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The Influence of Continental Sources of Aerosols on the Marine Stratocumulus during FIRE IFO-I

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INTRODUCTION

The effects of aerosols on the microphysical characteristics of marine stratocumulus clouds can have a significant impact on climate processes through modification of cloud radiative properties. 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. The results of comparisons between aircraft-measured microphysical characteristics and satellite-detected radiative properties of marine stratocumulus clouds are resented here. These results are extracted from Mineart (1988) and Durkee and Mineart (1989) where the analysis procedures and a full discussion of the observations are presented. Due to the space available, only a brief description of the 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 2 (0.86 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 cloud-penetrating missions in support of the field operations from 29 June - 19 July 1988.

RESULTS

Mineart (1988) presents four case studies that show a consistent relationship between cloud microphysical characteristics and cloud radiative properties. The most dominant effect is observed in cloud reflectance at 3.7 μm wavelength (AVHRR channel 3). Fig. 1 shows the observed relationship between aircraft-measured cloud droplet size and satellite-measured cloud reflectance. At this wavelength, moderate absorption by the cloud droplets limits the dependence of cloud reflectance on cloud thickness and liquid water content (primary determinants of reflectance at visible wavelengths). Therefore the primary determinant of cloud brightness at 3.7 μm is the cloud droplet size distribution (reflectance increases with decreasing droplet size). The dashed lines in Fig. 1 are the theoretical relationships for three size distributions.

The effects of droplet size on cloud reflectance are also theoretically expected at shorter wavelengths although the effects of cloud thickness and LWC will be come more important as absorption decreases. To assess the effects at 0.63 μm wavelength (AVHRR channel 1), reflectance values were normalized to a constant LWC (0.3 g m^{-3}) and thickness (200 m). The results of normalization are shown in Fig. 2. Although the relationship appears weak and there is significant scatter, a decrease in reflectance with increasing droplet size is suggested ($\approx$ 10% decrease with droplet size increase from 5 to 12 μm radius).

The primary modifier of cloud brightness at 3.7 μm wavelength shown in Fig. 1, is influence from continental air masses (Mineart, 1988). Presumably, continental air containing significantly more CCN than marine air, produces clouds with smaller droplets relative to clouds in typical marine air masses. These microphysical differences between marine and continental clouds can be observed in the satellite-detected radiative properties of the clouds. The connection between cloud brightness and continental air mass is made through analysis of air motion trajectory calculations. Cloud brightness is directly related to cloud droplet size distribution through analysis of particle measurements made on board the NCAR Electra aircraft. Analysis of CCN measurements on board the Electra still need to be performed.

Continental aerosol sources were observed during the FIRE IFO to interact with marine stratocumulus in three ways:

1) **During periods of large scale offshore flow and subsequent cloud development.** Most of these events occur to the north of the main stratus deck (coastal OR and northern CA during the FIRE IFO). The continentally influenced air-mass then moves southward under the influence of the subtropical high pressure system and is incorporated into the main stratus deck.

2) **By local scale offshore flow and entrainment into the cloud.** This off shore flow is usually confined to stable layers just above preexisting cloud. Hudson has reported large increases in CCN concentration above cloud during the FIRE IFO (reported in Albrecht, et al., 1988). These processes need further study.

3) **By direct injection into the cloud in coastal regions, especially from urban sources.** Durkee (1989) reports several cases of urban influence on aerosol and cloud processes. These effects are identified by the spatial and temporal relationships to urban centers.

Composites of satellite-measured radiative characteristics have been prepared to assess the large-scale effects of continental aerosol sources on cloud characteristics. Tettelbach (1987) presented the first monthly summary of the eastern North Pacific Ocean. Fig. 3 and 4 are the results of cloud reflectance composites for August 1986. These results illustrate a clear distinction between cloud reflectance at 3.7 μm and 0.63 μm wavelengths. As mentioned above, 0.63 μm reflectance is primarily determined by cloud thickness and LWC. The brightest clouds in Fig. 1 (AVHRR channel 1) are associated with the large scale divergence pattern of the subtropical high and the region of coldest upwelled water along the northern CA and OR coast. Reflectance at 3.7 μm is determined mostly by droplet size. Fig. 4 (AVHRR channel 3) shows bright clouds are associated with the coastal regions of CA, with the brightest clouds occurring immediately downwind of Los Angeles, CA. Summaries of the FIRE IFO time period and other months of 1987 are being processed and should be ready for presentation at the workshop.

CONCLUSIONS

Relationships between cloud reflectance and cloud characteristics have been illustrated by comparing AVHRR satellite data and aircraft measurements. A relationship of higher reflectances from smaller cloud droplet size spectra is confirmed for 3.7 μm wavelength (AVHRR channel 3) and is suggested for 0.63 μm wavelength (AVHRR channel 1). 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 therefore smaller mean cloud droplet radius, than marine air masses. The strong dependence of 3.7 μm reflectance on cloud droplet size distribution allows inference of cloud composition characteristics from satellite observations. Further, satellite-detected cloud reflectance can be used to investigate the influence of continental air masses on marine cloud formation and subsequent effects on the cloud radiative properties.

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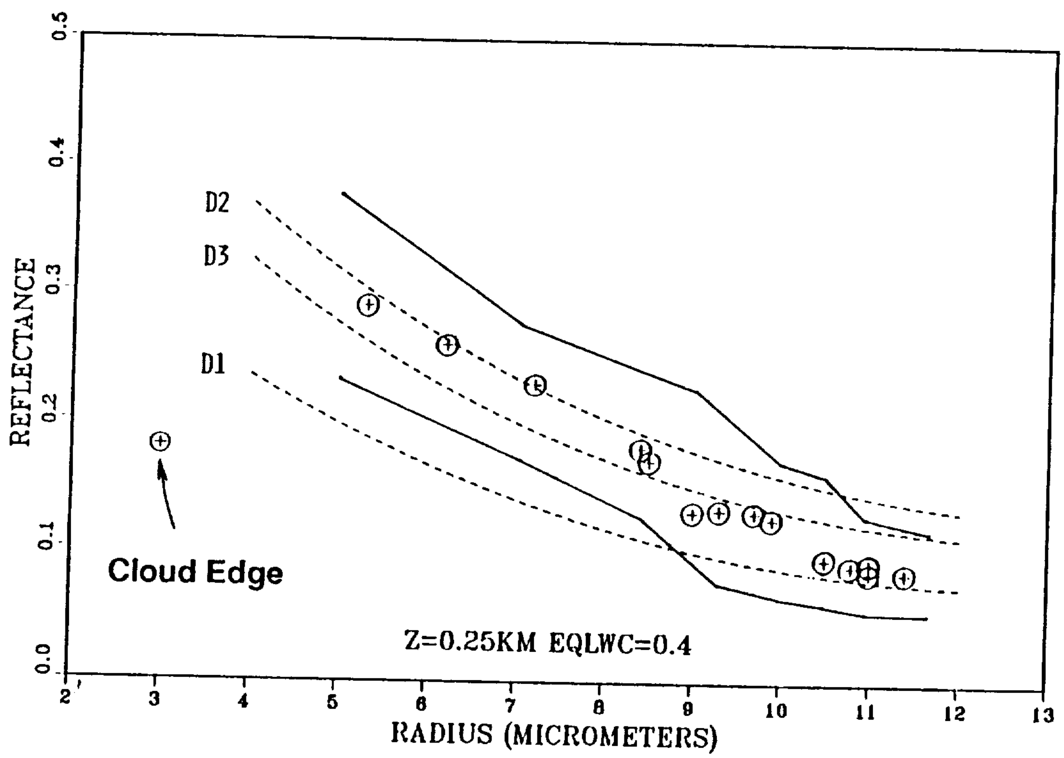

Fig. 1. Satellite-measured 3.7 μm reflectance vs aircraft-measured droplet size. Dashed lines indicate model reflectance for distributions of different widths (D2-narrow, D1-wide, D3-moderate). Solid lines indicate the 95% confidence interval for the data points.

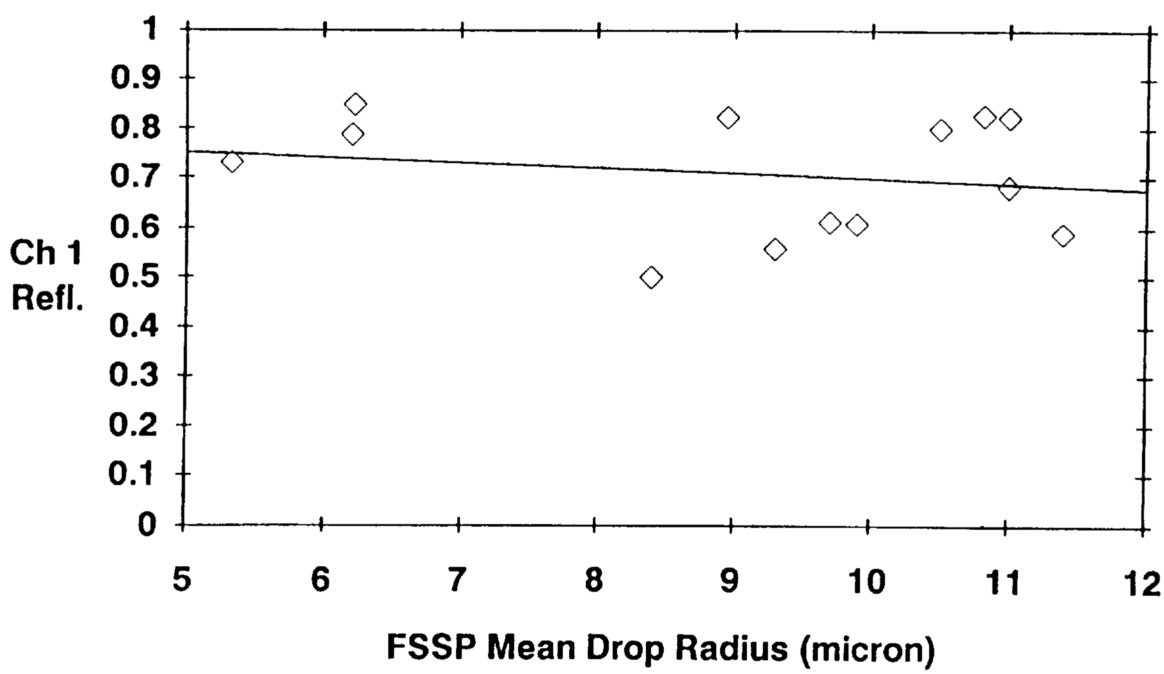

Fig. 2. Same as Fig. 1 but for 0.63 μm reflectance and normalized to thickness = 200 m and LWC = 0.30 gm m^{-3}.

Fig. 3. Cloud reflectance from composited AVHRR Channel 1 (0.63 μm wavelength) data for August 1986.

Fig. 4. Same as Fig. 3 but for AVHRR Channel 3 (3.7 μm wavelength) data.