THE HORIZONTAL STRUCTURE OF PRECIPITATING SYSTEMS IN THE TROPICS ACCORDING TO TRMM

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1. INTRODUCTION & DATA

The purpose of this study is to investigate the modes of precipitating systems' horizontal structure using the TRMM precipitation radar, and to examine environmental influences on precipitating systems horizontal structure using the National Centers for Environmental Prediction (NCEP) reanalysis.

This study uses three years of version 5 2A25 3-D attenuation corrected reflectivities from the period December 1997 through November 2000. Precipitation features (PFs) have been identified in a similar way as Nesbitt et al. (2000), however this study only uses the PR near surface reflectivity criteria is used in identifying PFs. That is, no microwave data is used to identify pixels within precipitation features. Seleted parameters from these data have been gridded on a 2.5° x 2.5° annually averaged grids matching the NCEP reanalysis grid described below. Note that the "shallow, isolated rain" rainfall type category has been assigned to "convective" as described in Schumacher and Houze (2003).

Monthly means of selected NCEP reanalysis parameters including temperature, specific humidity, vector wind, and omega, have been averaged into seasonal means for the period mentioned above. For this preprint, these data have been further averaged into a single annual average to be compared with the annual averaged TRMM data.

2. DETERMINING HORIZONTAL EXTENT

In addition to the parameters calculated for each feature as in Nesbitt et al. (2000), feature maximum dimension has been determined by fitting an ellipse (using a least-squares method) to the outside of the contiguous 20 dBZ rain area for each feature. Parameters of the ellipse recorded for each feature are length of the major axis, length of the minor axis, and orientation angle of the major axis of the ellipse relative to local east. An example appears in Figure 1.

3. REGIONAL VARIABILITY IN FEATURE SIZE

Figure 2 shows annual averages of selected horizontal extent characteristics of precipitation features in the datasets. It is apparent that mean feature area varies regionally by more than an order of magnitude. The smallest features appear under the subtropical high pressure systems in both hemispheres, while the largest features in the mean appear in the midlatitudes, extending from the downstream side of the continents into the nearby ocean. In the Tropics, the Sahel region of Western Africa contains the largest features (significantly larger than the Amazon or Maritime Continent, two other convectively active land areas). Features tend to be larger in terms of mean area over the east Pacific than the central Pacific.

The pattern of mean feature maximum dimension (middle panel) is similar to the pattern of mean area. To examine small differences between these two parameters, mean eccentricity (minor/major axis length, bottom panel) is plotted. Features over Tropical continents are more "round" than over the midlatitudes or the oceans.

4. EXAMINATION OF FEATURE TYPES BY HORIZONTAL AND VERTICAL DIMENSION

To explore modes of precipitation feature variability in both horizontal and vertical dimension, the TRMM precipitation features in the dataset described above have been broken into 6 categories: three based on

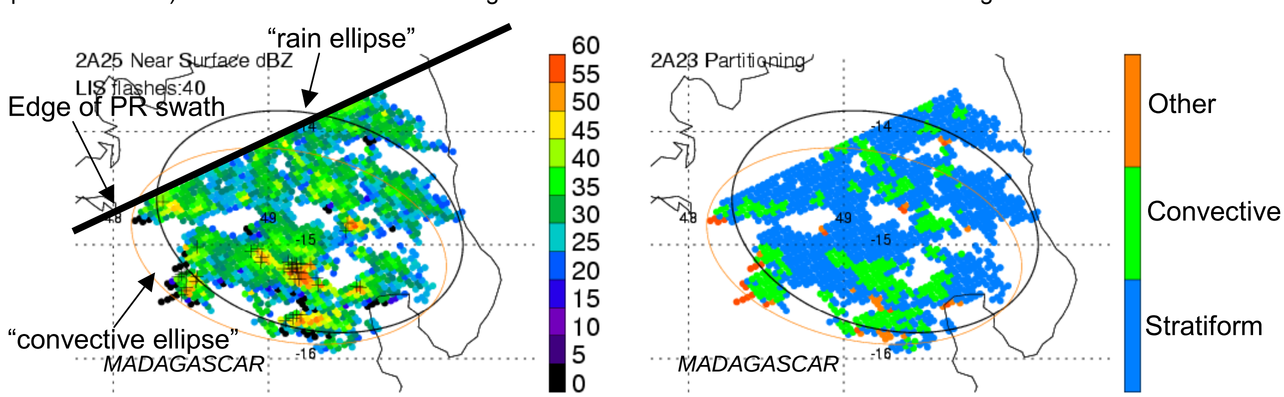

Figure 1. Example of the ellipse fitting algorithm for an MCS over Madagascar.

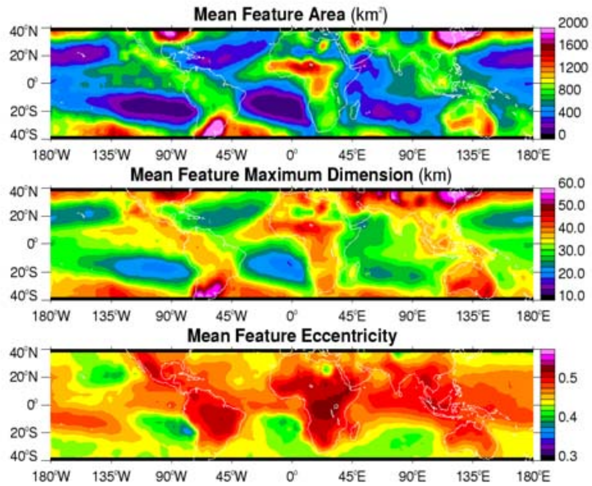

Figure 2. Mean precipitation feature area (km^2, top panel), mean feature maximum dimension (km, middle panel, and mean feature eccentricity (bottom panel).

horizontal extent (described by the first letter in the feature type acronym), and 2 according to vertical extent (described by the second letter in the feature type acronym). These are:

- LD, large, deep: Features with maximum horizontal extent ≥ 100 km and 20 dBZ echo top height ≥ 9 km,
- LS, large, shallow: Features with maximum horizontal extent ≥ 100 km and 20 dBZ echo top height < 9 km,
- MD, medium, deep: Features with maximum horizontal extent ≥ 32.3 km but < 100 km and 20 dBZ echo top height ≥ 9 km,
- MS, medium, shallow: Features with maximum horizontal extent ≥ 32.3 km but < 100 km and 20 dBZ echo top height < 9 km,
- SD, small, deep: Features with maximum horizontal extent < 32.3 km and 20 dBZ echo top height ≥ 9 km,
- SS, small, shallow: Features with maximum horizontal extent < 32.3 km and 20 dBZ echo top height < 9 km.

The maximum dimension criteria were selected at 100 km and 32.3 km to match the Houze et al. (1993) radar definition of an MCS and the mean feature maximum dimension in the TRMM dataset, respectively. Knowing that temperature profiles change seasonally, future work will focus on using temperature as a vertical coordinate to evaluate convective intensity.

5. TRMM-DOMAIN-WIDE CONTRIBUTION TO FEATURE POPULATION, RAINFALL

Table 1 shows, for each feature type outlined above, the number of features, the percentage of total TRMM-domain-wide (+/- 36° latitude) PR rainfall and stratiform rainfall, and the percentage of rainfall within each feature type classified as stratiform. It is apparent that there are roughly equal numbers of LD and LS features, while for medium- and small-sized features the populations are heavily skewed towards being shallow rather than deep.

Table 1. Selected characteristics of the features by type.

Feature type	Number of Features	% of Total Rainfall	% of Total Stratiform Rain	% of Rain Volume Stratiform
LD	133088	56.2%	52.4%	41.7%
LS	113582	16.4%	19.0%	60.2%
MD	218989	8.8%	4.6%	16.6%
MS	1030332	9.6%	12.8%	37.7%
SD	116247	1.1%	0.5%	10.3%
SS	4054065	7.7%	10.7%	31.9%

Features with horizontal dimension greater than 100 km contribute to nearly 73% of the TRMM total PR rainfall. The LD features are responsible for a majority of the rainfall and total stratiform rainfall in the TRMM domain, despite being comprised of only 41.7% of their total stratiform rainfall estimated in the mean. By contrast, despite similar numbers, the LS features are contribute 16.4% and 19% of the total and stratiform portion of rainfall. The rainfall volume percentage from these features is comprised of 60.2% stratiform rain.

MD features are about twice as common as each of the large system categories, but only contribute about 9% of the total rainfall volume. They contribute only about 5% of the total stratiform rainfall within the TRMM domain because their rainfall is classified as being 84.4% convective. Medium shallow features are nearly 5 times more common than MD features, but contribute less than 1% more to the total rain volume. These features rainfall volume is about 38% stratiform, thus these features contribute about 13% of the total stratiform rain in the TRMM domain.

The small-sized features (those less than 32.3 km in maximum horizontal dimension) contribute only about 9% of the rainfall budget in the TRMM domain. They are very numerous, however (over 4.1 million features). The SS features consist of the majority of these small features, and they contribute about 8% of PR rainfall. Rainfall volume from these small, shallow features has been classified as about 32% stratiform, even after the shallow, isolated rain category has been assigned to convective. SD features only contribute 1.1% of the total PR rainfall and that rain is largely classified as convective (~90%).

6. REGIONAL VARIABILITY BY FEATURE TYPE

Figure 3 shows maps of the fractional contribution to total rainfall from the six types of features. It is apparent that LD features (panel a) contribute the majority of rainfall in most heavily raining areas of the Tropics over both land and ocean. The La Plata basin in South America has the rainfall budget most dominated by this feature type. The southern plains of the US and coastal China are also another midlatitude area dominated by

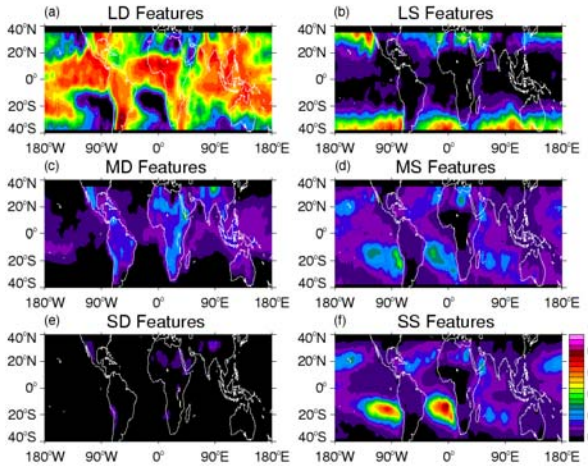

Figure 3. Fractional contribution to total PR rainfall from the six feature types.

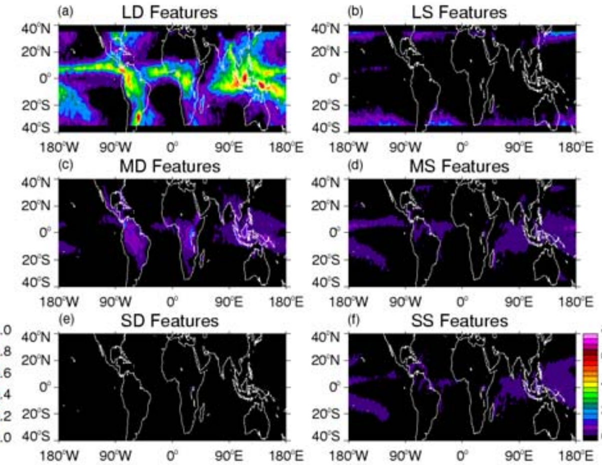

Figure 4. PR Rainfall (mm/day) from the six feature types.

these features. Areas under the subtropical gyres at midlatitudes rarely see rainfall contributions from this feature type.

In the Tropics, the rainfall budgets in central and western equatorial Africa and the east Pacific adjacent to Central America are also dominated by LD features. Interestingly, LD rain contributions tail off towards the west downstream of these areas. The West Pacific near the maritime continent, South China Sea, and the Bay of Bengal are also areas with high fractions of rainfall from these LD systems.

Areas with relative contributions to total rainfall from LS systems (panel b) greater than 0.4 are confined to the midlatitudes, generally in areas frequented by baroclinic disturbances. In areas equatorward of 20° latitude, contributions to total rainfall from LS systems are less than 5 percent, except near and eastward from Hawaii to the Pacific Coast of North America.

Continental locations are favored for contributions of greater 20 percent from MD features (panel c). The elevated areas of the Andes, Sierra Madre, the Sahara, eastern Africa, and the Tibetan plateau are favored for the highest TRMM-domain-wide contributions from MD features. It is noteworthy that the West Pacific ITCZ sees a higher rainfall contribution from these MD features than the East Pacific or Atlantic ITCZs.

MS features (panel d) contribute more than 5 percent of total PR rainfall in most areas, except for over areas with large contributions from LD features in panel a. These MS features have their highest contributions to total rainfall under the subtropical gyres, also having a relative maximum over the Central Pacific ITCZ.

SD features have the smallest contribution to total rainfall (Table 1) and regionally only contribute more than 5% of the total rainfall over dry or elevated regions. This may be the case because the dry environmental conditions oppose the development of widespread stratiform rain from strong convective regions.

SS feature (panel f) rain fractions are maximized in similar areas as MS features are (panel d). The magnitude is significantly higher in these regions, however.

Figure 4 shows the rain amount from the six feature types. It indicates that the ITCZ is where the highest rain amounts from LD features exist within 20° of the equator. The La Plata Basin is also an area exceeding 5 mm/day LD rainfall. LS rainfall (panel b) exceeds 1 mm/day in the subtropical areas where baroclinic disturbances exist. In addition, an area of the Central Pacific ITCZ also shows rainfall amounts greater than 0.5 mm/day from LS features. This may be due the presence of weak MCSs that do not contain any PR pixels of 20 dBZ reflectivity at 9 km.

MD feature (panel c) rainfall exists mostly over Tropical Continents where relatively strong updrafts are more likely to meet the reflectivity threshold at 9 km. This rainfall pattern contrasts with the pattern of MS features (panel d), where MS feature rainfall is concentrated mostly over the ocean. This contrast is simply a reflection of the regional variability in the strength of convection (Nesbitt et al. 2000, Petersen and Rutledge 2001).

SD features (panel e) only contribute to more than 0.5 mm/day of rainfall along the higher terrain of the east-central Congo basin. Throughout the oceanic ITCZs and the SPCZ and parts of the Caribbean Sea and Central Pacific, SS feaures (panel f) contribute more than 0.5 mm/day of rainfall.

Figure 5 shows zonal 2.5° latitude-box annual averages, separated by feature type, of rain rate, contribution to total rain rate, and fractional rain type partitioned by convective and stratiform components. LD features rain rate in both convective and stratiform components is the

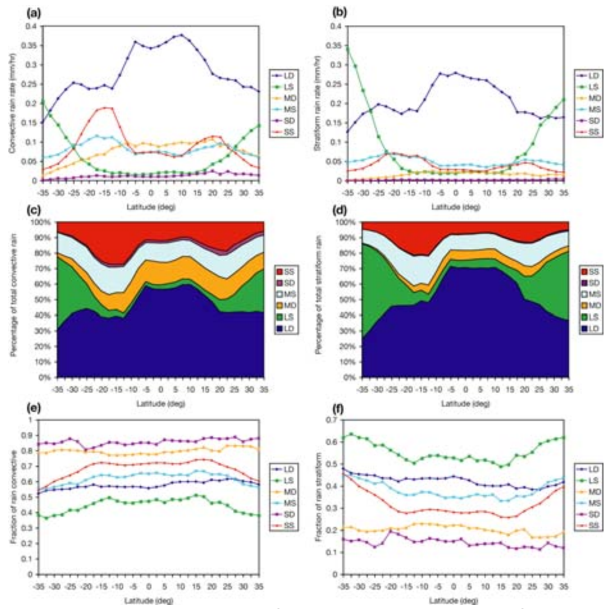

Figure 5. Zonal averages of: convective (a) and stratiform (b) rain rate by feature type; percentage contribution to total convective (a) and stratiform (b) rainfall by feature type; and the fraction of rain convective (a) and stratiform (b) by feature type.

highest in the deep Tropics, with a secondary max at about 25 south due mainly to the LD rainfall maximum in the La Plata Basin. They also contribute to more than 50% of the convective rain and nearly 70% of the stratiform rain within 10 degrees of the equator.

Poleward of 20 degrees in both hemispheres is where rain rates from LS features pick up in fractional rain contribution; these features are responsible for more than 60% of the total rainfall at 35°S, while are responsible for 45% at 35°N. This difference is likely due to the higher fraction of land in the northern hemisphere causing more intense or more non-frontal convective systems.

MD features tend to have a rainfall rate maximum in both convective and stratiform components at low latitudes, while MS and SS features rainfall rates and fractional contribution peak at about ± 20° latitude.

In terms of rain fraction being convective vs. stratiform, there is relatively little latitudinal variation. The notable exception is for LS features, which are significantly more convective at low latitudes (approaching the convective rain fraction of LD features), while tending to be more stratiform at high latitudes. This is likely due to the features being MCSs (frontal systems) at low (high) latitudes.

7. TRMM MEASURABLES VS. NCEP REANALYSIS PARAMETERS

Figures 7 and 8 show scatter plots of fractional contribution to total rainfall versus selected parameters from the NCEP reanalysis (from the times matching the TRMM data). The parameter is labeled on the x-axis, with the color of the symbol indicating the PR rain rate at that location. The correlation coefficient from a multiple linear regression fit (obtained from several NCEP variables used in the analysis) is indicated at the top of the plot for reference.

While much more detailed analysis will be presented at the conference due to space constratints, it is apparent that there are clear, multivariate-dependent relationships between these variables and the types of systems seen by TRMM. Future analysis will focus on more detailed seasonal comparisons to evaluate the relationship between TRMM measurables and their environments.

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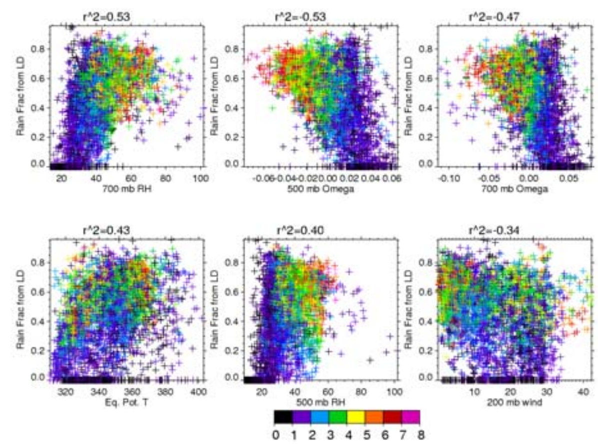

Figure 6: Fraction of rainfall in LD features vs. selected NCEP reanalysis annual mean fields for each grid box. Symbol color indicates PR rainfall rate (mm/day) according to the color scale.

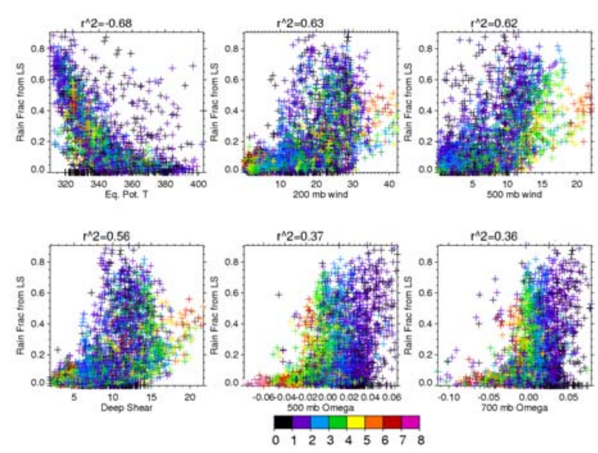

Figure 7. Same as Figure 5, but for LS features.