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Convective and Microphysical Characteristics of Extreme Precipitation Revealed by Multisource Observations over the Pearl River Delta at Monsoon Coast

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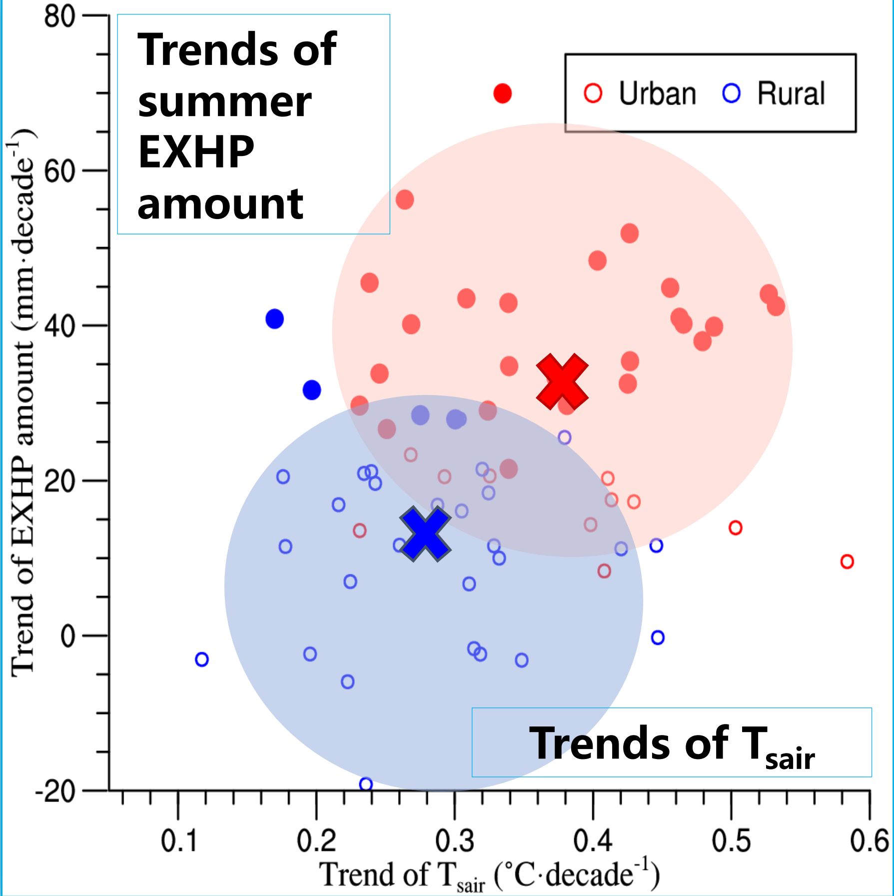
Outline

- **Background & objective**
- **Data & methods**
- **Results**
- **Conclusions**

Background: Great challenges in prediction and projection of extreme precipitation

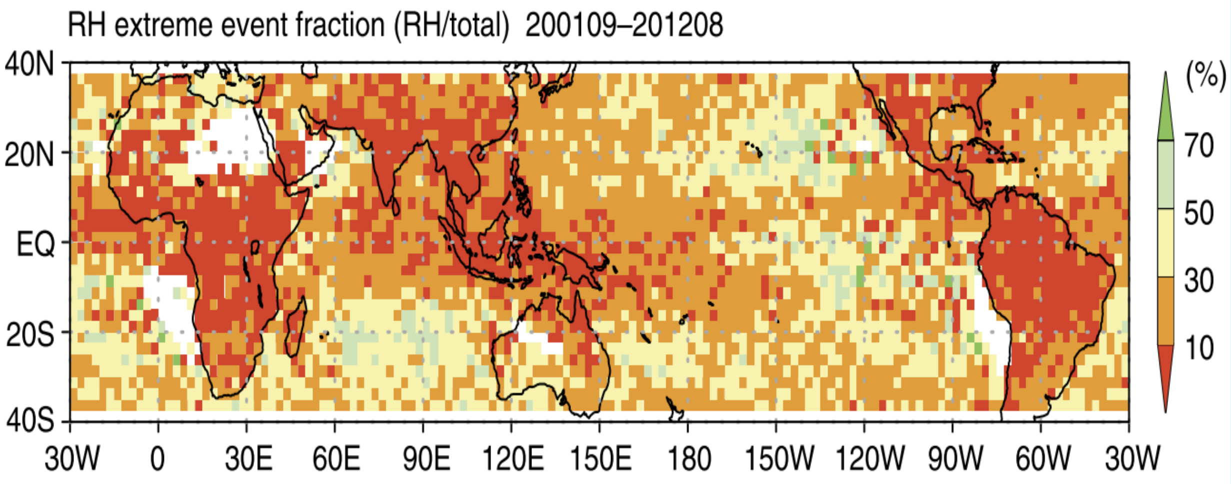
- **Largest economic losses and deaths** (Easterling et al. 2000)
- **Increasing trends at hourly, daily, and longer temporal scales in association with**
  - **climate warming** (Lenderink and Van Meijgaard 2008; Berg, et al., 2013; Donat et al., 2016)
  - **rapid urbanization** (Shepherd et al., 2002; Kishtawal et al., 2010; Wu et al., 2019; Jiang et al., 2020)
- **While thermodynamic contribution well understood** (summary in O'Gorman 2015), **dynamical contribution unclear, especially mesoscale and convective processes** (Muller, 2013; Feng et al. 2016; Prein et al., 2017; Rasmussen et al. 2020)



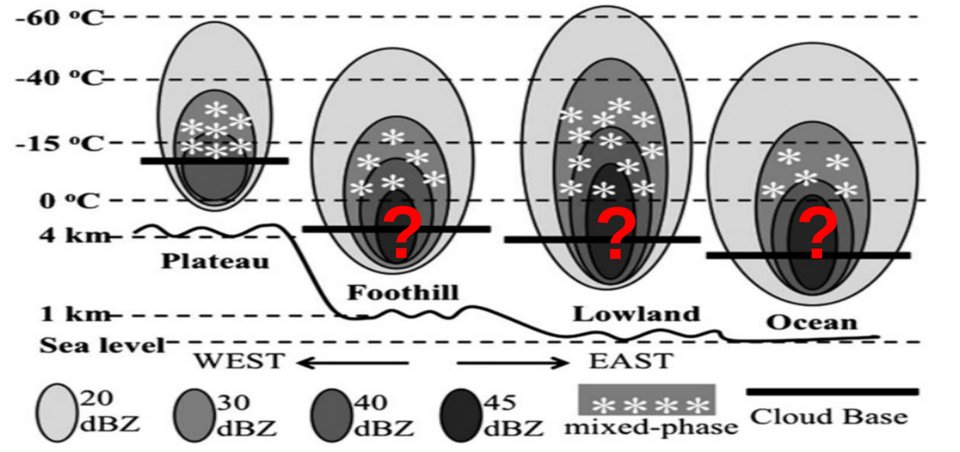
1975-2018 Trends over the Yangtze River Delta at East China coast
(From Jiang, Luo*, Zhang, 2020 JC)

Background: Overlapping fraction between extreme precipitation and extreme convection is controversial.

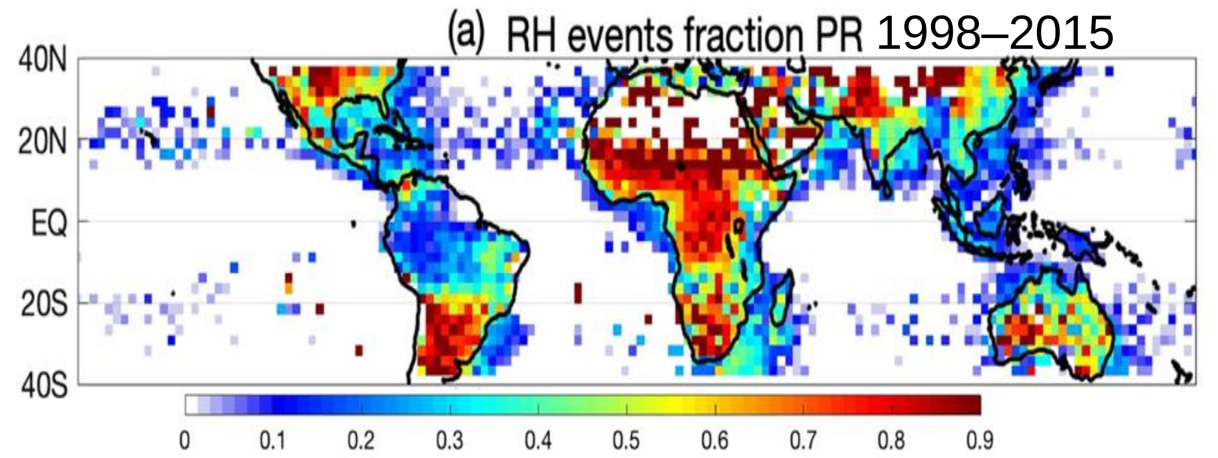
Microphysical characteristics of extreme precipitation are not well known.



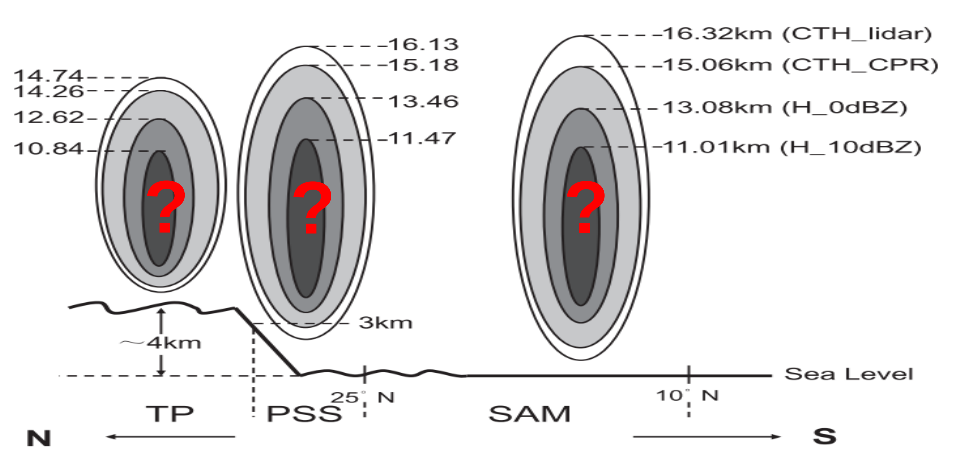
(Hamada et al., 2015, *Nat. Comm.*)



Schematics of deep convection over the Tibetan Plateau and the regions to its east（Xu, et al., 2013, *MWR*）



(Wang & Tang, 2020,*GRL*)



Schematics of deep convection over the Tibetan Plateau, its south slope, and the southern Asian monsoon region（Luo, et al., 2011, *JC*）

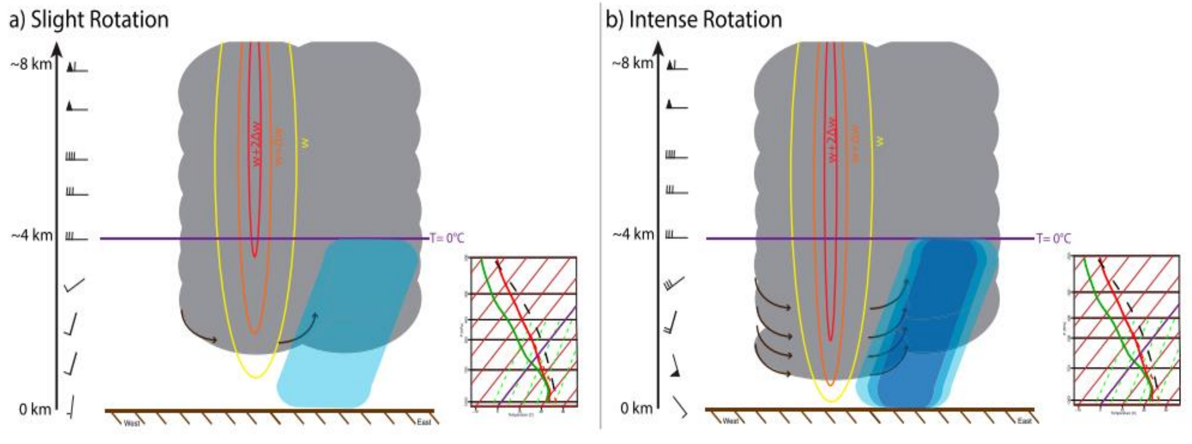
Background: Weaker convective systems can produce heavy precipitation. Statistical relationship between extreme short-term rain and rotation at monsoon coasts is unknown.

- **Active warm-rain microphysical processes** (Liu & Zipser, 2009; Sohn et al., 2013; Hamada et al., 2015)
- **Sometimes accompanied by low-level meso-γ-scale rotation** (Morales et al., 2015; Nielsen and Schumacher 2018, 2020; Li et al., 2021)

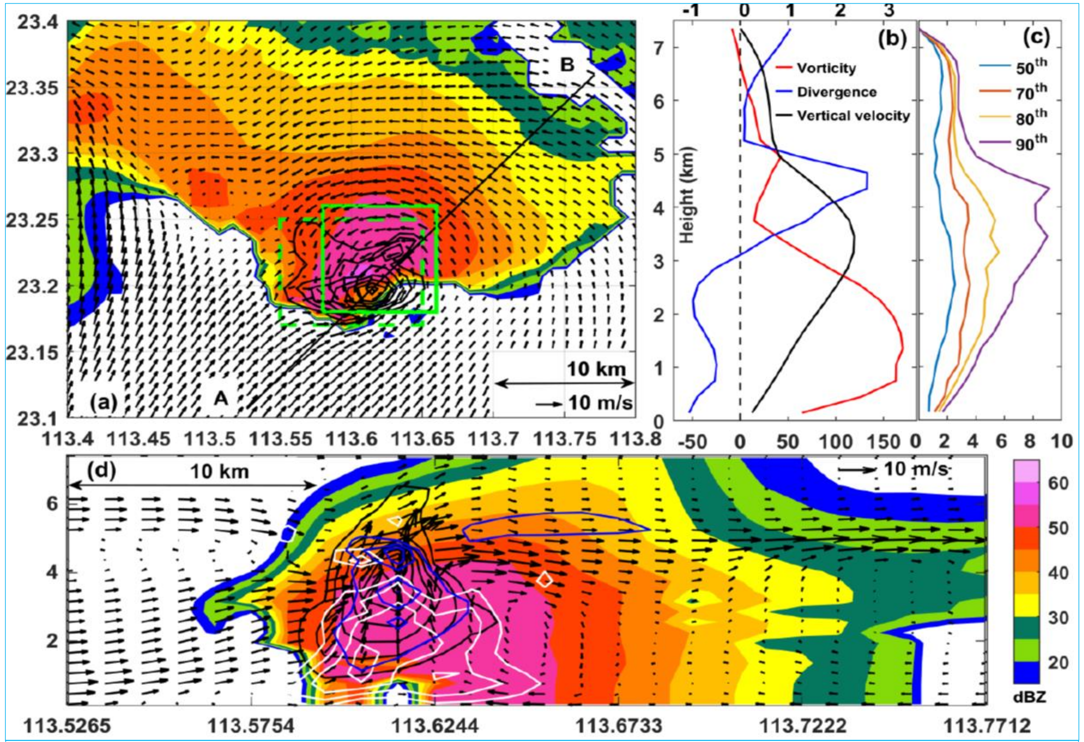
$$\frac{\partial w}{\partial t} = \underbrace{\mathbf{v}\cdot\nabla_h w}_{\text{Advection}} \underbrace{\underbrace{- \frac{1}{\rho_0}\frac{\partial p'_B}{\partial z} - g\frac{\rho'}{\rho_0}}_{\text{Buoyancy}\,(B)} \underbrace{- g q_h}_{\text{Drag}}}_{\text{Total buoyant acceleration (ACCB)}} \underbrace{\underbrace{- \frac{1}{\rho_0}\frac{\partial p'_{DL}}{\partial z}}_{\text{Linear dynamic acceleration}} \underbrace{- \frac{1}{\rho_0}\frac{\partial p'_{DNL}}{\partial z}}_{\text{Nonlinear dynamic acceleration (NLD-VPPGF)}}}_{\text{Total dynamic acceleration (ACCD)}}$$

$$p' \propto \underbrace{\underbrace{e'^2_{ij}}_{\text{Splat}} \underbrace{- \frac{1}{2}|\boldsymbol{\omega}'|^2}_{\text{Spin}}}_{\text{Nonlinear dynamic } (p'_{DNL})} + \underbrace{2\mathbf{S}\cdot\nabla_h w'}_{\text{Linear dynamic } (p'_{DL})} - \underbrace{\frac{\partial B}{\partial z}}_{\text{Buoyant } (p'_B)}$$

(Markowski et al., 2010)



Schematic summarizing the precipitation enhancement mechanism discussed in Nielsen and Schumacher (2018) (From Nielsen and Schumacher 2020)

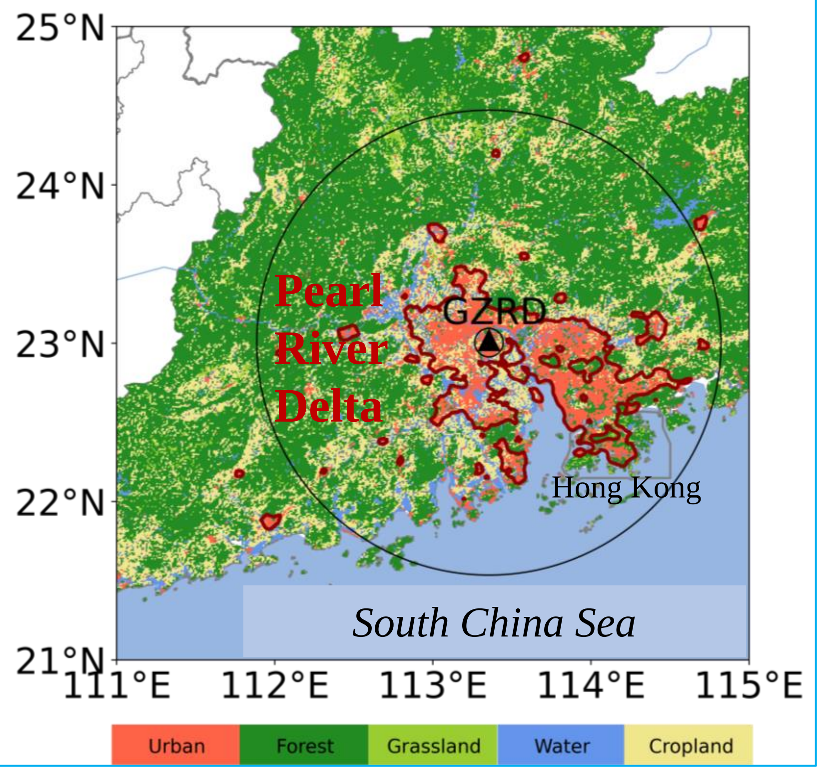


Maximum hourly rain rate (219 mm h^{-1}) influencing the capital city Guangzhou on May 7, 2017 was accompanied by a meso-γ-scale vortex（Li, Luo*, et al., 2021, *TGRS*）

Objective

To document the convective and microphysical characteristics of extreme precipitation on a typical monsoon coast (South China)

- **Convective intensity**
- **Liquid- and mixed-phase microphysics**
- **Meso-γ-scale rotation**



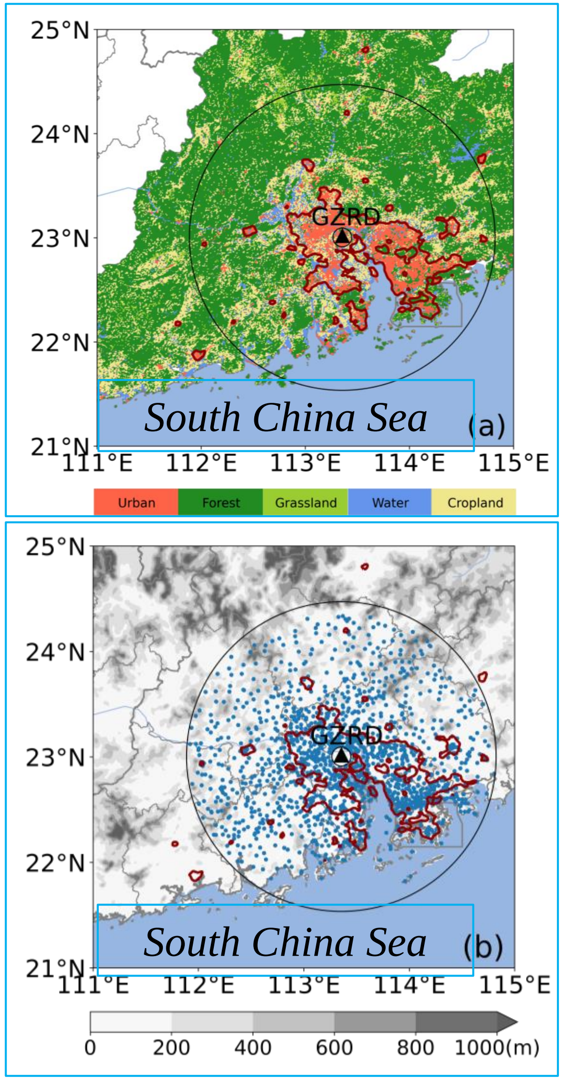
Data & Methods

➢ Instruments

- **Guangzhou Dual-POL radar** (6min, 250m)
- 2D-Video-Distrometers
- Low-frequency E-field detection array
- AWSs

➢ Methods:

- **QPE** based on specific attenuation and specific differential phase (Wang, Cocks, et al., 2019 *JHM*)
- **IWC & LWC retrieval** (Carey & Rutledge, 2000 *MWR*)
- **Rain DSD retrieval** (Zhang et al., 2001 *TGRS*)
- **Azimuthal shear calculation:** linear least squares derivatives (LLSD) technique (Smith and Elmore 2004)



Method (*cont.*): Definition & two examples of EPF

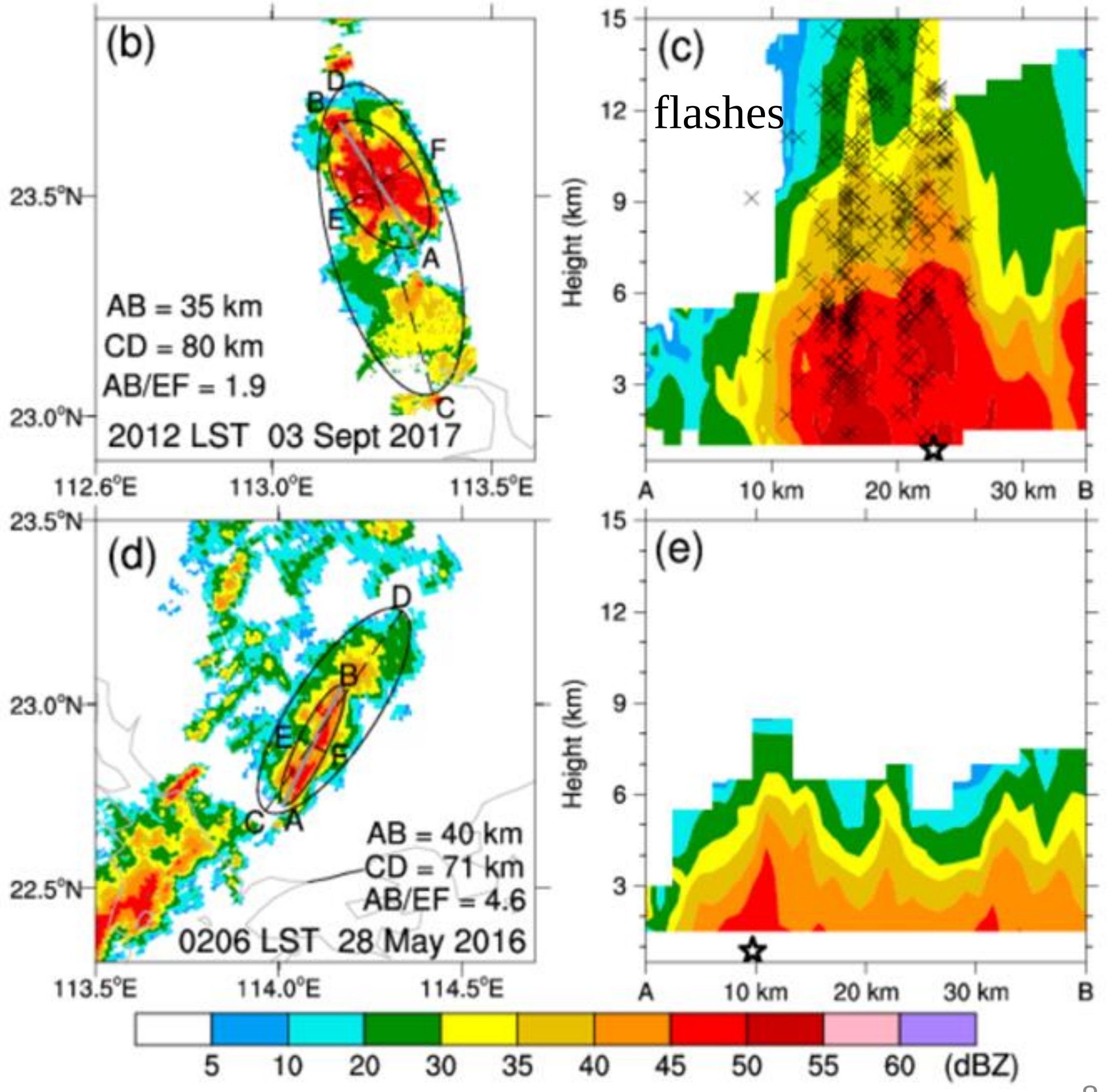
Definition of an **extreme precipitation feature (EPF)**:

- A contiguous area of strong radar reflectivity (≥ 40dBZ)
- ≥ 3.1875 km^2
- ≥ 0.5 km^2 of extreme rain (>114 mm h^{-1}; the 99.9th percentile of 6-min rain accumulation)

An **event-based method** similar to the PF in the TRMM dataset (Liu et al., 2008, *JAMC*)

①

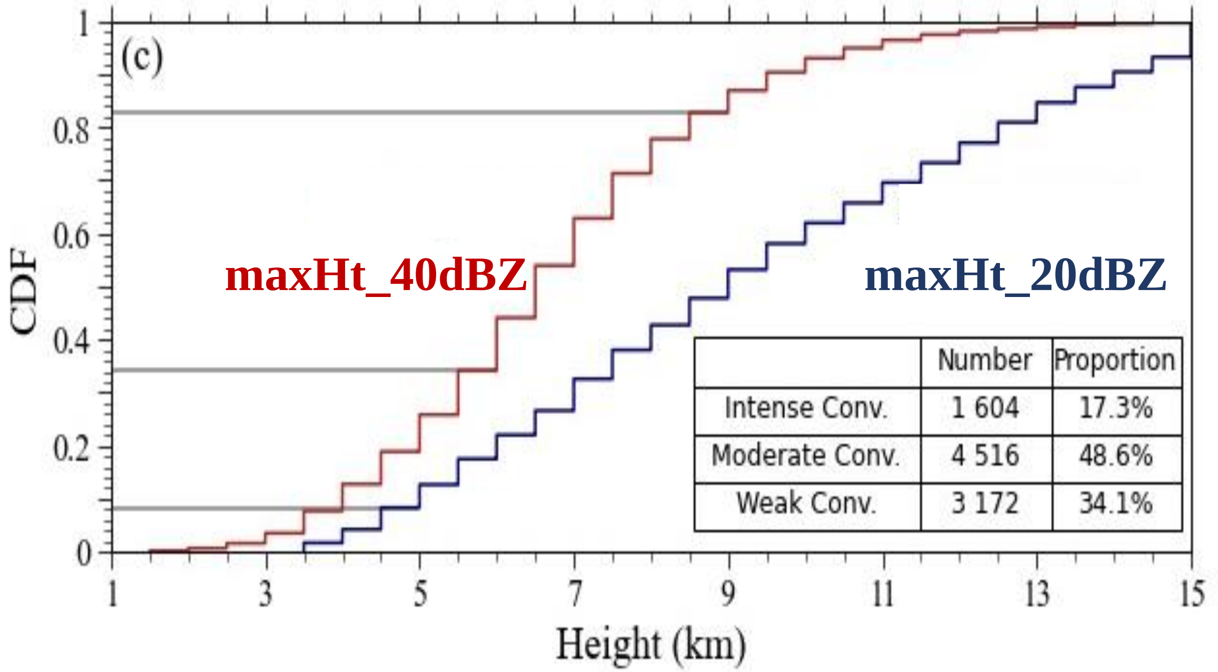
②



Results: Convective intensity of EPFs

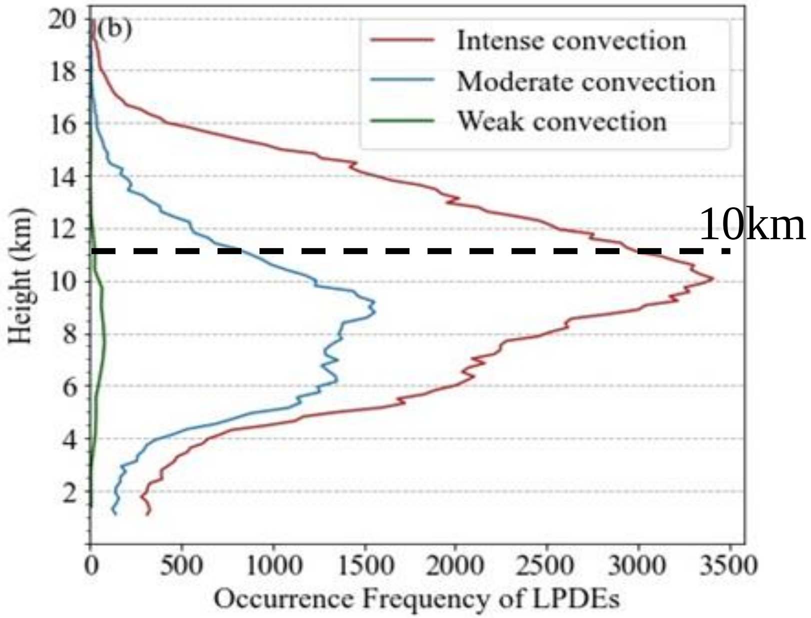
Totally 9292 EPFs in two warm seasons

- **17.3% intense convection:** **maxHt_40dBZ ≥ 9 km** (-22℃), strong mixed-phase process
- **48.6% moderate convection:** **maxHt_40dBZ of [6 km, 9 km)**
- **34.1% weak convection:** **maxHt_40dBZ < 6 km** (-4℃), limited mixed-phase process



	Number	Proportion
Intense Conv.	1 604	17.3%
Moderate Conv.	4 516	48.6%
Weak Conv.	3 172	34.1%

4%, 37.7%, 81.2% with lightning



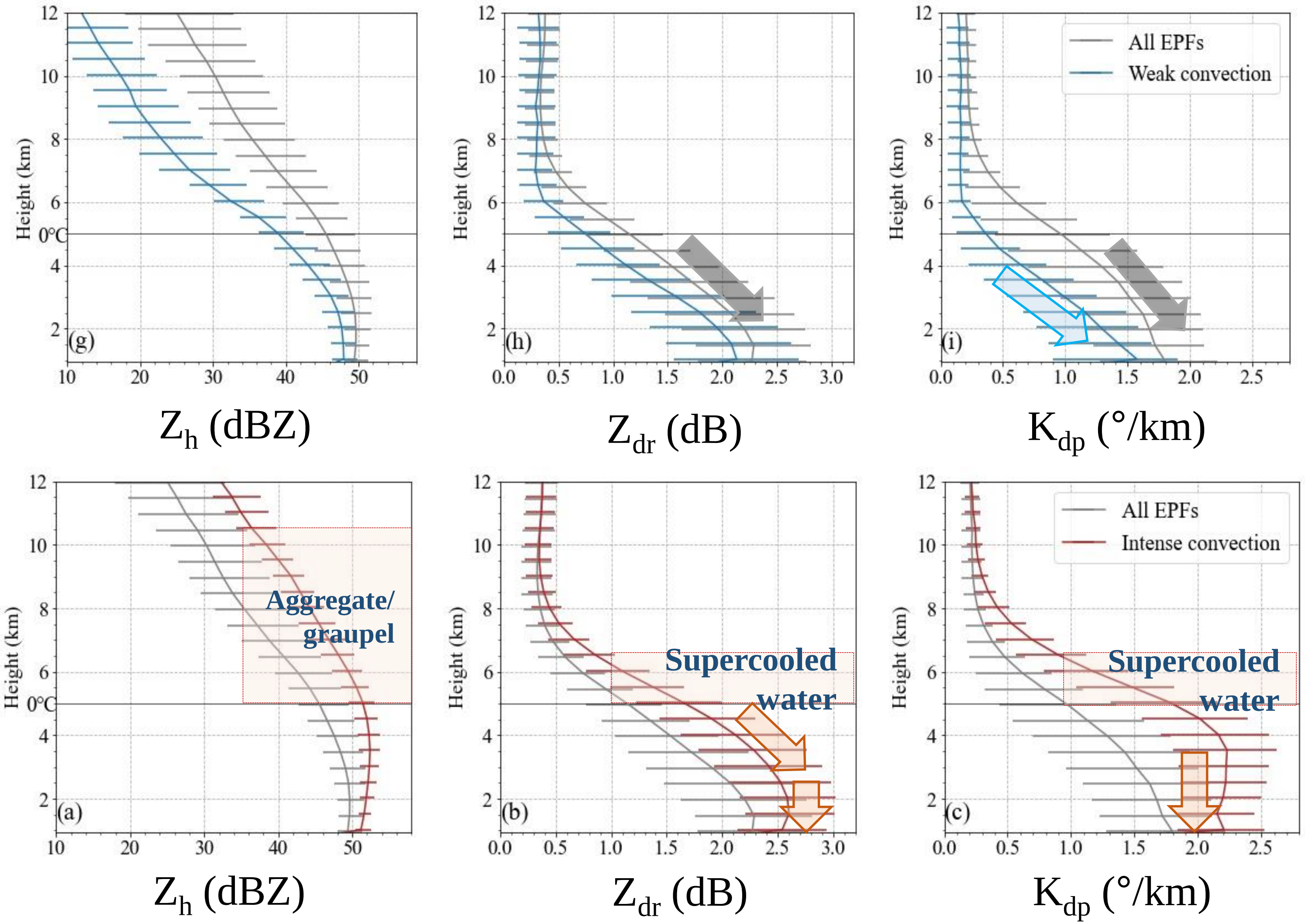
LPDEs: Lightning pulse discharge events

Results: Liquid- and mixed-phase microphysics of EPFs

Vertical profiles of the 95th percentile: mean (solid) & 25th-75th% (bar)

All EPF
vs.
Weak convection

All EPF
vs.
Intense convection



LWP/IWP =
- **Weak 4.8**
- **Moderate 3.9**
- Intense 2.6

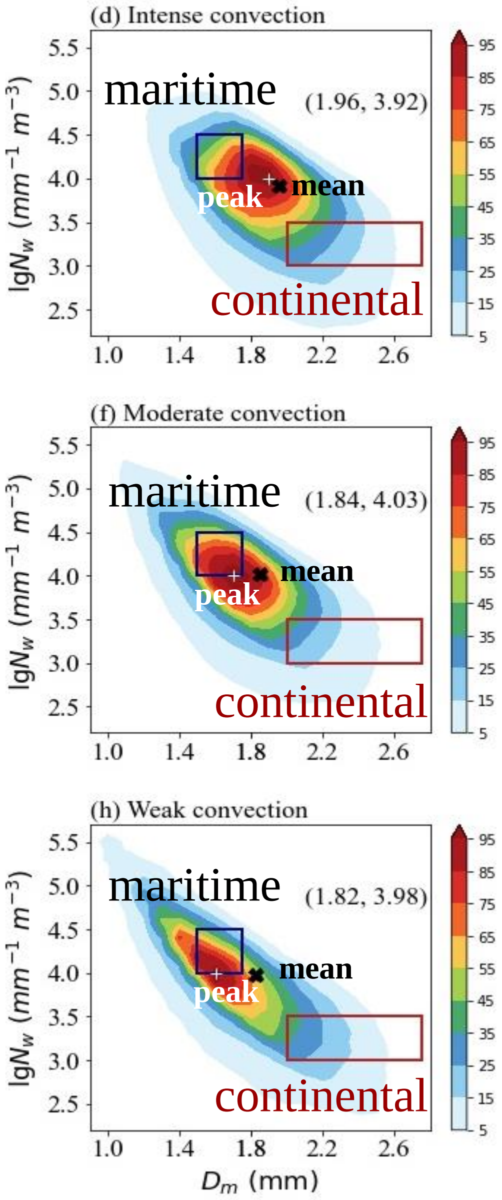
- **Overall significant contribution of warm-rain processes, esp. with weak convection**
- **About 2/3 EPFs contributed by melting of aggregates and graupels formed by aggregation and riming**

Results: Rain DSD & Liquid-phase microphysical processes

Intense conv.

Moderate conv.

Weak conv.



- **Rain DSD:**
  - **High concentration** regardless of convective intensity
  - **Mostly moderate size** (smaller with weaker convection)
- **Liquid-phase microphysics**
  - **Coalescence dominant** (78.6→86.3→91.8%)
  - **Size sorting, breakup, and evaporation limited** (19.4→12.0→6.4%)

$\Delta Z_h = Z_{h\_1.5km} — Z_{h\_3.0km}$

$\Delta Z_{dr} = Z_{dr\_1.5km} — Z_{dr\_3.0km}$

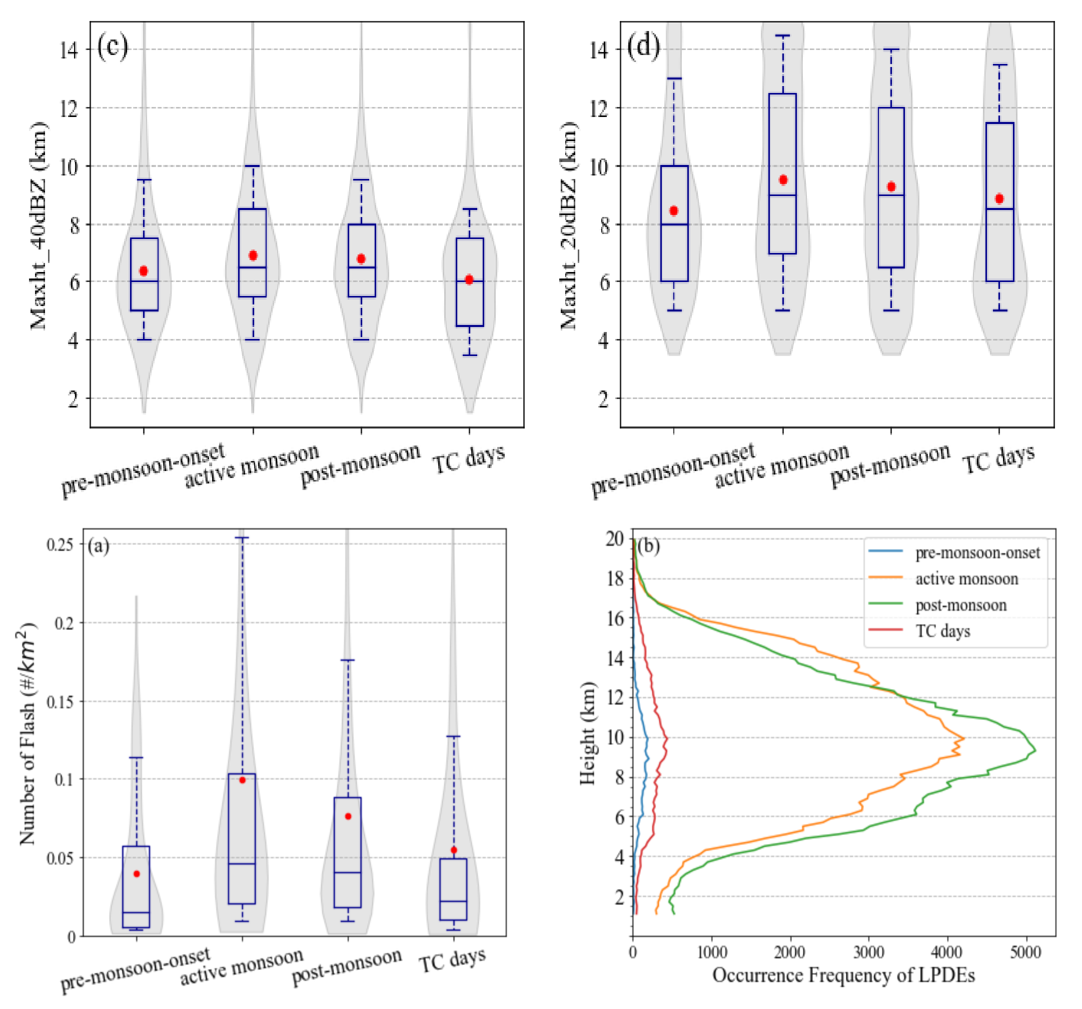
Results: Seasonal variations of EPF convective intensity & microphysics

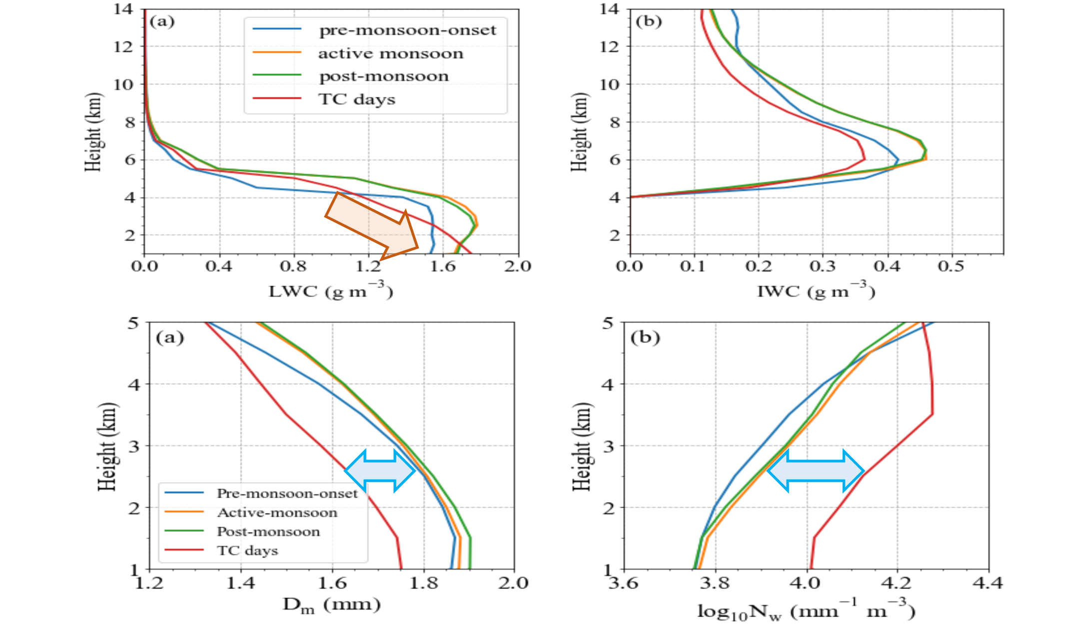
Pre-monsoon-onset: 1 April−23 or 18 May (658 EPFs)

Active monsoon: 24 May−19 June; 19 May−29 June (2108 EPFs)

Post-monsoon: 20 or 30 June − 30 Sept. (5807 EPFs)

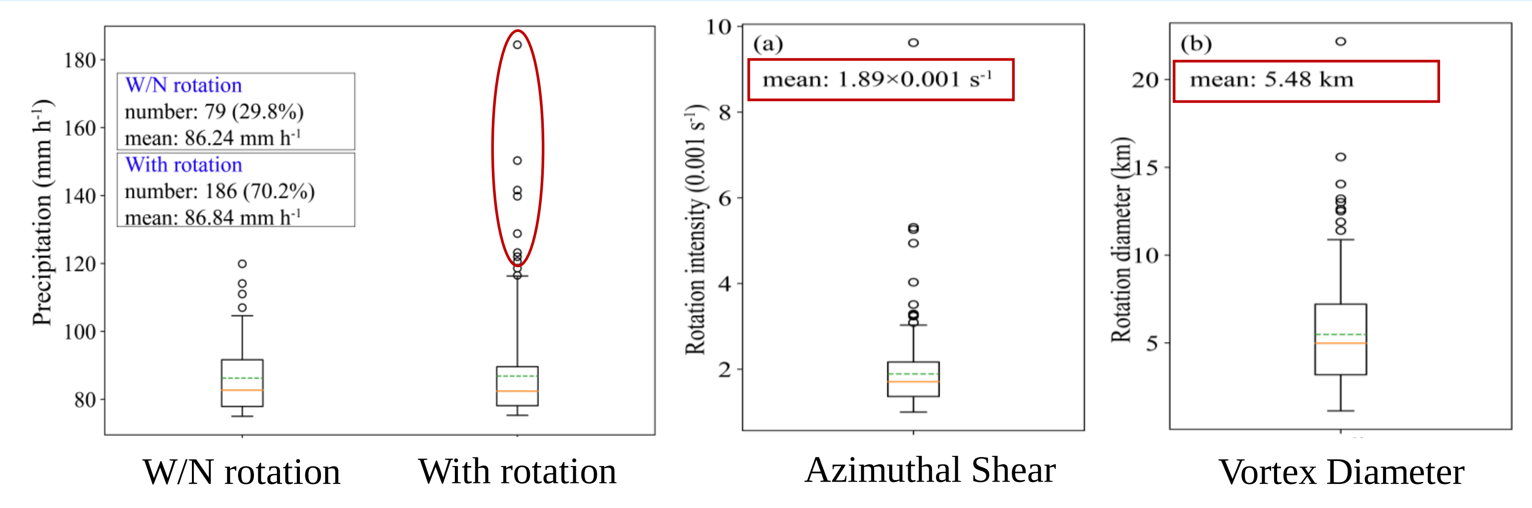
TC days: 18 days (719 EPFs)



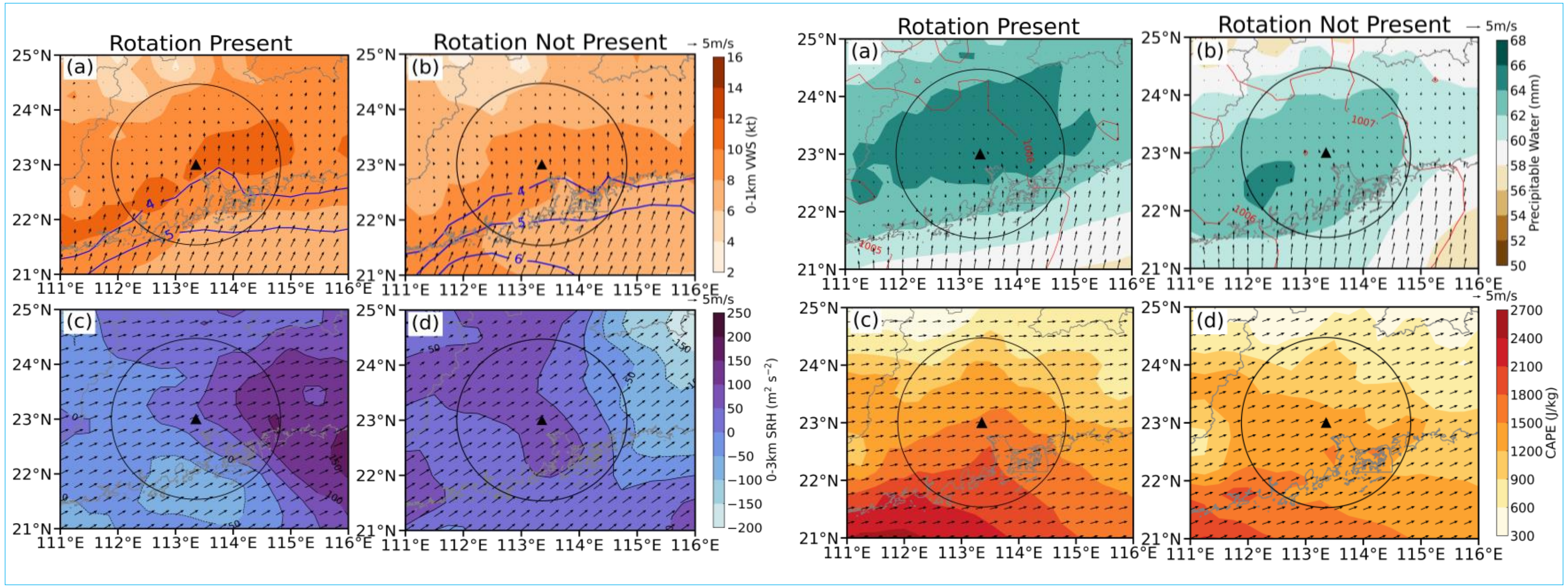


- **More intense convection during the *active monsoon* and the *post-monsoon periods***
- **Even more active accretion and auto-conversion of liquid drops on the *TC days*, with a higher concentration of smaller raindrops in thicker warm-cloud layers**

Results: Meso-γ-scale rotation associated with extreme hourly precipitation (EXHP; gauge observations >75 mm h^{-1})



- **265 EXHP records** in 2016−2019 warms seasons, **70% with rotation**
- **No correlation between EXHP and azimuthal shear**
- **Weak rotation** (comp. to tornado-producing mesocyclones in eastern U.S.)

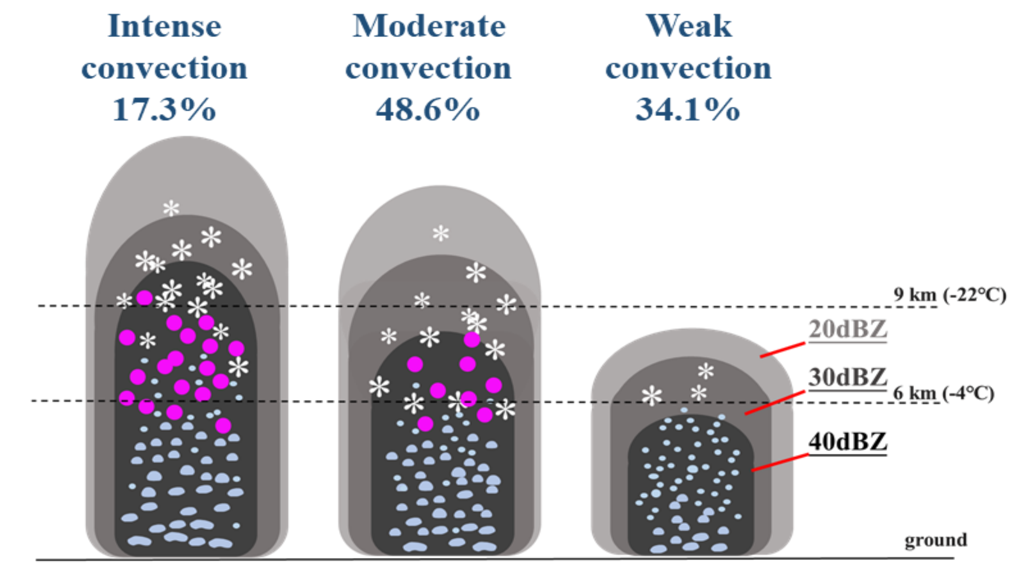


- **Rotation likely results from strong condensation-induced latent heat release**
  - PW: 64−66 mm
  - CAPE: 900−2100 J kg^{-1}
  - Smaller 0-1km VWS & 0-3km SRH than their counterparts in the U.S.

Conclusions: Convective and microphysical characteristics of extreme precipitation at monsoon coast (South China)

Based on long-term observations with minute-and-*sub*kilometer resolutions, we have found

- Overall, extreme rain rate (≥114 mm h^{-1}) contributed significantly by the warm-rain processes, especially with weaker convection
- Rain DSD features a high concentration & mostly moderate size of raindrops
- Coalescence dominates the liquid-phase microphysical processes
- On the *TC days*, even more active accretion and auto-conversion of liquid drops with a higher concentration of smaller raindrops in thicker warm-cloud layers



- 70% EXHP (>75 mm h^{-1}) with meso-γ-scale rotation, but no correlation between their intensity
- Weak rotation likely results from strong condensation-induced latent heat release in high PW, moderate-to-high CAPE, low VWS environments

Thanks for your attention!

- Yu, S., Y. Luo*, C. Wu*, D. Zheng, W. Xu, 2022: Convective and microphysical characteristics of extreme precipitation revealed by multisource observations over the Pearl River Delta at monsoon coast. *Geophysical Research Letters*, 49, e2021GL097043. https://doi.org/10.1029/2021GL097043.
- Yu, S., Y. Luo*, C. Wu, 2022: Seasonal variations of convective and microphysical characteristics of extreme precipitation over the Pearl River Delta at monsoon coast. To be submitted.
- Luo, Y.*, J. Zhang, Q. Zhang, and coauthors, 2022: On the relationship between meso-γ-scale rotation and extreme short-term precipitation over the Pear River Delta at monsoon coast. To be submitted.

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