

RETRIEVAL OF EFFECTIVE DIAMETER VARIATIONS IN TROPICAL CUMULONIMBUS.

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1. INTRODUCTION

It is of considerable importance to understand the impacts (if any) of aerosols and other atmospheric constituents on clouds. These impacts may include modification of the optical properties, coverage, dynamical behavior, and/or hydrological role of clouds. The most basic variables that must be measured in order to make progress are cloud coverage, optical thicknesses, and size distributions of the cloud hydrometeors.

The recent launch of MODIS (Moderate Resolution Imaging Spectroradiometer) on board NASA's polar orbiting EOS (Earth Observing System) satellites promises significant advances in observation of the size distribution, using several near-infrared wavelengths. Daytime near-IR reflectivity is particularly helpful since it is quite sensitive to ice particle size (see Liou (1992) for further information). Models are required to relate backscattered intensities to cloud properties, due to dependence of intensity on viewing geometry and cloud optical depth τ . Uncertainties in these models include assumptions about crystal shape, parameterization of the scattering phase function, and other approximations. They are difficult to test rigorously against observations. Here, we present an analysis of a long record of AVHRR (Advanced High Resolution Radiometer) 3.7 μm reflectivity off of cumulonimbus clouds (Cb) that can be used to do this.

2. METHODOLOGY

2.1 Data

We employ 13 years of AVHRR data which Sherwood (2002a, 2002b) used to determine the sensitivity of tropical Cb ice size distributions to tropospheric aerosol, and to reveal a subsequent impact of size changes on stratospheric water vapor. Here, however, we focus on the angular distribution of backscattered solar near-IR radiation. While it is not possible to observe this for an individual cloud, we observe it by averaging over many clouds of a specific type (Cb).

When clouds contain enough water to be sufficiently opaque, their reflectivity approaches a value that does not depend on further changes in τ . At near-IR wavelengths this occurs for optical depths of only $\tau \sim 10$ or greater, due to water's relatively large imaginary index of refraction (hence absorption) compared to that at visible wavelengths. Though tropical Cb clouds are responsible only for a small percentage of total cloud cover on Earth, and their microphysical properties may differ from those of more extensive, stratiform clouds, they have the advantage of possessing sufficiently large τ to reach this limit consistently, significantly simplifying our interpretation of the data. Further, Cb (being an extreme class of cloud) can be identified relatively unequivocally by IR observations.

Observed reflected radiance depends not only on cloud properties but on the sun/satellite viewing geometry Ω , characterized by the solar and satellite zenith angles θ_0 and θ respectively and by the relative sun-satellite azimuth ϕ . As described by Sherwood (2002a), the effect of $\Omega \equiv \{\theta_0, \theta, \phi\}$ was estimated and removed by fitting all the Cb reflectivities $I_{3.7}^{\text{ref}}$ to the

following model:

$$I_{3.7}^{\text{ref}}(\mathbf{x}, t, \theta_0, \theta, \phi) / S(t) = G(\theta_0, \theta, \phi) H(t) \alpha(\mathbf{x}, t). \quad (1)$$

Here S is the solar constant integrated over the filter response function for the specific satellite and channel, G is the variation of reflectance with Ω (assumed universal for all tropical Cb clouds), H is the variation with time (if any) of the tropical mean reflectivity and of the satellite calibration, and α is proportional to the actual 3.7 μm reflectivity of the cloud scene at time t and location \mathbf{x} . The function G is normalized so that $G(0, 0, 0) = 1.0$, and H so as to have unit mean, making α the reflectivity for a nadir insolation and view (with any tropical mean anomaly removed) and $H\alpha$ the reflectivity with all time variations included. G is related to the more common bi-directional reflectance distribution function (BRDF) by the factor $\cos(\mu_0)$. Functions G and H were then found by an iterative procedure that minimizes the variance of the central values of α among the bins.

2.2 Model

The MODIS effort includes a library of radiative transfer calculations for different size distributions as a function of sun-satellite geometry (King et al., 1997). The MODIS calculations employ the technique of Yang and Liou (1998) and are based on a mixture of bullet rosettes, hollow columns, and solid plates. A standard mixture is used for all clouds thought to be ice clouds, and it is unclear whether this mixture is representative, particularly in the special case of Cb clouds. Other calculations of anticipated reflectivity include those of Minnis et al. (1998).

3. RESULTS

The results are shown in Fig. 1 for the observed Cb and MODIS distributions, respectively. The overall results show encouraging agreement, with the MODIS simulations capturing the peak at forward azimuths that emerges at lower solar zenith angles, although not capturing its full intensity. Reflected intensities in this peak considerably exceed those at solar nadir. The MODIS model does not appear to capture the weak peak observed for backward azimuths. This peak does appear in some of the calculations of Minnis et al. (1998), which were based on various ice models. Thus, features such as these may help distinguish between different ice models, at least for representing cold cumulus clouds.

Acknowledgments

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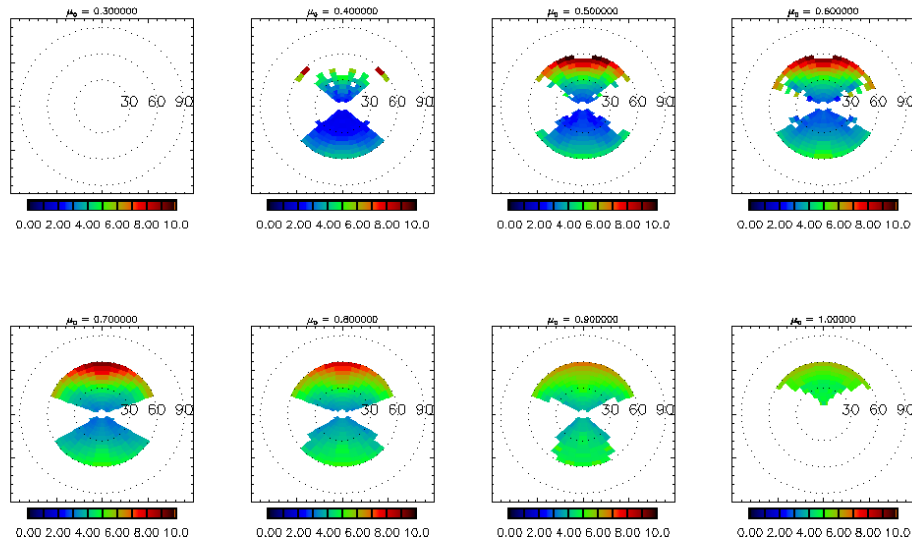


FIG. 1: Plots showing the angular distribution of backscattered reflectance (%) at different values of μ_0 (cosine solar zenith angle) as a function of satellite zenith angle (radial coordinate) and sun-satellite azimuth angle (angular coordinate), with backward azimuths at the bottom and forward at the top of each plot. The AVHRR instrument does not view all possible angles, so those plots have gaps.

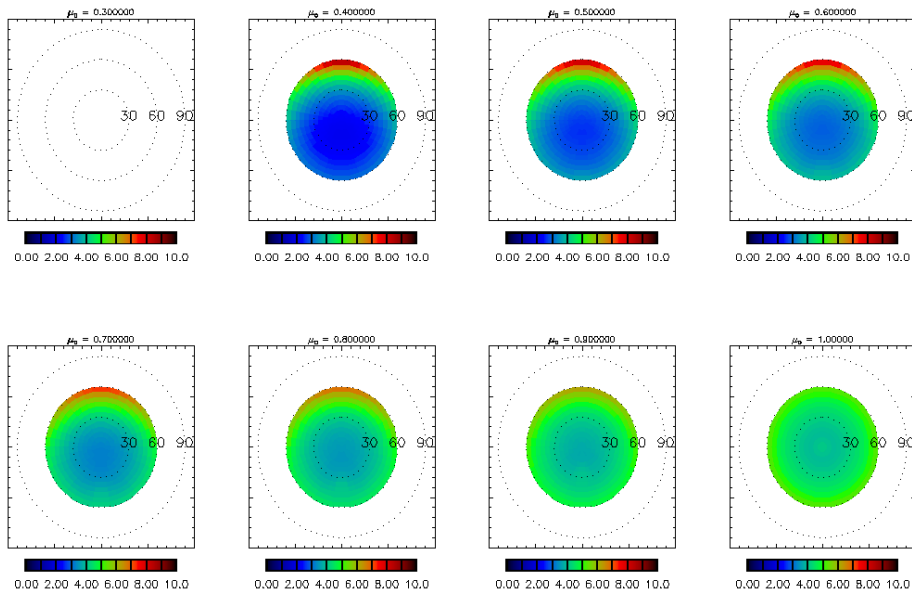


FIG. 2: Same as Fig. 1, except for MODIS library calculation using $r_e = 37.31 \mu \text{m}$.

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