AN EXAMINATION OF THE IMPACT OF DRIZZLE DROPS ON SATELLITE-RETRIEVED EFFECTIVE PARTICLE SIZES

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1. INTRODUCTION

In general, cloud effective droplet radii are remotely sensed in the near-infrared using the assumption of a monomodal droplet size distribution. It has been observed in many instances, especially in relatively pristine marine environments, that cloud effective droplet radii derived from satellite data often exceed 15 µm or more. Comparisons of remotely sensed and in situ retrievals indicate that the former often overestimates the latter in clouds with drizzle-size droplets. To gain a better understanding of this discrepancy, this paper performs a theoretical and empirical evaluation of the impact of drizzle drops on the derived effective radius.

2. DATA AND METHODOLOGY

The primary datasets consist of in situ microphysical data taken off the coast of California during the second Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) experiment (Stevens et al., 2003) during July 2001 and the Drizzle and Entrainment Cloud Study (DECS) during July 1999. The droplet size distributions for two cases were selected for analysis. One was observed during flight R07 around 1100 UTC, 24 July during DYCOMS-II in a relatively homogeneous deck in conditions described as heavy drizzle (Vanzanten et al. 2004). The other was constructed of measurements taken on a DECS flight during 16 July in a transit from a relatively homogeneous stratus cloud deck into a rift area, which is a region within a marine stratocumulus deck where the cloud is dissipating apparently from drizzle processes (Sharon et al., 2004).

Data from the tenth Geostationary Operational Environmental Satellite (GOES-10) were also used to assess the large scale context of the measurements and, for the DECS case, to derive cloud properties, in particular, the effective radius, r_e, using the approach of Minnis et al. (2001). Similarly, cloud properties were retrieved from the Visible Infrared Scanner (VIRS) on the Tropical Rainfall Measuring Mission satellite over-pass during the DECS flight as described by Minnis et al. (2002). Figure 1a shows the infrared GOES-10 image taken off the California coast at 1100 UTC during the DYCOMS-II flight. Compared to the areas of broken cloudiness nearby (e.g., Fig. 1b), the cloud deck was relatively homogeneous. The droplet size distribution measured during the flight from two different probes were combined to account for both cloud and drizzle droplets. A lognormal fit to the resulting size distribution is shown in Fig. 1c. Inclusion of the drizzle data only increase r_e by 0.3 µm.

The rift area sampled by the DECS flight (Fig. 2) consisted primarily of broken clouds while nearby deck was more homogeneous. The retrieved values of r_e

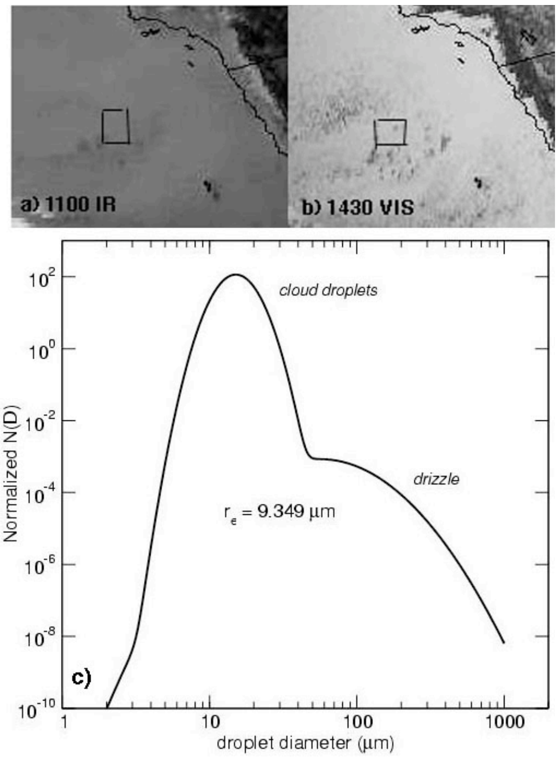

Fig. 1. (a&b) GOES-10 imagery during DYCOM-II flight RF-07, 24 July 2001. Box indicates approximate location of aircraft measurements around 1100 UTC. (c) lognormal fit to combined cloud and drizzle droplet size distribution.

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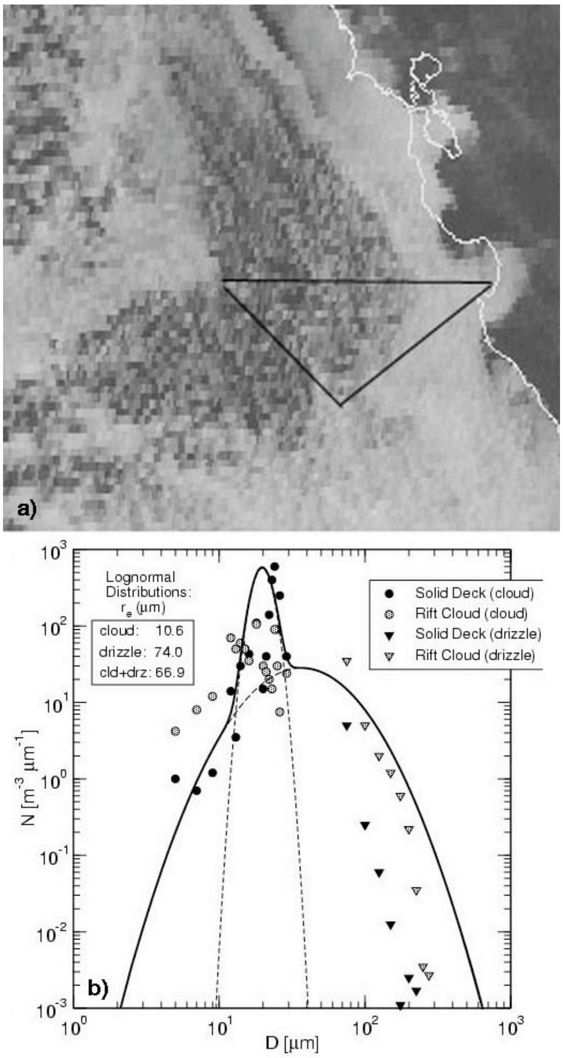

Fig. 2.(a) GOES-10 visible image at 1800 UTC, 16 July 1999. Triangle shows the DECS flight path into and out of the rift. (b) droplet size distributions in deck and rift

from both the GOES-10 and VIRS (Fig. 3) increase dramatically from around 15 μm in the deck region to greater than 25 μm in the rift zone. The effective radii are smaller than 9.5 μm near the coast south of the rift, but the droplets are larger over the remainder of the domain, which is criss-crossed by ship tracks. The large droplet sizes are retrieved form both the 2-km VIRS and 4-km GOES data. Other analyses show that the large droplets are retrieved even at 1-km resolution. The drizzle in the rift clouds (Fig. 3b) increases the effective radius from 10.6 μm up to 56 μm. The number of drizzle-sized drops is much smaller in the deck cloud.

To understand how these drizzle droplets affect the radiation field and the radiation budget, the distributions are used in Mie scattering calculations to compute single-scatter albedos at two wavelengths, 1.6 and 3.9 μm, that are commonly used to retrieve r_e. The impact of drizzle is estimated by starting with

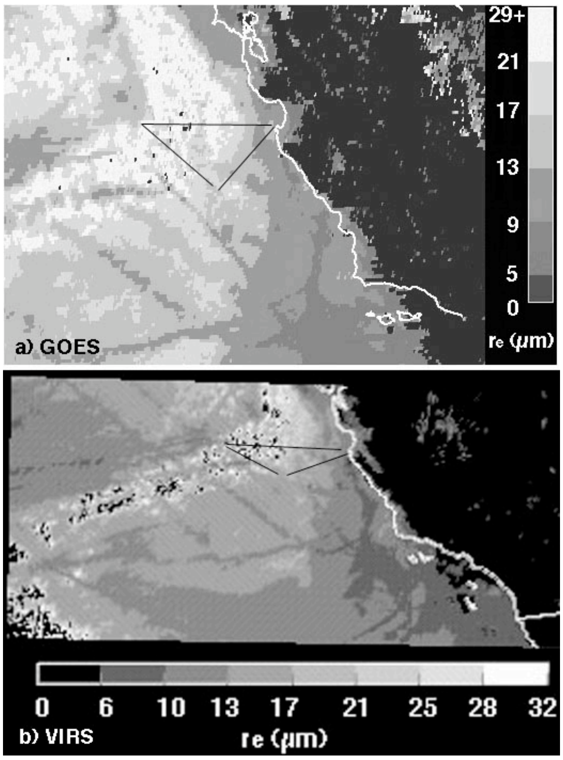

Fig. 3. Satellite-retrieved effective droplet radii at 1800 UTC, 16 July 1999.

the basic drizzle distribution in Fig. 1c and increasing the drizzle component by factors of 2 from 2 to 96. Figure 4 shows an example of a modified drizzle case along with the droplet distributions used in the satellite retrievals (Minnis et al., 1998). The theoretical and enhanced observed distributions are markedly different. Increasing the drizzle by a factor of 32 raises r_e by 10 μm, but the result is still unlike the extreme distribution found in the rift cloud.

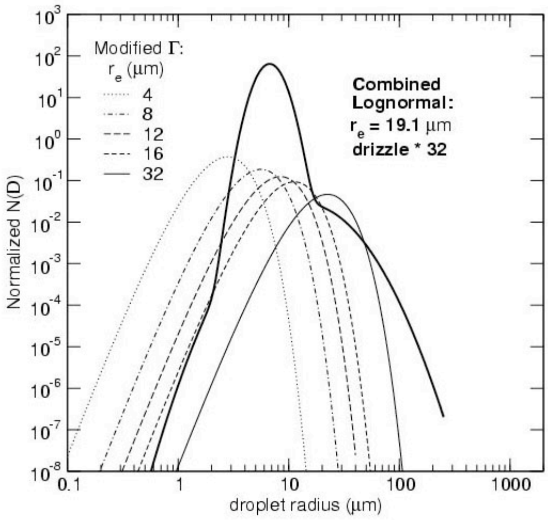

Fig. 4. Droplet size distributions for satellite retrievals of r_e and cloud-drizzle droplet distribution from Fig. 1c with enhanced drizzle component.

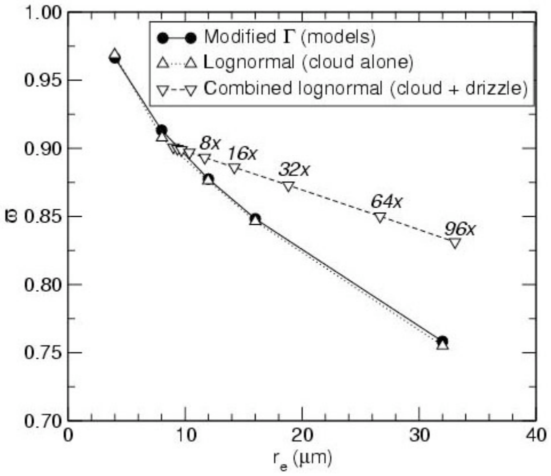

Fig. 5. Single-scatter albedo at 3.9 µm for model and enhanced observed droplet size distributions.

3. RESULTS

3.1 3.9 µm

The single-scatter albedo, SSA or ω_o, from the model clouds and the enhanced observations are plotted in Fig. 5 for 3.9 µm. At this wavelength, the lognormal and modified gamma, used by Minnis et al. (1998), produce nearly identical values of ω_o for drizzle-free clouds. The lognormal distribution from the cloud part of the distribution in Fig. 1c also produces the same SSA as the modified gamma distribution indicating that the retrieved value and actual values of r_e should be similar. When drizzle droplets are added to the distribution, the SSA decreases with increasing r_e at a lower rate than that from the model clouds. Thus, as the number of drizzle droplets near cloud top increases, the retrieved value of r_e will increase but will tend to underestimate the actual value.

For example, when the drizzle amount is enhanced by 96X, the retrieved value would be on the order of 19 µm compared to the true value of 33 µm. The SSA for the rift cloud (Fig. 2) without the drizzle is 0.8897, which is nearly the same as the modified gamma distribution result. When the drizzle droplets are added, ω_o = 0.6911, which is close to a value extrapolated from the model curve in Fig. 5. This similarity is probably due to the resemblance of the actual combined distribution in Fig. 2b to the shape of modified gamma distribution (e.g., Fig. 4).

The shape of the single-scattering phase function is also negligibly modified by the inclusion of drizzle. Adding-doubling calculations were used to assess the impact on the reflectance fields. The results mimic the variations seen in Fig. 5. The retrieved r_e would be too small in most of the enhanced drizzle cases.

3.2 1.6 µm

The values of SSA for all of the cases were also computed for a wavelength of 1.6 µm. The results in Fig. 6 are different than those in Fig. 5. SSA is less sensitive to the shape of the droplet size distribution

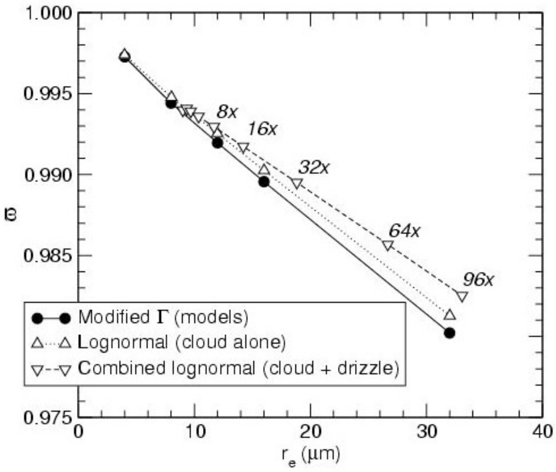

Fig. 6. Same as Fig. 5, except at 1.6 µm.

and decreases at nearly the same rate as SSA derived from the modified gamma distribution. Thus, in this instance, the inferred underestimate of r_e in drizzle cases using the 3.9-µm data would be much less severe using the 1.6-µm data. At a drizzle enhancement of 96X, the retrieved r_e would be ~ 27 µm compared to 19 µm from the 3.9-µm retrieval.

Generally, the 3.9-µm retrieval should yield a larger value of r_e when no drizzle droplets are present. The larger droplets tend to occur at the top of the cloud and the 3.9-µm retrieved effective radius corresponds to a smaller depth into the cloud than that from 1.6 µm because the water droplets are so much more absorptive at 3.9 µm. The inclusion of the drizzle droplets suggests a reversal of that inferred relationship. It might be possible to use a combination of retrievals from the two channels to identify those areas with heavy drizzle.

VIRS data taken off the coast of Peru were analyzed using 1.6 and 3.9-µm data separately to estimate r_e. Three different regions were examined: one with small droplets and the other two with larger droplets. Histograms of the retrieved droplet sizes are plotted in Fig. 7 for each region. In the region with small droplets, r_e (1.6 µm) < r_e (3.7 µm). In both areas with larger droplets, the 1.6-µm histogram is broader than its 3.9 counterpart. Despite equality in the mean droplet sizes, the retrievals from 1.6 µm data tend to produce more excessively large and very small droplets than those from the 3.9-µm retrievals. Because the droplet model effective radii are limited to 32 µm, there were 3% of no-retrievals at 1.6 µm because the observed reflectance was less than any in model lookup table. This result is consistent with Figs. 5 and 6 in that the clouds with the heaviest drizzle can still be interpreted at 3.9 µm when the 1.6-µm reflectance is off the charts.

4. CONCLUDING REMARKS

The results presented here represent only a few cloud droplet distributions. Many additional microphysical measurements are available for processing and

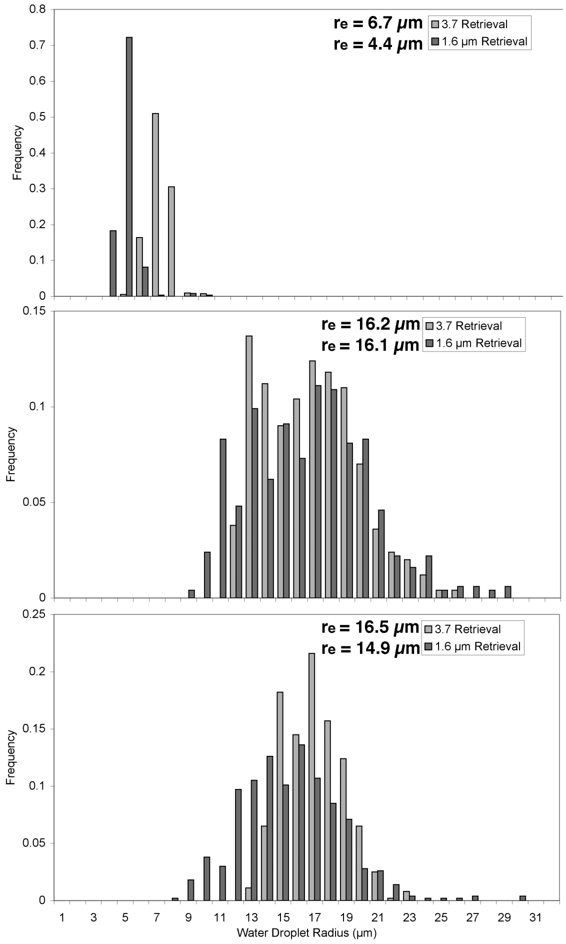

Fig. 7. Effective radius histograms derived off the coast of Peru using the 1.6 and 3.7-μm channel son VIRS.

analysis. Direct comparisons with the satellite retrievals can also be made in a few instances. Further analyses should carefully account for the height variation of the cloud droplet size distributions.

The results are encouraging for the detection of drizzle from satellite data, at least, during the daylight period. The suggested combination of retrievals could be used on a variety of satellites currently operating.

Acknowledgements

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References

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., et al., 2001: A near-real time method for deriving cloud and radiation properties from satellites for weather and climate studies. *Proc. AMS 11th Conf. Satellite Meteorology and Oceanography*, Madison, WI, Oct. 15-18, 477-480.

Minnis, P., et al., 2002: A global cloud database from VIRS and MODIS for CERES. *Proc. SPIE 3rd Intl. Asia-Pacific Environ. Remote Sensing Symp. 2002*, Hangzhou, China, October 23-27, Vol. 4891, 115-126.

Sharon, T. M., B. A. Albrecht, H. H. Johnson, P. Minnis and M. M. Khaiyer, 2004: Aerosol and cloud microphysical characteristics of rifts and gradients in marine stratocumulus clouds. Submitted, *J. Atmos. Sci.*

Stevens, B., et al., 2003: Dynamics and Chemistry of Marine Stratocumulus - DYCOM-III. *Bull. Am. Meteorol. Soc.*, 579-593.

Vanzanten. M. C., B. Stevens, G. Vali, and D. H. Lenschow, 2004: Observations of drizzle in nocturnal marine stratocumulus. Submitted, *J. Atmos. Sci.*