Necessary Conditions for Rapid Intensification as Derived from 11 Years of TRMM Tropical Cyclone Precipitation Feature (TCPF)

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Motivation

- Previous studies suggest that both rainfall **(Rao and MacArthur 1994, Cecil and Zipser 1999)** and convective intensity indicated by IR cloud top Tb, lightning, and radar reflectivity profiles **(Steranka et al. 1986, Lyons and Keen 1994, Simpson et al. 1998, Kelley et al. 2004 &2005, Molinari et al. 1999, Jiang 2012)** in the inner core are related to tropical cyclone (TC) intensity change.
- However, no comprehensive comparisons have been made to distinguish the relative importance of total rainfall and deep convection in the inner core to TC intensity change, especially rapid intensification (RI).

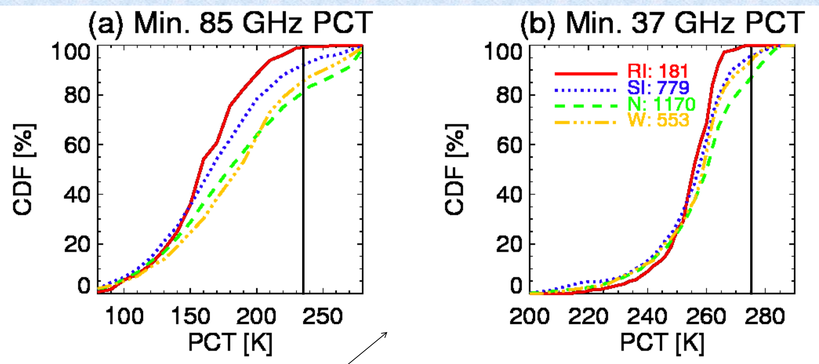
Objectives of This Study

- What's the necessary condition for RI in terms of inner core properties? Is extremely intense convection, such as how towers, necessary? Sufficient?
- Quantitative comparison of rainfall and convective properties derived from one single satellite platform – TRMM in terms of their relationships to TC intensity changes: Rapidly Intensifying (RI), Slowly Intensifying (SI), Neutral (N), and Weakening (W).
- Convective properties: radar dBZ profile, 85/37 GHz PCT **(Spencer et al. 1989, Cecil et al. 2002),** and lightning;
- Rainfall properties: rain rate, raining area, volumetric rain.

Data

- TRMM Tropical Cyclone Precipitation Feature (TCPF) database **(Liu et al. 2008, Jiang et al, 2011)**: **http://tcpf.fiu.edu**
- Collocated TRMM observations (PR, TMI, LIS, & VIRS) in TCs between 1998-2008; only considering observations **over ocean**.
- Three sub-regions are subjectively separated, i.e., inner core (IC), inner rainband (IB), and outer rainband (OB) by following **Cecil et al. (2002).**
- Only parameters within the **inner core** region are analyzed (except for the lightning analysis).

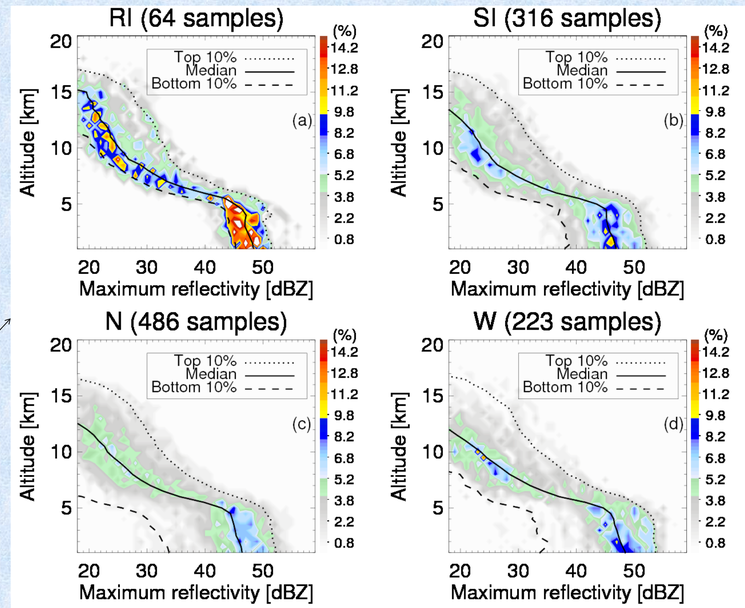
Passive Microwave Convective Properties: 85/37 GHz PCTs



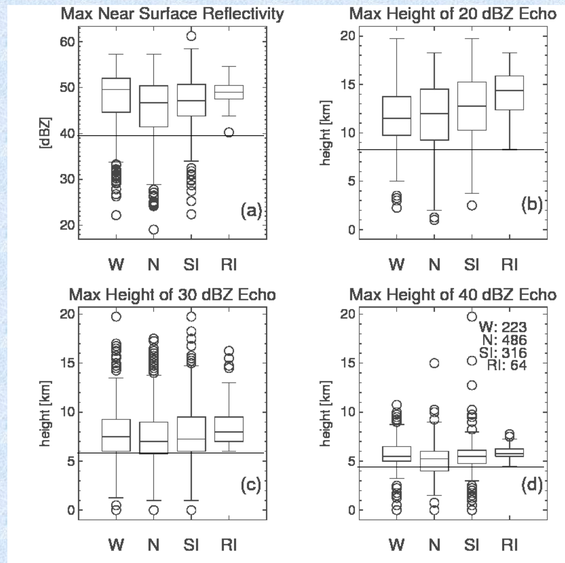
- RI storms do not necessarily have the strongest convection in the inner core.
- Necessary conditions for RI: min 85 PCT < ~235K; min 37 GHz PCT < ~275K.

- The distribution is highly concentrated around the median profile for RI storms, but spreads out for other intensity change categories.
- About 50% of RI storms have hot towers (defined as 20 dBZ height > ~14 km) in the inner core, while the other 50% do not. Other categories have lower % of hot towers .

CFADS of Maximum Radar Reflectivity

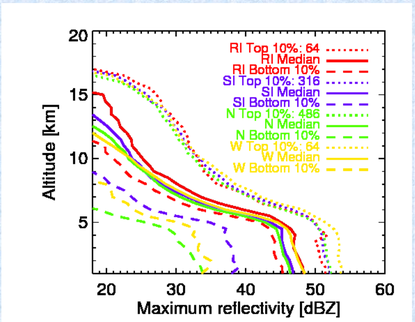


Box and Whisker Plots of Reflectivity Parameters



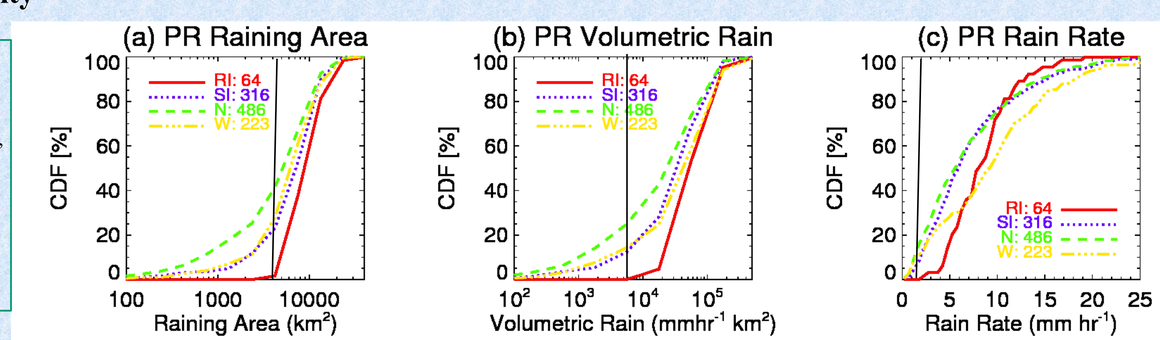
- Necessary conditions for RI :
  1) Max. near sfc dBZ > ~40 dBZ (>~20-25 dBZ for SI, N, W storms)
  2) Max. 20 dBZ height > ~8 km (> ~2-4 km for SI, N, W storms)
  3) Max. 30 dBZ height > ~6 km (> 0 km for SI, N, W storms)
  4) Max. 40 dBZ height > ~4 km (> 0 km for SI, N, W storms)

Top 10%, Median, and Bottom 10% of Vertical Profiles of Maximum Radar Reflectivity



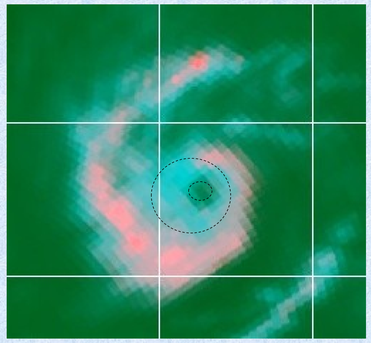
- The largest distinction is the bottom 10th percentile, where RI storms have much stronger dBZ profiles than SI, N, and W storms

TRMM Radar Rainfall Properties

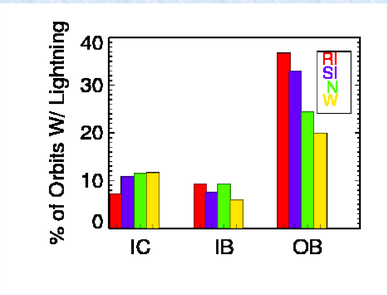


- RI storms always have the largest raining area & volumetric rain in the inner core, followed by SI, W, and N storms.
- Rain rate in the inner core is not well related to TC intensity change.
- Necessary conditions for RI: inner core raining area > ~4,000 km^2; volumetric rain> 5,000 mm/h km^2; rain rate > 2 mm/h

Consistent with the Warm Rain Ring Feature Associated with RI

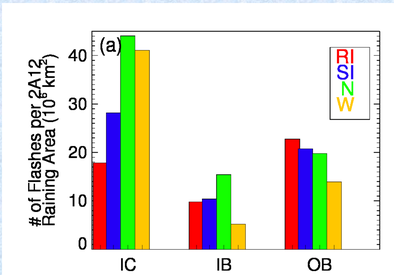


% of TC Orbits with Lightning



- **RI** storms have the **lowest %** of TC orbits having at least one flash in the **inner core**, while the weakening storms have the highest %.
- RI storms have the **highest** % of TC orbits w/ lightning in the **outer rainband** region, while the weakening storms have the lowest %.

Flash Density (per Raining Area)



- **RI** storms have the **lowest** flash density in the **inner core**, but the **highest** in the **outer rainband** region.
- Lightning (IC & GC total) activities in the inner core (outer rainband) is negatively (positively) correlated to TC intensity change, consistent with *DeMaria et al. (2012),* but inconsistent with *Molinari et al. (1999 GC only)*.
- Lightning has double peaks, one in the IC and the other in the OB. This study found that IC's peak is larger than OB's peak, again inconsistent with *Molinari et al. (1999)*.

Summary

- RI storms do not necessarily have stronger convective intensity in the inner core than storms in other intensity change stages. Extremely intense convection (e.g. hot towers) is neither necessary nor sufficient condition for RI, although % of hot towers is the highest in RI storms.
- Instead, this study found that larger raining area and volumetric rain in the inner core are necessary conditions for RI. Moderate convective intensity is also a necessary condition.
- Symmetric, well-organized inner core precipitation structure is the key for RI.
- Total lightning (including in-cloud, intra-cloud, and cloud-to-ground) activities in the **inner core** (*outer rainband*) has a **negative** (*positive*) relationship with storm intensity change.

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