	<b>Radiance Simulator v4 Top-level Design</b>	Doc ID :NWPSAF- MO-DS-054 Version : 1.2.1 Date : 06/06/2025
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## Radiance Simulator v4 Top-level Design

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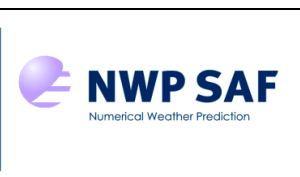
This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 7 September 2021, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, DWD and Météo France.

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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 developments
1.2	07/04/2025	J. Hocking	Updates after further developments
1.2.1	06/06/2025	J. Hocking	Correct minor typo after DRR

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## 1. INTRODUCTION

This document defines the top-level design for Version 4 of the Radiance Simulator, in accordance with the requirements of the NWP SAF.

### 1.1 Reference documents

[RD-1] NWPSAF-MO-DS-053, Radiance Simulator Product Specification

[RD-2] NWPSAF-MO-UD-061, Radiance Simulator User Guide

### 1.2 Design Drivers

Version 4 of the Radiance Simulator extends the capabilities of version 3 based on requests from users. Each release of RadSim is based on the latest version of RTTOV and exploits the new features available.

As described in [RD-1] the key updates for RadSim v4.0 are as follows:

- 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<sub>2</sub>, and CH<sub>4</sub>. For 60L CAMS, this includes fields for CO and SO<sub>2</sub>. For 137L CAMS this includes CO<sub>2</sub>, N<sub>2</sub>O, CO, CH<sub>4</sub>, SO<sub>2</sub>, and fields for CAMS aerosol species. In all cases this also includes fields for hydrometeor simulations.
- 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.

The preferred practice for implementing new features in RadSim is to integrate them into the existing code framework with as few changes as possible. Many updates do not require a large development effort, such as adding new outputs, or adding ingest of data from a new NWP model if the format is already supported. Updating the RTTOV interface to that of the latest model is also usually a straightforward task although RTTOV v14 represents a significant change to the previous version and as such more work is required to adapt to it.

For the use of heterogeneous surface capability in RTTOV v14, a new namelist variable has been added to RadSim, *multi\_surface*, which, when set to true, will exploit land and sea-ice fraction information where available in the model fields or the observation data file (depending on how the simulations are configured). Each profile is associated with three

surface types (land, sea, sea-ice), with area coverage fractions from the input data. Surface properties are assigned to each of the three surfaces according to the user configured settings (e.g., using emissivity/BRDF atlases, or internal RTTOV emissivity/reflectance models).

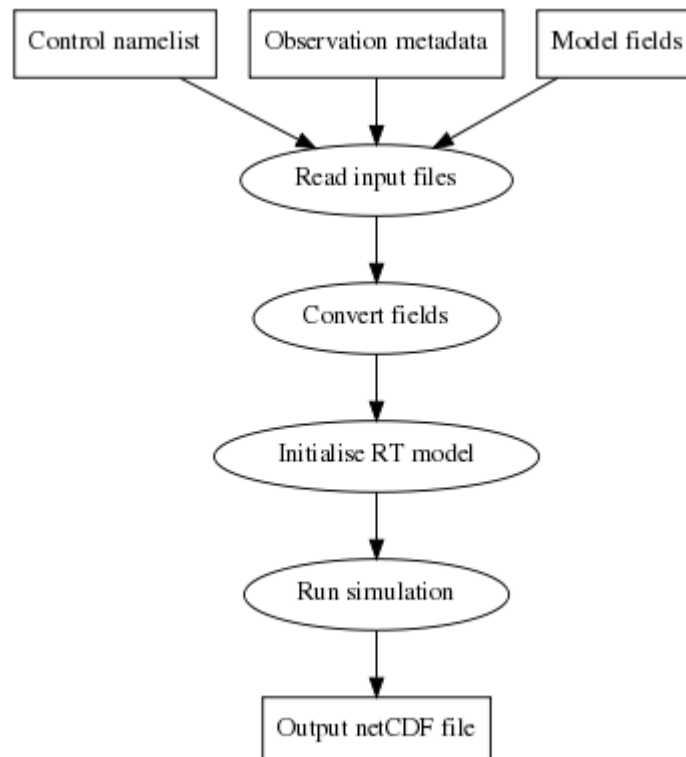
The other updates for RadSim v4 are relatively straightforward modifications or extensions to the existing capabilities.

## 2. SOFTWARE FUNCTIONS


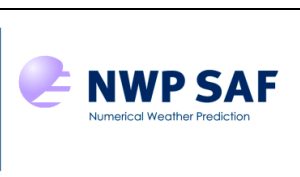
The main components of the Radiance Simulator are:

- **Input** of control, observation, and model data from external files
- **Field conversions** – calculation of humidity, identification of grid points with footprints, interpolation to observation locations and times etc
- **Initialisation and set-up** of the radiative transfer model (RTTOV)
- **Processing** - performing the simulation; looping over all observations, transferring model data to RT model profiles, and calling the RT model.
- **Output** of the simulated radiances and other data.

The sequence of main functions is represented in Figure 1 below.



**Figure 1:** Main functions, input and output of the Radiance Simulator.

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### 3. DATA FLOWS

#### 3.1 Input, Initialisation and Set-up.

The simulations are controlled via a Fortran namelist configuration file. Users can run RadSim by calling a script which sets up environment variables and calls the RadSim executable. In this case the path to the namelist file is supplied by the user on the command line or in an environment variable. Alternatively, a Python script is available which can be used to generate a namelist file and then run RadSim using this namelist in a single call from the command line.

As a minimum, users need to specify the following in the namelist file:

- Type of model data to ingest.
- Path to the model field data file.
- The location of the RTTOV coefficient file directories
- Satellite instrument identifiers (consistent with those used by RTTOV)

Optional configuration includes:

- Channels to simulate
- Path to an observation data file
- Run time options including those to configure RTTOV e.g. for scattering simulations
- Output definitions including output file location and variables to be written out

Model fields can be provided in several formats:


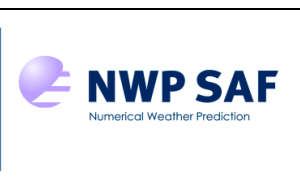
- GRIB (data from ECMWF, DWD ICON model, HARMONIE-AROME model, data from JMA)
- NetCDF (data from ECMWF)
- Met Office fieldsfiles/PP files
- NWP SAF diverse profile datasets (60, 91 or 137 level sets from the ECMWF model, the 60 level set from MACC, and 60 and 137 level sets from CAMS are supported)

The optional observation data file allows simulations to be performed at observation locations, otherwise they are done at model grid/profile locations. The file contains latitude, longitude, satellite zenith angle and other meta-data for each observation (one observation per row in ASCII format, or alternatively the data can be provided in a netCDF file). More details can be found in the User Guide [RD-2].

#### 3.2 Processing / Simulation

The main processing steps are:

- Read in model field data or profile dataset

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- Perform variable conversions as required. Conversions supported are:  $\theta$  to T; dewpoint to specific humidity; relative humidity to specific humidity (and vice versa); orography to land/sea mask; rain/snow flux to mixing ratio.
- Set up RTTOV model
- Read in observation data file (if required)
- Calculate geostationary satellite zenith and azimuth angles (if required)
- Identify grid points lying within each observation footprint (if required)
- Interpolate fields (if required) to the observation locations (bilinear or nearest neighbour interpolation for rectangular lat/lon grids, nearest neighbour only for unstructured grids) and times (linear or nearest neighbour interpolation).
- Rotate grid (if required)
- Calculate solar zenith and azimuth angles (if required)
- Call RTTOV for each profile to be simulated
- Set QC flags (to indicate valid RT calculation, observation within model domain, etc)
- Perform any calculations required for requested outputs (such as mean radiances over footprints and CADS height assignments)

### 3.3 Output

- Write output to a netCDF file

## 4. IMPLEMENTATION ASPECTS

### 4.1 Distribution


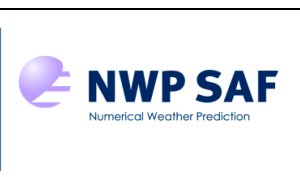
Source files will be distributed as a gzipped tar file. The file contains: Fortran source code and interface files, an installation script with configuration files for different compilers, example namelist and observation data files, a basic test script to test for successful implementation, Python scripts (for generating RadSim namelists and running RadSim from the command line, generating observation data files for geostationary sensors, and plotting datasets from RadSim output files), user documentation, and a Release Note containing instructions on how to install and run the code.

### 4.2 External libraries

Fortran versions of the following libraries are required. These are straightforward to download and install if they are not already available. See the User Guide [RD-2] for more details.

- RTTOV (version 14)
- netCDF (version 4.0 or later)
- ecCodes (version 2.23.0 or later) \*

\* Only required if ingesting model data in GRIB format. Most functionality is available with ecCodes v2.0.0, but support for ICON cloud liquid and ice particle size fields requires v2.23.0 or later.

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### 4.3 Compiler requirements

One of the following Fortran compilers is required:

- ifort - v17.0.7 or later
- pgfortran - v18.7-0 or later
- gfortran – v8.1 or later
- nagfor – v6.1 or later

Further details on compiler support are given in the User Guide (RD-2). Older compiler versions may work, but those given above are the versions tested and hence supported.

The Python scripts require Python v3.10 or later. Older Python versions may work, but only the stated version or later is supported.

### 4.4 External file interfaces

The Radiance Simulator contains code to read NWP model fields from the following types of file:

- 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


Other inputs are a Fortran namelist file for run-time options and an ASCII or netCDF file containing observation meta-data. The observation meta-data file is of a format specific to the Radiance Simulator. The ASCII and netCDF formats are described in the User Guide [RD-2].

Output is to a netCDF file. The format is described in the User Guide [RD-2].

The Python script for generating observation data files for geostationary sensors requires ancillary data related to the specific sensor. This is provided in a netCDF file, the format of which is described in the User Guide [RD-2].

### 4.5 Build method

An installation (build) script is provided. Users need to specify the compiler and the location of external libraries in a configuration file before running the script.

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## 4.6 Run-time considerations

It is possible to configure the Radiance Simulator to process extremely large datasets that may exceed the capabilities of the host platform. Built-in batching mechanisms usually mitigate the problem enough such that users are able to run these simulations successfully, but care should be taken when selecting output options. For example, if running simulations for a hyper-spectral sounder like IASI, channel-dimensioned arrays such as emissivity require huge amounts of memory, and also disk space if they are to be stored in the output file. There are two parameters that can be tuned to assist in getting the code to run to completion in the event of memory limitations – the maximum number of user-defined data points (observations) and the maximum array size for output data. These parameters define the sizes of the batches that are used in processing. The footprint simulation capability can also be demanding in terms of memory requirements, and this is controlled by reducing the number of observations processed per batch. Further details are given in the User Guide [RD-2].

Users are recommended to compile both RTTOV and RadSim with OpenMP support to take advantage of multiple threads. This is beneficial for all RadSim runs with a substantial number of profiles to simulate (e.g. thousands or more) since the radiative transfer calculations in RTTOV are usually the most time-consuming part of a RadSim run. When footprint simulations are enabled in RadSim, the process of identifying the model grid points within each footprint in RadSim is expensive and this can also take advantage of multiple threads via OpenMP. This is noted in the User Guide [RD-2].