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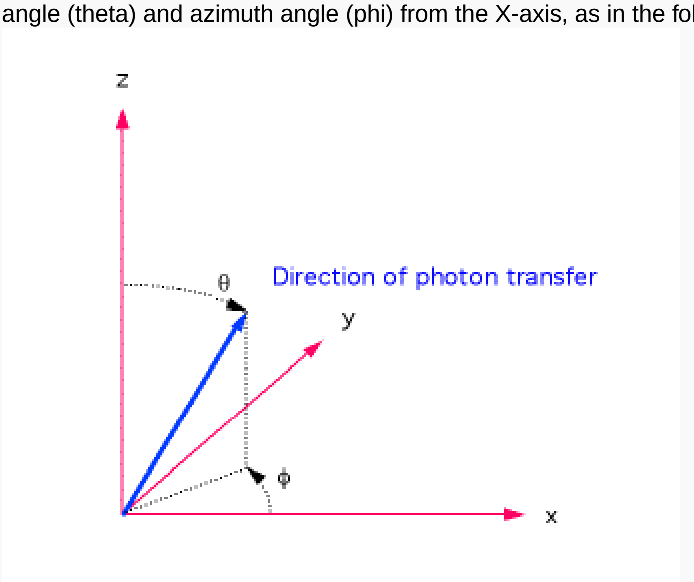
3. Model descriptions

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 flowing figure is an algorithm flow chart.

Geometry

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



The incident and emergent directions for pixel radiances can be specified by the user. The source zenith and azimuth angles are defined as theta0 and phi0, respectively. Similarly, emergent zenith and azimuth angles are defined as theta1 and phi1, respectively. The x-, y- and z-coordinate is defined in 0 – xmax, 0 – ymaxand zmin – zmax, respectively. The horizontal boundary condition is cyclic. The vertical boundaries z=zmin and zmax correspond to bottom and top, respectively, of the atmosphere (BOA and TOA, respectively).

Surface

The surface is modeled as one of four 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 nz.

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 nx, ny, and nz3, respectively. Modeled atmospheric media include the followings:

- Scattering media: For each one medium, extinction coefficient, single scattering albedo and a ID number of definition of phase function are arbitrarily specified. The user defines some kinds of phase function. Properties can be specified in 1D (for layers) and/or in 3D (for 3D cells):

1. three kinds of media specified for each 1D layer
2. several kinds of media specified for each 3D cell

- Gaseous absorbing media: Modeled by correlated k-distribution. The absorption coefficients are specified for both 1D layers and 3D cells

Integrators

Various radiative quantities can be computed by the code:

- Upward/downward/direct fluxes at layer interfaces (area-averaged fluxes)
- Voxel-averaged 3-D heating rates
- Pixel-averaged radiances at arbitrary layer interfaces
- Camera images (angle-average radiances looking from arbitrary points)
- Local fluxes at arbitrary points (pathlength-resolved)
- Average pathlengths normalized by vertical layer depths (so-called air-mass factor)

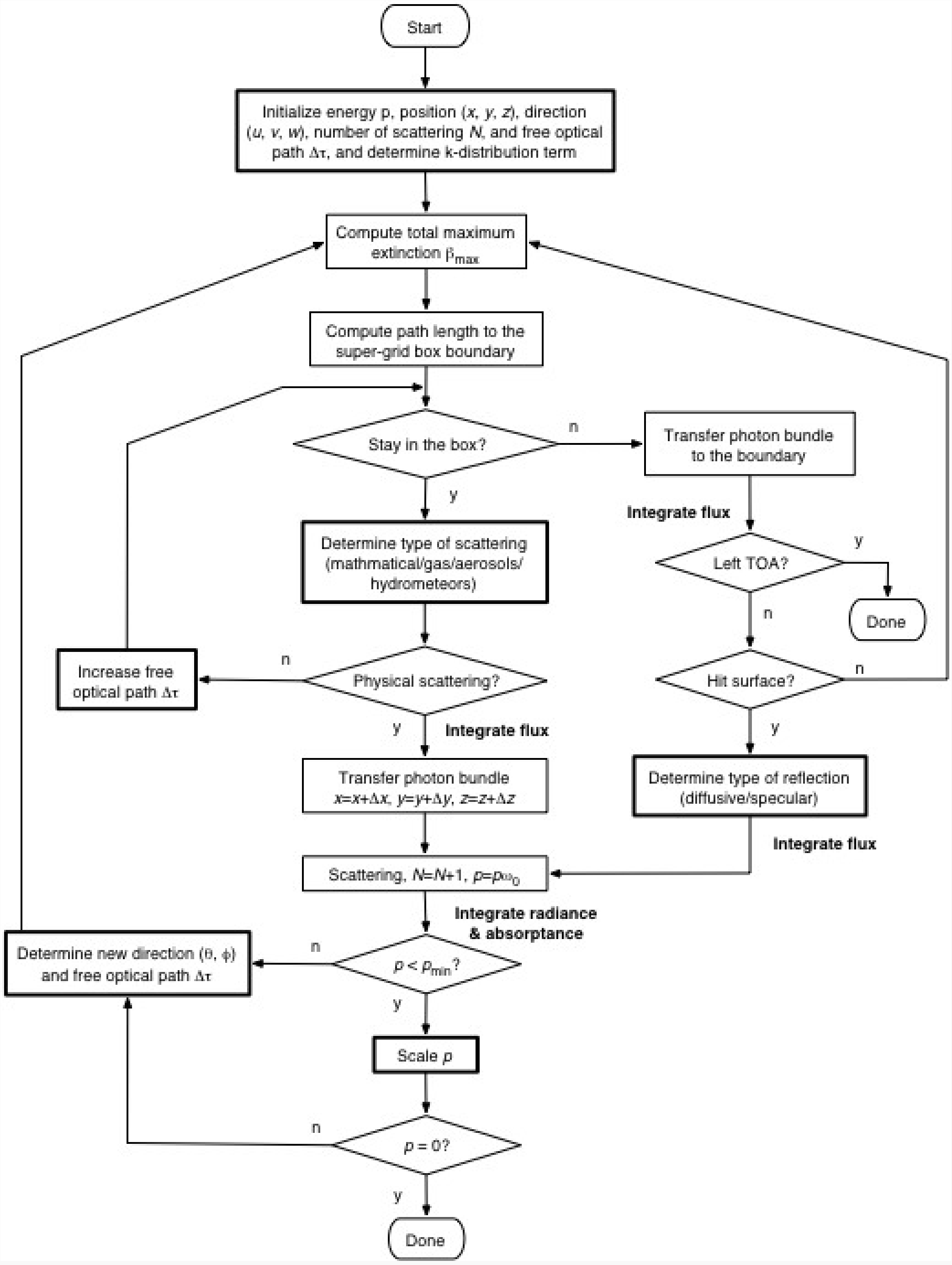
The area-averaged flux detectors are specified at layer boundaries for upward, downward and direct fluxes. The flux is computed as pixel-averaged quantity.
The area-averaged radiances at layer boundaries are defined by the user with zenith and azimuth angles (therdcand phirdc, respectively). The numbers, nxrand nyr, of pixels along x- and y-axes are given by the user. That definition is independent of flux.

Methods and techniques

Various methods and techniques are used in the code, for better performance. Some of them are described in Iwabuchi (2006, J. Atmos. Sci.).

- The maximum cross section technique applied to super-cells
- The local estimation method
- Variance reduction techniques
- 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. The user specifies the number of truncation regimes (nchi), light-diffusivity thresholds (chihi & chilo), and maximum truncation factor (fmax).


Start
Initialize energy p, position (x, y, z), direction (u, v, w), number of scattering N, and free optical path Δτ, and determine k-distribution term
Compute total maximum extinction βmax
Compute path length to the super-grid box boundary
Stay in the box?
n
y
Transfer photon bundle to the boundary
Integrate flux
Left TOA?
y
Done
n
Determine type of scattering (mathmatical/gas/aerosols/ hydrometeors)
Physical scattering?
n
Increase free optical path Δτ
y
Integrate flux
Hit surface?
n
y
Transfer photon bundle x=x+Δx, y=y+Δy, z=z+Δz
Determine type of reflection (diffusive/specular)
Integrate flux
Scattering, N=N+1, p=pω0
Integrate radiance & absorptance
Determine new direction (θ, φ) and free optical path Δτ
n
p < pmin?
y
Scale p
n
p = 0?
y
Done

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