Evaluation of RTTOV-14 in the ECMWF NWP system

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RTTOV-14 developments

- Since the last ITSC, a major release of RTTOV, v14.0, was made available to users by the EUMETSAT NWP-SAF consortium. RTTOV-14.0 enable all simulations through the core RTTOV interface and eliminate the separate RTTOV-SCATT interface/model for hydrometeor scattering simulations for microwave sensors.

RTTOV-14.0 features include:

- Improved representation of the atmospheric profile that better matches the way that NWP models represent the atmosphere (Figure 1).
- Improvements related to the treatment of surface emissivity and reflectance, including the capability to represent heterogeneous surfaces within the satellite field of view.

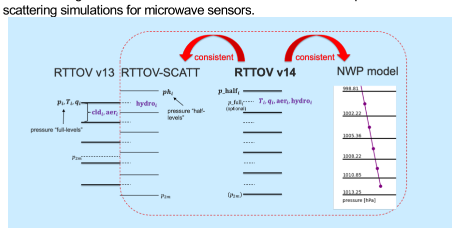


Figure 1: Input atmospheric profile structure in RTTOV v13 and RTTOV-SCATT, and the new structure in RTTOV v14. The representation of the vertical profile has changed in v14 in respect of the way the pressure levels and layers are defined.

RTTOV-14.0 assessment in the ECMWF's IFS

- The move from RTTOV v13.2 (Control) to RTTOV v14 was tested for its forecast impact in experiments based on two periods, 1st June 2022 to 31st August 2022 and 1st December 2020 to 28th February 2023. The experiments use a full observing system that follows that used in ECMWF operations and are based on the standard testing configuration at TCo399 (about 25 km horizontal resolution) with a 12-hour assimilation window. Background errors are held fixed between the two experiments and come from a separate ensemble data assimilation experiment based on the cycle 49r1 configuration.
- Replacing RTTOV v13.2 with RTTOV v14 shows a neutral to positive forecast impact. Figure 2 shows the impact on vector wind errors, but similar results are seen in relative humidity and temperature. Figure 3 shows the Southern and Northern extratropics impact on geopotential height at 500 hPa (Z500) forecasts, which is neutral at short and medium range forecasts.

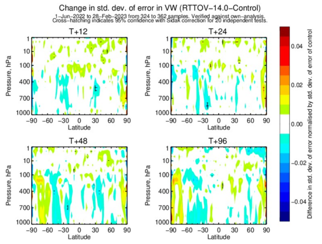


Figure 2: Difference in RMSE of vector wind (VW) error between RTTOV v14.0 and RTTOV v13.2 (Control) experiments, normalised by the RMSE of the Control experiment. Verification is against own-analysis. Cross-hatching shows statistical significance at the 95% confidence level based on 20 independent tests per panel. Captions T+N describe the forecast time N in hours.

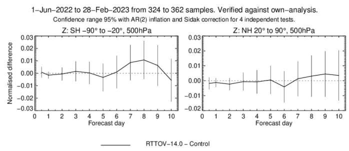


Figure 3: Normalised change in the RMSE of 500hPa geopotential forecasts resulting from RTTOV-14.0 upgrade for Southern and Northern extratropics as a function of forecast range. Error bars show the statistical significance range at the 95% confidence level based on 4 independent tests in the figure, and correcting for time correlations using an autoregressive AR(2) model.

- Figure 4 shows that IASI fits to most channels sensitive to the stratospheric and tropospheric temperature and moisture improve by up to about 0.1% at background, indicating that temperature and mid and upper-tropospheric humidity is better in agreement with IASI. Broadly similar impacts are seen for other infrared sensors (CrIS) or microwave sensors (ATMS humidity-sounding channels). AMSU-A fits in channel 5 and 8 shows small but detectable degradation in background fit, however there is slightly improved fit to channels 1 and 2, which peak in the lower troposphere as well as to the stratospheric AMSU-A channels 13 and 14.
- Figure 5 summarises the impact on the fit to independent observations. Positive short- range forecast impact is suggested by radiosondes and aircraft temperature observations, radiosonde humidity observations in the upper troposphere, as well as atmospheric motion vector winds. Robust and statistically significant positive improvements are seen at altitudes where GPS-RO radio occultation measurements are increasingly sensitive to humidity (i.e. the lower troposphere) and slight degradation (up to 0.1%) in altitude range 14 to 20 km.

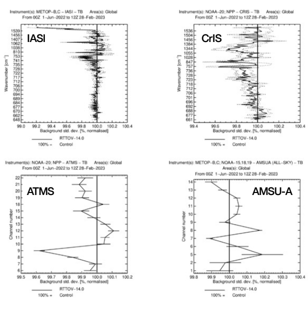


Figure 4: Changes in global background fits to observations resulting from using RTTOV v14 in assimilation runs. The observation types are IASI (top left), CrIS (top right), ATMS (bottom left) and AMSU-A (bottom right).

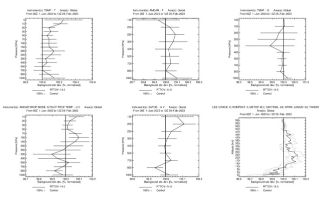


Figure 5: Changes in global background fits to temperature from radiosondes (top left), temperature from aircraft (top middle), humidity from radiosondes (top right), vector wind from radiosondes, profiler, pilot, and aircraft observations (bottom left), atmospheric motion vector winds (bottom middle) and GNSSRO bending angle (bottom right) for RTTOV v14 against the Control with RTTOV v13.2. Values are normalised to the control so that a shift left indicates a reduction in error.

- RTTOV-14.0 introduces new science capabilities that pave the way for future developments, and current research projects will benefit from this upgrade implementation successfully submitted for Cy50r1.

Updated geostationary RTTOV coefficients database in the IFS

- Work has been successfully carried out to upgrade the whole suite of geostationary RTTOV coefficients with the visible/infrared coefficients based a new underlying line-by-line (LBL) model (LBLRTM_12.8), v13 predictors on 54 levels. Advantages include version v13 predictors, all variable O_3+CO_2 are the recommended coefficients version for multi-spectral VIS/IR instruments; includes a new optical depth scheme and predictors; trained with updated infrared and visible spectroscopy; consistent with most other operational IFS coefficients.
- The performance of the assimilation system based on the new RTTOV coefficients has been assessed by running 4D-Var experiments using version 49r1 of the ECMWF forecasting model. Evaluation of the v13 coefficients for the GEOS sensors shows improved simulations compared to observations (Figure 7) and they are planned for use operationally in Cy50r1.

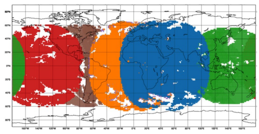


Figure 6: The operational geostationary ring combines data from 5 satellites: GOES-18 and GOES-19, SEVIRI on Meteosat-9 and Meteosat-10 and Himawari-9.

Short-range forecast impact

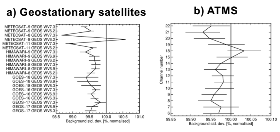


Figure 7: Normalised difference in the standard deviation of background departures between v13 GEOS IR experiment and the Control for: a) geostationary radiances; b) ATMS. Results show improved simulation for geostationary radiances using the latest RTTOV coefficient database and improved fit to ATMS temperature and humidity chs. 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: temperature

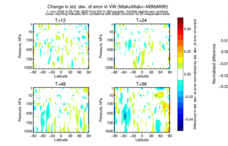


Figure 8: Normalised difference in the standard deviation of the forecast error in the temperature between the between v13 GEOS IR and Control experiments. Each experiment has been verified against its own analysis, and negative numbers indicate a reduction in the forecast errors from using v13 GEOS IR coefficient databases. Hatching indicate statistical significance at the 95 % level.

Forecast impact: Z500

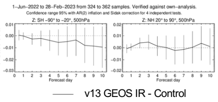


Figure 9: Normalised change in the RMSE of 500hPa geopotential forecasts resulting from v13 GEOS coefs. upgrade for Southern Hemisphere (left) and Northern Hemisphere (right). Each experiment has been verified against its own analysis, and negative numbers indicate a reduction in the forecast errors from v13 GEOS coefs. update.

Impact of varying CO_2 for hyperspectral IR sounder simulations

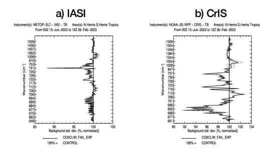


Figure 10: Improvements to the simulation of IASI and CrIS observations, from the use variable CO_2 in the radiative transfer. Experiments cover the period JJA 2022 and DJF 2023. The 100% line represents the standard deviation of misfit for the control (with fixed CO_2) to IASI / CrIS radiances.

- RTTOV coefficients allow changing the concentrations of variable trace gases for hyperspectral IR sounder simulations. However, current calculations are still carried out using a global fixed CO_2 profile.
- We have tested the impact on the assimilation system when CO_2 profiles used in the RTTOV calculations are obtained from a bi-dimensional monthly mean climatology derived from one year of CAMS reanalysis. CO_2 mixing ratios used in the RTTOV calculation vary with altitude, latitude and month.
- Results show that the analysis produced by the system based on the CO_2 climatology improves the fit to hyperspectral radiances up to 8-10% in the CO_2-sensitive stratospheric channels (Figure 10), and smaller gains are observed in the tropospheric channels. This better modelling of IR data does translate into improved fits to other independent observations but has no significant impact on headline scores.
- The use of variable CO_2 in RTTOV for ERA6 is being investigated. Initial tests using a CAMS climatology scaled appropriately in time to match global concentration evolution has shown worthwhile benefits in bias reduction for several historical IR sensors.

RTTOV-14 applications: Simulated satellite imagery for forecasters

- The generation of near-real-time simulated satellite images from the ECMWF medium-range forecast (tool for Member State forecasters / analysts) has been further developed to include visible simulated images (Fig. 11b) in addition to the existing infrared images (Fig. 11a)
- Reflectances that would be seen at a visible wavelength are computed during the model run from every grid point of the forecast model. But note: the area of coverage includes high latitudes; every pixel is assumed to be an overhead (nadir) view; the sun (i.e. the solar illumination) is always assumed to be directly overhead. This means that cloud structures can still be seen at locations and times even when in reality it is dark, but also that, unlike on real visible images, shadowing from clouds is never represented.
- Simulated imagery is an integral part of the operational IFS, available within the standard delivery times of all ECMWF data and products and displayed in Open Charts, echarts, e.g., https://charts.ecmwf.int/
- For NWP, visible observations from both LEO and geostationary satellites will offer, more direct benefit through their use in data assimilation. Operational monitoring of visible reflectances is planned to become an operational standard with the upcoming model upgrade (Cy50r1).

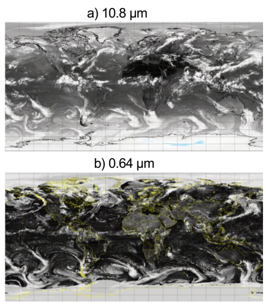
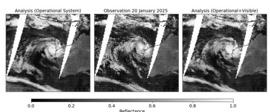


Figure 11: A 10-day forecast from the IFS e-suite initialized on April 14th, 2024 at 12 UTC.

Figure 12: Case example of tropical cyclone Sean focusing on OLCI on Sentinel-3A/-3B 655 nm visible reflectances on January 20, 2025: (left) IFS analysis assimilating full observing system, (middle) OLCI observation, and (right) improved IFS analysis when also assimilating OLCI data.



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