Situation-dependent observation errors for AMSU-A tropospheric channels in the ECMWF forecasting system

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Introduction

At ECMWF radiances from AMSU-A temperature sounding channels are actively assimilated from instruments aboard 7 different polar-orbiting satellites, providing a very good global coverage. The tropospheric channels are particularly important for weather prediction but they suffer from cloud contamination and uncertainties in surface temperature and emissivity since they are surface-sensitive. When assimilating the radiances of these channels we must define observation errors, which should include these uncertainties as well as the instrument noise. However, currently fixed values of 0.28 K and 0.20 K are applied for channels 5 and 6 – 7 respectively.

Here we present a method for calculating situation-dependent observation errors which depend on the surface temperature, surface-to-space transmittance and liquid water path. The approach follows methods outlined by B. Candy, K. Lean et al (personal communication) and Di Tomaso et al (2013) but includes a non-constant liquid water path error. Preliminary results of assimilation trials using these observation errors are also shown.

Situation-dependent observation errors

The total observation error, σ_o, can be written as a summation of a surface term, liquid water path (lwp) term and instrument noise term σ_N, as follows:

$$\sigma_o{}^2 = \sigma_{surface}{}^2 + \sigma_{lwp}{}^2 + \sigma_N{}^2 \quad (1)$$

A fixed value of 0.25 K was used for channel 5 instrument noise and 0.20 K for channels 6 and 7. These values were estimated from background departures. The liquid water path error was set to zero over land since the liquid water path is not calculated over land. Surface and lwp errors were calculated as follows.

Surface errors

The forward model error due to emissivity errors, $\sigma_{surface}$, can be approximated to (English 2008):

$$\sigma_{surface} \approx T_S \tau^2 \sigma_\varepsilon \quad (2)$$

σ_ε : error in ε, the surface emissivity
τ : surface-to-space transmittance
T_S: skin temperature

The above equation assumes an isothermal atmosphere with a radiative temperature equal to the skin temperature, T_S. We do not consider contributions from errors in the skin temperature, because, in the ECMWF 4D-Var assimilation system, the skin temperature is retrieved during the analysis as a sink variable.

The emissivity errors were estimated for different surface types by fitting (1), with the surface term defined by (2) and $\sigma_{lwp}= 0$, to the root mean-square background departures for channel 5 AMSU-A. The following values were obtained for σ_ε:

Surface Type	Emissivity uncertainty σ_ε
Sea	0.015
Sea-ice	0.050
Snow-covered land	0.050
Snow-free land	0.022

Note that for sea the value was obtained using only data where lwp < 0.05 kg/m².

Liquid water path errors

The liquid water path is calculated over ocean from AMSU-A window channels 1 and 2, following the method of Grody et al (2001). Assuming $\sigma_{surface} \approx 0$ we fit (1) to the root mean square background departures and found that σ_{lwp} could best be approximated by a quadratic fit for channels 5 and 6 and a linear fit for channel 7 (with a very low slope of 0.20 for channel 7):

channel 5: $\quad \sigma_{lwp}= 2.00 lwp^2 + 0.79 lwp \quad (3)$
channel 6: $\quad \sigma_{lwp}= 0.54 lwp^2 + 0.30 lwp \quad (4)$
channel 7: $\quad \sigma_{lwp}= 0.20 lwp \quad (5)$
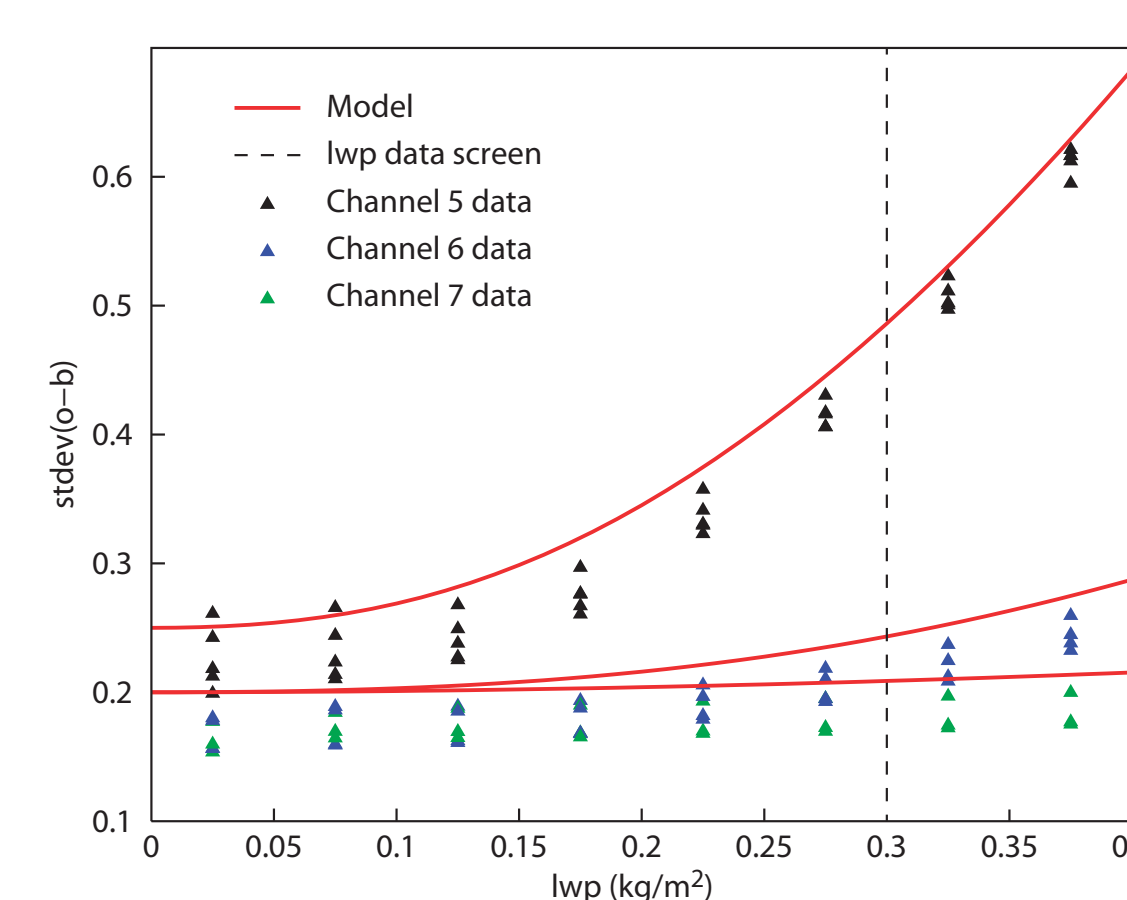
Figure 1 Standard deviation of background departures as a function of binned liquid water path values for channels 5, 6 and 7 of AMSU-A. The different points indicate different satellites. The red lines show the best fits and the black dashed line indicates the liquid water path value above which data is not used for channels 5 or 6.

Preliminary assimilation trials

Situation-dependent observation errors allow us to both 'weight' the data in a more accurate manner and to introduce more data over high orography, the South Pole and in cloudy regions.

The following experiments were run over 2 months for the period 15 June 2013 – 14 August 2013:

Control: The operational 4D-VAR model (version 40R1) at T511 with 137 vertical levels, including some contributions to cycle 40R2. Observation errors for AMSU-A channels 5 – 7 are constant.

Situation-dependent observation errors: The same as the control with observation errors changed to (1) – (5) for channels 5 – 7.

Extended coverage over cloudy regions: The same as 'Situation-dependent observation errors' with the window channel background departure check removed over ocean and replaced by a scatter index check. As with the control, data are also not used for channels 5 and 6 if the liquid water path exceeds 0.3 kg/m².
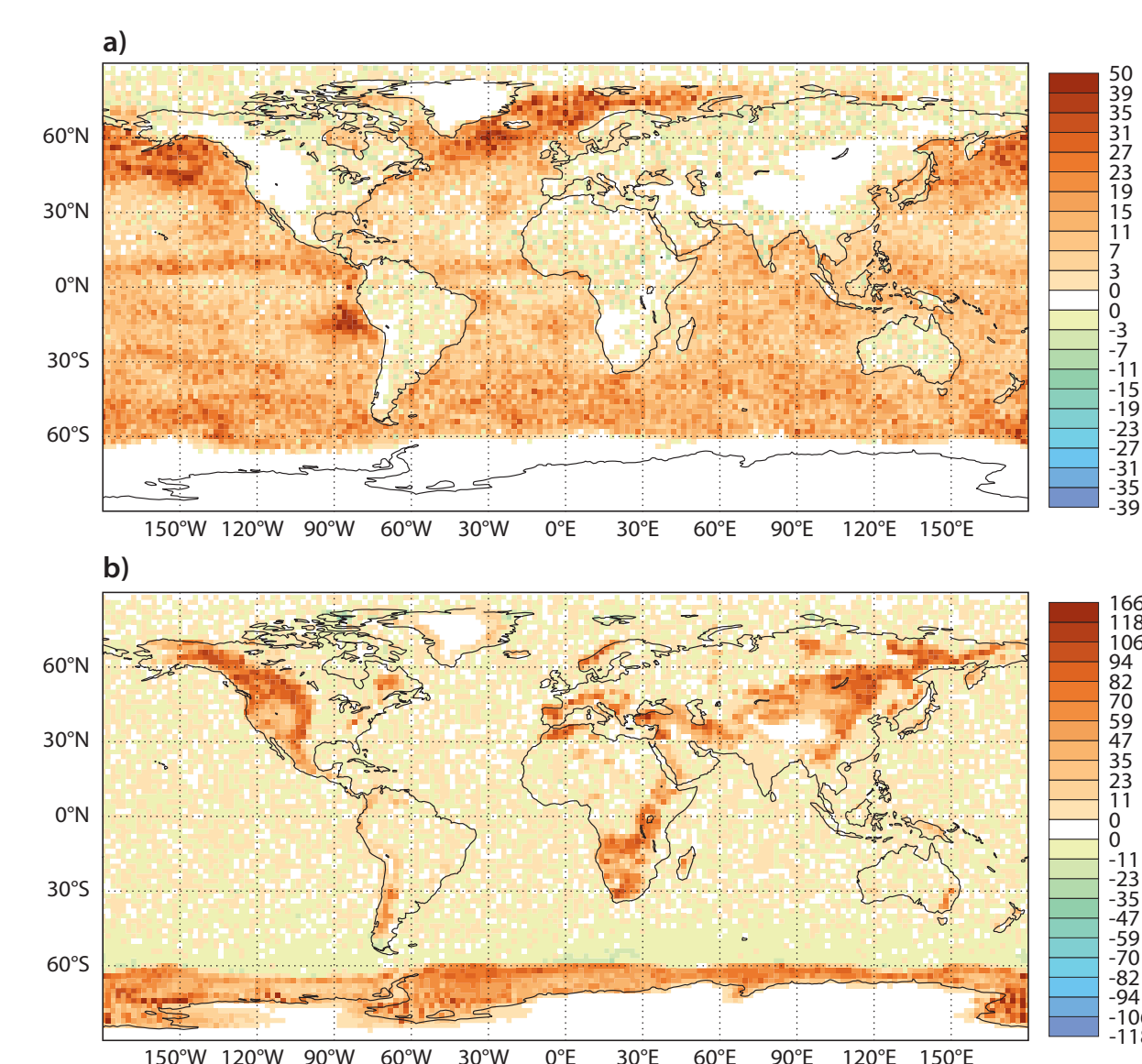
Extended coverage over high orography: The same as 'Situation-dependent observation errors' with channel 5 coverage extended over sea-ice in the Southern Hemisphere (it is currently blacklisted operationally) and data for channels 5 – 7 introduced over high orography. Instead, we reject data with observation errors larger than 0.35 for channel 5 and 0.28 for channel 6 (2 x the noise).

Figures 2 and 3 show the new observation errors for channel 5 and areas where more data were used.
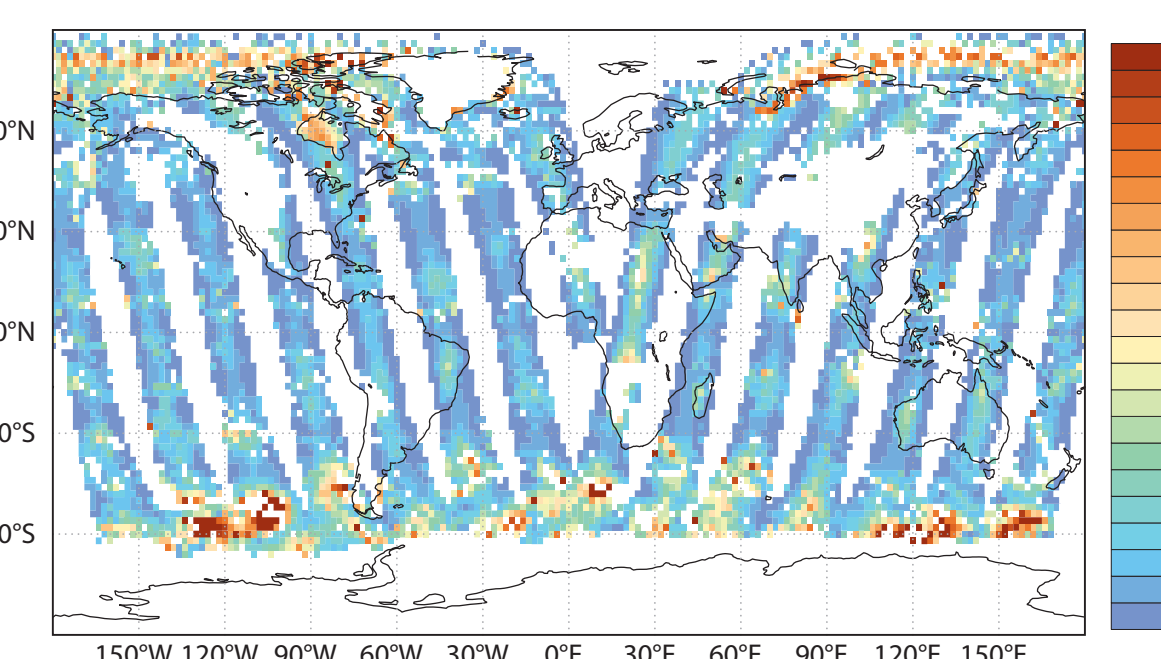
Figure 2 Observation errors for Metop-B AMSU-A channel 5 for 15 June 2013. The edges of the scanline have lower observation errors due to lower surface-to-space transmittance. Higher observation errors over land, sea-ice and high liquid water path can also be seen.

The extended coverage experiments used more data:

Figure 3 Change in the number of data used for MetOp-B AMSU-A channel 5 (1 month average) between a) 'Extended coverage over cloudy regions' experiment and control and b) 'Extended coverage over high orography' and control

Results

Results of the experiments with the new situation-dependent observation errors indicated a generally neutral impact on globally averaged forecast scores:
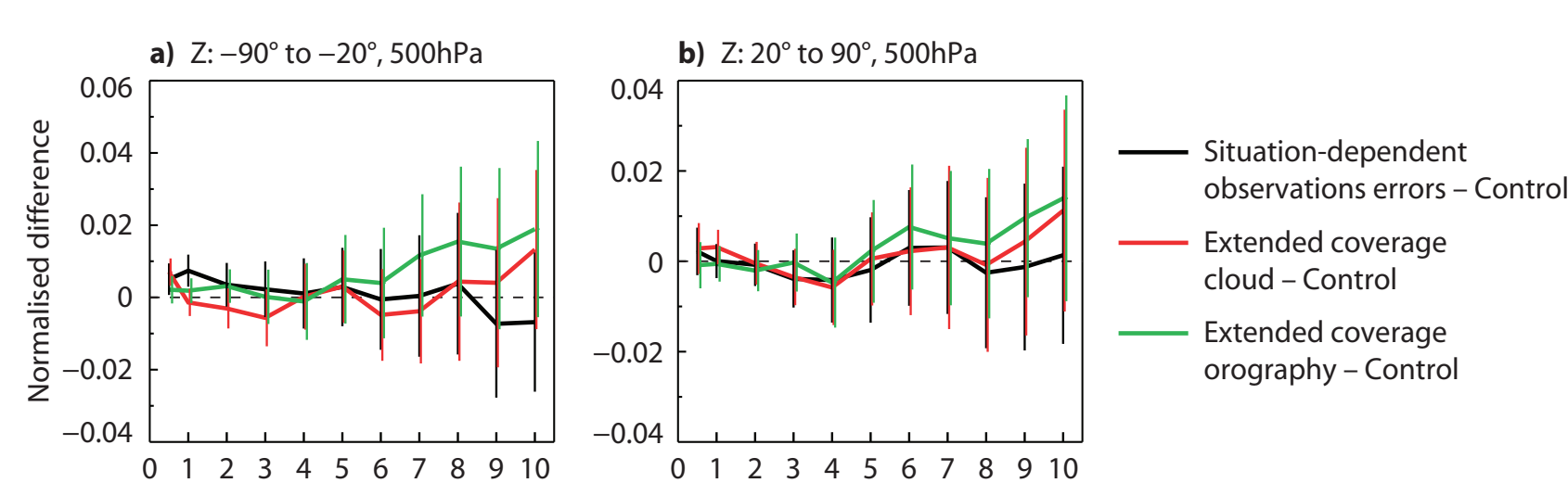
Figure 4 Normalised difference in the root mean square forecast error for 500 hPa geopotential as a function of forecast day (x axis). Values are averaged for 2 months over a) Northern hemisphere extra-tropics and b) Southern hemisphere extra-tropics. Error bars indicate 95 % confidence intervals and values below zero indicate an improvement.

### Extended coverage in cloudy regions

Extending the coverage in cloudy areas produced a mainly neutral impact on forecast scores (see figure 4) but reduced the standard deviation of background departures for ATMS.
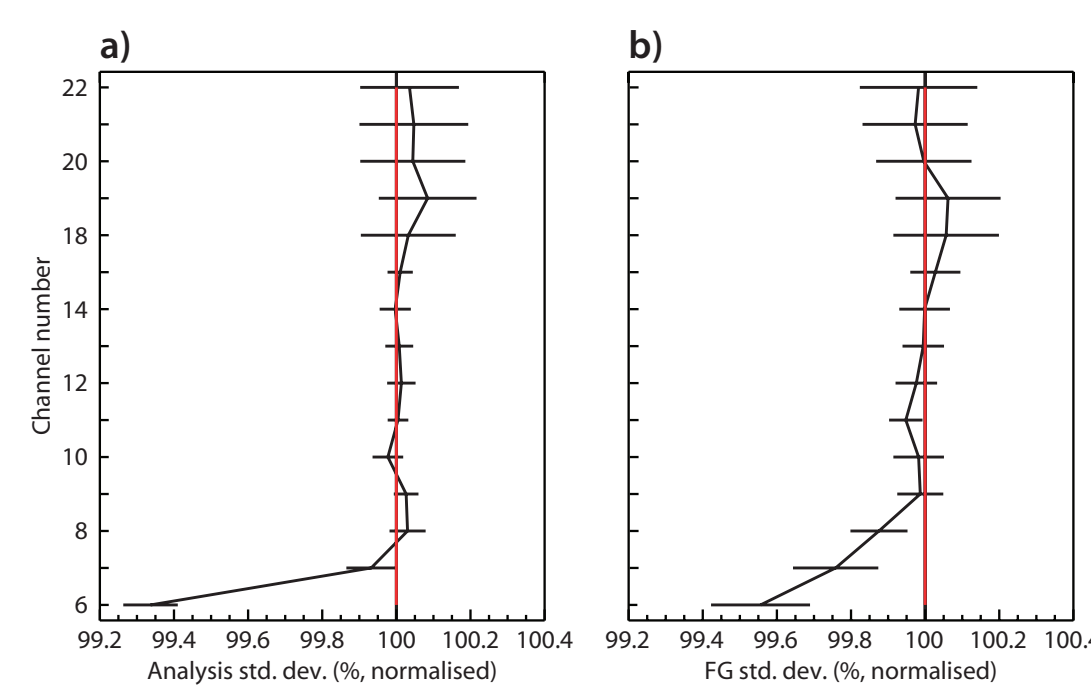
Figure 5 Standard deviation of a) analysis departures and b) background departures for the ATMS instrument (averaged globally) of the 'Extended coverage over cloudy regions' normalised by the values of the control experiment.

Extended coverage over high orography

Extending the coverage over high orography changed the mean forecast fields over the South Pole and Greenland, and the forecast impact over Antarctica is mixed. Elsewhere, the use of the additional data leads to a neutral to slightly positive impact on forecast scores.
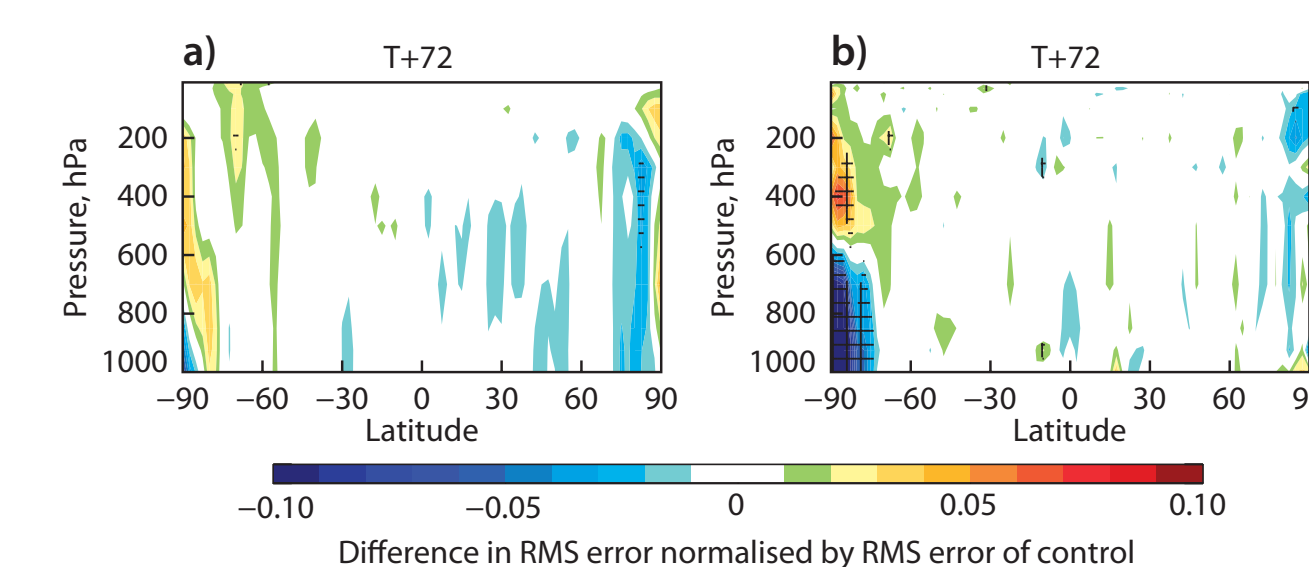
Figure 6 Change in the root mean square day 3 a) geopotential and b) temperature forecasts minus analysis between the 'extended coverage over orography' experiment and control as a function of latitude (x axis) and pressure (y axis). Blue indicates a reduction in day 3 forecast error and red an increase.

Conclusions

• Introducing situation-dependent observation errors allowed us to extend usage of AMSU-A channels 5 – 7 in cloudy areas over ocean and high orography over land,

• Results indicated a neutral impact when the new observation errors were used without extending data usage,

• Extending AMSU-A usage in cloudy areas appears promising,

• Extending coverage over high orography appeared to have a neutral to slightly positive impact in the northern hemisphere but a mixed positive/ negative impact over Antarctica. This latter requires further investigation..

References

Di Tomaso, E., N. Bormann and **S. English**, 2013: Assimilation of ATOVS radiances at ECMWF: third year EUMETSAT fellowship report, 26pp, available online: http://www.ecmwf.int/publications/library/do/references/show?id=90804

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Grody, N., Zhao, J., Ferraro, R., Weng, F., Boers, R., 2001: Determination of precipitable water and cloud liquid water over oceans from the NOAA-15 advanced microwave sounding unit. *J. Geophys. Res.*, **vol 106**, no. D3, pp. 2943 - 2953.

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