4.2.1 Drizzle formation in stratus.

The mechanism for drizzle formation in marine stratus remains an important current topic with many uncertainties. One element in developing an understanding of this process is to characterize the spatial and temporal history of drizzle drops. Simple descriptions of upward moving parcels are invalid in stratus, and generalized formulations of turbulence are not much help on this score. With the hope that clues can be derived from examining the association between air motions and drizzle plus cloud droplets of different sizes, we have embarked on such an analysis, confined up to this point to considering vertical motions only.

Several previous studies have shown positive correlations between upward air velocity (positive w) and cloud droplet concentration (N_D) in marine stratus or stratocumulus clouds (Curry, 1986; Hudson and Svensson, 1995; Hudson and Li; 1995, Vali et al., 1998, hereafter V98). In addition, it was shown in V98 that the Doppler velocity (reflectivity-weighted particle velocity) correlates positively with reflectivity in the upper half of the cloud depth, one interpretation of which is that the concentrations of drizzle drops is greater in upward moving air volumes. To test that interpretation, we examined how droplet spectra vary with air velocities in the in situ data (FSSP and 1D probes) from both the 1995 and 1999 field projects off the Oregon coast.

An example, demonstrating the nature of the results obtained so far, is shown in Fig. 1. The pattern shown is fairly typical of 22 level flight segments analyzed from 8 different days. In order to maintain sufficient sample sizes even for size ranges of low concentrations, the velocity stratification is restricted to separating the uppermost and lowermost 20% of the range of vertical air velocity values. Ratios of the droplet concentrations in the upper 20% of vertical air velocities to the concentrations in the lower 20% of vertical air velocities vs. drop diameter are shown in the figure. As this example shows, ratios above unity are found over two size regions: small cloud droplets and drizzle drops. For these size ranges there are more drops in upward moving air than in downward moving air. Between these sizes, near 25 μm diameter, the ratios drop below unity indicating the reverse situation. The features just described do not exhibit clear variations with height within the cloud layer. They do support the deduction drawn from the radar evidence cited earlier and further sharpen the need to ascertain what processes lead to these results.

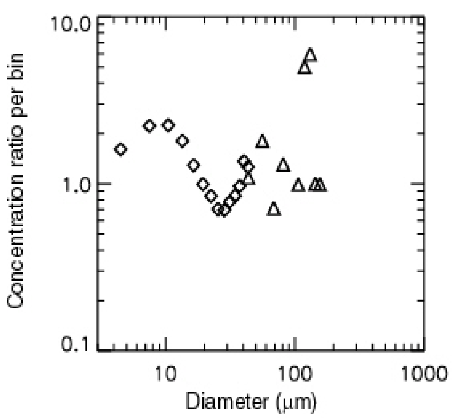

Fig. 1. Ratio of drop concentrations in the 80th percentile of vertical velocities to drop concentration in the lower 20th percentile of vertical velocities.

The most robust of the three features illustrated in Fig. 1 is the finding of ratios exceeding unity at the small end of the cloud droplet spectrum. This feature, coupled with the fact that the total droplet concentration is dominated by droplets of small sizes is equivalent to the positive correlation between total drop concentration and vertical velocity found by many investigators, as mentioned above. The reason may be thought to be activation of more droplets at cloud base when updraft velocities are greater, plus lesser mixing in rising parcels of greater velocities. However, for this explanation to hold, the size at which the peak in correlation is found should increases with altitude and this is not the case in the data so far examined. This dilemma can be restated as: Why do cloud droplet spectra at all altitudes contain droplets of the smallest detectable sizes? An instrumental artifact can not be completely ruled out as the cause, but it is not very likely either.

At the large end of the spectrum, the higher number of drizzle drops in association with greater vertical velocities may possibly be due to such parcels providing longer time for the coalescence process to be active and develop the larger drops. A definite weakness of this explanation is the low likelihood that vertical velocities are sufficiently steady-state for this effect to be realized. More difficult yet is to explain the paucity of the larger cloud droplets (those near 25 µm diameter) in upward moving air compared to downward moving air. Entrainment may come into play here but in yet undiscovered ways.

We have initiated additional analyses of the phenomenon described above. S. Gill will be focussing on the issue as the topic of his Ph.D. dissertation. The direction of the research at the moment is to stratify the data according to the direction of the vertical air velocity, identifying significant 'pulses' of various horizontal extents coincident with anomalies in the total drop concentration, or in LWC, or in some limiteed size range of the cloud droplet or drizzle drop population. The direction of the vertical velocity provides a first order association with uprafts and cloud formation on the one hand and entrainment and downdrafts on the other.

Another intriguing piece of evidence, indicating that a rather complex model will be needed to describe cloud base processes in stratus, is shown in Fig. 2 The diagram shows an example of the relationship between reflectivity, *Z*, and Doppler velocity in the vertical, for two altitude levels below cloud base and at two levels above it. Mean velocities are shown for each reflectivity value for a sample of 9.2 km horizontal extent. So far we have found the pattern depicted here to be general.

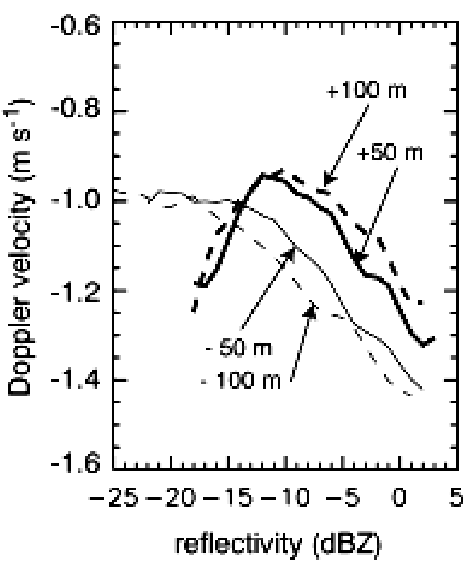

Fig. 2. Comparison of the relationship between reflectivity and Doppler velocity at different altitudes near cloud base.

In the absence of vertical air motions and for normal drop spectra, a monotonic relationship would be expected: greater reflectivities would correspond to greater fall velocities. While this appears to be the case below cloud base, the relationship has a pronounced peak and a reversal in slope for low reflectivities just above cloud base. This range of reflectivities constitute about 25% of the total sample. Clearly, the finding presents a perplexing question regarding how to imagine the entry of air from below cloud base into the cloud and the modeling of the CCN to droplet transition. Observationally, the pattern in Fig. 2 represents the transition from negative to positive correlations between reflectivity and Doppler velocity, as shown in Fig. 7 of V98.

Since the reflectivity ascribable to cloud droplets within 100 m of cloud base is less than -25 dBZ (cf. Fig. 6 in V98), a 'closed' parcel of air moving vertically from below cloud base to above, or vice versa, would have no noticable change in reflectivity for the observed values shown in the figure. In that sense, reflectivity can be considered a virtual tracer for small altitude changes across cloud base. Using that notion, the meaning of Fig. 2 seems to be the following: For $Z > -13$ dBZ, the slower fall velocity above cloud base could be a consequence of parcels getting lifted above cloud base and accelerating upwards due to the buoyancy associated with condensation. For this same region in Z, the process may be one of moving from above cloud base to below with an accompanying reduction in Z due to evaporation and an increase in the downward velocity. Either explanation is plausible. However, it is difficult to imagine why parcels with $Z < -13$ dBZ would have greater downward velocities above cloud base than below.

The foundation of the dilemma with respect to condensation in stratus is the applicability of ideas connected to parcels getting lifted across cloud base so that the theoretical link between CCN, updraft velocity and the resulting cloud droplet concentrations remain valid. The absence of organized updrafts argues against that model, but the near-adiabatic LWC profiles give it strong support. The statistical comparison of Snider et al. (2000) also appears to validate the idea. However, the two aspects of observations described here raise serious enough questions about the model to indicate that some elaboration of the basic model is definitely needed.

We intend to pursue the question with further analyses of the data already in hand, as well as with new data to be collected in the DYCOMS II experiment. The prospect of having two-dimensional motion fields from the radar instead of just the vertical component promises significant additional clarification of the processes. Also, the different cloud regime of the DYCOMS data set will provide a helpful dimension to the study.