8A.1 PROFILER RETRIEVED DSD EVOLUTION IN THE TROPICS AND MID-LATITUDES

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1. INTRODUCTION

In precipitation conditions VHF profilers simultaneously detect echoes from the clear air and from hydrometeors, with roughly equal magnitude. Simultaneous echo detection means VHF wind-profiling radars are excellent tools for rainfall studies, as clear-air and rainfall information can be retrieved with a single system. However, these systems are limited in the smallest retrievable raindrop size. VHF profilers can be used to study the vertical evolution of the drop size distribution (DSD) in the fall from cloud to ground. Understanding rainfall evolution and the associated dominant microphysical processes are important for quantitative precipitation estimation, and for deriving accurate scanning radar reflectivity-rain-rate relationships. The current study is concerned both with DSD evolution, and the examination of the DSD retrieved with different VHF wind profiling radars.

Data from profilers in the tropics and mid-latitudes have been analysed. Tropical data were collected in Darwin during the TWP-ICE campaign conducted in January and February 2006. Data were collected using a Boundary Layer Profiler (BLP), operating at 54.1 MHz. Mid-latitudes data are being collected at Buckland Park (BP), 36 km north of Adelaide. Buckland Park is the University of Adelaide's field site, and at the time of this study, operated both a BLP), and a Stratospheric Tropospheric Profiler (STP). Both profilers operate at 55 MHz. Rain events, particularly those which consist of continuous rain for an hour or more, pass over Buckland Park infrequently, and thus data collection is an on-going process.

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2. EQUIPMENT

2.1 DARWIN ARM SITE, NORTHERN TERRITORY, AUSTRALIA

Data from the tropics were collected in Darwin, in northern Australia, using an ATRAD Pty Ltd 24 element Yagi antenna array BLP, operating at 54.1 MHz. The system has a peak power of 7.5 kW. The profiler was installed in Darwin in 2005, to participate in the Tropical Warm Pool - International Cloud Experiment (TWP-ICE). The profiler is located next to Darwin airport, on an ARM (Atmospheric Radiation Measurement) mobile site. The ARM site is within the footprint of a C-band dual-polarisation scanning radar (CPOL). During TWP-ICE, CPOL completed a volume scan consisting of 17 tilts, and two RHI scans, one of which was over the profiler. This provided a unique opportunity to examine rain events, as seen by two systems, in a common volume.

The BLP array is arranged in 3 groups of 9 antennas, where each group is arranged on a 3 x 3 square grid, and the centre of each group forms the vertices of a triangle. The profiler estimates horizontal winds, in low and high modes, using the Spaced Antenna Full Correlation Analysis technique. Low mode raw data are used to retrieve DSDs, resulting in two minute resolution. The low mode uses a 750 ns length pulse, acquiring data with 100 m height resolution from 300 m up to 3400 m. The radar was limited by its acquisition system, and cannot sample more than these 30 range gates at this resolution.

2.2 BUCKLAND PARK, SOUTH AUSTRALIA, AUSTRALIA

Data from the mid-latitudes were collected at Buckland Park, South Australia. The BLPis very similar to the Darwin system, but operates at a slightly higher frequency (55 MHz), and has a peak power of 12.5 kW. For the purposes of this experiment, the BP BLP was operated in low mode only. The ST profiler is a Doppler Beam Steering system, and estimates winds from radial line of sight velocities. The antenna array consists of 144 Yagi antennas, arranged on a square 12 by 12 grid. The system is capable of measuring radials in the vertical, and all 4 cardinal directions at 15° offzenith. For the purposes of this study, the STP was run in low mode with a vertical beam only. This system routinely operates with a peak power of 40 kW. However, in August 2011, the system was upgraded to 80 kW for a 1 month period, during which two rain bands passed over the profiler site.

The instruments at BP present a unique opportunity to sample rain events with two different VHF profilers. The BLP, with a small footprint, has a beamwidth of ~30^{o}, while the STP, being a larger Doppler system, has a beamwidth of ~7^{o}. The major limitation in VHF DSD studies is the inability to resolve small drops, because the relevant portion of the precipitation echo is obscured by the clear-air peak. The clear-air peak is broadened both by turbulence, and through beam-broadening. The STP, with a smaller beamwidth than the BLP, will suffer less from beam-broadening, and therefore may be capable of retrieving smaller dropsizes.

The STP upgrade to 80 kW presents a unique opportunity to examine DSD retrievals with a higher power system. During the upgrade period, the STP ran two experiments, the first at full power (80 kW), and the second at half power (40 kW). This was done so that any power related differences could be observed in a single rain band.

Both of the BP profilers operate at 55 MHz, and must therefore operate in an interleaved fashion. Because both profilers operated single experiments to collect rainfall, the systems ran with two minute resolution as standard, and with a three minute resolution when the STP was upgraded to 80 kW.

3. METHOD

3.1 DSD RETRIEVAL METHOD

Well-established techniques exist for retrieving the DSD using vertically pointing VHF Doppler radars, e.g. Rajopadhyaya et. al. [1993], Cifelli et. al. [2000] and Lucas et. al. [2004]. These radars can simultaneously detect clear-air and precipitation echoes, with roughly equal magnitude. The clear-air peak is centered near 0 ms^{-1}, and is widened through beam broadening and turbulence effects within the sample volume. The precipitation echo is centered near -10 ms^{-1}, and is broadened by turbulence and shifted due to the clear air vertical motion. These effects are corrected through a deconvolution of the precipitation peak by the clear-air peak. To perform the deconvolution, the clear-air and precipitation peaks must first be separated into distinct functions. The peaks are first separated as close to the point of overlap as possible. The clear-air spectrum is then fitted with a Gaussian function, and an exponential tail added to the precipitation peak. This tail is used only to perform the deconvolution, and is not included in the resultant DSD, as it represents that part of the spectrum which cannot be resolved at frequencies near 50 MHz..

The clear air and precipitation functions are then deconvolved using either a parametric or direct deconvolution technique. The parametric method involves assuming a form for the DSD, such as a Gamma distribution. Varied parameters are input into the assumed form, and each solution is convolved with the clear-air spectrum. Nonlinear least squares curve fitting is then used to determine which set of parameters fits the observed spectrum best. An alternative approach is to perform a direct deconvolution using a Fourier transform, which has the advantage of not forcing the DSD to a particular form. This technique was first proposed by Gossard [1988], and used in studies such as Rogers et al [1993] and Rajopadhyaya et al [1993]. Schafer et al [2002] compared the two techniques, using a dual-frequency system, and concluded the direct method results in retrievals as good as or better than the parametric technique, particularly in the case of spectral widths greater than 2 ms^{-1}, or median drop diameters greater than 3 mm. While analytical forms of the DSD are useful because they can be integrated, they do not permit study of the evolution of the shape of the DSD. Since evolution is the focus of the current study, retrievals have been calculated using a Fourier transform deconvolution procedure.

As stated above, VHF profilers cannot detect small drops, despite their abundance, because the relevant part of the precipitation spectrum is obscured by the clear-air peak. Scatter from these small hydrometeors instead adds to the turbulence component of the clear-air [Rajopadhyaya, 1994]. The smallest retrievable drop in any given spectrum is then dependent on the atmospheric conditions under which the sample was taken. If the precipitation peak is large compared to the clear-air, such as is the case in heavy convective rainfall, smaller drops can be retrieved than in the case of mild stratiform conditions, where the precipitation echo is smaller. The effect of the missing small drops on the median drop diameter calculation was examined in a modeling study [Dolman, 2010]. As a result, a mapping function was created by analytically integrating a Gamma function, fitted to a retrieved DSD, holding $\mu = 1$. All median drop diameters presented in the current work have been corrected using this mapping function.

3.2 MICROPHYSICAL CLASSIFICATION

In Darwin, each event which passed over the profiler during TWP-ICE was retrieved, quality controlled and analysed. Storms were classified as occurring under a break or active monsoon regime, and sub-classified as stratiform, convective or transitional. Particular attention was given to storm evolution in time and height, as well as to changes in the microphysical processes affecting surface rainfall. Events were first placed in morphological context by examining consecutive CPOL PPI displays, and RHI scans were inspected to determine echo-top height and vertical structure; for example, evidence of a bright band. Profiler cross-sections of reflectivity, rainrate, liquid water content, median drop diameter and vertical velocity, in conjunction with the RHI, were used to classify convective, stratiform or transitional segments of the storm. By way of example, Figure 1 shows profiles of reflectivity measured by CPOL from consecutive RHI scans (top) and a BLP cross-section (bottom) of reflectivity, for a storm which passed over the profiler on 18 February 2006. Through inspection of these images, and in conjunction with consecutive PPIs, the storm has been classified as indicated by the legend between the images. This particular storm was a convective line, with trailing stratiform precipitation, separated by a transition region.

Average profiles in time were then taken through these segments, and examined for evidence of a dominant microphysical process.

When evaporation is the dominant process, the smallest drops evaporate first, and hence the median drop diameter will increase with decreasing height. Rainfall, on average, consists of many small drops and fewer large drops. Thus, if the smaller drops are evaporating, the water content will decrease. Since reflectivity is dependent on the sixth power of the diameter, it will only slightly decrease with the loss of small drops. When collision-coalescence is the dominant process, small drops are lost as they collide and merge with other drops, resulting in larger drops and hence an increase in the median drop diameter. The liquid water content does not change, but reflectivity will increase with the increased number of large drops. When break-up is the dominant process, the opposite of the collision-coalescence case is expected. The liquid water content will not change, but the reflectivity and median drop diameter will decrease with the decrease in large drops.

In Adelaide, data collection is on-going. The method used for determining microphysical process is the same as in Darwin, but it is not possible to compare the data with a scanning weather radar. Instead, retrievals from two different VHF profilers are compared.

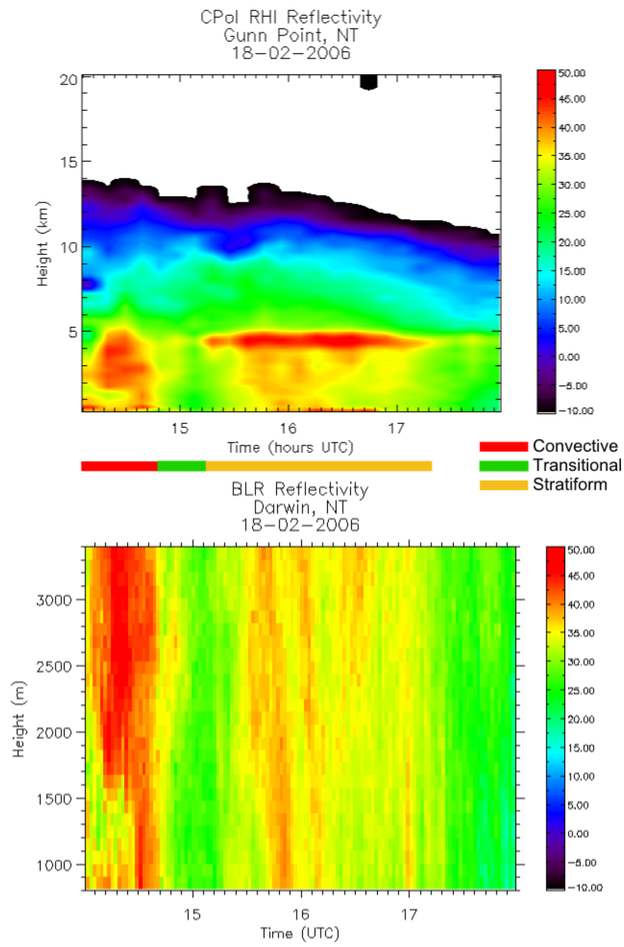

Figure 1 CPOL RHI (top) and profiler cross-section (bottom) of reflectivity. The storm has been classified as indicated by the legend between the images, and consisted of a convective line, with trailing stratiform precipitation, separated by a transition region. (note the difference in height scales)

4. RESULTS

4.1 DARWIN

As illustrated in Table 1, both the storm type and structure varied between the TWP-ICE sampled active monsoon and break conditions. Active monsoon storms were typically tropical squall lines with trailing stratiform precipitation, while storms sampled during the break were typically convective cells. It is seen from Table 2 that evaporation is the dominant process affecting DSD evolution. This is expected in stratiform regions, as evaporation drives the characteristic weak downdrafts. It is somewhat more surprising in convective regions, and is an important result in modeling both the total water reaching the surface and latent heat release.

It was found that in the transition regions (defined here as the section of the rainband between the convective core and the trailing stratiform precipitation) there was no evidence of a dominant microphysical process. Transition regions are thus true to their name, and are transitioning from precipitation caused by intense upwards motions in convective regions, to that resulting from melting ice particles aloft in the stratiform region. It was also found that transition regions were characterized by median drop diameters between 0.7 and 1.0 mm. Given transition regions are characterized by low reflectivity, it is not surprising that only small drops were retrieved here.

	Date	Storm Type
Monsoon	05/01/06	Squall line with trailing stratiform precipitation
	19-20/01/06	Squall line with trailing stratiform precipitation
	22/01/06	Stratiform rainfall
	23/01/06	Squall line with trailing stratiform precipitation
Break	07/02/06	Convective burst with small region stratiform precipitation
	10/02/06	Stratiform rainfall
	16/02/06	Convective burst
	18/02/06 (1)	Convective burst
	18/02/06 (2)	Leading convective line with trailing stratiform precipitation

Table 1 Storm description for all storms which passed over the Darwin BL during TWP-ICE

	Date	Dominant Process
Build-up stratiform	05/01/06	Evaporation
Build-up convective	05/01/06	Evaporation
Monsoon stratiform	19-20/01/06	Evaporation
	22/01/06	Equilibrium-like
	23/01/06	Collision-coalescence
Monsoon convective	19-20/01/06	Evaporation
	23/01/06 (1)	Evaporation
	23/01/06 (2)	Evaporation
Break stratiform	07/02/06	Evaporation
	10/02/06	Evaporation
	18/02/06 (2)	Evaporation/Break-up
Break convective	07/02/06	None
	16/02/06	Evaporation
	18/02/06 (1)	Evaporation
	18/02/06 (2)	Evaporation/Break-up

Table 2 Dominant microphysical process for all storms which passed over the Darwin BL during TWP-ICE

The following figures show the median drop diameter from all storms as a histogram, separated first into monsoon and break regimes, and then into stratiform and convective rainfall.

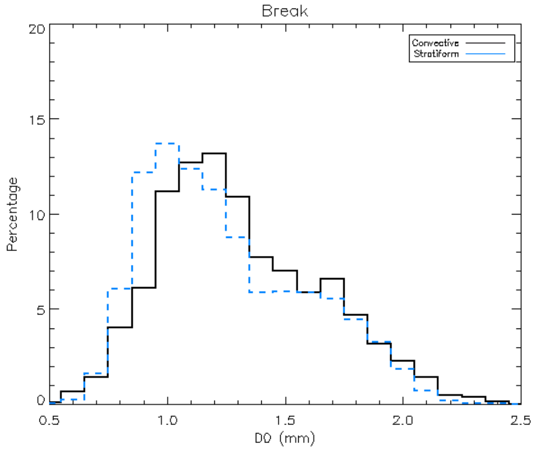

Figure 2 Median drop diameter histogram of all storms which occurred under a break regime, separated into convective (black) and stratiform (blue) storms

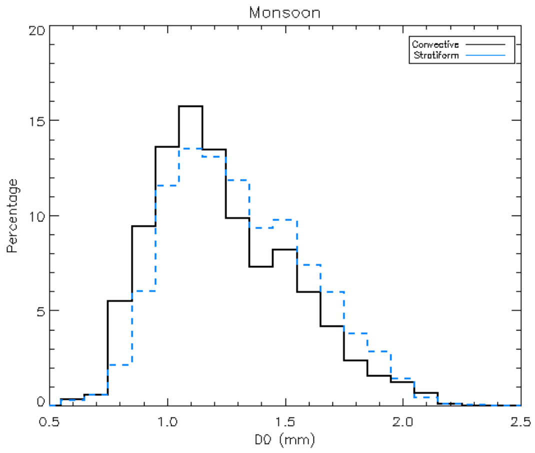

Figure 3 Median drop diameter histogram of all storms which occurred under a monsoon regime, separated into convective (black) and stratiform (blue) storms

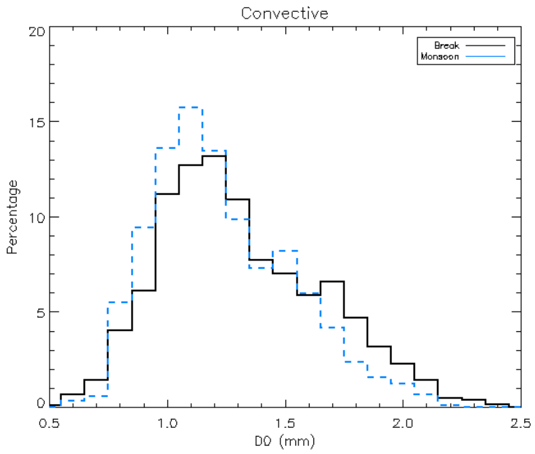

Figure 4 Median drop diameter histogram of all convective storms which occurred under break (black) and monsoon (blue) conditions

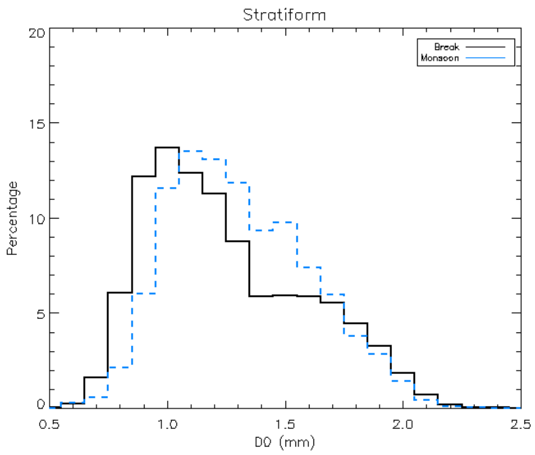

Figure 5 Median drop diameter histogram of all stratiform storms which occurred under break (black) and monsoon (blue) conditions

Comparing stratiform and convective rainfall in both seasons reveals little difference. In the monsoon season, there are higher percentages of large drops in the in the stratiform rainfall than the convective. This is not surprising, as stratiform rainfall in the monsoon largely occurred with an associated bright band, where large drops form from the melting of large ice aggregates. In the break, the mode of D0 for convective rainfall is 0.2 mm higher than in the stratiform. The break season is associated with intense convective bursts, and comparatively little widespread rainfall, which fits with this result. Comparing rainfall types between seasons, larger drops in stratiform rainfall are seen in the monsoon season, as expected due to the frequent presence of the bright band in the monsoon. In convection, larger drops were observed in the break, as expected when storms are more intense.

4.2 BUCKLAND PARK

A stratiform rainfall event, associated with a cold front, passed over BPon 30 April 2011. The reflectivity, as retrieved by the BLP, is shown in Figure 6, and as retrieved by the STP in Figure 7. A calibration factor for this event was derived for each radar using a co-located rain gauge. Both images show continuous rainfall, with three periods showing increased reflectivity, and evidence of a bright band. Comparing Figure 6 and Figure 7, it appears the BLP is showing slightly greater reflectivities than the STP. A scatter plot comparing reflectivity values is shown in Figure 8. It appears there is a constant offset between values, with the BL consistently measuring higher values. This is most likely the effect of inaccurate calibration factors, and more rain events need to be collected to improve this calculation.

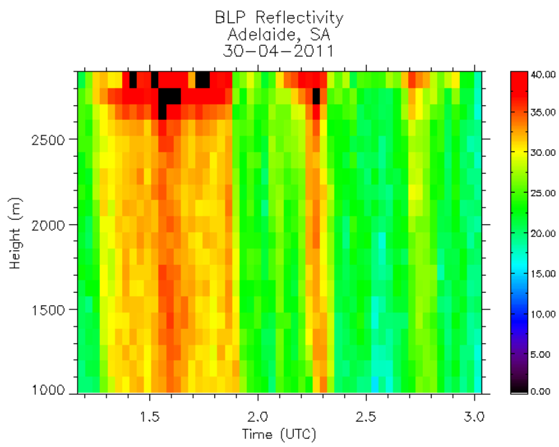

Figure 6 BP BL profiler reflectivity

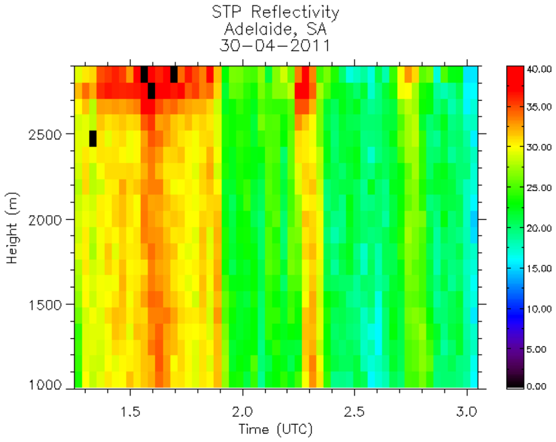

Figure 7 BP ST profiler reflectivity

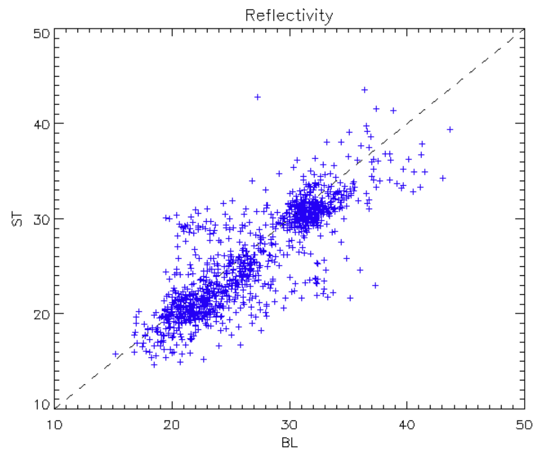

Figure 8 Scatter plot showing the reflectivity measured on the BP BL, against that measured on the BP ST

During the ST 80 kW upgrade period, two rain events passed over Buckland Park. An hour of quality controlled reflectivity data, retrieved with the profiler running at 40 kW is shown in Figure 9, and the same hour with the profiler running at 80 kW in Figure 10. This hour was chosen as the rainfall was ‘drizzle-like’. Here, the precipitation echo is small in comparison to the clear-air, and the distinction between the echoes unclear. Comparison of these figures shows the 80 kW system retrieved rainfall where the 40 kW system did not, for example at 0.4 UT. Examination of the clear-air spectral width, and the location of the divide between peaks, shows no difference between the powers. We believe the increased precipitation returns are due to the spectra being ‘cleaner’ at higher powers. Examination of individual spectra supports this idea. It should also be noted that the 80 kW system retrieved precipitation information down to the same height of 700 m as the 40 kW system, demonstrating that even at high power, the system’s digital transmit-receive path recovered quickly.

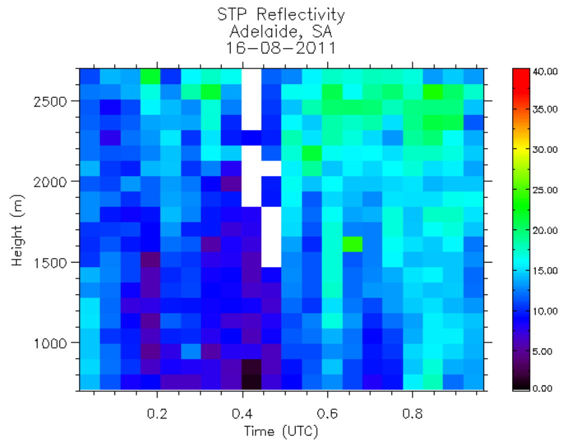

Figure 9 BP ST profiler reflectivity at 40 kW

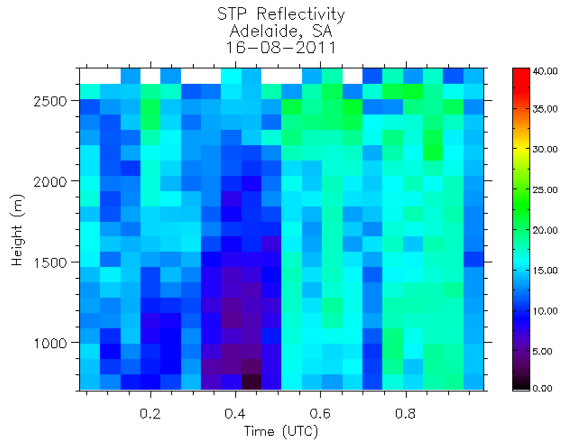

Figure 10 BP ST profiler reflectivity at 80 kW

5. CONCLUSIONS

This study has examined VHF profiler drop size distribution retrievals in the tropics and at mid-latitudes. DSDs retrieved in the tropics, using a boundary layer profiler, in a single wet season, reveal little difference between synoptic regimes, although the data set is from a single wet season, and there is considerable variability between the events. In the mid-latitudes, data collected thus far indicate that beam-width does not play a role in limiting 55 MHz DSD retrievals, and that higher powers increase performance. These results are somewhat speculative and true conclusions will be drawn as data is collected.

6. REFERENCES

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