Radiance Simulator v4 Product Specification

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Change record			
Version	Date	Author / changed by	Remarks
0.1	09/09/2024	J. Hocking	Initial version
1.0	26/09/2024	J. Hocking	Updates after internal review
1.1	25/10/2024	J. Hocking	Updates after further development
1.2	07/04/2025	J. Hocking	Updates after final developments

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1. INTRODUCTION

This document defines the specification for Version 4 of the NWP SAF Radiance Simulator, 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-DS-048, RTTOV v14 Product Specification
[RD-2] NWPSAF-MO-UD-061, Radiance Simulator User Guide
[RD-3] NWPSAF-MO-SW-002 Development Procedures for Software Deliverables
[RD-4] NWPSAF-MO-TV-052, Radiance Simulator Test Plan

2. PURPOSE

The NWP SAF Radiance Simulator is a tool designed to support pre-launch scientific studies and pre-operational development work for new satellite instruments. It provides a straightforward means of generating simulated radiance datasets from NWP model analysis or background fields using the NWP SAF fast radiative transfer model RTTOV [RD-1]. The capability to model radiances from new satellite instruments is limited only to those instruments supported by RTTOV which is usually many months or years prior to launch.

The Radiance Simulator is increasingly being used in other applications, for example the generation of simulated imagery, studies involving comparison of radiative transfer simulations with observations, and studies involving simulation of historical satellite sensors.

3. REQUIREMENTS REVIEW

The user requirements are considered in relation to the NWP SAF CDOP-4 proposal and in terms of explicit user requests received by the NWP SAF.

3.1 Development activity as planned in the NWP SAF CDOP-4 proposal

In addition to the tasks of maintaining the code and providing support to users, the CDOP-4 proposal lists the following developments for the Radiance Simulator:

1. Maintain RTTOV compatibility for the RadSim package and exploit new features of RTTOV.

2. Extend the tool to simulate radiances for new instruments.

3. Further development of orbit simulation for new instruments/satellites.

4. Accounting for slant view paths which intersect multiple NWP model grid columns for high resolution models.

Each release of the RTTOV package is followed by an update to the Radiance Simulator (item 1 above) which allows users to benefit from new functionality implemented in RTTOV. RadSim v4 will therefore be updated to work with RTTOV v14. New functionality in RTTOV v14 will be exploited. For RadSim v4.0, based on RTTOV v14.0, the main development here is the ability to treat inhomogeneous surfaces. This will be activated on a switch in RadSim and will allow for simulated profiles to be associated with a combination of land, sea, and sea-ice surface types according to the land and sea-ice fractions provided in the input model and/or observation data files.

Item 2 above is automatically fulfilled for the vast majority of sensors without the need for any code updates once an RTTOV coefficient file is available for a new sensor.

It has been decided that the orbit simulation capability (item 3) will remain restricted to geostationary sensors as generic support for sensors in low-Earth orbit is extremely complex due to wide variety of sensor types, scanning configurations, and so on. Input files for creating RadSim observation data files for new geostationary sensors will be created on user request.

Item 4 is planned for implementation in RadSim v4.1 or v4.2. This will involve computing the horizontal location of the satellite view path at each pressure level in the atmosphere according to the observation latitude/longitude and the satellite zenith and azimuth angles and interpolating the model fields at each level accordingly.

3.2 Other user requests received by the NWP SAF

The following requests for new capabilities were received from users and will be supported in RadSim v4.0:

- RTTOV developers at DWD requested support for ingest of ICON-ART fields in GRIB format including the ICON-ART aerosol fields supported by RTTOV.
- Users at DWD requested optional output of clear-sky radiances/brightness temperatures/reflectances in addition to total radiances for cloudy simulations.
- A user at BOM requested support (and supplied code) for reading UM model data for only a subset of forecast times instead of all times in the input fieldsfile.
- A user at BOM requested support (and supplied code) for providing observation data files in netCDF format as an alternative option to the existing ASCII format (much more efficient for large sets of observations).
- A user at ECMWF requested support for more variable trace gases. These are available in the NWP SAF 60L profile datasets from MACC and CAMS short-range forecasts, so the ability to ingest these datasets will be added. In addition, the new 137L CAMS dataset which includes all optional variable trace gases supported by RTTOV will become available in time to implement ingest of this in RadSim v4.0.
- Users at EUMETSAT requested the ability to specify magnetic field variables in the observation data file to allow use of Zeeman-enabled RTTOV coefficients.
- A user at IPMA requested that ecCodes be an optional dependency so that it is only required when ingesting model data in GRIB format.
- A user pointed out the linear interpolation of model fields can result in physically inconsistent profiles, and that interpolation of cloud fields is not necessarily optimal.

Options for nearest-neighbour interpolation to use model data from the nearest grid point and/or nearest timestep will be added.

3.3 Summary

The main updates for RadSim v4.0 are the following:

- Update to support RTTOV v14.0 including new features, in particular support for heterogeneous surfaces.
- Options for nearest neighbour spatial and temporal interpolation.
- Support for ingest of ICON-ART fields including aerosol species supported by RTTOV.
- Support for ingest of NWP SAF 60L MACC and CAMS, and 137L CAMS profile datasets. For MACC this includes fields for CAMS aerosol species, CO_2, and CH_4. For 60L CAMS, this includes fields for CO and SO_2. For 137L CAMS this includes CO_2, N_2O, CO, CH_4, SO_2, and fields for CAMS aerosol species. In all cases input fields for hydrometeor simulations are supported.
- Option to include magnetic field variables in the obs data file to enable Zeeman simulations.
- Optional output of clear-sky radiances for cloudy simulations.
- Support reading only a subset of forecast times for UM fieldsfiles.
- Option to supply observation data files in netCDF format.
- Make ecCodes an optional dependency, required only when ingesting model data in GRIB format.

4. FUNCTIONALITY

The radiance simulator performs the following functions:

- *RQ-4.1 Ingest of NWP model fields*, provided in common data formats. This includes support for the following formats:

    - GRIB (ECMWF, ICON, ICON-ART, HARMONIE-AROME, JMA)
    - NetCDF (ECMWF)
    - Met Office fieldsfiles / PP files
    - NWP SAF 60L profile dataset from ECMWF analyses
    - NWP SAF 91L profile dataset from ECMWF short-range forecasts
    - NWP SAF 137L profile dataset from ECMWF short-range forecasts
    - NWP SAF 60L profile dataset from MACC short-range forecasts
    - NWP SAF 60L profile dataset from CAMS short-range forecasts
    - NWP SAF 137L profile dataset from CAMS short-range forecasts

  Model fields consist of:

    - Half-level pressure
    - Full-level pressure
    - Temperature
    - Humidity
    - Ozone

- CO_2
- N_2O
- CO
- CH_4
- SO_2
- Density
- Cloud liquid water
- Cloud ice water
- Rain mixing ratio
- Snow mixing ratio
- Cloud fraction
- Surface pressure
- Surface skin temperature
- Surface air temperature
- Surface humidity
- Surface wind
- Sea-ice fraction
- Land fraction / land/sea mask
- Orography
- CAMS aerosol species supported by RTTOV aertable files
- ICON-ART aerosol species supported by RTTOV aertable files

Some fields are optional depending on the chosen configuration.

- *RQ-4.2 Ingest of observation files (optional)*. The user may provide observation metadata including observation locations and viewing geometry and other fields to allow simulations to be performed at those locations. These can be in ASCII or netCDF format.

- *RQ-4.3 Interpolation of model fields to observation locations and times*. This is optional, dependent on the above. If model fields are provided at multiple forecast times, they can be interpolated temporally as well as spatially. If no observation data are provided, simulations are performed at model profile locations and using the fields at the first forecast time in the model fields file. Interpolation is either (bi-)linear or nearest neighbour, chosen by user.

- *RQ-4.4 Footprint simulations (if observation data are provided).* The option also exists to return the average simulated radiance for all grid points falling within the observation footprint modelled as an ellipse with semi-major/minor axes (radii) in km and azimuthal orientation specified in the observation file.

- *RQ-4.5 Calculate solar zenith and azimuth angles.* Simulations may include solar radiation. Users may input solar zenith and azimuth angles explicitly or RadSim may calculate them.

- *RQ-4.6 Prepare input to, and run, radiative transfer model*. The model used in this release is RTTOV v14. Depending on the availability of the required model fields, scattering simulations can be run. The Principal Components based model within RTTOV (PC-RTTOV) may be used for clear-sky and cloudy simulations.

- *RQ-4.7 Output simulated data to a file*. Output fields include:

    - Brightness temperatures and reflectances, or radiances
    - Input observation data
    - Simulation meta-data

    Optional output fields include:

    - Clear-sky brightness temperatures and reflectances, or radiances
    - Surface emissivities and BRDFs
    - Jacobians (T, q, O_3, Tskin, wind u/v, surface emissivity)
    - Level-to-space transmittances
    - Pressure half- and full-level altitudes
    - Height assignments consistent with the NWP SAF CADS package
    - Model profiles at obs (simulation) locations

RQ-4.8 A separate tool is provided to generate input observation files representing geostationary orbit simulations. Sensors currently supported include MSG SEVIRI, Himawari AHI, and GOES ABI. Given an input netCDF file containing pixel latitudes and longitudes, some basic information about the satellite, and a scan date/time, the tool generates observations for every pixel (or a user-specified subset of pixels). The resulting file can be used with the Radiance Simulator.

5. INPUTS / OUTPUTS

The main inputs to the radiance simulator will be:

- A control file (Fortran namelist file) containing all the information required to run the simulations. This includes paths to observation and model data files, RTTOV coefficient files and run-time options such as scattering and emissivity/BRDF processing and output file control.

- An observation file (optional) containing observation-specific information required for the simulation. This includes latitude, longitude, and other meta-data fields such as surface type, surface height and satellite zenith angle.

- An NWP model file containing the fields required for the radiance calculation.

The output of the radiance simulator is:

- A netCDF file containing simulated data and other fields (see section 3). These are documented fully in the User Guide [RD-2].

6. DOCUMENTATION

A User Guide [RD-2], incorporating technical and scientific descriptions of the code is provided.

7. LIMITATIONS

Simulations can only be performed for an instrument if the appropriate RTTOV coefficients are available.

There are some other limitations that users should be aware of:

- Met Office UM data files:
  - The use of packed files is not supported. The UM *convieee* routine should be used to unpack the data in advance of running the Radiance Simulator. Temporal interpolation is not supported for UM PP files.
- GRIB files:
  - Currently those originating from ECMWF, from the DWD ICON model, from the ICON-ART model, from the HARMONIE-AROME model, and from JMA are supported. Support for other sources may be added in future releases based on user requests and the availability of test datasets.
  - The ICON and ICON-ART models use an irregular grid: currently only nearest-neighbour spatial interpolation is available for this.
  - Support for JMA datasets is currently limited to clear-sky simulations only.
- NetCDF files:
  - Currently only those originating from ECMWF are supported. Support for other sources may be added in future releases based on user requests and the availability of test datasets.
- Footprint simulations:
  - Footprints are modelled as ellipses. This may not be the optimal choice for all types of sensor, for example visible/IR radiometers where pixel footprints are more rectangular.
- Orbit simulations:
  - The orbit simulation capability is restricted to geostationary satellites.

8. REQUIREMENTS

The requirements set out here will be explicitly mapped to the testing performed on the package in the Radiance Simulator Test Plan [RD-4].

8.1 Functional Requirements

- *RQ-8.1* The Radiance Simulator shall perform all the functions listed in Section 4 of this document (RQ-4.1 - RQ-4.8).
- *RQ-8.2* The software should be successfully built, following the instructions in the User Guide [RD-2].
- *RQ-8.3* The test cases shall run to completion and shall have no unexpected differences relative to the reference results provided in terms of the accuracy of the output products.

8.2 Operational Requirements

There are no specific operational requirements. This is a standalone research tool and is not intended for operational use.

8.3 Performance Requirements

Speed of execution is not a primary consideration in the Radiance Simulator specification. Execution times are mostly dominated by the time required to run the radiative transfer model (RTTOV) which is an external package. The exception to this may be in the footprint simulation capability where the identification of grid points lying within observation footprints can take a significant proportion of the runtime, depending on the number of grid points in the ingested NWP model fields. This is mitigated using OpenMP on systems with multiple CPUs/cores. Examples of execution times will be provided in the Results section of the Test Plan [RD-4]. Furthermore, for multiple RadSim runs using simulations at the same locations (such as for geostationary sensors), the footprint metadata can optionally be written out after the first call to RadSim and then read in on subsequent calls to speed up the processing.

RQ-8.4 The Radiance Simulator shall support multi-threading via OpenMP.

RQ-8.5 The speed of execution of the Radiance Simulator shall be similar to the previous version for comparable configurations (bearing in mind that this is dependent on the relative performance of the corresponding RTTOV versions).

8.4 Portability Requirements

RQ-8.6 The software should compile and run on a range of Linux platforms and with different compilers.

8.5 Resource Requirements

RQ-8.7 There are no specific resource requirements, but the Radiance Simulator should be able to handle large input and output datasets.

8.6 Design Requirements

RQ-8.8 The Radiance Simulator is written in Fortran-90 with the addition of a small number of Fortran 2003 features.

RQ-8.9 Documentation should be provided as described in section 7 of [RD-3].

8.7 Interface Requirements

RQ-8.10 The following programming interfaces (APIs) are required to allow the I/O of necessary input and output files in certain common data formats:

- netCDF (version 4.0 or later)
- RTTOV (version 14)

Optional, but required for ingest of model data in GRIB format:

- ecCodes (version 2.23.0)