RECENT DEVELOPMENTS IN THE USE OF ATOVS DATA AT ECMWF

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Abstract

Early 2007 saw the operational use of ATOVS data from METOP-A, Europe’s first operational polar-orbiting weather satellite, launched 19 October 2006. Operational monitoring of the first ATOVS data from METOP-A at ECMWF commenced two weeks after launch, and the quality of AMSU-A and MHS data was found comparable to that of similar instruments on the NOAA satellites. Assimilation trials show a positive forecast impact over the Southern Hemisphere. Similarly, data from the HIRS instrument showed expected quality, and adding the METOP-A HIRS instrument to the assimilation system results in a more neutral forecast impact.

Other recent developments include work towards the improved use of surface-sensitive microwave data over land in the ECMWF system. Experiments have been performed with methods recently developed at Météo France, based on a dynamic retrieval of surface emissivity from window channels and FG information. Applying this approach to data from AMSU-A and AMSU-B/MHS leads to smaller First Guess departures for surface-sensitive channels over land, and small positive forecast impact over both hemispheres. Bias correction and quality control require further attention.

INTRODUCTION

Data from the ATOVS family of instruments (AMSU-A, AMSU-B/MHS, HIRS) continue to contribute substantially to forecast skill in global numerical weather prediction (NWP). Currently, ATOVS data from six different polar orbiting satellites are available at ECMWF (NOAA-15-18, AQUA, METOP-A).

ASSIMILATION OF ATOVS DATA FROM METOP-A

Monitoring

On 19 October 2006, EUMETSAT entered the era of operational polar-orbiting weather satellites with the launch of METOP-A. Data from AMSU-A were routinely made available to users less than two weeks after launch, enabling swift feedback on data quality from monitoring within NWP systems, and early preparation for the operational use of the data. Operational monitoring of the data at ECMWF commenced on 2 November 2006, with monitoring of MHS and HIRS data later that year. METOP-A is able to fill the gap in AMSU-A coverage in the morning orbit left after the failure of the NOAA-17 AMSU-A instrument (Fig. 1).

Monitoring statistics showed very quickly that the quality of the data from all three instruments was as expected. Standard deviations and biases of First Guess (FG) departures were comparable to similar instruments on other platforms (e.g., Fig. 2), and the temporal stability was also excellent. In case of AMSU-A and MHS we compared the statistics with those from NOAA-18, whereas for HIRS data from NOAA-17 was used. Note that METOP-A flies the HIRS-4 instrument which boasts a somewhat smaller field of view than the HIRS-3 instrument onboard NOAA-17. Nevertheless, monitoring
statistics for the data after cloud screening showed little difference between the statistics for the two instruments.

![Figure 1](image)

**Figure 1:** Coverage of AMSU-A observations considered in the ECMWF assimilation system for a 6-hour period from 21 Z to 3 Z.

![Figure 2](image)

**Figure 2:** Standard deviations of FG (solid) and analysis (dotted) departures [K] for used AMSU-A data for the period 1-10 June 2007 over the Southern Hemisphere. Black indicates statistics for the METOP-A instrument, whereas red indicates statistics for the NOAA-18 instrument. b) As a), but for MHS. c) As a), but for HIRS compared to the HIRS instrument on NOAA-17.

Significant degradation of the HIRS data was observed in January, resulting from interference from the LRPT-B facility on METOP-A which was switched on during that time. After EUMETSAT’s decision to disable the LRPT-B facility, the data quality returned back to normal.

**Assimilation experiments**

In preparation for the operational use, assimilation experiments were performed in which the new data was added to the operational set of observations. This operational set included AMSU-A data from four other satellites, AMSU-B/MHS data from three other satellites, and HIRS data from NOAA-17. AIRS data and a range of other conventional and satellite data were also included. Three experiments were performed:

**CTL:** Experiment with the operational data use at the time.

**AMSU-A/MHS:** As control, but with METOP-A AMSU-A and MHS data added.

**HIRS:** As AMSU-A/MHS, but with METOP-A HIRS data added.
All experiments used ECMWF’s 12-hour 4DVAR, with a model resolution of T799 (~25 km) with 91 levels in the vertical up to 0.01 hPa, and an analysis resolution of T255 (~80 km) also with 91 levels in the vertical. The experiments were conducted for the period 5 December 2006 - 2 January 2007.

Comparison of the AMSU-A/MHS experiment with the CTL revealed a clear positive forecast impact over the Southern Hemisphere throughout the troposphere (e.g., Fig. 3). Forecast impact over the Northern Hemisphere was more neutral. This highlights that adding a fifth AMSU-A and a fourth AMSU-B/MHS is still providing significant additional information to the assimilation system, at least as long as the coverage is complementary, as is the case for AMSU-A on METOP-A.

Comparison of the HIRS and the AMSU-A/MHS experiments showed a neutral impact from adding the extra HIRS instrument to the system (Fig. 3). The impact may be smaller due to the presence of AMSU-A/MHS in the same orbit in our experiment configuration. Also, additional investigations highlight some short-comings in the cloud-detection currently used for HIRS (not shown), and these might restrict the otherwise achievable impact. Retuning of the cloud detection for HIRS is currently underway.

Based on the above results, ECMWF became the first NWP centre to use METOP-A data operationally when data from AMSU-A and MHS were introduced in the operational assimilation system on 11 January 2007. HIRS data were added to the operational assimilation on 19 March 2007, to foster the robustness of the set of observations used in the system.
IMPROVED USE OF SURFACE-SENSITIVE MICROWAVE DATA OVER LAND

The use of surface-sensitive microwave data over land is currently fairly limited in the ECMWF system. This is primarily due to difficulties in the specification of the land surface emissivity and/or skin temperature. The situation is different over sea, where lower emissivities, together with accurate emissivity models and sea surface temperature analyses are aiding the data use. In operations, the current scheme for assigning land surface emissivities is based on a scenes classification algorithm and typical, regression-based emissivity estimates for given land surfaces (Kelly and Bauer 2000). The scheme allows the assimilation of AMSU-A channels 5 and above, and AMSU-B/MHS channels 3 and 4, at least over land with low orography.

Method

Here we investigate a method recently employed at Météo France for the improved specification of land surface emissivity (Karbou et al. 2005). The method dynamically retrieves emissivity from suitable window channels, using FG information to estimate the other required terms in the radiative transfer equation. The retrieved emissivity is then applied for the forward calculations for the sounding channels.

Rearranging the radiative transfer equation yields:

\[
T_b = T_s \epsilon \Gamma + T_{atm}^+ + (1 - \epsilon) T_{atm}^- \Gamma
\]

\[
\epsilon = \frac{T_b - T_{atm}^+ - T_{atm}^- \Gamma}{T_s - T_{atm}^- \Gamma}
\]

Where \( T_b \) is the brightness temperature in a window channel, \( T_s \) is the skin temperature, \( \epsilon \) is the surface emissivity, \( T_{atm}^+ \) and \( T_{atm}^- \) are the atmospheric upwelling and down-welling brightness temperatures respectively and \( \Gamma \) is the net atmospheric transmissivity.

We apply this method to data from the AMSU-A and AMSU-B/MHS instruments. For AMSU-A, channels 2 (at 31.4 GHz) and 3 (at 50.3 GHz) are candidates for window channels for the emissivity estimation. The choice between the two is a trade-off between two aspects: Maximising the sensitivity to the surface (in order to reduce errors in the emissivity estimation) on the one hand, and reducing the frequency extrapolation required if emissivities are retrieved at one frequency and the applied at another on the other. The former favours channel 2, whereas the latter favours channel 3. For AMSU-B/MHS channel 1 is used to estimate the emissivity for the other sounding channels.

The above scheme was tested in the ECMWF assimilation scheme over the period 26 August - 26 October 2006. Four experiments were performed:

**CTL:** The control experiment in which the current operational land emissivity was used.

**EXP1:** Surface emissivities were retrieved dynamically, using channel 2 for AMSU-A, and channel 2 for AMSU-B/MHS.

**EXP2:** As EXP1, but the bias correction model allowed a constant offset over land for channels 4 and 5 of AMSU-A.

**EXP3:** As EXP2, but channel 3 was used for the AMSU-A emissivity retrieval.

For all four experiments we employed ECMWF’s 12-hour 4DVAR, with a model resolution at T511 (~40 km) and 91 levels in the vertical up to 0.01 hPa, and an analysis resolution of T159 (~125 km). AMSU-A channels 5-14 were used, with some restrictions over high orography for channels 5 and 6. Cloud and rain screening was based on a simple departure check on channel 4, with departures outside ± 0.7 K considered cloud or rain contaminated. All three experiments included all observations assimilated operationally at the time, in particular AMSU-A data from 4 satellites, and AMSU-B/MHS data from 3 satellites.

Departure statistics
Using retrieved emissivities greatly reduces the departures between simulated and observed brightness temperatures (BTs) for the lower tropospheric channels over land when compared to the currently used emissivity scheme (Fig. 4). This is true for all experiments with the dynamically retrieved emissivity. The finding suggests an improved specification of the surface emissivity in these experiments.

Figure 4: Histograms of FG departures for NOAA-16 AMSU-A channels 4 to 6 (before bias correction). Black shows the departures with the current operational scheme, blue the departures with emissivities retrieved with AMSU-A channel 3.

FG-departure statistics for bias-corrected channel 4 and 5 over land in EXP1 show residual observation-minus-FG biases, while for the same experiment there is no bias over sea (Fig. 5). The bias changes with scan angle, with the largest biases for the central fields of view which are most sensitive to the surface. The bias in channel 4 can potentially degrade the performance of the currently employed cloud/rain screening which assumes that channel 4 is unbiased. Biases in channel 5 are likely to lead to systematic increments over land.

Figure 5: Histograms of FG-departures for NOAA-16 AMSU-A channel 4 (after bias correction) for EXP1. Solid red lines show the data for the central fields of view, green dashed lines the outer fields of view. The left plots is for data over sea, the right for data over land.

Biases in the FG-departures of surface-sensing channels can be a result of systematic errors in the skin temperature or emissivity estimation. In our assimilation, different methods are used for land and sea to estimate these parameters. Therefore it would be desirable to have a separate bias correction over these areas. A new 2-month analysis experiment (EXP2) was set up in which we allow a bias offset over land. Results show that this indeed reduces the bias over land (not shown). However,
more work may be required to account for the different scan characteristics over land and sea noted earlier.

The analysis of FG-departure statistics for day and night conditions for the operational emissivity scheme revealed a diurnal variation of biases in the surface sensing channels (not shown). Such variations suggest possible errors in the skin temperature estimation used for emissivity retrievals. Correcting biases related to the skin temperature errors are a challenging problem as these errors are dependent on surface type. Desert is one example of a surface type for which skin temperature is difficult to define as the penetration depth for dry sand is a few centimeters for microwaves (Prigent et al. (1999). When the dynamic emissivity retrieval approach is used, these errors will get aliased into the retrieved emissivities, resulting in erroneous emissivity estimations. However, errors in the skin temperature will be compensated to some extent by the errors in retrieved emissivity.

Biases observed in FG-departures can also be a result of using the 31.4GHz (channel 2) observations to derive emissivities for the 50 GHz channels (channels 3, 4, 5, 6). For some types of surfaces like snow or desert, the emissivity in the microwave region has a significant dependence on frequency. To investigate this aspect, another 2-month analysis experiment was set up (EXP3), with emissivities being retrieved from 50.3 GHz observations. By comparing bias maps calculated for EXP2 and EXP3, biases are more homogenous when channel 3 (50.3 GHz) is used to retrieve emissivities (Fig. 6). Also, compared with maps of mean FG-departures from the control experiment, both EXP2 and EXP3 biases appear much smaller and more homogenously distributed.

![Figure 6: Mean FG-departures [K] for NOAA-16 AMSU-A channel 4 for EXP2 (top) and EXP3 (bottom).](image)

**Forecast impact**

In terms of forecast scores, using channel 3 derived emissivities generally resulted in a positive impact over both hemispheres (Fig. 7). This is an encouraging result, as it suggests that the new emissivity method is capable of producing improved analyses. More experimentation over different seasons is required to confirm and better characterise the forecast impact.
CONCLUSIONS

The addition of ATOVS data from METOP-A yielded significant forecast improvements over the Southern Hemisphere in the ECMWF system, even though the data is now the fifth AMSU-A instrument and the fourth AMSU-B/MHS instrument assimilated in the system. METOP-A fills the previous gap of AMSU-A data in the morning orbit. Since their operational assimilation (from 11 January 2007 for AMSU-A and MHS, and 19 March 2007 for HIRS), the instruments have proved stable as expected, with FG-departure statistics comparable to those for similar instruments.

Improvements for the specification of surface emission for the assimilation of surface-sensitive microwave radiances are currently under investigation at ECMWF. Experiments that use emissivities dynamically retrieved from window channels to specify the emissivity for the sounding channels show encouraging results. A significant reduction in the FG-departures for the surface-sensitive sounding channels is observed, together with an increase in the number of observations that can be considered for assimilation. Experiments over a 2-month period indicate positive forecast impact from the revised emissivity specification. Bias correction and quality control, especially in cloudy or rainy areas and over certain surface types require further attention.

REFERENCES