Radar/Radiometer Retrievals of Cloud Liquid Water and Drizzle: Analysis Using Data from a Three-Dimensional Large Eddy Simulation of Marine Stratocumulus Clouds

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Introduction

Marine stratocumulus clouds are believed to play an important role in the earth's energy budget through their effect on the radiation budget (e.g., Cox 1971). To evaluate the impact of stratocumulus clouds on climate, long-term cloud monitoring with extensive spatial coverage is imperative. Central to this problem are measurements of cloud liquid water and drizzle.

This need prompted the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory to develop techniques for retrieving cloud liquid water content and drizzle characteristics using a K_α-band Doppler radar (Kropfli et al. 1990) and microwave radiometer (Hogg et al. 1983). The instruments were deployed on the island of Porto Santo in the Madeiras during the recent Atlantic Stratocumulus Transition EXperiment (ASTEX), June 1992. Unfortunately, there were no useful overflights of the island, and there are no direct in situ measurements against which to compare the remote measurements.

In this paper, we will use a data set generated by a three-dimensional (3-D) large eddy simulation (LES) model as a surrogate for real data. The model results presented here do not represent an ASTEX case study; they are simply synthetic data of a marine stratocumulus capped boundary layer which are used to analyze the behavior of the remote sensing retrievals. The model is the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University. The version used here includes explicit treatment of cloud condensation nucleus and droplet size spectra (Cotton et al. 1993; Feingold et al., in press; Cotton et al., this issue). Because RAMS is able to resolve droplet size distributions, it is ideal for comparing various integrated moments of the distribution (e.g., LWC, *Z*, etc.) with similar parameters measured either in situ or by remote sensors.

Model-derived information on droplet spectra and vertical velocities is used to calculate radar reflectivity factors, Doppler velocity spectra, and integrated liquid water paths (LWP). These parameters are then used as input to the retrieval method. Finally, the derived parameters are compared with the actual parameters generated by the model.

Description of the Remote Sensing Techniques

The method for retrieving cloud liquid water content (LWC) and drizzle parameters is discussed in a paper by Frisch et al. (in press) and a companion presentation Frisch et al. (this issue) and is only briefly outlined here.

Cloud Liquid Water Content

The cloud droplet size distribution is assumed to conform to a lognormal distribution with three parameters: *N* the droplet concentration, r_g the geometric mean radius, and σ the standard geometric deviation. Profiles of cloud LWC are derived from range-gated radar reflectivity *Z* measurements, together with a radiometer measurement that provides an integrated LWC measurement over the depth of the cloud. It is also assumed that *N* is invariant with height (a fairly good assumption for marine stratocumulus clouds; see Nicholls 1984) and the breadth of the size distribution σ is a fixed constant.

Drizzle

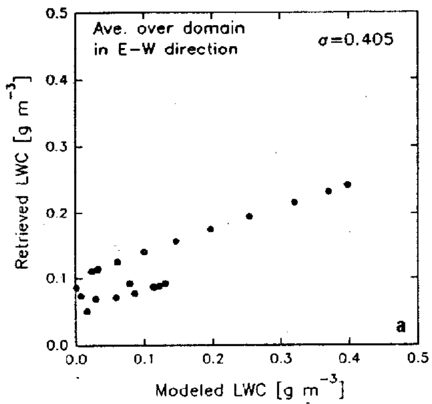
Characteristics of the drizzle size spectrum are derived from three moments of the Doppler velocity spectrum: reflectivity *Z*, the sixth moment weighted mean fall velocity V_z, and the second moment $V_z^{(2)}$. These three measurements, together with a functional form for drop terminal velocity $V_f(r)$, can be used to retrieve the three parameters of the lognormal function, *N*, r_g and σ, at the vertical resolution of the radar.

Analysis of the Retrieval

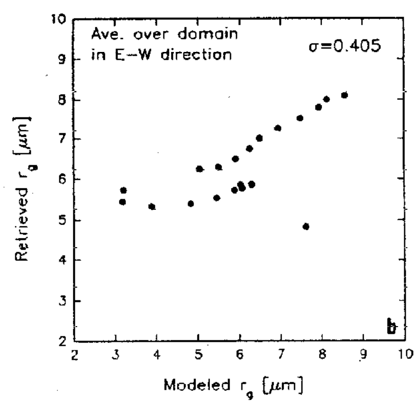
Cloud Liquid Water Content

During the field experiment, data were averaged over periods of tens of minutes. In simulating these measurements, we have averaged model data in a similar fashion. Figure 1a shows a plot of LWC derived using V_i ($_i$ represents vertical resolution—37 m in the case of the radar and 25 m for the model) and LWP as calculated from the model data as a function of the true model values. We see here a clear linear relationship which falls somewhat off the ideal 1:1 relationship, underestimating LWC at values ~>0.2 gm^{-3} and overestimating LWC for values lower than 0.2 gm^{-3}. Some of the extraneous points at low LWC are associated with points near cloud boundaries, where the retrieval assumptions are violated. Results in Figure 1a are insensitive to the assumed value of σ.

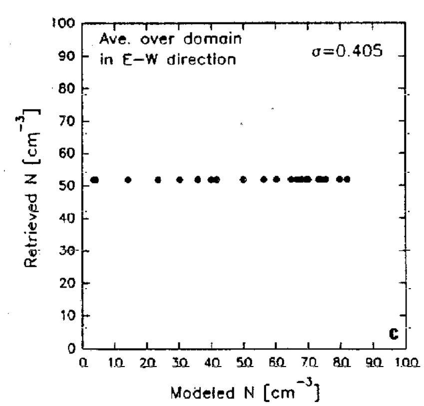
Figures 1b and 1c are the same as Figure 1a, but for the retrieved values of r_{gi} and *N*. These results *are* sensitive to the assumed value of σ.



a) cloud LWC



b) cloud droplet geometric mean radius



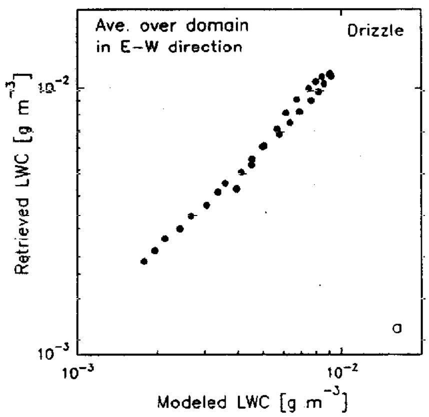
c) cloud droplet concentration

Figure 1. Comparison of retrieved **cloud fields** as a function of the model values.

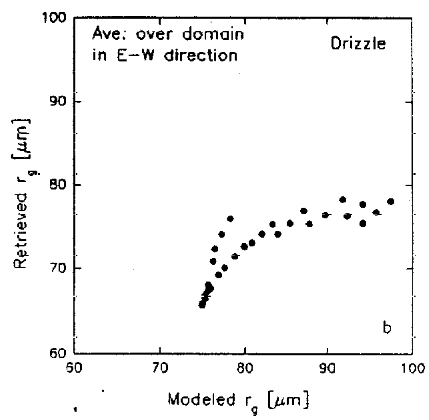
Drizzle

Comparison of model-derived drizzle parameters (N_i, r_{gi} and σ_i) with those derived from the three radar moments requires an assumption of a lower cutoff of the drop-size spectrum. For the model data, we have defined drizzle drops as those with radii >50 µm; for the simulated radar data, drizzle is defined by a lower threshold of -5 dBZ in accordance with the field measurements of Frisch et al. (in press).

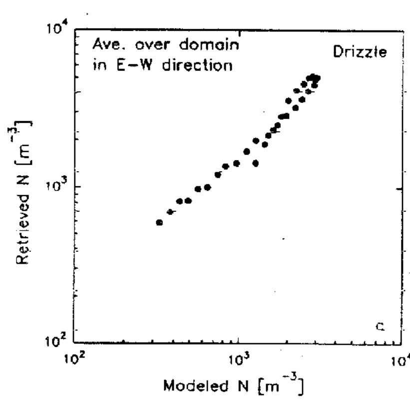
Figures 2a, 2b, and 2c show comparisons of the three fields LWC, r_{gi} and N_i as derived from the retrieval compared with the actual model data. We note a good comparison for drizzle water content (overestimate of about 20%, Figure 2a) and a general tendency to underestimate r_{gi} and overestimate N_i. Some of this discrepancy can be attributed to the definition of the lower cutoff mentioned above. Other differences are likely attributable to the very strong weighting of the radar measurements to the larger drops; the three moments used in the retrieval are effectively weighted by the 6th (Z), 7th (V_z), and 8th powers ($V_z^{(2)}$) of the drop sizes.



a) drizzle LWC



b) drop geometric mean radius



c) drop concentration

Figure 2. Comparison of retrieved **drizzle fields** as a function of the model values.

Summary

A synthetic marine stratocumulus data set generated by the RAMS model has been used to evaluate retrievals of cloud and drizzle microphysical parameters based on radar/radiometer measurements. Results show a consistent linear relationship between retrieved cloud LWC and the model data. For the case of drizzle, comparisons show good estimates of water content with a trend to underestimate drop size and overestimate number concentration. Future work will examine methods for improving these techniques.

Acknowledgments

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