Final Technical Report: NASA Research Grant NAG-1-935—Cloud Properties as Deduced from Satellite Observations

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This report discusses three major accomplishments resulting from the work on this project. The first was the simultaneous observations from both satellite and *in situ* aircraft of the effects of ship exhaust on cloud microphysics and the consequent changes in cloud reflectivity. The observations took place during the FIRE Marine Stratocumulus IFO and the details are reported in Radke et al. (1989) (copy attached). The observations confirmed the interpretation of earlier satellite observations which indicated that the CCN added by the pollution increased the number of cloud droplets but made the droplets smaller (Coakley et al., 1987). These changes in microphysics and cloud reflectivity in response to pollution had been predicted by Twomey (1977). In addition, the aircraft observations indicated that clouds with smaller droplets suppress the formation of drizzle which commonly occurs for low-level maritime clouds. Consequently, polluted clouds not only have larger numbers of droplets which increases cloud reflectivity but also they retain more liquid water which also increases cloud reflectivity.

Second, the satellite observations collected during the FIRE Marine Stratocumulus IFO were analyzed to reveal differences in the reflectivities of uniform and broken clouds. The results indicated that broken stratiform clouds have reflectivities which are approximately 80% of the reflectivities for their uniform counter parts. The details are reported in Coakley (1990) (copy attached). As broken clouds appear to be the dominate characteristic of global cloud systems, the result implies that estimates of the reflectivities based on plane-parallel radiative transfer theory, as often used in general circulation climate models, would lead to an estimate of the planetary albedo that is high by 10% were the climate models to accurately reproduce the area covered by clouds and their liquid/ice water contents. Observations at 3.7 μm indicated that there may be a systematic shift in droplet sizes from the center of clouds to cloud boundaries. The result expanded the earlier findings by Coakley and Davies (1986) and are consistent with rudimentary models for the effects of entrainment on cloud microphysics (Jonas, private communication).

Third, in collaboration with Jack Snider (NOAA/Wave Propagation Laboratory) the relationship between liquid water path and cloud reflectivity was examined. Liquid water paths for overcast stratiform clouds were obtained from the NOAA microwave radiometer on San Nicolas Island during the FIRE Marine Stratocumulus IFO and cloud reflectivities were obtained from the AVHRR. The study was marred by the large calibration errors in the AVHRR visible channels. Nevertheless, the study showed that factors which could have affected the relationship: the reflectivity of the underlying ocean surface, the anisotropy of reflected radiation, subpixel-scale variability in the

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liquid water path and reflectivity, and variations in cloud droplet sizes were insufficient to account for the large discrepancies between the observed and theoretical relationships for liquid water path and cloud reflectivity. This work is reported in a paper being prepared for publication (Coakley and Snider, 1990)

During the course of the work the grant supported two graduate students working towards advanced degrees: Fu-lung Chang, who is working towards a Master's Degree in Atmospheric Sciences and David Judge, who received his Master's Degree in Computer Science and is now working towards a PhD in Computer Science.

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