Relating Tropical Cyclone Intensification Rate and Inner-Core Features Using 16-yr TMI data

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Background & Motivation

- Precipitation and convection of tropical cyclones (TCs) have been linked with both TC intensity and intensity change in many satellite-based observational studies.
- A strong linear correlation between the inner-core precipitation and convection with TC intensity was found (Cecil and Zipser 1999; Jiang et al. 2019).
- It has been showed that a gradual increase of the degree of symmetry of shallow to moderate precipitation is a precursor of TC rapid intensification (RI) (DeMaria et al. 2012; Kieper and Jiang 2012; Jiang and Ramirez 2013; Zagrodnik and Jiang 2014; Alvey et al. 2015; Tao and Jiang 2015).
- Positive relationships between future TC intensification rate and inner-core convective and precipitation properties were found as well, but the relationships were not linear because the impact of current TC intensity was not removed (Jiang and Ramirez 2013; Zagrodnik and Jiang 2014; Alvey et al. 2015; Tao and Jiang 2015).
- 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.

Objectives

- Following Su et al. (2020)'s method of decoupling the dependency of precipitation and convection parameters on TC intensity and that on TC intensification rate, we will **refine the relationships between TC intensification rate and TC inner-core convective and precipitation parameters** using 16-yr high resolution TRMM TMI data (5 km x7 km spatial resolution)

- We will also **quantify the relationship between TC intensity rate and the symmetry of precipitation and convection features** in the inner core

Data & Methodology

- **TMI data:** 16-year (1998-2013) Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) observations for global TCs (7 km x5 km spatial resolution)
- **Global Best Track (HURDAT2 & JTWC) dataset**
- **The vertical wind shear:** derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis datasets
- **TMI overpass selection criteria:**
  - TMI overpasses must capture the storm center.
  - The storm center must be over water at the current observational time and 24 hours in the future.
  - Storms undergoing extratropical transition are excluded.
- **Overpass classification: 16 categories as follow**
  - 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).

Sample Size

- ***Vmax***: Current TC Maximum Sustained Surface Wind Intensity
- ***Vmax24***: Future 24 h Intensity
- ***Dvmax24* = *Vmax24* – *Vmax***: Future 24 h Intensity Change

# of TMI overpasses	W $Dvmax_{24} \le -10\ kt$	N $-10kt < Dvmax_{24} < 10\ kt$	SI $10kt \le Dvmax_{24} < 30\ kt$	RI $Dvmax_{24} \ge 30\ kt$	Total
TD $0kt < Vmax < 34kt$	**49**	**1666**	**434**	**44**	**2193**
TS $34kt \le Vmax < 64kt$	**727**	**1434**	**862**	**225**	**3248**
H12 $64kt \le Vmax < 96kt$	**697**	**541**	**338**	**188**	**1764**
H35 $Vmax \ge 96kt$	**539**	**297**	**135**	**19**	**990**
Total	**2012**	**3938**	**1769**	**476**	**8195**

- 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).

Parameters Examined

- **TMI 2A12 (GPROF) Rain Rate** (Kummerow et al. 1997)
- **85-GHz Polarization Corrected Brightness Temperature (PCT85),** which is an indicator of total amount of ice. Moderate PCT85 values indicate rain, but very low PCT85 values indicate deep convection (Nesbitt and Zipser 2003).
- **Precipitation type parameters** derived from TMI 37-GHz observations (by following the algorithm by Jiang et al. 2019, JGR) using horizontally polarized T_B (H37) and PCT (PCT37) in the 37 GHz Channel.
  - **% Occurrence of stratiform rainfall**:
    $260 \leq$ PCT37 ≤ 270 and H37 < 225
    Or $260 <$ PCT37 < 275 and H37 ≥ 225
  - **% Occurrence of shallow convection**:
    PCT37 ≥ 275 and H37 ≥ 225
  - **% Occurrence of deep convection**:
    PCT37 ≤ 260

Precipitation type	Region	Definition (T_B in K)
Precipitation-free	1 (green)	PCT37 > 270 and H37 < 225
Shallow convection or weak stratiform precipitation	2 (weak cyan)	PCT37 ≥ 275 and 225 ≤ H37 < 255
Shallow convection	3 (bright cyan)	PCT37 ≥ 275 and H37 ≥ 255
Stratiform precipitation	4 (green/pink)	260 < PCT37 ≤ 270 and H37 < 225
	5 (weak cyan/pink)	260 < PCT37 < 275 and 225 ≤ H37 < 255
	6 (bright cyan/pink)	260 < PCT37 < 275 and H37 ≥ 255
Deep convection	7 (pure pink)	PCT37 ≤ 260

(From Jiang et al. 2019)

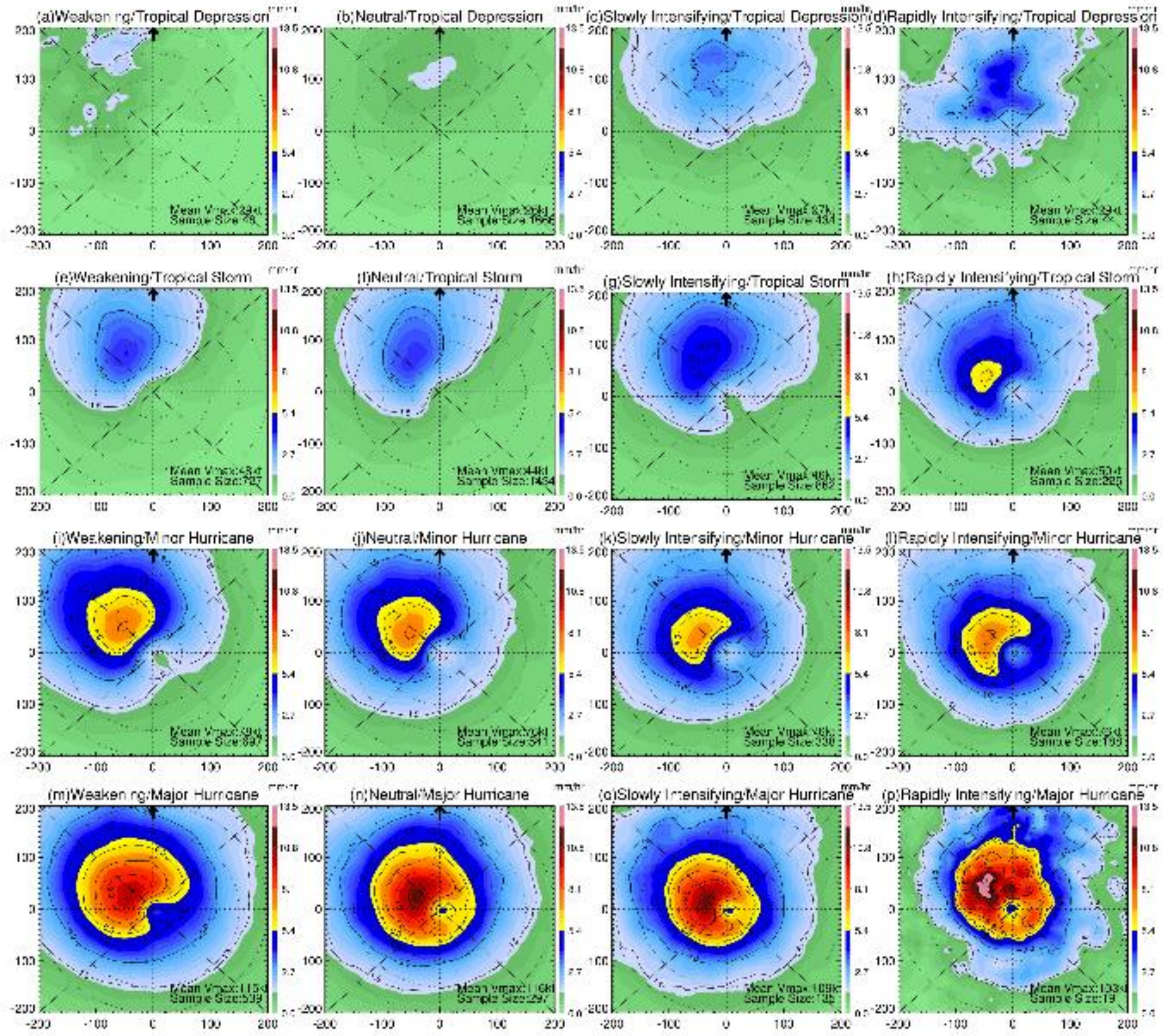
- **Axisymmetric Index** (γ, Miyamoto and Takemi 2013 and Shimada et al. 2018):

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

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.

Composite Shear-Relative Distribution of Rain Rate

W N SI RI



TD

TS

H12

H35

Shear pointing upward

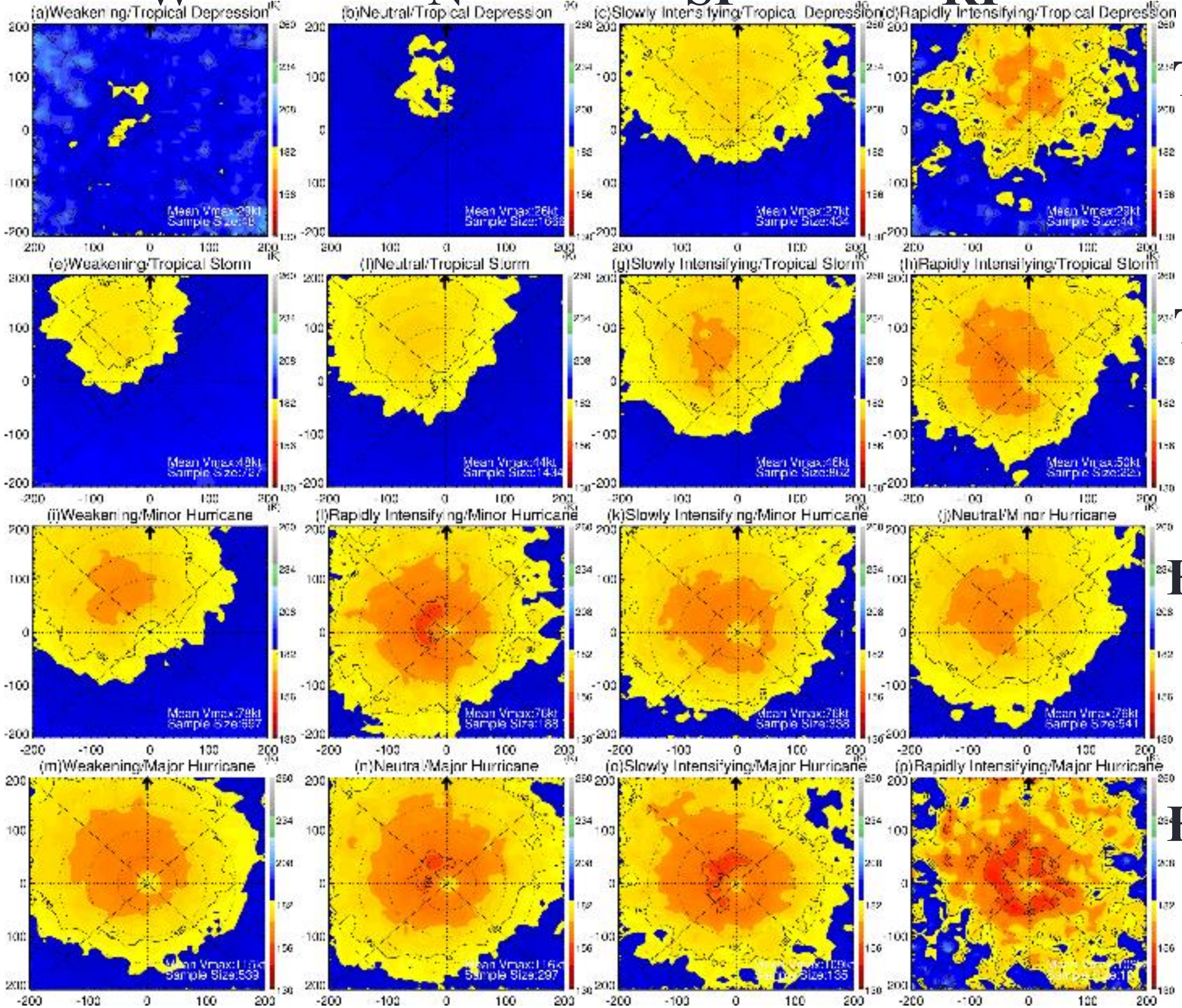
For each TC intensity change category, the mean rain rate increases with TC intensity, from tropical depression to major hurricane.

For each TC intensity category, the rain rate increases with intensification rate, from weakening to neutral, to slowly intensifying, and then reach the maximum in the rapidly intensifying stage.

Generally, as TC intensity and intensification rate increases, rainfall distribution gets more spread out from down-shear and left-shear quadrants to up-shear and right-shear quadrants.

Composite Shear-Relative Distribution of PCT85

W N SI RI



TD

TS

H12

H35

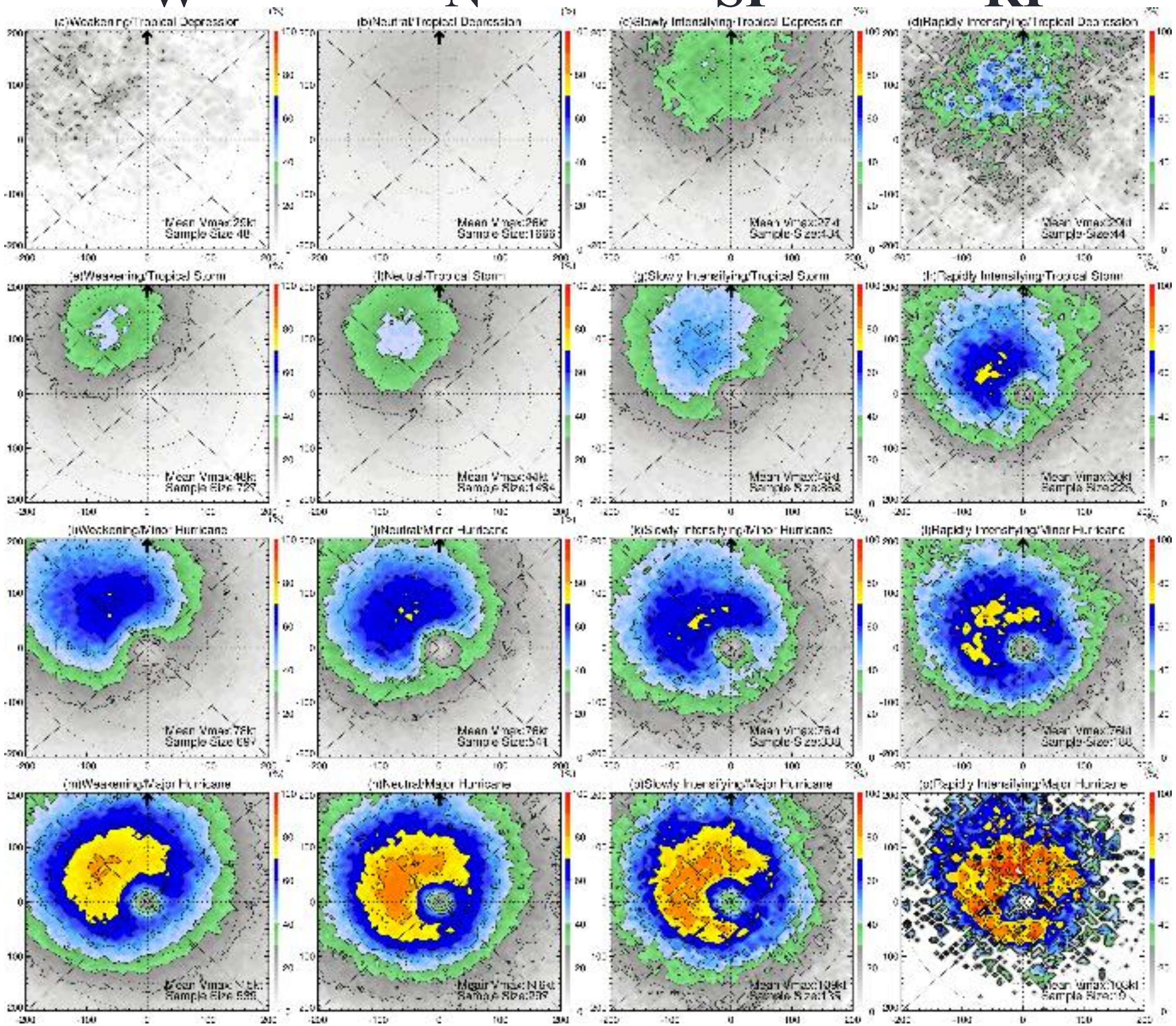
Shear pointing upward

The mean value of 85-GHz PCT decreases (indicating that moderate rainfall or convective intensity increases) with the increasing of both TC intensity and intensification rate.

Similar as the rainfall distribution, as TC intensity and intensification rate increases, the 85-GHz PCT distribution gets more spread out from down-shear and left-shear quadrants to up-shear and right-shear quadrants.

Composite Shear-Relative Distribution of Stratiform Occurrence

W N SI RI



TD For each TC intensity change category, with TC intensity increasing, the stratiform rainfall occurrence becomes larger.

TS For each TC intensity category (except for TDs), the stratiform rainfall occurrence increases with the increasing of TC intensification rate.

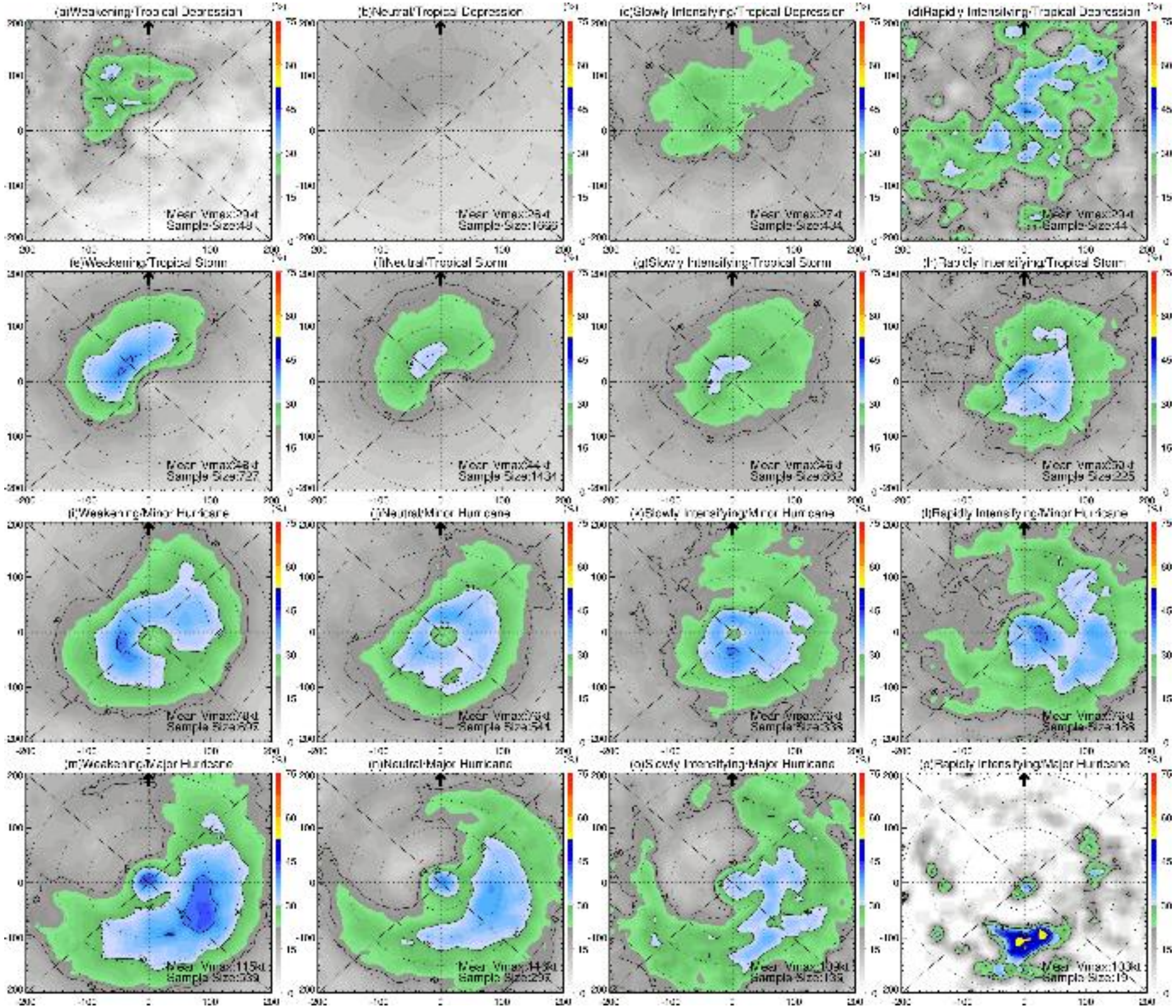
H12 Similar as the rainfall distribution, as TC intensity and intensification rate increases, The distributions of stratiform rainfall occurrence gets more spread out from down-shear and left-shear quadrants to up-shear and right-shear quadrants.

H35

Shear pointing upward

Composite Shear-Relative Distribution of Shallow Convection Occurrence

W N SI RI



TD

TS

H12

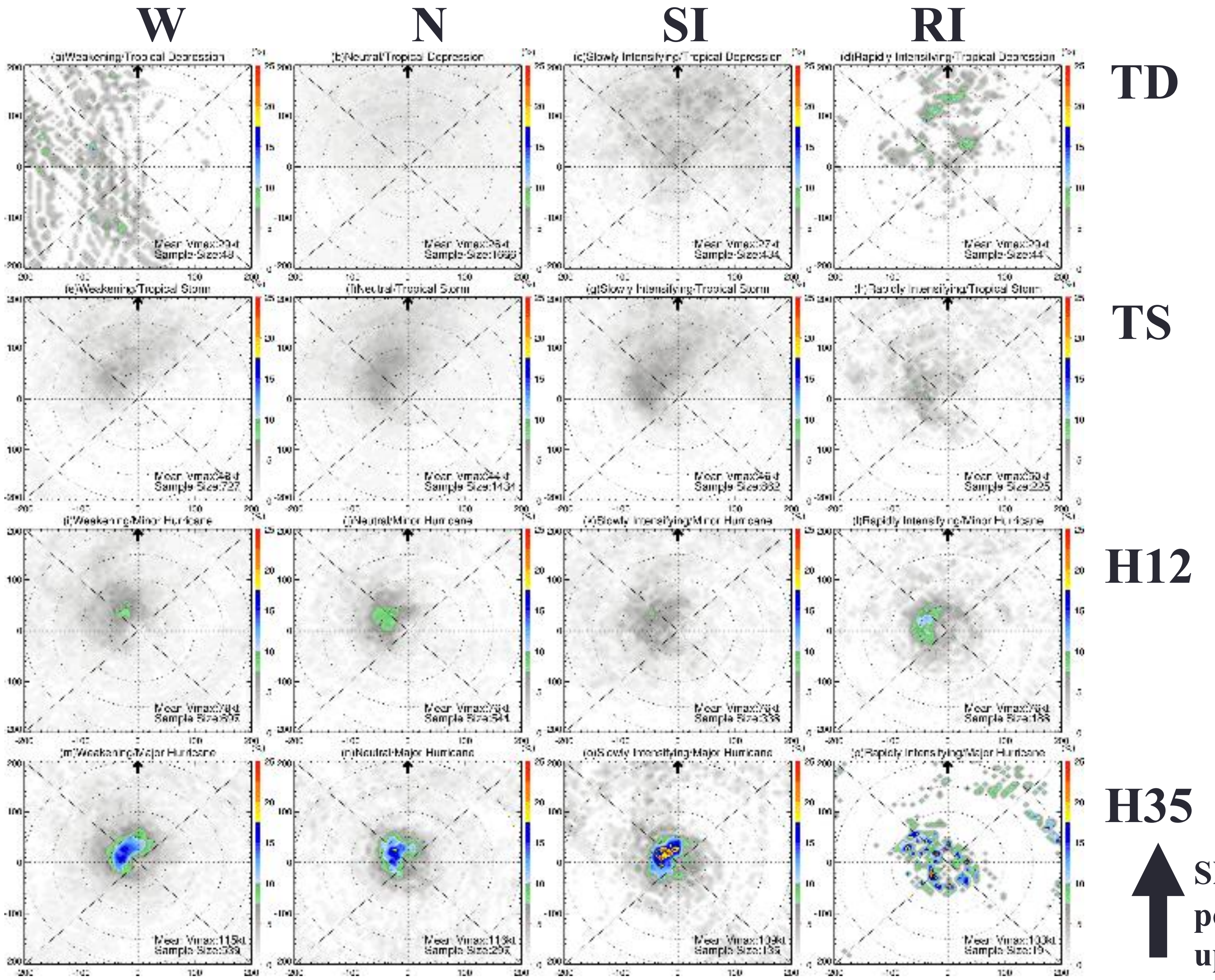
H35

The maximum percentage of shallow convection occurrence occurs in minor hurricanes. No clear relationship is seen with either TC intensity or intensification rate.

The distribution of the shallow convection occurrence rotates from down-shear-left to up-shear-right from low intensity and intensification rate categories to high intensity and intensification rate categories.

Shear pointing upward

Composite Shear-Relative Distribution of Deep Convection Occurrence



For minor and major hurricanes, deep convection is mainly concentrated within the 100-km from the TC center.

The magnitude of deep convection occurrence increases with both TC intensity and intensification rate.

A highly symmetric pattern of deep convection is seen for the RI/major hurricane category.

Shear pointing upward

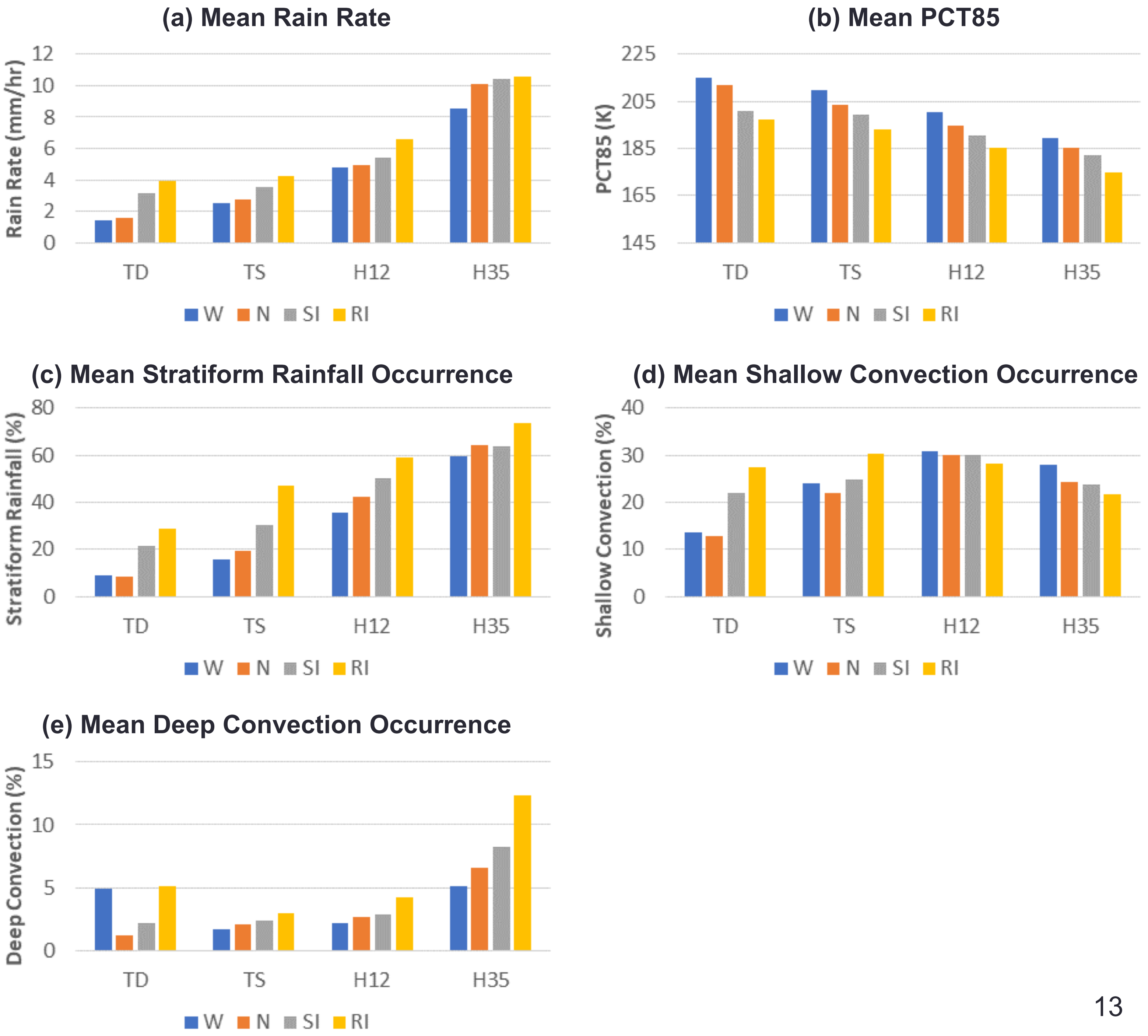
Radius of Maximum Azimuthally Averaged Rain Rate (RMR)

Mean RMR (km)	**W** $Dvmax_{24} \leq -10\ kt$	**N** $-10kt < Dvmax_{24} < 10\ kt$	**SI** $10kt \leq Dvmax_{24} < 30\ kt$	**RI** $Dvmax_{24} \geq 30\ kt$
TD $0kt < Vmax < 34kt$	**115**	**95**	**65**	**55**
TS $34kt \leq Vmax < 64kt$	**65**	**65**	**65**	**45**
H12 $64kt \leq Vmax < 96kt$	**65**	**55**	**55**	**45**
H35 $Vmax \geq 96kt$	**45**	**35**	**35**	**45**

- As shown in the table, the RMR ranges from 45 km to 115 km on average. Similar as the RMW, for each TC intensity change category, the RMR decreases with TC intensity. Interestingly, for each TC intensity category (except for major hurricanes), the RMR also decreases with TC intensification rate. In general, RI storms have the smallest RMR.
- In the next two slides, we'll use 1.7*RMR for each TMI overpass as the TC inner core size.

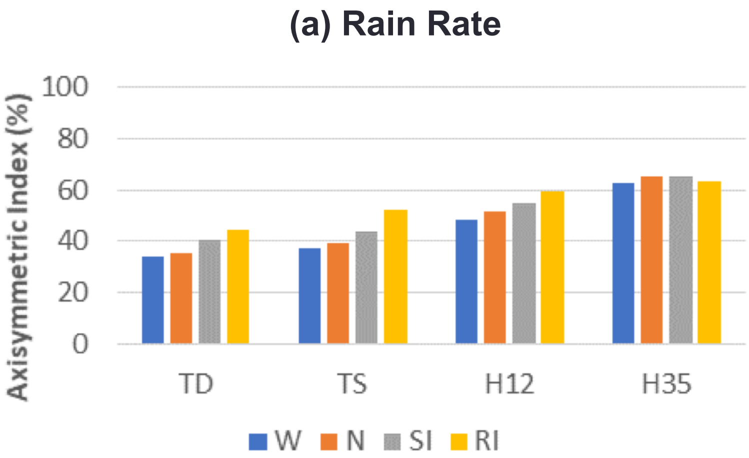
Averaged Precipitation & Convection Parameters in the Inner Core

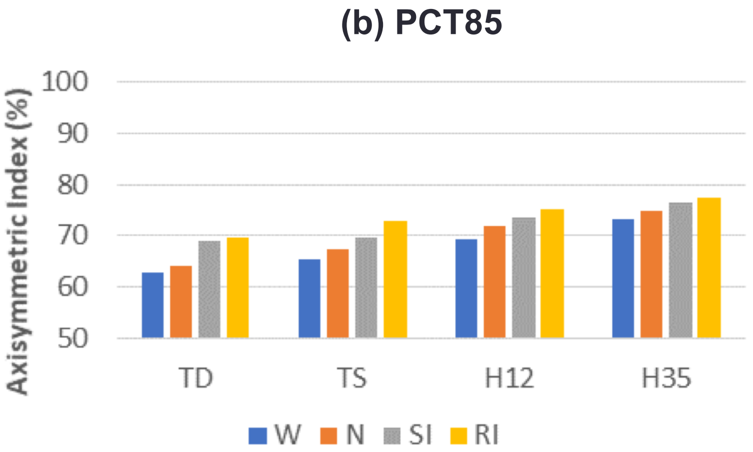
- Generally, there are strong positive & linear relationships between TC intensity/intensification rate and the inner-core mean precipitation and convective parameters, including rain rate, convective intensity, stratiform occurrence, and deep convection occurrence.
- The mean shallow convection occurrence doesn't have a clear relationship with TC intensity or intensification rate:
  - For TD & TS, the relationship is positive, while for minor and major hurricanes, it is negative.

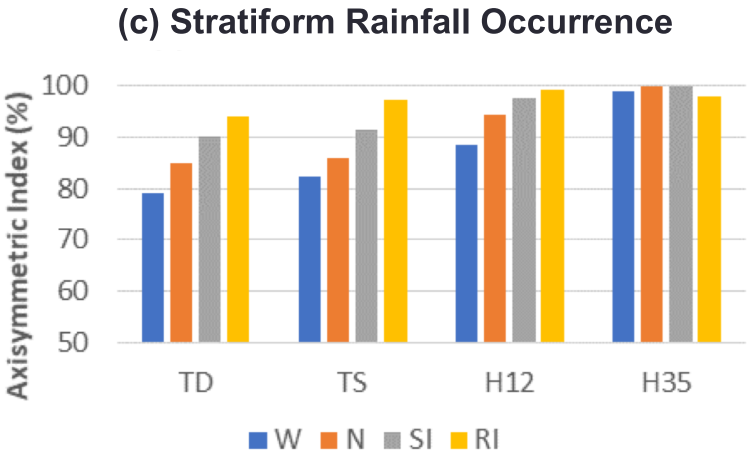


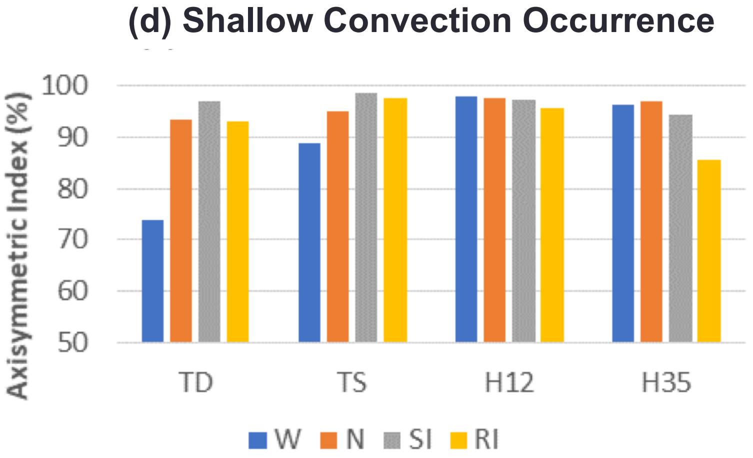
Axisymmetric Index of Precipitation & Convection Parameters in the Inner Core

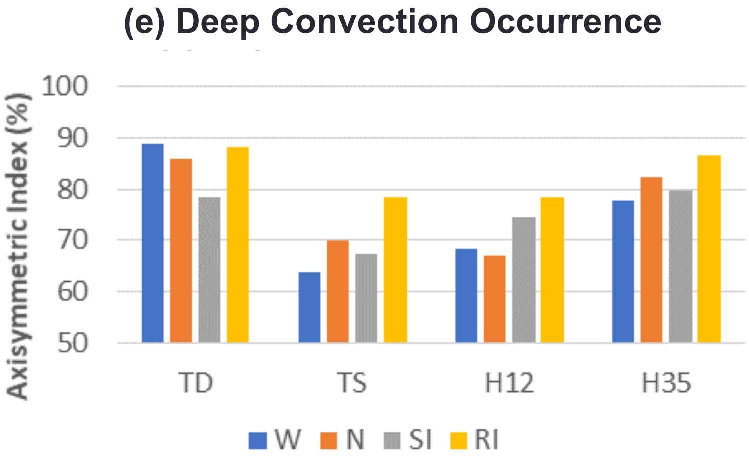
- Generally, the degree of symmetry of **rain rate, convective intensity, stratiform occurrence, and deep convection occurrence** in the inner core increases linearly with both TC intensity and intensification rate.
- Small exceptions are seen in the rain rate and stratiform occurrence parameters for the RI/H35 category probably due to the very strong down-shear-left enhancement as seen in the 2D composite plot.
- Unexpected high values of the axisymmetric index of the deep convection occurrence for TDs are probably due to the contamination by surrounding convections in these weak TC systems.











- No clear relationship is found between the axisymmetric index of shallow convection occurrence and TC intensity/intensification rate.

Conclusion

- 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.
- 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, stratiform occurrence, and deep convection occurrence.
- It is also found that the symmetry of rain rate, convective intensity, stratiform occurrence, and deep convection occurrence in the inner core increases linearly with the TC intensification rate.
- Interestingly, we found that the RMR, an alternate measure of RMW decreases with TC intensification rate.
- These results could be used to develop a statistical model to predict TC intensification and RI using satellite rainfall estimates.