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Monte Carlo and Approximate Albedo Estimates for Tropical Convective Cloud Scenes as perceived by MISR

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1. Introduction

An area of radiative transfer that has not yet achieved closure is the realistic yet computationally-feasible modeling of the radiative effects of large-scale broken cloud fields. To date, the Independent Pixel Approximation (IPA), which captures the effects of optical depth variability alone, has been shown to acuurately represent the domain-average fluxes of not only stratocumulus clouds, but also of statistically-representative samples of small, marine, tropical cumuli occurring under convectively-suppressed conditions.

In the study presented here, we extend the investigation to clouds occurring under convectively-active conditions. Such a cloud type may possess the optical and geometrical variability that is most significant at the horizontal resolution of the most progressive general circulation models, or about 50 by 50 km.

For these clouds, the apriori assumption is made that the Tilted Independent Pixel Approximation (TIPA;Varnai and Davies, 1999) will more closely capture the domain-average albedo at low Sun. This approximation uses the distribution of optical thicknesses along the slant path of the Sun (as opposed to the vertical optical thickness used within the IPA), so that at oblique Sun angles the cloud fraction apparent to the Sun is used. TIPA requires more input information, however, and is therefore more difficult to implement.

We seek to answer these questions:

1. How well do IPA and TIPA perform on a complicated cloud type?

2. Can a simple additional parameterization improve the correspondence between the ICA and TIPA results to the Monte Carlo results?

These questions are addressed here in a preliminary study using 10 cases from 2 orbits. A pdf version of the conference poster (with plots) is available through http://www.etl.noaa.gov/∼pzuidema.

2. Case Description

The data come from the Multiangle Imaging SpectroRadiometer (MISR) instrument on the Terra spacecraft. The unique instrument feature is that it has 9 cameras, at the viewing angles of 0°, $\pm26°$, $\pm45°$, $\pm60°$, and $\pm70°$. The instrument possesses channels at 3 visible and 1 near-infrared wavelengths (443, 555, 670, and 865 nm). The multi-angle viewing allows for an operational stereo retrieval of the cloud height and cloud winds. The cloud heights are at a 1.1 km spatial resolution and about a 500 m vertical resolution. While the cloud heights of the selected cases are reasonable, they have not been validated.

The case selection emphasized clouds with significant structure over open ocean that could be completely confined within a 50 by 50 km domain. The latter allows for periodic boundary conditions within the Monte Carlo model, and allows for conclusions that are relevant to GCM scales. The selected cases came from 2 orbits on Sept. 28, 2001, and Sept. 30, 2001, in the vicinity of the maritime continent (western tropical Pacific and Indonesia). Active convection can be expected here even during the normally convectively quiescent 10:30 A.M. local time of the TERRA orbit. The solar zenith angle for cases 1-3 is about 32° and for cases 4-10 is about 20°. The cloud fraction is high (>80%) for all the cases.

3. Optical Depth Retrieval, 3D extinction coefficient construction

The most important assumption made is the use of plane-parallel theory to provide the initial optical depth estimate. The retrieved optical depths are underestimates, caused by a neglect of the photon leakage out of the cloud sides in the plane-parallel retrieval. Thus, the three-dimensional radiative transfer effects discussed here should be interpreted as a lower bound.

The optical depths are retrieved using the 0.67 μm channel nadir reflectances, which are available at a 275 m spatial resolution. The nadir reflectances are the least impacted by cloud-top and cloud-side variability of any of the viewing angles. Likewise, the low-latitude locations have high solar zenith angles that diminish the impact of sub-pixel variability upon the optical depth estimate. The selected cases do not fall within the sun glint region of the orbit.

The optical depth retrieval was done using lookup tables created with the radiative transfer code Streamer (Key, 2001). This code includes clear-sky radiative processes and uses DISORT to compute the cloudy radiation. Clouds were partitioned into ice and liquid, where clouds with cloud tops above 11 km were treated as all ice, clouds with heights below 5.5 km as all liquid, and clouds with cloud top heights between 5.5 and 11 km as a height-weighted mixture of liquid and ice. A spherical

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ice habit is assumed. While all scenes contain pixels with optical depths of 100 (the maximum retrieved), the large proportion of opticallly-thin pixels for all the cases accounts for a mean cloud optical depth that varies from only 1.9 to 10.4.

A three-dimensional extinction field was constructed with a cloud base assumed at 500 m (roughly the lifting condensation level over the tropical ocean), and a minimum extinction value of 0.25 km^{-1}. The latter restriction was implemented so that optically thin, upper-level cirrus retain a high cloud base.

4. Monte Carlo model

The forward spectral Monte Carlo (MC) model assumes conservative scattering, a Lambertian underlying surface, and a Mie scattering phase function. Both ice (effective radius=30 μm) and liquid (effective radius=10 μm) particles are considered. The TIPA and IPA calculations are done using the same Monte Carlo code. Only the spectral albedo at 0.67 μm is considered. Calculations are done at the true solar zenith angle, and at 5 values for the cosine of the solar zenith angle: 1.0, 0.8, 0.6, 0.4, and 0.2.

5. Results

5.1 *How well do TIPA and IPA perform ?*

The 10-case-mean values for the MC, TIPA, and IPA albedos as a function of the solar zenith angle are shown in Fig. 1. The TIPA results retain the form of the MC results, but possess a positive offset reflecting its neglect of a horizontal photon transport that ultimately eases downward photon transmission. The IPA albedos underestimate the reference MC results at solar zenith angles far from nadir, reflecting IPA's neglect of the contribution to albedo from cloud sides. Individual cases can show much larger disagreements.

5.2 *Can a simple additional parameterization improve the correspondence between the IPA,TIPA, and the Monte Carlo results?*

The cases with the largest disagreements between the Monte Carlo and the approximate albedos, are those clouds possessing a larger fraction of high optical depths. While a correlation is seen between (Monte Carlo - TIPA), (Monte Carlo - IPA) albedos and the cloud optical depths, the best correlation exists between the albedo difference and the cloud height of the optically-thicker ($\tau > 20$) clouds: r=0.89 for MC-TIPA albedo, and r=-0.72 for MC-IPA albedo. Note that, because the cloud base is set at 500 m, that a high correlation to cloud height, in effect signals a high correlation to cloud thickness.

6. Summary

The Monte Carlo domain-averaged spectral albedos of 10 cases representative of active tropical convection were compared to the albedos calculated using the Independent Pixel Approximation and the Tilted Independent Pixel Approximation. TIPA, because it takes the contribution from the cloud sides into account, performs slightly better than IPA at low Sun and maintains a constant offset from the MC results at all solar zenith angles. The TIPA-MC albedo difference also correlates slightly better than the IPA-MC albedo difference to an easily-measured cloud property, the cloud height of the optically-thick pixels. This is basically a correlation to cloud thickness, as a constant cloud base at roughly the lifting condensation level is assumed for such pixels. Cloud fraction was not found to be a useful cloud property, as it was always high.

Aside from examining more cases, a validation of the cloud heights needs to be performed, and broadband rather than spectral albedo values would be more useful. In addition, the assumption of a spherical shape for the ice particles can be improved upon through an examination of the multi-angle reflectances.

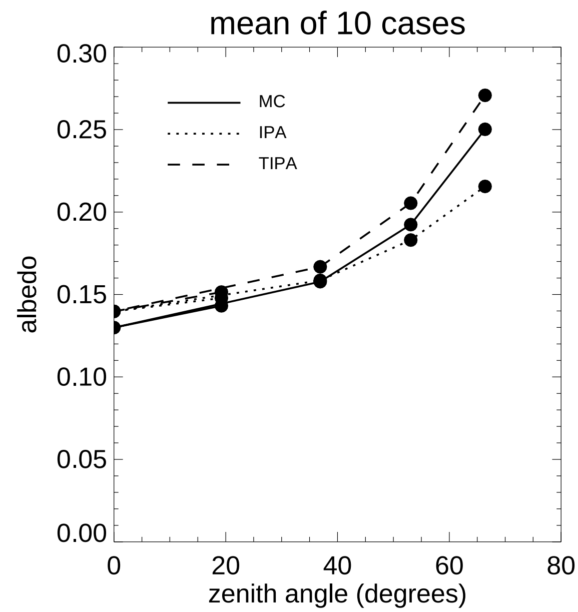

FIG. 1: 10-case-mean domain-averaged spectral Monte Carlo, IPA, and TIPA albedo

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REFERENCES

Key, J., 2001: Streamer user's guide. *Cooperative Institute for Meteorological Satellite Studies* 96 pp.

Varnai, T. and R. Davies, 1999: Effects of cloud heterogeneities on shortwave radiation: Comparison of cloud top variability and internal heterogeneity. *J. Atmos. Sci.*, **56**, 4206–4224.