Radiance Simulator v3 Product Specification

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Change record			
Version	Date	Author / changed by	Remarks
0.1	12/10/2020	J. Hocking	Initial version
0.2	04/02/2021	J. Hocking	Minor updates: clarify user requirements for footprint and orbit simulation capabilities; footprints modelled as ellipses rather than circles; add ingest of JMA GRIB data.
0.3	31/03/2021	J. Hocking	Update after internal review (expand acronym)
0.4	26/04/2021	J. Hocking	Updates after DRR: add RQ-XX identifiers.

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1. INTRODUCTION

This document defines the specification for Version 3 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-039, RTTOV Product Specification
[RD-2] NWPSAF-MO-DS-051, Radiance Simulator User Guide
[RD-3] NWPSAF-MO-SW-002 Development Procedures for Software Deliverables
[RD-4] NWPSAF-MO-TV-047, 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-3 proposal and in terms of explicit user requests received by the NWP SAF.

3.1 Development activity as planned in the NWP SAF CDOP-3 proposal

In addition to the tasks of maintaining the code and providing support to users, the CDOP-3 proposal lists the following developments for the Radiance Simulator:

1. Maintain RTTOV compatibility for the RadSim package.

2. RadSim v2 plans:
   a) move to NetCDF v4 only to support files larger than 4GB
   b) modify build system to be more RTTOV-like
   c) allow RadSim to be run via a command-line script without manually editing the config file
   d) add support for multi-threaded RTTOV simulations using OpenMP
   e) enable variable O3 and CO2 in RTTOV simulations
   f) additional features are possible depending on user requirements, complexity of implementation, and availability of suitable test data

3. RadSim v3 plans:
   a) Include orbit simulation capability for new satellites
   b) Accounting for variability within the observation footprint to support assimilation studies at the convective scale

4. Support for other GCM (Global Circulation Model) data will be implemented in response to user requests.

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 v3 will therefore be updated to work with RTTOV v13.

Versions 2.1 and 2.2 of the Radiance Simulator (released June 2018 and September 2019 respectively) introduced many new capabilities. These include items 2a, 2c, 2d and 2e above. It was decided not to change the build system (item 2b) since there was no evidence of users having problems compiling the Radiance Simulator and hence no perceived user requirement to change it. There were numerous other updates including support for the majority of RTTOV simulation types and features, allowing users control over all relevant RTTOV options, enabling solar radiation, and enabling use of the RTTOV Principal Components based models PC-RTTOV and HTFRTC. The capability to carry out temporal interpolation between model fields at different forecast times was implemented in response to user requests. Under item 4, RadSim v2.2 introduced the capability to ingest GRIB data from the DWD ICON model, and ECMWF data in netCDF format, both in response to user requests.

Items 3a and 3b are planned for implementation in RadSim v3. Item 3a was requested by at least one user to simplify the generation of simulated observations. Orbit simulation will be implemented via a separate tool that will generate suitable observation data files for use with RadSim. The initial capability will be restricted to geostationary sensors, but this could be extended in the future in response to user requirements.

The footprint simulation capability (item 3b) was also requested by at least one user to account for variability in surface and cloud fields within the satellite field of view. It is intended for use with fields from convection-resolving models where the grid cells are much smaller than the satellite sensor field of view. In this case the user will specify semi-major/minor axes (radii, in km) of an elliptical footprint and the satellite azimuth angle for each observation in the input observation file, and RadSim will return the mean of the radiances computed over all grid points falling within each elliptical footprint.

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 v3:

- KNMI requested support for ingest of HARMONIE fields in GRIB format.
- Timo Hanschmann and Paul Poli (EUMETSAT) requested support for JMA GRIB files.
- Chris Merchant (University of Reading) requested support for additional Jacobian outputs (surface emissivity, skin temperature and 10m wind u/v).

- The Copernicus Climate Change Services Data Rescue project required the ability to output height assignments consistent with the NWP SAF CADS package.

3.3 Summary

The main updates for RadSim v3 are the following:

- Update to support RTTOV v13 including new features.
- Initial implementation of orbit simulation capability (via a separate tool which generates observation files for use with RadSim).
- Footprint simulation capability.
- Support for ingest of HARMONIE GRIB files.
- Support for ingest of JMA GRIB files (clear-sky simulations only).
- Support for additional optional outputs based on user requests (in particular additional Jacobians and CADS height assignments).

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, DWD ICON, HARMONIE, JMA)
    - NetCDF (ECMWF)
    - Met Office fieldsfiles / PP files
    - NWP SAF 60L profile dataset from ECMWF analyses
    - NWP SAF 91L profile dataset from ECMWF analyses
    - NWP SAF 137L profile dataset from ECMWF analyses

    Model fields consist of:

    - Level pressure
    - Temperature
    - Humidity
    - Ozone
    - Density
    - Cloud liquid water
    - Cloud ice water
    - Rain mixing ratio
    - Snow mixing ratio
    - Cloud fraction
    - Surface wind
    - Surface pressure
    - Surface skin temperature
    - Surface air temperature
    - Surface humidity
    - Sea-ice fraction
    - Orography

Some fields are optional depending on the chosen setup.

- *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.

- *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.

- *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 version 13. Depending on the availability of the required model fields, visible/infrared and microwave scattering simulations can be run. The Principal Components based models within RTTOV (PC-RTTOV and HTFRTC) may be used for clear-sky 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:

    - Surface emissivities and BRDFs
    - Jacobians (T, q, O3, Tskin, wind u/v, surface emissivity)
    - Level-to-space transmittances
    - 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 orbit simulations. The initial capability will be restricted to geostationary imagers such as 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 will generate 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, RT coefficient files and run-time options such as cloud 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 HARMONIE 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 model uses an irregular grid: currently nearest-neighbour spatial interpolation is used for this, but a more sophisticated interpolation scheme may be implemented in a future release.
  - 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.

- The following processing options are not included but may be in a future release:
  - Use of variable trace gases (CO_2, N_2O, CO, CH_4, SO_2) profiles. Note that the Radiance Simulator does allow the RTTOV background CO_2 profile to be scaled so that historical (or indeed future) concentrations of CO_2 can be represented.
  - Use of aerosol profiles.
- 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. The tool may be expanded to additional satellite types in the future, based on user requirements.

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. Lengthy 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 by the use of OpenMP on systems with multiple CPUs/cores available. Examples of execution times will be provided in the Results section of the Test Plan.

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.

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 in order to allow the I/O of necessary input and output files in certain common data formats:

- ecCodes (version 2.0.0 or later)
- netCDF (version 4.0 or later)
- RTTOV (version 13)
- HDF5 (version 1.8.8 or later) is required for some RTTOV functionality