Evaluation of the radiative transfer model RTTOV-13.0 at ECMWF

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1. Introduction

The use of satellite radiance observations in NWP depends directly on the accuracy of the radiative transfer model, RTTOV (*Saunders et al., 2020*), developed within the context of EUMETSAT NWP-SAF activity. This study summarizes the evaluation in the IFS of the very latest release of the radiative transfer model, RTTOV-13.0 with updated microwave scattering model RTTOV-SCATT and coefficient databases. An overview of the performance of RTTOV-13 in the IFS will be presented along with a look at recent harmonization and upgrades of infrared radiative transfer, spectroscopy and trace gas assumptions via the replacement of all RTTOV coefficients for hyperspectral sounders. The evaluation is performed through comparisons of radiative transfer simulations with RTTOV-12.2 and through an analysis of departure characteristics against observations. The impact on forecasts is also investigated through a series of assimilation experiments.

Scientific changes from RTTOV-12.2 to RTTOV-13.0 relevant to the IFS include:

- Updates to RTTOV-SCATT (*Geer, 2021; Geer et al., 2021*)
  - Scientific bugfix in the downward scattered radiation;
  - Reduced minimum cloud fraction threshold;
  - Approximate treatment of polarised scattering from oriented ice particles;
  - New interface allows for an arbitrary number of hydrometeors determined by the "hydrotable" optical property files;
  - New default microphysical configuration; New active sensor capability;
- General updates (*Hocking et al, 2021*)
  - New optical depth coefficient files are available based on an updated optical depth parameterization;
  - Changes to treatment of cosmic MW background radiation) in MW simulations;
- Treatment of scattering from surfaces
  - The specular vs lambertian scattering from the surface has been modified to allow a mix of both types to be included in the calculation and it can now be specified per channel;
- IR scattering
  - Updated cloud liquid water optical properties based on updated refractive index dataset.

2. RTTOV-13.0 assessment in the ECMWF's IFS

Assimilation experiments were run in the CY47R1.4 version of the ECMWF system at TC_O399 resolution (~29 km) over 7 months period (20th June to 30th September 2019 and 1st December 2019 to 31st March 2020):

- **Control**: ECMWF data assimilation and forecasting model with all operational observations and using RTTOV-12.2 and the IFS operational IR and MW coefficient files.
- **RTTOV-13.0**: Same system configuration as Control, except that RTTOV-13.0 replaced RTTOV-12.2
- **RTTOV-13.0 + v13 MW**: Same system configuration as RTTOV-13.0 , except using the new v13 optical depth parametrisations for all MW sensors.

Results vs Control

- **RTTOV-13+ v13 MW** and **RTTOV-13** have similar impacts to fits to in situ temperature and humidity from radiosondes and in situ wind observations from radiosondes, profiler, pilot, and aircraft (e.g., Fig. 1 a-c)
- **RTTOV-13+ v13 MW** improves fits to temperature and humidity sensitive observations from ATMS and CrIS more than **RTTOV-13** (Fig.1 d-e)
- Features in the background fits for the all-sky sensors: some channels have reduced std. dev. and others increased std. dev: at high frequencies (e.g., 183 GHz) the std. dev. is better; at mid frequencies (e.g., 89 - 157 GHz), increased scattering improved biases and skewness but also increased std. dev. (Fig.1 g-i)
- Results of the RTTOV-13.0 with updatedv13 microwave coefficients files provide generally neutral to positive forecast impact.

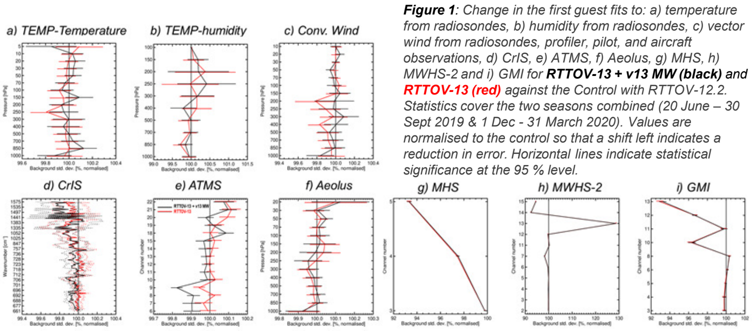

*Figure 1: Change in the first guest fits to: a) temperature from radiosondes, b) humidity from radiosondes, c) vector wind from radiosondes, profiler, pilot, and aircraft observations, d) CrIS, e) ATMS, f) Aeolus, g) MHS, h) MWHS-2 and i) GMI for **RTTOV-13 + v13 MW (black)** and **RTTOV-13 (red)** against the Control with RTTOV-12.2. Statistics cover the two seasons combined (20 June – 30 Sept 2019 & 1 Dec - 31 March 2020). 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.*

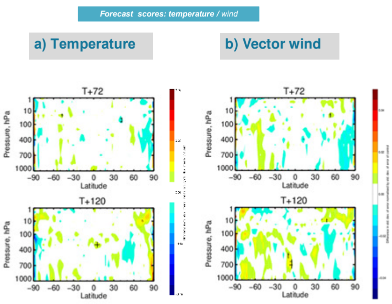

*Figure 2a: Normalised difference in the standard deviation of the forecast error in the: a) temperature and b) vector wind at day 3 (top) and day 5 (bottom) between the **RTTOV-13 + v13 MW** and Control experiments. Each experiment has been verified against its own analysis.*

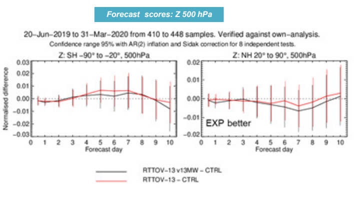

*Figure 2b: Change in RMSE of extra- tropical 500hPa geopotential height forecasts for **RTTOV-13 + v13 MW (black)** and **RTTOV-13 (red)** against the Control.*

3. Infrared Radiative Transfer improvements in the IFS

A third experiment has been carried out, **RTTOV-13 + v13 MW + IR** - same configuration as RTTOV13 + v13 MW run, but using harmonized infrared coefficients updated with the state-of-the-art line-by-line calculations (LBLRTM12.2), a new fast transmittance scheme for variable trace gases and more vertical layers.

RTTOV coeffs. for hyperspectral sounders	Control	RTTOV-13 + v13 MW + IR	Advantage
Line-by-line (LBL) model and spectroscopy	kCARTA / LBLRTM_11.1	LBLRTM_12.2	State-of-the-art spectroscopy / CO_2 (CH_4) line mixing / water vapour continuum → more accurate simulations
Global trace gas (CO_2, CH_4, N_2O, CO) profiles used in the simulations	Fixed: old (e.g. 377 ppmv for CO_2) climatological values	Variable: current (e.g. 401 ppmv for CO_2) climatological values	The CO_2 profile can be updated on a regular basis to reflect current concentrations → smaller biases
Fast transmittance model	V7 (fixed trace gases)	V9 (variable trace gases)	
Number of vertical levels	43 / 54	101	Reduction of representativeness errors due to the interpolation of atmospheric profiles from the ECMWF vertical pressure grid into the fixed RTTOV vertical pressure grid
V9 CO_2 fast transmittance model	N/A	Modifications to the CO_2 predictors	Improved fit to LBL data in the spectral regions affected by CO_2 line mixing effects
AIRS error covariace matrix	Diagonal	Full	Optimal use of AIRS data

Results vs Control

- Almost universal statistically significant positive impact on the fit to background observations (e.g., Fig. 3).
- Statistically significant positive impact on very short range (day 1-2) 500 hPa geopotential scores (Fig. 4).
- Statistically significant positive impact on temperature scores in the tropics. (Fig. 5)
- Greatly reduced mean values of first-guess departures for hyperspectral sounders.

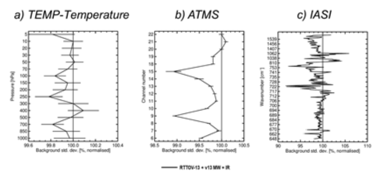

*Figure 3: Normalised difference in the standard deviation of background departures between **RTTOV-13 + v13 MW + IR** experiment and the Control for a) temperature from radiosondes, b) ATMS, c) IASI. Results show improved first-guess fits to radiosonde temperature observations, improved fit to ATMS temperature and humidity chs., improved fit to IASI channels. 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.*

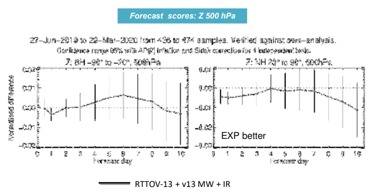

*Figure 4: Change in RMSE of extra- tropical 500hPa geopotential height forecasts for **RTTOV-13 + v13 MW + IR** against the Control. Results for the two seasons considered here have been combined.*

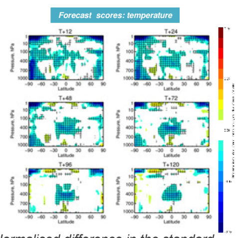

*Figure 5: Normalised difference in the standard deviation of the forecast error in the temperature between the between **RTTOV-13 + v13 MW + IR** and Control experiments. Each experiment has been verified against its own analysis, and negative numbers indicate a reduction in the forecast errors from using RTTOV-13 MW and IR coefficient databases. Hatching indicate statistical significance at the 95 % level.*

4. Summary

- Upgrade and harmonization of infrared radiative transfer, spectroscopy and trace gas assumptions in the IFS via replacement of all RTTOV coefficients for hyperspectral sounders. The RTTOV V9 CO_2 fast transmittance model - which is used with the new RT coefficients - has also been revised to reflect changes in the physics of the LBL CO_2 line mixing model. This has resulted in a better fit to background observations and significant positive forecast impact. Changes were submitted to IFS CY47R3 – planned to become operational in October 2021.
- RTTOV-13.0 with updated v13 MW coefficient files are considered for submission in CY48R1 of the IFS configuration for operational implementation in 2022. Results from experiments in the ECMWF operational NWP system are positive, showing similar or reduced background standard deviations with the RTTOV-13 and the new v13 MW predictors coefficients files for a variety of microwave and infrared sensors; positive impact on forecast scores;
- The new v13 coefficient databases for the infrared sensors trained with LBLRTM 12.8, also available with RTTOV-13.0, have been evaluated in passive monitoring runs. Results from these initial experiments are encouraging and are documented in *Hocking et al, 2021.* Further examinations are needed to assess the impact of using the IR coefficients based on the new v13 predictors and evaluate their benefit in an assimilation context.

References

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Acknowledgements

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