1. INTRODUCTION

The Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE) provided the opportunity to observe mesoscale convective systems (MCSs) in the tropical Western Pacific Ocean. Previous studies have shown that the driving force of global circulation is the result of latent heat released during the formation of tropical precipitation (Simpson et al. 1988). One of the goals of TOGA COARE was to determine and understand MCSs in the tropical Pacific Ocean (TOGA COARE Operations Plan, 1992).

MCSs are generally composed of two precipitation types, convective and stratiform. Precipitation type plays an important role in the vertical transport of heat, moisture, and momentum in the atmosphere. To estimate budgets for these parameters, a detailed analysis of the vertical structure is required. This paper uses high resolution radar data collected during TOGA COARE to estimate representative vertical reflectivity structures for convective and stratiform precipitation over a large range of rainfall intensities.

2. RAINFALL AND VERTICAL REFLECTIVITY STRUCTURE DATA

During the Intensive Observing Period (IOP) (November 1992-February 1993) of TOGA COARE, two shipborne 5-cm Doppler radars collected high temporal (10 min) and spatial (250 m) resolution three-dimensional reflectivity, Doppler velocity, and spectral width data. The NASA TOGA radar was on board the People’s Republic of China’s R/V Xiangyanghong 5 (PRC #5) and the Massachusetts Institute of Technology (MIT) radar was on board the USA R/V John V. Vickers. Except for a few days for port calls, at least one radar provided continuous sampling of precipitation structures during TOGA COARE. When both radars were deployed in the Intensive Flux Array (IFA), the ships were separated by 150 km (W-E), which provided a sampling area of approximately 400 km (W-E) by 300 km (N-S).

Reflectivity data from the shipborne radars were used to generate the products analyzed in this study. Polar reflectivity data were converted to rainfall rates using a reflectivity-rainfall relationship based on a study by Tokay and Short (1996). Rainfall rate estimates were then transformed into a 2km x 2 km fixed-Earth Cartesian grid. When both radar datasets were available, the rainfall fields were merged. Convective and stratiform precipitation components were determined from the rainfall maps using a modified texture algorithm developed by Steiner and Houze (1993). A detailed description of the techniques and results of the rainfall analysis can be found in papers by Short et al. (1995) and Kucera et al. (1995).

To determine vertical structure of reflectivity, the polar reflectivity data were transformed into Constant Altitude Planned Position Indicators (CAPPIs). CAPPIs were generated at eight height levels (1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.5, and 6.0 km) using a nearest-neighbor sampling scheme. CAPPIs were processed into the same Cartesian grid used in the rainmap generation. Vertical reflectivity profiles were extracted only when they were within 60 km range of the radar. This was done to achieve high resolution sampling at each level.

Vertical reflectivity profiles were partitioned into convective and stratiform components and then further categorized by rainfall intensities. For each grid point that contained a rainfall rate value, a vertical reflectivity profile was extracted from the CAPPIs. Convective/stratiform and rainfall maps were used to categorize vertical reflectivity profiles by precipitation type. In the last step, profiles were separated by rainfall intensity, and the mean profile was calculated for each rainfall intensity. For our study, we only used profiles that contained valid data at all eight height levels. The following section provides the results of our vertical reflectivity profile study from the shipborne radar dataset.

3. ANALYSIS OF VERTICAL REFLECTIVITY STRUCTURE

Vertical reflectivity profiles are shown in Figures 1 and 2 for stratiform and convective precipitation, respectively. In both figures, the mean reflectivity profile averaged over all rainfall intensities is shown by the dashed curve. The two precipitation regimes have remarkably different reflectivity profiles, which has also been shown in detail by Szoke et al (1986) for the GARP Atlantic Tropical Experiment (GATE).

In figure 1, stratiform reflectivity profiles shown are for rainfall intensities ranging from 0.25 mm/hr to 6.0 mm/hr. The mean reflectivity profile averaged over all rainfall intensities occurred at a rainfall rate of 3 mm/hr. In all the profiles, there is a distinct bright band (increased reflectivity due to melting hydrometeors) centered near a height of 4.5 km (~0°C), which is one of the characteristics associated with stratiform precipitation (Houze, 1993; DeMott et al., 1995; Steiner et al., 1995). Generally, the profiles indicate that reflectivity remains constant or increases slightly until reaching the bright band where the reflectivity increases up to a factor of 2-3 before decreasing rapidly above the bright band. At the higher rainfall intensities,
reflectivity decreases more rapidly with height. In general, stratiform reflectivity profiles have similar characteristics over a broad of range rainfall intensities.

Figure 1: Estimated stratiform reflectivity profiles observed by the shipborne radars during TOGA COARE. Profiles (solid lines) are for rainfall rates of (left to right) 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0, respectively. The mean stratiform profile is indicated by a dashed line, which occurred at a rainfall rate of 3 mm/hr.

Figure 2 shows how convective reflectivity profiles vary with rainfall intensities ranging from 1.0 mm/hr to 128 mm/hr. The mean convective profile occurred at a rainfall rate of 68 mm/hr. The convective profiles have similar characteristics except under light rainfall rate conditions. Reflectivity profiles for rainfall intensities of 1.0, 2.0, and 4.0 mm/hr have features similar to stratiform profiles. This is probably the result of moderate stratiform precipitation being classified convective precipitation, which may be an artifact of the convective/stratiform texture algorithm. Otherwise, convective profiles decrease in reflectivity with height at a rate of 1 dB/km except for the largest rainfall intensities. Our mean reflectivity profiles have similar characteristics to the profiles generated in a study by Szoke et al. (1986). They had calculated the mean reflectivity profile for 296 cells in GATE.

Sui et al. (1996) have been using the rainfall data set to determine the characteristics of rainfall in disturbed and undisturbed conditions during TOGA COARE. They defined disturbed conditions as when the area mean brightness temperature was less than 270 K and the standard deviation greater than 19 K. Otherwise, the conditions are considered undisturbed. Using Figure 2 of Sui et al. (1996), mean convective and stratiform reflectivity profiles were extracted for undisturbed (13-17 November, 29 November-4 December) and disturbed (20-29 December) conditions. The reflectivity profiles from these periods were compared to the overall mean profiles.

Figure 3 shows the mean convective and stratiform profiles for undisturbed conditions. The mean stratiform profile (dashed line) occurred at a rainfall rate of 2.8 mm/hr. The mean convective profile (solid line) occurred at a rainfall rate of 29.3 mm/hr. The plot shows that both the convective and stratiform profiles have convective characteristics. During undisturbed periods, most of the precipitation was generated by small isolated convection or in weak organized systems (Sui et al., 1996). Therefore, most of the precipitation that was categorized as stratiform was weak or dissipating convection. Because the precipitation during undisturbed conditions was weak and isolated, mean rainfall intensities were much lower than the overall mean.

Figure 3: Mean stratiform (dashed line) and convective (solid line) vertical reflectivity profiles for undisturbed conditions.

Mean convective and stratiform profiles for disturbed conditions are shown in Figure 4. The mean stratiform (dashed line) and convective (solid line) vertical reflectivity profile occurred at rainfall intensities of 3.0 mm/hr and 68.0 mm/hr, respectively, which is nearly the same as the overall mean. Therefore, these organized mesoscale systems that most often develop in disturbed conditions contribute the most to the total rainfall. Houze (1993) indicates that these systems account for over 90% of the total rainfall in the tropics. However, a recent study by Rickenbach (1993) shows that only about 75% of the total rainfall can be attributed to organized systems in TOGA COARE. In disturbed conditions, the mean stratiform profile has a
distinct bright band and the mean convective profile decreases with height at 1 dB/km, which is typical of MCSs. In summary, these highly organized systems, which occur mainly in a disturbed environment, contribute significantly to mean reflectivity profiles and total rainfall in the tropics.

Radar-derived mean convective and stratiform reflectivity profiles were also compared to vertical profiler data collected on Kapingamarangi Atoll in the South Pacific. Figure 5 shows mean stratiform reflectivity profiles generated from radar (solid line) and vertical profiler (dashed line) data. The two profiles agree very well at all levels below the bright band. The disagreement above this level is probably the result of lower vertical resolution of the radar beam, especially at the farthest ranges. Mean convective profiles are shown in Figure 6. Again, the convective reflectivity profiles have similar features but are offset by as much as 15 dB. The large separation in location of the instruments is probably the main factor for the large differences in the mean. The largest rainfall rate the vertical profiler sampled during TOGA COARE was about 58 mm/hr. On the other hand, shipborne radars observed rainfall rates over 200 mm/hr. Although the convective profiles differ in the mean, the method used to categorize convective and stratiform precipitation from radar data resulted in excellent agreement with the features of the profiles sampled by the vertical profiler.

4. SUMMARY AND CONCLUSIONS

This study is a first step in determining accurate estimates of the vertical reflectivity profiles for convective and stratiform precipitation. Stratiform reflectivity profiles had consistent characteristics over most rainfall intensities. The profiles were composed of nearly constant reflectivity below the bright band, an increase in reflectivity by a factor 2-3 within the bright band, and rapid decrease in reflectivity above the bright band. There was an indication that the reflectivity decreased more rapidly at the highest stratiform rainfall rates, which could be the result of more efficient aggregation of ice crystals. Convective reflectivity profile characteristics deviated more about the mean than stratiform reflectivity profiles. At the weakest rainfall intensities, the profiles had similar characteristics to stratiform profiles, which could be the result of an incorrect classification of the stronger stratiform precipitation. At the highest rainfall intensities, the profiles decreased rapidly with height, which is an indication that strong convective cores and wind shear were located in the lower levels.

Comparisons of the reflectivity profiles in undisturbed and disturbed conditions indicate that disturbed conditions contribute most to the mean profiles. Undisturbed conditions are characterized by isolated or weakly organized convection. This is reflected in the mean stratiform reflectivity profile, which doesn’t indicate a bright band under these conditions. In a disturbed environment, mean reflectivity profiles have distinct features that are found in organized MCSs. Differences in the mean reflectivity profiles for disturbed conditions are relatively small compared to mean reflectivity profiles for all conditions. This result will be an important factor when estimating latent heating of the atmosphere from tropical convection.

As seen in Figures 5 and 6, reflectivity profiles sampled from shipborne radars agreed well with vertical profiler data. Differences in the profiles

Figure 4: Same as Figure 3 except for disturbed conditions.

Figure 5: Mean stratiform vertical reflectivity profiles from the Kapingamarangi Atoll vertical profiler (dashed line) and shipborne radars (solid line) during TOGA COARE.

Figure 6: Same as Figure 5 except for mean convective vertical reflectivity profiles.
are probably due to limitations of the instruments and differences in sampling area.

In conclusion, the results of this vertical profile study agree with results from previous studies. One of the goals of TOGA COARE was to accurately estimate latent heating from mesoscale convective systems. The results of this study are an important step in achieving this goal.

5. ACKNOWLEDGMENTS

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6. REFERENCES


