Development of Lookup Tables and Validation Effort in Support of CRTM

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Overview

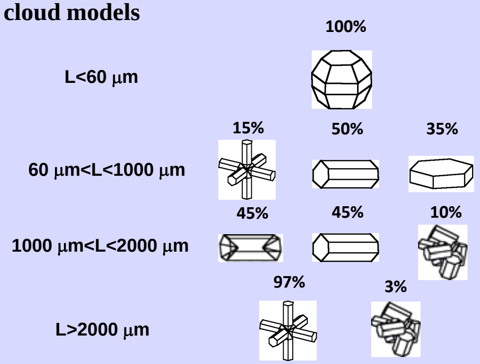
- Accurate simulation of radiation at the top of the atmosphere is extremely important for understanding both the surface and atmospheric properties, and for ultimately improving the assessment of the Earth’s radiant energy budget.

- Radiance simulations require use of the full scattering phase function, and often involve representing the scattering phase function in terms of a series of Legendre polynomials. In practice, how one decides on an appropriate set of Legendre polynomials for the phase function expansion is not always straightforward since the scattering phase functions can be quite complex.

- We apply the δ-fit method to the RT simulations involving dust aerosols, water clouds, and ice clouds. To examine the trade-off between computational efficiency and reasonable accuracy, we investigate the sensitivity of the RT calculations for dust aerosols, water clouds, and ice clouds at both visible and IR wavelengths to the number of Legendre polynomials in the phase function expansion. The intent of this effort is to optimize the efficiency of the RT simulations without sacrificing much accuracy.

- To assess the accuracy of the Community Radiative Transfer Model (CRTM) developed and maintained by the Joint Center for Satellite Data Assimilation (JCSDA), we compare the CRTM simulations with those based on a combination of the DIScrete Ordinate Radiative Transfer (DISORT) and the line-by-line radiative transfer model (LBLRTM).

Ice cloud models



100%

L<60 μm

15% **50%** **35%**

60 μm<L<1000 μm

45% **45%** **10%**

1000 μm<L<2000 μm

97% **3%**

L>2000 μm

Baum et al., 2005

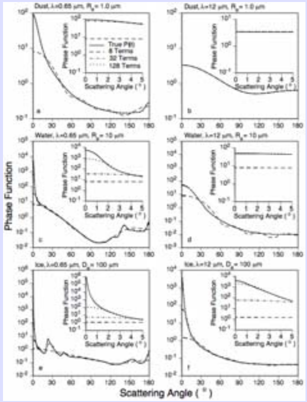
Comparison of phase functions

Quantitatively, the truncation of the phase function can be expressed in terms of the following relation:

$$P(\theta) = 2f\delta(\cos\theta - 1) + (1 - f)P'(\theta)$$

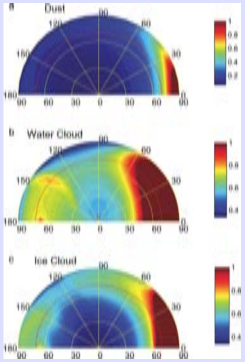
where P is the original phase function, P’ is the truncated phase function, δ is the Dirac-delta function, and f is the portion of the scattered energy in conjunction with the truncated peak in the function.

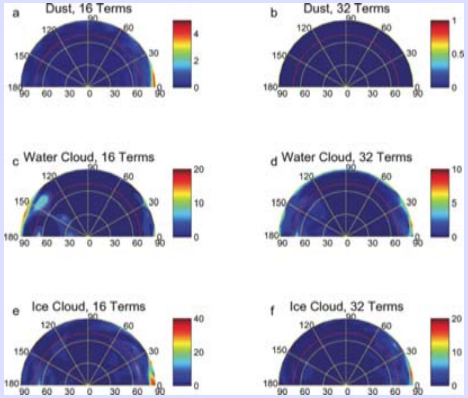
The figure shows the original scattering phase functions (P) and the term (1-f)P’ for dust, water clouds, and ice clouds at two wavelengths: 0.65 μm (left column) and 12.0 μm (right column). The term (1-f)P’ is computed by using 8, 32 or 128 Legendre polynomial expansion terms.



Simulations of reflectances

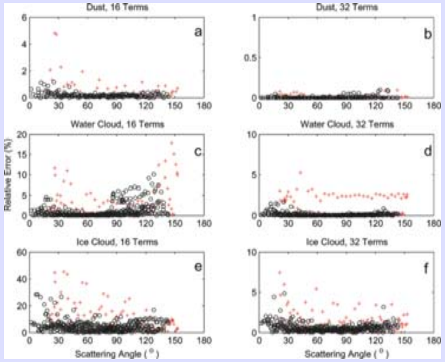
Simulated bidirectional reflectances obtained by using 128 terms of the Legendre Polynomials at a wavelength of 0.65 μm for dust, a water cloud and an ice cloud. The solar zenith angle is 60°. The optical depth τ=1 and R_e=1 μm are assumed for dust; τ=20 and R_e=10 μm for the water cloud; and τ=5 and D_e=100.0 μm for the ice cloud. The red arc in each panel represents a satellite-viewing zenith angle of 70°.





The relative errors of bidirectional reflectances obtained for the scattering phase functions re-constructed in terms of 16, and 32 Legendre Polynomials at a wavelength of 0.65 μm for dust layer, a water cloud and an ice cloud. The solar zenith angle is 60°. The optical depth τ=1 and R_e=1 μm are assumed for the dust layer; τ=20 and R_e=10 μm for the water cloud; and τ=5 and D_e=100.0 μm for the ice cloud. The red arc in each panel represents a satellite viewing zenith angle of 70°.

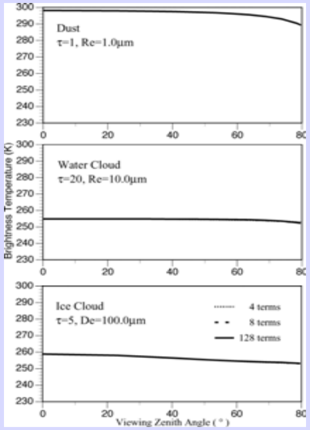
The relative errors of bidirectional reflectances obtained for scattering phase functions reconstructed with 16, and 32 Legendre Polynomials at a wavelength of 0.65 μm for dust, water cloud and ice cloud. The solar zenith angle is 60°. The optical depth τ=1 and R_e=1 μm are assumed for a dust layer; τ=20 and R_e=10 μm for the water cloud; and τ=5 and D_e=100.0 μm for the ice cloud. The black circles denote the relative errors for viewing angles smaller than 70° and the red crosses represent relative errors at viewing angles larger than 70°.



Simulations of brightness temperatures

Simulated brightness temperatures over a dust layer (upper panel), a water cloud (middle panel) and an ice cloud (lower panel) at λ=12.0 μm. The surface and cloud (dust layer) temperatures are assumed to be T_s=300K and $T_{\text{cloud or dust}}$=255K, respectively. The optical depths and effective particle sizes for the dust layer, water cloud and ice cloud are indicated in each panel.

For all three scattering media, the simulated brightness temperatures based on 4 terms of the phase function expansion are indistinguishable from the results obtained with 8 or 128 terms, even for viewing zenith angles as large as 80°. Therefore, at infrared wavelengths, 4 terms of the Legendre polynomials are sufficient in RT simulations when small viewing zenith angles are used.



Summary and conclusions

- Three bulk-scattering property datasets were computed for dust aerosols, and water and ice clouds at wavelengths from 0.225 to 20.0 μm.

- The sensitivity of bidirectional reflectances to the number of the phase function expansion terms was investigated. It can be concluded from the error analyses that 32 terms of Legendre polynomials for the phase function expansion in the cases of water and ice clouds can be employed to have relative errors smaller than 5% at all possible satellite zenith and azimuth angles at visible wavelengths, whereas only 16 Legendre polynomials are required for dust at the same wavelengths.

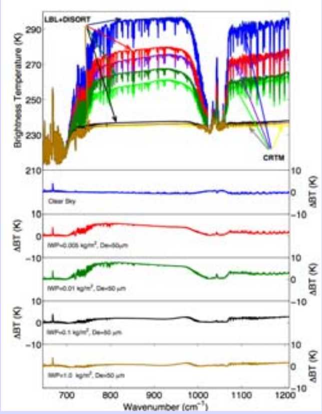
- Brightness temperatures were simulated for dust, and water and ice cloud layers at a wavelength of 12.0 μm. At this IR wavelength, 4 terms in the Legendre polynomial expansion of the phase function are sufficient in the RT computation for the three particle types (liquid droplets, ice crystals, and dust partiicles).

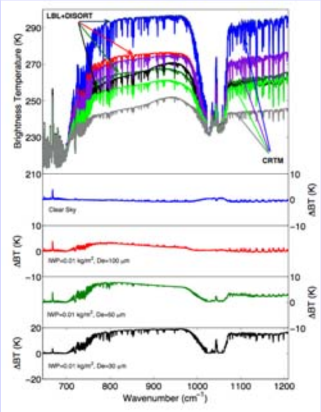
- Our preliminary simulations suggest that improvements on the CRTM forward model are still needed in the computation of radiances over thin ice clouds or ice clouds containing small ice cloud particles.

Validation of CRTM

To assess the accuracy of CRTM, we set up a rigorous model based on a combination of DISORT and a LBLRTM. We compared IASI band 1 (645-1210 cm^{-1}) brightness temperatures (BT) simulated from the CRTM forward model with those based on the LBL+DIRSORT model for clear-sky and cloudy cases.

The figure below shows the differences of the IASI band 1 brightness temperatures (ΔBT) between using the CRTM forward model and LBL+DISORT model. The ice cloud water paths for ice cloud layers are assumed to be 0.005, 0.01, 0.1 and 1.0 kg/m^2. The effective particle size of ice clouds is 50 μm. The surface and cloud-top temperatures are 300.0 and 232.0 K, respectively.





The figure above shows the comparison of IASI band 1 (645-1210 cm^{-1}) brightness temperatures (BT) simulated from the CRTM forward model and the LBL+DISORT model for clear-sky and cloudy cases. The ice cloud water path for ice cloud layers is assumed to be 0.01 kg/m^2. The effective particle sizes are assumed to be 30, 50 and 100 μm. The surface and cloud-top temperatures are 300.0 and 232.0 K, respectively.

The brightness temperature differences (ΔBT) for IASI band 1 substantially increase with the decrease of ice cloud water path and the ice particle size, particularly, in the atmospheric window region. The slope of the BTs at the wavenumbers between 760-960 cm^{-1} is sensitive to the effective particles size for the LBL+DISORT approach, while the sensitivity of the BT slope to the particle size is relatively weak in the the CRTM results.

Comparison of CPU time for the two models on a dual 2.6 GHz 64-bit AMD Operation System

	Clear sky	**Cloudy sky**
CRTM	**9.66 s**	**13.96 s**
LBL+DISORT	**375.62 s**	**542.70 s**