1.9 A Comparison Of Cloud Microphysical Properties Derived Using VIRS 3.7 µm And 1.6 µm Data

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1. INTRODUCTION

One of the main objectives of the Clouds and the Earth's Radiant Energy System (CERES) project is the retrieval of cloud physical and microphysical properties simultaneously with observations of broadband radiative fluxes (Wielicki et al., 1998). These cloud parameter sare used for three main purposes:

1) to provide data for radiation-cloud climate feedback studies

2) to provide scene identification data for the construction and application of angular distribution models

3) to be used as input to radiative transfer calculations of intra-atmospheric fluxes

For the first CERES instrument, currently in operation aboard the Tropical Rainfall Measuring Mission (TRMM) spacecraft, cloud properties are being derived using multispectral data from the Visible Infrared Scanner (VIRS). For daytime retrievals of cloud particle phase and size, the first-generation operational CERES algorithm relies primarily on the 3.7-µm channel. These algorithms were developed using current operational satellites that only measure the near-infrared spectrum in the 3.7-3.9 µm window. The new generation Advanced Very High Resolution Radiometer (AVHRR) instruments replaces the 3.7-µm channel with a channel in the 1.6-µm window during the daytime. Since the VIRS instrument observes both the 3.7-µm and 1.6-µm channels simultaneously, this makes VIRS a powerful tool for providing a comparison of cloud microphysical properties derived from these two wavelengths which could be used to bridge past and future retrievals from AVHRR. For this paper, we will present the first comparison of simultaneous cloud phase and particle size retrievals from these two channels on VIRS.

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2. METHODOLOGY

The derivation of cloud particle size and optical depth using measurements in the visible and the absorbing near-infrared (NIR) is now a well-established technique (Arking and Childs, 1985). In general, most previous work has focused independently on either water clouds Nakajima and King, 1990; Han et al., 1994) or ice clouds (Baran et al., 1996). In addition, apart from Han et al., these retrievals have only been applied to limited case studies and not to global, operational retrievals.

The goals of CERES require that the cloud retrieval algorithm must be able to not only derive cloud microphysical parameters but also objectively determine the ice/water phase of the particles for the full array of viewing conditions encountered during operational, global processing. A prototype of the CERES algorithm has been used successfully to derive both water and ice properties from global AVHRR data (Minnis, et al., 1997). However, this algorithm used only the 3.7-µm channel for NIR information. The incorporation of 1.6-µm data into the CERES algorithm has two primary goals. First, an independent derivation of cloud particle size can be made for comparison with the 3.7-µm result. This is particularly beneficial for cases where dual solutions occur with 3.7-µm. Second, the 1.6-µm / 0.65-µm reflectance ratio can be used to provide an additional phase selection criterion.

2.1 Retrievals using 3.7 µm data

Currently, the cloud particle size and phase are determined for CERES using the 3.7-µm data as the NIR channel. The algorithm matches observations at 3.7, 0.65, and 10.8 µm to parameterizations of model calculations of cloud emittance and reflectance for a wide range of water droplet and ice particle sizes (Minnis, et al., 1998). The algorithm attempts to derive both an ice particle and a water droplet solution for each VIRS pixel. If both an ice particle and a water droplet solution are physically realistic, the phase is determined by consistency checks with:

1) The effective cloud temperature (T_c). Only water solutions are allowed for T_c > 273 K and only ice solutions are allowed for T_c < 233 K.

2) The 11.9 µm observation. The 10.8 - 11.9 brightness temperature difference is compared with model values for the ice and water solutions.

3) A cloud layer classification from a regional analysis of 0.65 and 10.8 µm data.

4) Default T_c threshold. If there is no other indicator, then clouds with T_c < 253 K are classified as ice and clouds with T_c > 253 K are classified as water.

2.2 Retrievals using 1.6 µm data

The retrieval of particle size is analogous to the 3.7-µm method. Cloud reflectance and absorption models for 1.6 µm are combined with estimates of surface albedo and atmospheric molecular absorption to calculate top-of-the-atmosphere (TOA) reflectances that are compared with observations. For cloudy skies, we express the top of the atmosphere 1.6-µm reflectance as:

$$\rho_{NIR} = \rho_c \exp[-\tau_1 (1/\mu_o + 1/\mu)] + \alpha_{sNIR} \exp[-\tau_1(1/\mu_o + 2.04) + \tau_2 4.08] [1 - \alpha(dif) - a(dif)] [1 - \alpha(\mu_o) - a(\mu_o)]$$

Where α_{sNIR} is the surface albedo; ρ_c is the cloud reflectance; τ_1 and τ_2 are the optical depth of the atmosphere above and below the cloud; μ and μ_o are the cosines of the viewing and solar zenith angles; $\alpha(dif)$ and $\alpha(\mu_o)$ are the diffuse and direct cloud albedos; and $a(dif)$ and $a(\mu_o)$ are the diffuse and direct cloud absorption. The atmospheric optical depths have been parameterized as a function of the precipitable water, surface pressure, solar zenith angle, and latitude and they are based on the results of detailed radiative transfer calculations using correlated k-distribution calculations for the VIRS NIR channel following the method of Kratz (1995). The cloud absorption is parameterized as a function of total precipitable water and pressure level. The surface albedos have been derived globally from the first month of VIRS data (Sun-Mack, et al., 1999).

3. RESULTS

3.1 Particle size

Initial comparisons of particle sizes retrieved using 1.6 and 3.7 µm for selected cases over the ARM Southern Great Plains site have yielded mixed results. The operational 3.7-µm algorithm has derived water droplet radii that agree well with surface-derived estimates except in cases with thin cirrus contamination (Dong, et al., 1999). The 1.6-µm retrievals have been less consistent, with more variance in derived radii. A full comparison of results will be presented at the conference.

3.2 Phase determination

The use of 1.6-µm data for objective phase determination has been more successful. An initial processing of one month of VIRS data from January 1998 (Minnis et al., 1999) has been used to develop models of the 1.6-µm / 0.65-µm reflectance ratio *R*. For these data, the ice/water phase was selected using the process described in Section 2.1. Tables of *R* as a function of solar zenith angle, optical depth, and surface type have been developed.

Summaries of means and standard deviations (σ_R) of *R* as functions of cloud optical depth are presented in Figs. 1 and 2 for ocean and cropland/grassland regions, respectively. Although there is overlap between the range of water and ice ratios, there is a trend toward increasing separation of R_{ice} and R_{water} with increasing optical depth. This is a useful addition to our phase determination since the 10.8 - 11.9 µm temperature difference only provides phase information for thin clouds.

Operationally, the ratios as a function of solar zenith angle are used if the first two classification steps described in Section 2.1 fail. R_{ice} and R_{water} show a statistically greater separation for a specific solar zenith angle than those shown in Figs. 1 and 2 which combine the full range of angles. For successful classification, the observed value of *R* must be within $R_{model} \pm \sigma_R$ for one phase and outside of $R_{model} \pm \sigma_R$ for the other.

The month of January 1998 has been re-processed using the these ratios in the phase

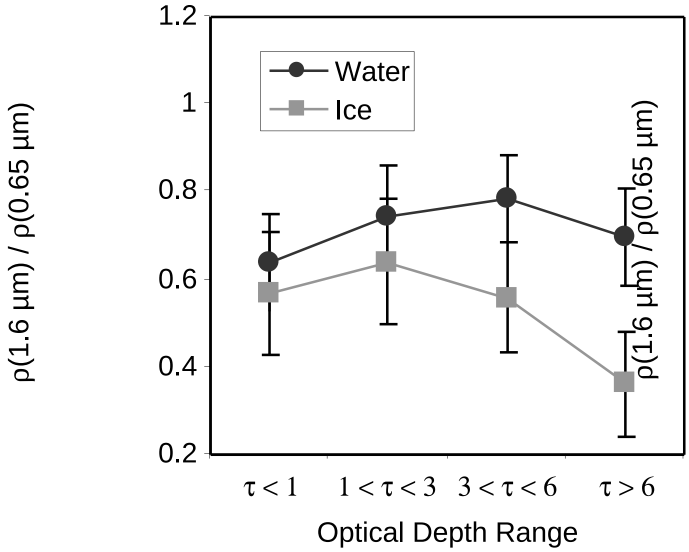

Fig. 1. Near-infrared / visible reflectance ratio as a function of cloud optical depth for ocean regions. The error bars show plus/minus one standard deviation.

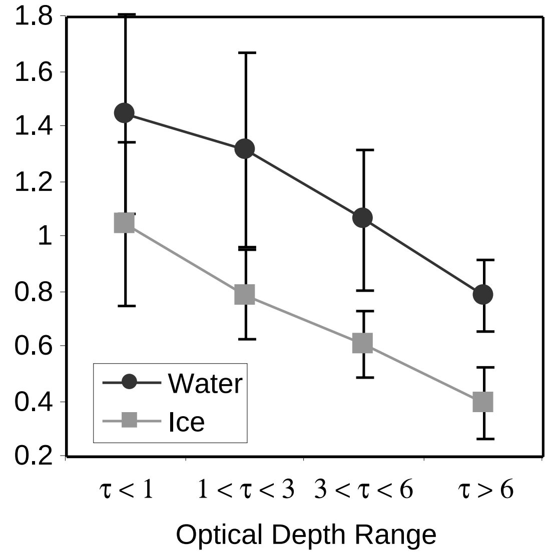

Fig. 2. Same as Fig. 1 except for cropland/grassland regions

determination algorithm. Overall, the percent of clouds classified as super-cooled water changed only slightly on a global basis as would be expected. However, for specific cases such as optically thick clouds with effective temperatures near 253 K, there is a reduction in the number of cases where the default selection is used.

4. CONCLUDING REMARKS

Accurate cloud microphysical property retrievals are an essential element of the CERES project. Global, operational algorithms for deriving these properties have relied on NIR observations only in the 3.7-µm spectral region since this has been the only channel available on the AVHRR instruments in the past. The addition of the 1.6-µm channel on VIRS provides supplementary information that can assist in choosing among multiple solutions and in phase determination.

Future work will include the incorporation of the1.6-µm retrievals into the operational CERES cloud algorithm. Also, the empirically derived NIR-visible reflectance ratios will be compared with model predictions to determine whether further refinements can be made in the phase selection process.

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