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

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Introduction

In the IOMASA (Integrated Observing and Modeling of the Arctic Sea ice and Atmosphere) project, Norwegian Meteorological Institute (met.no) and partners develop methods for assimilating AMSU-A brightness temperatures over sea ice surfaces in HIRLAM 3D-Var.

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 in the region. 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 HIRLAM models.

Assimilating AMSU radiances in wave bands with contribution from the surface is very sensitive to surface emissivity, and the quality depends on a good handling of the surface properties. Effort must therefore be put into making a correct estimate of the microwave emissivites of the Sea Ice surface.

This poster presents recent developments in sea ice emissivity estimation and some results from a parallel experiment in which AMSU-A radiances over sea ice is assimilated by the HIRLAM 20 model at met.no.

Assimilation experiment

A parallel study is conducted to assess the impact of assimilating the upper tropospheric AMSU-A channels over Sea Ice in the HIRLAM 20 model.

Cloud check

It is necessary to ensure that the observations are uncontaminated by clouds, as is assumed by RTTOV7, and to bring the observation error characteristics close to Gaussian, as is assumed by the assimilation system. As a first approach, each AMSU-A band is assigned a maximum and minimum value for the departure between observed and calculated Brightness Temperature. The thresholds are found by subjective inspection of a large number of collocated observations from the pre-processing chain.
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.

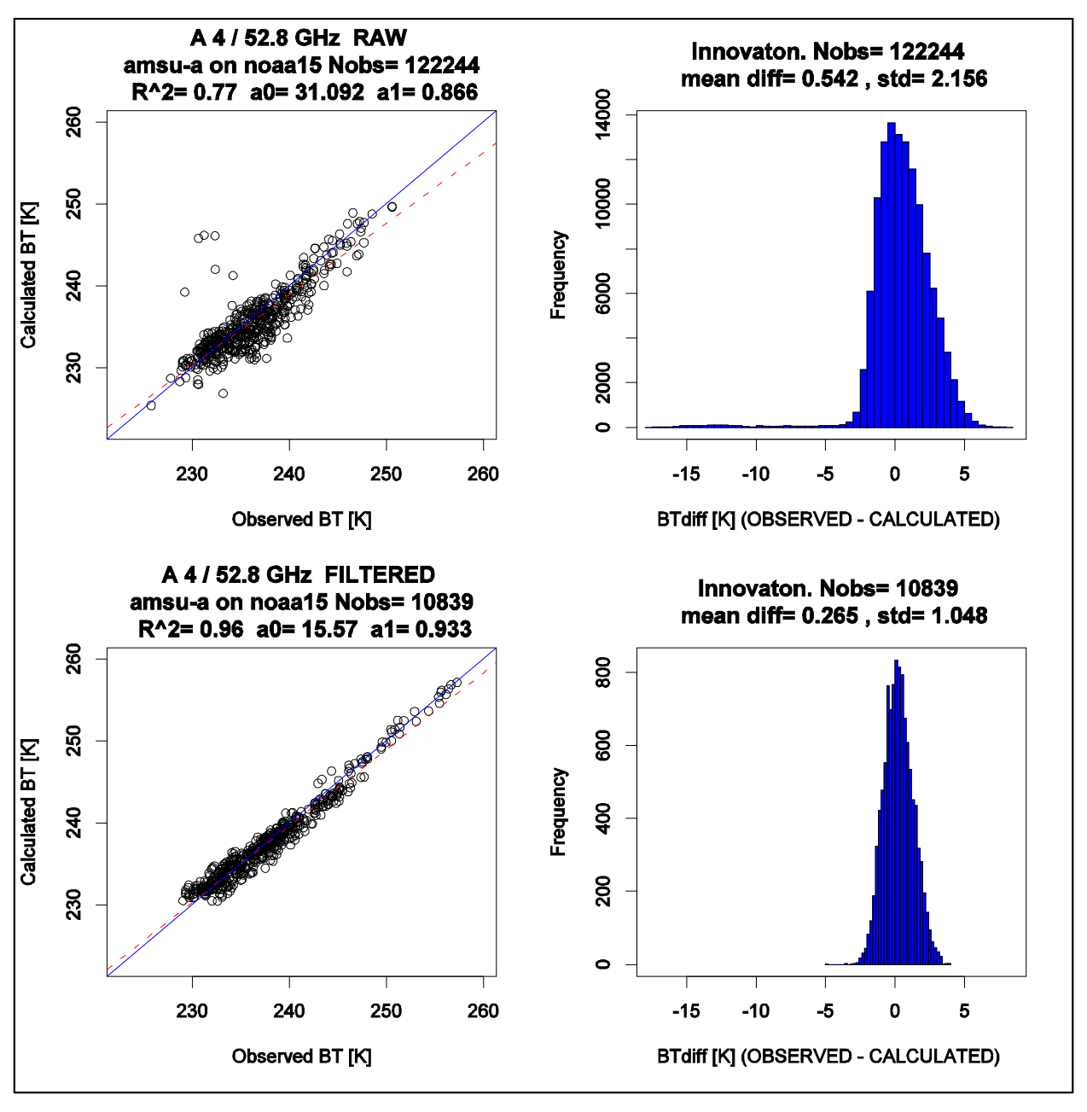

Figure 6: Example from AMSU-A channel 4 (52.8 GHz) on Noaa 15. **Top:** (Observed – Calculated) BT distribution before trimming. **Bottom:** Trimmed near-Gaussian distribution.

Initial results

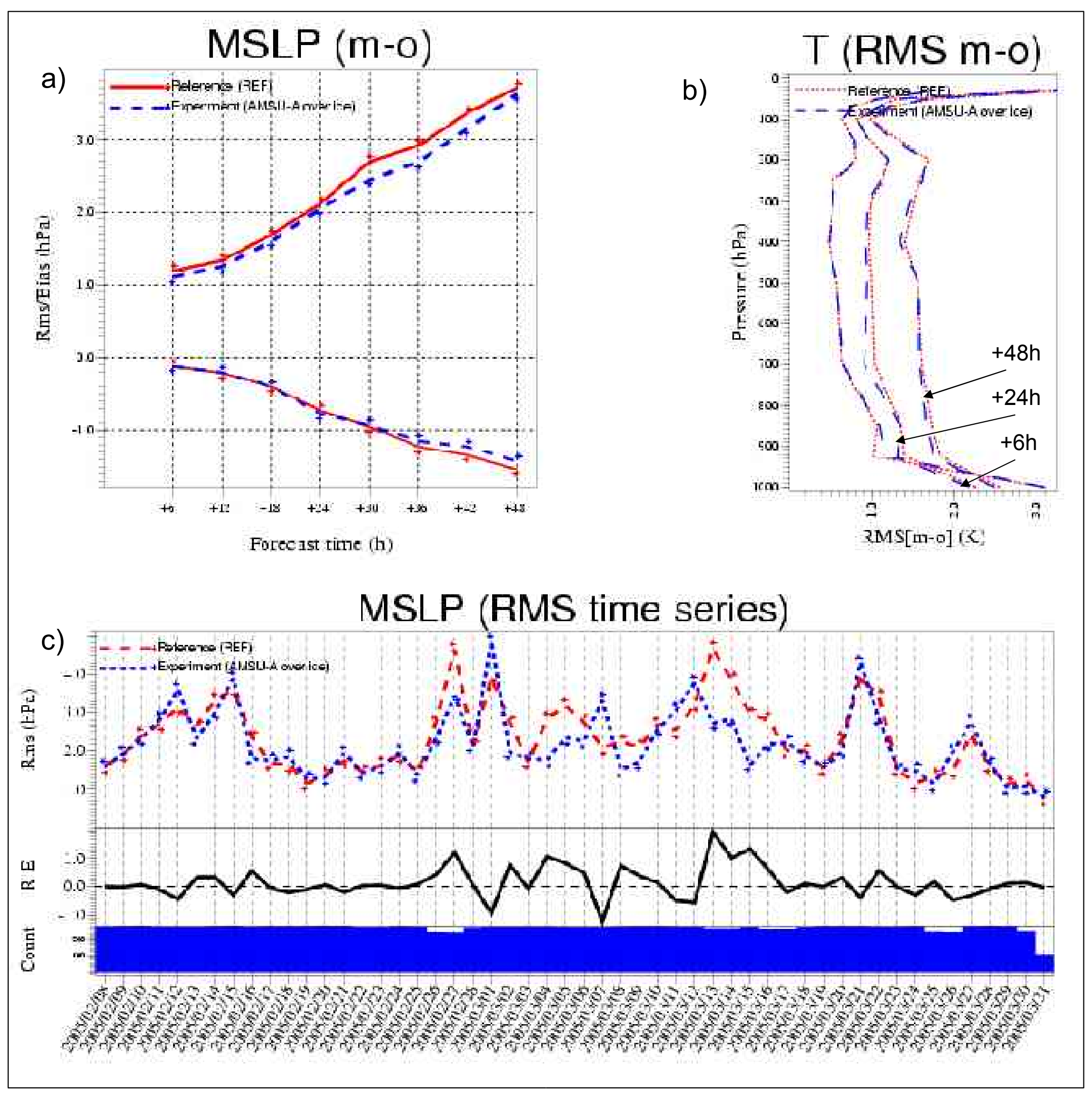

Figure 7: Results from first parallel experiment.
b) The RMS error in Mean Sea level Pressure as a function of forecast time
c) The RMS Temperature error as a function of pressure level and forecast time.
d) Time series of the daily contribution to the RMS error in MSLP

The control run without AMSU-A assimilation is in **RED**, the experiment with assimilation of AMSU-A is in **BLUE**

In this initial experiment, only AMSU-A channels that are not sensitive to the surface emissivity (i.e. channels 6 to 10) are used for the analysis, while the lower channels (1 to 5, 11 to 15) are monitored in passive mode to make an assessment of the behaviour of the forward model. Later, the ambition is to include some of the lower channels (4 and 5) as well, handling surface emissivity as outlined above.

The Control run (REF) is a version of HIRLAM 20 without any assimilation of AMSU-A or QuikScat data. The Experiment is identical, except for the added AMSU-A observations over the ice covered Arctic. We run with 3-hourly assimilation cycle.

The verification is performed against the EWGLAM observation station set over Europe.
The added AMSU-A information over sea ice have a slightly positive impact on the 48-hour forecast in the test period of February and March 2005. Continued work is going on to tune the model and improve bias correction and gross error checks.

Operational set-up and data flow

Norwegian Meteorological Institute runs HIRLAM on three different domains, with 22km, 11km and 5 km horizontal resolution, as shown in figure 1. Only the largest and coarsest model has it's own 3D-Var assimilation system for observations. The lateral boundaries to this model are frames produced by the ECMWF Global Model.

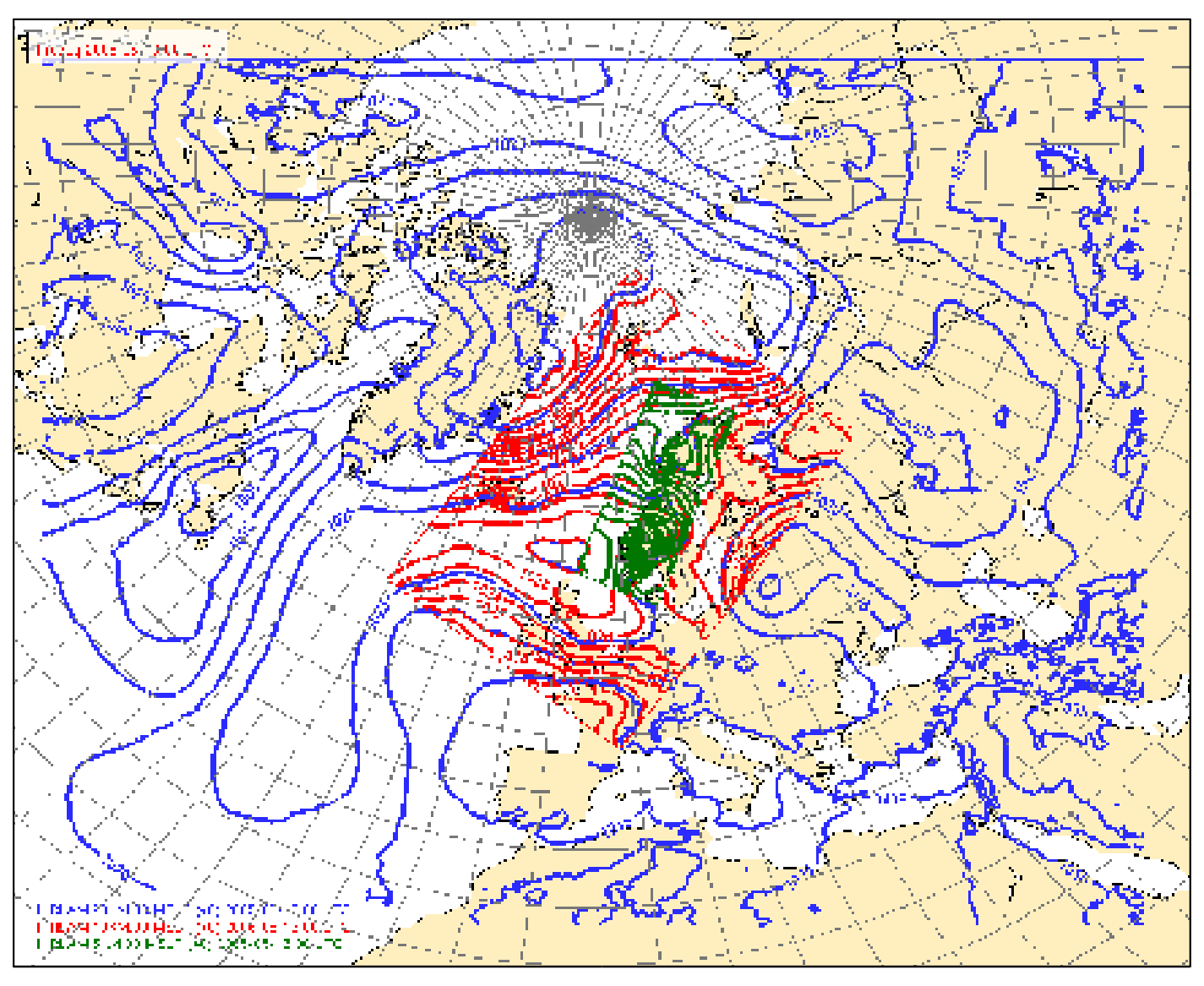

Figure 1: Three different HIRLAM domains running operationally at met.no: Hirlam-20 (22km / BLUE), Hirlam-10 (11km / RED) and Hirlam-5 (5km / GREEN)

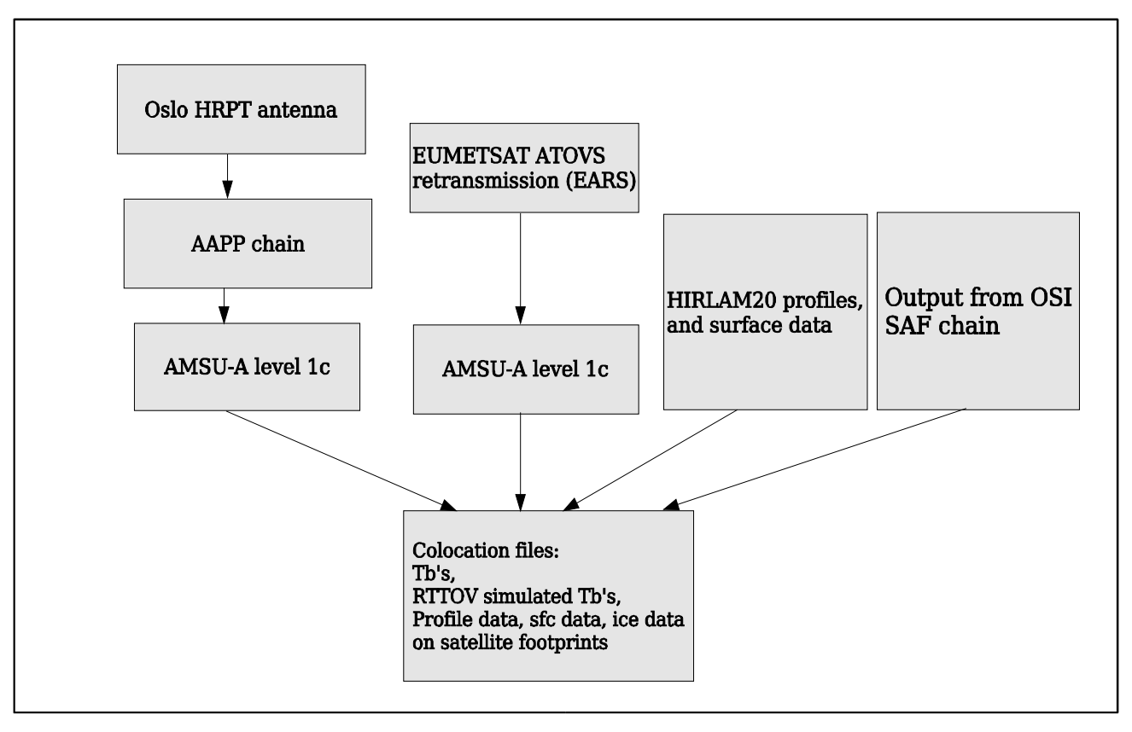

Figure 2: Schematic of the pre-processing data flow for AMSU-A at met.no

Figure 2 gives an overview of the pre-processing data flow for the AMSU-A data at met.no, before the observations are passed into the HIRLAM 3D-Var system. ATOVS data is received both by the local antenna in Oslo, and by the EUMETSAT ATOVS Retransmission Service (EARS).
The collocation files allow production of statistics for comparison of forward-modeled Brightness Temperatures using the HIRLAM model profiles and the corresponding observed values, and are used for quality control of the observations and ice emissivity calculations.

Surface Emissivity of Sea Ice

As an initial approach we let the emissivity depend on daily retrievals of multi-year and first-year sea ice concentrations from the Ocean and Sea Ice Satellite Application Facility of EUMETSAT (OSI SAF). Arctic sea ice retrievals on a 10 km grid, based mainly on SSM/I, are available daily, and the service is extended to also produce estimates of multi-year and first-year ice concentrations (figure 3).

Over fully sea ice covered areas, the OSI SAF products are used to subdivide the surface into concentrations of first-year (c_F) and multi-year (c_M) sea ice, with $c_F + c_M = 1$. The surface emissivity is then estimated as

$$\varepsilon = c_F \varepsilon_F + c_M \varepsilon_M$$

ε_F and ε_M are typical emissivities for first-year and multi-year sea ice, estimated separately for each AMSU-A channel.

The modelled emissivities are used by the RTTOV7 forward model to calculate radiances from the HIRLAM model profiles. Figure 4 shows the effect of using modelled emissivities compared to running RTTOV7 with a fixed value of $\varepsilon = 1$.

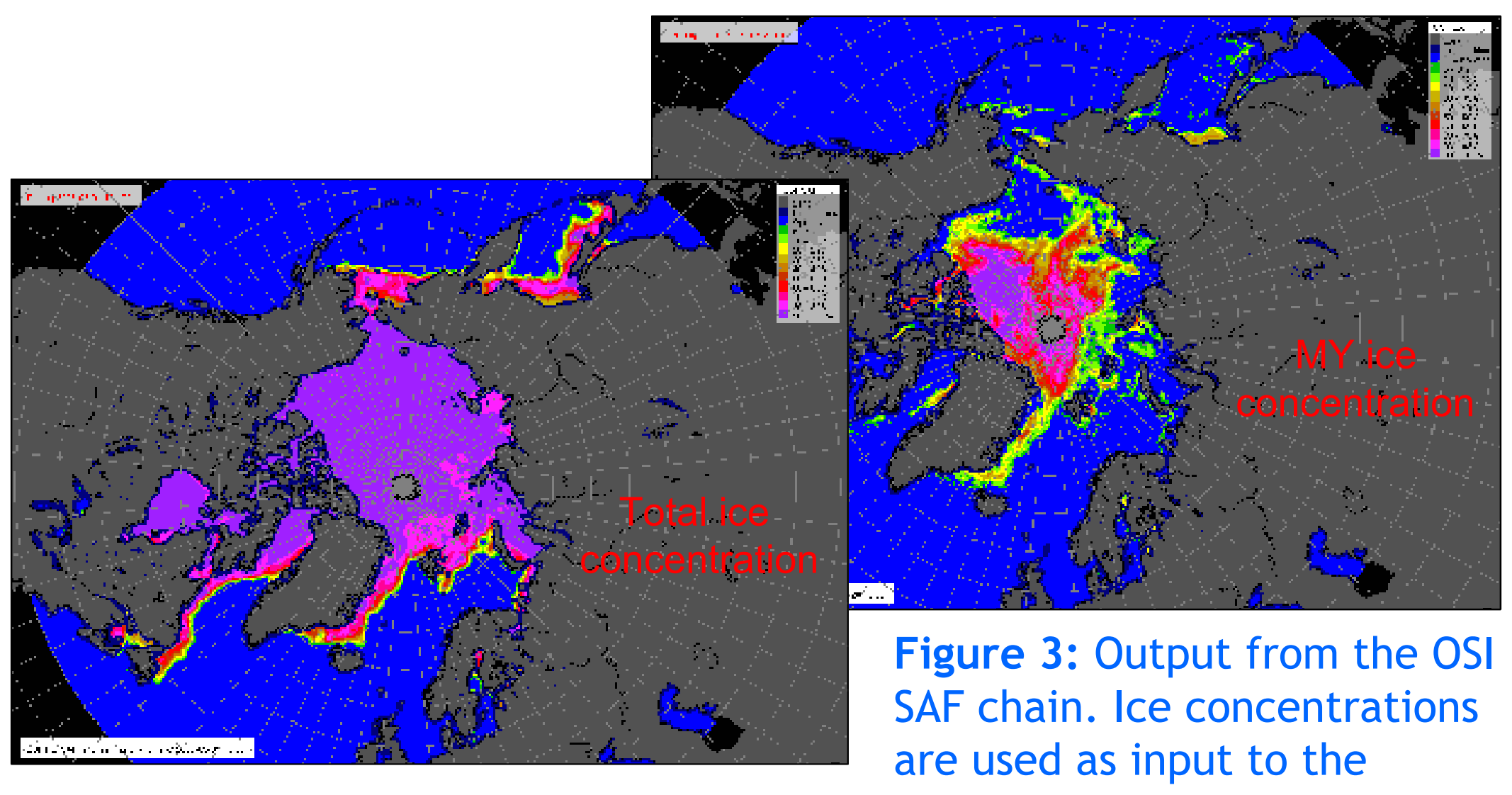

Figure 3: Output from the OSI SAF chain. Ice concentrations are used as input to the emissivity calculations

Future Extensions

An 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 and also take into account atmospheric water vapour and temperature profiles. Incidence angle dependence will also be included in the emissivity model.

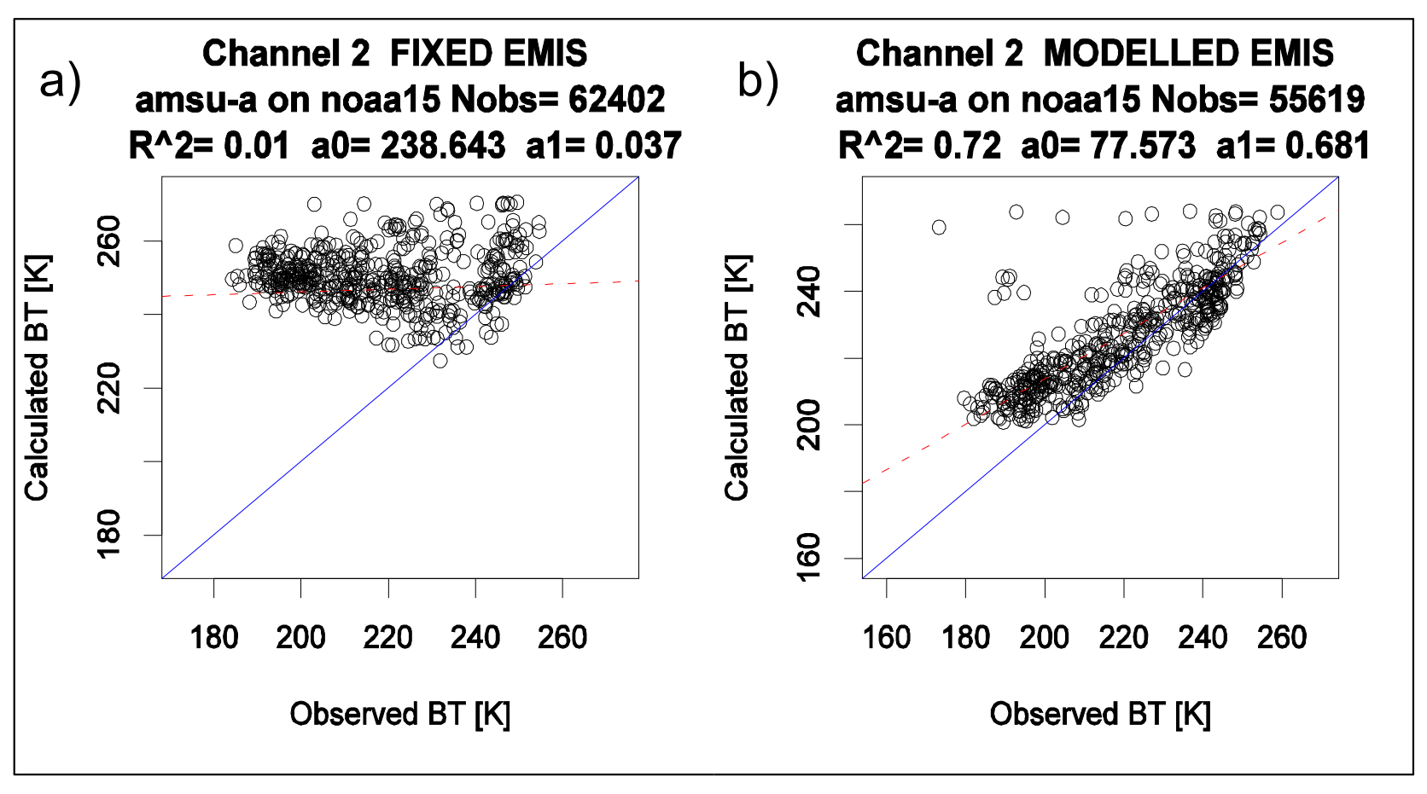

Figure 4: Observed vs. calculated Brightness Temperatures for AMSU-A channel 2 / 31.4 GHz. a) Fixed surface emissivity ($\varepsilon = 1$). b) Modelled surface emissivity.

Empirical determination of FY and MY ice emissivities

We use simplified theory for microwave radiative transfer, where the main assumptions are that
- The atmospheric attenuation can be reasonably approximated by an absorption coefficient and an effective atmospheric temperature T_a
- The water vapour load is minimal so the main contribution to the absorption is from oxygen

Then the surface emissivity can be 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 coefficient α is defined as:

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

T_{dn} represents the downwelling radiation as calculated by MWMOD for the simplified atmosphere with a minimal water vapour contribution.

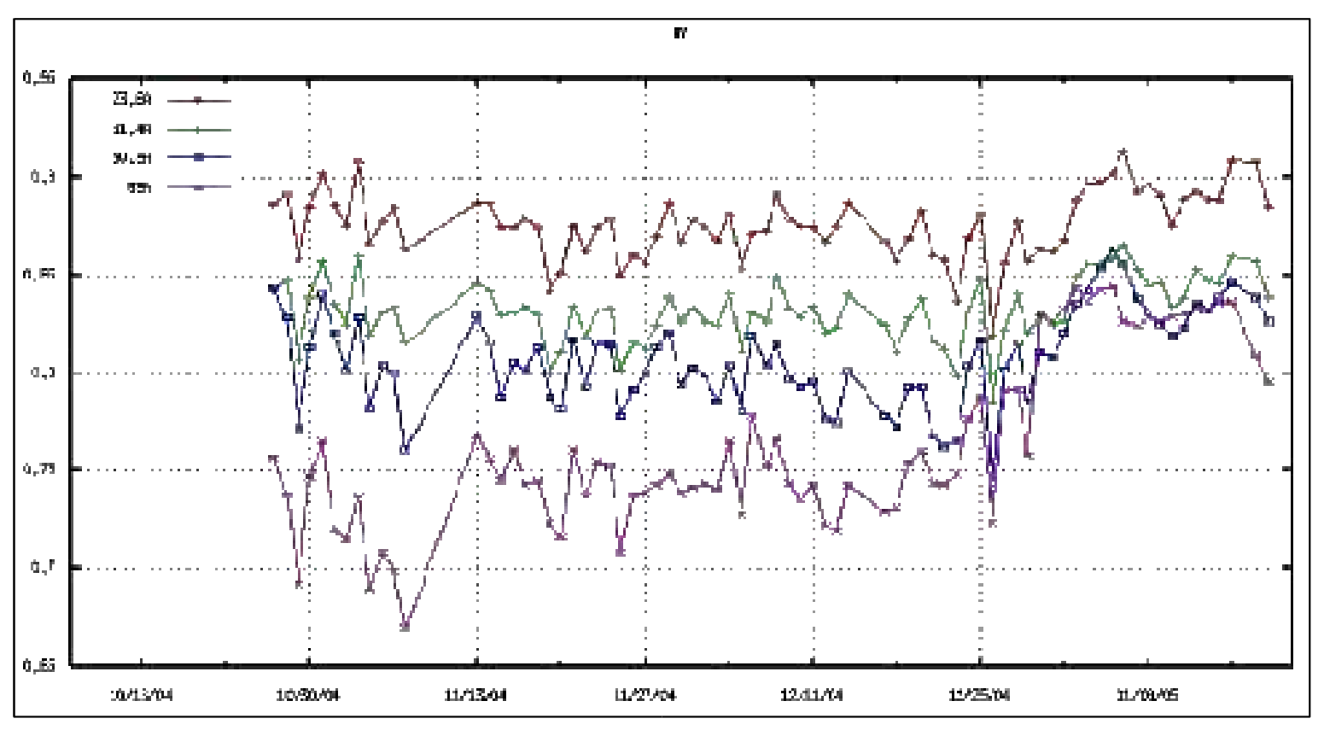

Figure 5: Example time series of AMSU-A emissivities for a limited area of Multi Year ice north of Greenland.

Conclusion and future work

Satellite observations are the main source of observation information in NWP over the ice covered Arctic regions. Improving methods for using this information helps improve the initial state of the HIRLAM NWP model, and is expected to be beneficial for forecasts over Europe.

A surface emissivity estimate of some accuracy is most important for the lower channels, but it indirectly affects all channels through the cloud check on the observed data. As we are not using any independent cloud mask on the AMSU-A data, it is important that the thresholds for the gross error check are set in an optimal way, and this is dependent of a good emissivity estimate. New emissivity formulations will lead to re-tuning of the thresholds.

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

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