The Role of Precipitation and Convective Features on Tropical Cyclone Intensification Derived from 16-yr TRMM Observations

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Introduction

- Previous studies have argued that the Intensity of precipitation and convection in the inner core of TCs have a positive relationship with TC intensification (Jiang and Ramirez 2013; Zagrodnik and Jiang 2014; Alvey et al. 2015; Tao and Jiang 2015; Tao et al. 2017).
- However, because of the impact of current TC intensity, the relationship between future TC intensification rate and inner-core convective and precipitation properties is not linear for the whole spectrum of intensification rate. As shown by Alvey et al. (2015), the convective intensity is high in the weakening stages, decreases from weakening to neutral, and increases from neutral to SI to the RI stage.
- Fischer et al. (2018) was the first study that removed the dependency of precipitation parameters on TC current intensity by a normalization method. Recently, Su et al. (2020) found a linear relationship between TC intensification rate and rainfall rate from the multi-satellite 3B42 dataset (in low spatial resolution of 25 kmx25 km) by grouping TCs into various intensity & intensity change categories. However, their results did not include the relationship between TC intensification rate with the convective features or with the symmetry of the convective/precipitation parameters in TC inner core.

Data and Methodology

- **Sixteen-year (1998-2013) 6-hourly Joint Typhoon Warning Center (JTWC) & National Hurricane Center HURDAT2 best track data**
- **Sixteen-year (1998-2013) TMI data including 2A12 rainfall rate and brightness temperatures in 37 & 85 GHz.**
- **Axisymmetric Index is used** (γ, Miyamoto and Takemi 2013 and Shimada et al. 2018):

$$\gamma(r,z,t) \equiv \frac{\bar{\phi}(r,z,t)^2}{\bar{\phi}(r,z,t)^2 + \int_0^{2\pi} \phi'(r,\lambda,z,t)^2 d\lambda/2\pi}.$$

Here, $\bar{\phi}(r,z,t)$ represents the azimuthal mean, while $\phi'(r,\lambda,z,t)$ is the deviation from the azimuthal mean of each point.

- **Three precipitation types (stratiform rainfall, shallow convection, and deep convection) are separated by polarization-corrected brightness temperature (PCT37) as well as vertically and horizontally-polarized 37 GHz brightness temperatures (V37 & H37) using the method in Jiang et al. (2018).**
- **Sixteen categories are classified for overpasses**

Four TC intensity categories: tropical depression (TD), tropical storm (TS), minor hurricane (H12), and major hurricane (H35).

For each intensity category, four 24-h future intensity change stages are defined: rapidly intensifying (RI), slowly intensifying (SI), neutral (N), and weakening (W) by following Jiang and Ramirez (2013).

- **The inner core size of each TC for every TMI overpass is determined using the radius of maximum azimuthally mean rain rate (RMR), which is considered as an alternate measure of the radius of maximum wind (RMW).**

Precipitation type	Definition
Precipitation-free	$PCT_{37} > 270$ when $H_{37} < 225$
Stratiform Rainfall	$260 < PCT_{37} \leq 270$ when $H_{37} < 225$; $260 < PCT_{37} < 275$ when $H_{37} \geq 225$
Shallow Convection	$PCT_{37} \geq 275$ when $H_{37} \geq 225$
Deep Convection	$PCT_{37} \leq 260$

Sample Size: Numbers of the TMI overpasses in different event stages

- A majority of RI cases are TSs and minor hurricanes.
- It is very rare for a major hurricane or a TD to undergo RI (about 2% versus 7-10% for TSs and minor hurricanes).

	W	N	SI	RI	Total
TD	48	1666	434	44	2192
TS	727	1434	862	225	3248
H12	697	541	338	188	1764
H35	539	297	135	19	990
Total	2011	3938	1769	476	8194

Results

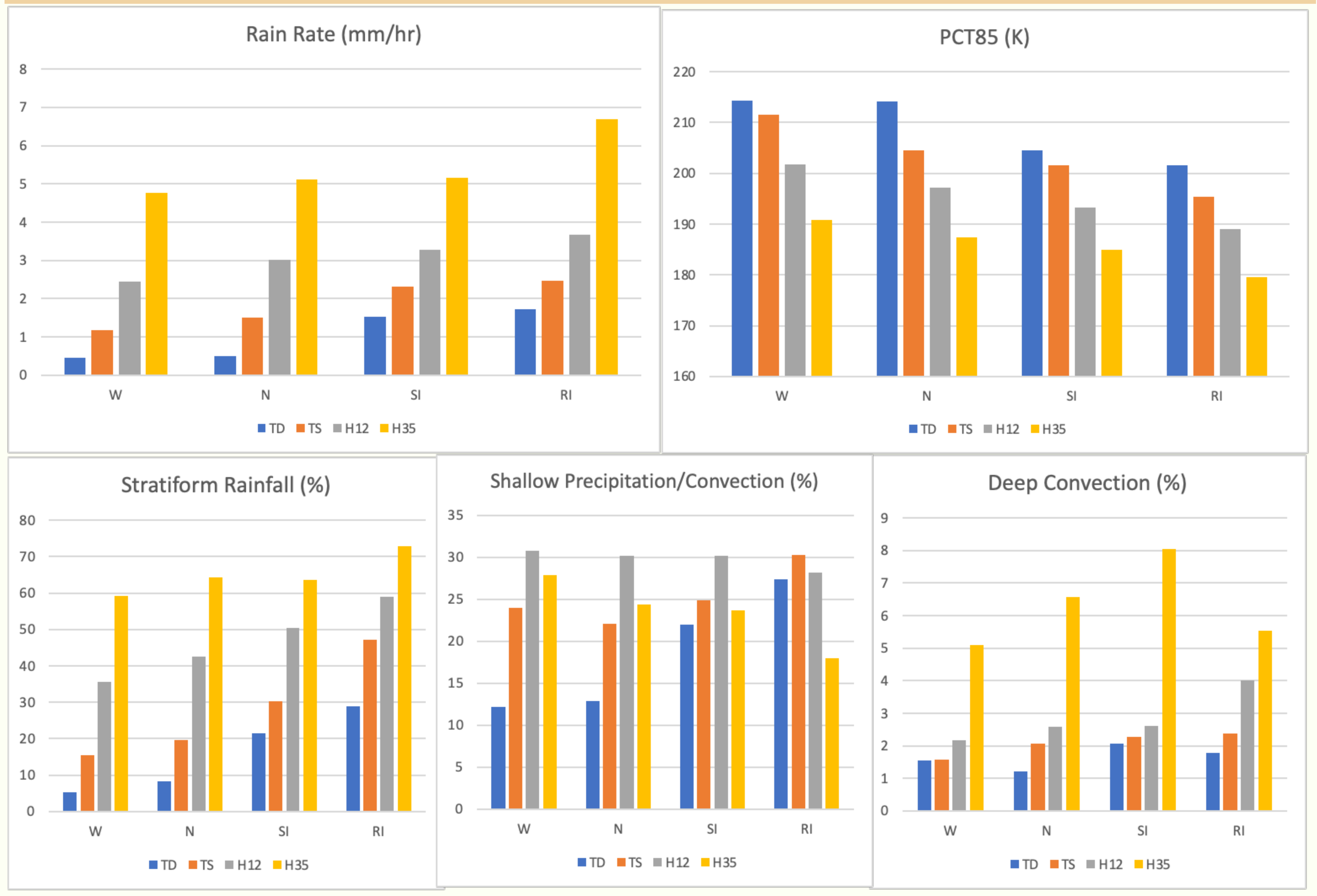
RMR within TC inner core.

Letters represent the statistical significance of the difference at 95% (c), 99% (b), and 99.9% (a) confidence levels

RMR (km)	W	N	SI	RI	W-N	N-SI	SI-RI
TD	96.25	98.14	79.40	70.00	1.89	-18.74[a]	-9.40
TS	88.58	87.06	74.86	59.13	-1.52	-12.2[a]	-15.73[a]
H12	72.78	66.87	58.78	51.33	-5.91[c]	-8.09[b]	-7.45[c]
H35	52.55	45.30	41.52	42.89	-7.25[b]	-3.78	1.37

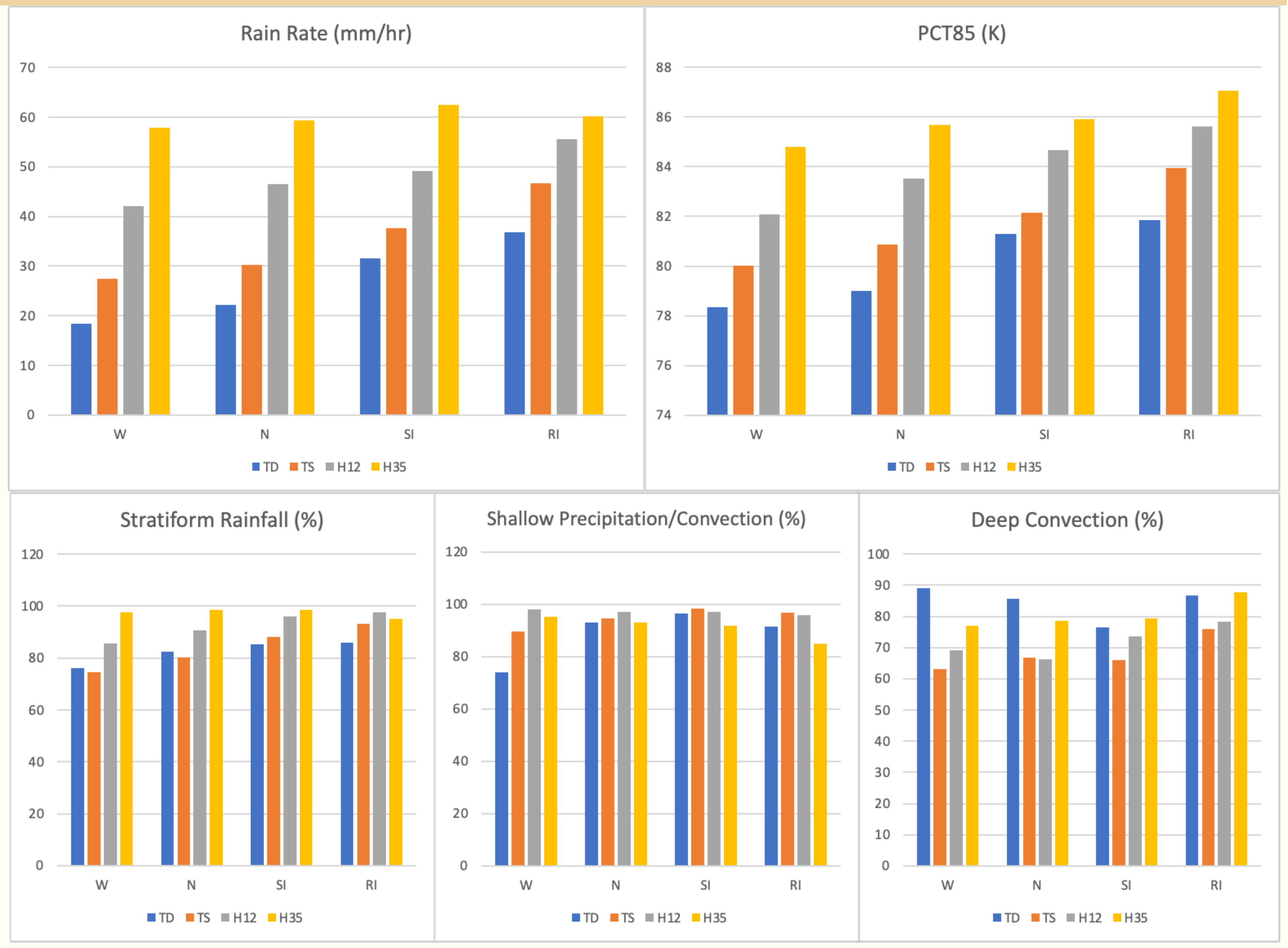
- As shown in the table, the RMR ranges from 41 km to 98 km on average. Similar as the radius of maximum wind, for each TC intensity change category, the RMR decreases with TC intensity. Interestingly, for each TC intensity category (except W-TD versus N-TD and SI-H35 versus RI-H35), the RMR also decreases with the TC intensification rate. In general, RI storms have the smallest RMR.
- In order to cover most of the heavy rainfall and convection in the TC core region and exclude rains from outer-rainbands, 1.7× RMR is applied as TC inner core size.

Averaged Precipitation & Convection Parameters in the Inner Core



- In general, the inner core mean rain rate, convective intensity, and stratiform rainfall occurrence have a statistically significant linear and positive relationship with TC intensification rate.
- For shallow convection, in general, the inner-core averaged shallow precipitation/convection occurrence increases with TC intensification rate for TD and TS, and decreases for H12 and H35.
- With the increase of TC intensity, deep convection occurrence increases. While with the increase of TC intensification rate, no clear linear relationship exists for deep convection.

Averaged Axisymmetric Index of Precipitation & Convection Parameters in the Inner Core



- The inner-core mean axisymmetric index of rain rate and stratiform rainfall occurrence increases significantly with the increase of TC intensification rate for each intensity category, except in the H35 category. The RI-H35 storms have significantly more asymmetric rainfall and stratiform rainfall distributions than SI-H35 storms.
- The degree of symmetry of the TC inner core PCT_{85} increases significantly with 24-h future intensification rate for all TC intensity categories (at least 95% confidence level).
- For TCs with initial intensity in TD, TS, and H35 categories, the RI group has a significantly more asymmetric pattern on shallow convection than the SI group at a 95% confidence level or above.
- For TCs with initial intensity in TD, TS, and H35 categories, the RI group has a significantly more symmetric pattern on deep convection than the SI group at a 95% confidence level or above.

Summary and Conclusions

- **By using 16 years of TMI data, we were able to decouple the dependency of precipitation and convection parameters on TC intensity and that on TC intensification rate.**
- **Generally, a strong, positive, and linear relationship is found between TC intensification rate and the inner-core mean precipitation and convective parameters, including rain rate, convective intensity, and stratiform occurrence. Although the inner-core mean deep convection occurrence increases linearly with TC intensity for each intensity change category, it doesn't have a clear relationship with the TC intensification rate.**
- **It is also found that the symmetry of rain rate, convective intensity, stratiform occurrence except for SI-H35 and RI-H35, and deep convection occurrence in TS, H12, and H35 in the inner core increases linearly with the TC intensification rate.**
- **Interestingly, we found that the RMR decreases with TC intensity and intensification rate.**