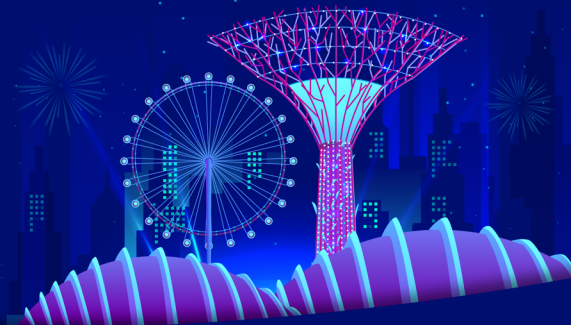




Shifting hotspot of tropical cyclone clusters in a warming climate

Zheng-Hang Fu, Fudan University, fuzh23@m.fudan.edu.cn

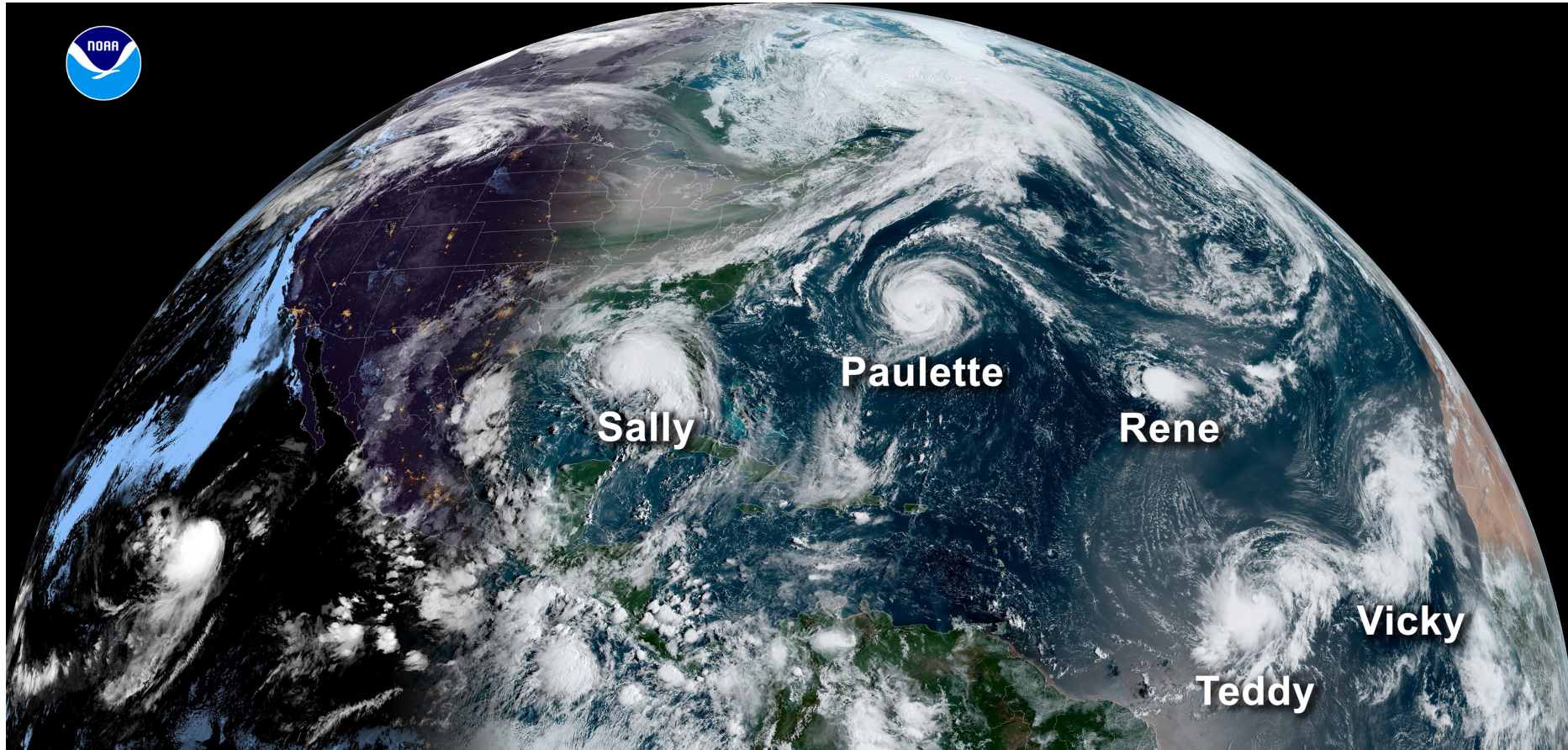
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Collaborators:

Dazhi Xi (HKU); Shang-Ping Xie (Scripps); Ning Lin (Princeton); Jiuwei Zhao (NUIST); Xin Wang
(Fudan); Johnny CL Chan (CityUHK)

2025/07/30

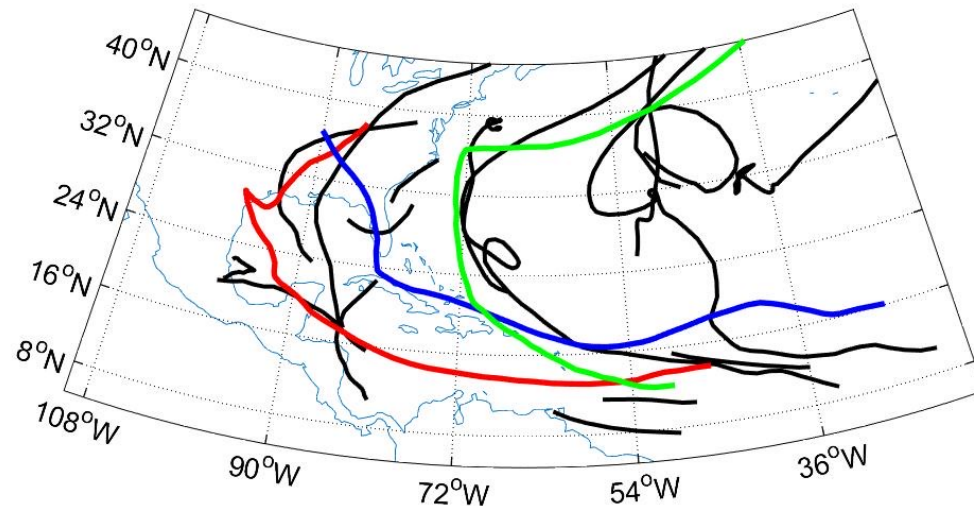
Tropical cyclone cluster events



Multiple tropical cyclones (TCs) could be present concurrently within one ocean basin, and **these clusters** can induce **compound hazards** within a short time window.

Extreme TC cluster season over the NA

North Atlantic Hurricane Season 2017



The season featured 17 named storms, 10 hurricanes, and 6 major hurricanes. Most of the season's damage was due to hurricanes Harvey, Irma, and Maria.

Harvey (CAT4, red)

Texas, 08/26 red

Fatalities: 107

Damage: \$125 billion



Irma (CAT5, blue)

Florida, 09/10 blue

Fatalities: 134

Damage: \$77.16 billion



Maria (CAT5, green)

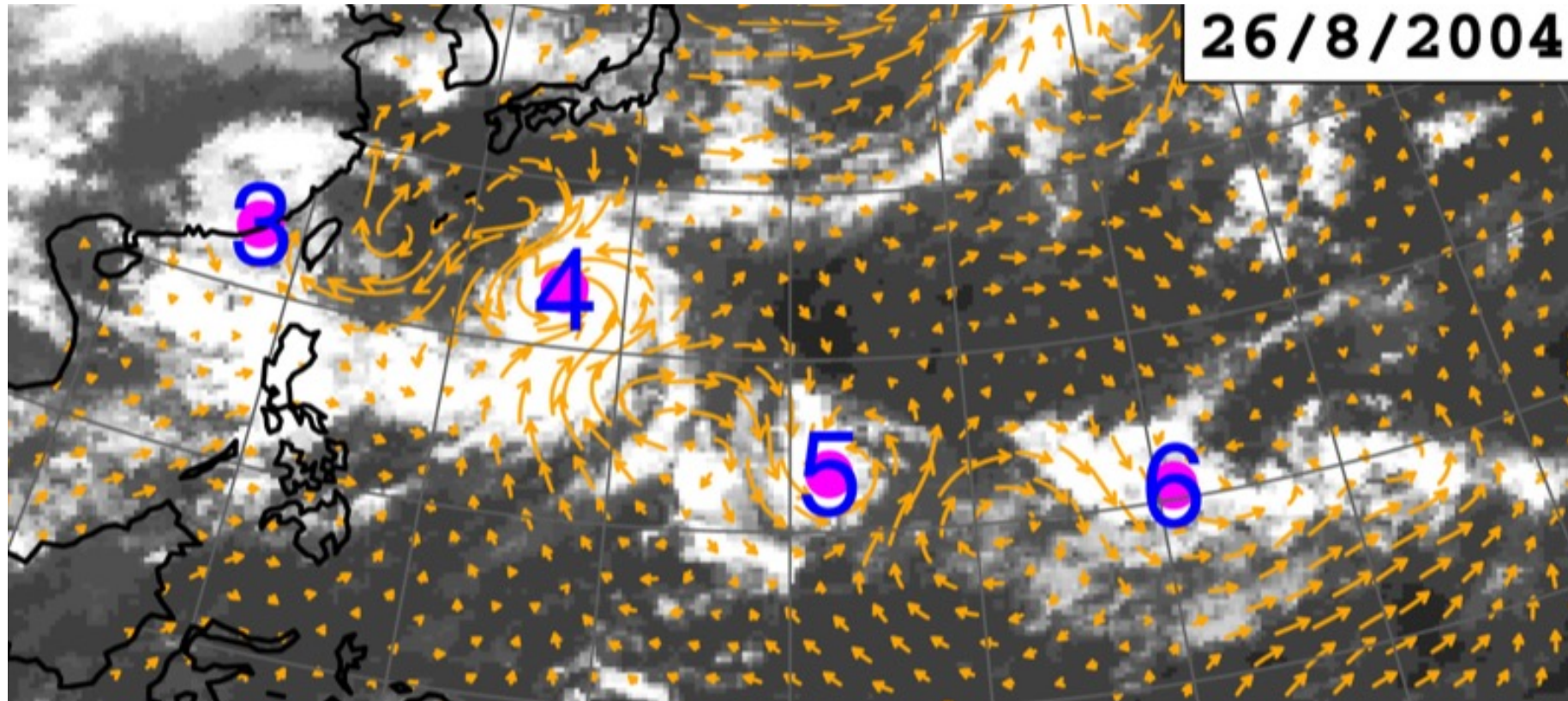
Puerto Rico, 09/20, green

Fatalities: 3059

Damage: \$91.61 billion



Extreme TC cluster season over the WNP



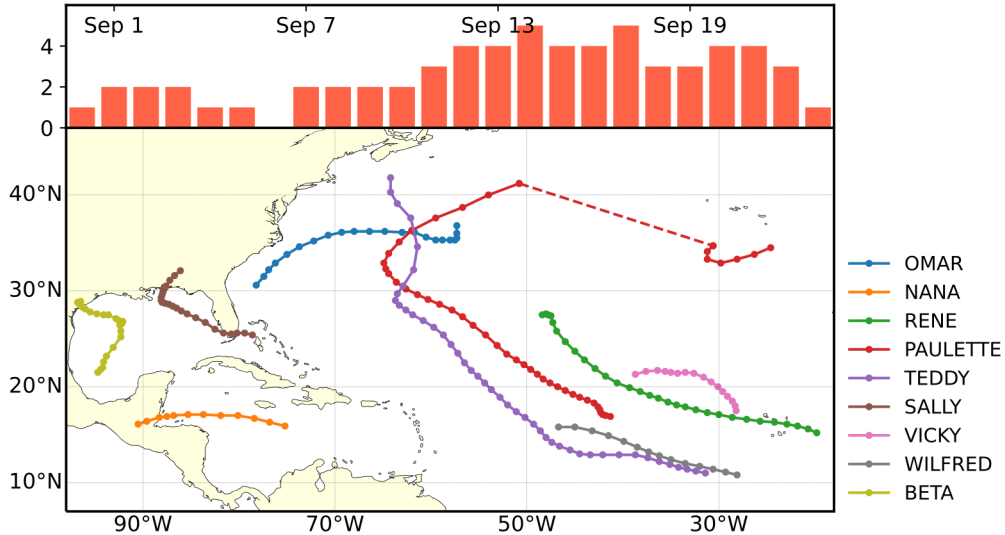
Hu et al. (2018) GRL

A train-like TC cluster event occurred in the summer of 2004.

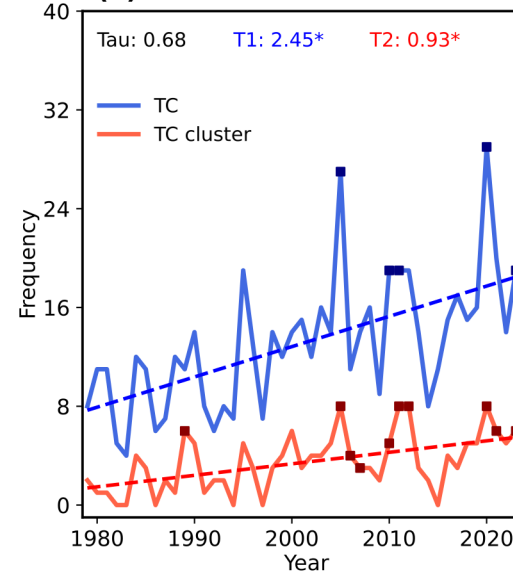
Nine disturbances intensified into TCs within 34 days, five of which made landfall in East Asia.

Observed shifts of TC cluster Hotspot

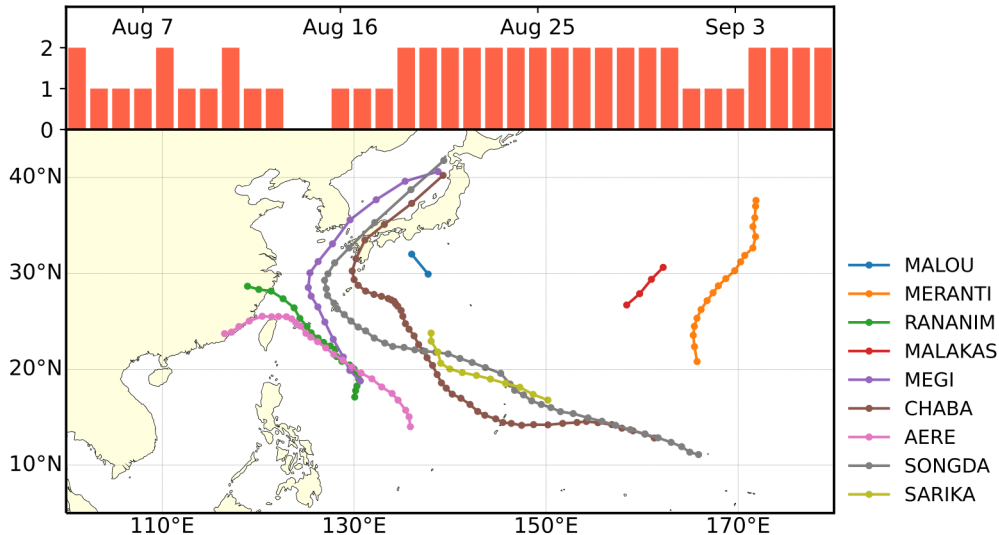
(a) Extreme NA TC cluster season: Aug 31 - Sep 23, 2020



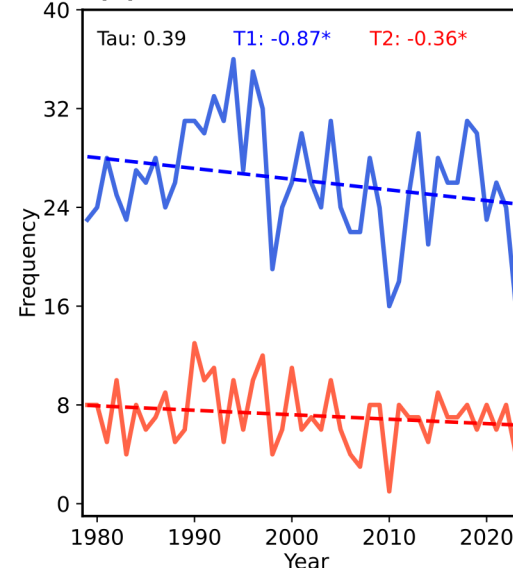
(b) NA



(c) Extreme WNP TC cluster season: Aug 4 - Sep 7, 2004



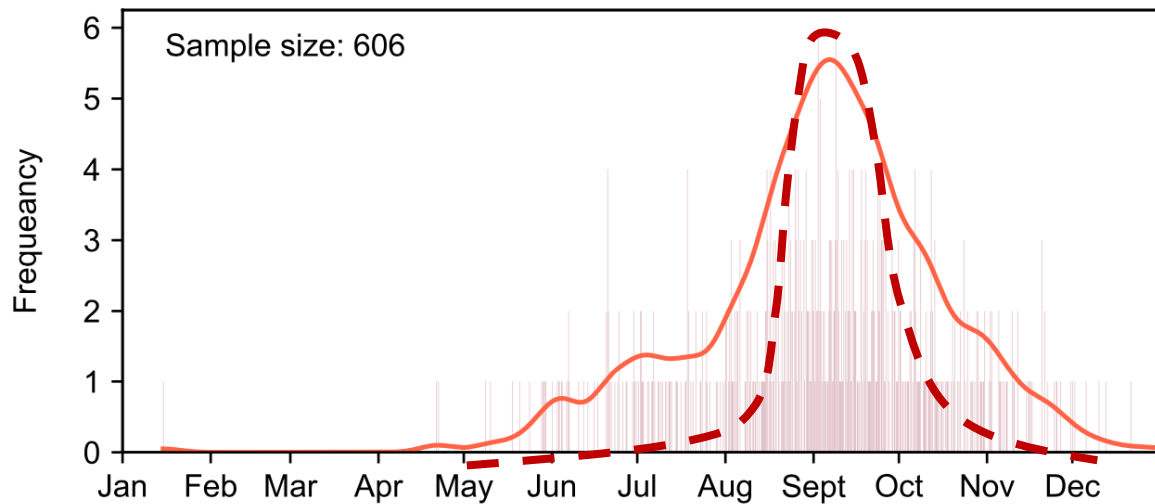
(d) WNP



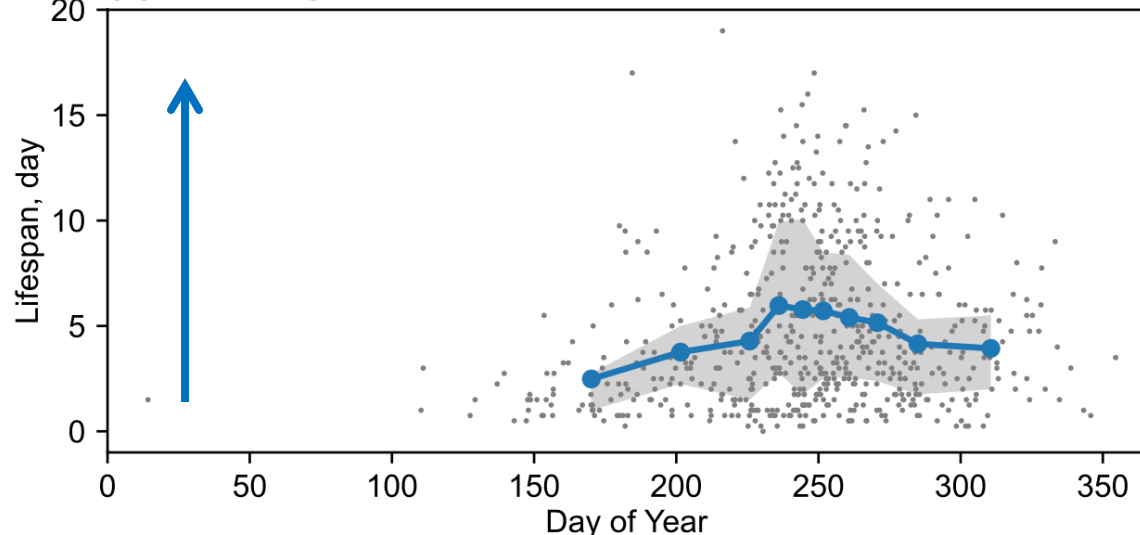
- Historically, WNP is home for most TC cluster events.
- In recent years, North Atlantic has witnessed more TC clusters.
- TC cluster frequency in the NA has reached or even surpassed that of the WNP **nine times (~1/2) since 2005.**

Statistical perspective: What controls TC cluster changes?

(a) NA: TC genesis time



(c) NA: TC genesis time & lifespan

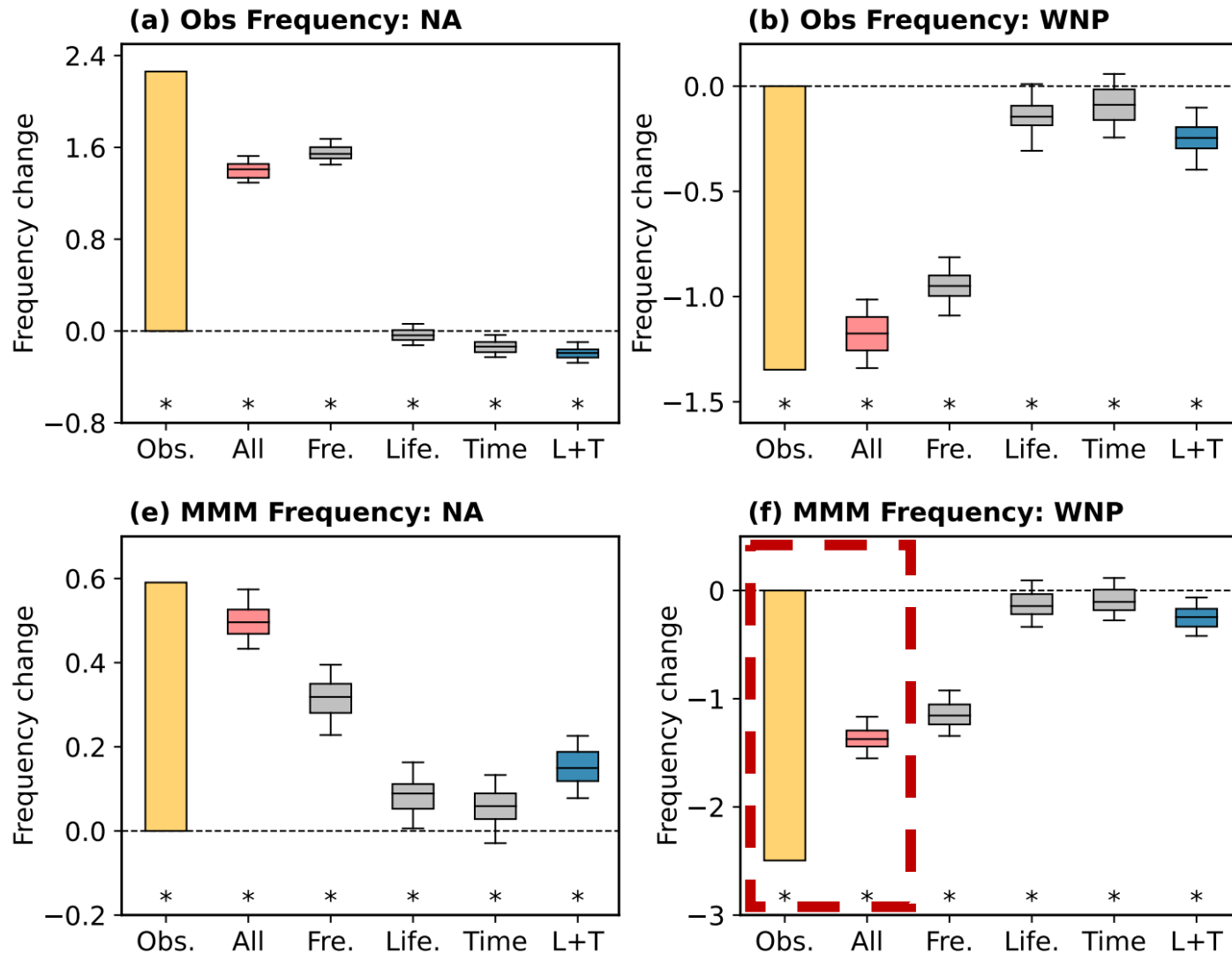


- ✓ Annual TC frequency
- ✓ TC seasonal cycle
- ✓ TC lifespan

The Probabilistic Model:

1. Annual TC frequency is assigned based on the observed frequency
2. TC occurs **independently** follow a non-homogenous Poisson process with Poisson rate specified by **observed seasonal cycle**
3. Probabilistically simulated TC **lifespan** is **drawn from the fitted distribution** of observed TCs (conditional PDF).

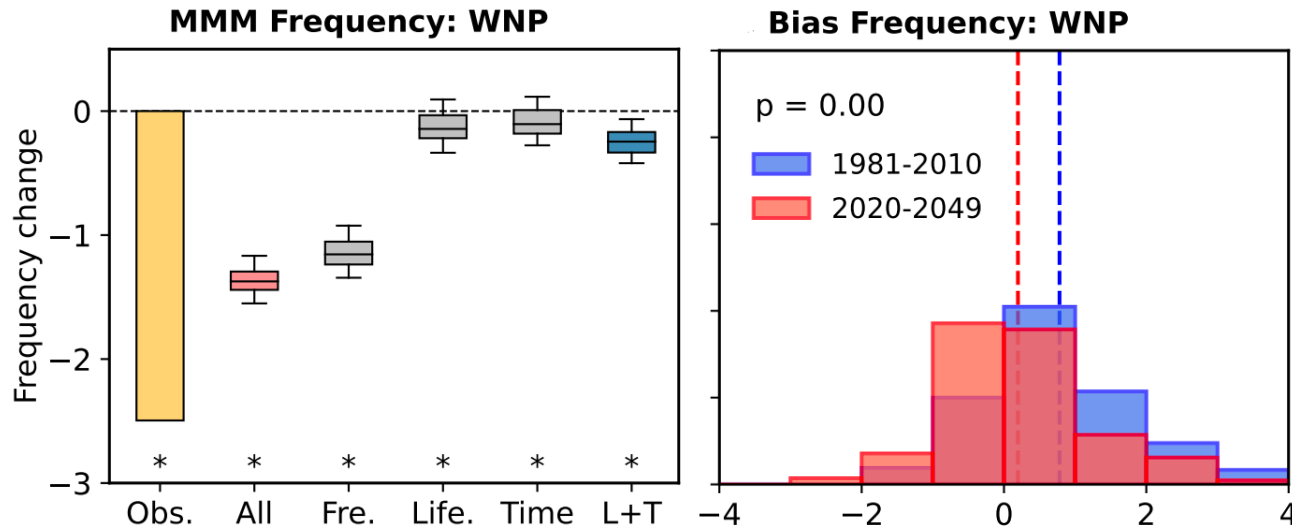
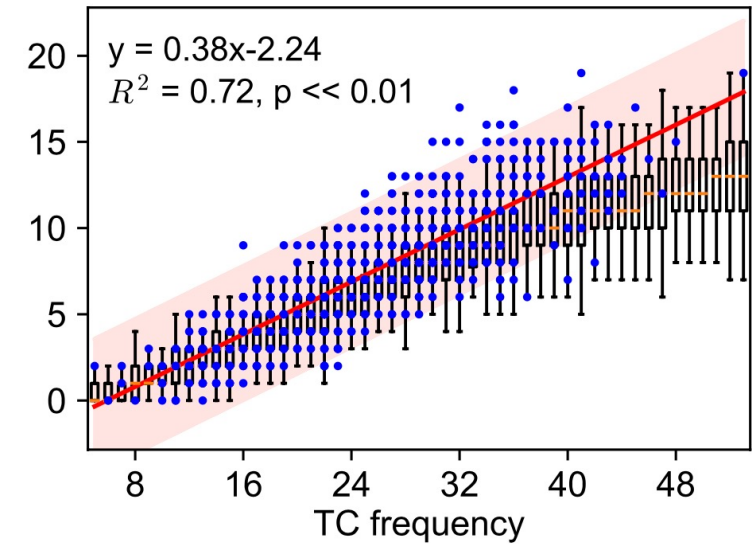
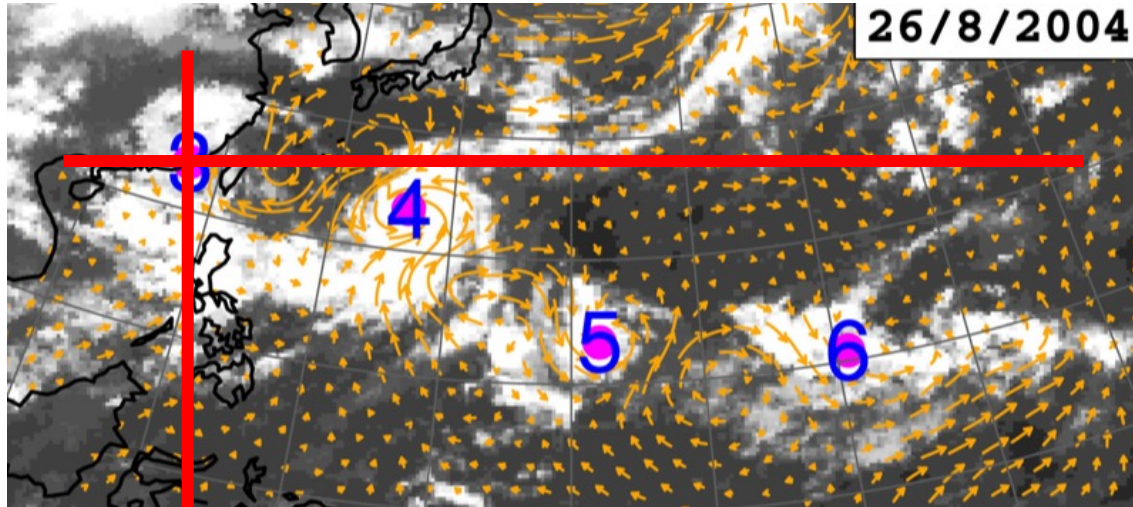
Statistical perspective: What controls TC cluster changes?



Change of TC cluster frequency in observations from 1979-2000 to 2001-2022 and in the CMIP6 HighResMIP models from 1981-2010 to 2020-2049.

- TC frequency is the leading contributor for TC cluster frequency change.
- TC seasonality and lifespan play a secondary role.

Statistical perspective: Identifying dynamically-linked TC clusters

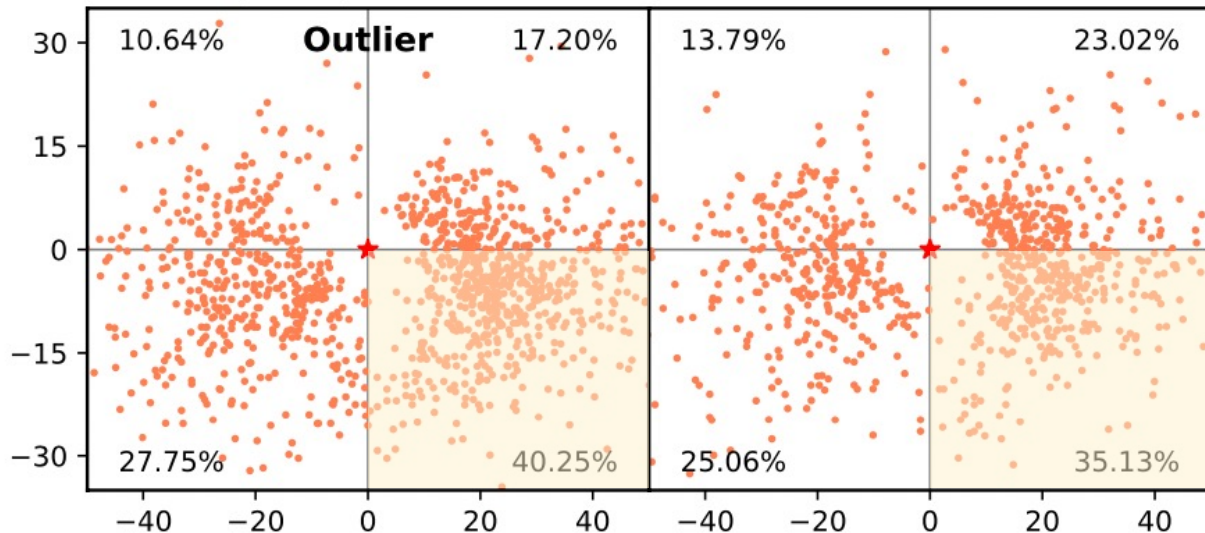
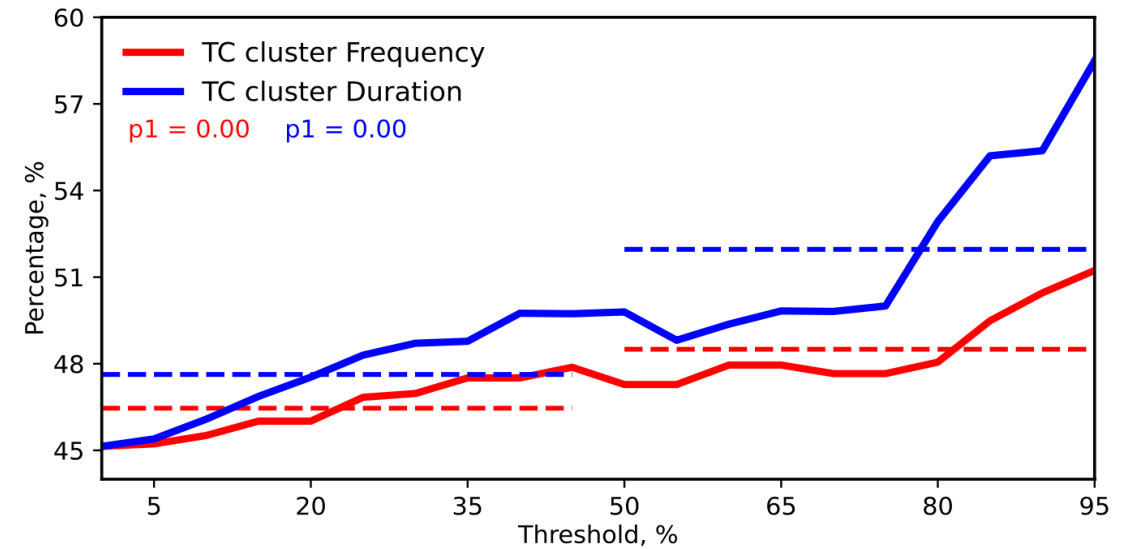
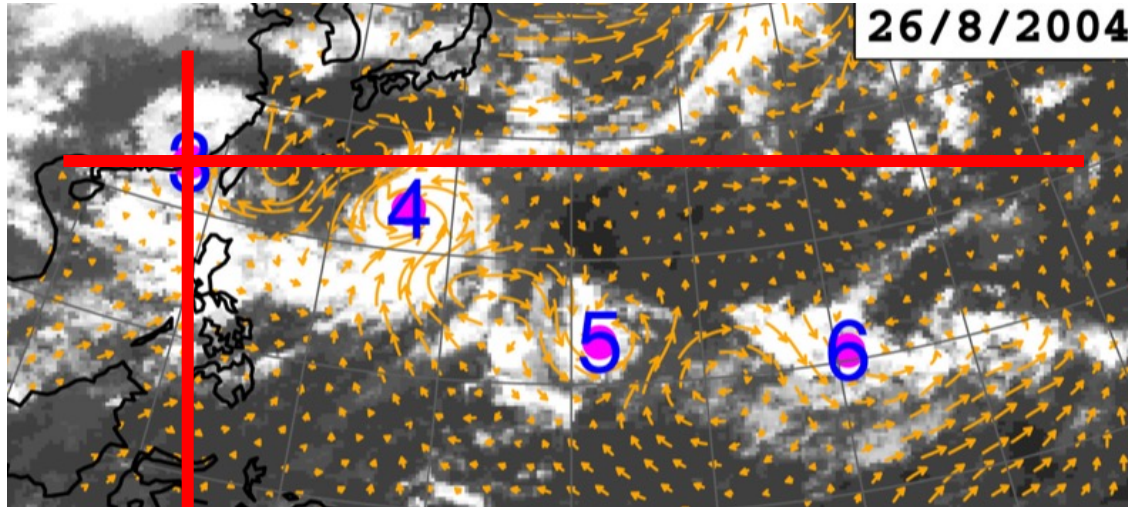


Outliers: years of TC cluster frequency beyond explanation of the probabilistic model.

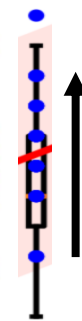
Independent Assumption

Dependency -> Dynamic linkage

Statistical perspective: Identifying dynamically-linked TC clusters



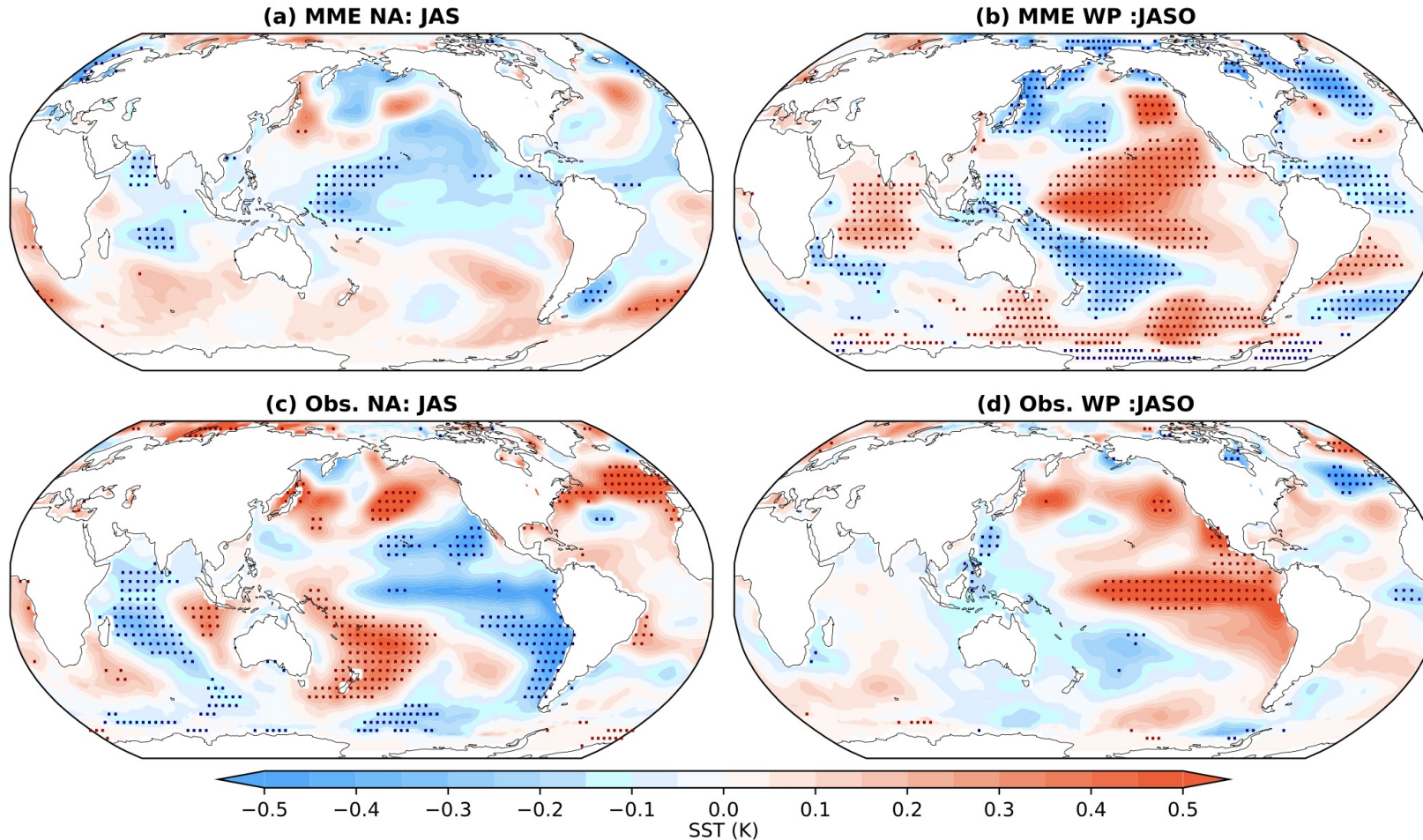
Outlier



- **Increased ratio** of subsequent TC genesis in the southeastern quadrant.
- This approach robustly **identified** the role of **dynamical connections** in TC clusters **for the first time**.

Red star: pre-existing TC Orange dot: subsequent TCs

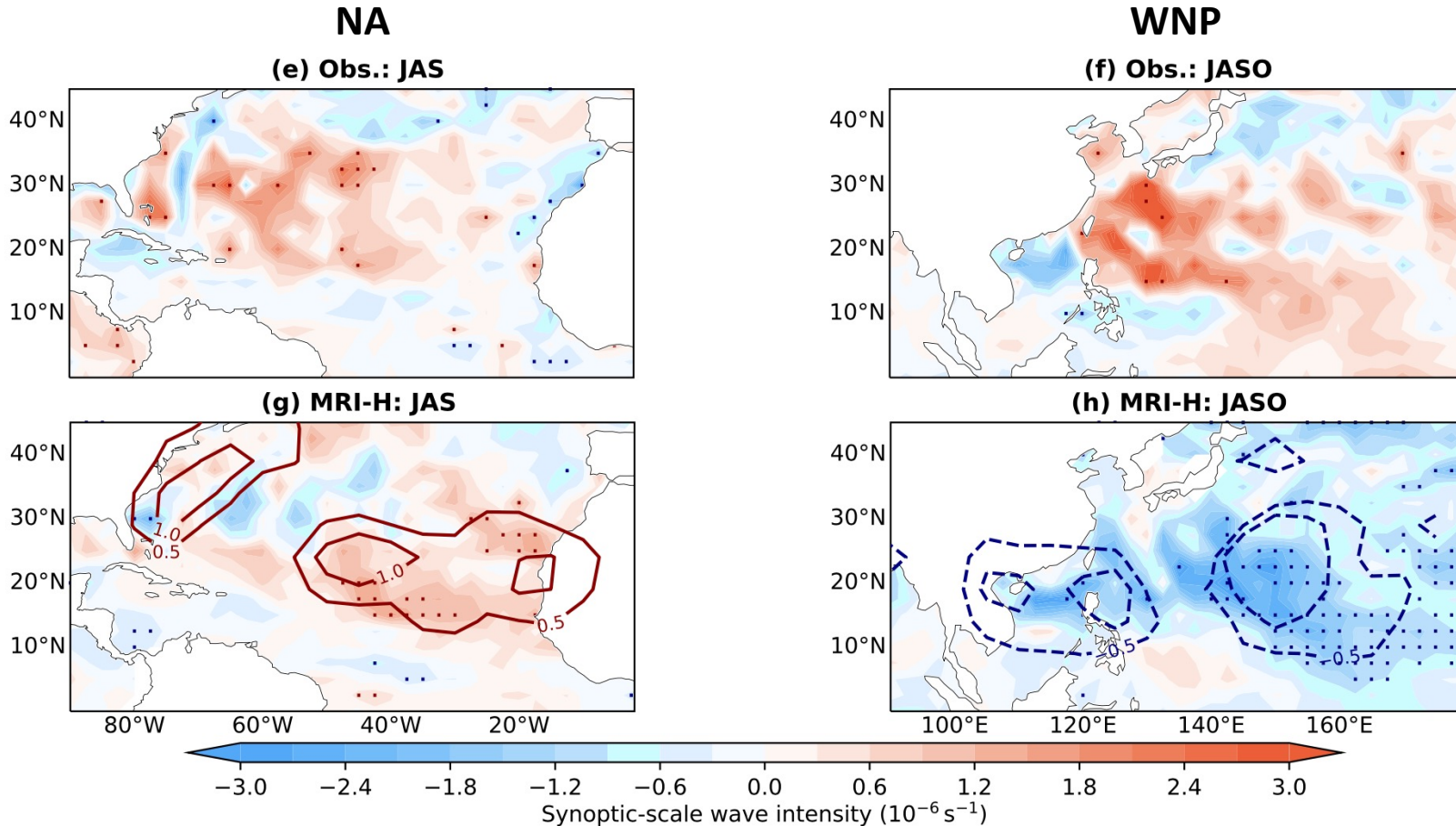
Physical perspective: Favorable Large-Scale Condition for TC cluster



- The enhanced dynamical connections between TCs over the WNP and NA are associated with El Niño and La Niña conditions, respectively.

SST differences between years with high TC cluster dynamic connections and years with low TC cluster dynamic connections.

Physical perspective: Role of synoptic-scale waves



NA: strengthened synoptic-scale wave activity intensities likely related to African easterly waves.

WNP: reducing of synoptic-scale wave activity intensities in the confluence zones.

Two synergistic effects

- Promote **dynamically linked TC clusters**.
- Provide TC seeds and increase the TC frequency (**probabilistic TC cluster**)

$$\zeta^s = \frac{\partial v^s}{\partial x} - \frac{\partial u^s}{\partial y} + \frac{u^s}{a} \tan \varphi$$

MRI-H: La Niña-like warming pattern

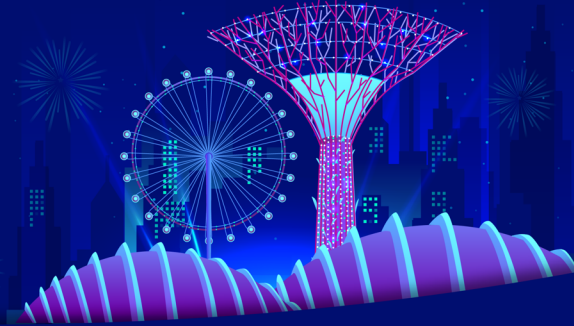
Conclusion

1. We develop a probabilistic model assuming that TCs are mutually independent and occur randomly.
Against this baseline, we identify outliers as clusters with dynamic interactions between TCs.
2. The TC frequency is the primary driver of TC cluster changes, and TC seasonality and lifespan play a secondary role.
- 3. Shifting TC cluster hotspot from the WNP to the NA:**
 - Probabilistic perspective: **La Niña-like warming** decreases TC frequency over the WNP while increasing it over the NA.
 - Physical linkage perspective: **La Niña-like warming** suppresses WNP dynamically connected TC clusters by weakening synoptic-scale wave activity, whereas it enhances NA dynamically connected TC cluster events by strengthening synoptic-scale wave activity.

Fu, Z.H.[†], D. Xi[†], S.-P. Xie, W. Zhou^{*}, N. Lin, J. Zhao, X. Wang, and J.C.L. Chan, 2025: Shifting hotspot of tropical cyclone clusters in a warming climate. *Nature Climate Change*, 15, in press.

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Sands Expo & Convention Centre, Marina Bay Sands Singapore



Thank you!

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