

Initial results from using ATMS data at ECMWF

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Abstract

This paper reports on the first experiences with ATMS data at ECMWF, both in terms of the contribution to the calibration/validation exercise, and in terms of preliminary assimilation trials. Comparisons in brightness temperature space against short-term forecasts are used to further establish the fidelity of the data.

Monitoring of ATMS data against short-term forecasts show that the data are generally of good quality, with a noise performance that is well within specification and, after appropriate averaging, comparable to or better than that of AMSU-A. Biases vary smoothly with scan-positions, even before an appropriate antenna pattern correction has been established, and ATMS looks better than AMSU-A in this regard. Outer scan positions can be assimilated without restrictions due to biases, and together with the wider swath this leads to a much improved coverage from ATMS compared to one AMSU-A.

The analysis and forecast impact in preliminary assimilation trials is significantly positive over the Southern Hemisphere, whereas forecast impact over the Northern Hemisphere is more neutral.

Introduction

The Suomi-NPP satellite was launched on 28 October 2011, as a preparatory satellite for the next generation of operational meteorological polar orbiting satellites of the USA. It carries two payloads of particular relevance to Numerical Weather Prediction (NWP), the Advanced Technology Microwave Sounder (ATMS) and the Cross-track Infrared Sounder (CrIS). ATMS is the new microwave temperature and humidity sounding radiometer, building on the AMSU-A and MHS heritage, whereas CrIS is an infrared radiometer, with 1305 spectral channels.

This paper reports on an early evaluation of ATMS data, in terms of a comparison against short-term forecasts to calibrate and validate the data, and in terms of preliminary assimilation trials. The results presented here have been obtained during the calibration/validation phase for ATMS, and data characteristics are therefore subject to change as the data processing is further improved. At the time of ITSC-18, a continuous real-time data dissemination to European members of the cal/val team had not been established, and hence the results reported here are based on an offline dataset which was kindly made available by NRL, and converted to BUFR with AAPP. CrIS data were not available to NWP centres at the time of ITSC-18, and hence experience with this data will be reported elsewhere.

ATMS

ATMS is a 22 channel microwave radiometer that combines AMSU-A and MHS heritage channels with one additional temperature channel and two humidity sounding channels (Table 1, see also Muth et al. 2004). All channels are sampled every 1.11° at 96 scan positions, with a cross-track swath width of 2300 km, significantly wider than AMSU-A or MHS.

Table 1: ATMS channels. The FOV size differs by channel, as indicated by shading: orange indicates a FOV of 75 km at nadir, blue 32 km, and green 16 km. The polarisation changes with cross-track scan position, and only the polarisation at nadir is given. ¹ indicates a polarisation difference to the equivalent AMSU-A or MHS channel, ² indicates a new channel not previously available on AMSU-A or MHS, and ³ indicates a channel for which the central frequency has changed significantly compared to MHS.

Channel number	Frequency [GHz] and polarisation at nadir	Channel number	Frequency [GHz] and polarisation at nadir
1	23.8 V	12	$57.29 \pm 0.3222 \pm 0.048$ H
2	31.4 V	13	$57.29 \pm 0.3222 \pm 0.022$ H
3	50.3 H ¹	14	$57.29 \pm 0.3222 \pm 0.010$ H
4	51.76 H ²	15	$57.29 \pm 0.3222 \pm 0.0045$ H
5	52.8 H ¹	16	88.2 V
6	53.596 ± 0.115 H	17	165.5 H ^{1,3}
7	54.4 H	18	183.31 ± 7 H ¹
8	54.94 H ¹	19	183.31 ± 4.5 H ²
9	55.5 H	20	183.31 ± 3 H
10	57.29 H	21	183.31 ± 1.8 H ²
11	$57.29 \pm 0.3222 \pm 0.217$ H	22	183.31 ± 1 H

Of particular relevance to NWP is that the spatial sampling, field of view (FOV), and noise characteristics of the temperature-sounding channels of ATMS differ markedly from those of AMSU-A. The data are sampled more densely (1.11° compared to 3.33°), with a smaller footprint (32 km at nadir compared to 48 km), but larger noise (e.g., specification of 0.5 K compared to 0.25 K for tropospheric sounding channels). To achieve a performance comparable to AMSU-A, and to reduce the noise to levels desirable for NWP, averaging of ATMS footprints is necessary. Several approaches have been developed; here we consider only the simplest method, averaging of the neighbouring 3 scan-positions and scan-lines (referred to as 3x3 averaging). This averaging will be applied to channels 3-22, and unless indicated otherwise only statistics for averaged data will be shown here.

Another aspect of ATMS is that channels 1 and 2 have a significantly larger FOV size than the sounding channels (75 km compared to 32 or 16 km), even after the 3x3 averaging. So the spatial detail represented in these channels does not match that of the temperature sounding channels. Channels 1 and 2 are frequently used in quality control decisions for NWP, and this mis-match in scales has to be kept in mind when adopting quality control procedures from AMSU-A.

Experiments and quality control

ATMS brightness temperatures have been assessed in the ECMWF assimilation system. To do so, two experiments are presented here: a control experiment in which ATMS data are passively monitored, and another experiment in which ATMS data are actively assimilated. Both experiments use ECMWF's 12 h 4DVAR system, with a spatial model resolution of T319 (~60 km), an incremental analysis resolution of T159 (~125 km) and 91 levels in the vertical. The period for the experimentation is 15 December 2011 – 6 February 2012, and 10-day forecasts were calculated from each 0 Z analysis.

In the ATMS experiment, the temperature sounding channels 6-15 and the humidity sounding channels 18-22 are used (channels 6-8 and 18-22 over open sea only). The quality control for cloud or rain contaminated observations is as follows: If the absolute value of the FG-departure for channel 3 is larger than 5 K, channels 6-8 and 18-22 are excluded. In addition, if an observation-based estimate of the liquid water path is larger than 0.12 kg/m^2 , channels 6, 7, and 18 are excluded ($>0.15 \text{ kg/m}^2$ for channel 8). This estimate is based on channels 1 and 2, and follows Grody et al. (2001). Furthermore, a threshold check on a scattering index is used for the humidity sounding channels, excluding data for which $T_{b16} - T_{b17} - (-46.94 + 0.248 \theta) > 10 \text{ K}$ (following Bennartz et al. 2002, with θ the zenith angle in degrees). Bias correction is done in the variational framework (e.g., Dee 2004), and the bias predictors are the same as for equivalent AMSU-A or MHS channels (see Bormann and Bauer 2010). The data are thinned to a resolution of 140 km.

Due to problems with initial versions of the antenna pattern correction for ATMS, our results are based on so-called antenna temperatures, ie, values before antenna pattern correction.

Analysis of departure statistics

In the following, we present an evaluation of ATMS data in terms of departure statistics against clear-sky brightness temperatures simulated from short-term forecasts as used in ECMWF's 4DVAR assimilation system. Monitoring against short-term forecasts from NWP is a powerful tool for calibration/validation of new satellite data, and only the main findings are summarised here.

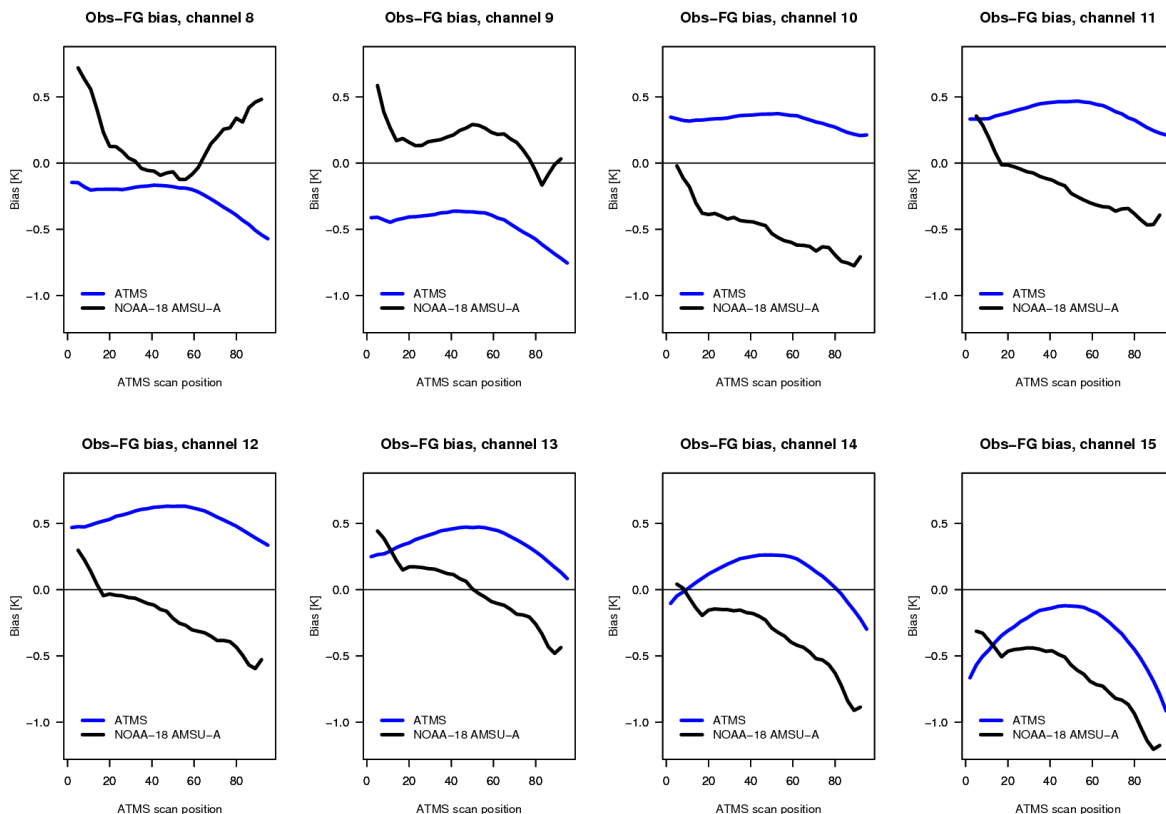


Fig. 1: Observation minus FG bias (before bias correction) as a function of ATMS scan position for ATMS channels 8-15 (blue), in comparison to equivalent AMSU-A channels/scan-positions from NOAA-18 (black). Statistics are based on all data over sea, between $\pm 60^\circ$ latitude, for the period 20-29 December 2011.

A comparison of scan-position dependent biases for ATMS and AMSU-A is given in Fig. 1. Note that the AMSU-A values are based on antenna-corrected data, and include a “gamma” adjustment in the radiative transfer calculations. Two main points are worth noting: 1) The scan biases are considerably smoother for ATMS, especially for the outermost scan positions, for which the AMSU-A data tends to show marked differences in the bias characteristics. Due to these different bias characteristics, the outermost 3 AMSU-A scan-positions on either side are currently not assimilated at ECMWF. It appears that such a cautious data selection is not necessary for ATMS, and instead data from all scan positions can be used. Combined with the wider swath width, this leads to a significantly better coverage of useable data from ATMS compared to AMSU-A (33 % more footprints after averaging). 2) The magnitude of the biases for ATMS is overall comparable to that of AMSU-A, bearing in mind the differences in terms of antenna pattern correction and radiative transfer simulations.

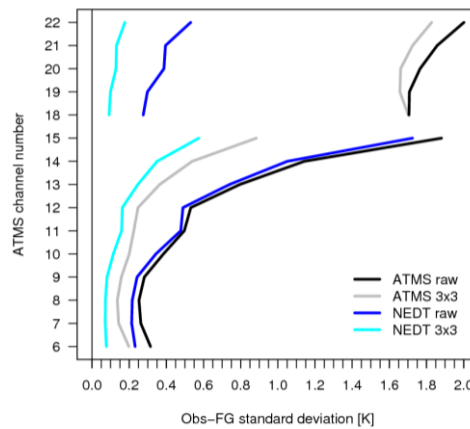


Fig. 2: Standard deviation of FG-departures after quality control for ATMS channels 6-15 and 18-22. Black indicates values before footprint averaging, grey after averaging 3x3 footprints. Blue and cyan are estimates of random instrument noise as provided in the data, before and after averaging, respectively. Based on data over sea after bias correction and quality control for 20-29 December 2011.

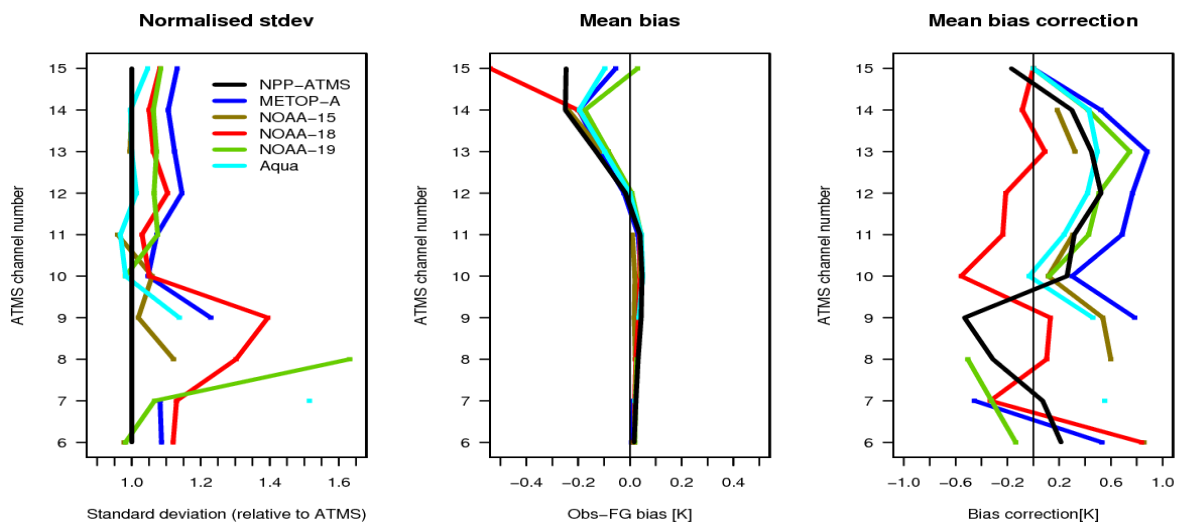


Fig. 3: FG-departure statistics for ATMS temperature sounding channels after 3x3 averaging, in comparison to equivalent AMSU-A channels for all other AMSU-A instruments currently assimilated at ECMWF. The three panels show the standard deviation, normalised to one for ATMS (left), the mean bias after bias correction (middle), and the mean bias correction (right) Statistics are based on data after bias correction and quality control for 20-29 Dec. 2011.

Standard deviations of FG-departures suggest a noise performance of ATMS that is well within specifications, and overall consistent with pre-launch measurements (cf, Bell et al. 2011 for pre-launch noise measurements). This can be seen in Fig. 2, primarily for the temperature sounding channels. Also shown are the average instrument noise as provided in the data, and the difference between the standard deviations of FG-departures and the noise values is broadly consistent with estimates for the errors in short-term forecasts, before and after averaging. After the 3x3 averaging, the performance of ATMS is typically comparable to or better than that of AMSU-A instruments currently used in the ECMWF system (Fig. 3).

For the humidity channels, the evaluation against the FG is less stringent, as the errors in the FG, the representativeness and the quality control are larger, but the overall performance is nevertheless consistent with that of MHS data.

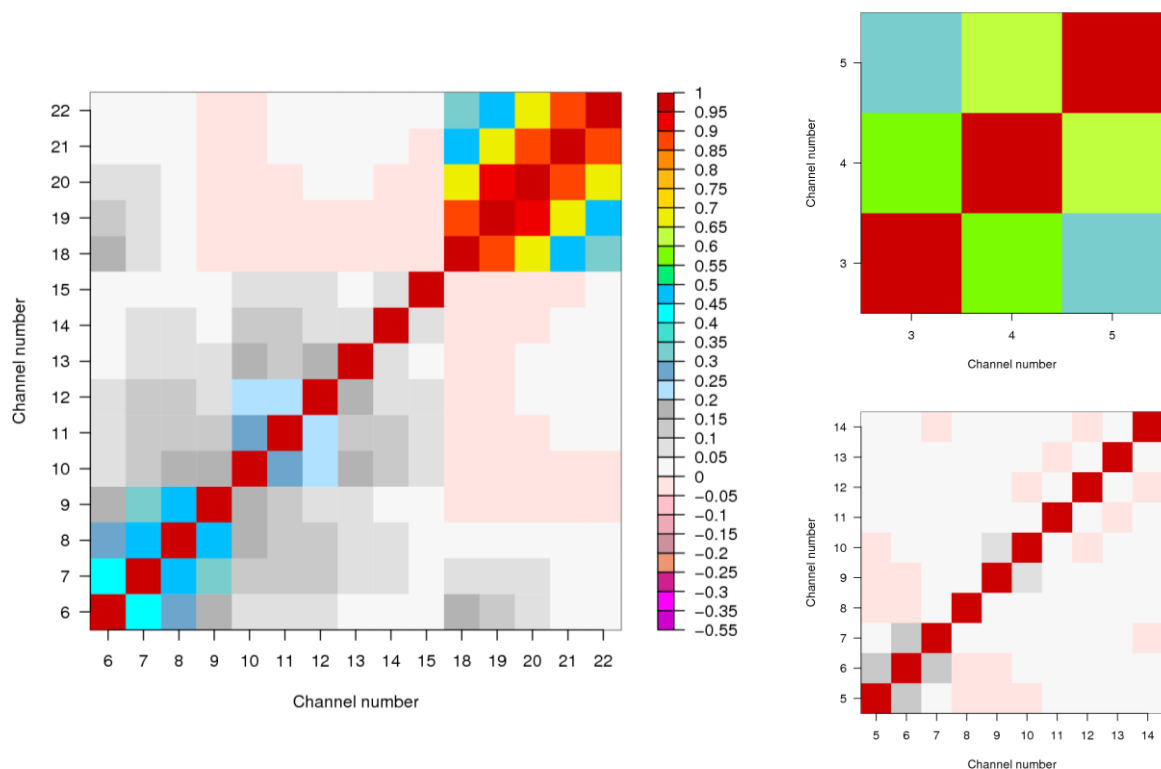


Fig. 4: Estimates of inter-channel error correlations based on the Desroziers diagnostics for ATMS (left). For comparison, estimates for NOAA-18 are also shown on the right, with MHS at the top and AMSU-A at the bottom. The former can be used for comparisons with ATMS channels 18, 20, and 22, whereas the latter can be used for comparisons with ATMS channels 6-15. Statistics are based on data for 21-31 December 2011, over sea, after bias correction and after quality control.

While the characteristics in terms of FG-departure statistics suggest a performance of ATMS comparable or better than AMSU-A in terms of noise, closer analysis suggests that currently there is a notable difference in the size of the contributions of random and correlated noise. An estimate of spatial and inter-channel error correlations for ATMS points to the presence of errors that are correlated spatially and between channels (e.g., Fig. 4), with the size of these correlations being considerably larger for ATMS than for AMSU-A counterparts. These correlations have been calculated from departures obtained from the assimilation of ATMS data, using the Desroziers et al. (2005) diagnostic, following the approach of Bormann and Bauer (2010).

The error correlations noted above are likely related to scanline-dependent biases noticeable as weak striping effects in maps of FG-departures (e.g., Collard et al. 2012, Doherty et al. 2012). These effects may be due to a sub-optimality of the calibration configuration, leading to correlated calibration errors. Further investigations into these phenomena are necessary and it is likely that this aspect will be improved during the calibration/validation phase.

Further aspects of ATMS data have been studied on the basis of departure statistics, such as the temporal stability and within-orbit biases. Overall, the performance for the temperature sounding channels was found at least comparable to that of current AMSU-A instruments. Employing departure-based methods described in Lu et al. (2011) also gives no indication of significant pass-band shifts for the temperature sounding channels (not shown).

Assimilation results

We will now discuss the results from our initial assimilation trials with ATMS data. These trials were motivated by the overall good quality of the ATMS data, as summarised in the above departure characteristics. In our trials, ATMS was added to the full observing system used operationally at ECMWF at the time, which includes conventional data as well as radiances from 5 AMSU-A instruments, 3 MHS instruments, 2 HIRS instruments, as well as from AIRS and IASI. In particular, NOAA-18 (AMSU-A & MHS), NOAA-19 (AMSU-A & MHS), and Aqua (AMSU-A) already provide similar microwave sounding data in this system in orbits very similar to NPP.

Analysis diagnostics show consistently a positive impact on tropospheric humidity from the assimilation of ATMS data, as evidenced through reduced standard deviations of FG-departures for humidity sounding channels from microwave as well as infrared sounding instruments (e.g., Fig. 5). This suggests smaller errors in the FG and hence a positive impact on short-term forecasts. Otherwise, departure statistics are overall largely unaltered, suggesting ATMS is generally consistent with the rest of the observing system.

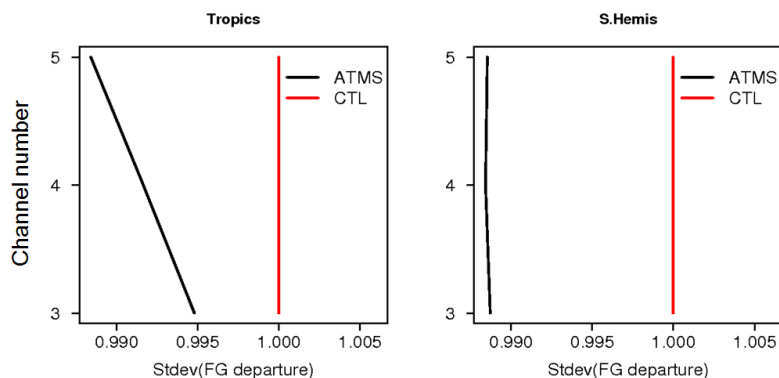


Fig. 5: Standard deviations of FG departures for all used MHS data combined, normalised to one for the CTL experiment. Red shows statistics for the CTL, black for the ATMS experiment, over the Tropics (left) and the Southern Hemisphere extra-tropics (right).

The forecast impact from the assimilation of ATMS data is neutral to significantly positive. The impact is significantly positive for the Southern Hemisphere geopotential, where it reaches 2 % over a range of forecast lead times and tropospheric levels (translating to an improvement in forecast skill of around 1-2 h in terms of forecast lead time). The forecast impact over the Southern Hemisphere is especially encouraging, given that the NPP orbit is already fairly well observed in terms of microwave

sounding observations. It appears that the additional observations and their resulting influence of reducing analysis uncertainty are still providing benefit in the assimilation system.

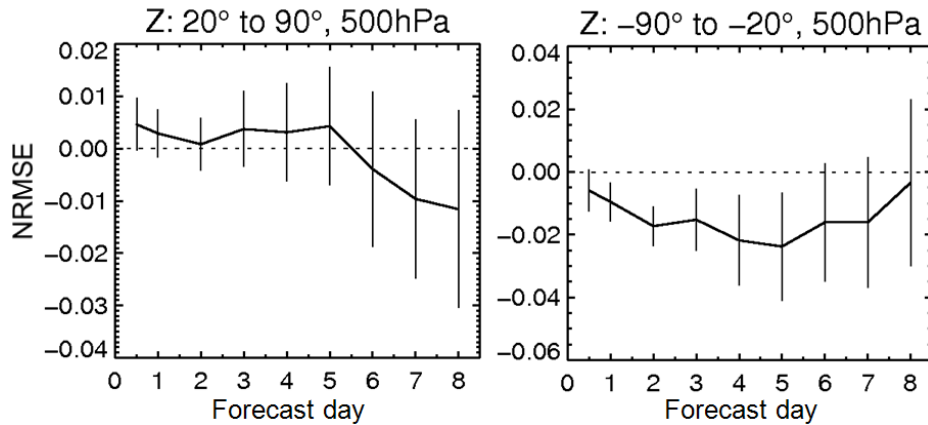


Fig. 6: Normalised difference in the root mean squared forecast error for the 500 hPa geopotential as a function of forecast range (days) for the ATMS and the control experiment. Negative values show a reduction of forecast errors resulting from the assimilation of ATMS data. Results for the Northern Hemisphere are shown on the left, Southern Hemisphere on the right. The period is 15 December 2011 – 6 February 2012, and the verification is again each experiment's own analysis (46-54 cases). The error bars indicate 95 % statistical confidence intervals.

It is worth noting that the experiments presented here use an observation error for the tropospheric temperature sounding channels of ATMS of 0.35 K (rising to 1.4 K for channel 15). This specification of the observation error is considerably larger than the one used operationally now at ECMWF for equivalent AMSU-A channels (0.2 K). Experiments were also conducted with this smaller observation error, as it appears justified from the departure statistics presented earlier. While the forecast impact was still positive over the Southern Hemisphere, the results were slightly worse than the ones presented here. This is in contrast to a large positive forecast impact that recently resulted from reducing the observation errors for AMSU-A from 0.35 K to 0.2 K for the tropospheric and lower stratospheric sounding channels in the ECMWF system. The lack of improvement from the observation error reduction may be related to the error correlations noted earlier for the pre-operational ATMS data, as these are neglected in the assimilation system.

Conclusions

This paper reports on the first experiences at ECMWF with ATMS data, both in terms of the contribution to the calibration/validation exercise, and preliminary assimilation trials. The main findings are:

- The instrument appears to be performing well, with noise values well within specifications and, after averaging, comparable to or better than current AMSU-A instruments.
- Scan-biases are much smoother than commonly found for AMSU-A, even before antenna pattern correction, allowing the outer scan positions to be included in the assimilation. Together with the wider swath this leads to a significantly improved coverage of useable observations with ATMS compared to AMSU-A.

- The analysis and forecast impact is significantly positive over the Southern Hemisphere, whereas forecast impact over the Northern Hemisphere is more neutral.

The forecast impact results from these initial experiments are encouraging, especially given the number of observations already assimilated from a similar orbit. The current results are preliminary in various ways: in particular, they use a relatively low spatial resolution of the assimilation system, and quality control procedures may need to be refined, for instance, bearing in mind the scale-mismatch between the quality control channels 1 and 2 and the other assimilated sounding channels. Also, ATMS data are still subject to refinements, the optimisation of the calibration mentioned here being one example. Furthermore, further trials over different seasons are required to confirm our findings. These aspects will be addressed once the real-time dissemination of ATMS data to European users has been established.

References

- Doherty, A. et al., 2012: Early analysis of ATMS data at the Met Office. Proceedings of the 18th International TOVS Study Conference, Toulouse, France.
- Bell, W., N. Bormann, T. McNally, S. English, Q. Lu, C. Peubey, A. Booton, N. Atkinson, 2011: Preparations for the assessment of NPP data at ECMWF and The Met Office. 2011 EUMETSAT Meteorological Satellite Conference, Oslo, Norway [available online: http://www.eumetsat.int/Home/Main/AboutEUMETSAT/Publications/ConferenceandWorkshopProceedings/2011/groups/cps/documents/document/pdf_conf_p59_s4_04_bell_v.pdf]
- Bennartz, R., A. Thoss, A. Dybbroe, and D.B. Michelson, 2002: Precipitation analysis using the Advance Microwave Sounding Unit in support of nowcasting applications. *Meteorol. Appl.*, 9, 177-189.
- Bormann, N. and P. Bauer, 2010: Estimates of spatial and inter-channel observation error characteristics for current sounder radiances for NWP, part I: Methods and application to ATOVS data. *Q.J.Roy.Meteorol.Soc.*, **136**, 1036-1050.
- Collard, A., J. Derber, R. Treadon, N. Atkinson, J. Jung, K. Garrett, 2012: Toward assimilation of CrIS and ATMS in the NCEP Global Model. Proceedings of the 18th International TOVS Study Conference, Toulouse, France.
- Dee, D., 2004: Variational bias correction of radiance data in the ECMWF system. Proceedings of the ECMWF workshop on assimilation of high spectral resolution sounders in NWP, ECMWF, Reading, UK, 97-112.
- Desroziers, G., L. Berre, B. Chapnik and P. Poli, 2005: Diagnosis of observation, background and analysis-error statistics in observation space. *Q.J.Roy.Meteorol.Soc.*, **131**, 3385-3396.
- Grody, N., J. Zhao, R. Ferraro, F. Weng, and R. Boers, 2001: Determination of precipitable water and cloud liquid water over oceans from the NOAA-15 Advanced Microwave Sounding Unit. *J.Geophys.Res.*, 106, D3, 2943-2953.
- Lu, Q., W. Bell, P. Bauer, N. Bormann, C. Peubey, 2011: Characterizing the FY-3A microwave temperature sounder using the ECMWF model. *J. Atmos. Oceanic Technol.*, **28**, 1373-1389.
- Muth, C., Lee, P.S., Shiue, J. and Webb, W.A., 2004: Advanced Technology Microwave Sounder on NPP and NPOESS, in Proc. 2004 IEEE Geosci. Rem. Sens. Symp., Anchorage, AK, Sep 20-24, pp 2454- 2458.