

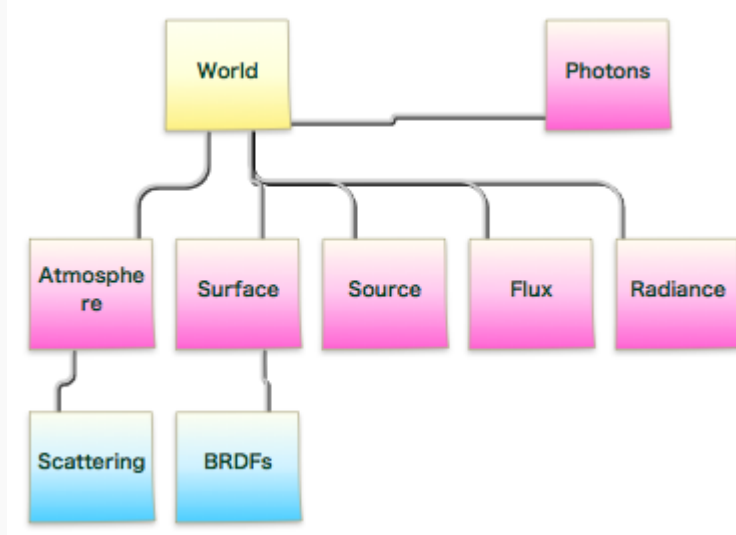
- [3. Model descriptions](#)
 - [General](#)
 - [Geometry](#)
 - [Surface](#)
 - [Atmosphere](#)
 - [Phase functions](#)
 - [Integrators](#)
 - [Algorithms](#)
 - [Methods and techniques](#)
 - [General concepts assumed in the MCARaTS RT solver](#)
 - [Experiment](#)
 - [Computational jobs](#)
 - [Radiative sources](#)
 - [Data sets in input property data files](#)
 - [Scattering order](#)

[Edit](#)

3. Model descriptions

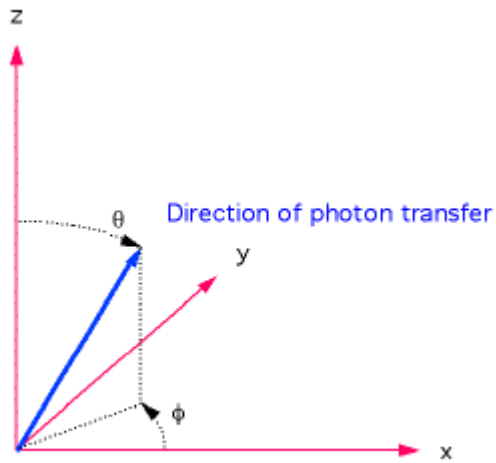
General

MCARaTS numerical world is composed of several modules. Some concepts behind them are described below.



Geometry

The position of photon is defined in the 3D Cartesian coordinate system. The direction of photon transport is defined by zenith (polar) angle (θ) and azimuth angle (ϕ) from the X-axis, as in the following figure.



The incident and emergent directions for pixel radiances can be specified by the user. The zenith and azimuth angles of source light-transport direction are defined as θ_0 and ϕ_0 , respectively. Similarly, emergent zenith and azimuth angles are defined as θ_1 and ϕ_1 , respectively. The horizontal boundary condition is cyclic. The vertical boundaries $z=z_{\min}$ and z_{\max} correspond to the bottom and top, respectively, of the atmosphere (BOA and TOA, respectively).

Surface

The surface is modeled as one of the following models

- black (no reflection)
- Lambertian model
- Diffuse-specular mixture model: diffuse reflection is Lambertian, and specular reflection is Fresnellian for rough surface facets.
- Rahman-Pinty-Verstraete BRDF model
- Li-Sparse-Ross-Thick BRDF model

Surface model and its parameters can vary two-dimensionally.

Atmosphere

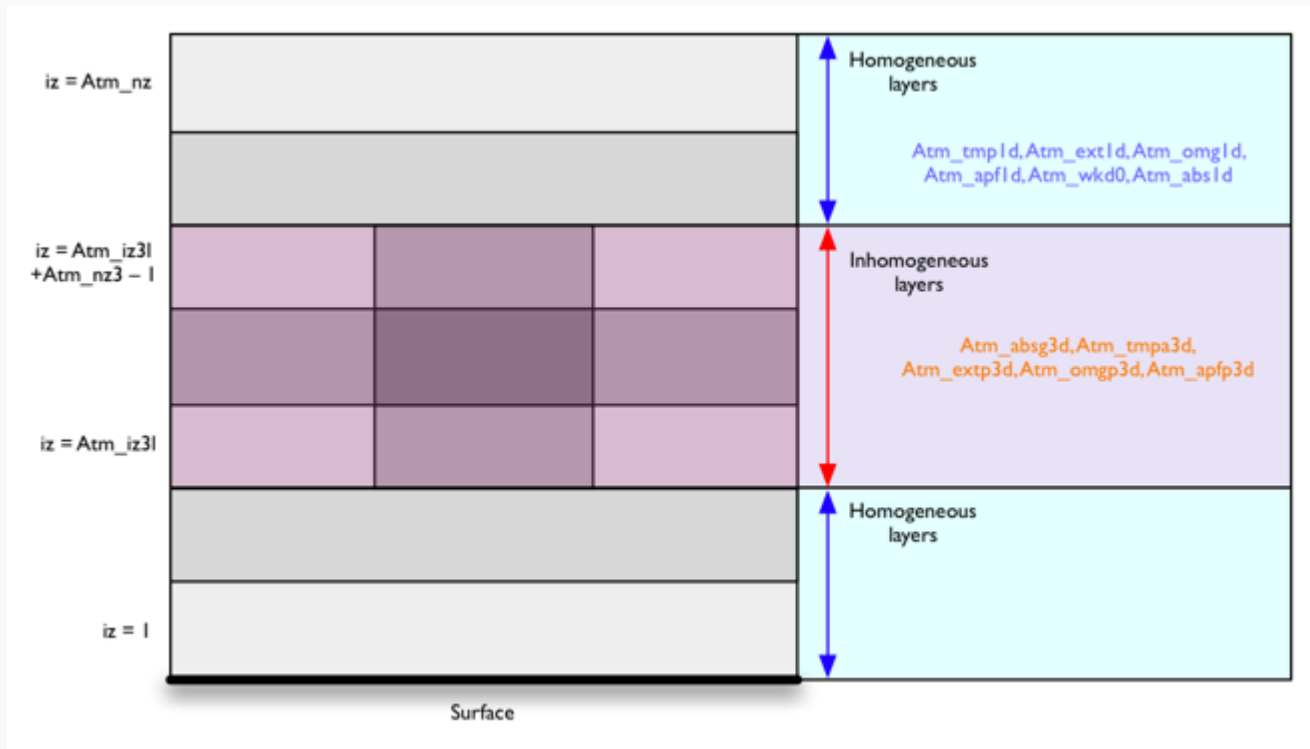
The model atmosphere is divided into cell volumes three-dimensionally. The number of layer is defined as n_z .

The user can specify cloud layers ("3D layers") arbitrarily with horizontal inhomogeneity. Other layers are assumed to be horizontally homogeneous. The 3D layers are divided into cells in the vertical and horizontal directions. The numbers of 3D cells in x -, y -, and z -directions are defined as n_x , n_y , and n_z , respectively.

Modeled atmospheric media include the followings:

- Scattering constituents: For each one constituent, extinction coefficient, single scattering albedo and a specification parameter for phase function are arbitrarily specified. The user defines multiple kinds of phase function, which can be Rayleigh scattering phase function, Henyey-Greenstein function, or a function interpolated from user-specified database.
- Gaseous absorbing constituents: Modeled by correlated k-distribution.

All properties can be specified in 1D (for layers) and/or in 3D (for 3D cells). The atmosphere and surface system is schematically illustrated in the figure below.



Phase functions

One method for phase function data representation is to prepare the phase functions for

- multiple kinds of aerosol polydispersions,
- multiple types of hydrometeors (e.g., cloud water and ice, drizzle droplets, rain water, snow, and graupel)
 - different shapes,
 - different size distributions, and/or
 - different effective radii and effective variances.

Total number of phase functions could be 100 to 10,000, which is significantly smaller than the number (1,000,000 or larger) of atmospheric cells in usual cases. To obtain highly accurate radiance estimates, every phase functions should be tabulated for 200 or more points of scattering angles.

In the mcarats, the phase functions should be given in a database file, and 3D distribution of a phase function specification parameter should be given. The latter data should be specified cell-by-cell, so that used computer memory should be a word length multiplied by the number of atmospheric cells.

Thus, the strategy to prepare the phase function database and 3D distribution of phase function specification parameter is economical for limited computer memory!

In addition, the phase function specification parameter is not digitalized in the latest version. The phase functions used in the code are interpolated from the database table!

Integrators

Various radiative quantities can be computed by the code:

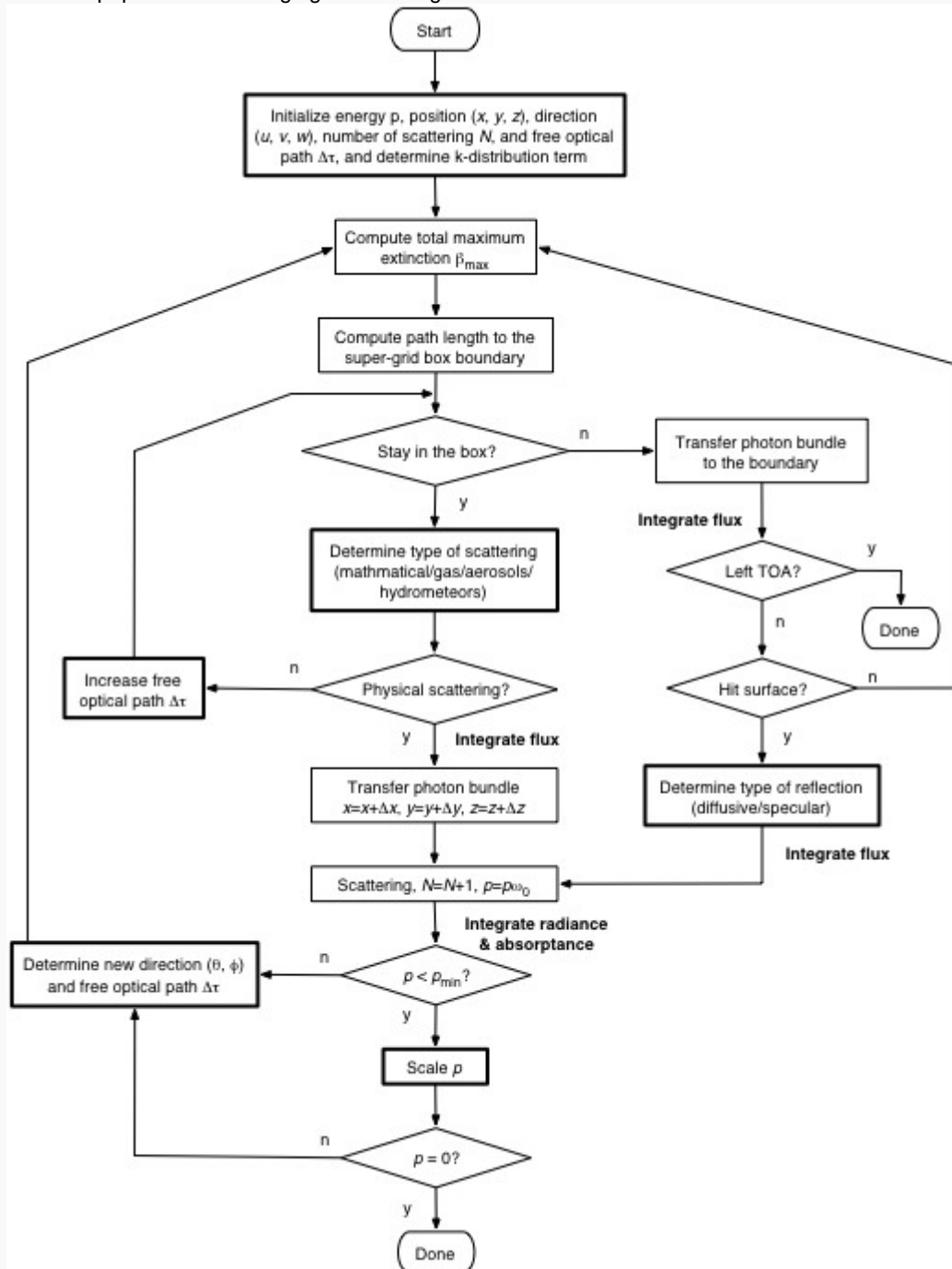
- Upward/downward/direct fluxes at layer interfaces, averaged over finite areas
- Voxel-averaged 3-D heating rates
- Radiances
 - Radiances averaged over finite horizontal areas at arbitrary layer interfaces
 - Local radiances averaged over finite solid angles, looking from arbitrary points
 - Radiances averaged over finite horizontal areas and for planes at arbitrary layer interfaces
- Pathlength statistics for the radiances
 - Layer air mass factors
 - Air mass factors for user-specified weighting functions
 - Time-resolved radiance histogram

For radiances, the user should specify the location of view point, field of view (FOV), and FOV-center direction with zenith and azimuth angles, a method of angular pixel mapping, and numbers of angular pixels.

Algorithms

Used algorithms are described in Iwabuchi (2006, J. Atmos. Sci.). The model uses Monte Carlo methods for simulating photon trajectories and samples fluxes, heating rates, radiances, and other radiometric quantities. The local estimation method is used for

radiance averaged over some specific area or over specific solid angle. The maximum cross section method is used for acceleration of photon tracing in inhomogeneous media. Other methods useful for variance reduction are also used and documented in the scientific paper. The following figure is an algorithm flow chart.



Methods and techniques

Various methods and techniques are used in the code, for better performance. Some of them are described in Iwabuchi & Kobayashi (2008, FRCGC Tech. Rep.).

- The maximum cross section technique applied to super-cells
- The local estimation method
- Collision-forcing method for optically-thin media
- Truncation approximations for forward-peaked phase functions
- Numerical diffusion
- The Russian roulette method
- Parallelization using MPI

The method of truncation of forward peak of phase function is incorporated. The truncation fraction adaptively increases with the order of scattering (Iwabuchi & Suzuki 2009 JQSRT).

General concepts assumed in the MCARaTS RT solver

Experiment

One experiment is performed by one namelist input file and one output data file. More precisely, six I/O files can be used in a single

experiment:

Intent File

```
in  namelist file
in  scattering database file
in  atmospheric property data file
in  surface property file
out result output file
out GrADs control file for the output
```

Several files are optional. Details are described in [Chapter 4](#).

Computational jobs

In a single experiment, multiple jobs can be performed. These jobs are defined in the namelist input file. For each job, atmospheric and surface data, radiative sources, and target quantities can be configured by the user. Scattering phase function database is initialized first, and used commonly for all jobs.

Radiative sources

In a single job, multiple radiative sources can be set, and results will be obtained for them. A type of radiative source can be local source with arbitrary angular spread, solar source incident from the top of atmosphere, thermal source, or solar plus thermal source. The source type and property of source can be different for each source configuration. For example, three radiative sources can be set:

1. Solar source with zenith angle of 60 degrees
2. Solar source with zenith angle of 65 degrees
3. Thermal source at a wavelength 11 micrometer

Data sets in input property data files

In the input data files for atmospheric and surface properties, multiple data sets can be stored. The files can be binary or text format. In mcarats simulations, data sets to be read in can be easily chosen by data set indexes in the namelist file, if the file is in binary format. This data set can be different for respective computational jobs.

IMPORTANT NOTE : Binary format is highly recommended, because the data can be read in faster than text format. In the future versions, it is likely that only binary format files could be accepted.

Scattering order

Is 0 for direct beam. After the first-order scattering, the order is set to 1. In the current version, some numerical techniques are controlled depending on the scattering order.

[Edit](#)

[Next](#) / [Return](#)