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Validation of the Two-Layer Model for Correcting Clear Sky Reflectance Near Clouds

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Executive Summary

A two-layer model was developed in our earlier studies to estimate the clear sky reflectance enhancement near clouds. This simple model accounts for the radiative interaction between boundary layer clouds and molecular layer above, the major contribution to the reflectance enhancement near clouds for short wavelengths. We use LES/SHDOM simulated 3D radiation fields to valid the two-layer model for reflectance enhancement at 0.47 µm. We find:

- The simple model captures the viewing angle dependence of the reflectance enhancement near cloud, suggesting the physics of this model is correct.
- The magnitude of the 2-layer modeled enhancement agree reasonably well with the "truth" with some expected underestimation.

We further extend our model to include cloud-surface interaction using the Poisson model for broken clouds. We found that including cloud-surface interaction improves the correction, though it can introduced some over corrections for large cloud albedo, large cloud optical depth, large cloud fraction, large cloud aspect ratio. This over correction can be reduced by excluding scenes (10 km x 10km) with large cloud fraction for which the Poisson model is not designed for. Further research is underway to account for the contribution of cloud-aerosol radiative interaction to the enhancement.

Two-Layer Model

$$\rho = \Delta R = \frac{\alpha_c(\lambda) T_m(\tau(\lambda),\Omega_0)}{1-\alpha_c(\lambda) R_{m,diff}(\tau(\lambda))} \left[T_{m,diff}(\tau(\lambda),\Omega) - T_{m,beam}(\tau(\lambda),\Omega) \right]$$

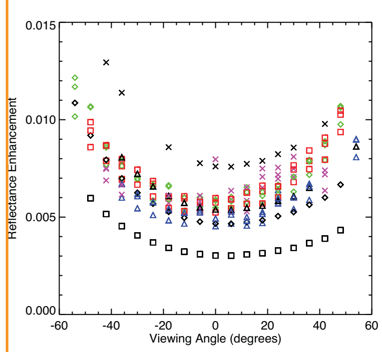
Where α_c is cloud albedo, $\mathbf{\Omega_0}$ and $\mathbf{\Omega}$ are the direction of the Sun and the direction of the viewing direction of the satellite.
Expression of transmittance and reflectance for molecular layer with optical depth of $\tau(\lambda)$.

	Name	Input Flux (source)	Expression
$T_m(\tau_0,\Omega_0)$	*Flux Transmittance*	F_0 (Beam flux)	$F(\tau=\tau_0)/F_0\cos(\Omega_0)$
$T_{m,diff}((\tau_0,\Omega)$	*Radiance Transmittance*	F_0 (Isotropic flux)	$\pi I(\tau=\tau_0,\Omega)/F_0$
$R_{m,diff}(\tau_0)$	*Reflectance*	F_0 (Isotropic flux)	$F(\tau=0)/F_0$
$T_{m,beam}((\tau_0,\Omega)$	*Beam Transmittance*	I_0 (Beam radiance)	$\exp(-\tau_0/\cos(\Omega))$

SHDOM Simulations

- 26 fields (cloud liquid water content and relative humidity) were simulated using the UCLA large eddy simulation (LES) model
- Combined 26 LES cumulus fields with 40 GEOS-5 aerosol profiles to make 80 cloud/aerosol scene (20 km x 20 km x 15 km).
- Radiances were simulated using SHDOM at 500 m MODIS resolution with 23 viewing direction appropriate for MODIS Aqua.
- MOD04 cloud masking procedure is applied to select "good" pixels. There are 100188 "good" pixels in all 80 cloud scenes, and number of "good" 10 km x 10 km boxes is 3154.

Compare 2-Layer Model and SHDOM Truth



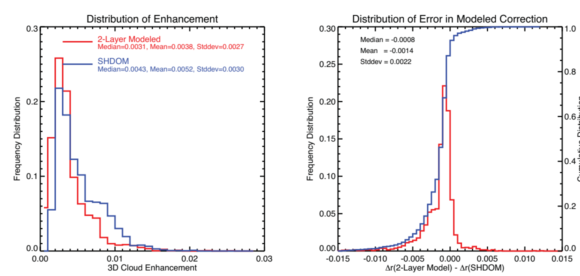
2-Layer modeled ΔR (black) vs SHDOM simulated ΔR (color).

The simple model capture the viewing angle dependence of the enhancement.

The variability of the 2-layer model results comes from different cloud properties (e.g., COD&CF).

The variability of SHDOM results comes from different cloud and aerosol properties

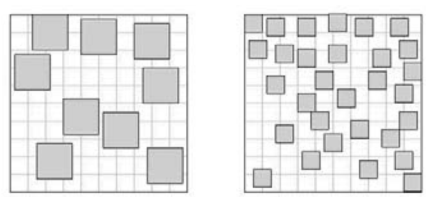
Compare Statistics Between 2-Layer Model and SHDOM Truth



The 2-layer model estimated enhancement agree reasonable well with some expected underestimation.

Poisson Stochastic Model for Broken Cloud

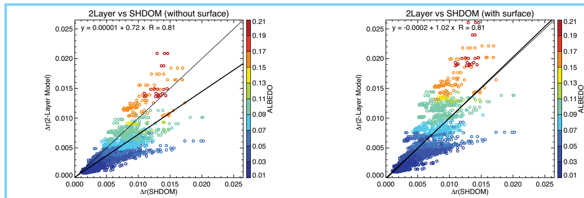
CF = 0.3
Cloud aspect ratio of 2



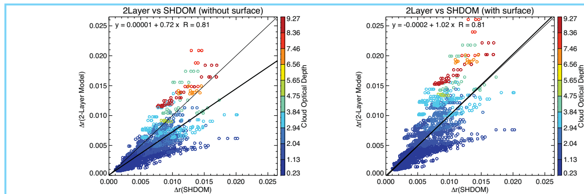
CF = 0.3
Cloud aspect ratio of 1

A fast Monte Carlo scheme for Poisson model of broken clouds is used compute 3D cloud induced diffuse flux to account for cloud-surface effect. This is an example of the Poisson distribution of broken cloud field (from Marshak et al., 2008).

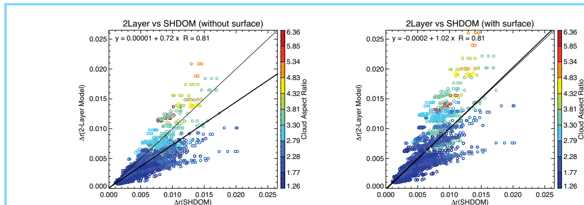
With and Without Cloud-Surface



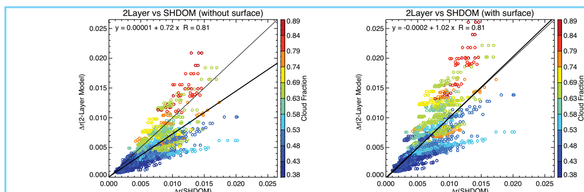
Left: The 2-layer model accounts for 72% of the enhancement. Right: the 2-layer model with Poisson clouds for correcting cloud-surface bring the estimates close to the truth. But this leads to large over correction for large cloud albedo.



Similar to above but with cloud optical depth indicated.



Similar to above but cloud aspect ratio indicated.



Similar to above but cloud fraction indicated.

Simply rejecting scenes with large cloud cover(CF > 0.63) for cloud-surface effects excludes some over corrections. Over all correction is 80%. The rest is due to cloud-aerosol radiative interaction.