

DAYTIME CLOUD PROPERTIES FOR CERES FROM VIRS ON THE TRMM SATELLITE

P. Minnis, D. F. Young, B. A. Wielicki

Atmospheric Sciences Division
NASA Langley Research Center
Hampton, Virginia, USA

P. W. Heck, W. L. Smith, Jr.

AS&M, Inc.
Hampton, Virginia, USA

T. D. Murray, S. Sun-Mack

Science Applications International Corporation
Hampton, Virginia, USA

Proceedings of ALPS 99 Symposium

Meribel, France
18-22 January 1999
WK2-O-02, pp. 1,4

DAYTIME CLOUD PROPERTIES FOR CERES FROM VIRS ON THE TRMM SATELLITE

Minnis, Patrick; Young, David F.; Wielicki, Bruce A.

Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681 USA

Heck, Patrick W.; Smith, W. L., Jr.

AS&M, Inc., Hampton, VA 23666 USA

Murray, Tim D.; Sun-Mack, Sunny

Science Applications International Corporation, Hampton, VA 23666 USA

Introduction

A complete understanding of the interaction of clouds with the radiation budget of the Earth-atmosphere system, at a minimum, requires simultaneous measurements of cloud properties and the broadband radiation field. The Clouds and Earth's Radiant Energy System (CERES; Wielicki et al., 1998) experiment on the 35°-inclined-orbit Tropical Rainfall Monitoring Mission (TRMM) satellite and the upcoming Sun-synchronous EOS satellites has been designed to meet that requirement. To complement the 10-km CERES broadband radiation budget measurements, cloud properties are being determined from high-resolution, multispectral imagers on these satellites. Cloud-top height or temperature as well as optical depth are the primary determinants of outgoing longwave radiation (OLR) in cloudy atmospheres. The optical depth, the phase, and effective size of the cloud particles govern the cloud shortwave albedo and the surface insolation. Cloud layering affects the radiative divergence within the atmosphere and cloud-base altitude influences the longwave radiation arriving at the surface. Because CERES will be deriving the surface radiation and a roughly resolved radiative flux profile in the troposphere, all of these properties are needed for each measurement.

The combination of these cloud properties with the broadband fluxes also constitutes an unprecedented dataset for determining cloud radiative forcing and for constraining general

circulation models. This paper provides a brief description of the initial methods for retrieving these cloud properties from daytime multispectral imager radiances, a summary of the preliminary results, and an initial assessment of the retrievals.

Data

The 2-km resolution Visible InfraRed Scanner (VIRS) flown on the TRMM satellite measures radiances at 0.65, 1.6, 3.75, 10.8, and 12.0 μm . It scans in a cross-track direction out to a nadir angle of 45°, which translates to a maximum viewing zenith angle of 48°. For each VIRS pixel, the CERES processing system assigns a scene classification that is some category of clear or cloudy (Minnis et al., 1999), estimates of clear-sky radiance for each channel, a temperature and humidity profile, and surface elevation. The data analyzed here are the Version-1 VIRS radiances for January 1998. The 0.65- μm calibration was adjusted by increasing the gain by 5% to match the visible channel on other satellites. Except for a few easily identified periods with large calibration swings, the Version-1 VIRS visible and infrared calibrations appear to be quite stable. The 3.75- μm calibration has not been tested against other satellite data so far because the same channel is not available on most satellites. Nearly exact angular matching is required for a useful calibration check, so data from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA satellites are infrequently available for comparison. The

solar constant used for computing the channel-3 reflectance is equivalent to a blackbody temperature of 355.4K.

Retrieval Technique

A set of algorithms was developed to derive cloud height, optical depth, phase, effective particle size, and water path from these channels for each pixel. The main algorithm used during the daytime is the VIST (Visible Infrared Solar-Infrared Technique) described by Minnis et al. (1995). Given the clear-sky radiances for a particular set of solar zenith θ_o , viewing zenith, and relative azimuth angles, the VIST computes the spectral radiances expected for both liquid-droplet and ice-water clouds for a range of optical depths $\tau = 0.25$ to 128 for a particular cloud temperature T_c . The effective radii r_e for the model clouds range from 2 to 32 μm and the effective diameters D_e for the hexagonal ice column model clouds vary from 6 to 135 μm . The model cloud radiances are computed using the reflectance and emittance parameterizations of Minnis et al. (1998). The VIST matches the observed visible (0.65 μm), solar infrared (3.75 μm), and infrared (10.8 μm) radiances to the parameterization estimates of the same quantities. The process is iterative and computes results for either ice or liquid clouds. The phase is determined by a combination of tests that incorporate the final cloud temperature, but often it follows the phase selected for the initial guess. For example, an ice solution often cannot be retrieved for a low cloud because the observed 3.75- μm temperature T_3 is too high to match any of the model results. Conversely, T_3 may be too low to match any of the water droplet calculations for some high clouds. The phase selection is also required to be physically reasonable. Thus, no ice clouds are allowed for $T_c > 273\text{K}$ and no liquid clouds are permitted for $T_c < 233\text{K}$. The VIST has been partially validated for other satellites through comparisons with in situ (e.g., Young et al., 1998) and radar (Mace et al., 1998) data.

The cloud ice or liquid water path is derived from the retrieved values of τ and particle size. Cloud-top height is the altitude or pressure from the nearest vertical temperature profile that corresponds to T_c . The cloud thickness is defined using a set of crude empirical parameterizations based on τ , T_c , and phase. Cloud base height is defined as the difference between the cloud-top height and the thickness. The VIST is applied to all pixels having $\theta_o \leq 78^\circ$. After analysis, the VIRS pixel results are convolved to match the corresponding CERES scanner pixel using the scanner's point spread function to weight the results. The properties are convolved according to altitude with only two layers permitted for a given CERES pixel. Four altitude layers are defined: low, 1100 to 700 mb; low-middle, 700 – 500 mb; high-middle, 500 – 300 mb; and high, 300 – 50 mb. This convolution procedure can include some higher clouds in lower layers and vice versa depending on the two cloud layers selected for the CERES pixel.

Results

Of the 55.7% of the pixels classified as cloudy, only 22% were categorized as ice clouds. The remaining 78% were determined to be primarily liquid water clouds. The low clouds accounted for 54% of all of the observed clouds, while 18, 19, and 9% were classified as low-middle, middle-high, and high, respectively. The average cloud thickness is 53 mb, while the greatest mean cloud thickness is estimated at 133 mb for the middle-high layer. The mean value of r_e is 15.5 μm . Over ocean, land, and desert, $r_e = 16.1, 13.4,$ and 11.4 μm , respectively. The corresponding values of D_e are 68.5, 63.2, and 61.0 μm , while the mean D_e is 66.7 μm . The average value of τ is 9.4, while the logarithmic mean τ is 8.6. The mean layer optical depths are 5.4, 10.2, 12.8, and 23.2 for low, low-middle, middle-high, and high clouds, respectively. These optical depths and particle sizes correspond to mean liquid and ice water paths of 78 and 384 gm^{-2} , respectively.

Discussion

These initial values of cloud phase frequency and particle size from VIRS are significantly different compared to previous estimates. The areal coverage of ice clouds (~12%) is much less than other estimates such as those from surface observations (Warren et al., 1986, 1988) which show high cloud amounts averaging ~22 and 35% over ocean

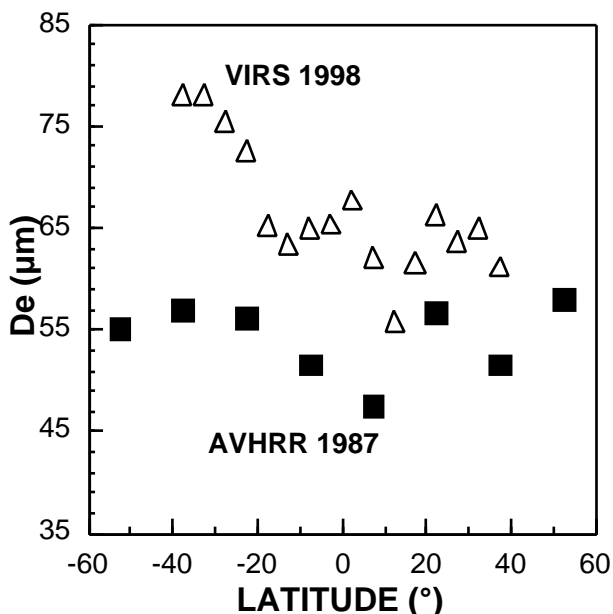


Fig. 1. Mean effective ice crystal sizes from January 1987 NOAA-9 and preliminary 1998 VIRS data analyses.

and land, respectively, during the boreal winter between 40°S and 40°N. The mean radii are considerably larger than found in previous studies. Using January 1987 NOAA-9 AVHRR data, Minnis et al. (1997) derived values of r_e that are approximately 2 μm smaller than those derived here. The dependence of r_e on surface type, however, is similar for both the VIRS and AVHRR retrievals. The mean ice crystal sizes are 10 μm larger than those determined by Minnis et al. (1997). Figure 1 compares the zonal mean values of D_e derived from VIRS and by Minnis et al. (1997). The VIRS data are greater at all latitudes, especially in the southern hemisphere. Additionally, the VIRS results show a dependence of D_e on surface type that was absent in the NOAA-9 retrievals. Although the optical depths increase

dramatically with altitude as may be expected, only 4% of the ice clouds have < 3 .

Preliminary comparisons with radar and radiometer data in central Oklahoma indicate that values of r_e derived for stratus clouds from VIRS are 1 – 4 μm greater than the surface-based values. The optical depths appear to be similar for the two datasets. Cloud altitude is generally well within 1 km of the radar results. Most of the altitude differences are attributable to insufficient resolution in the temperature profiles.

There are a variety of possible reasons for the discrepancies in cloud microphysics compared to previous estimates. Some differences may be attributable to the El Nino raging during January 1998, but this phenomenon is unlikely to cause a wholesale increase in cloud particle size. The larger ice and water droplet sizes may be due to overestimates of cloud optical depth because of the gain increase. A newer edition of the VIRS data (Version 4) has a gain that is 7% less than that used here. If the visible optical depths are reduced, the particle size will tend to decrease because the temperature differences between channels 3 and 4 will remain constant forcing the model selection to a lower value of r_e or D_e . It is likely that a channel-1 gain decrease will have only a minor impact on particle size. The percentage differences, ~15%, in particle size are essentially equal for both liquid and ice. This difference could be due to an overestimate of the channel-3 solar constant.

The phase selection appears to favor water droplets. Limited examination of the analysis procedure found that a low-level liquid-water cloud solution was often found for thin cirrus clouds. The temperature selection criteria quite often resulted in these clouds being classified as low clouds despite the existence of a cirrus cloud solution. This effect can explain the lack of thin cirrus clouds in the summary and the frequent occurrence relatively large water droplets. The low-cloud selection tendency can be eliminated using several different tests. One is the prediction of the channel-5 temperature T_5 using the resultant ice and liquid optical

properties. If the value of T_5 derived with the ice model is closer to the observed value, then ice would be selected. Otherwise, the liquid result would be retained. Another approach uses a visible-infrared approach that classifies the clouds as low, middle, or high clouds using fixed particle sizes. It will then be assumed that if a cloud classified as high in this manner has a viable ice solution, then it will be classified as an ice cloud. Finally, the 1.6- μm channel may be useful for phase classification, especially for optically thick clouds. Discrimination of single and multilayered clouds will aid in the derivation of statistics uncontaminated by more than one cloud layer.

Future Research

Many of the algorithmic and calibration shortcomings of the present analysis will be examined and presented. Some of the changes will be implemented so that revised results will be available. Resolution of calibration issues and the phase selection will likely eliminate many of the apparent discrepancies found in this preliminary dataset. Improved vertical profiles of temperature and humidity will also reduce errors in altitude determination and atmospheric attenuation corrections. Further validation with other independent data sources such as surface radar and radiometer retrievals of cloud microphysics will be invaluable for resolving any remaining discrepancies.

References

- Warren, S.G., C.J. Hahn, J. London, R.M. Chervin, and R.L. Jenne, Global distribution of total cloud cover and cloud type amounts over land. *NCAR Tech. Note NCAR/TN-273+STR*, 229 pp., 1986
- Warren, S.G., C. J. Hahn, J. London, R.M. Chervin, and R. L. Jenne, 1988: Global distribution of total cloud cover and cloud type amounts over ocean. *NCAR Tech. Note NCAR/TN-317+STR*, 212 pp.
- Mace, G. G., T. P. Ackerman, P. Minnis, and D. F. Young, 1998: Cirrus layer microphysical properties derived from surface-based millimeter radar and infrared interferometer data. *J. Geophys. Res.* **103**, 23,207-23,216.
- Minnis, P., D. F. Young, D. A. Spangenberg, P. W. Heck, D. R. Doelling, Q. Trepte, and Y. Chen, 1999: Cloud mask for CERES from VIRS on the TRMM satellite. *Proc. ALPS 99 Symposium*, Meribel, France, Jan. 18-22.
- Minnis, P., D. P. Kratz, J. A. Coakley, Jr., M. D. King, D. Garber, P. Heck, S. Mayor, D. F. Young, and R. Arduini, 1995: Cloud Optical Property Retrieval (Subsystem 4.3). "Clouds and the Earth's Radiant Energy System (CERES) algorithm theoretical basis document, Volume III: Cloud Analyses and Radiance Inversions (Subsystem 4)", *NASA RP 1376 Vol. 3*, edited by CERES Science Team, December, pp. 135-176.
- Minnis, P., D. P. Garber, D. F. Young, R. F. Arduini, and Y. Takano, 1998: Parameterization of reflectance and effective emittance for satellite remote sensing of cloud properties. *J. Atmos. Sci.*, **55**, 3313-3339.
- Minnis, P., D. F. Young, B. A. Baum, P. W. Heck, and S. Mayor, 1997: A near-global Analysis of cloud microphysical properties using multispectral AVHRR data. *Proc. AMS 9th Conf. Atmos. Radiation*, Long Beach, CA, Feb. 2-7, 443-446.
- Wielicki, B. A., B. R. Barkstrom, B. A. Baum, T. P. Charlock, R. N. Green, D. P. Kratz, R. B. Lee, P. Minnis, G. L. Smith, D. F. Young, R. D. Cess, J. A. Coakley, Jr., D. A. H. Crommelynck, L. Donner, R. Kandel, M. D. King, A. J. Miller, V. Ramanathan, D. A. Randall, L. L. Stowe, and R. M. Welch., 1998: Clouds and the Earth's Radiant Energy System (CERES): Algorithm overview. *IEEE Trans. Geosci. Remote Sens.*, **36**, 1127-1141.
- Young, D. F., P. Minnis, D. Baumgardner, and H. Gerber, 1998: Comparison of in situ and satellite-derived cloud properties during SUCCESS. *Geophys. Res. Lett.*, **25**, 1125-1128.