

Thomas J. Greenwald\*  
Colorado State University, Fort Collins, Colorado

Sundar A. Christopher  
University of Alabama, Huntsville, Alabama

## 1. INTRODUCTION

Reflectance measurements at visible and near-IR wavelengths above marine stratocumulus have shown the effects of drizzle on cloud microphysics (e.g., Nakajima and Nakajima, 1995). These effects are usually manifested as a negative correlation between cloud droplet effective radius and visible optical depth. This occurs because drizzle formation tends to deplete the cloud water content (thus reducing the optical depth) while at the same time increasing the effective radius of the droplet size distribution (Considine, 1997).

This study explores the potential of the GOES-9 imager visible and near-IR reflectance measurements for providing bulk microphysical information about drizzling marine stratocumulus. The unique aspect of this work is that coincident data from a ship-based C-band doppler radar are used to evaluate the satellite results. A case was selected in the eastern Pacific on September 4, 1997 at 0100 UTC in conjunction with the Pan American Climate Studies Tropical Eastern Pacific Process Study (TEPPS) (Yuter and Houze, 1998).

## 2. DATA

The GOES-9 imager is one of a new series of advanced geostationary sensors with improved infrared spatial resolution and radiometric sensitivity (Ellrod et al., 1998). Full resolution channel 1 (0.52-0.74  $\mu\text{m}$ ), channel 2 (3.79-4.04  $\mu\text{m}$ ), and channel 4 (10.2-11.2  $\mu\text{m}$ ) data are used here. Channel 4 data are used to correct for thermal emission in the channel 2 data (e.g., Greenwald et al., 1999). The visible (channel 1) and near-IR (channel 2) reflectance data are then used in simultaneously retrieving droplet effective radius ( $r_e$ ) and visible optical depth (Greenwald et al., 1999).

This study also uses reflectivity data from a highly sensitive C-band (5.37 cm) doppler radar, which was on board the NOAA ship Ronald H. Brown during the 1997 TEPPS (Yuter and Houze, 1998).

## 3. RESULTS AND DISCUSSION

Figure 1 shows GOES-9 visible and near-IR reflectance imagery along with the radar reflectivity at 1-km altitude. Both GOES-9 images indicate strong signatures that relate closely to the lines of drizzle cells. Most

of these cells had reflectivities of 5-10 dBZ with a maximum of 17 dBZ. Higher visible reflectance (white) indicates larger optical depths, while lower near-IR reflectances (dark) signify larger cloud droplets.

Figure 2 illustrates the GOES-9 data and radar reflectivity vertical cross-section along the line A-B shown in Figure 1. Missing  $r_e$  retrievals indicated clouds that were too thin for an unambiguous retrieval of  $r_e$  and optical depth. Remarkably, the lowest near-IR reflectance (0.05) corresponds with the most intense drizzle cell. Retrievals of  $r_e$  showed that the largest drop sizes (24-28  $\mu\text{m}$ ) were indeed associated with the more intense cell. For the weaker cell, effective radii were 18-24  $\mu\text{m}$ . In areas outside of the drizzle,  $r_e$  was 12  $\mu\text{m}$ . The twin peaks in the visible reflectance also agreed well with the positions of the two drizzle cells.

These results provide strong evidence that GOES-9 imager measurements contain important information regarding the microphysics of drizzling marine stratocumulus. The GOES-9 imager is thus an additional tool that may be useful in studying the time/space evolution of the microphysics of these clouds.

## 4. ACKNOWLEDGMENTS

Support was provided by the DoD Center for Geosciences grant DAAL01-98-2-0078 MOD 01. S. Christopher was supported by NASA grant NAGW-5195. GOES-9 data were supplied by the National Climatic Data Center (NCDC). We thank Sandra Yuter for the C-band radar data and Joyce Chou for performing the cloud property retrievals and helping to produce the figures.

## 5. REFERENCES

- Considine, G. D., 1997: Modeling the diurnal variability in cloud microphysics in boundary layer clouds, *J. Geophys. Res.*, **102**, 1717-1726.
- Ellrod, G. P. R. V. Achutuni, J. M. Daniels, E. M. Prins, and J. P. Nelson, III, 1998: An assessment of GOES-8 imager data quality, *Bull. Amer. Meteor. Soc.*, **79**, 2509-2526.
- Greenwald, T. J., S. A. Christopher, J. Chou, J. Liljegen, 1999: Intercomparison of cloud liquid water path derived from the GOES-9 imager and ground based microwave radiometers for continental stratocumulus, *J. Geophys. Res.* (*in press*).
- Nakajima, T. Y., and T. Nakajima, 1995: Wide-area determination of cloud microphysical properties from

\* Corresponding author address: Dr. Tom Greenwald, CIRA, Colorado State Univ., Fort Collins, CO 80523-1375; e-mail: greenwald@cira.colostate.edu.

NOAA AVHRR measurements for FIRE and ASTEX regions, *J. Atmos. Sci.*, **52**, 4043-4059.  
 Yuter, S. E., and R. A. Houze, Jr., 1998: Convection and stratus in the Tropical Eastern Pacific: The Pan

American Climate Studies Tropical Eastern Pacific Study, *Bull. Amer. Meteor. Soc.*, submitted.

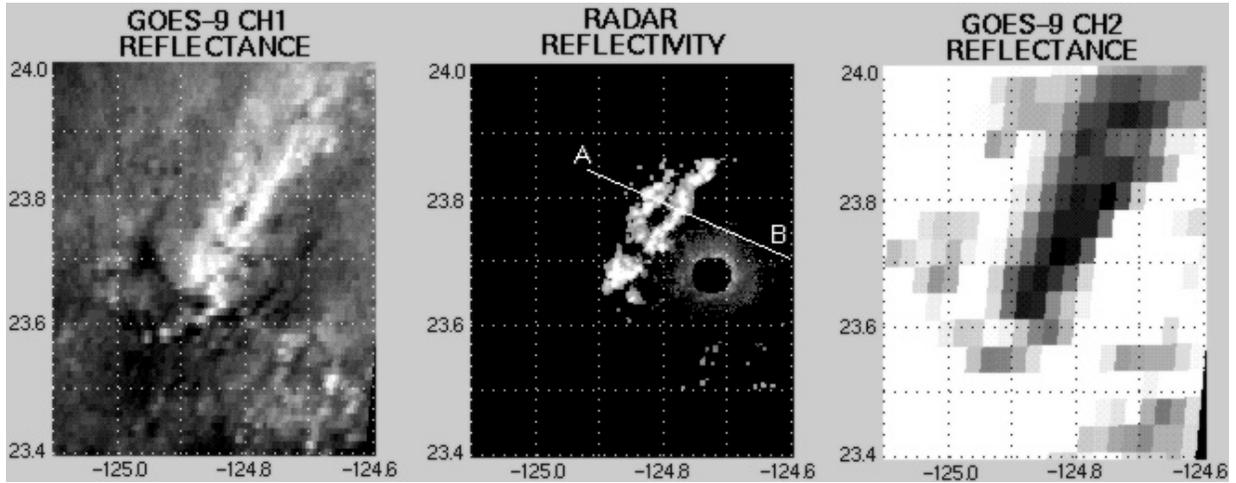


Fig. 1. Images of GOES-9 visible (left) and near-IR (far right) reflectances on September 4, 1997 at 0100 UTC. C-band radar reflectivity at 0105 UTC is shown in middle. Whitch areas indicate larger values.

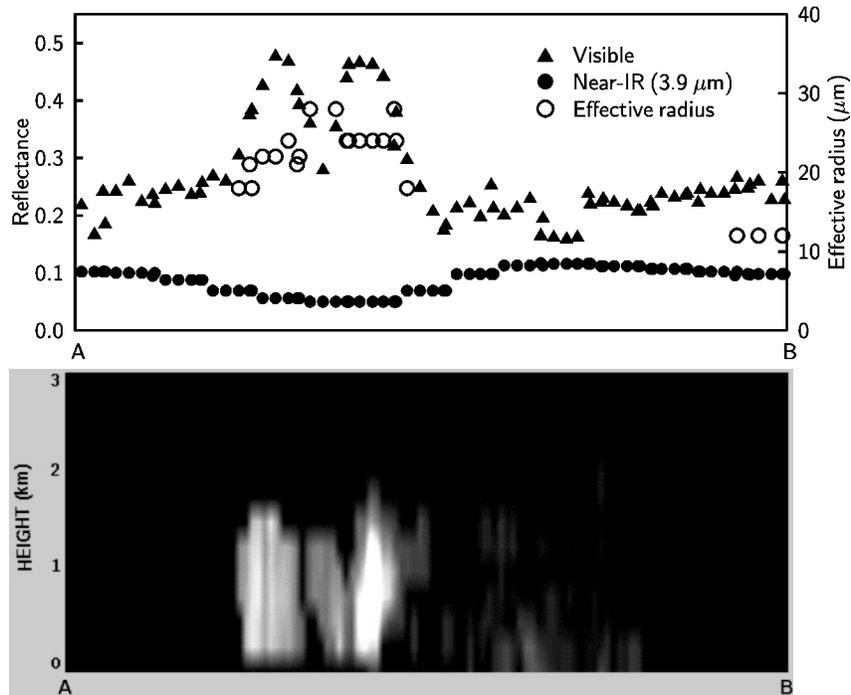


Fig. 2. GOES-9 visible and near-IR reflectance and effective radius retrievals (top) and corresponding radar vertical cross-section (bottom) along the line A-B shown in Figure 1.