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| NWP SAF | RTTOV version 13 Product Specification | Doc ID : NWPSAF-MO-DS-039 Version : 1.1 Date : 19.10.2020 |
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NWP SAF

RTTOV version 13
Product Specification

Version 1.1

19th October 2020

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RTTOV Version 13 Product Specification

This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 7 December 2016, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, DWD and Météo France.

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1. INTRODUCTION

This document defines the specification for Version 13 of RTTOV, in accordance with the requirements of the NWP SAF. The Product Specification describes the deliverable from the point of view of the user.

1.1 Reference documents

[RD-1] NWPSAF-MO-UD-046 RTTOV v13 user guide

[RD-2] NWPSAF-MO-TV-044 RTTOV v13 Test Plan

[RD-3] NWPSAF-MO-TV-046 RTTOV v13 Science and Validation Report

2. PURPOSE

RTTOV is a fast radiative transfer model for simulating top-of-atmosphere visible, infrared (IR) and microwave (MW) clear-sky and cloudy radiances for downward-viewing space-borne sensors. It is intended for use in NWP data assimilation systems, retrieval applications (for example 1DVAR), generating simulated imagery, reanalysis projects and instrument cal/val activities, among others. It consists of a forward model and associated tangent linear (TL), adjoint (AD) and Jacobian (K) models.

3. FUNCTIONALITY

RTTOV v13 will perform the following functions

Simulations types:

RTTOV v13 will carry out the following kinds of simulations

- RQ-3.1 Visible and IR (0.4 – 100 microns), and MW (1 – 1000 GHz) clear-sky simulations.
- RQ-3.2 MW clear-sky simulations treating cloud liquid water as an absorber only
- RQ-3.3 IR simulations with a simple black cloud top at given pressure and with given cloud fraction.
- RQ-3.4 Visible simulations with a simple Lambertian cloud top at given pressure and with given cloud fraction.
- RQ-3.5 Visible/IR scattering simulations in the presence of aerosols and/or clouds with pre-defined particle optical properties.
- RQ-3.6 Visible/IR scattering simulations in the presence of aerosols and/or clouds with user-provided particle optical properties.
- RQ-3.7 MW scattering simulations of passive radiances in the presence of cloud and/or hydrometeors (via the RTTOV-SCATT interface).
- RQ-3.8 MW radar simulations in the presence of cloud and/or hydrometeors (via the RTTOV-SCATT interface).
- RQ-3.9 Principle Component (PC) simulations for hyperspectral IR sounders.
- RQ-3.10 Tangent linear (TL), adjoint (AD) and Jacobian (K) calculations for all simulation types except HTFRTC for which only a Jacobian model will be implemented in RTTOV.

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- RQ-3.11 Simulation of Zeeman effect in high-peaking SSMI/S and AMSU-A channels.
- RQ-3.12 Simulation of SSU radiances with correction for varying CO₂ cell pressure in the instrument.
- RQ-3.13 Optional inclusion of bias correction for non-local thermodynamic equilibrium effects.
- RQ-3.14 Option to treat the surface as a Lambertian reflector, and as a partial Lambertian/specular reflector via a “specularity” parameter.
- RQ-3.15 Capability to run simulations with multiple threads using OpenMP.

Coefficient input/output:

RQ-3.16 RTTOV v13 will provide subroutines to read RTTOV coefficient files in ASCII, Fortran unformatted (“binary”) and HDF5 formats. These subroutines will allow a subset of channels to be read from the coefficient files. The exceptions are RTTOV-SCATT hydrotables which are not available in HDF5 format and optical properties for all channels must be read in (i.e. no channel subsets), and HTFRTC coefficients which are available in ASCII and netCDF format.

RQ-3.17 RTTOV v13 will provide an executable to convert coefficient files between ASCII, binary and HDF5 formats and to optionally extract a subset of channels to a new coefficient file. The exceptions are RTTOV-SCATT hydrotables for which a separate executable is used to convert ASCII to binary format and channel extraction is not possible, and HTFRTC for which no conversion between formats or channel extraction (outside RTTOV) is available.

RQ-3.18 RTTOV v13 will provide executables to convert RTTOV v10/v11 format optical depth (*rtcoef*) files to and from RTTOV v12 format. These will work with ASCII and HDF5 format files. (RTTOV v13 reads all v12 format coefficient files).

Surface emissivity and BRDF:

RQ-3.19 RTTOV v13 will provide internal models for sea surface reflectance and emissivity.

RQ-3.20 RTTOV v13 will provide atlases for land surface BRDF and emissivity which can be used to provide BRDF and/or emissivity values for input to RTTOV.

RTTOV GUI:

RQ-3.21 RTTOV v13 will provide a graphical user interface (GUI) which enables direct and Jacobian (K) model simulations to be performed and the results visualised. The RTTOV GUI will support clear-sky, visible/IR scattering and PC-RTTOV simulations including use of the land surface emissivity and BRDF atlases and will provide a 1DVAR capability.

RTTOV wrapper:

RQ-3.22 RTTOV v13 will provide interfaces so that it may be called from C++ and Python. The RTTOV wrapper will support clear-sky, and visible, IR and MW scattering direct and K model simulations, including use of the land surface emissivity and BRDF atlases.

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4. SOFTWARE ORGANISATION

The Fortran source code is stored in a number of directories under the *src/* directory. The directories group source files broadly according to function. The following directories are included in the package provided to users:

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| <i>brdf_atlas</i> | subroutines for accessing the land surface BRDF atlas |
| <i>coef_io</i> | subroutines for reading/writing coefficient files |
| <i>coef_io_11</i> | subroutines for converting v12-format <i>rtcoef</i> files to/from v10/v11 format |
| <i>emis_atlas</i> | subroutines for accessing the land surface emissivity atlases |
| <i>gui</i> | subroutines for the Fortran side of the RTTOV GUI |
| <i>hdf</i> | subroutines for input/output of RTTOV structures and data in HDF5 format |
| <i>main</i> | core subroutines and modules for RTTOV |
| <i>mw_scatt</i> | subroutines for the RTTOV-SCATT MW scattering model |
| <i>mw_scatt_coef</i> | subroutines for generating hydrotable files for RTTOV-SCATT |
| <i>other</i> | ancillary subroutines which may be helpful for users |
| <i>parallel</i> | subroutines defining the parallel (OpenMP) interface to RTTOV |
| <i>test</i> | subroutines for testing RTTOV and example code for users |
| <i>wrapper</i> | subroutines for the Fortran side of the C++/Python wrapper |

The compilation process creates a library for each subdirectory in *src/*. Users only need to link against those libraries which are used in their application. Information on this is given in the User Guide [RD-1].

In addition to the Fortran source code the package also contains the Python source files for the RTTOV GUI in the top-level *gui/* directory and the C++ and Python source files and example code for the C++/Python wrapper in the top-level *wrapper/* directory.

5. INPUTS / OUTPUTS

The primary inputs to RTTOV are the atmospheric and surface variables describing the profile to be simulated. These are grouped into the *rttov_profile* structure which is described fully in the User Guide [RD-1].

The *rttov_direct* (direct model) subroutine accepts as input:

- a structure of type *rttov_options* containing options which configure various aspects of the simulation
- an array of type *rttov_profile* containing the input atmospheric and surface data pertinent to the simulation being performed, size [*nprofiles*]
- a coefficient structure pre-populated by calling the *rttov_read_coefs* subroutine (or *rttov_read_coefs_htfrtc* for HTFRTC simulations)
- an array of type *rttov_chanprof* containing lists of channels and profiles for every radiance to be simulated, size [*nchanprof*]
- an array of surface emissivities [*nchanprof*]
- a logical array for selecting RTTOV's internal emissivity calculation if true [*nchanprof*]
- an array of surface BRDFs [*nchanprof*]

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- a logical array for selecting RTTOV's internal BRDF calculation if true [*nchanprof*]
- optional structures containing optical parameters for visible/IR aerosol and cloud scattering simulations [*nlevels, nchanprof*]
- optional list of channels for which to calculate reconstructed radiances [*nchannels_rec*]

The outputs are arrays of:

- surface to space transmittances [*nchanprof*]
- level to space transmittances [*nlevels, nchanprof*]
- overcast radiances at each input level [*nlayers, nchanprof*]
- overcast radiance from user-specified cloud top [*nchanprof*]
- radiances [*nchanprof*]
- brightness temperatures [*nchanprof*] (not for channels below 3 microns)
- bi-directional reflectance factors (BRFs) [*nchanprof*] (solar-affected channels only)
- PC scores [*npcscores, nprofiles*]
- reconstructed radiances and BTs [*nchannels_rec, nprofiles*]
- surface emissivities used by RTTOV [*nchanprof*]
- surface BRDFs used by RTTOV [*nchanprof*]

The tangent linear (TL), adjoint (AD) and Jacobian (K) models accept the same inputs and generate the same outputs as the direct model. They have the following additional inputs and outputs.

The *rttov_tl* (TL model) subroutine additionally accepts as input:

- an array of type *rttov_profile* containing the input atmospheric and surface data perturbations around the input profile, size [*nprofiles*]
- an array of surface emissivity perturbations [*nchanprof*]
- an array of surface BRDF perturbations [*nchanprof*]

For each of the direct model output arrays listed above, there is a corresponding additional TL output array containing the changes in the output variables of the linearised model corresponding to the input perturbations.

The *rttov_ad* (AD model) subroutine additionally accepts as input:

- input increments either in radiance [*nchanprof*], brightness temperature [*nchanprof*], PC score [*npcscores, nprofiles*] or reconstructed radiance [*nchannels_rec, nprofiles*] according to the simulation type and user settings. In retrieval/assimilation contexts, the input increments usually corresponding to the gradient of a cost function with respect to the satellite radiances.

The additional AD output arrays are:

- an array of type *rttov_profile* containing the atmospheric and surface variable adjoints (typically the gradient of the cost function with respect to the profile variables), size [*nprofiles*]
- an array containing the surface emissivity adjoints [*nchanprof*]
- an array containing the surface BRDF adjoints [*nchanprof*]

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The *rttov_k* (Jacobian model) subroutine additionally accepts as input:

- input scale factors (commonly 1) either in radiance [*nchanprof*], brightness temperature [*nchanprof*], PC score [*npcscores*, *nprofiles*] or reconstructed radiance [*nchannels_rec*, *nprofiles*] according to the simulation type and user settings. The values scale the computed Jacobians.

The additional Jacobian output arrays are:

- an array of type *rttov_profile* containing the Jacobians either for radiances [*nchanprof*], brightness temperatures [*nchanprof*], PC scores [*npcscores*, *nprofiles*] or reconstructed radiances [*nchannels_rec*, *nprofiles*] with respect to the atmospheric and surface variables according to the simulation type and user settings.
- an array containing the surface emissivity Jacobians [*nchanprof*]
- an array containing the surface BRDF Jacobians [*nchanprof*]

6. SYSTEM REQUIREMENTS

6.1 Language

RQ-6.1 RTTOV is written in Fortran2008 except for the LAPACK routines included in the code (taken from the Fortran77 source). It makes use of commonly supported F95 and F2003 features and one common F2008 intrinsic. The test suite additionally makes use of Perl (v5.6 or later) and Python3. The RTTOV GUI is written in Python3 which uses *f2py* to interface to the Fortran GUI subroutines. The wrapper supports calls to RTTOV from C++ and Python3, the latter also using *f2py*.

6.2 Supported platforms

RQ-6.2 Unix/Linux platforms including Mac OS X and Cray. RTTOV is tested with several compilers as listed in the User Guide [RD-1]. RTTOV supports parallel processing using OpenMP via RTTOV's parallel interface and is also tested in an operational MPI environment. The full list of platforms/compilers with which RTTOV v13 has been successfully tested is given in the Test Log accompanying the Test Plan [RD-2].

6.3 Performance

RQ-6.3 RTTOV v13 shall be comparable to (or more efficient than) RTTOV v12.3 in speed and memory requirements for equivalent simulations. Comparisons of RTTOV v12.3 and v13 in terms of speed and peak memory usage for a variety of simulation types will be documented in the Test Log accompanying the Test Plan [RD-2].

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6.4 Interface requirements

RQ-6.4 The interface to RTTOV v13 will be very similar to that for RTTOV v12. The differences will result from the requirements of new functionality and improvements to the consistency of the interface.

6.5 Operational and resource requirements

RQ-6.5 The core RTTOV v13 calculation routines (*rttov_direct/tl/ad/k.F90* and *rttovscatt/_tl/_ad.F90*) shall be “thread safe” to be able to run on MPP machines.

7. DOCUMENTATION

The following user documentation is included in the RTTOV package:

- *NWPSAF_ReleaseNote_RTTOV13.0.pdf* - summary of the package contents and compilation instructions
- *users_guide_rttov13_v1.0.pdf* - user guide giving full details of how to compile and run RTTOV and how to incorporate it into the user’s application
- *rttov-quick-start.pdf* - beginner’s guide to help new users get started
- *rttov_gui_v13.pdf* - user guide for RTTOV GUI
- *rttov-wrapper.pdf* - user guide for the C++/Python interface to RTTOV
- *rttov-test.pdf* - detailed description of the RTTOV test suite

8. LIST OF REQUIREMENTS

This section details specific requirements to be addressed in the RTTOV v13 Test Plan [RD-2].

RQ-8.1 RTTOV v13 shall perform all the functions listed in Section 3 of this document (requirements RQ-3.1 - RQ-3.21).

RQ-8.2 The software should be successfully built, following the instructions in the User Guide [RD-1].

RQ-8.3 The software should meet the system requirements listed in Section 6 of this document (requirements RQ-6.1 - RQ-6.5).

RQ-8.4 The various test suite scripts shall run to completion and shall have no unexpected differences relative to the reference results provided.

RQ-8.5 RTTOV v13 will reproduce RTTOV v12 radiances to within expected margins for identically configured simulations. The differences in radiances between v12 and v13 are less than 1mK for identically configured simulations due to the updated values of physical constants in v13. Differences due to changes in default values of options, updated visible/IR spectroscopy, and the new v13 predictors are documented in the Science and Validation Report [RD-3].