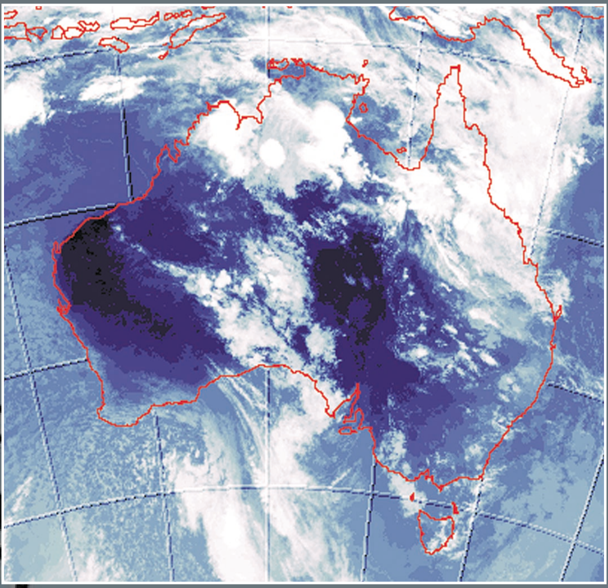

Towards direct assimilation of SSM/I radiances in 4D-Var

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SPECIAL SENSOR MICROWAVE / IMAGER (SSM/I) DATA has been incorporated in the assimilation system of the European Centre for Medium-Range Weather Forecasts (ECMWF) through a one-dimensional variational retrieval (1D-Var) of water vapour path (WVP) since 1997 [1,2] and near-surface wind speed (SWS) since 1999. For the preparation of direct radiance assimilation, research experiments with the operational ECMWF four-dimensional variational assimilation (4D-Var) have been carried out employing the (NWP SAF) radiative transfer package RTTOV-6 [3] and the fast sea-surface emissivity model FASTEM-2 [4].

Radiative Transfer Modelling

RTSSMI

In the framework of the 1D-Var assimilation, the radiative-transfer modelling package of [5] was implemented. Atmospheric absorption is calculated from regression fits to explicit calculations with a line-by-line model. Surface emission is calculated explicitly through a two-scale geometric optics model. Non-precipitating cloud liquid-water path (LWP) is included.

RTTOV

The main generic difference between RTSSMI and RTTOV is the explicit treatment of multi-angular radiance reflection by RTSSMI vs. the methodology of FASTEM-2 which integrates specular and non-specular contributions to an effective emissivity [6]. In extension to the standard RTTOV version, cloud emission was implemented at ECMWF [7].

Radiance statistics – 1

Two 4D-Var experiments have been set up: (1) a control experiment with the assimilation of water vapour path and near-surface wind speed from SSM/I data and (2) an SSM/I radiance assimilation experiment with the RTTOV package. Figures 1 and 2 show the brightness temperature (TB) departures between model first-guess (FG; bias corrected), analysis (AN), model FG (uncorrected) and the observations (OBS) over 4 days (July 1–4, 2001). The table lists departure averages and standard deviations per SSM/I channel in the order 19v, h, 22v, 37v, h, 85v, h, respectively:

- RTTOV produces much better FGs, i.e. smaller FG departures (except at 37.0(v) GHz).
- The spread of the distributions is much smaller for RTTOV at all frequencies.
- The better agreement at lower frequencies indicates a better sea-water permittivity model in RTTOV.
- The good performance of RTTOV at 37.0 GHz and comparing vertical and horizontal polarizations at the same frequency shows a good quality of the surface roughness parametrization.

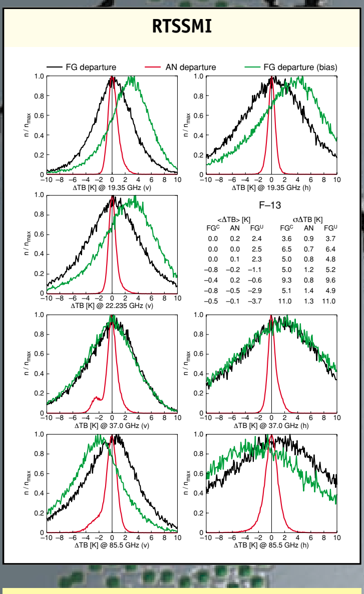

Figure 1 FG-OBS departures from global F-13 SSM/I observations using RTSSMI.

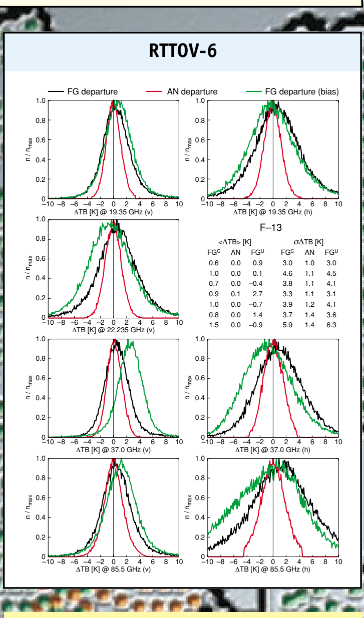

Figure 2 FG-OBS departures from global F-13 SSM/I observations using RTTOV

Radiance statistics – 2

Figures 3 and 4 show the FG departures as a function of integrated water vapour path to analyse their dependence on atmospheric transmission. The transmission is used differently in both codes to account for the reflection of downwelling radiances which are integrated over the hemisphere. First-order linear fits are superimposed to illustrate systematic trends:

- RTTOV shows little dependence on atmospheric transmission.
- RTSSMI seems to underestimate the reflection of radiation indicated by too small FG TBs; a trend that increases with frequency and is stronger at horizontal than vertical polarization.

Figures 5 and 6 show a similar comparison for wind speed:

- Again, RTTOV has little problems to properly account for increasing surface roughness with wind speed. However, vertically polarized TBs show a worse match than those horizontally polarized. There, RTTOV seems to overestimate roughness contributions.
- RTSSMI performs well for vertically polarized TB but shows a strong increasing negative bias with increasing wind speed at all frequencies for horizontally polarized TBs.

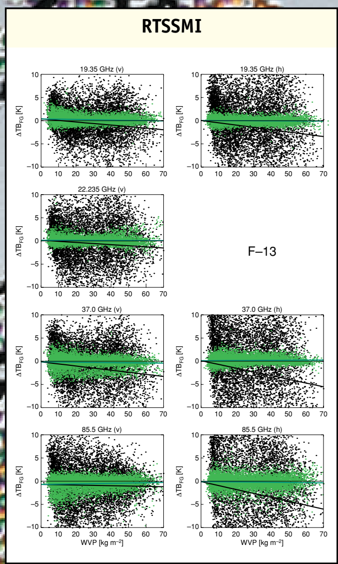

Figure 3 FG-OBS departures (black: FG bias corrected; green: analysis) as a function of WVP for F-13 SSM/I and RTSSMI.

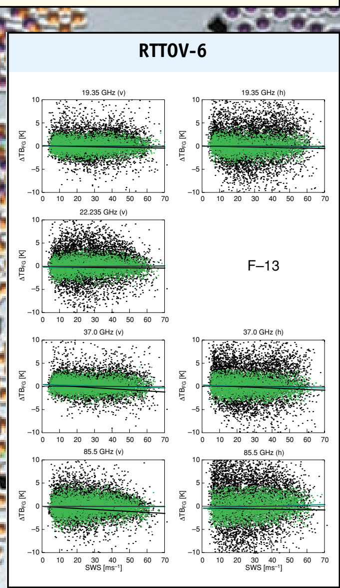

Figure 4 As Figure 3 for RTTOV.

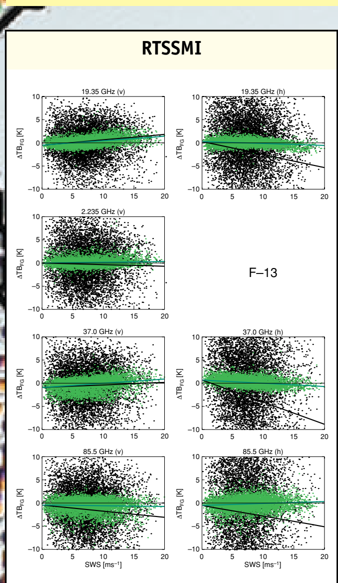

Figure 5 As Figure 3 for SWS.

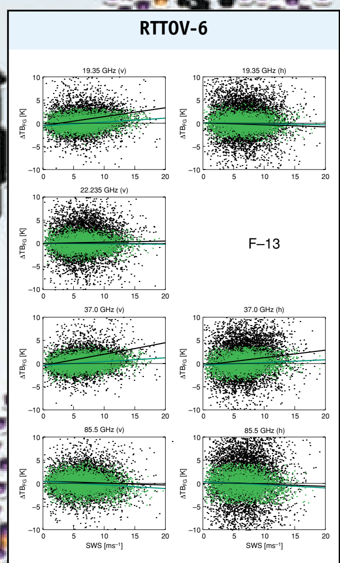

Figure 6 As Figure 5 for RTTOV.

Case Study

Finally, Figure 7 shows an example of WVP retrievals from 1D-Var in the south-eastern Indian Ocean on July 1, 2001.

Cross-sections of LWP, WVP, and SWS (Figure 8) and 19h, 22v, and 37v FG-OBS TB departures (Figure 9) along A-B were extracted where a strong gradient of both WVP and SWS was observed in North-South direction.

Generally, the largest departures occur where model clouds strongly differ from the observed ones. FG and retrieved WVP and SWS are fairly similar. RTTOV shows similar or better performance under all conditions at 19.35 GHz (h) due to the better permittivity model. At 22.235 GHz (v) and 37.0 GHz (v) both models produce almost identical results for all combinations of dry/moist and calm/windy environments.

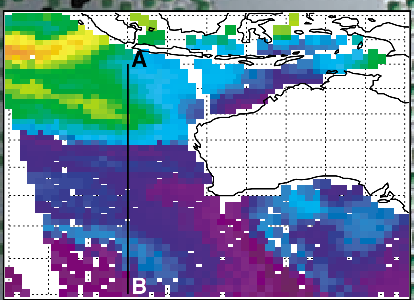

Figure 7 1D-Var WVP retrievals SE Indian Ocean on July 1, 2001 (note A-B cross-section).

Perspectives

To increase the number of observations to be used for the assimilation of SSM/I radiances, the inclusion of clouds is of utmost importance. The treatment of clouds requires their inclusion in the forward modelling of the radiative transfer and the updating of the FG cloud-model liquid-water path along with those parameters being part of the control vector (wind speed, water vapour).

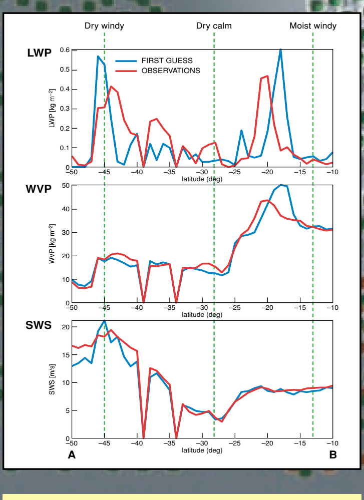

Figure 8 Cross-section (see A-B, Figure 7) of FG (blue) and retrieved (red) LWP, WVP, and SWS.

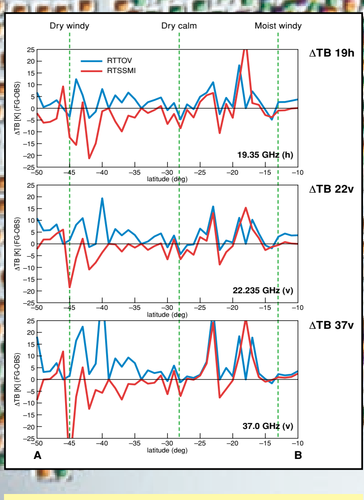

Figure 9 See Figure 8 for FG-OBS TB departures (blue: RTTOV, red: RTSSMI).

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