Recent developments in the use of ATOVS data at ECMWF

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Introduction

Data from the ATOVS series of instruments continue to play a major role in the ECMWF assimilation system. Level 1c radiances are assimilated in clear-sky conditions, subject to a number of quality control checks. The data contribute significantly to the current forecast skill.

In the following, we will briefly summarise the status of the assimilation of ATOVS data at ECMWF, before highlighting some recent and upcoming changes in the use of ATOVS data. The latter includes the correction of an incorrect use of a parameterisation of the Zeeman effect for AMSU-A, a change in the bias correction for AMSU-A channel 14, and a planned change in the bias correction for HIRS (and AIRS) short wave channels.

Status of ATOVS data at ECMWF

Currently, ATOVS data from six satellites are assimilated (Table 1), subject to data availability and quality. Where available, data from the EARS system are also used, improving greatly the data coverage for our early-delivery analyses that are used to produce the operational forecasts. Data from the Asia-Pacific RARS system (e.g., Griersmith 2008) are monitored operationally since 3 June 2008, with a view to later operational use.

For NOAA-16 and AQUA, the lower tropospheric channels are not used, as the cloud/rain quality control for these currently relies on channel 4, which is very noisy for these satellites. Alternative ways of quality control are being investigated, so that these channels can be used again in the future.

Table 1: Current use of ATOVS data at ECMWF.

	HIRS	AMSU-A	AMSU-B/MHS	EARS
NOAA-15	No: unstable	Yes (not ch 6, 11, 14)	No: quality	Yes
NOAA-16	No: unstable	Yes (not ch 5-7/8)	No: quality	Yes
NOAA-17	Yes	Instrument failed	Yes	Yes
NOAA-18	No: unstable	Yes	Yes	Yes
AQUA	n/a	Yes (not ch 5-7)	n/a	n/a
METOP-A	Yes	Yes	Yes	n/a

The latest additions to the ATOVS data use have been the AMSU-A, MHS, and HIRS instruments from METOP-A which was launched 19 October 2006. The first AMSU-A and MHS data were received and monitored operationally within two weeks after launch, and the AMSU-A and MHS radiances were assimilated operationally from 11 January 2007 onwards, thus becoming the first METOP-A data to be used operationally by an NWP centre. This was after the monitoring confirmed that the data characteristics were within expectations, and after a short assimilation trial demonstrated a small positive impact from using the extra data in the operational system (e.g., Fig. 1).

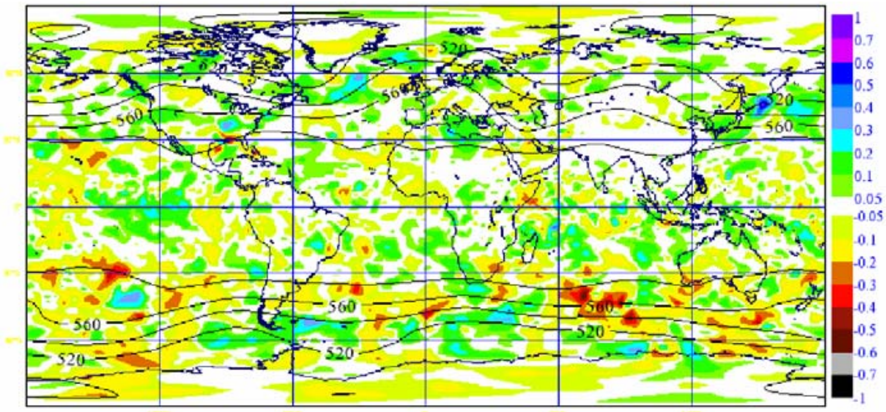

Figure 1: Colours indicate the normalised difference in the root mean square error of the 3-day 500 hPa geopotential forecast between the experiment with METOP-A AMSU-A and MHS and the control, averaged over 17 cases between 12 and 28 December 2006. Yellow/red colours indicate an improvement from the assimilation of METOP-A data. Contours show the mean geopotential [gpdm].

Update of RTTOV coefficients for AMSU-A

During the production of the ERA-40 reanalysis (e.g., Uppala et al. 2005), it was found that significant discrepancy existed between the treatment of the top stratospheric channels of SSU and AMSU-A, in particular between channel 3 of SSU and channel 14 of AMSU-A during the polar winters. The weighting functions for these two channels peak at similar altitudes. However, while the analysis followed one instrument, significant residual analysis departures remained in the other (e.g., Fig. 2), and these differences could not be resolved through retuning of the bias correction. As a result, channel 3 of SSU was excluded from the reanalysis after 3 July 1999.

Detailed investigations revealed that the origin of the discrepancy was an incorrect parameterisation of the Zeeman effect used in the line-by-line (LBL) model that was used to train RTTOV, the radiative transfer model employed in the ECMWF assimilation system (e.g., Saunders et al. 1999). The stratospheric channels of AMSU-A are located in the O_2 absorption band between 50 and 60 GHz. The O_2 molecule has a permanent magnetic dipole moment in the ground electronic state. In the presence of a geomagnetic field, isolated O_2 lines are split into a number of sub-lines because of the Zeeman effect. The Zeeman splitting of the O_2 lines becomes important for radiation originating from those regions of the atmosphere where the line-width becomes comparable to the effect from Zeeman splitting (e.g., pressures lower than 10 hPa) and for frequencies close to resonance. In the case of AMSU-A, Zeeman splitting has a measurable impact on the uppermost channel 14. While RTTOV itself does not include a parameterisation for the Zeeman effect, the LBL model used to train RTTOV included a scalar approximation of the Zeeman effect, as defined by Liebe et al. (1993). In this approximation, the Zeeman effect is modelled through a simple broadening of the O_2 absorption line.

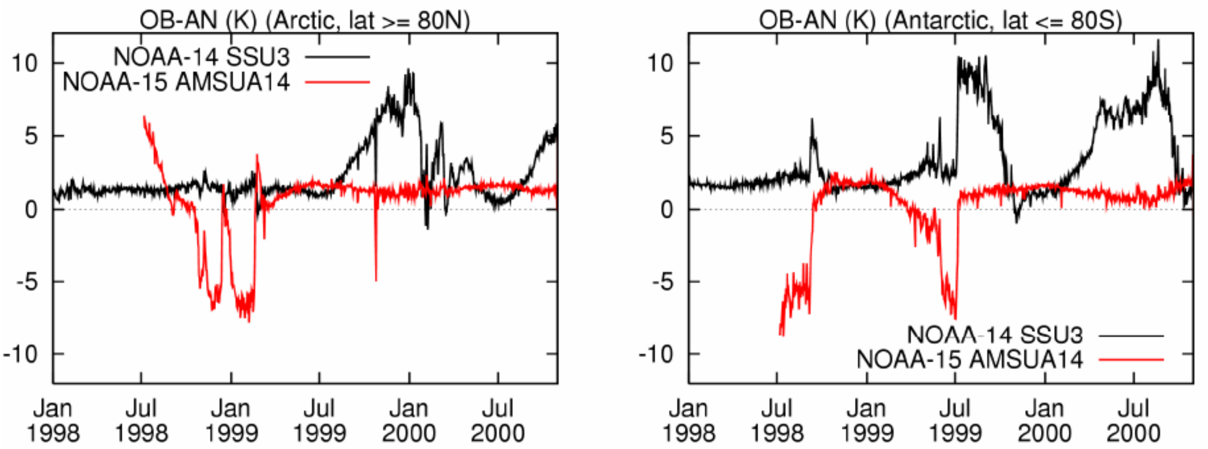

Figure 2: Mean uncorrected observation minus analysis departures for SSU channel 3 on NOAA-14 (black) and AMSU-A channel 14 on NOAA-15 (red) over the Arctic (left) and Antarctic (right) in ERA-40.

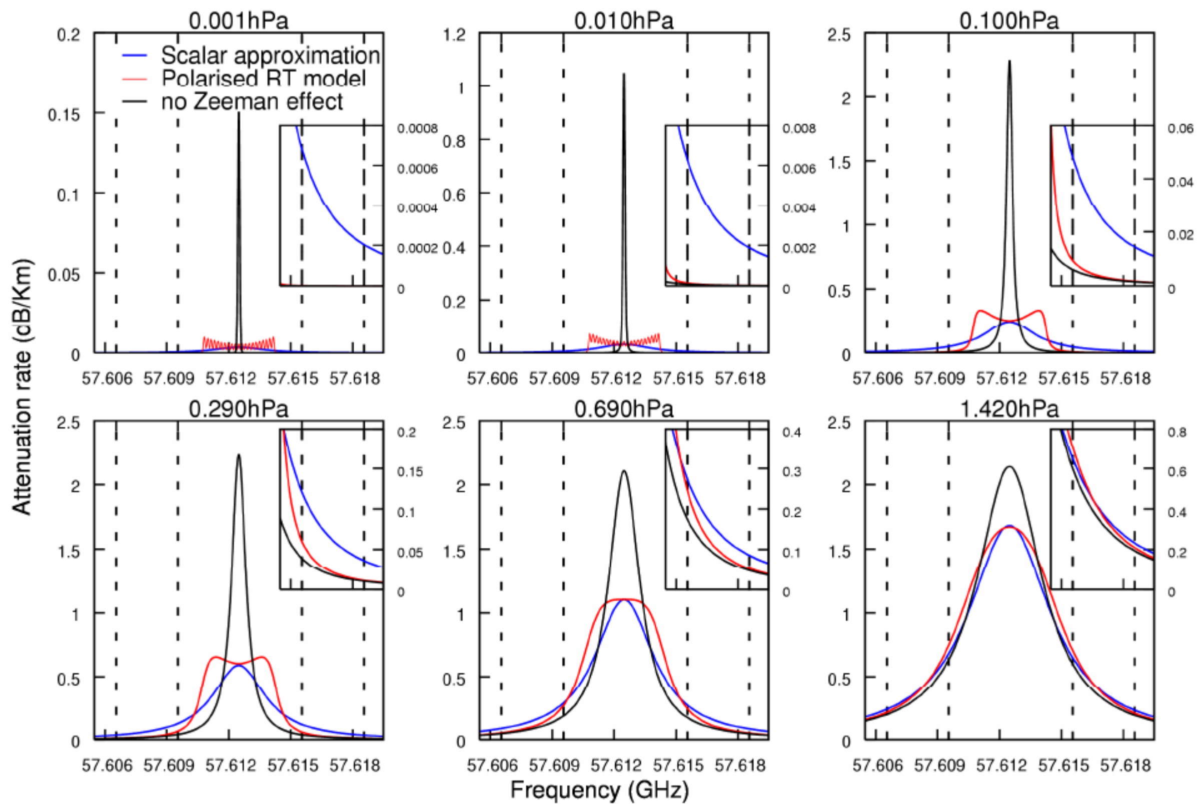

Figure 3: Attenuation rates near the pass-bands of AMSU-A channel 14 for pressures from 0.001 to 1.420 hPa for the US Standard Atmosphere. The pass-bands are indicated by the dashed vertical lines. The inset panels provide a more detailed view of these regions. Results for the scalar approximation are shown in blue, from the polarised radiative transfer model in red, and for a radiative transfer model without the Zeeman effect in black. The assumed magnetic field strength is 60 μT.

The scalar approximation to the Zeeman effect works well in the line-centre, but performs rather more poorly in the wings of the line and therefore in the pass-bands of AMSU-A channel 14. This can be best seen in attenuation rates calculated with a full polarized radiative transfer model and those calculated with the scalar approximation (e.g., Fig. 3). In the pass-bands of AMSU-A channel 14, the scalar approximation significantly overestimates the attenuation, resulting in anomalously low transmittances for AMSU-A channel 14. Weighting functions obtained from the polarised RT model are in fact much closer to those calculated without taking the Zeeman effect into account (Fig. 4).

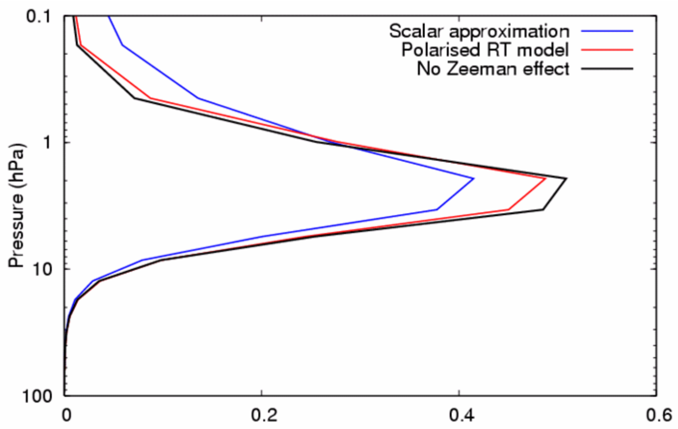

Figure 4: Weighting functions for the US Standard Atmosphere for AMSU-A channel 14, computed with a radiative transfer model with the scalar approximation of the Zeeman effect (blue), the polarised radiative transfer model (red), and a radiative transfer model that does not include the Zeeman effect (black). The assumed magnetic field strength is 60 μT.

Consequently, neglecting the Zeeman effect in the radiative transfer calculations for AMSU-A leads to a better consistency between the radiative transfer calculations for SSU and AMSU-A. This is highlighted in Fig. 5 which shows differences (in brightness temperature) between SSU channel 3 and AMSU-A channel 14 for a sample of observations collocated using the Simultaneous Nadir Overpass method, together with differences obtained from radiative transfer calculations. With the scalar approximation used, the differences from the radiative transfer simulations disagree significantly with the observed differences over the polar winters, whereas much better agreement is obtained when the Zeeman effect is neglected.

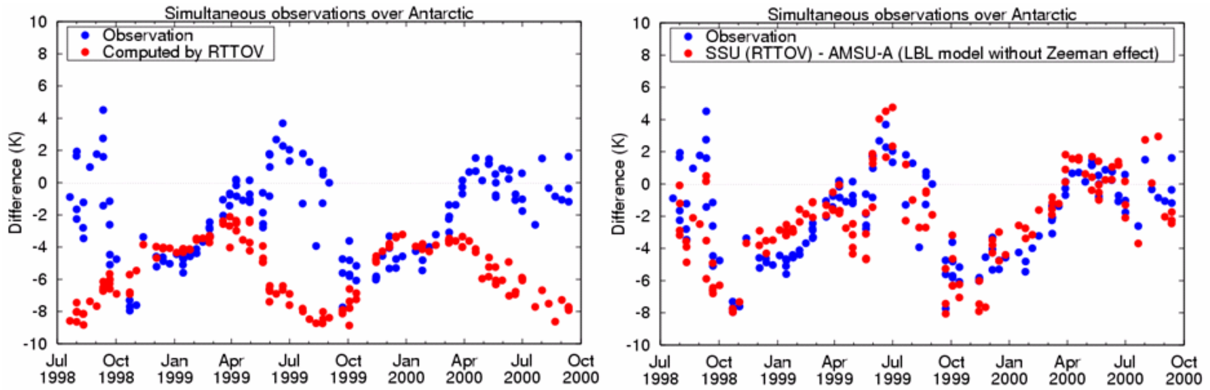

Figure 5: Differences (in brightness temperatures) between NOAA-11 SSU channel 3 and NOAA-15 AMSU-A channel 14 for a sample of data collocated using the Simultaneous Nadir Overpass method over the Antarctic region. Differences obtained from observations are shown in blue, whereas differences obtained from radiative transfer calculations are shown in red. Left: Radiative transfer computations are taken from RTTOV with the original coefficients. Right: Radiative transfer computations are taked from RTTOV for SSU, but a LBL model that excludes the Zeeman effect for AMSU-A. Note that due to different channel characteristics (not least infrared vs microwave) the differences between SSU channel 3 and AMSU-A channel 14 are expected to be non-zero.

New RTTOV coefficients have been generated for AMSU-A that neglect the Zeeman effect, and these coefficients have been used successfully in the ERA-Interim reanalysis (Uppala et al. 2008). The use of these new coefficients led to a reduction of spurious oscillations in the stratosphere over the winter poles (Fig. 6), and allowed a simultaneous use of SSU channel 3 and AMSU-A channel 14. The new coefficients were also introduced in the operational assimilation at ECMWF on 6 November 2007.

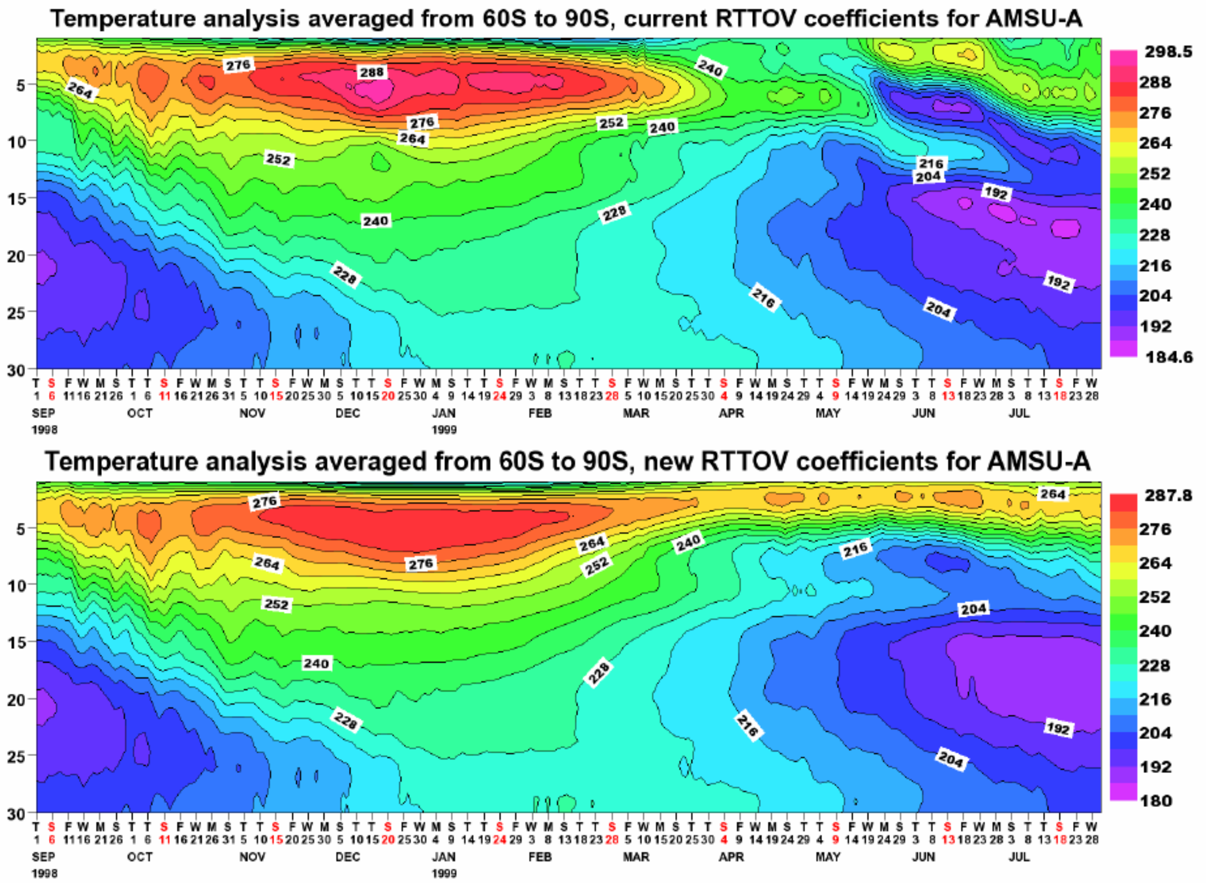

Figure 6: Timeseries of profiles of the mean temperature analysis over the South Polar region for a reanalysis experiment with the old RTTOV coefficients (top) and the new RTTOV coefficients without an implicit Zeeman parameterisation (bottom). The vertical axis in model levels, with level 25 at around 100 hPa, 14 at 10 hPa, and 5 at 1 hPa.

Assimilation of AMSU-A channel 14 without bias correction

Since 12 September 2006 ECMWF has been using a variational bias correction (VarBC) as described in Dee (2004) and Auligné et al. (2007). While this approach has been very successful in achieving a good consistency between the radiance bias corrections for different channels, instruments, and satellites, in agreement with other observations, problems were soon noted for stratospheric temperature channels. The bias corrections for these channels exhibited drifts, resulting in rather large bias corrections being applied to the data (exceeding 3 K for the highest AMSU-A channels after about a year of operational use of VarBC, e.g., Fig 7). The main reasons for this are the lack of other "anchoring" temperature observations in the upper stratosphere, and the fact that the current implementation of VarBC does not include a penalty for large bias corrections. As a result, the bias correction can drift to a state consistent with the climate of the forecast model.

To avoid this problem, it was decided to "anchor" the upper stratospheric temperature analysis by assimilating channel 14 of AMSU-A without bias correction. This is a somewhat pragmatic approach, based on the experience that model biases in the upper stratosphere tend to be much larger than estimates of biases in AMSU-A channels, especially over the polar regions. Residual scan biases and inter-satellite biases for AMSU-A channel 14 are neglected in the new approach for similar reasons.

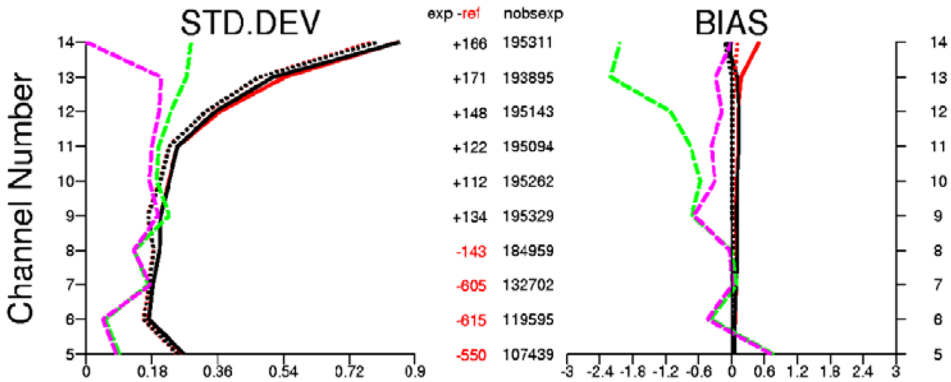

Figure 7: Departure statistics [K] for used NOAA-18 AMSU-A radiances over the Northern Hemisphere extra-tropics in June 2007. Solid lines indicate observation minus First Guess departures, whereas dotted lines show observation minus analysis departures, with statistics from an experiment with setting the bias correction of AMSU-A channel 14 to zero in black, and statistics from an experiment in which VarBC was allowed to evolve freely for over a year in red. Also shown are statistics for the bias correction for the experiment with no bias correction in AMSU-A channel 14 in pink and for the other experiment in green. Standard deviations are shown on the left, and biases on the right. The numbers between the two panels indicate the number of observations used (right) and the difference relative to the control experiment (left).

Other stratospheric channels (of AMSU-A, AIRS, and IASI) also show reduced bias corrections when AMSU-A channel 14 is assimilated without bias correction (e.g., Fig. 7). The bias correction for these channels is allowed to evolve freely through VarBC, and the finding that the bias corrections for stratospheric channels settle at values close to zero indicates a good consistency within the radiance observations. As a result, stratospheric temperature analyses are colder by a few degrees Kelvin, leading to better agreement with the independent SPARC climatology (not shown). The change to assimilate channel 14 of AMSU-A without a bias correction was implemented in operations on 6 November 2007, together with the updated RTTOV coefficients without an inappropriate Zeeman parameterisation

Revised bias correction for HIRS and AIRS short wave channels

Infrared short-wave channels are affected by solar radiation, for instance, through effects arising from the absence of local thermal equilibrium (LTE). LTE is usually assumed in today's fast radiative transfer models, and as a result, ECMWF's use of IR short-wave channels is restricted to channels for which this effect is relatively small. The only short-wave channels used are currently channels 14 (4.525 μm) and 15 (4.474 μm) of HIRS, and channels up to channel number 1928 (4.464 μm) for AIRS. Nevertheless, recent monitoring results showed that even these channels exhibit non-negligible day/night biases, especially HIRS channel 15 and AIRS channel 1928 (Fig. 8). The day/night differences are more notable in METOP-A than in NOAA-17 HIRS data, and some of the differences reach 0.4 K.

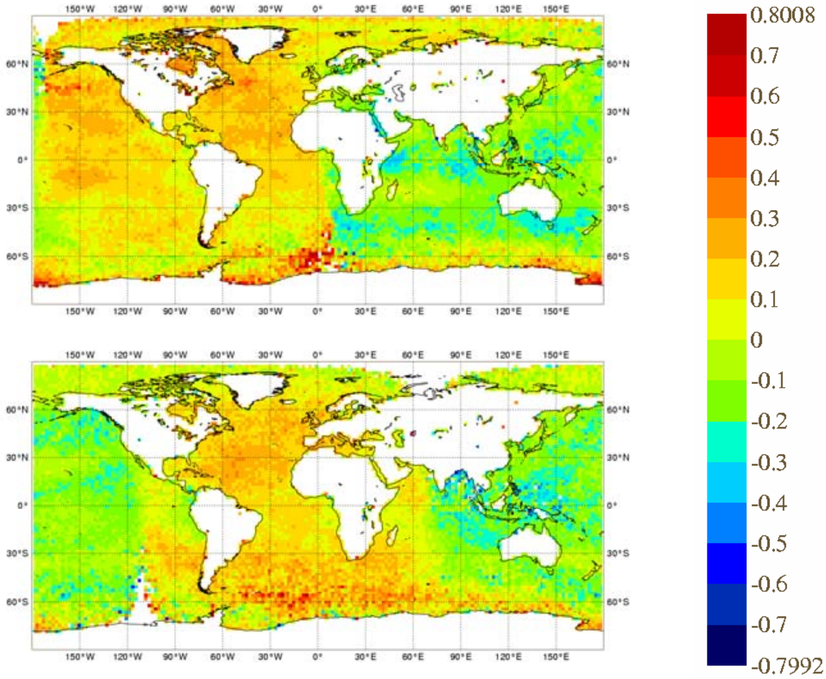

Figure 8: Top: Mean observation minus First Guess departures [K] for used METOP-A HIRS channel 15 radiances, after bias correction. Statistics for July 2007 are shown, with observation times restriced beween 9-21 Z to separate descending and ascending orbits. Bottom: As top, but for AQUA AIRS channel 1928.

To address the day/night bias we examine here a modification to the bias correction model used for the short-wave channels, following work by McMillin and Crosby (2000). They showed that the solar effects for HIRS channel 15 can be modelled through a linear regression against the cosine of the solar zenith angle (for day-time data). In agreement with their findings, histograms of First Guess departures against the cosine of the solar zenith angle suggest that the residual biases may be adequately modelled using a predictor that is zero during nighttime and the cosine of the solar zenith angle during daytime (Fig. 9).

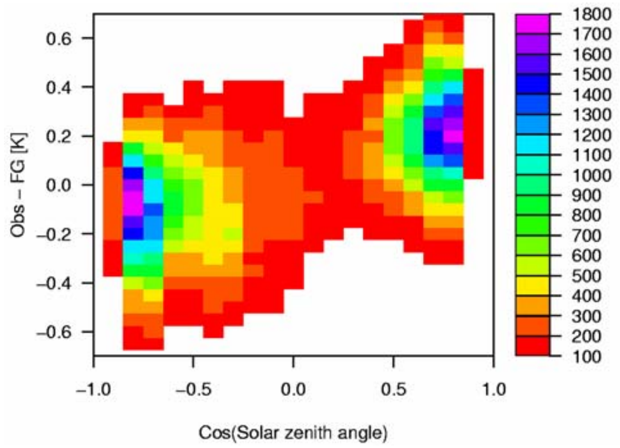

Figure 9: Histogram of observation minus First Guess departures (after bias correction without the additional day/night predictor) for METOP-A HIRS channel 14 as a function of the cosine of the solar zenith angle.

The modification of the bias correction was tested within a 2-month assimilation experiment over the period 1 June - 31 July 2007, using ECMWF’s 12-hour 4DVAR system, with a T511 (~40 km) model resolution, T159 (~125 km) incremental analysis resolution, and 91 levels in the vertical. The control experiment employed the standard bias correction model for all HIRS and AIRS channels (i.e., linear in four layer thicknesses and a 3rd order polynomial in the scan angle), used within VarBC. In the experiment with the modified bias corrections, a (linear) predictor, zero during nighttime and the cosine of the solar zenith angle during daytime, was added to the bias model for HIRS channels 14 and 15, and AIRS channels 1921-1928. We discard the first 14 days of the experiment, to allow VarBC to spin up the bias model for the additional predictor.

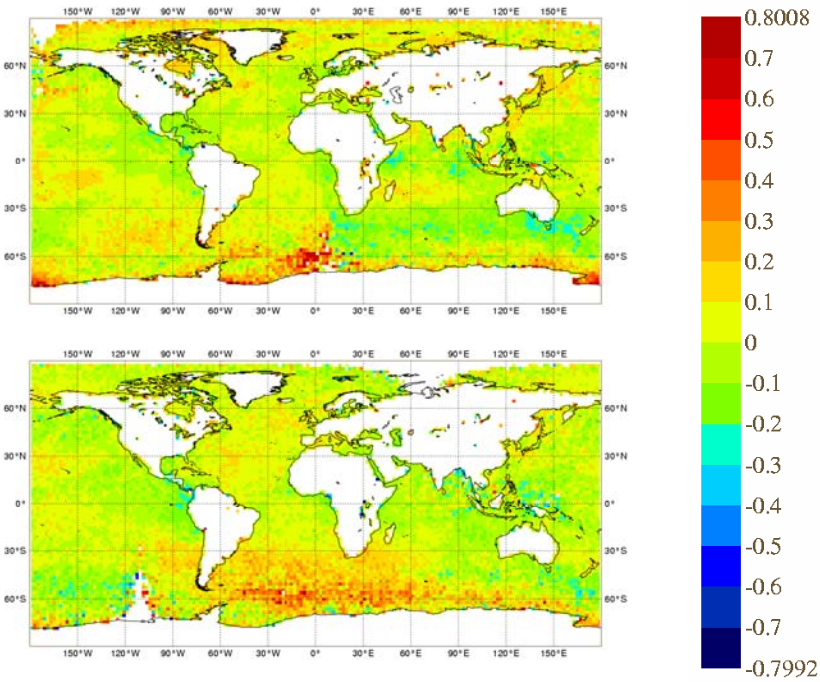

Figure 10: As Fig. 8, but with adding the extra day/night predictor to the bias correction model as described in the main text.

The additional bias predictor successfully reduces the day/night biases otherwise observed in mean FG departures (e.g., Fig. 10). While some day/night biases are still present, these are confined to the Southern Hemisphere mid-latitudes (associated here with higher solar zenith angles) for this experiment. The modification has a notable effect on the analyses of the mid-tropospheric geopotential (up to 3 gpm at 500 hPa), but a neutral effect on forecast scores (not shown). This is a positive finding, as additional experimentation showed that removing the affected channels altogether has a negative forecast impact, demonstrating that these channels are beneficial even despite the day/night biases.

Summary and conclusions

In this paper, we summarised some recent and upcoming developments in the use of ATOVS data at ECMWF. The main points are:

- ATOVS data from METOP-A has been assimilated operationally at ECMWF for well over a year now, with AMSU-A and MHS data being assimilated since 11 January 2007, and HIRS data since 19 March 2007. A small positive forecast impact was noted over the Southern Hemisphere from the additional data.
- Revised RTTOV coefficients for AMSU-A have been generated that exclude a scalar parameterisation of the Zeeman effect in the line-by-line model. This parameterisation was found to be inadequate for the pass-bands of AMSU-A channel 14, and the revised

coefficients allow better consistency with SSU data when both instruments are assimilated at the same time in the reanalysis. The same coefficients are used in operations since 6 November 2007. RTTOV coefficients without the inappropriate Zeeman parameterisation are also available via the RTTOV website. Future work will investigate the use of a fast parameterisation of the Zeeman effect, following work of Han et al. (2008).

- AMSU-A channel 14 is now assimilated without a bias correction since 6 November 2007 to anchor the upper stratospheric temperature analysis within VarBC.
- A revised bias correction that reduces day/night biases in the HIRS and AIRS short-wave channels used operationally will be implemented later in 2008.

Further work on an enhanced usage of ATOVS data includes the improved treatment of surface-sensitive microwave radiances over land (e.g., Krzeminski et al. 2008), a revision of quality control decisions, and the use of data in cloudy regions.

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