Towards a Generic Radiative Transfer Model for the Earth's Surface-Atmosphere System: ESAS-Light

ESTEC Contract No AO/1-5433/07/NL/HE

WP1300:

Consolidation of a nominal set of requirements for libRadtran demonstration version

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1 Introduction

On the basis of the literature surveys about radiative transfer tools (Emde et al., 2008a, WP1100 report) and about forward model requirements (Emde et al., 2008b, WP1200 report), the preliminary requirements given in Annex 1 of SoW (2007) have been revised. Most of the preliminary requirements are planned to be met by the *libRadtran* toolbox demonstration version to be completed within this ESA study. The demonstration version shall provide the main radiative transfer forward modelling capabilities needed to simulate and analyse measurements of current and future ESA missions. In this version the domain of application will be restricted to terrestrial environments.

2 General requirements of demonstration version

Req 1-1 *libRadtran* shall provide forward modelling capabilities for the Earth's surface-atmosphere system for the sun light and the Earth emitted light.

Req 1-2 *libRadtran* shall enable simulations from the UV to TIR: from at least 0.2 to 50 μm. This means that libRadtran is able to simulate the observations of passive instruments looking at the Earth.

Req 1-3 *libRadtran* shall enable radiative transfer simulations in the Earth surface-atmosphere system with various degrees of precision and computational speed. For each module of the toolbox, the precision of the computation shall be adjustable. For example, in the Monte Carlo module the number of photons shall be an input parameter and in the discrete ordinate module the number of computational streams.

Req 1-4 *libRadtran* shall enable to simulate radiance spectra with high, medium or low spectral resolution. Absorption of all standard atmospheric gaseous species in the Earth's atmosphere shall be taken into account. *libradtran* shall provide standard profiles of the gaseous species.

Req 1-5 *libRadtran* shall enable simulations of land and ocean surfaces. It shall provide input databases including the spectral albedo and BRDFs of various surface types.

Req 1-6 *libRadtran* shall enable simulations of clouds and aerosols at various altitudes and various types. It shall provide input data of cloud and aerosol optical properties (ice and water clouds, various aerosol types).

Req 1-7 *libRadtran* shall operate on PC systems under UNIX (SUN), Windows, Linux and MAC.

Req 1-8 *libRadtran* shall be coded in a language that can be run with no cost (no licence required) and that is widely used. Appropriate languages are for instance C, FORTRAN, C++, Python, Java ...

Req 1-9 *libRadtran* shall be designed in a modular fashion enabling easy implementation of new modules.

3 Functional requirements

3.1 Methodologies to solve the radiative transfer of light in the Earth atmosphere-surface system

Req 2-1 *libRadtran* shall provide at least the following methodologies to perform radiative transfer simulation in the Earth atmosphere-surface system:

- Monte Carlo model including polarisation for three-dimensional atmosphere
- Fast plane-parallel scalar code that is well validated
- Fast plane-parallel vector code

Req 2-2 *libRadtran* shall provide at least the following methodologies to compute the absorption cross section by atmospheric gases

- Correlated-k parameterization
- Read line-by-line absorption coefficients calculated by an external line-by-line model

Req 2-3 A user shall be able to solve the radiative transfer problem with any combination of methodologies mentioned in Req 2-1 and Req 2-2. This requirement is meant to enable users to choose the approach that best suits their forward modeling constraints. A user should be able for instance to compute top-of-atmosphere radiances either with a Monte Carlo model and line-by-line computation or with a plane-parallel scalar model and correlated-k coefficients.

Req 2-4 *libRadtran* shall enable simulations of the Raman scattering.

Req 2-5 *libRadtran* shall enable the simulation of refraction through the atmosphere.

3.2 Description of the Earth atmosphere-surface system

Req 2-6 *libRadtran* shall enable the simulation of radiative transfer in plane-parallel media (where the clouds are modeled as homogeneous layers and the surfaces simple flat surfaces, see also Req 2-1). The user shall be able to select the number of model layers.

Req 2-7 The water-air interface reflectance model shall be parameterizable at least by the two models of Cox and Munk (1954a,b) and Ebuchi and Kizu (2002).

Req 2-8 *libRadtran* shall enable the simulation of the interaction of light with the water surfaces in the IR spectral domain and particularly in the TIR in order to enable simulation of top of atmosphere brightness temperatures.

Req 2-9 *libRadtran* shall enable the simulation of the interaction of light with a variety of flat land surfaces, for which spectral and directional properties may be parameterized. The surfaces modelled shall include the following types:

- Vegetation
- Snow / Ice
- Urban surfaces
- Bare soils

Req 2-10 The library compiling surface spectral and directional properties from the previous requirement shall be expandable by user defined spectral and directional surface properties.

Req 2-11 *libRadtran* shall enable the simulation of the interaction of light with various predefined clear sky atmospheres representative of the latitudinal variations of molecular scale height, aerosol vertical distribution, aerosol types, water vapour vertical distribution, trace gases vertical distribution.

Req 2-12 *libRadtran* shall enable to simulate radiative transfer through clouds using predefined parameterizations or pre-calculated databases of cloud optical properties (water and ice clouds)

Req 2-13 *libRadtran* shall enable users to perform a simulation with user-defined atmosphere-surface system. The users shall be able to modify at least

- Atmospheric gases concentration and vertical distribution
- Pressure, temperature profiles
- Aerosol properties: type, optical thickness, vertical distribution, scattering phase function/matrix, Angstroem coefficient, and single scattering albedo, visibility etc.
- Cloud properties: height, vertical distribution, cloud particle scattering phase function/matrix, optical thickness, effective particle size, phase (ice, water, mixed phase) etc.
- Surface reflective/emission properties pending on the surface type: BRDF, spectral reflectance, etc
- Altitude of target and altitude at which radiative transfer parameters shall be output
- Geometry of observation (nadir, limb, occultation)
- Geometry of illumination (arbitrary sun position)

Req 2-14 *libRadtran* shall enable simulations in spherical model atmospheres.

3.3 Simulated output

Req 2-15 *libRadtran* shall output monochromatic or spectrally integrated quantities at any height within the atmosphere (from surface to top-of-atmosphere). At least the following quantities shall be output:

- polarized radiances / reflectances / brightness temperatures

- irradiances in solar and thermal wavelength range (direct, diffuse, downward and upward)
- actinic fluxes
- heating rates
- optical properties of molecules, aerosols and clouds
- transmission, reflectance

4 Human Machine Interface (HMI) Requirements

4.1 Input parameters and output quantities

Req 3-1 A GUI with limited functionality should help users to start with libRadtran. The GUI shall enable the user to generate input files by selecting various options from a menue. The GUI shall also include documentation of the various options. Advanced users still need to work with the input files.

Req 3-2 Users shall be able to run *libRadtran* in batch mode.

Req 3-3 The HMI shall enable the user to enter all parameters of a simulation by providing an input file.

Req 3-4 *libRadtran* shall provide a summary spreadsheet displaying the inputs and outputs of the simulation carried out.

4.2 Input and output data visualization

Req 3-5 Plotting utilities in *libRadtran* shall enable the user to visualize the following inputs to simulations:

- Aerosol, cloud and Rayleigh scattering phases functions
- Atmospheric temperature and pressure profiles
- Atmospheric gas densities and cross-section profiles
- Absorption coefficients
- Surface BRDF via polar diagrams
- Profiles of optical properties

Req 3-6 Plotting utilities in *libRadtran* shall enable the user to visualize the following outputs of simulations (when applicable):

- Radiance / reflectance / brightness temperature spectrum at any user defined altitude (from surface to top-of-atmosphere)
- Surface and top-of-atmosphere radiance distribution as polar diagram
- Spectral atmospheric transmission of single gaseous component

5 Help requirements

Req 4-1 *libRadtran* shall have a help document describing all the toolbox functions. Each functionality of the toolbox shall be explained. The input and output parameters modifiable by the users shall be clearly listed and their role explained.

Req 4-2 The readability of the code shall be optimised. All routines shall start with a header describing what the routine does, its inputs, its outputs, how to use it, who has written the routine, when it has been written and other useful information. All routines shall be commented in detail.

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