Storm Morphology and Rainfall Characteristics of TRMM Precipitation Features

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TRMM as a Cloud Model Validator

In the past...
- “Scale separation” in traditional GCM convective parameterizations make it difficult to compare model and observations (Grabowski 2004)

But now...
- Global CRM’s and MMFs exist which resolve convective systems, and can generate statistics of “observable” quantities for evaluation of cloud structures in both the horizontal and vertical
- TRMM can provide statistical validation of CRM simulations of the horizontal and vertical structure of precipitation, especially for deep convective systems
Motivation

Many previous studies have examined the horizontal structure of storms:

- IR cloud clusters regionally (e.g., Williams and Houze 1987, Mapes and Houze 1993) and globally (e.g., Machado and Rossow 1998)
- Radar echoes regionally using ground based radar (López 1977, Rickenbach and Rutledge 1998) and the TRMM PR (Nesbitt et al. 2000)
- With TRMM, we can examine the spatial variation of rainfall Tropics-wide and obtain “climatological” averages of storm characteristics
Factors influencing rainfall systems’ horizontal structure

- Convective Forcing
- Convective and Mesoscale Dynamics
- Microphysics, Rainfall
- Convective system- Large Scale Feedbacks

Yuter and Houze (1995)
Goals of this study

- What is the parameter space of the precipitating features’ echo horizontal dimension?
- How do features of various horizontal scales contribute to rainfall in a given region?
- What is the relationship between vertical and horizontal structure of these systems?
- How do storms of different types scale in rainfall contribution as a function of total rainfall?
TRMM Instruments

- Precipitation Radar (PR)
  - 215 km swath
  - $K_a$ Band - 14 GHz - 2.2 cm
  - 17 dBZ minimum detectable signal
  - 4 x 4 x 0.25-1.5 km resolution
  - Calibrated to within ± 1 dBZ

- TRMM Microwave Imager (TMI)
  - 759 km swath
  - 9 channels, 10 - 85 GHz, dual polarization, elliptically-scanning
  - Resolution varies from 5 x 7 km at 85 GHz to 60 x 60 km at 10 GHz
  - Rainfall retrievals based on different physics over land and ocean

- Visible and Infrared Scanner (VIRS)
  - 720 km swath
  - Measures radiances at 5 channels from 0.6-12 µm

http://trmm.gsfc.nasa.gov
The Precipitation Feature Database

- Joint effort among University of Utah, Colorado State University, University of Alabama at Huntsville, NASA GSFC/TSDIS
- Brought forth a massive meteorological “data mining” effort to identify and classify rain systems within the TRMM PR and TMI swaths
- With “version 6” reprocessing, we have transitioned processing to GSFC
  - Level 1: PR/TMI/VIRS/LIS data compressed by a factor of 40
  - Level 2: Statistics calculated for PR-only, PR/TMI, and TMI-only identified precipitation features
- Roughly 36 million PR-defined PFs identified between 1998 - 2004
**Methodology**

- A PF is defined as an area of contiguous pixels with PR reflectivity $\geq 20$ dBZ.
- For this study, we analyzed 3 years of version 6 PFs (1998-2000).
- Ellipses are fitted to the perimeter of each PF using a least squares technique to estimate maximum dimension.
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Fig. 1. Schematic of two scenes containing PFs within the PR swath. In (a) and (c), VIRS 10.7 µm $T_b$ and 85 GHz PCT 31-Dec-1999 22:50 UTC. In (b) and (d), PR Near Surface Reflectivity 4-Jan-2000 7:35 UTC. In each scene, the major and minor axes of the best fit ellipse are labeled.
Fig. 3. CDFs of (a) feature area and (b) FMD for all features (dark solid lines), non-edge features (grey solid lines), and edge features (dashed lines). Low plots show the relative fraction of features intersecting the PR swath boundary as a function of feature area (c) and maximum dimension (d).
Population and rainfall of PR edge features

Number Fraction of Edge Features

Rainfall Fraction of Edge Features
Distributions of feature area over land and ocean comparing PR 2A25 and TMI 2A12 near surface rain.
Feature size distributions on log-normal paper

(a) Land

Williams and Houze (1987)
Land - Maritime Continent
213 K IR Area
PR
Echo Area
TMI
Rain Area
Cruz (1973) EMD
Venezuela
Miller et al. (1975) EMD
W. North Dakota

(b) Ocean

Mapes and Houze (1993) 208 K IR Area
198 K IR Area
PR
Echo Area
Williams and Houze (1987)
Ocean - Maritime Continent
213 K IR Area
TMI
Rain Area
PR
Echo Area
López (1976) EMD
NW Atlantic

Normalized CDF (%)
Area (km²)
FMD (km)
Regional feature size variability

log Mean Feature Rain Area (km$^2$)

Mean Feature Rain Maximum Dimension (km)
## Selected feature characteristics

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of features ($\times 10^3$)</td>
<td>15389</td>
<td>2733</td>
</tr>
<tr>
<td>Number fraction</td>
<td>.82</td>
<td>.18</td>
</tr>
<tr>
<td>Mean $RR_{\text{cond}}$ (mm/hr)</td>
<td>2.71</td>
<td>2.81</td>
</tr>
<tr>
<td>Mean $RR_{\text{uncond}}$ (mm dy$^{-1}$)</td>
<td>2.48</td>
<td>2.02</td>
</tr>
<tr>
<td>Mean feature area (km$^2$)</td>
<td>189</td>
<td>371</td>
</tr>
<tr>
<td>Mean feature maximum dimension (km)</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Fraction of rain stratiform</td>
<td>.54</td>
<td>.48</td>
</tr>
</tbody>
</table>
Frequency distributions of feature size and rainfall contribution

(a) Frequency distribution of feature size

(b) Frequency distribution of rainfall contribution

Legend:
- Blue dashed line: ocean number
- Blue solid line: ocean rain volume
- Red dashed line: land number
- Red solid line: land rain volume
# Feature Type Definition

<table>
<thead>
<tr>
<th>PF Type</th>
<th>FMD Criteria</th>
<th>ETH Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow (S)</td>
<td>-</td>
<td>ETH ≤ 4.5 km (MSL)</td>
</tr>
<tr>
<td>Small “Cold” (SC)</td>
<td>FMD &lt; 100 km</td>
<td>ETH &gt; 4.5 km</td>
</tr>
<tr>
<td>Large “Mid-level” (LM)</td>
<td>FMD ≥ 100 km</td>
<td>4.5 &gt; ETH &gt; 9.5 km</td>
</tr>
<tr>
<td>MCS</td>
<td>FMD ≥ 100 km</td>
<td>ETH ≥ 9.5 km</td>
</tr>
</tbody>
</table>
Rainfall fraction by feature type

Fig. 10. Shaded contour map of fraction of rainfall by feature type.
Examination of rainfall budgets

Total rain volume

\[ \sum R_{\text{vol}} = A_r \bar{RR}_{\text{cond}} = n_f \bar{ARR}_{\text{cond}} \]

number of features
mean feature area

mean conditional rain rate

= \( n_f A \left[ f_{a_s} \bar{RR}_{\text{cond}} + (1 - f_{a_s}) \bar{RR}_{\text{cond}_c} \right] \)

fraction of area
mean stratiform conditional rain rate
mean convective conditional rain rate

raining area
mean conditional rain rate

raining area
mean conditional rain rate

raining area
mean conditional rain rate

raining area
mean conditional rain rate
Mean feature area (km$^2$)

- **Ocean**
  - Shallow: 50 km$^2$
  - Small cold: 42 km$^2$
  - Large mid-level: 205 km$^2$
  - MCS: 11,166 km$^2$

- **Land**
  - Shallow: 205 km$^2$
  - Small cold: 170 km$^2$
  - Large mid-level: 5,605 km$^2$
  - MCS: 9,445 km$^2$
Conditional rain rate (mm hr$^{-1}$)

- Shallow
- Large mid level
- Small - cold
- MCS

Ocean - Convective: 2.5
Land - Convective: 2.7
Ocean - Stratiform: 1.3
Land - Stratiform: 1.2

Small - cold:
- Ocean: 2.8
- Land: 2.8
- Ocean: 2.5
- Land: 2.5

Large mid level:
- Ocean: 7.0
- Land: 7.0
- Ocean: 7.8
- Land: 7.8

MCS:
- Ocean: 11.5
- Land: 11.5
- Ocean: 1.7
- Land: 1.7

Shallow:
- Ocean: 12.8
- Land: 12.8
- Ocean: 9.4
- Land: 9.4
If features rain less over land, then how can the continental rain rate be even close to the oceanic rain rate?

It’s all about the types of convective systems that occur!!
Fraction of number of features

- Ocean
  - Shallow: 0.5%
  - Large mid-level: 20.2%
  - Small cold: 0.6%
  - MCS: 78.7%

- Land
  - Shallow: 0.8%
  - Large mid-level: 58.5%
  - Small cold: 39.0%
  - MCS: 1.6%
Fig. 12. Shaded contour maps of (a) log mean rain volume per feature (mm hr\(^{-1}\) km\(^2\)), (b) mean conditional rain rate (mm hr\(^{-1}\)), and (c) log estimated number of features (yr\(^{-1}\) [2.5\(^\circ\)]\(^2\)). The 1 and 3 mm dy\(^{-1}\) contours of PR unconditional rain rate are shown by the black solid and dashed lines, respectively.
TRMM precipitation feature database provides an excellent test bed for comparing with statistics from CRM and MMF-climate simulations.

Land-ocean differences in convective system populations and characteristics important in controlling rainfall rates and amounts.

More convective rainfall, higher relative occurrence of heavier raining but less frequent features over land.

This study provides the framework to quantitatively compare observations and CRMs.
Rain Area vs. Ellipse Fit Area

Fig. 2. Shaded log-log density plot of feature rain area versus ellipse fit area.

Edge of PR swath
Fraction of features hitting the edge of the PR swath

![Graphs showing the fraction of features hitting the edge of the PR swath as a function of feature area and maximum dimension.](image)