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Large-scale Variability in Marine Stratocumulus Clouds Defined from Simultaneous Aircraft and Satellite Measurements

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Satellite images often show significant variations in the structure of marine stratocumulus clouds on scales ranging from 10 km to 1000 km. This is illustrated in Fig. 1 where a GOES West satellite image shows a well-defined variation in cloud structure near 32 N, 122 W on 30 June 1987. Aircraft measurements were made with the UK C-130 and the NCAR Electra on this day as part of the FIRE Marine Stratocumulus IFO. The UK C-130 made measurements in a solid cloud area at approximately 32.5 N, 123.5 W and just north of a more textured cloud area sampled by the Electra at approximately 31 N, 122 W. In this paper we compare the mean, turbulent, and the microphysical structure of the clouds sampled in these two areas and attempt to explain the differences in cloud structure at regions E and B in Fig. 1.

The two aircraft used in this study were comparably instrumented and both flew along-wind and cross-wind legs of about 60 km in length at several levels in the boundary layer to make estimates of turbulent quantities. Mean profiles of temperature, mixing ratio, winds, and microphysical quantities were obtained during slow ascents and descents.

In an attempt to identify any systematic differences between the measurements made with the two aircraft, we analyzed data that were collected on 14 July 1987 with the C-130 and the Electra flying in close formation at an altitude of 250 m. In general, both the mean and the standard deviation of the temperature, moisture, pressure and the sea surface temperature were in good agreement during the intercomparison. The mean temperature from the two aircraft differed by about 0.2°C and the mixing ratio differed by about 0.1 g/kg.

The mean flow in the regions sampled by the C-130 and the Electra on 30 June was weak. A 1028 mb high was centered about 1500 km west of the Oregon and Washington coast and resulted in relatively weak pressure gradients off the coast of southern California (Kloesel et al., 1988). Boundary layer winds were about 4 m/s from the northwest. The sea surface temperature was about 18°C in the area of the Electra compared with 16°C at the more northerly location of the C-130. These differences in temperature are reflected in the potential temperature profiles made during the early part of the mission (1100 LST) shown in Fig. 2. The boundary layer temperature at the Electra's location is about 2°C warmer than that at the C-130. The C-130 sounding is about 1-1.5 g/kg drier than the Electra as shown by the mixing ratio profiles in Fig. 3. Although the cloud thickness is about the same in the two regions,

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the cloud liquid water content measured from the C-130 is about 0.2 gm^{-3} greater than that measured with the Electra (Fig. 4). Soundings taken later in the experiment from 1600-1800 LST show similar differences in the boundary layer temperature and moisture (Fig. 5 and 6).

The thermodynamic structures at the two locations are similar. The inversion is at a height of about 900 m at both sites and varies little with time. The air just above the inversion, however, is drier in the area sampled by the Electra than it is in the area sampled by the C-130. This results in a 10 K decrease in equivalent potential temperature (THETAE) across the inversion in the Electra sounding with no jump in THETAE at the inversion for the C-130. A well-defined moist layer extends from about 1250-1750 m in the C-130 sounding. This moist layer is capped by a weak inversion. Evidence of a moist layer is also present in the Electra sounding. These soundings indicate that the relatively complicated moisture stratification above the inversion on this day appears to have a large areal extent.

The soundings at both locations show a stable layer at about 450 m, which indicates some decoupling (Nicholls, 1984). This stable layer is better defined later in the day (Fig. 5), which is consistent with the diurnal variations described by Nicholls. Although small cumuli were observed beneath and sometimes penetrated into the main stratus deck in both areas sampled, the stable layer is better defined in the Electra sounding than in the C-130 sounding. Lidar observations from the Electra indicate a cumulus cloud base near the weak stable layer at 450 m, which is about 200 m below the stratus deck. In addition, the moisture structure clearly shows the decoupling (Fig. 6). The lower layer is shallower in the late afternoon sounding than in the earlier sounding. This may be due to the moistening of the low levels and a drying of the cloud layer associated with the decoupling.

The microphysical and turbulence data are being compared in an attempt to explain the differences in the cloud liquid water content obtained with the two aircraft and the differences in cloud structure shown by the GOES image. In addition, data are being analyzed for three other days during the experiment when coordinated downstream flights were made with the Electra and the C-130.

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References:

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Nicholls, S., 1984: The dynamics of stratocumulus: Aircraft observations and comparisons with a mixed layer model. Quart. J. Roy. Meteor. Soc., 110, 783-820.

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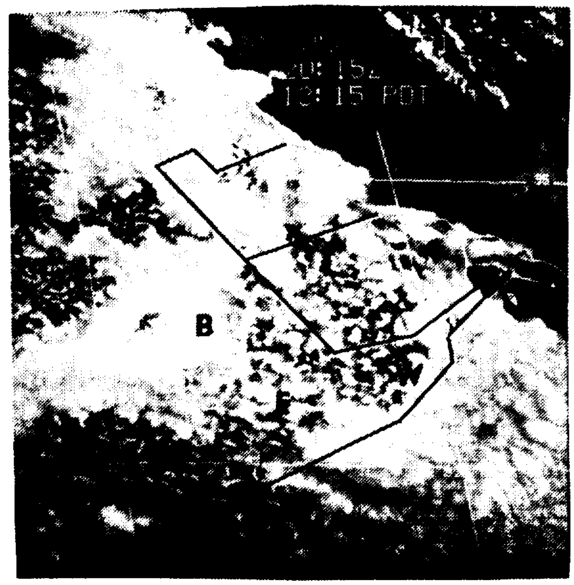

Figure 1. GOES West visible image for 30 June 1987 at 2015 UTC. The 'B' marks the general area sampled by the UK C-130 and the 'E' marks the region sampled by the NCAR Electra.

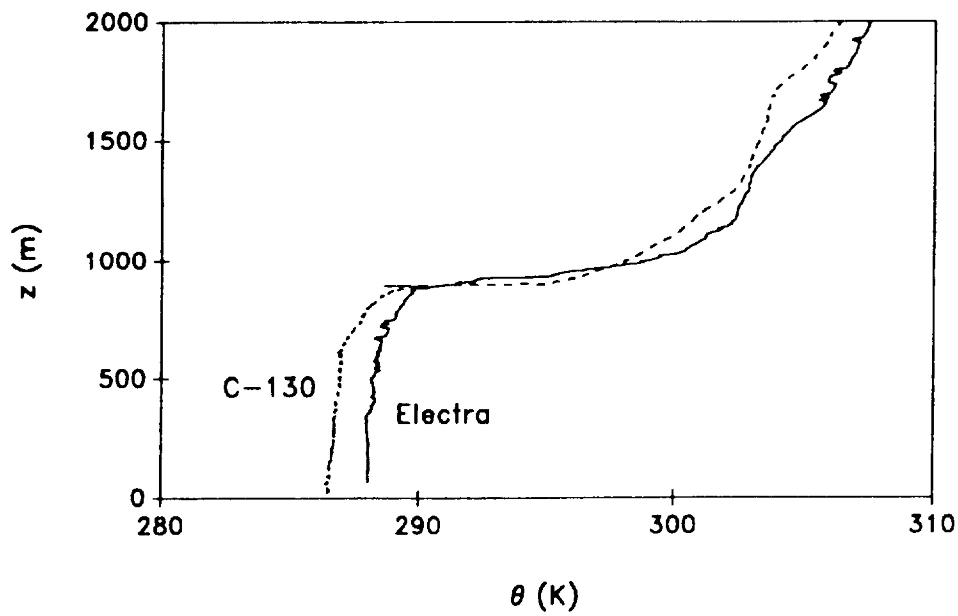

Figure 2. Potential temperature profile from the C-130 at approximately 9:45 UTC and the NCAR Electra at approximately 19:10 UTC on 30 June 1987.

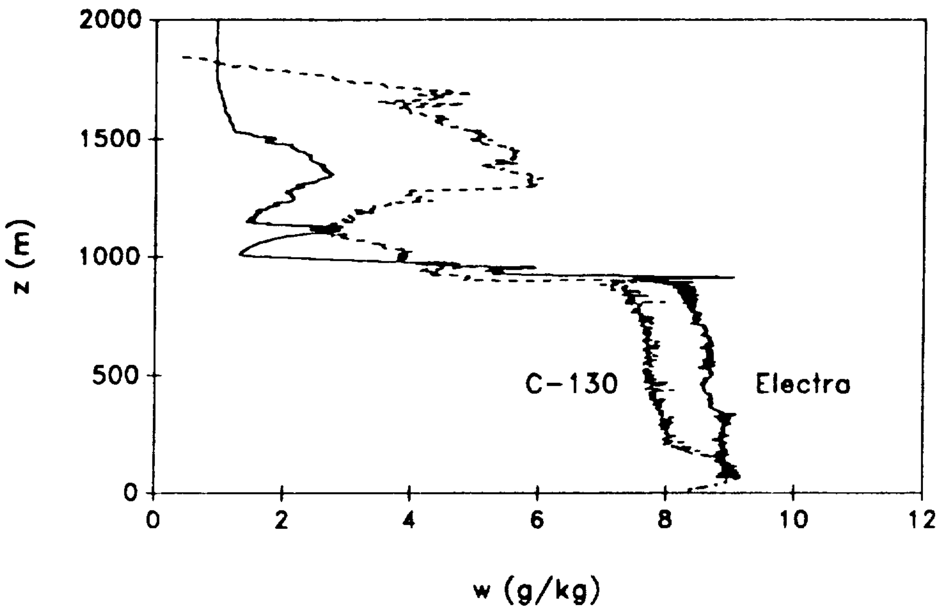

Figure 3. Same as Fig. 2 but for mixing ratio.

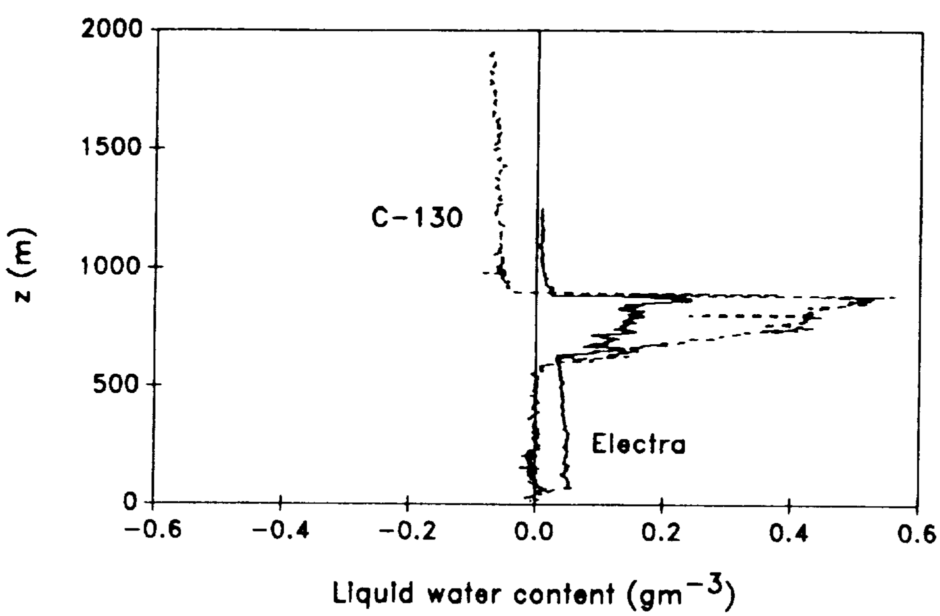

Figure 4. Same as Fig. 2 but for liquid water. Offsets have not been removed.

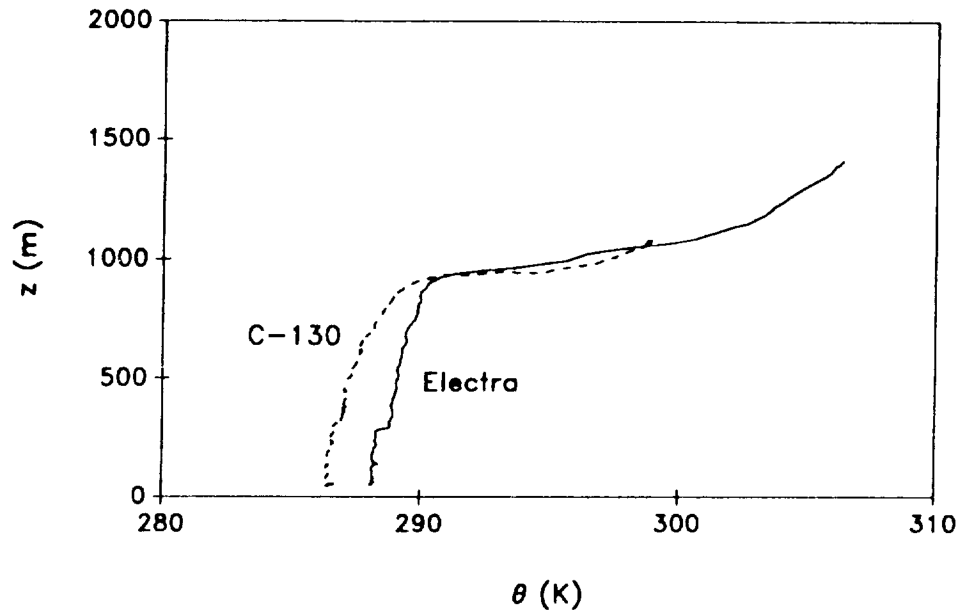

Figure 5. Potential temperature profile for the C-130 at approximately 22:35 UTC and the NCAR Electra at 23:29.

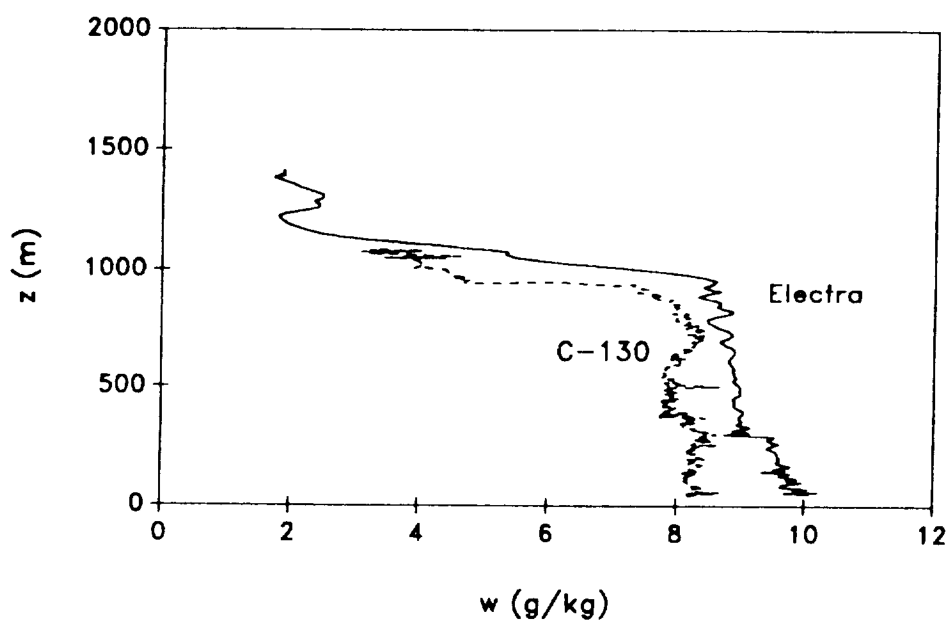

Figure 6. Same as Fig. 5 but for mixing ratio.