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THE STRUCTURE OF VERTICAL DRAFTS IN NOCTURNAL OCEANIC TROPICAL CLOUD CLUSTERS OBSERVED DURING EMEX

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1. INTRODUCTION

The Equatorial Mesoscale Experiment (EMEX) was conducted in the northern Australian region during January-February 1987 with the specific objective of diagnosing the convective and mesoscale vertical circulations within tropical cloud clusters and deducing the atmospheric diabatic forcing by these organized precipitation systems. This paper describes the vertical velocity structures observed in some of the tropical cloud clusters sampled during EMEX.

2. DATA AND METHODS OF ANALYSIS

The data were collected using the tail Doppler-radar of the NOAA WP-3D aircraft during 70 km long (about 9 min) V-shaped flight legs through the convective and stratiform regions of the cloud clusters. The data have been used in two modes to estimate the vertical velocities.

First, the radar beams at vertical incidence (VI) have been arranged into x-z cross sections of radar reflectivity and particle vertical velocity along the flight track. Approximately 70 cross sections have been examined, representing four of the ten flight missions during EMEX. These cross sections have horizontal resolution of 850 m and vertical resolution of 150 m. Using fallspeed-reflectivity relationships for rain and snow, vertical air velocity fields have been obtained, with an uncertainty of about 1 m/s (Atlas et al, 1973).

In the second technique, pseudo-dual-Doppler analysis, data from consecutive flight legs have been combined, initially assuming no vertical motion, to yield horizontal velocities. (Jorgensen et al., 1983). Divergence was then calculated from these winds and integrated downward using the anelastic continuity equation to give a vertical velocity field. The horizontal winds were adjusted and new divergence and vertical velocity fields were calculated. This procedure was iterated until the mean of the absolute value of the changes in the horizontal winds were less than 0.1 m/s at each level. During the integration of the divergence field, upper boundary conditions of $w = 0.25$ m/s in the convective analysis and $w = 0.1$ m/s in the stratiform analysis were assumed. In addition, the condition $w=0$ at the sea surface was enforced; residual mass flux at the surface was distributed through the depth of each grid column in proportion to an estimate of the uncertainty of the dual-Doppler winds at each height. (Biggerstaff et al. 1988).

3. RESULTS

3.1 Convective Region

Figure 1 shows a vertical incidence cross-section of radar reflectivity in dBZ and calculated vertical air velocity (w) from a flight leg through intense convection Here, the aircraft flew beneath a 10 km wide region of upward motion extending from 10 to 16 km above mean sea level (MSL) with a maximum value of 14 m/s at 13 km. This updraft was apparently embedded in downward moving air with a peak value of -6 m/s at 9 km. The updraft was above a tower of high reflectivity, indicating heavy precipitation.

While this cross-section has one of the most intense vertical drafts seen in the VI analyses, it illustrates some features which were quite typical in other VI cross-sections. First, the strongest vertical drafts in many of the intense convective regions sampled were observed at upper levels. The magnitudes of these drafts were typically 5 to 10 m/s . Secondly, strong downdrafts were frequently observed adjacent to the updrafts, even at upper levels. Thirdly, vertical drafts at upper levels tended to be broader than drafts at lower levels. However, this might reflect sample bias since the aircraft did not fly through the most intense reflectivity cores at flight level.

Deep continous drafts with absolute values of w larger than 1 m/s have also been observed, including an updraft 10 km in width from 0 to 14 km MSL, with a peak value of 12 m/s at 10 km MSL, and a downdraft 12 km in width from 0 to 15 km MSL, with a peak value of -10 m/s at 14 km MSL. However, other VI cross-sections show numerous narrower and weaker vertical drafts, similiar to those observed at flight levels by LeMone and Zipser (1980). Almost all significant vertical drafts were near some extremum in the reflectivity field, but no simple relationship between the spatial distributions of vertical velocity and reflectivity is apparent.

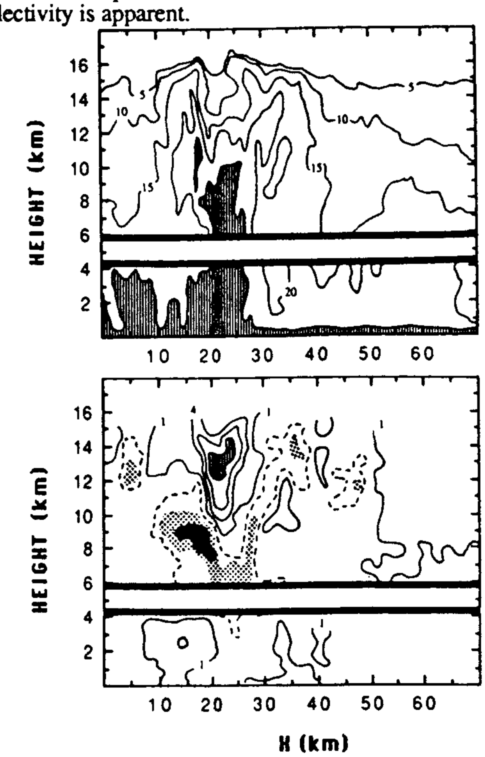

FIG. 1. Vertical incidence radar cross section from 2052 to 2101 UTC 29 January 1987. No data is available in the strip from 4-6 km. (a) Radar reflectivity, with contour interval 5 dBZ. Hatched area denotes > 25 dBZ. (b) Vertical air velocity w, assuming terminal fallspeeds from Atlas et al (1973) for snow (1-3 m/s) and rain (6-8 m/s). Solid contours are 1, 4, 7, 10 m/s. Hatched area denotes w >10 m/s. Dashed contour is -1 m/s, stippling denotes areas of w < -2 m/s, heavy stippling denotes w < -4 m/s.

Results from a pseudo-dual-Doppler analysis in the convective region of the 2-3 February 1987 cloud cluster show up and down drafts with maximum vertical velocities of 10 to 15 m/s, in accordance with the VI results in other cloud clusters. The pseudo-dual-Doppler technique has horizontal resolution of about 4 km, much coarser than the VI technique, and relies on observations taken several minutes apart. But deep, wide, nearly vertically oriented vertical drafts are apparent in the strong reflectivity regions of these analyses, again in apparent agreement with the VI results. In-cloud mean upward motion within the most active 20 km X 20 km subdomain of the analysis region peaks smoothly at 7.5 km MSL with a maximum of about 1.4 m/s (see Fig. 2).

3.2 Stratiform Region

In other studies (for a review see Houze, 1989) the maximum value of the mean vertical air velocity (w) in stratiform areas has been found to be on the order of 0.1 m/s. This is much smaller than the uncertainity in absolute estimates of w from the VI technique. However, horizontally averaged raw Doppler velocities do indicate that downward particle vertical velocity above the freezing level of the anvil cloud decreases with height. This is consistent with a mesoscale updraft, possibly increasing with height, and vertical divergence of the ice particle fall velocity as the condensate falls out. In addition, spatially coherent variations in vertical velocity with magnitudes of 0.5 to 1.0 m/s were observed in the precipitating stratiform anvils. These cellular structures could be the remnants of decaying convective cells, or overturning as a result of instability released whenever the lapse rate became super-moist-adiabatic, or they could represent microphysical variation in particle fallspeeds.

Results from a pseudo-dual-Doppler analysis in a decaying portion of the stratiform region of the 2-3 February 1987 cluster show a mid-level peak in the mean convergence, deep mean downward motion below 7 km, and a weak mesoscale updraft aloft (Fig 2). The weakness of the upper-level mesoscale updraft in this case may reflect the decaying stage of the precipitation, or merely the lack of radar coverage above 10 km, where divergence may have been significant. Other analyses in deeper, more vigorous stratiform precipitation areas will help clarify this point.

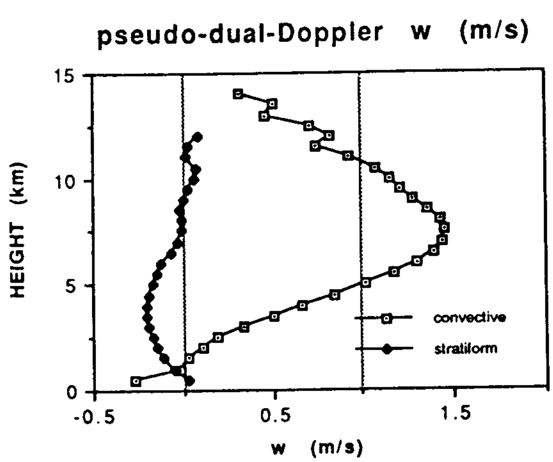

FIG. 2. Mean profiles of pseudo-dual-Doppler vertical air velocity for convective (~20 km X 20 km) and stratiform (~40 km X 40 km) areas, from the cluster of 2 February 1987.

4. CONCLUSIONS

Airborne Doppler-radar data in the convective areas of tropical cloud clusters show deep, broad up and down drafts with peak vertical motions around 10 m/s. The strongest drafts have been observed at upper levels. Upper-level downdrafts, stronger than the uncertainity in the particle fallspeeds, were frequently observed in intense convective regions. These strong upper-level up and down drafts may play an important role in the heat budget of tropical cloud clusters.

Both pseudo-dual-Doppler and Vertical Incidence (VI) methods of analysis show qualitatively similiar vertical velocity structures. However, the VI method has much better spatial and temporal resolution and thus shows some narrower drafts than those obtained from the pseudo-dual-Doppler method.

Areas of stratiform precipitation showed a midlevel maximum in convergence and significant horizontal variations in particle vertical velocity, suggesting that these "stratiform" rain areas may contain weak convective circulations.

5. ACKNOWLEDGEMENTS

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