On the Relationship between Intensity and Rainfall Distribution in Tropical Cyclones Making Landfall over China

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Outline

• Introduction
• Data and methodology
• Asymmetric TC rainfall (related to intensity)
• Axisymmetric TC rainfall (related to intensity)
• Conclusions
1. Major Scientific issue related with TCs

- There have been advances in TC track forecasts in the past decades, but relatively-slow developments on TC intensity and rainfall forecasts.
- What relationship between TC intensity and rainfall during landfall?

*Fitow (2013)*

(a) OBS: 0600Z-0700Z  
(b) OBS: 0700Z-0800Z  
(c) OBS: 0600Z-0800Z
Factors to impact TC rainfall

- Size
- Intensity
- Track (direction/speed/location)
- Topography/land-sea
- Large-scale environment/ET
- Vertical wind shear
Vertical wind shear

Rain asymmetry

(Chen et al. 2006)
Topography

Asymmetry of TC rain

- Boundary VWS
- Frictional convergence
- Accompanying latent heat
- Rainfall enhancement

(Chen and Yau, 2001)
Land-sea contrast

Rain asymmetry

(Li et al, 2013)
Symmetric part is about 50%.

Yu et al. 2015
Objectives of this study

- Rainfall traits (including asymmetry and axisymmetry) of TCs prior to, during, after landfall over China
- What controls the landfalling TCs rainfall asymmetry change?
- What mainly influence the TC axisymmetry?
2. Data and methodology

- STI/CMA Best Track data (2001-2015)
- TRMM 3B42 rainfall data (3h, 0.25degree)
- NCEP Final reanalysis data (6h, 1degree)
- Japan reanalysis data (6h, 20km)
- Composite analysis & Fourier decomposition

The spatial structure of the first-order asymmetry ($M_1$) can be represented by

$$M_1 = \left[ a_1 \cos(\theta) + b_1 \sin(\theta) \right] / R$$

$$a_1 = \sum_i [R_i \cos(\theta_i)] , \quad b_1 = \sum_i [R_i \sin(\theta_i)]$$
3. TC asymmetries prior to, during, after landfall

- Tracks of 133 TCs making landfall in different regions of China during 2001-2015:
  - (a) Hainan (HN), (b) Guangdong (GD), (c) Taiwan (TW), (d) Fujian (FJ), (e) Zhejiang (ZJ).
Asymmetric rainfall vs. intensity

a): Averaged shear: 8 m/s

Vertical wind shear

14h before landfall

at landfall

24h after landfall

Weaker TCs (CAT23)

b): Averaged shear: 6 m/s

Vertical wind shear

14h before landfall

at landfall

24h after landfall

Stronger TCs (CAT456)
Rainfall asymmetries vs. coastline & shear

24h before landfall
(l), <5 m/s
(l), 5–7.5 m/s
(l), >7.5 m/s

at landfall
(II), <5 m/s
(II), 5–7.5 m/s
(II), >7.5 m/s

24h after landfall
(III), <5 m/s
(III), 5–7.5 m/s
(III), >7.5 m/s

Low shear
Modest shear
High shear
4. TC axisymmetric rainfall vs. intensity

- TCs of higher intensity have higher peak azimuthal-mean rain rate.
**CAT2-TS**

**CAT3-STS**

**CAT4-TY**

**CAT5-STY**

**CAT6- SuperTY**

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**Total rain vs. TC intensity**

- **Graph a:** Frequency of distribution of total rain (mm/h) for CAT23 and CAT456 categories.
- **Graph b:** Box plot showing total rain (mm/h) for different TC categories (CAT2-TS, CAT3-STS, CAT4-TY, CAT5-STY, CAT6-SuperTY) with medians and outliers.
Rain area vs. intensity

- **a)** Rain area (R > 0 mm/h)
- **b)** Rain area (R > 2 mm/h)
- **c)** Rain area (R > 5 mm/h)

Graphs showing the fractional rain area by TC category for different rainfall intensities.
Maximum rain rate vs. intensity

[Boxplot showing the distribution of maximum rain rate across different TC categories]
CAT23

Rainfall

CAT456

Rain component contribution

(0.22, 0.15, 0.11, 0.09)

(0.20, 0.13, 0.10, 0.08)
Intensity change vs. Rain change

The lower the peak the rain rate is, the larger the radius is at which the peak rain rate occurs.

The correlation coefficient: 0.77
The more rapidly a TC decays during landfall, the more the rain rate decreases.

To decaying TCs, the axisymmetric rainfall contribution relative to the total rainfall decreases steadily with TC intensity decrease, while the asymmetric (wavenumbers-1-4) rainfall increases.
5. Conclusions

• In landfalling TCs, TC intensity plays little role in landfalling TC maximum rainfall locations over China.

• The wavenumber-one rainfall asymmetry shows the downshear to downshear-left rainfall maximum in landfalling TCs in general. But when VWS is less than 5 m s\(^{-1}\), the asymmetric rainfall maxima are more frequently located upshear and onshore.

• The average axisymmetric (wavenumber-0) component of rainfall is closely related to the TC intensity and intensity change.

• However, the maximum total rain, maximum rain area, and maximum rain rate are not absolutely dependent on TC intensity, suggesting that stronger TCs do not have systematically higher maximum rain rates than weaker storms.
Thank you for your attention

References


Samples and frequencies of TC intensity of 5 categories (CAT=2-6) from 24h prior to landfall (t=-24), landfall (t=0), to 24h after landfall (t=24) every 6 hours

<table>
<thead>
<tr>
<th>Time</th>
<th>TS (CAT=2, 17.2-24.4m/s)</th>
<th>STS (CAT=3, 24.5-32.6m/s)</th>
<th>TY (CAT=4, 32.7-41.4m/s)</th>
<th>STY (CAT=5, 41.5-50.9m/s)</th>
<th>SuperTY (CAT=6, ≥AT=6TY )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-24h</td>
<td>30 (27.1%)</td>
<td>14 (12.1%)</td>
<td>39 (33.9%)</td>
<td>19 (16.5%)</td>
<td>13 (11.3%)</td>
</tr>
<tr>
<td>-18h</td>
<td>27 (22.7%)</td>
<td>22 (18.5%)</td>
<td>39 (32.8%)</td>
<td>20 (16.8%)</td>
<td>11 (9.2%)</td>
</tr>
<tr>
<td>-12h</td>
<td>28 (23.3%)</td>
<td>20 (16.7%)</td>
<td>40 (33.3%)</td>
<td>22 (18.3%)</td>
<td>10 (8.3%)</td>
</tr>
<tr>
<td>-6h</td>
<td>23 (19.1%)</td>
<td>24 (20.0%)</td>
<td>41 (34.2%)</td>
<td>26 (21.7%)</td>
<td>6 (5.0%)</td>
</tr>
<tr>
<td>0h</td>
<td>28 (24.1%)</td>
<td>25 (21.6%)</td>
<td>37 (31.9%)</td>
<td>22 (19.0%)</td>
<td>4 (3.4%)</td>
</tr>
<tr>
<td>6h</td>
<td>42 (39.6%)</td>
<td>32 (30.2%)</td>
<td>28 (26.4%)</td>
<td>3 (2.83%)</td>
<td>1 (0.9%)</td>
</tr>
<tr>
<td>12h</td>
<td>46 (51.1%)</td>
<td>25 (27.8%)</td>
<td>18 (20.0%)</td>
<td>1 (1.4%)</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>18h</td>
<td>42 (59.2%)</td>
<td>17 (23.9%)</td>
<td>11 (15.5%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24h</td>
<td>40 (72.7%)</td>
<td>8 (14.5%)</td>
<td>7 (12.7%)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Samples of TCs intensity change of 5 categories (RI, SI, Unchanged, SD, RD) from 24h prior to landfall (t=-24), landfall (t=0), to 24h after landfall (t=24) every 6 hours

<table>
<thead>
<tr>
<th>Time</th>
<th>RI (ΔV≥15 m/s, 24h)</th>
<th>SI (ΔV=0-15 m/s, 24h)</th>
<th>Unchanged (ΔV=0 m/s, 24h)</th>
<th>SD (ΔV=-15-0 m/s, 24h)</th>
<th>RD (ΔV≤-15 m/s, 24h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-24h (t=-24)</td>
<td>3</td>
<td>73</td>
<td>26</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>-18h (t=-18)</td>
<td>4</td>
<td>71</td>
<td>21</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>-12h (t=-12)</td>
<td>4</td>
<td>67</td>
<td>17</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>-6h (t=-6)</td>
<td>5</td>
<td>52</td>
<td>30</td>
<td>33</td>
<td>2</td>
</tr>
<tr>
<td>0h (t=0)</td>
<td>5</td>
<td>34</td>
<td>21</td>
<td>60</td>
<td>3</td>
</tr>
<tr>
<td>6h (t=+6)</td>
<td>0</td>
<td>13</td>
<td>10</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>12h (t=+12)</td>
<td>0</td>
<td>5</td>
<td>8</td>
<td>73</td>
<td>28</td>
</tr>
<tr>
<td>18h (t=+18)</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>69</td>
<td>33</td>
</tr>
<tr>
<td>24h (t=+24)</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>64</td>
<td>29</td>
</tr>
</tbody>
</table>
Averaged rainfall distributions (unit: mm) in landfalling TCs in different regions of China during 2001-2009: (a) Hainan, (b) Guangdong, (c) Taiwan, (d) Fujian, (e) Zhejiang.

X and Y axes are distance (×0.1 degree) from the TC center (origins). Stage (I) is 24-h prior to landfall, stage (II) is at the time of landfall, and stage (III) is 24-h after landfall. The color scale indicates the amplitude of the averaged rainfall in mm in every 6 h.
The 6-hourly amplitude (× 100%) of the wavenumber-0, 1, 2, 3, and 4 components of TC rainfall relative to the total rainfall
A cyclonic rotation from South China to East China in the location of the rainfall maximum of landfalling TCs is identified, which is related with the environmental VWS cyclonic rotation.

(Yu et al. 2015)
The vertical wind shear is one main factor to the rain asymmetric distribution.

Vertical wind shear

(a) HN

(b) GD

(c) TW

(d) FJ

(e) ZJ

The wavenumber-one rainfall asymmetry (unit: mm) relative to the vertical wind shear.