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AIRBORNE DOPPLER RADAR OBSERVATIONS OF GUST FRONTS AND MID-LEVEL INFLOW IN COARE MESOSCALE CONVECTIVE SYSTEMS

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1. INTRODUCTION

Mesoscale convective systems (MCS's) are composed of an ensemble of thunderstorms, which form a cloud system with separate convective and stratiform precipitation regions. Two important circulation features associated with these systems are the gust front and mid-level inflow. The gust front is a sloping interface between convective inflow and outflow; the mid-level inflow transports air of low moist static energy into and across the stratiform precipitation region. Often the mid-level inflow enters from the rear of the system, and sometimes it takes the form of a rear inflow jet (e.g., Smull and Houze 1987). The gust front can affect the intensity and lifetime of convection (e.g., Rotunno et al. 1988). The mid-level inflow can influence the gust front circulation and thereby impact the system evolution, especially if it extends to the convective region (e.g., Weisman 1992). The gust front and mid-level inflow both participate in the fluxes of heat, moisture and momentum across the ocean-atmosphere interface and throughout the atmosphere.

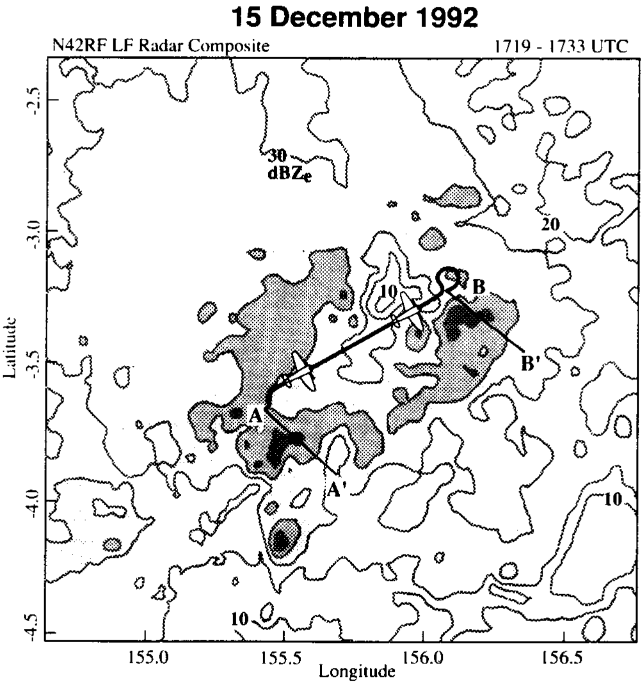

Figure 1. Reflectivity composite from the NOAA WP-3D N42RF lower fuselage radar for the period 1719-1733 UTC on 15 December 1992. The 10, 20, 30 and 40 dBZ_e contours are plotted with values greater than 30, 40 and 45 dBZ_e filled with light, medium and dark shades of gray respectively. The aircraft track for this time period is superimposed along with cross sections A-A' and B-B' referenced in Fig. 3.

Airborne Doppler radar data collected by two NOAA WP-3D aircraft during the Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Research Experiment (COARE) document both gust fronts and mid-level inflows of MCS's over the western tropical Pacific warm-pool region. Our analysis combines high radial resolution (75-150 meters) reflectivity and Doppler velocity data and lower resolution (1000-1500 meters) three-dimensional wind syntheses. This paper attempts to summarize gust front and mid-level inflow features observed throughout the experiment.

2. SLOPING CONVECTION

The spectrum of convection in COARE (Mapes and Houze 1993) was similar to that in GATE in that it was dominated by MCS's exhibiting discretely propagating, non-squall characteristics (Houze and Betts 1981). Figures 1 and 2 show examples of this type of structure. The large

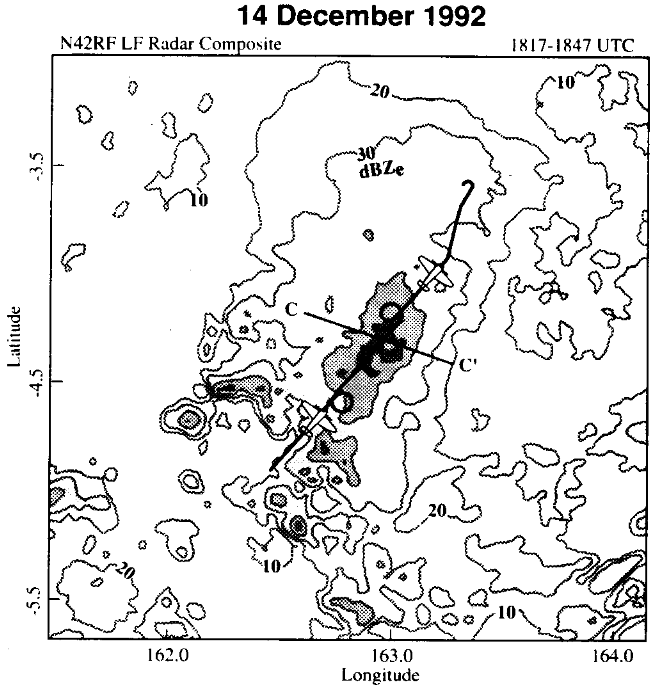

Figure 2. Same as Fig. 1 except for the period 1817-1847 UTC on 14 December 1992. Cross section C-C' is referenced in Fig. 4.

areas of stratiform precipitation occurred by successive formation and decay of the often irregularly arranged convective regions (Leary and Houze 1979). The airborne Doppler radar data suggests that COARE MCS's contained organized, sloping gust front interfaces separating convective inflows and outflows. Organized, mid-level inflows passing through large extents of stratiform precipitation regions were also frequently observed. These phenomena, which have been more commonly associated with continuously propagating, squall-line systems, appear to be an important component of the discretely propagating systems observed in COARE.

Two examples of gust-front interfaces along the SW-NE oriented precipitation region in Fig. 1 demonstrate the three-dimensional nature of COARE MCS's (Fig. 3). Vertical cross-section A-A' shows inflow coming from a primarily southerly direction (i.e., the light gray region in Fig. 3b) while B-B' shows inflow coming from a primarily northerly direction (i.e., the black region in Fig. 3d). In other words, the gust fronts in these two cross-sections are tilted in nearly opposite directions. It is unclear what ramifications this complex type of structure may have on the momentum transport properties of COARE MCS's.

The slopes and echo tops associated with these two gust fronts are quite similar (cf. Fig. 3a and c). Data obtained throughout the experiment show that the deepest convection was associated with the most erect gust front interfaces, a result consistent with the vorticity concepts discussed by Rotunno et al. (1988). One way that this result became evident was through the evolution of the convection. As an area of convection evolved through its mature and decaying phases, its depth decreased and the slope of the associated gust front decreased (i.e., became less and less erect). Significant increases (decreases) in the depth of convection and in the slope of gust front interfaces were observed over distances as small as 5-10 km.

3. MID-LEVEL INFLOW

A typical example of a mid-level inflow in COARE is provided in Fig. 4 and is associated with the large region of stratiform precipitation in Fig. 2. A narrow band of easterly momentum begins on the eastern edge of the precipitation region at ~6 km altitude (the light gray shading in Fig. 4b) and, proceeding westward, gradually descends through the bright band (cf. Fig. 4a) to ~3km altitude. Although not clearly evident in this cross-section, most mid-level inflows in COARE began at the bases of anvil echoes on the periphery of precipitation regions. Some mid-level inflows descended to the surface while others descended only a short distance and remained elevated (such as in Fig. 4b). Elevated inflows were not observed close to regions of active convection. There were also instances where the inflow would be restricted to the edge of a stratiform precipitation region.

The magnitude of horizontal motion for the inflow in Fig. 4b approaches 12 m s^{-1}. It was not uncommon to observe mid-level inflows with magnitudes as high as

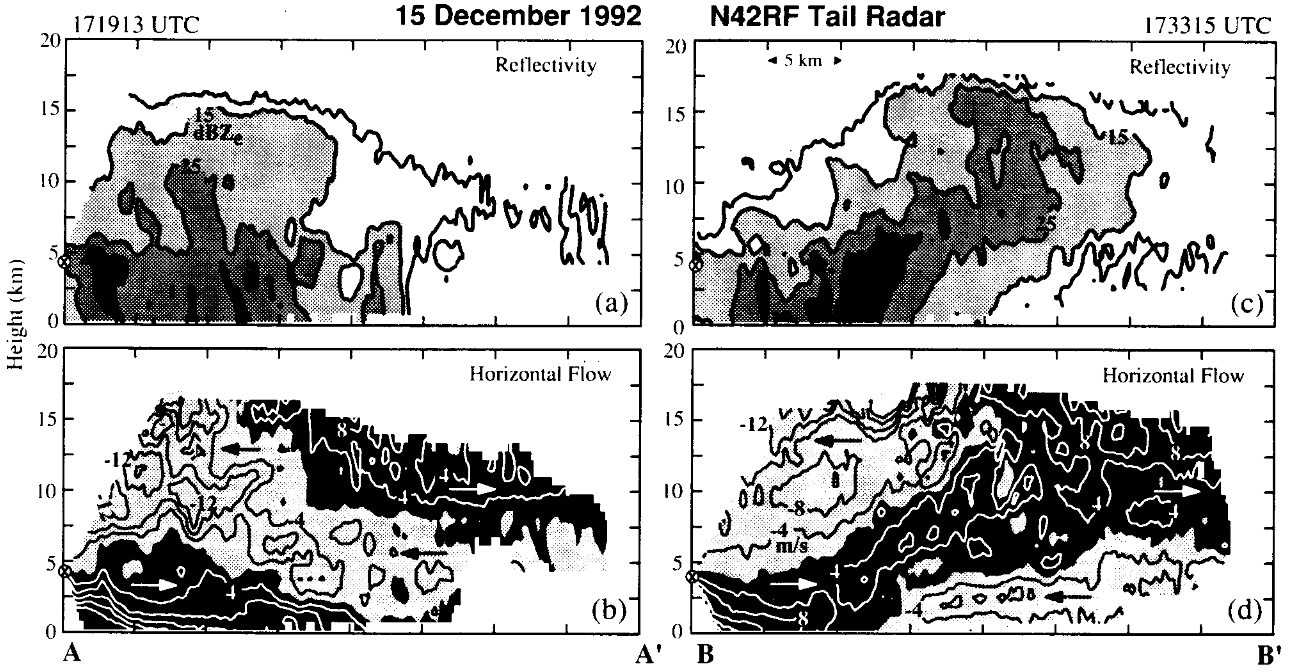

Figure 3. Reflectivity and horizontal flow (the horizontal component of radial velocity) from individual scans of the NOAA WP-3D N42RF tail Doppler radar for 171913 UTC (a,b) and 173315 UTC (c,d) on 15 December 1992. Reflectivity is contoured at 5, 15, 25 and 35 dBZ_e. Light gray, medium gray, dark gray and black shading correspond to each of these levels, respectively. Positive values of horizontal flow (motion left to right) are shaded in black with white contours at 4 m s^{-1} intervals starting at 4 m s^{-1}. Negative values of horizontal flow (motion right to left) are shaded in light gray with black contours at -4 m s^{-1} intervals starting at -4 m s^{-1}. The location of the aircraft/radar is indicated by a ⊗ while the orientation of the scans (A-A', B-B') with respect to the horizontal reflectivity structure is shown in Fig. 1.

15-20 m s^{-1}. Considering the slowly propagating nature of COARE MCS's, this result suggests that system relative inflow strengths were greater than those shown by sounding data in the vicinity of tropical oceanic convection (Smull and Houze 1987).

The relationship between mid-level inflows and the air motions below them exhibited two modes. For some cases (such as in Fig. 4b), the low level airflow opposed that of the mid-level inflow. In that particular case, the strongest mid-level easterly momentum overlaid the strongest low level westerly momentum. For other cases, the low level air motions were in approximately the same direction as the mid-level momentum.

Given the three-dimensional complexity of COARE MCS's, it is unclear whether the commonly used term "rear inflow" is an accurate description for the mid-level inflows observed during the experiment. A related question deals with the forcing mechanisms of mid-level inflows in COARE. Past studies of mid-latitude MCS's (e.g., Smull and Houze 1987; Weisman 1992; Yang and Houze 1995) have suggested that a combination of buoyancy generated pressure minima in both convective and stratiform precipitation regions is the critical forcing mechanism for rear inflow jets. However, these studies were associated with highly organized, squall-line systems. The relative importance of the convective and stratiform pressure minima for mid-level inflows in the less organized, COARE MCS's may be different.

4. CONCLUSIONS

Within some MCS's in COARE, channels of inflow air in adjacent convective regions sloped upward but in opposite directions. This definitive observation presents a confused picture of convective momentum transport. Mid-level inflow channels were strong and extensive but not always entering on the rear side of an MCS.

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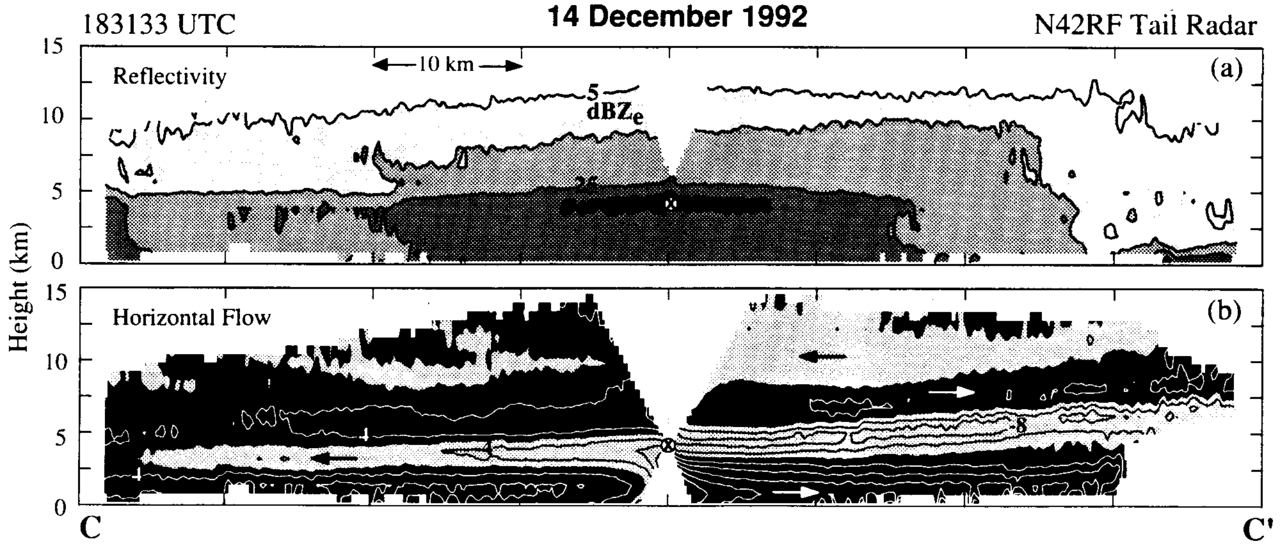

Figure 4. Same as Fig. 3 except for 183133 UTC on 14 December 1992. The orientation of the scan (C-C') with respect to the horizontal reflectivity structure is shown in Fig. 2.