First Year and Multi Year ice emissivities

As a first approach, areas of typical near total FY-ice (Kara Sea) and near total MY-ice (North of Greenland) are defined, and stable periods with minimal water vapour load are selected. Typical surface emissivities of First Year (FY) and Multi Year (MY) ice are determined empirically for the selected study areas, using a simplified theory for microwave radiative transfer.

The main assumptions in this theory are:

- The atmospheric attenuation can be reasonably approximated by an absorption factor α and effective atmospheric temperature T_a
- The water vapour load is minimal during selected periods so the main contribution to the absorption is from oxygen.

The surface emissivities for all AMSU channels are estimated from the measured brightness temperature T_b:

$$\varepsilon=\frac{T_b-\alpha T_a-(1-\alpha)\alpha T_a-T_{sp}(1-\alpha)^2}{T_s(1-\alpha)-\alpha T_a(1-\alpha)-T_{sp}(1-\alpha)^2}$$

where the absorption factor α is defined as:

$$\alpha=\frac{T_{dn}-T_{sp}}{T_a-T_{sp}}$$

T_{dn} represents the downwelling radiation calculated by the radiation model MWMOD for a simplified atmosphere with a minimal water vapour contribution. T_{sp} is the downwelling radiation coming from space.

This approach leads to a set of typical emissivities for each of the two ice types for all AMSU-A and AMSU-B frequencies. Table 1 shows the emissivity values for AMSU-A. In figure 1 the time evolution of the emissivity of Multi Year ice in a selected study area north of Greenland for 4 AMSU-A surface channels can be seen.

Table1: Emissivity values of FY and MY ice for 15 AMSU-A channels.

AMSU-A channel	Frequency (GHz)	First Year Ice	Multi Year Ice
1	23.8	0,971	0,874
2	31.4	0,970	0.829
3	50.3	0.928	0.796
4	52.8	0.928	0.796
5	53.6	0.928	0.796
6	54.4	0.928	0.796
7	54.9	0.928	0.796
8	55.5	0.928	0.796
9	57.3	0.928	0.796
10	57.3	0.928	0.796
11	57.3	0.928	0.796
12	57.3	0.928	0.796
13	57.3	0.928	0.796
14	57.3	0.928	0.796
15	89.00	0.913	0.744

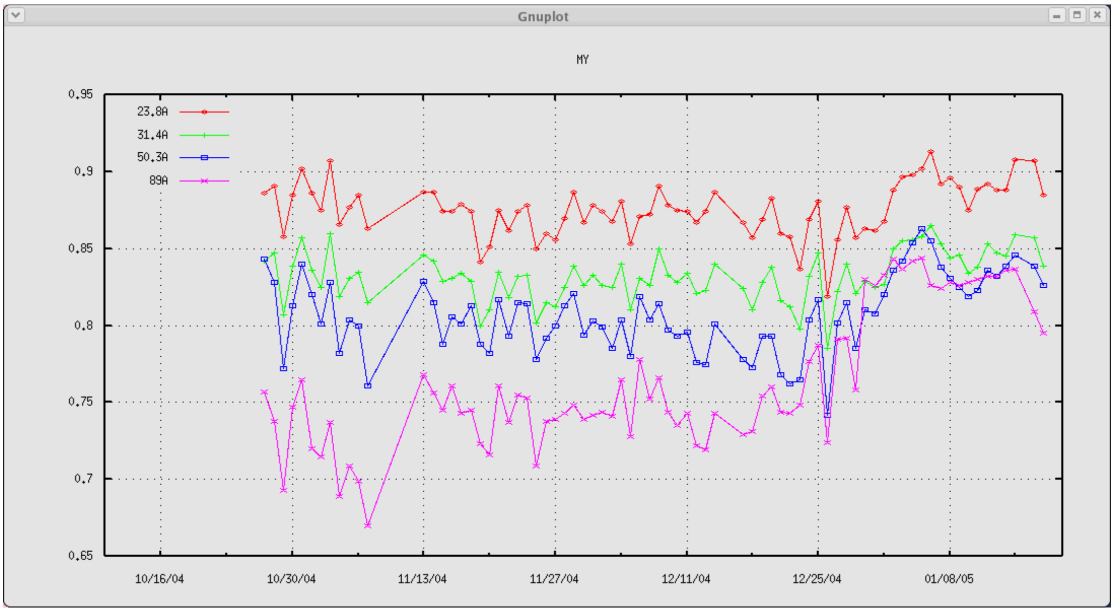


Figure 1. Time series of AMSU-A emissivities for a limited area of Multi Year ice north of Greenland. Example for channels 1 (23.8 GHz), 2 (31.4GHz), 3 (50,3GHz) and 15 (89 GHz)

b) Emissivity in each AMSU-A footprint

The typical emissivity values are used in combination with the ice concentration products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) to determine the surface emissivity in each AMSU-A footprint.

Since the properties of the ice surface usually change slowly, information from recent passages of microwave radiometers can help determine the ice concentration in the AMSU-A footprints.

The OSI SAF provides daily sea ice retrievals from the Arctic on a 10 km grid, based mainly on SSM/I (Breivik et al. 2001). The service has recently been extended to also produce estimates of FY and MY ice concentrations.

Over completely sea ice covered areas, the surface within each AMSU-A footprint is subdivided into concentrations of FY (c_{FY}) and MY (c_{MY}) sea ice from the OSI SAF products, with $c_{FY} + c_{MY} = 1$. The surface emissivity is estimated as

$$\varepsilon = c_{FY}\,\varepsilon_{FY} + c_{MY}\,\varepsilon_{MY}$$

Here ε_{FY} and ε_{MY} are the typical emissivities for FY and MY sea ice, which are estimated separately for each AMSU channel with the method described above.

The calculated surface emissivities are given to the forward model RTTOV7 to calculate radiances from the HIRLAM20 model profiles. Figure 2 shows the effect of using these modelled emissivities compared to running RTTOV7 with a fixed value of $\varepsilon = 1$ for the surface channel 31.4 GHZ. The modelled emissivities result in less spread and better fit between the calculated and observed brightness temperatures. However, the estimated emissivities for MY ice still seem to be too large; the calculated brightness temperatures are systematically higher than the observed values (bottom row). Also, the outlying row of points in the bottom left scatter plot (calculated brightness temperatures of around 260K) indicates that in some cases the OSI SAF products have FY ice, while in reality we have MY ice .The two tops in the bottom right histogram also reflects this; the FY ice is centred close to zero, and the MY ice has an offset of about -15K.

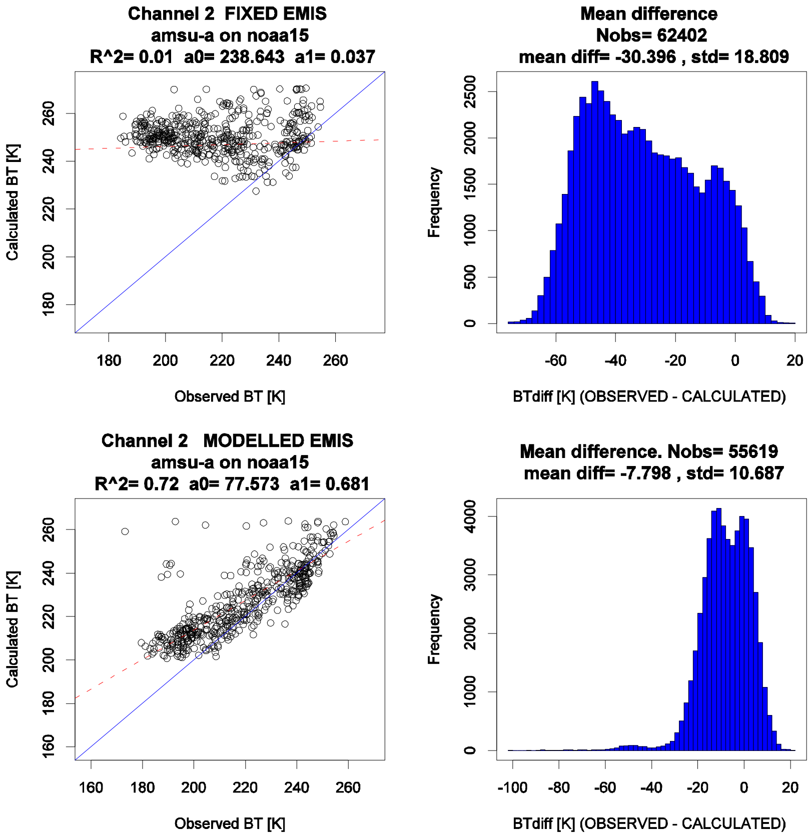


Figure 2. The effect of using a modelled surface emissivity (bottom row) compared to a fixed emissivity of $\varepsilon=1$(top row) in RTTOV7. Example for AMSU-A channel 2 (31.4 GHz). Note that the scales on the x-axis differ slightly for the two rows.

Results from parallel assimilation experiment

Several parallel experiments focusing on the impact of the added AMSU-A observations in the HIRLAM20 model at are conducted at met.no. In the initial assimilation experiments, only AMSU-A channels that are not sensitive to the surface emissivity (ie channels 6 to 10) are used in the assimilation, while the lower peaking channels (1 to 5) are monitored in passive mode to assess the behaviour of the forward model. Later, the ambition is to include some of the lower peaking channels (4 and 5) as well. Some of the AMSU-A channels receive nearly all their radiation from the surface, and are therefore very sensitive to the surface emissivity. These channels (AMSU-A channels 1, 2, 3 and 15) are currently not used over open sea, and will probably not be used over sea ice.

The observations are assumed to be uncontaminated by clouds (assumption by RTTOV7), and the error statistics of the observations is assumed to be Gaussian (assumption by the assimilation system). At the moment we do not have an efficient cloud mask for AMSU-A over ice. Therefore, as a first approach, a gross error check is performed on the observations before the assimilation, where the brightness temperature difference between the observation and the model value from RTTOV7 is calculated and compared to a set of threshold values set individually for each AMSU-A channel. The thresholds are determined by subjective inspection of a large number of collocated observations from the pre-processing system. The entire AMSU-A observation is rejected for use in the analysis if it is outside the threshold range for any of the channels.

Work is going on to develop more general methods for identifying gross errors, based on fitting Gauss functions to the error distributions and using Bayesian Risk Theory to determine the thresholds.

Some preliminary results from an assimilation experiment are presented here. The model results are verified against a subset of the EWGLAM stations over Northern Europe, including several North Atlantic and Arctic stations. This is where the impact of the added observations is expected to be largest. For verification the forecasts originating from the midnight cycle are used. The forecasts are verified at the main synoptic hours (0Z, 6Z, 12Z, 18Z).

Figure 3 shows verification against surface observations as a function of forecast range for Mean Sea Level Pressure (MSLP), Surface Temperature (TS) and Wind Speed at 10 meters (FF10). The 'Reference' experiment (red solid lines) contains only conventional observations, whereas the 'AMSU-A over ice' experiment (blue dashed lines) is identical to the Reference except for the added AMSU-A observations from regions covered by sea ice. The curves for the two experiments are quite close to each other, except for the sea level pressure (MSLP), where the AMSU-A experiment scores better for the period.

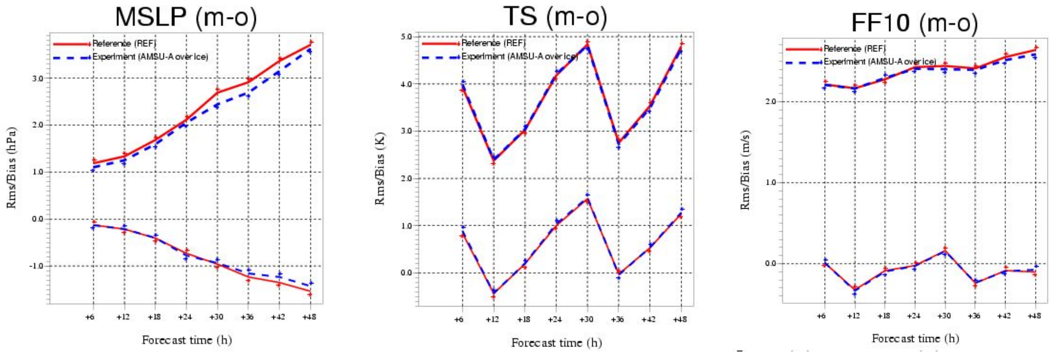
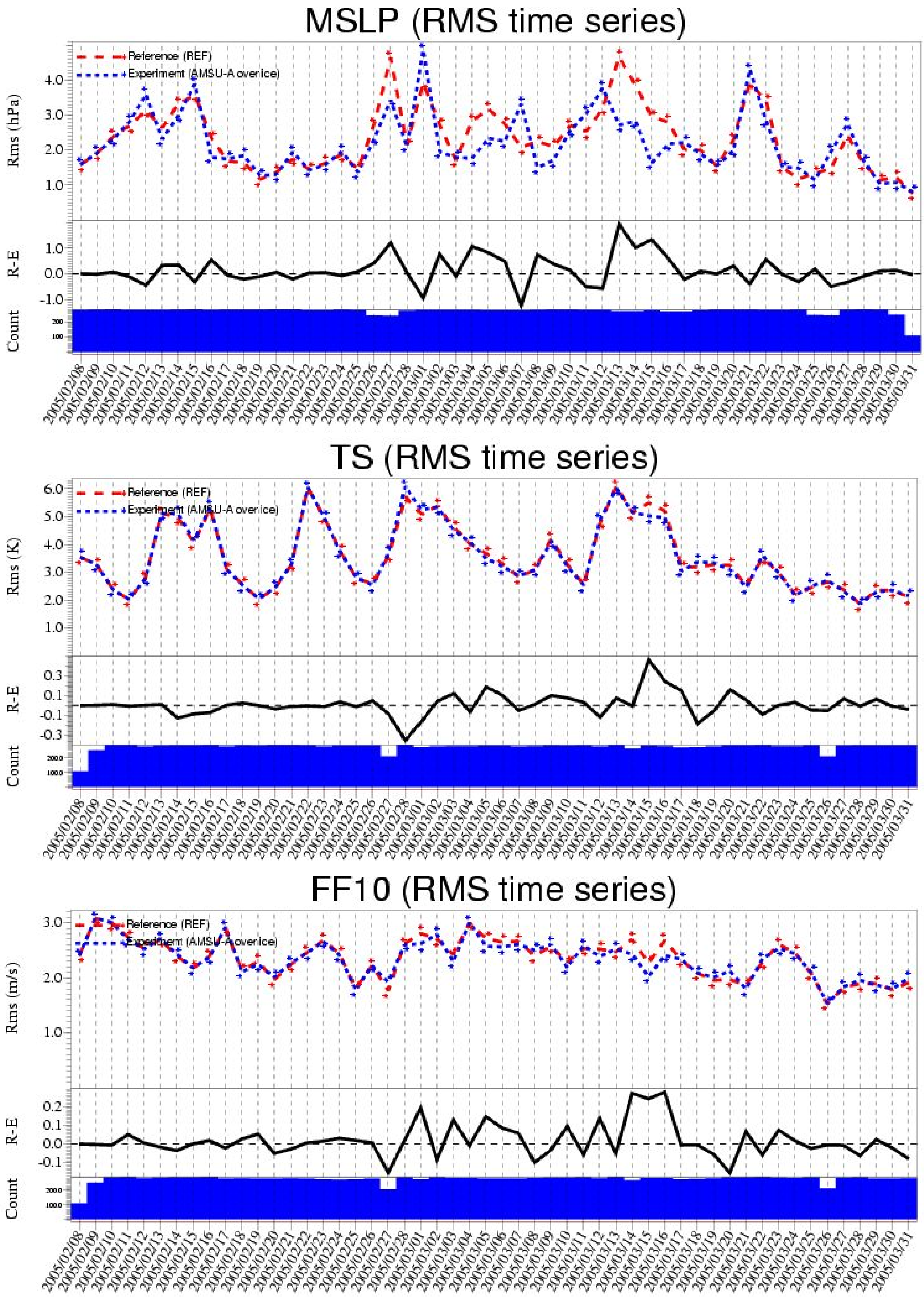


Figure 3. RMS error (upper curves) and bias (lower curves) of the forecasts as a function of forecast length for Mean Sea Level Pressure (MSLP), Surface Temperature (TS) and Wind Speed at 10 m (FF10).


MSLP (RMS time series)

TS (RMS time series)

FF10 (RMS time series)

Figure 4. Daily contributions to the Root Mean Squared (RMS)error in MSLP, TS and FF10.

Figure 4 shows time series for the daily contribution to RMS errors (averaged over all forecast ranges from 6 to 48 hrs) in the two experiments. Such plots are useful in determining whether the observed impact originates from a single case or is a more general feature. For MSLP we seem to have longer periods where the AMSU-A experiment is better than the Reference, confirming the statistics shown above for the whole period.

The added AMSU-A observations have a slight positive effect on the 48-hour forecasts in the test period of February and March 2005.

Conclusions and future work

A method for determining the surface emissivity in each AMSU-A footprint, where typical emissivity values for First Year and Multi Year ice are used in combination with the ice concentration products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF), is presented.

Further investigation of the fit between observations and brightness temperatures modelled with these emissivities is ongoing. In the near future we expect to improve the simplified calculations by also taking into account atmospheric water and temperature profiles. Incidence angle dependence will also be included in the emissivity model.

Use of AMSU-A data over sea ice now gives a neutral to positive impact. The impact study showed periods of large errors in MSLP where improvements were found in the experiment. The time period of the experiment seems too short to conclude definitely, but the results are encouraging.

Until now the surface emissivity is calculated at each satellite footprint and used as a fixed value. One possible extension would be to include the emissivity in the control variable and let the assimilation system decide on the optimal value.

Acknowledgment

The authors wish to thank the IOMASA project team for valuable contributions to this study. This work has been done at met.no and DTU for the EU Fifth Framework Programme project IOMASA (Integrated Observing and Modelling of the Arctic Sea Ice and Atmosphere), project number EVK3-2001-00116.

References

Breivik, L.-A., S. Eastwood, Ø. Godøy, H. Schyberg, S. Andersen, and R. Tonboe, Sea ice products for EUMETSAT Satellite Application Facility, *Canadian Journal of Remote Sensing*, **Vol. 27, no. 5,** 2001

Schyberg, H., T. Landelius, S. Thorsteinsson, F.T. Tveter, O. Vignes, B. Amstrup, N. Gustafsson, H. Järvinen, and M. Lindskog, Assimilation of ATOVS data in the HIRLAM 3D-Var System, *HIRLAM Technical Report*, **no. 60**, 2003

Vignes, O., Tveter, F.T and Schyberg, H. 2005. Results from the Winter 2003/2004 HIRLAM Analysis Impact Study. *met.no report* **6,** 2005, available from *http://met.no/english/r_and_d_activities/publications/2005/index.html*

INTERNATIONAL
ATOVS
WORKING GROUP

Proceedings of the Fourteenth International TOVS Study Conference

Beijing, China
25-31 May 2005