N91-10502

Marine Stratocumulus Cloud Characteristics from Multichannel Satellite Measurements

PHILIP A. DURKEE AND GARY M. MINEART

Department of Meteorology
Naval Postgraduate School
Monterey, California 93943

INTRODUCTION

Understanding the effects of aerosols on the microphysical characteristics of marine stratocumulus clouds, and the resulting influence on cloud radiative properties, is a primary goal of FIRE. The effect of aerosols on clouds and the impact on climate processes have recently been discussed by several authors (Twomey et al., 1984; Coakley et al., 1987, Charlson et al., 1987). Of particular concern in this presentation is the potential for observing variations of cloud characteristics that might be related to variations of available aerosols. Some results from theoretical estimates of cloud reflectance will be presented. We also present here the results of comparisons between aircraft-measured microphysical characteristics and satellite-detected radiative properties of marine stratocumulus clouds. These results are extracted from Mineart (1988) where the analysis procedures and a full discussion of the observations are presented. Due to the space available, only a brief description of the procedures and the composite results will be presented.

The satellite data used here are from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) collected at the Scripps Satellite Oceanography Facility. The AVHRR channel 1 (0.63 μm), channel 3 (3.7 μm), and channel 4 (11 μm) data were used in the analysis. Cloud microphysical data were obtained by instruments on the NCAR Electra during MABL cloud-penetrating missions in support of the IFO from 29 June - 19 July 1988.

RESULTS

Theoretical Reflectance Estimates

Cloud reflectance can be estimated from cloud droplet distributions that represent anticipated conditions in marine stratocumulus clouds. Model cloud droplet distributions were generated using the modified gamma distribution after Deirmendjian (1969). Modal radii of 4 and 8 μm were used to show the effects of change in droplet size. The results presented here are for a constant liquid water content of 0.4 g m^{-3}. Three distributions at each mode radius were chosen to illustrate the effects of distribution width. The droplet size distribution curves for the two mode radii are shown in Fig. 1. The optical properties of the cloud droplet distributions were calculated using Mie calculations after Wiscombe (1980). Reflectance was calculated using the delta-Eddington approximation from

Joseph et al. (1976), applied at 45° solar zenith angle and cloud thickness ranging from 10 to 750 meters.

Fig. 2 illustrates the dependency of reflectance on cloud droplet size distribution, at a constant liquid water content (LWC) of 0.4 g m^{-3}, for 0.63 μm (AVHRR channel 1 3) and 3.7 μm wavelength (AVHRR channel 3). Reflectance decreases as droplet size increases for both wavelengths.

Fig. 3 shows reflectance dependence on cloud thickness. Channel 1 reflectance increases sharply in the first few hundred meters and then asymptotically approaches a value of 1.0 with increasing cloud thickness. Channel 3 reflectance rises quickly at cloud thickness below 0.1 km and then remains constant. Therefore, reflectance in channel 3 does not vary with cloud thickness once the cloud is greater than about 100 m thick. This is due to the moderate absorption by water droplets at 3.7 μm wavelength.

FIRE IFO Aircraft/Satellite Comparisons

Mineart (1988) presents four case studies that show a consistent relationship between cloud microphysical characteristics and radiative properties. Here we present only the composite results. The results of comparisons between coincident aircraft and satellite observations are displayed in Figs. 4 and 5.

The 3.7 μm (AVHRR channel 3) reflectance in Fig. 4 displays an excellent correlation with cloud droplet size. The outlying data point at 3 μm represents an observation of a cloud edge (about 80 m thick), where the decrease in cloud thickness dominates the drop size effect on reflectance. Fig. 4 also compares the channel 3 results with the model cloud reflectance data shown in Fig. 2. The variations closely match the expected values from simple theoretical estimates. Also, the shift toward model distribution D1 (broadest distribution) at large droplet sizes and the shift toward model distribution D2 (narrow distribution) at the smaller droplet sizes is consistent with the shift in distribution shape observed in the aircraft measurements (not presented here, see Mineart, 1988).

Fig. 5 relates 0.63 μm (AVHRR channel 1) reflectance to cloud thickness. Cloud thickness values are estimated from APN-159 radar altimeter and PMS-King LWC data. The vertical and horizontal bars indicate the 95% confidence intervals. The data show increasing channel 1 reflectance with increasing cloud thickness, which is consistent with the dependence shown in Fig. 3. Although channel 1 reflectance should vary as a function of droplet radius with constant cloud thickness and LWC, we have not analyzed enough cases to separate variations due to drop size from variations due to LWC and cloud thickness.

CONCLUSIONS

Relationships between cloud reflectance and cloud characteristics have been illustrated by comparing AVHRR satellite data and aircraft measurements. At 0.63 μm (AVHRR channel 1) reflectance variations relate strongly to cloud thickness. Also, The expected relationship of higher reflectances from smaller cloud droplet size spectra is confirmed for 3.7 μm wavelength (AVHRR channel 3). This dependence is closely approximated by model cloud reflectance estimates. Although not presented here, Mineart (1988) showed that a primary source of droplet size variations is related to continental/marine air mass differences. Continental air masses are generally have higher concentrations of aerosols, higher concentrations of cloud droplets, and a shift towards a smaller mean cloud droplet radius. The strong dependence of channel 3 reflectance on cloud droplet size distribution allows inference of cloud composition characteristics from satellite observations.

References

Charlson, R. J., J. E. Lovelock, M. O. Andreae, and S. G. Warren, 1987: Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature*, 326, 655-661.

Coakley, J. A., Jr., R. L. Bernstein and P. A. Durkee, 1987: Effect of ship-stack effluents on cloud reflectivity. *Science*, 237, 953-1084.

Deirmendjian, D., 1969: *Electromagnetic scattering on spherical polydispersions*. Elsevier, New York, 290pp.

Joseph, J. H., W. J. Wiscombe and J. A. Weinman, 1976: The delta-Eddington approximation for radiative flux transfer. *J. Atmos. Sci.*, 33, 2452-2459.

Twomey, S., M. Piepgrass and T. L. Wolfe, 1984: An assessment of the impact of pollution on global cloud albedo. *Tellus*, 36B, 356-366.

Wiscombe, W. J., 1980: Improved Mie scattering algorithms. *Applied Optics*, 19, 1505-1509.

Figures

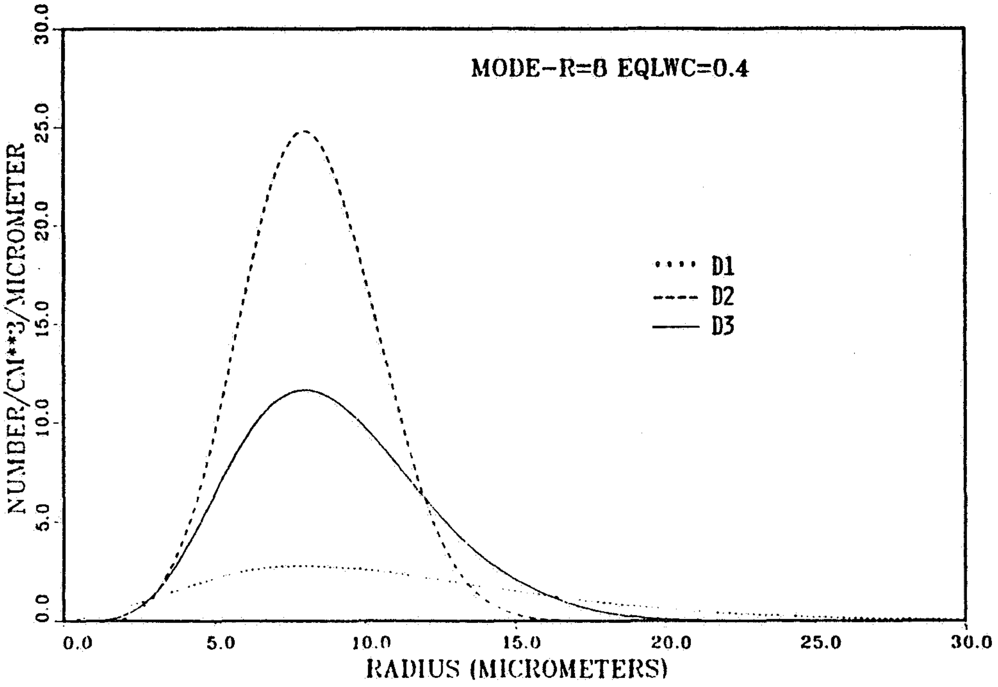

Fig. 1. Model Cloud Droplet Distributions for a modal radius = 4 μm, LWC=0.4 g m^{-3}. D1, D2, and D3 represent three modified gamma distributions of varying width.

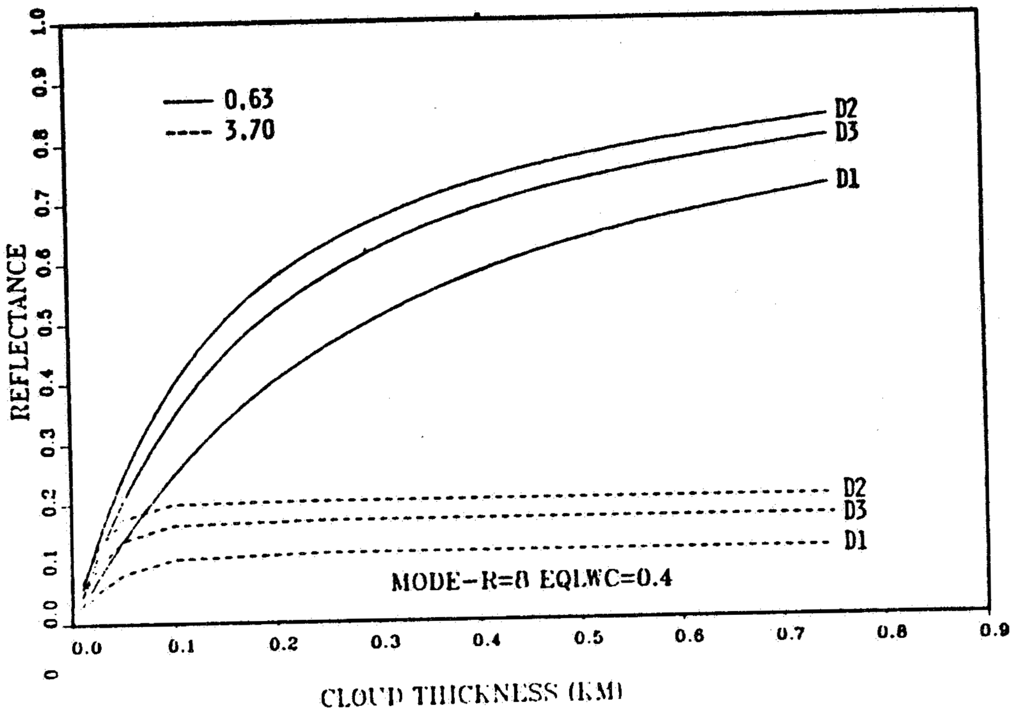

FIG. 2. Reflectance verses cloud thickness for solar zenith angle=45°, modal radius=8 μm, LWC=0.4 g m^{-3} and at the three modified gamma distributions (D1, D2, and D3).

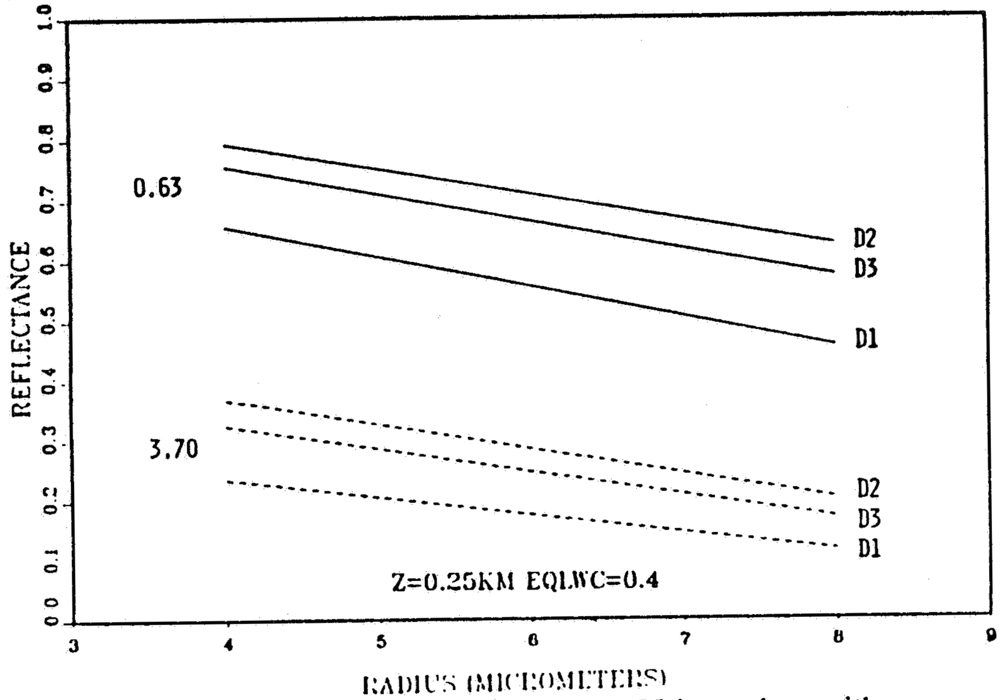

FIG. 3. Reflectance verses droplet radius for z=0.25 km, solar zenith angle=45°, LWC=0.4 g m^{-3} and at the three modified gamma distributions (D1, D2, and D3).

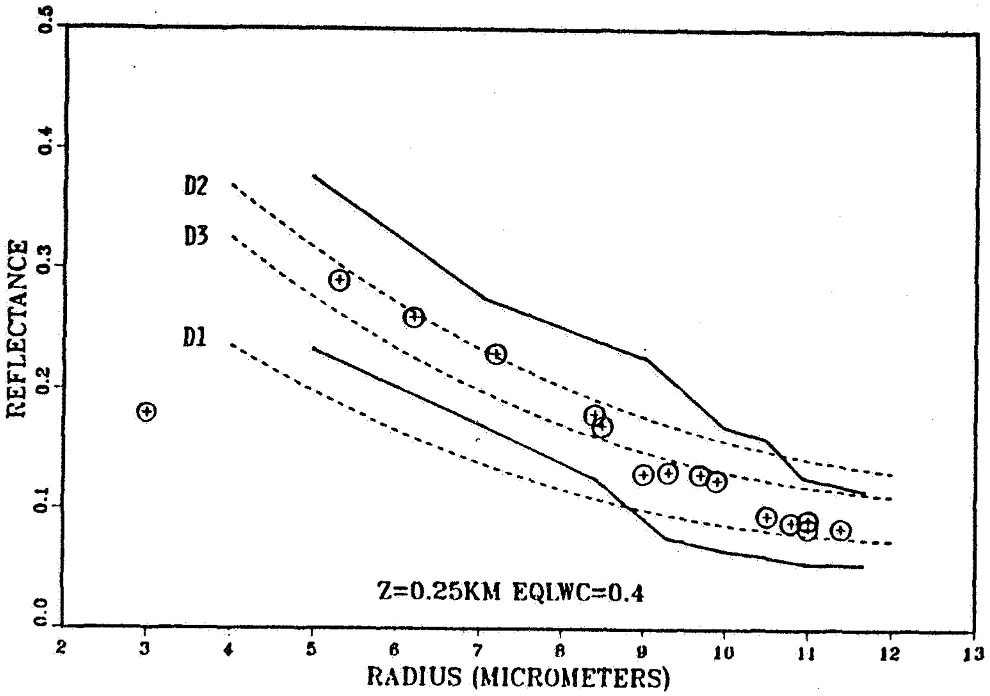

FIG. 4. Reflectance at 3.7 μm wavelength from AVHRR analysis versus droplet radius from NCAR Electra measurements. Solid lines indicate the 95% confidence interval for the data points. Dashed lines indicate model cloud reflectance estimates for droplet distributions D1, D2, and D3.

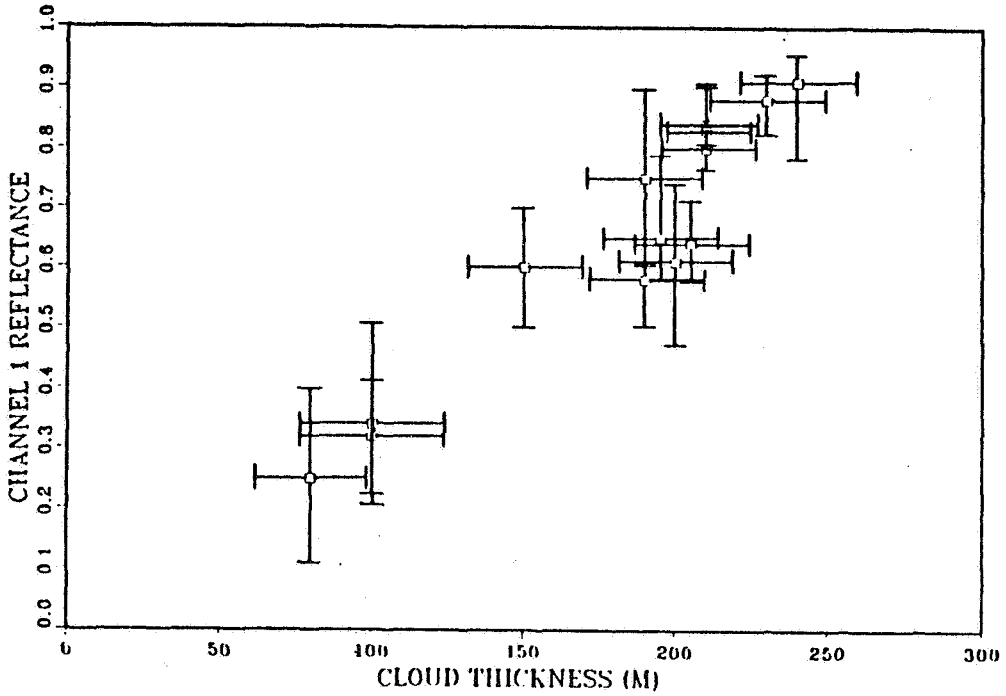

FIG. 5. Reflectance at 0.63 μm wavelength from AVHRR analysis versus cloud thickness from NCAR Electra measurements. Brackets indicate 95% confidence intervals for reflectance and cloud thickness.