239 AN EVALUATION OF RAINDROP SIZE DISTRIBUTION AS A FUNCTION OF HEIGHT USING S-POL POLARIMETRIC RADAR DATA FROM DYNAMO

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1. INTRODUCTION

Understanding the the nature and processes of raindrop size distributions (DSDs) is important to storm microphysics and rain rate estimation. In this paper we investigate DSDs as a function of altitude using NCAR's polarimetric S-band radar (S-Pol) data collected during DYNAMO (Dynamics of the Madden-Julian Oscillation) observation campaign. S-Pol gathered polarimetric data from 1 October 2011 to 15 January 2012 on the Addu Atoll, Maldives which is approximately 1074 km south-southeast of the tip of India and about 0.63° latitude below the equator.

DSDs are typically characterized using the Gamma distribution,

$$N(D) = N_0 D^{\mu} \exp^{(-\Lambda D)} \tag{1}$$

where D is the equivalent sphere diameter, N is the concentration, N_0 is the amplitude, μ is the shape factor, and Λ is the slope of the distribution. A family of Gamma curves is given in Bringi et al. (2003) as well as a discussion of DSDs from various climatic regimes and storm types. It is well known that the DSDs evolve as they fall to earth due to coalescence, breakup, and evaporation. Hu and Srivastava (1995) use two models to investigate the evolution of DSDs versus height. Their model predicted slopes for the tail of the Gamma distribution of 65 cm^{-1} however, numerous experimental observations with disdrometers show slopes in the 20 to 25 cm^{-1} range (Hu and Srivastava 1995; Barthes and Mallet 2013). These authors suggest that the models either under estimate the effects of coalescence or over estimate the breakup process and Barthes and Mallet (2013) adjust the parameters of their model so that a slope of 20 to 25 cm^{-1} is achieved for heavier rain rates in equilibrium.

There have been several studies of DSD evolution versus height using dual frequency (UHF and VHF) wind profiler techniques. Kirankumar et al. (2008) observed 16 rain events at Gadanki, India from April to September 2000. They found that in general both μ and Λ increased with decreasing height. This indicates a loss in small drop concentration from evaporation which by itself indicates that D_0 (median volume diameter) should increase with decreasing height. Their data, however, showed the opposite: larger values of D_0 at higher heights and lower D_0 at lower heights. Cifelli et al. (2000) examined 8 mesoscale convective systems at Darwin, Australia again using dual frequency profiler techniques. They also found that μ increased with decreasing height but they also observed that in general D_0 increased with decreasing height and ascribed it to evaporation. The increase in D_0 caused radar reflectivity to increase with decreasing height and they derived an appropriate R-Z relationship accordingly.

In this preliminary study, we infer DSD evolution versus height using polarimetric S-Pol data taken during DYNAMO from the entire 3.5 month observation period. Ratios of R-Z to R-K_{dp} integrated as a function of azimuth angle indicate an increase in water mass and an increase in D_0 which increases both R-Z and R-K_{dp} with decreasing height. Blockage to the west was significant with trees creating partial beam blockage to an elevation as high as 2.5 degrees; open ocean was mainly present to the east, which is the data we examine for this paper.

2. EXPERIMENTAL DATA

S-Pol was deployed on the Addu Atoll, on a strip of land recovered from the ocean. The only blockage to the radar beam was due to a few nearby structures, but mostly by trees and vegetation along the ring of the atoll. Figure 1 shows the location of S-Pol on the Addu Atoll.

For S-Pol, the MISMO Z-R rain rate estimate was used (Masaki Katsumata, personal communication with DYNAMO investigators):

$$R\text{-}Z = a\, z_h^b \tag{2}$$

where

$$a = 0.027366 \tag{3}$$
$$b = 0.69444 \tag{4}$$

with z_h in mm^6 m^3 and R-Z in mm hr^{-1}.

The rain rate estimator based on K_{dp} is (from Sachidananda and Zrnić (1987), Eq.(9)):

$$R\text{-}K_{dp} = sign(K_{dp})\, c\, |K_{dp}|^d \tag{5}$$

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where

$$c = 40.6 \quad (6)$$

$$d = 0.866 \quad (7)$$

with R-K_{dp} in mm hr^{-1} K_{dp} in $(^\circ)$ km^{-1}.

There were 29 days of significant precipitation (as seen from S-Pol). The total estimated rainfall was time- and range-integrated along each azimuth/radial from S-Pol. The R-Z values were only included if $K_{dp} > 0^\circ$. Due to the nature of the K_{dp} estimate, this removed occurrences of very light precipitation, or precipitation from small cumulus clouds (calculation of K_{dp} usually requires smoothing over at least 15 range gates, or a range of 2.25 km, and acts to filter-out small echoes and, coincidentally, echoes that are usually not well-developed in the vertical). Precipitation rates were summed in range (17 to 70 km) and time along each azimuth, after filtering on RATE_KDP exists (i.e., $K_{dp} > 0^\circ$). The RATE_KDP test ensured that sums were composed of the same population of rates, and indirectly ensures that rates are determined only from larger echoes, as noted, above. The range limit and the low elevation angles ensure that ice phase returns were not included in the estimates. The data were also filtered using the S-Pol PID (Particle IDentification) algorithm too ensure good meteorological echoes.

Figure 2 shows integrated R-Z by R-K_{dp} at 0.5°, 1.5°, 2.5° and 3.5° elevation angles as a function of azimuth angle. Again at each azimuth the rain rates along the entire azimuth at that elevation angle are summed from 17 km to 70 km. From roughly 170° to 360° the curves vary greatly and this is caused by beam blockage primarily due to trees. There is no blockage from 0° to roughly 80° and from about 110° to 130° thus we focus on this area to compare rain rate calculations. As the elevation angles decreases, the R-Z by R-K_{dp} ratio increases. This indicates that it is likely that the DSD is evolving as the drops fall. It is possible that integrating over polar coordinate angles could bias the the results and thus we next integrate rain rates over constant altitude PPIs (CAPPIs).

The DSDs of DYNAMO have been recently been studied using distrometer data in Thompson et al. (2013) (in this conference proceedings). They have adjusted the R-Z and R-K_{dp} coefficient values to:

for convective rain:

$$a = 0.074509,\ b = 0.62654,\ c = 62.628,\ d = 0.684,$$

for stratiform rain:

$$a = 0.035339,\ b = 0.62910,\ c = 38.326,\ d = 0.717..$$

The convective stratiform partition we use is based on a simple Z threshold: if $Z > 37$ dBZ in a one-gate column, then rain in that column is considered to be convective. The results, shown in Fig. 3, confirm that as the raindrops fall, R-Z and R-K_{dp} both increase. Additionally, Fig. 4 shows D_0 (raindrop mean volume diameter in mm) as a function of height corresponding to the data of Fig. 3. The D_0 is calculated using (Brandes et al. 2004)

$$D_0 = 0.171Z_{dr}^3 - 0.725Z_{dr}^2 + 1.479Z_{dr} + 0.717 \quad (8)$$

Thus, the D_0 increases as the raindrops descend from 3.5 km to 0.75 km AGL. This information along with Fig. 3 allows us to draw conclusions about the evolution of the "mean" DSD as a function of altitude during DYNAMO. Z is proportional to D^6 while K_{dp} is proportional to approximately $D^{4.27}$. Again, both R-Z and R-K_{dp} as well as D_0 increase as the raindrops fall from 3.5 to 0.75 km AGL. Additionally, the R-Z by R-K_{dp} ratio increases by about 14% from 3.5 km to 0.75 km. This indicates that 1) it is likely that coalescence is occurring which causes D_0 to increase, Z to increase and the ratio R-Z by R-K_{dp} to increase; and 2) since R-K_{dp} increases, the mass flux of water is increasing which intern indicates that there is supply of water vapor; i.e., the average cloud base during the sampled DYNAMO precipitation events, is a kilometer or lower. In fact, examining the the Gan soundings on the DYNAMO field catalog: http://catalog1.eol.ucar.edu/cgi-bin/dynamo/research/index shows that the LCL (Lifting Condensation Level, one measure of cloud base) was always quite low - about 1 km. Additionally, Figure 5 shows a PDF of ceilometer data from ARM AMF2 site on Gan (plot available from the DYNAMO Field Catalog website). It shows a cumulative product of ceilometer measured cloud base. This PDF (as a function of height) shows that the most frequent measured ceiling or cloud base height is just under 1 km.

3. CONCLUSIONS

This paper examined the evolution of DSDs as a function of height during the DYNAMO using polarimetric S-Pol data collected on Addu Atoll, Maldives. Total integrated rain rates from 29 days of significant rain events using both a R-Z and R-K_{dp} estimators were examined as a function of azimuth angle and height AGL. D_0 was calculated also. The results showed that the DSDs changed significantly as the raindrops fell: the D_0 became larger and the amount of rain water mass increased. These results have implications for rain rate estimators based on radar data during DYNAMO. An analysis of the evolution of DSDs as a function of height for an entire field campaign using integrated polarimetric radar data has not been shown before, to our knowledge.

Furthermore, previous studies have attributed observed DSD evolution to evaporation. Here it is very likely rain growth is occurring.

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Figure 1: *S-Pol on the Addu Atoll, Maldives. The latitude is about 0.63° below the equator.*

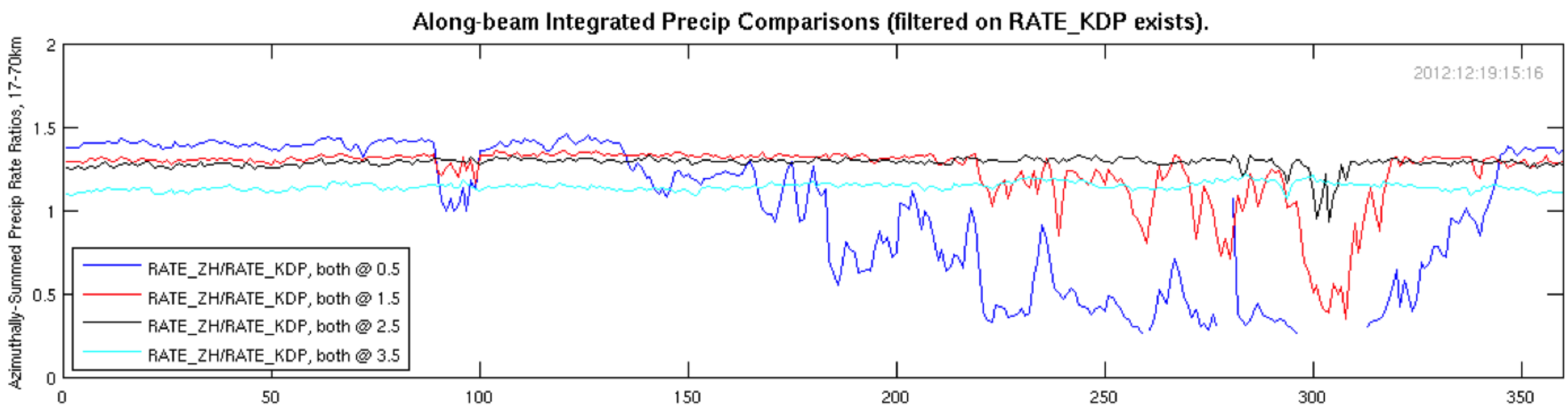

Figure 2: *Total integrated rain rate ratio, R-Z by R-K_{dp}, from S-Pol data on the Addu Atoll, Maldives as a function of azimuth angle using Eqs.(2 to 7). The dark blue, red, black and light blue curves are for elevation angles* $0.5°$, $1.5°$, $2.5°$, $3.5°$, *respectively.*

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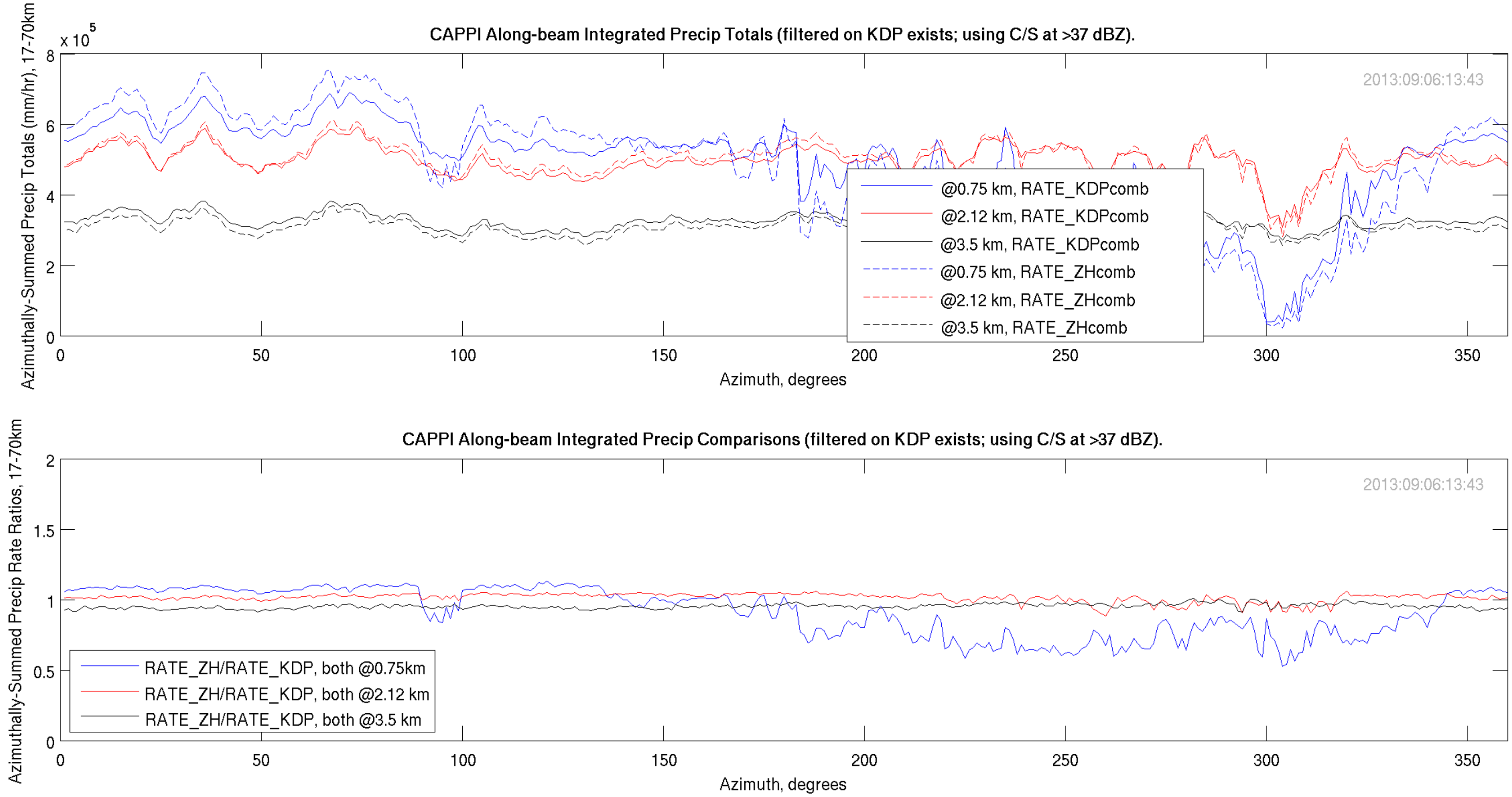

Figure 3: *Total integrated rain rates from S-Pol data on the Addu Atoll, Maldives as a function of azimuth angle for 0.75, 2.12 and 3.5 km agl.*

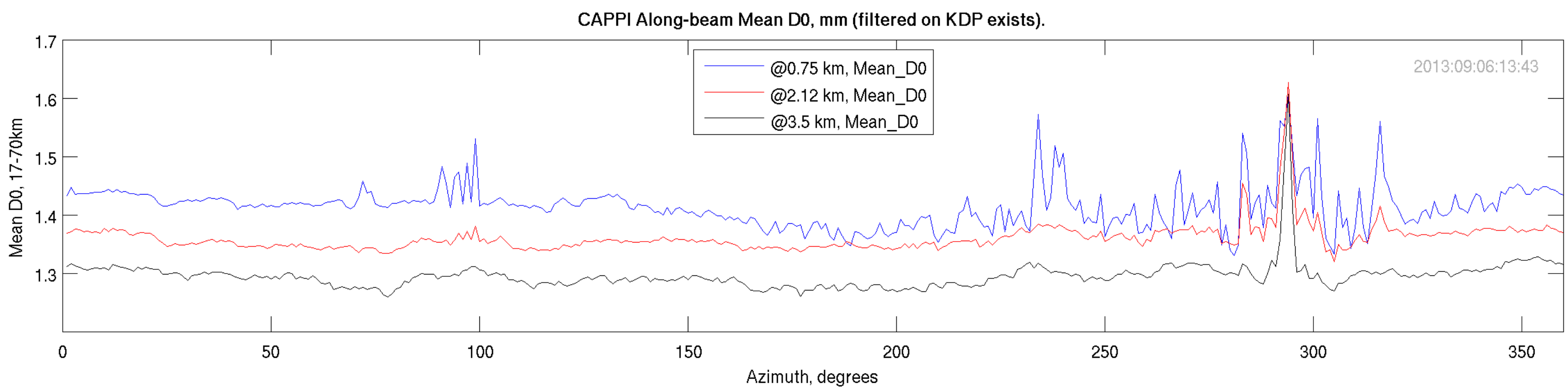

Figure 4: *Total integrated D_0 (mm) from S-Pol data on the Addu Atoll, Maldives as a function of azimuth angle for the same data as used in Fig. 3*

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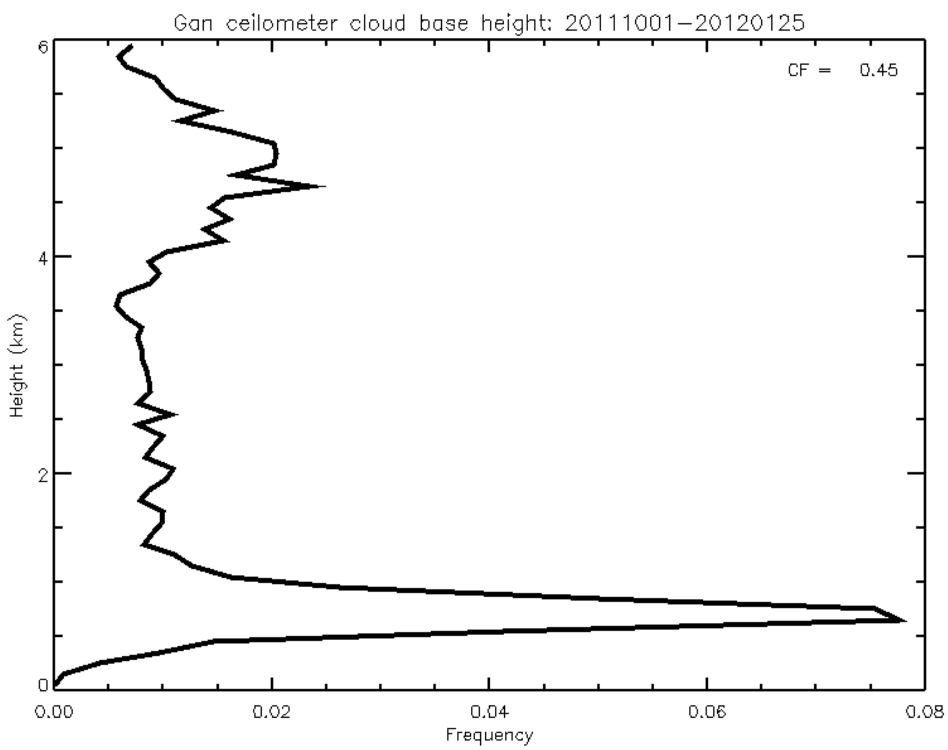

Figure 5: *PDF of ceilometer measured cloud base from ARM AMF2 site on Gan, Addu Atoll, Maldives.*