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CHARACTERISTICS OF AMAZONIAN RAIN MEASURED DURING TRMM-LBA

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1. INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) is a NASA satellite project initiated to address a gap in our ability to accurately observe detailed rainfall patterns over the tropical continents and oceans. To support TRMM, several field campaigns were conducted. The TRMM-LBA (Large-scale Biosphere Atmosphere) experiment was conducted over the southwestern region of the Amazon (state of Rondônia, Brazil) in order to provide detailed information on the precipitation characteristics in the interior of a tropical continent. Information from TRMM-LBA will be used for validation of TRMM satellite products and for the initialization and validation of cloud-resolving models and passive microwave retrieval and ground validation algorithms. TRMM-LBA was conducted in parallel with the WETAMC-LBA campaign aimed at examining the effect of land use change on rainfall in Amazonia.

During the TRMM-LBA field campaign, a variety of instrumentation was deployed during the wet season (January - February 1999) to measure rainfall including a rain gauge network and S-band polarimetric (NCAR S-POL) radar. The focus of this study is on the statistical properties of Amazonian rainfall that have a direct bearing on the above goals.

2. DATA AND METHOD

The S-POL data were carefully corrected for the presence of clear-air echo, ground clutter, anomalous propagation, second-trip echoes, partial beam blocking, precipitation attenuation, and calibration biases by applying polarimetric methods. Using an optimal polarimetric radar technique, maps of rain rate have been calculated from observations of S-POL horizontal reflectivity (Z_h), differential reflectivity (Z_{dr}), and specific differential phase (K_{dp}) every ten minutes from 10 January to 28 February 1999. From these rain rate estimates, daily and 30-day rain accumulation maps have been compiled. When validated against the rain gauge totals, preliminary S-POL estimates of monthly rainfall have a bias error in the range of –5% to –11% and a standard error of 14% to 20%. Details of the processing and validation methodology are described in Carey et al. (2000). A copy of this report and associated rain map images can be located on the web at http://radarmet.atmos.colostate.edu/trmm_lba/rainlba.html.

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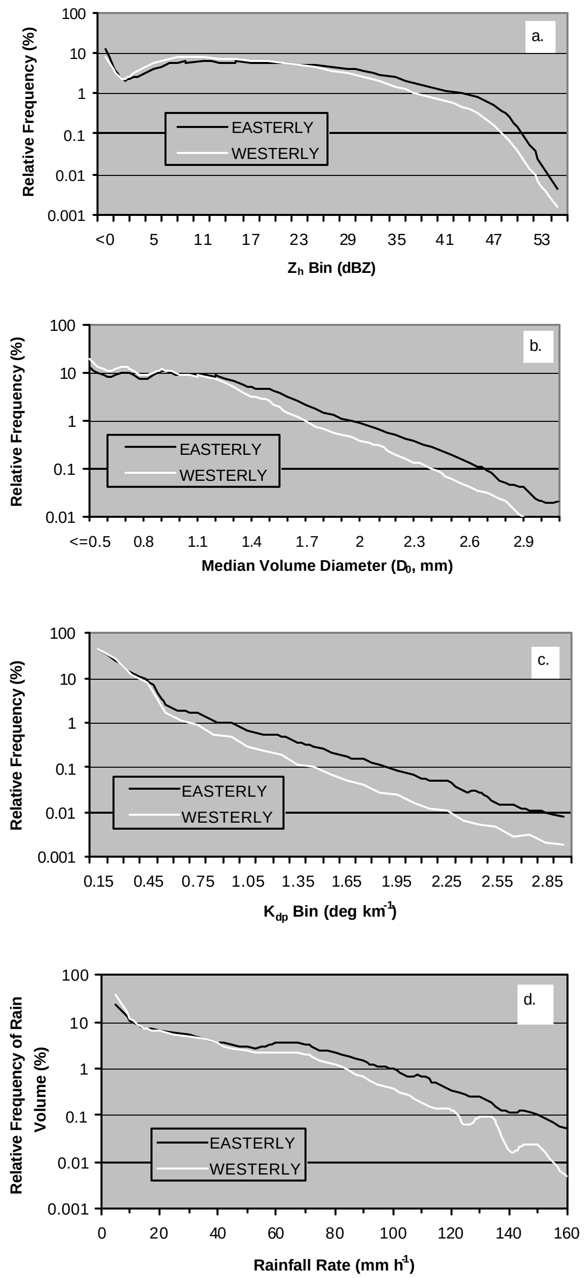

Fig. 1. Relative frequency (%) histograms of observed and derived S-POL radar quantities according to low-level wind regime. (a) Horizontal reflectivity (Z_h, 2 dBZ bins). (b) Median volume diameter (D_0, 0.1 mm bins) where $D_0 = 1.529*(Z_{dr})^{0.467}$. (c) Specific differential phase (K_{dp}, 0.2 ° km^{-1} bins). (d) Rain volume per rain rate bin (R, 5 mm h^{-1} bins).

3. RESULTS BY METEOROLOGICAL REGIME

Preliminary results from the TRMM-LBA field campaign suggest that wet season convection over Rondônia, Brazil occurs in distinct meteorological regimes as defined by the direction of the low-level wind direction (Rickenbach et al., 2001). Westerly wind periods feature modest CAPE, significant moisture through a deep layer, and shallow westerly wind shear. Conversely, easterly wind periods were associated with significantly larger CAPE, drier lower and middle tropospheric humidity, a stronger and deeper wind shear layer, and a weak low-level capping temperature inversion (Halverson et al., 2001). Williams et al. (2001) also noted a significantly higher (factor of two) mean CCN (cloud condensation nuclei) concentration during the easterly wind regime, associated with increased biomass burning.

These differences in the thermodynamic, kinematic, and aerosol properties of the regimes resulted in convective systems with contrasting properties. Convective systems that occurred during low-level easterlies were vertically developed, exhibited horizontal organization and were characterized by strong updrafts, an active mixed phase precipitation process, and ample lightning. Compared to rainfall in the easterly regime, convective systems occurring during low-level westerlies were characterized by lower peak reflectivities, less organization, more areal coverage of stratiform precipitation, mean vertical air motion that was lower by a factor of two, much lower ice water contents, and the near absence of an active mixed phase microphysical process and lightning (Cifelli et al., 2001; Rickenbach et al., 2001; Halverson et al., 2001; Williams et al., 2001).

Given these divergent descriptions of tropical convection in two distinct meteorological regimes over the western Amazon, we investigate the statistical properties of the rain drop size distribution (DSD) as revealed by the S-POL radar in each regime.

3.1 DSD Characteristics From S-POL Radar Data

As described in Carey et al. (2000) observed (Z_h, Z_{dr}, K_{dp}) and derived (D_0, R) radar quantities were interpolated to a 2 km x 2 km Cartesian grid at 1 km altitude within a 100 km range of S-POL for the period 10 Jan – 28 Feb 99. This rainfall data set is very large, totaling about 7.5×10^6 samples. The data set includes 21 (23) days of nearly continuous 24-hour per day radar coverage from 16 Jan – 28 Feb 99 and 3 (2) days of partial coverage during the westerly (easterly) regime. Approximately 63% (37%) of the grid points associated with rain occurred during the westerly (easterly) regime. The higher areal coverage of rain in the westerly regime is consistent with the findings of Rickenbach et al. (2001), who found more stratiform rain during this period. In the S-POL domain, the mean rain rate during continuous operations was 6.2 (5.9) mm day^{-1} and the mean rain accumulation was 137 (130) mm for the westerly (easterly) regime.

Despite a similar mean rain rate, the characteristics of the rain DSD's in each meteorological regime have significant statistical differences (Figs. 1a-d). As shown in Fig. 1a, the easterly (westerly) regime has a higher frequency of occurrence of moderate-to-high, $Z_h \geq 25$ dBZ, (low-to-moderate, $2 \leq Z_h < 25$) reflectivity. This is consistent with a higher stratiform fraction of rainfall during the westerly regime (Rickenbach et al., 2001). The easterly (westerly) regime has a higher percentage of large, $D_0 > 1$ mm, (small, $D_0 < 1$ mm) raindrops (Fig. 1b). As seen in Fig. 1c, significant specific differential phase ($K_{dp} \geq 0.5°$ km^{-1}) is more common in the easterly regime. This is consistent with a higher frequency of large rain rates ($R \geq 50$ mm h^{-1}) in the easterly regime (Fig. 1d). Low ($R < 15$ mm h^{-1}) rain rates are more common in the westerly wind regime. Interestingly, each regime has about the same frequency of occurrence of moderate ($15 \leq R < 50$ mm h^{-1}) rain rates.

Consistent with more vertically developed and intense convection characterized by strong updrafts, mixed phase ice processes and lightning, the easterly regime exhibits higher reflectivities, drop diameters, and rain rates. Similarly, lower reflectivities, drop sizes and rain rates in the westerly regime are consistent with monsoon-like convection and a higher fraction of stratiform rain. These differing properties of rainfall in the distinct meteorological regimes have important implications for the correct sub-grid parameterization of convection and rainfall in GCM's.

These rather straightforward and expected results are not the end of the regime dependent DSD differences however. As shown in Fig. 2, larger drops for a given value of horizontal reflectivity characterize DSD's in the easterly regime. For reflectivity bins between $15 < Z_h < 45$ dBZ, the mean D_0 is about 0.1 – 0.2 mm larger in the easterly regime. This bias in D_0 for a given Z_h between the regimes has implications for the Z-R relationships utilized in TRMM and ground validation algorithms and their associated biases and errors.

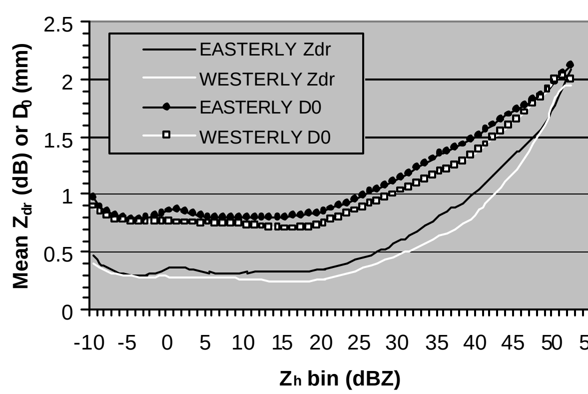

Fig. 2 Mean differential reflectivity, Z_{dr} (dB), and median volume diameter, D_0 (mm), per bin of horizontal reflectivity (Z_h, 1 dBZ bins) associated with each low-level wind regime. D_0 was calculated from Z_{dr} as in Fig. 1c.

Another way to examine DSD differences in the regime and their effect on Z-R relationships is to compute the mean Z_h and D_0 for a given rain rate bin (Fig. 3). As seen in Fig. 3, the mean D_0 for a given rain rate is about 0.1 to 0.2 mm larger in the easterly regime for R < 55 mm h^{-1}. The mean Z_h per R bin is typically about 0.4 to 1.1 dB larger in the easterly regime.

Similar to earlier studies (e.g., Sekhon and Srivastava, 1971), D_0 tends toward an equilibrium value (1.6 – 1.7 mm) or decrease slightly with rain rate at high R, R > 55 mm h^{-1}. This equilibrium D_0 is likely the result of balance being reached in the battle between drop coalescence and breakup during collisions at high R. Notice that the slope in the increase of Z with R decreases at about the same place, R = 55 mm h^{-1}.

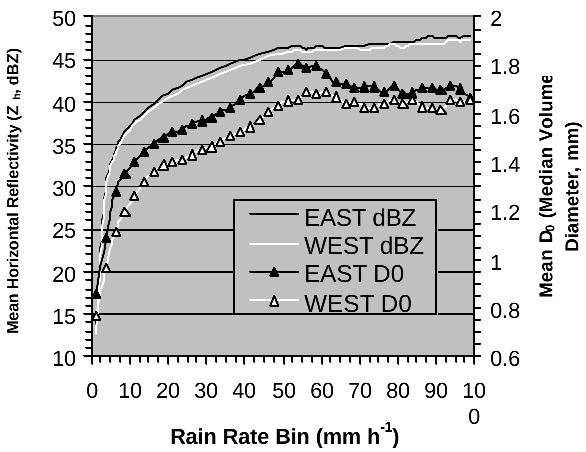

Fig. 3. Mean horizontal reflectivity (Z_h, dBZ) and median volume diameter (D_0, mm) per rain rate bin (2.5 mm h^{-1} bins) associated with each low-level wind regime. D_0 was calculated from Z_{dr} as in Fig. 1c.

We can further investigate the DSD differences between the regimes and their impact on Z-R relations by displaying a histogram of Z_h [and hence Z_{dr}, since Z_{dr} and Z_h are linearly related for fixed R in the R (Z_h, Z_{dr}) estimator] for one of the rain rate bins in Fig. 3, (e.g., 40 ≤ R < 42.5 mm h^{-1} as given in Fig. 4). First, it is interesting to note that this small range in R is associated with a 12 dB (17 dB if you include one outlier) range in Z. The mode of Z in each regime is the same (45 dBZ) but the distribution is different. For these rain rates, the easterly (westerly) regime DSD's possess a higher frequency of Z_h > 45 dBZ (< 45 dBZ) and Z_{dr} > 1 dB (< 1 dB). As shown in the next section, the DSD differences implied by Figs. 2-4 will result in different polarimetrically tuned Z-R relationships for each wind regime, particularly for R > 10 mm h^{-1}.

Table 1. Polarimetrically Tuned Z-R relations from LBA

Eqn.	Wind Regime	R Restriction	Z-R Equation
(1)	ALL	ALL R	$Z = 465 \cdot R^{1.08}$
(2)	ALL	$R \geq 10$ mm h^{-1}	$Z = 470 \cdot R^{1.10}$
(3)	EASTERLY	ALL R	$Z = 485 \cdot R^{1.08}$
(4)	EASTERLY	$R \geq 10$ mm h^{-1}	$Z = 531 \cdot R^{1.08}$
(5)	WESTERLY	ALL R	$Z = 444 \cdot R^{1.08}$
(6)	WESTERLY	$R \geq 10$ mm h^{-1}	$Z = 426 \cdot R^{1.11}$

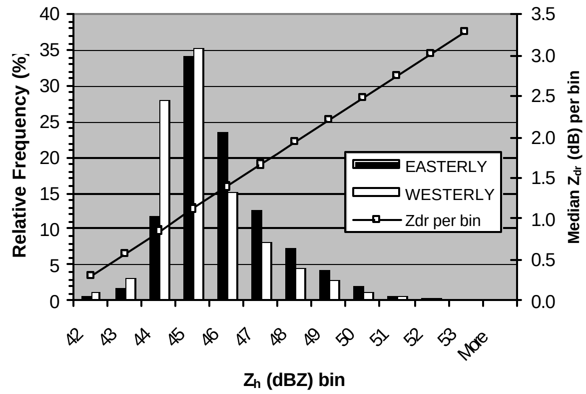

Fig. 4. Relative frequency histogram (%) of Z_h (dBZ) associated with rain rates that satisfy 40.0 ≤ R < 42.5 mm h^{-1} ("40" bin in Fig. 3) for each regime. The median Z_{dr} associated with each Z_h bin for R = 41.25 mm h^{-1} is shown as a line plot.

3.2 Polarimetric Tuning of Z-R Relationships

Since polarimetric radar estimates of rainfall are typically within 5 – 25% of gauge accumulations, one can use the polarimetric estimate to "tune" traditional Z-R relations for a given meteorological regime while avoiding the classical sampling differences between gauges and radar.

Using our gauge-validated estimates of rain rate we accomplished this task for the LBA data set for varying assumptions (Table 1). The largest difference in Z-R occurred between the two regimes at high rain rate. Ignoring DSD and hence Z-R differences in the regimes would immediately result in an 8% bias in the estimated rain rate at high R.

Note that this bias would be in addition to other typical regional biases found in Z-R relations. For example, the LBA February 1999 rain total using Eqn. (1) above was within 3% of the gauge rain totals. In comparison, the Z-R associated with the WSR-88D resulted in a monthly rain estimate that was 26% too low. Traditional tropical Z-R's (e.g., Rosenfeld et al., 1993; Short et al., 1997) produced monthly totals that were 22% to 24% too high!

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Carey, L. D., R. Cifelli, W. A. Petersen, and S. A. Rutledge, 2000: Preliminary Report on TRMM-LBA Rainfall Estimation Using the S-POL Radar. Colorado State University, Department of Atmospheric Science Paper, No. **697**, 19 p.

Cifelli, R., W. A. Petersen, L. D. Carey, and S. A. Rutledge, 2001: Radar Observations of the Kinematic, Microphysical, and Precipitation Characteristics of Two MCS's in TRMM-LBA. *J. Geophys. Res., Special Issue on TRMM-LBA*, **in review**.

Halverson, J. B., T. Rickenbach, B. Roy, H. Pierce, and E. Williams, 2001: Environmental Characteristics of Convective Systems During TRMM-LBA. *Mon. Wea. Rev.*, **in review**.

Rickenbach, T. M., R. N. Ferreira, J. Halverson, and M. A. F. Silva Dias, 2001: Mesoscale Properties of Convection in Western Amazonia in the Context of Large-Scale Wind Regimes. *J. Geophys. Res., Special Issue on TRMM-LBA*, **in review**.

Williams, E. and co-authors, 2001: The Green Ocean Over the Amazon: Implications for Cloud Electrification. *J. Geophys. Res., Special Issue on TRMM-LBA*, **in review**.