Evaluation of the RTTOV in the ECMWF NWP system

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1. Changes in the use of RTTOV at ECMWF

RTTOV version	IFS cycle usage	Features relevant to IFS	Impact
12.1	Cy45r1 Since 5th June 2018	RTTOV upgrade to version 12.1 included: Updated MW surface emissivity models; Retain sea surface emissivity model ISEM and UWiremis land emissivity atlas; Updated MW coefficient files; IR coefficient files unchanged, except format update.	Improved first-guess (FG) fit to many observation types; Neutral forecast scores impact (see Lupu *et al.*, 2017)
12.2	Cy46r1 Since 11th June 2019	RTTOV upgrade to version 12.2 included: a) Full upgrade to v12.2 code for RTTOV-SCATT and RTTOV (technical, but not bit-reproducible); b) New option in RTTOV-SCATT to carry out radiative transfer calculations on radiances instead of brightness temperatures (scientific); c) All MW optical depth coefficient files now contain band correction coefficients (scientific); d) New optional output structure in RTTOV-SCATT containing information required to perform all-sky emissivity retrievals (scientific). e) New liquid permittivity models in "Mie table" (see poster 5p.08)	Minor changes in FG fits to microwave instruments; On balance positive, particularly for MHS and SAPHIR; Neutral changes in forecast scores. The permittivity model by Rosenkranz (2015) has been chosen to replace Liebe (1989) - see poster 5p.08
12.3	Ready for future cycle implementation	No scientific changes compared to RTTOV-12.2, although code changes in the RTTOV v12.3 upgrade affect bit-reproducibility; It allows experimental use of new scientific features (e.g., option to treat surface as a Lambertian reflector; new CAMEL IR emissivity atlas derived from multi-year climatology; MFASIS fast visible cloud parameterisation update to account for variable water vapour in affected channels; updated parameterisation of the Baran ice optical property database).	Neutral impact on forecast scores; slight degradation in winter for ATMS channel 6 that is believed to be scientifically insignificant.

2. RTTOV-12.2 evaluation results

Assimilation experiments were conducted with the Cy45r1 version of the ECMWF's 4D-Var system at $T_{CO}399$ resolution (approximately 25 km) over 3 months period from 1st June to 30th August 2017.

- **Control**: ECMWF data assimilation and forecasting model with all operational observations and using RTTOV-12.1.
- **RTTOV at version 12.2**: Same system configuration, except that RTTOV-12.1 has been upgraded to RTTOV-12.2 through several incremental changes, as listed in section 1:
  - 12.2 no science: Option a);
  - 12.2 radiances: Options a) and b);
  - 12.2 radiances + band cor: Options a), b) and c);
  - 12.2 radiances + band cor + emis: Options a), b), c) and d).

Impact on first-guess departures

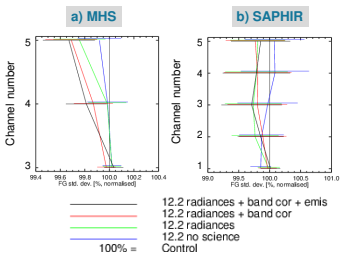


Figure 1: Normalised standard deviation of background departures between RTTOV-12.2 experiments and the Control for a) MHS on four satellites and b) SAPHIR. Values are for used data averaged globally for 3 month period (June to August 2017). Values are normalised to the Control so that a shift left indicates a reduction in error. The horizontal bars indicate 95% confidence interval.

Forecast impact

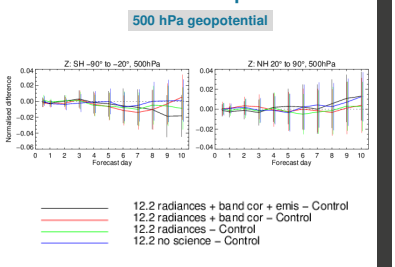


Figure 2: Normalised change in the RMSE of 500 hPa geopotential forecasts for the four RTTOV-12.2 experiments for Southern Hemisphere (left) and Northern Hemisphere (right). Each experiment has been verified against its own analysis, and negative numbers indicate a reduction in the forecast errors from using different RTTOV-12.2 updates.

3. RTTOV-12.3 evaluation results

Assimilation experiments based on Cy46r1 of the operational system have been run at the lower spatial model resolution $T_{CO}399$. Experimentation covers a 8-month period over two seasons (1st June 2018 to 15th September 2018 and 1st November 2018 to 15th March 2019).

- **Control**: ECMWF data assimilation and forecasting model with all operational observations and using RTTOV-12.2.
- **RTTOV-12.3**: Same system configuration, except that RTTOV-12.2 code has been upgraded to RTTOV-12.3

Short-range forecast impact

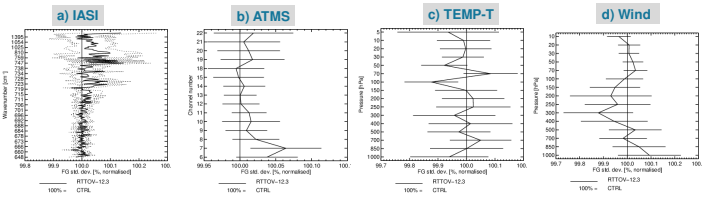


Figure 3: Standard deviation of background departures, normalised by the Control, for several observing systems: a) IASI on MetOp-A and MetOp-B, b) ATMS on S-NPP and NOAA-20, c) temperature from radiosondes and d) vector wind from radiosondes, profiler, pilot, and aircraft observations. Statistics cover the two seasons combined. Values are normalised to the control so that a shift left indicates a reduction in error. Horizontal lines indicate statistical significance at the 95 % level.

Forecast impact: 500 hPa geopotential

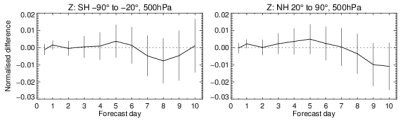


Figure 4: Normalised change in the RMSE of 500 hPa geopotential forecasts resulting from RTTOV-12.3 upgrade for Southern Hemisphere (left) and Northern Hemisphere (right). Each experiment has been verified against its own analysis, and negative numbers indicate a reduction in the forecast errors from RTTOV-12.3 update. Results for the two seasons considered here have been combined.

4. Updating the infrared spectroscopy and enhancing the representation of CO_2 in the RTTOV

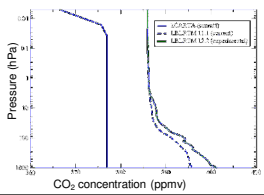
The assimilation of long-wave hyperspectral IR radiances currently uses a RTTOV fast model trained on a global mean CO_2 profile (e.g., *Figure 5*) that does not reflect present day CO_2 levels. To improve the RTTOV simulations assimilation trials have started where RTTOV uses CO_2 fields produced by the Copernicus Atmospheric Monitoring Service (CAMS) thus allowing the simulations to reflect the geo-variability of CO_2. Three assimilation experiments based on Cy46r1 of the operational system were conducted, covering the two period 1 June 2018 to 30 June 2018 and 1 November 2018 to 2 December 2018, as follows:

- **Control**: ECMWF data assimilation and forecasting model with all operational observations and using RTTOV-12.2 and the IFS operational infrared and microwave coefficient files;
- **Spectroscopy + Fixed CO_2 profile**: As Control, except updating the spectroscopy (e.g., *Table 1, experimental*) and the fixed CO_2 profile (e.g., Figure 5 green line, CO_2 value is 401 ppmv at 1100 hPa) used in the RTTOV calculations for hyperspectral sounders (IASI, CrIS, AIRS)
- **Spectroscopy + Variable CO_2 profile**: As control, except updating the spectroscopy and allowing prognostic CO_2 (e.g., CAMS variable CO_2) to be used in the RTTOV calculations for hyperspectral sounders (IASI, CrIS, AIRS)

Table 1: Current and experimental IR regression coefficients files.

IR sensors	Current	Experimental
IASI AIRS	Line-by-Line: kCARTA 52 profiles training set For fixed CO_2 profile, CO_2 value is 377 ppmv at 1100 hPa Vertical levels: 44	Line-by-Line: LBLRTM12.2 83 profiles training set Vertical levels: 101 V9 predictors
CrIS	Line-by-Line: LBLRTM11.1 83 profiles training set For fixed CO_2 profile, CO_2 value is 396 ppmv at 1100 hPa Vertical levels: 51	

Figure 5: The concentration for fix CO_2 profiles



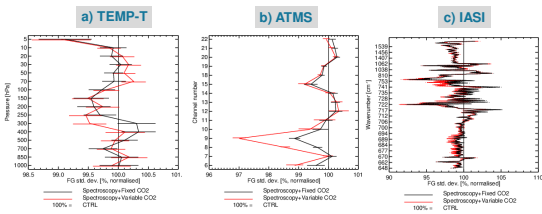


Figure 6: Normalised difference in the standard deviation of background fit between each of the experiments and the control for a) temperature from radiosondes, b) ATMS on S-NPP and NOAA-20 and c) IASI on MetOp-A/B. Experimentation covered two months over two seasons.

References

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Acknowledgements

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5. Summary

Latest developments in RTTOV are being exploited in order to improve the assimilation of radiances. RTTOV-12.2 has been operationally used at ECMWF since 11th June 2019, bringing upgrades to the observation operators RTTOV and RTTOV-SCATT. The upgrade allows RTTOV to use the most accurate science possible, it prepares the way for future sensors like Ice Cloud Imager (ICI) and will support future all-sky use of visible and IR satellite data. To ensure use of the most up-to-date and best supported coefficient files, MW gas optical property files have been upgraded including the use of band corrections. RTTOV-12.3 has been also evaluated within a full assimilation system and it is ready to be incorporated in a future IFS operational cycle upgrade. Work has continued to enhance the representation of CO_2 in the radiative transfer model used for the radiance assimilation. It remains a priority to use operationally the best IR spectroscopy and a more realistic CO_2 profile. Preliminary results show that the use of CAMS CO_2 global fields has a positive impact on the analysis.