Improvements to the SHDOM Radiative Transfer Modeling Package

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Introduction

The spherical harmonic discrete ordinate method (SHDOM) is an algorithm and FORTRAN computer code for three-dimensional (3D) atmospheric radiative transfer modeling (Evans 1998). The optical properties (extinction, single scattering albedo, and phase function) specified at grid points are input to SHDOM from a file. SHDOM has been distributed with a program for converting liquid cloud physical properties (liquid water content [LWC] and effective radius [r_e]) to optical properties using Mie theory. The package also included a program implementing the original Fu and Liou (1992) k-distribution for molecular absorption when performing broadband spectral integration with SHDOM.

A new SHDOM distribution was released on June 20, 2003, and includes several improvements to SHDOM and the other programs in the package. The major new features are (1) a new optical property file generation system for arbitrary mixtures of particles, including ice crystal scattering for the shortwave. The system is also more accurate than the previous one because it adaptively creates new phase functions to keep the phase function error for particle mixtures within user specified tolerances. (2) New longwave and shortwave broadband k-distribution programs based on the rapid radiative transfer model (RRTM) (Mlawer et al. 1997a and 1997b) from Atmospheric and Environmental Research (AER), Inc. (3) A version of the 6S ocean surface reflectance model, as modified by Norman Loeb of NASA Langley Research Center, added to SHDOM. This complements the existing land surface model of Rahman, Pinty, and Verstraete and the basic Lambertian and Fresnel reflectance models. (4) A visualization output mode for SHDOM that simulates camera or cross-track scanning images having accurate radiance values with the correct geometric perspective.

The new SHDOM distribution is available as a compressed UNIX tar file from the Web site http://nit.colorado.edu. Besides the FORTRAN codes, the distribution includes documentation files, UNIX scripts with examples of using the SHDOM system, and interactive data language (IDL) procedures for plotting SHDOM output files. The Web site also has online documentation and illustrated examples.

Several scientists have used SHDOM for one-dimensional modeling. Therefore, a plane-parallel version, called SHDOMPP, has been developed. SHDOMPP is optimized for plane-parallel radiative transfer, making it faster and more accurate. SHDOMPP is available in a separate distribution (see the Web site).

Optical Property Generation System

The optical property file generation system for SHDOM has been upgraded to be more flexible and accurate. Instead of the cloudprp program, there are now three FORTRAN 90 programs: make_mie_table.f90 and make_ice_table.f90 for making scattering tables and propgen.f90 for generating the property file from a particle properties file. The scattering table files have the extinction (for a mass content of 1 g/m^3), single scattering albedo, and Legendre series representation of the phase function tabulated as a function of particle effective radius for a single particle type. The particle properties file specifies the mass content (g/m^3) and effective radius (microns) of each particle component at each grid point.

The make_mie_table program generates scattering tables for gamma or lognormal size distributions of spherical particles with arbitrary index of refraction. If the particle type is water or ice then an integration across the specified wavelength band may be performed or the energy weighted center wavelength may be used. The maximum radius of the particle size distribution is now specified by the user because it is the critical determinant of the Mie calculation computer time. Make_mie_table uses an iterative procedure to adjust the size distribution to achieve the desired effective radius, so that one can be assured that the size distributions have the desired effective radii even if there is truncation of the theoretical distributions.

The make_ice_table program generates scattering tables in the shortwave for gamma distributions of one of eight ice crystal shapes using Ping Yang's single scattering properties (Yang et al. 2000). The scattering properties are tabulated for 56 wavelength bands from 0.20 to 5.0 microns and 24 particle lengths from 3 to 3500 microns. The eight ice crystal shapes are hollow column, solid column, plate, dendrite, rough aggregate, smooth aggregate, 4-bullet rosette, and 6-bullet rosette (shapes pictured in Yang et al. 2000). The individual scattering properties are stored in a text file (in a compressed format) of about 10 million bytes. The gamma size distributions are also adjusted iteratively to achieve the correct effective radii in the output scattering table. The Legendre series phase functions in the scattering tables may be converted to phase function versus angle (for plotting) with the program plotscattab.f90.

The propgen program allows an arbitrary mixture of any number of pure components at each grid point. It generates an optical property file for SHDOM from a particle file specifying the 3D distribution of mass content and effective radius for several types of particles, and the optical properties for these particle types specified in scattering table files. The extinction and single scattering albedo from all the components are combined exactly. The phase functions for the mixtures are approximate, however, because there is not enough memory to store a phase function for each grid point. Instead, the closest phase function to the correct one is used. If none of the phase functions in the scattering tables are within the user specified tolerances then the new mixture phase function is added to the list. Tolerances are specified for the asymmetry parameter and the maximum fractional error in phase function values. In addition to the scattering properties from particles, propgen also calculates and includes molecular Rayleigh scattering.

The SHDOM distribution contains a UNIX script that demonstrates the new property generation system using two-dimensional fields (X-Z) of liquid and ice cloud properties derived from the Millimeter Cloud Radar (MMCR) at Nauru on July 7, 1999. The example particle file specifies the mass content and effective radius distributions for a horizontally uniform dust aerosol layer from the surface to 1.4 km, a broken cumulus water cloud layer from 0.59 to 2.03 km, and a cirrus layer made of plates and rough aggregates from 8.75 to 14.75 km. Some of the optical properties output by propgen for this example are shown in Figure 1.

Visualization Output

There are two visualization output modes, both of which make byte or two byte integer binary images. The first one simulates images from a fixed position camera. For the camera mode the inputs are the position and pointing direction of the camera, and the number of pixels and pixel spacing vertically and horizontally. The second visualization mode simulates a cross track scanning instrument flying on an airplane. For this mode the inputs are the starting and ending aircraft positions, the distance along track between scans, the range of scan angles, and the scan angle increment between pixels.

Once SHDOM has solved for the spherical harmonic representation of the source function, it can rapidly calculate the radiance in any direction from any position in the medium. Though the speed depends on the viewing and medium geometry, up to thousands of pixels can be computed per second on a modern Pentium computer. This is much faster than the rate at which the Monte Carlo method can compute radiances.

The camera visualization mode can be used to simulate images of clouds from a ground based camera or even the whole sky imager (WSI). The SHDOM distribution contains a UNIX script, which demonstrates the visualization capability using the stratocumulus cloud field selected for phase II of the Intercomparison of 3D Radiation Codes (I3RC). This 64 by 64 by 16 field (55 by 55 by 25 m^3 grid spacing) was generated by Chin-Hoh Moeng's large eddy simulation (LES) model (Moeng et al. 1996). The effective radius was obtained from the LES liquid water content field assuming a fixed droplet concentration. The visualization example simulates the radiance at a wavelength of 0.67 microns. In addition to scattering by cloud droplets there is molecular Rayleigh scattering, but no molecular absorption or aerosol scattering. The surface albedo is 0.05. The solar zenith angle is 60 degrees and the Sun is due west. The cross track scanning image (Figure 2) is 400 by 235 pixels and has nadir viewing angles from -30 to 30 degrees across each scan line while the aircraft flies 7 km (twice the LES field width) to the North. The LES model and SHDOM assume periodic horizontal boundary conditions, so the field is infinitely replicated, and about six fields can be seen in the cross track scanning image. The camera image (Figure 3) is 600 by 450 pixels, or 60 by 45 degrees, and is pointed at 25 degrees elevation angle and 10 degrees west of north (so the Sun is to the left of the image). The image shows bits of clear sky peaking through the gray stratocumulus clouds and the bright sides of clouds facing the Sun.

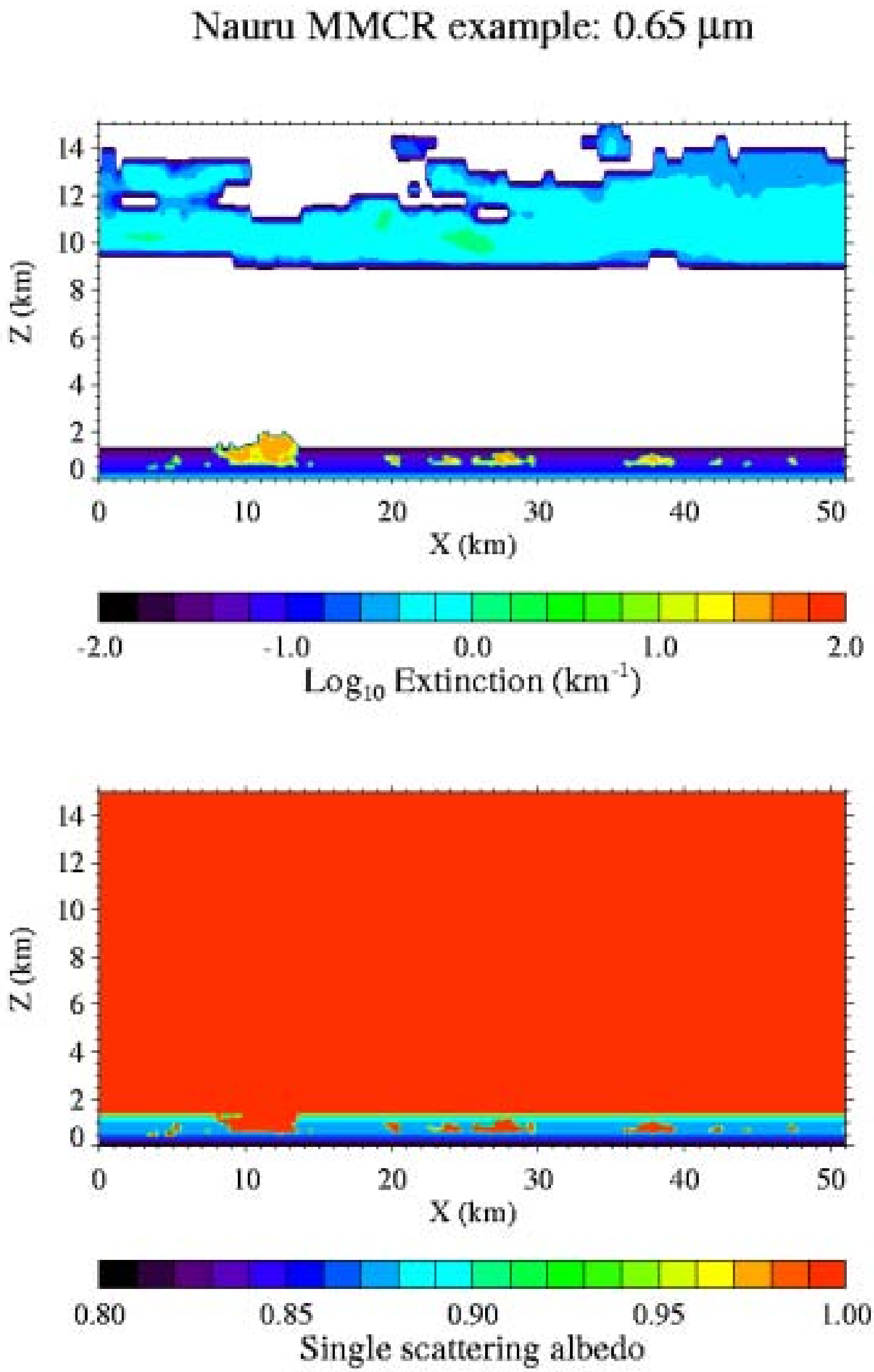

Figure 1. Log extinction (top panel) and single scattering albedo (bottom panel) at 0.65 micron wavelength from the propgen example. The single scattering albedo is low in the dust aerosols, but is near unity when mixed with the cumulus clouds.

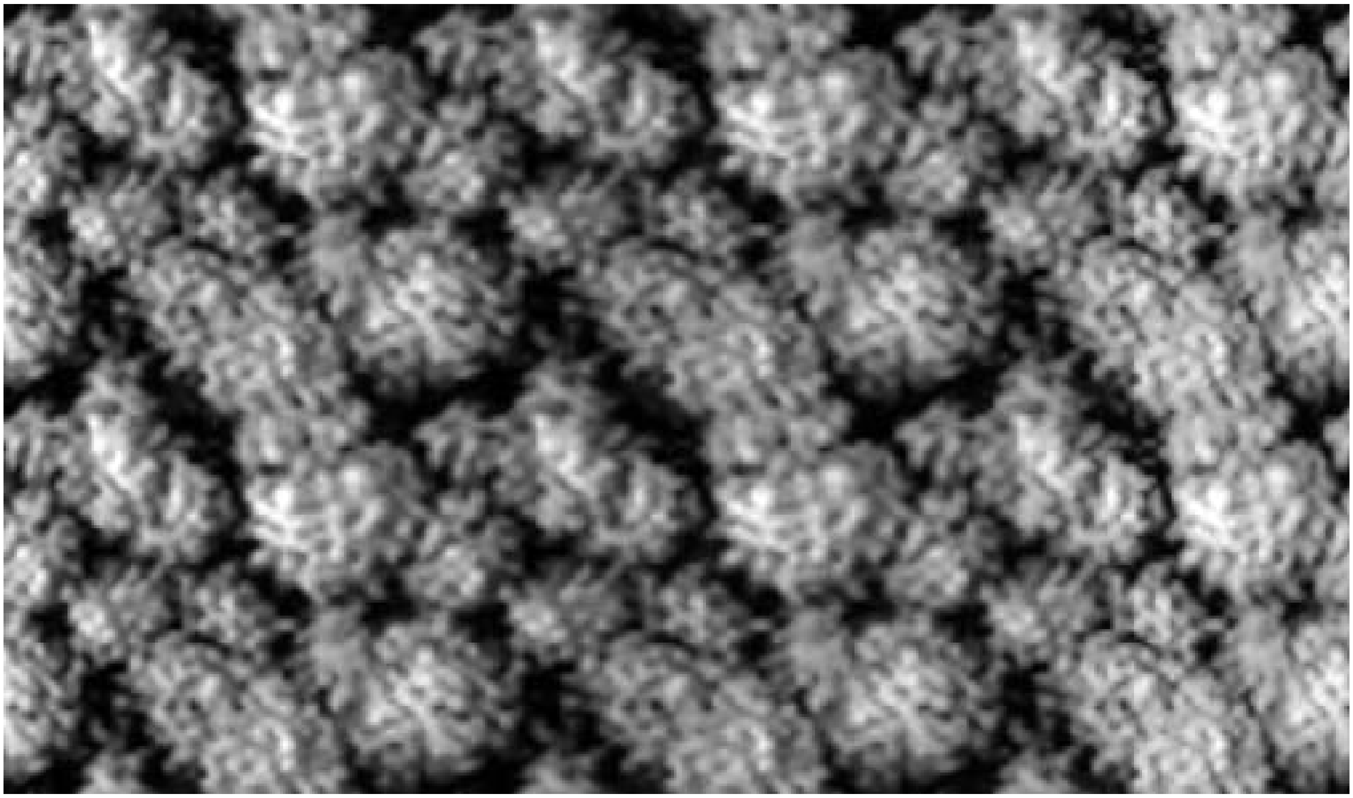

Figure 2. An aircraft based cross track scanning image simulated by SHDOM looking down at an LES stratocumulus field.

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Figure 3. A surface based camera image simulated by SHDOM looking up at an LES stratocumulus field.