Comparing Tropical Cyclone Rainfall Distribution and Asymmetries Before, During, and After Landfall Using 20-Year NASA IMERG Observations

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Introduction & Motivation

1. Rainfall-induced flooding from tropical cyclones (TCs) remains a significant cause of damages along the coasts (*Willoughby, 2012; Rapport, 2014*). Therefore, a better understanding of the precipitation patterns at different landfalling stages is an extremely important task.
2. Most of the previous studies have been mainly focusing on **TC rainfall over ocean** (*Lonfat et al. 2004; Chen et al. 2006; Rogers et al. 2003; Ueno 2007; Cecil 2007; Wingo & Cecil 2010; Pei and Jiang 2018*)
3. There are a few statistical studies about TC landfall rain, but mainly focusing on **rainfall asymmetries, not rainfall magnitude & raining area** (*Jiang et al. 2008, Xu et al. 2014, and Yu et al. 2017*)
4. Recently, *Touma et al. (2019)* found that the **highest rainfall intensity and the largest rainfall area over land occur when major hurricanes have weakened to tropical storms**, resulting in greater flood risk despite the weaker wind speeds. However, their study was using daily accumulates of rain gauge measurements over the land only.

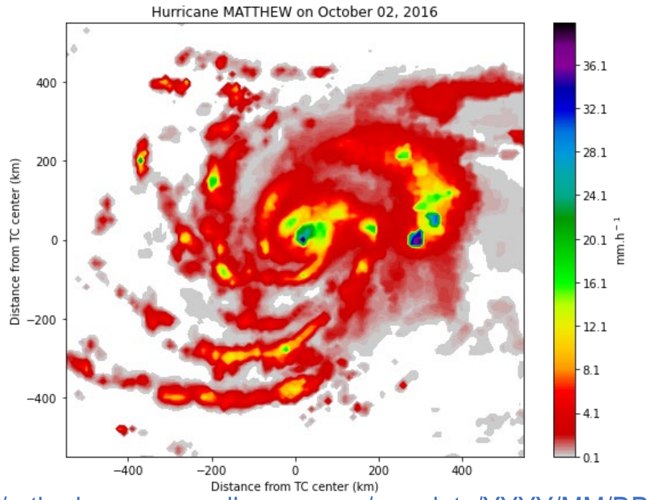
Therefore, the motivation of this study is to:

1) Refine the global TC rainfall climatology at different landfalling stages by using 20 years of NASA satellite observations, which have much higher spatial & temporal resolutions and larger spatial coverage than the rain-gauge data;

2) Compute TC rainfall intensity and raining area at post-landfall stage and compare with Touma et al. (2019, GRL)'s results.

Datasets

TRMM/GPM IMERG Rainfall Estimates

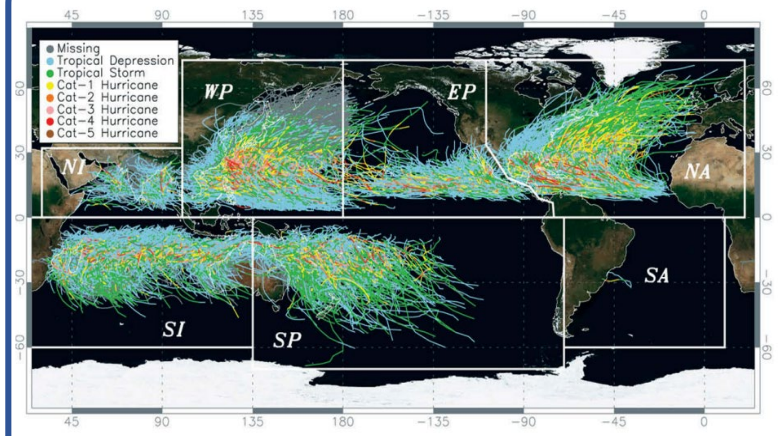


ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/YYYY/MM/DD/imerg/

NASA Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM) mission: **(IMERG)** datasets (**Huffman et al. 2019, 2020**):

- 30-Minute datasets, but only 3-hourly was used.
- 0.1 x 0.1-degree, pixel size.
- WGS84 coordinate systems assumed

International Best Track Archive



doi:10.1175/2009BAMS2755.1

International Best Track Archive for Climate Stewardship datasets (**IBTrACKS Vr.4, Knapp et al. 2010**):

- 3-Hourly.
- 27 storm attributes in seven different basins

Data period: 2000-2019 (20-yr)

- Total 1850 TCs in 6 global TC-prone basins
- Includes 750 landfalling TCs

Geospatial Datasets are also employed from https://international.ipums.org/international/index.shtml, and Cartopy. v0.11.2. 22-Aug-2014. Met Office. UK. https://github.com/SciTools/cartopy/archive/v0.11.2.tar.gz

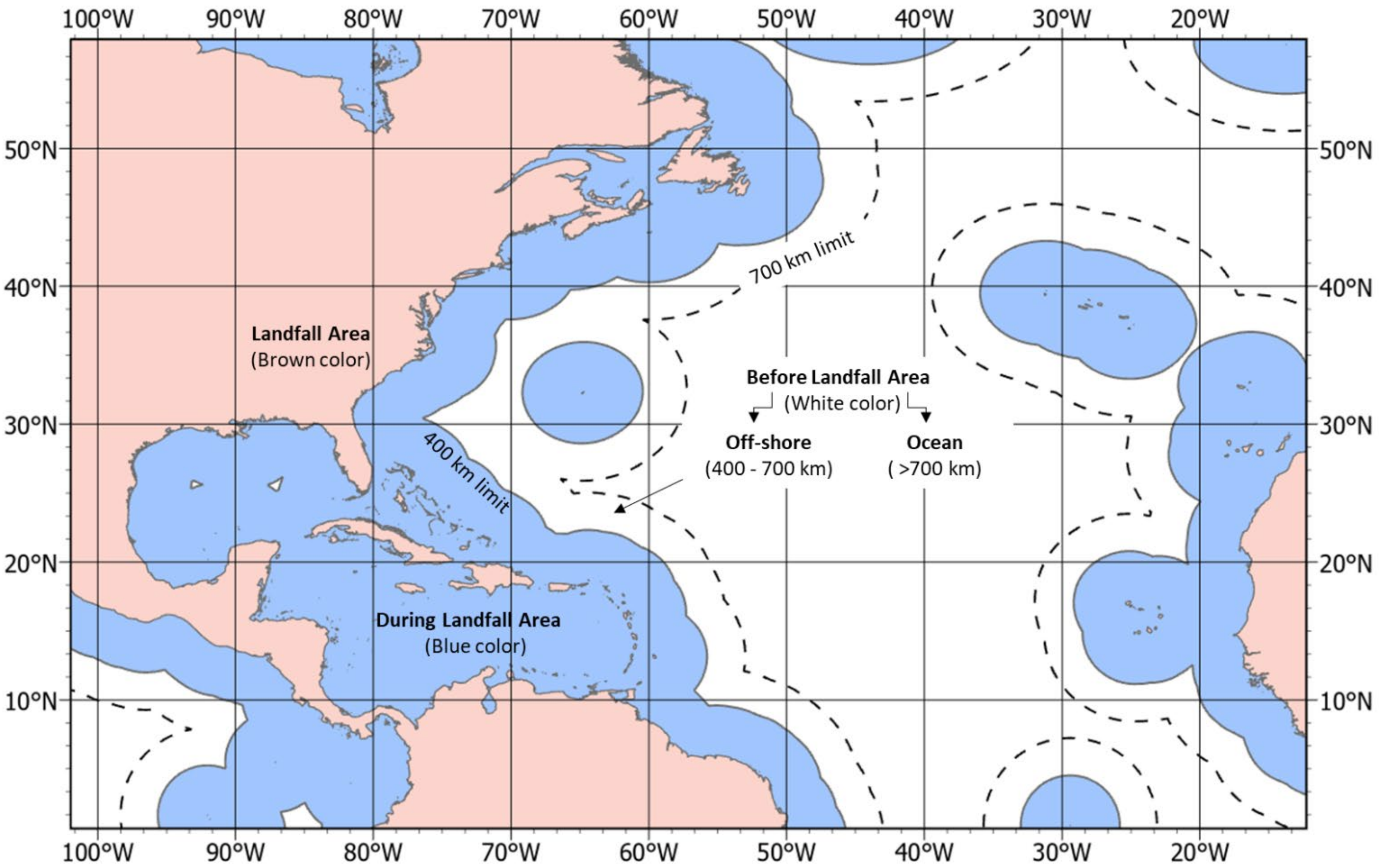
Methodology

1. **TC raining area definition:** Objectively define TC raining area from IMERG data (2000-2019) by following a precipitation feature based method, in which the center of rain cells are within 500-km of TC center (Jiang et al. 2011)
2. **Definition of 7 stages relative to landfall through a new approach that combine the strengths of three previous researches (next slide)**
    - Jiang et al. (2008), Xu et al. (2014), and Yu et al. (2017)
3. **Separation of IMERG overpasses using the following criteria:**
    - By 6 basins: ATL, ECPA, NWP, NIO, SIO, SPA
    - By TC intensity: Tropical depression (TD), Tropical storm (TS), minor hurricane (CAT12), & major hurricane (CAT35)
    - By 7 landfall stages:

Methodology (Cont.) – Landfall Classification

Proposed for This Study

Before Landfall:	**Ocean:** TC center >700km away from coast	
	Off-shore: TC center 400~700km away from coast	
During Landfall (Pre-land): TC center 0~400km away from coast	**Pre-land I:** TC raining area <50% over land	
	Pre-land II: TC raining area ≥50% over land	
After Landfall (Aft-land): TC center is over land	**Aft-land I:** TC raining area <50% over land	
	Aft-land II: TC raining area ≥50% & <100% over land	
	Aft-land III: TC raining area 100% over land	



Methodology (Cont.) – IMERG Sample Size

Results TC Rainfall Intensity (mm/hr) at Different Landfall Stages

Proposed for This Study

Before Landfall:	**Ocean:** TC center >700km away from coast
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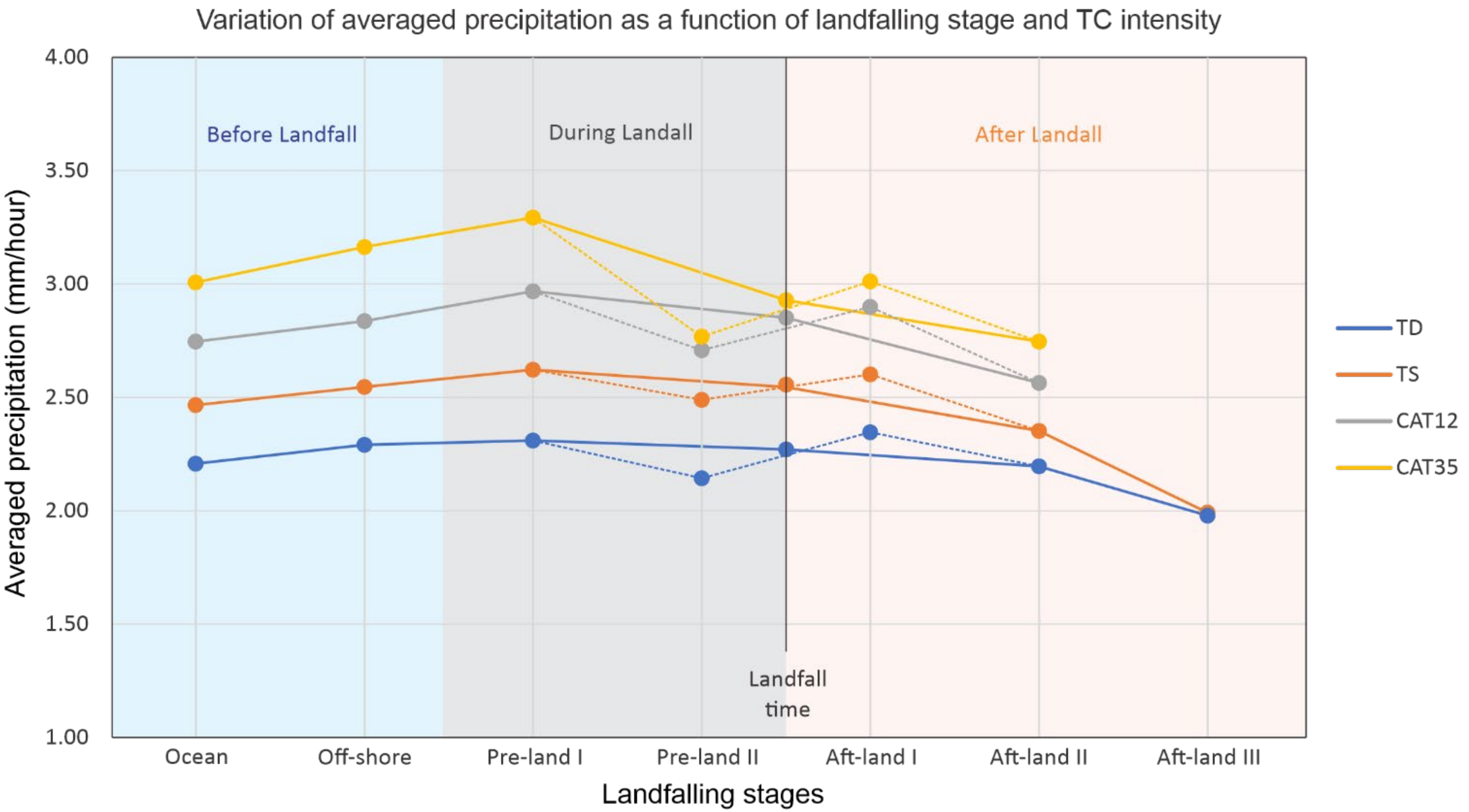
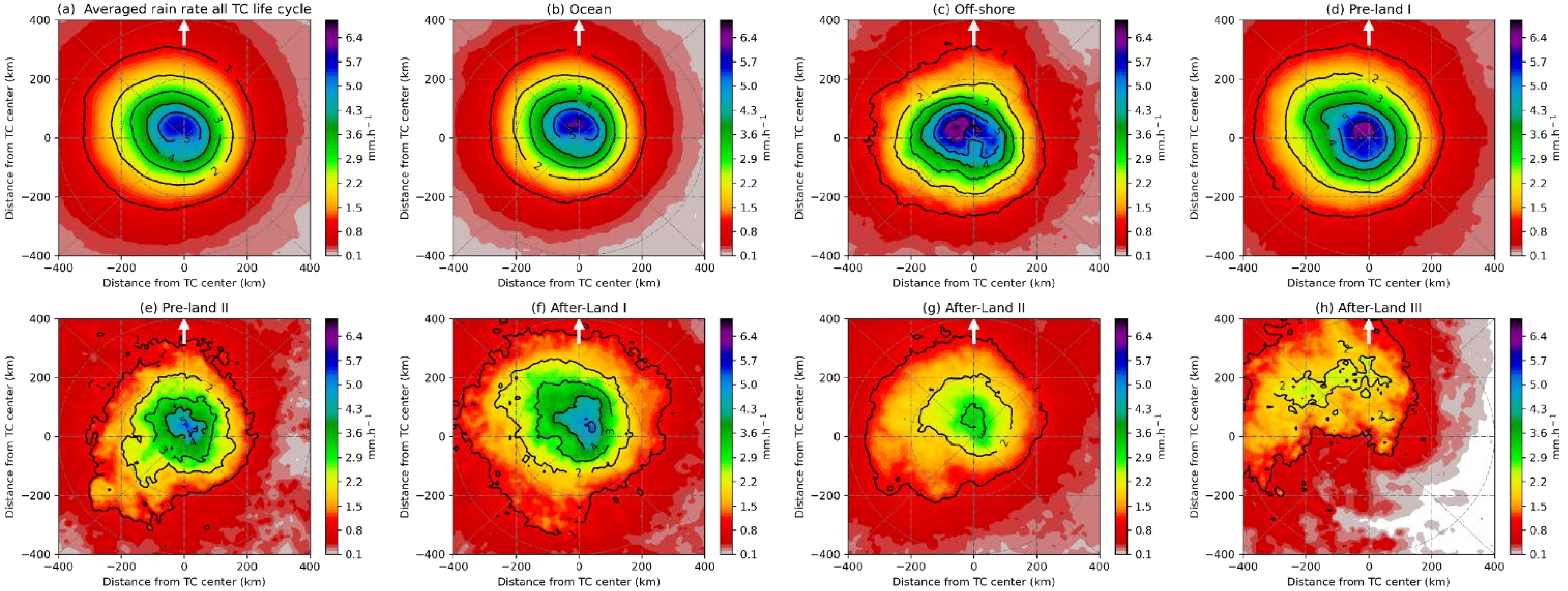


- **The TC rainfall intensity increases from before landfall to during landfall, but decreases steadily from pre-land II to after-land. This trend is consistent among different TC intensity categories.**

Results (Cont.) **Shear-relative composites of rainfall in the different landfalling stages**

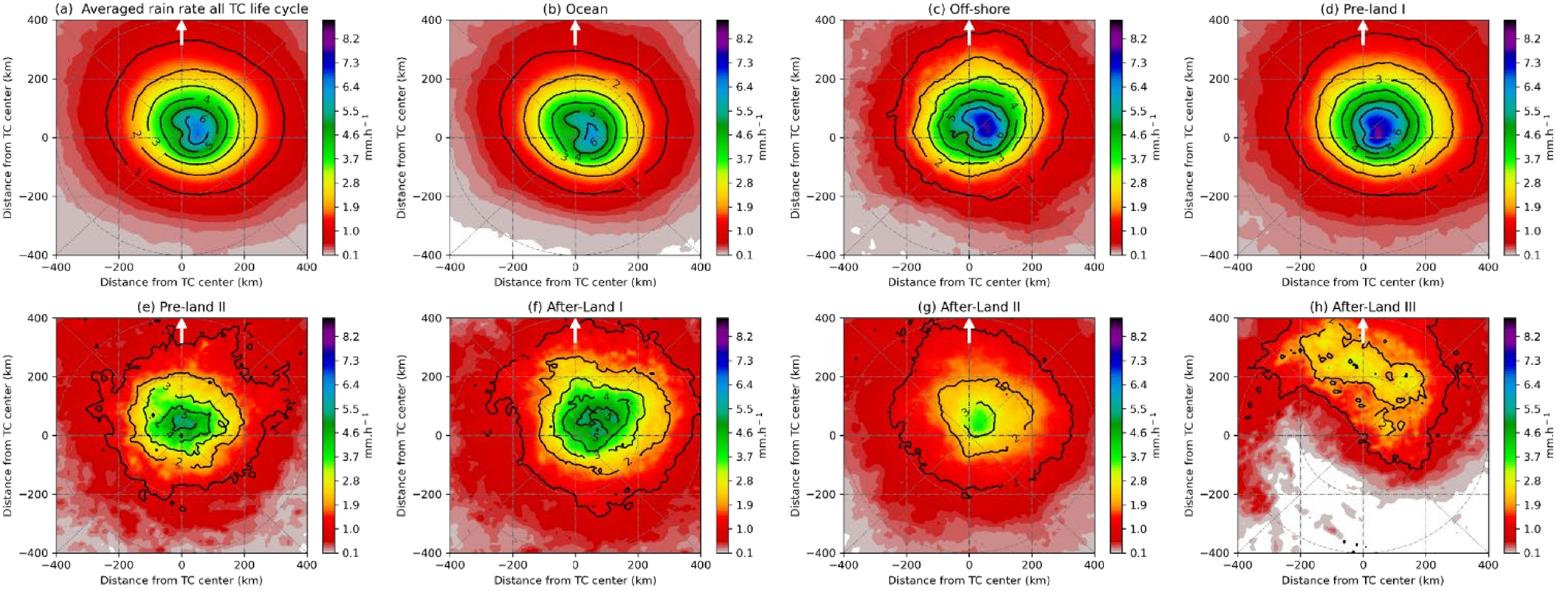
<u>Wind shear-relative plots</u> (Wind shear vector is pointing upwards)



Before landfall & Pre-land I: Down-shear Left; **Pre-Land II & After-land I:** Down-shear-right;
After-land II & III: down-shear then DL**.** Decreased rainfall intensity and enlarged raining area are seen after the Pre-Land II stage.

Results (Cont.) **Motion-relative composites of rainfall at different landfall stages**

Motion-relative plots (Direction of motion vector is pointing upwards)

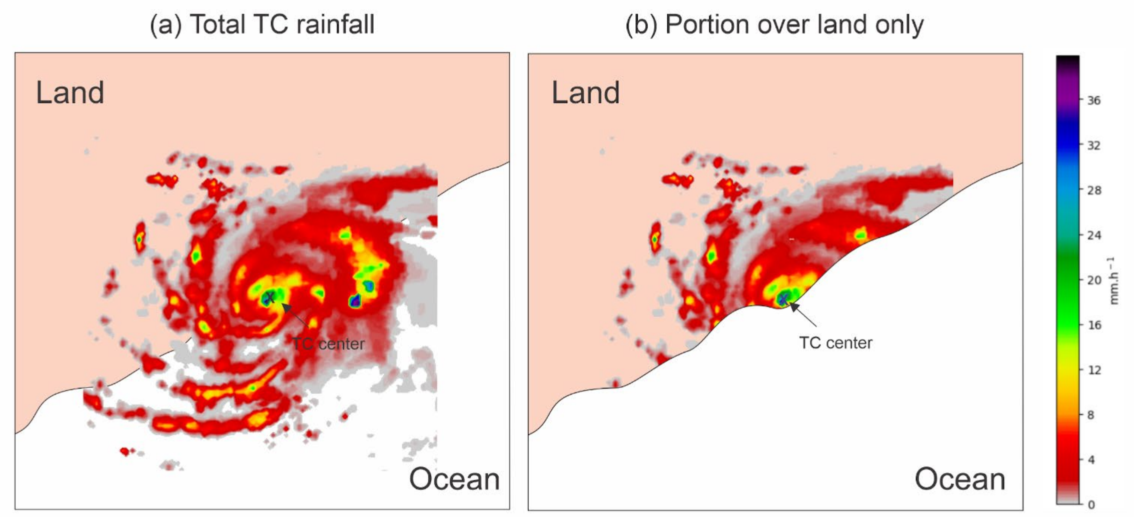


The asymmetry pattern is mainly **Down-Motion Right** except for **After-land III stage**, which is mainly **down motion**. Decreased rainfall intensity and enlarged raining area are after the Pre-land II stage.

CI/LMI Classification

1. **To compare with Touma et al. (2019) results, we further classify IMERG TC samples using a current intensity (CI) / lifetime maximum intensity (LMI) scheme**
   - 10 categories: TD/TD, TD/TS, TD/CAT12, TD/CAT35, TS/TS, TS/CAT12, TS/CAT35, CAT12/CAT12, CAT12/CAT35, and CAT35/CAT35.
   - For example, TS/CAT35 means that the current TC intensity at the IMERG observation time is TS, while the storm's LMI is major hurricane (CAT35).

2. **Then compute averaged TC rain rate, raining area, and volumetric rain (=rain rate * raining area) for over land portion of TC rainfall only for global TCs at 3 After-Landfall stages (Aft-Land I, II, & III).**



Results (Cont.) TC rain rate, raining area, and volumetric rain (Global)

Point Intensity/ LMI	Sample size	Average rain rate $mm.h^{-1}$	Average TC area km^2	Volumetric rain $mm.km^2.hr^{-1}$
TD/TD	146	2.13	267,508	595,715
TD/TS	1,105	2.18	283,009	599,036
TD/CAT12	399	2.22	251,954	524,224
TD/CAT35	387	2.37	**349,138**	**729,524**
TS/TS	602	2.50	274,831	621,434
TS/CAT12	632	2.60	273,169	634,463
TS/CAT35	653	2.62	**301,909**	**718,013**
CAT12/CAT12	129	3.37	254,426	651,937
CAT12/CAT35	426	3.46	243,429	702,966
CAT35/CAT35	130	3.97	205,698	629,466

Highest TC Overland Rainfall Intensity: CAT35/CAT35 (different with Touma et al. 2019's TS/CAT35)

Highest TC Overland Raining Area: TD/CAT35 & TS/CAT35 (same as Touma et al. 2019)

Highest TC Overland Volumetric Rain: TD/CAT35 & TS/CAT35

- **LMI is critical:** the averaged rain rate increases with LMI when the current intensity is the same.
- **Highest TC overland rainfall intensity, raining area, and volumetric rain are all from TCs with a LMI of major hurricane strength.**

Conclusions

- TC rainfall intensity increases from before landfall to during landfall, but decreases steadily from pre-land to after-land. This trend is consistent among different TC intensity categories.
- The asymmetry of TC rainfall shows down-shear-left maxima for both before and during landfalling stages. However, at during landfall and After-land stages, the precipitation maxima shift from down-shear-right, to down-shear, then to down-shear-left, with decreased rainfall intensity and enlarged raining area.
- Relative motion direction, TCs preserve the down-motion-right maxima during most of the landfalling process. However, at the After-land III stage, the precipitation maximum is down-motion only.

Conclusions (Cont.)

- The lifetime maximum intensity (LMI) of a TC is critical to determine its flooding potential over land. With the same current intensity, stronger LMI implies larger overland rain rate.
- Similar to Touma et al. (2019), we found that TCs at TD or TS intensity stages with a LMI of major hurricane strength produced the largest overland raining area and highest overland volumetric rain.
- However, in contrast to Touma et al. (2019), we found that TCs at major hurricane intensity stage with a LMI of major hurricane strength produced the highest overland rainfall intensity.

References:

Guzman, O. and H. Jiang, 2022: Climatology of Tropical Cyclone Rainfall Magnitude at Different Landfalling Stages: An Emphasis on After Landfall Rain. *J. Appl. Meteor. Climatol.*, under minor revision.

Touma, D., Stevenson, S., Camargo, S. J., Horton, D. E., & Diffenbaugh, N. S. (2019). Variations in the intensity and spatial extent of tropical cyclone precipitation. *Geophysical Research Letters,* 46, 13992– 14002. https://doi.org/10.1029/2019GL083452

Thanks!

Acknowledgments

Back-up

- Touma et al. (2019)’s result said that the highest TC overland rainfall intensity was from TS/CAT35, which is different with our result that the highest TC overland rainfall intensity is from CAT35/CAT35.

- There are two possible reasons:
  - 1) Their ”rainfall intensity" was actually defined as “daily accumulation mm/day”, not the real instantaneous rainfall intensity as measured by satellite.
  - 2) Rain gauge data might not be optimal to measure rainfall from major hurricanes (rain gauges could be destroyed by the strong winds of major hurricanes).