

Shifting hotspot of tropical cyclone clusters in a warming climate

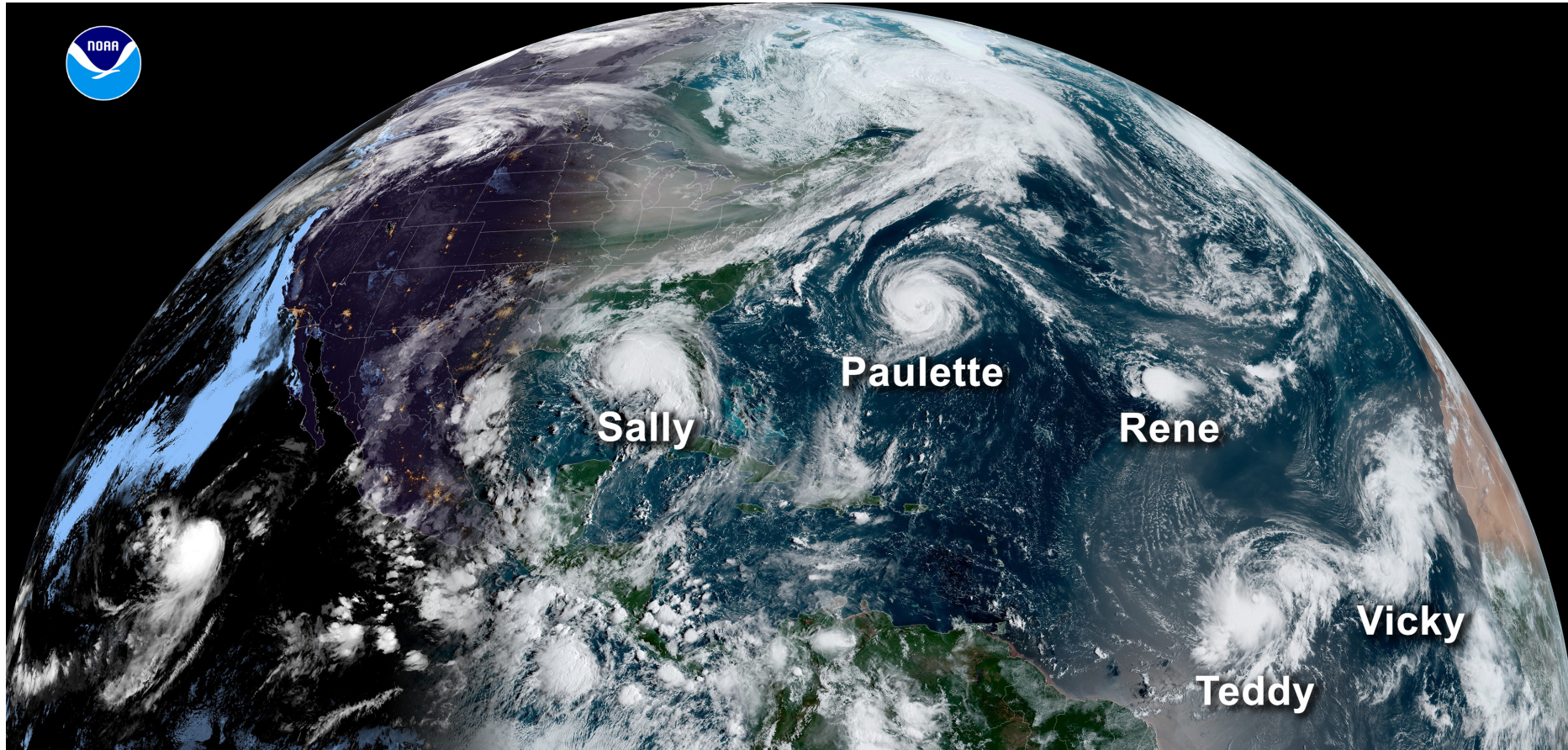
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2025/12/17

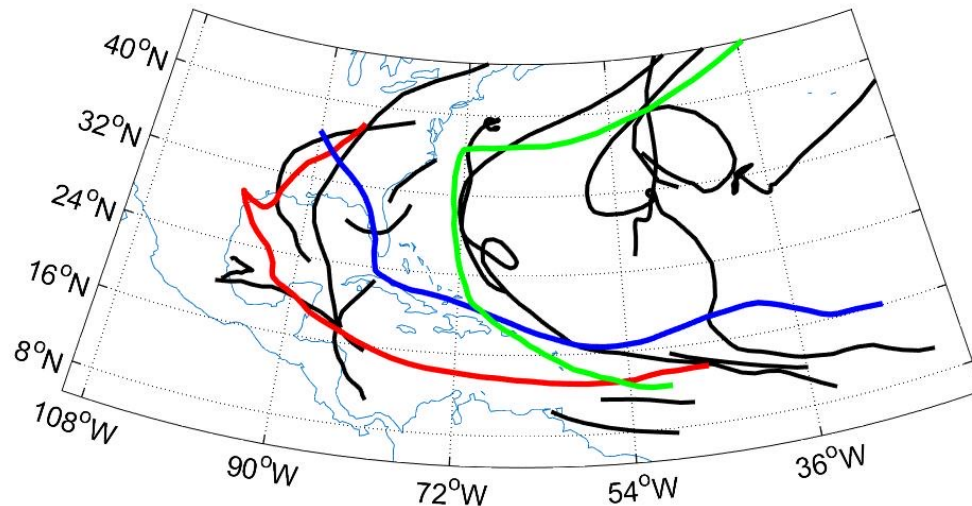
Tropical cyclone cluster events



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



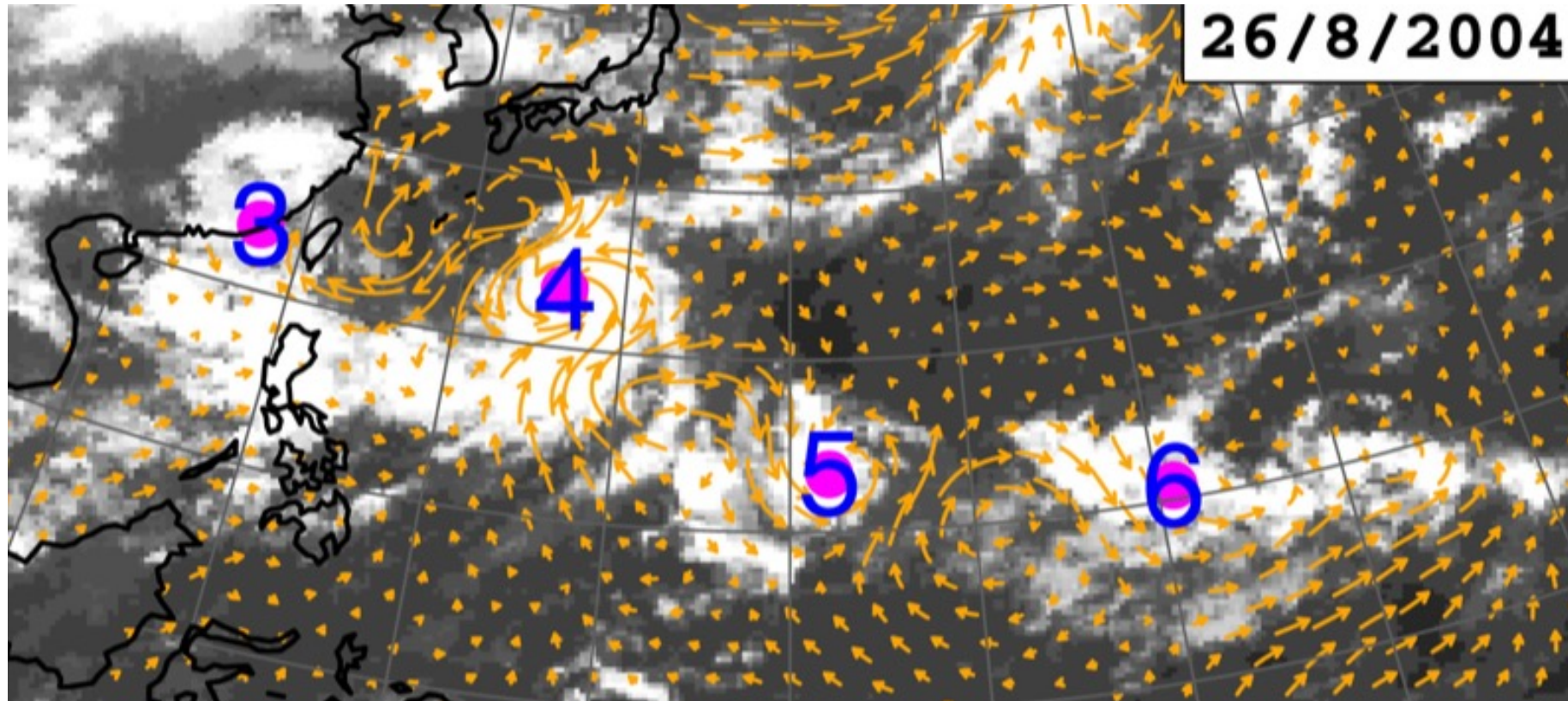
Irma (CAT5, blue)
Florida, 09/10 blue
Fatalities: 134
Damage: \$77.16 billion



Maria (CAT5, green)
Puerto Rico, 09/20, green
Fatalities: 3059
Damage: \$91.61 billion



Extreme TC cluster season over the WNP



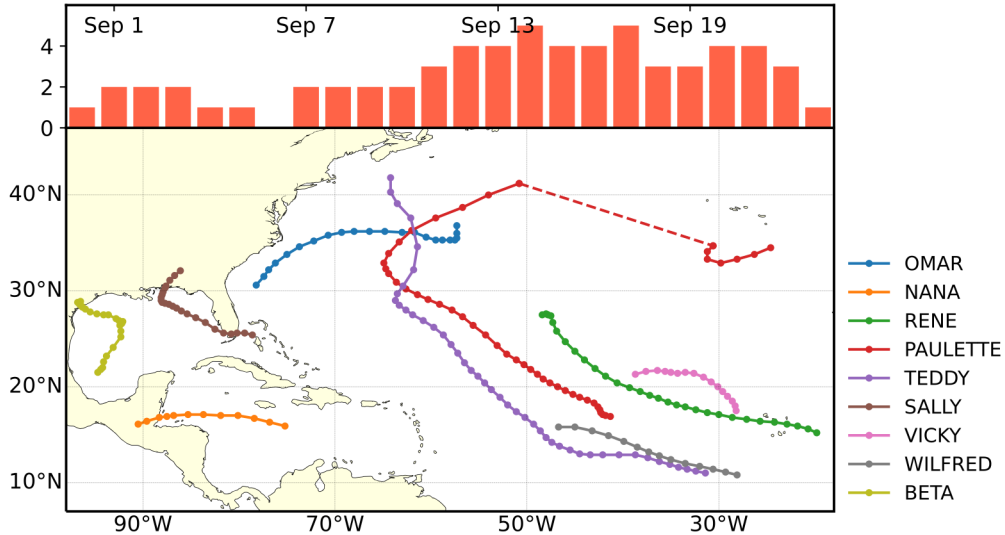
Hu et al. (2018) GRL

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

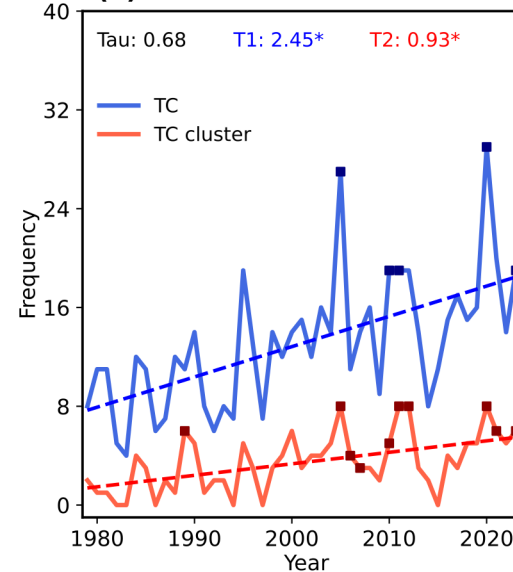
Nine disturbances intensified into TCs within 34 days, five of which made landfall in East Asia.

Observed shifts of TC cluster Hotspot

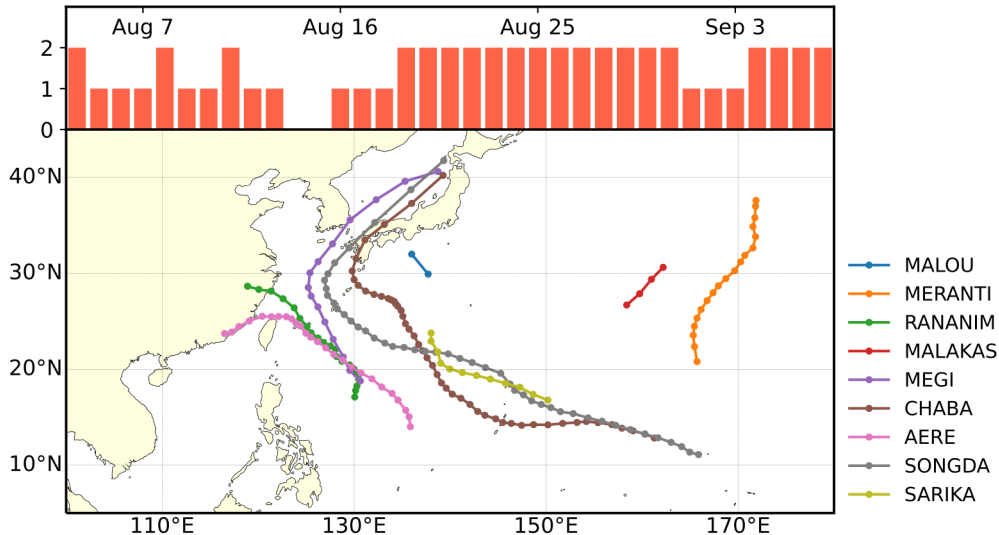
(a) Extreme NA TC cluster season: Aug 31 - Sep 23, 2020



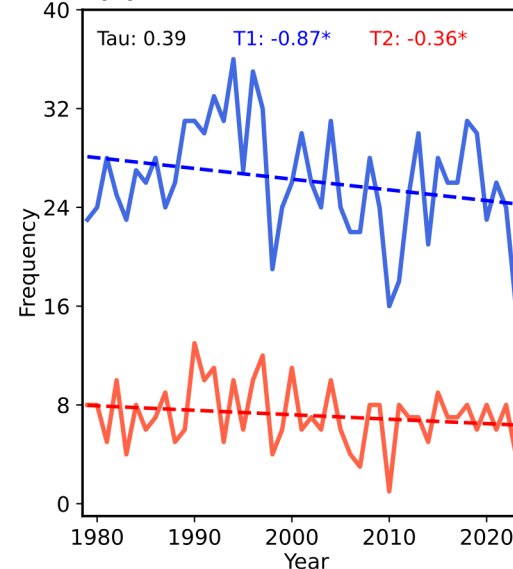
(b) NA



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



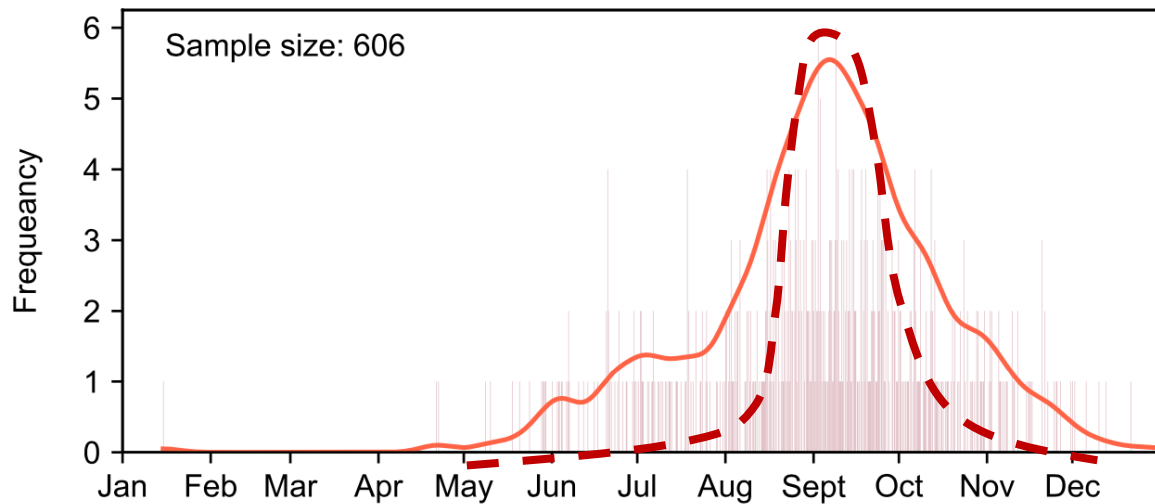
(d) WNP



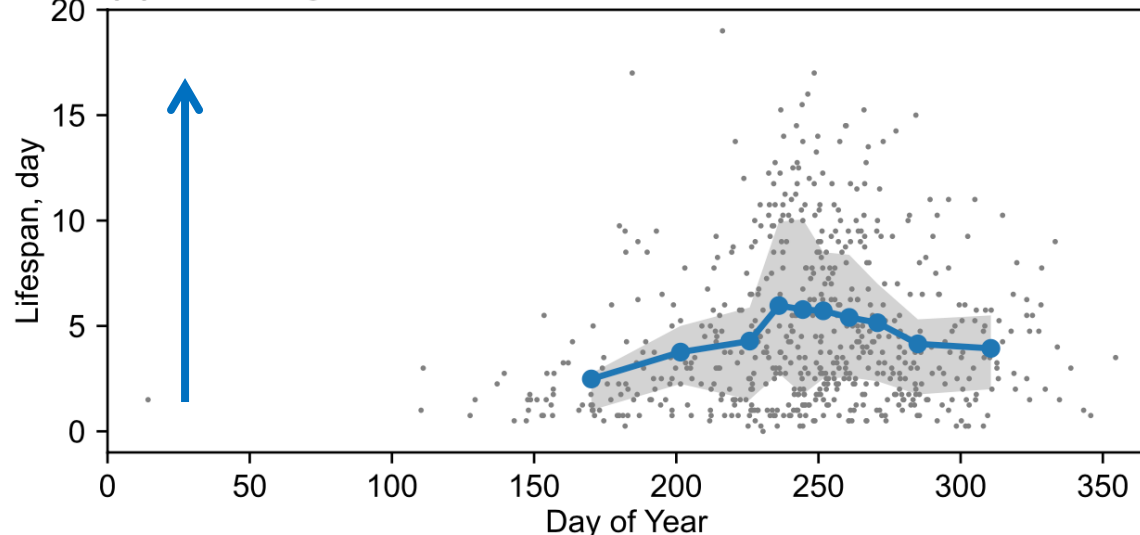
- Historically, WNP is home for most TC cluster events.
- In recent years, North Atlantic has witnessed more TC clusters.
- TC cluster frequency in the NA has reached or even surpassed that of the WNP **nine times (~1/2) since 2005.**

Statistical perspective: What controls TC cluster changes?

(a) NA: TC genesis time



(c) NA: TC genesis time & lifespan

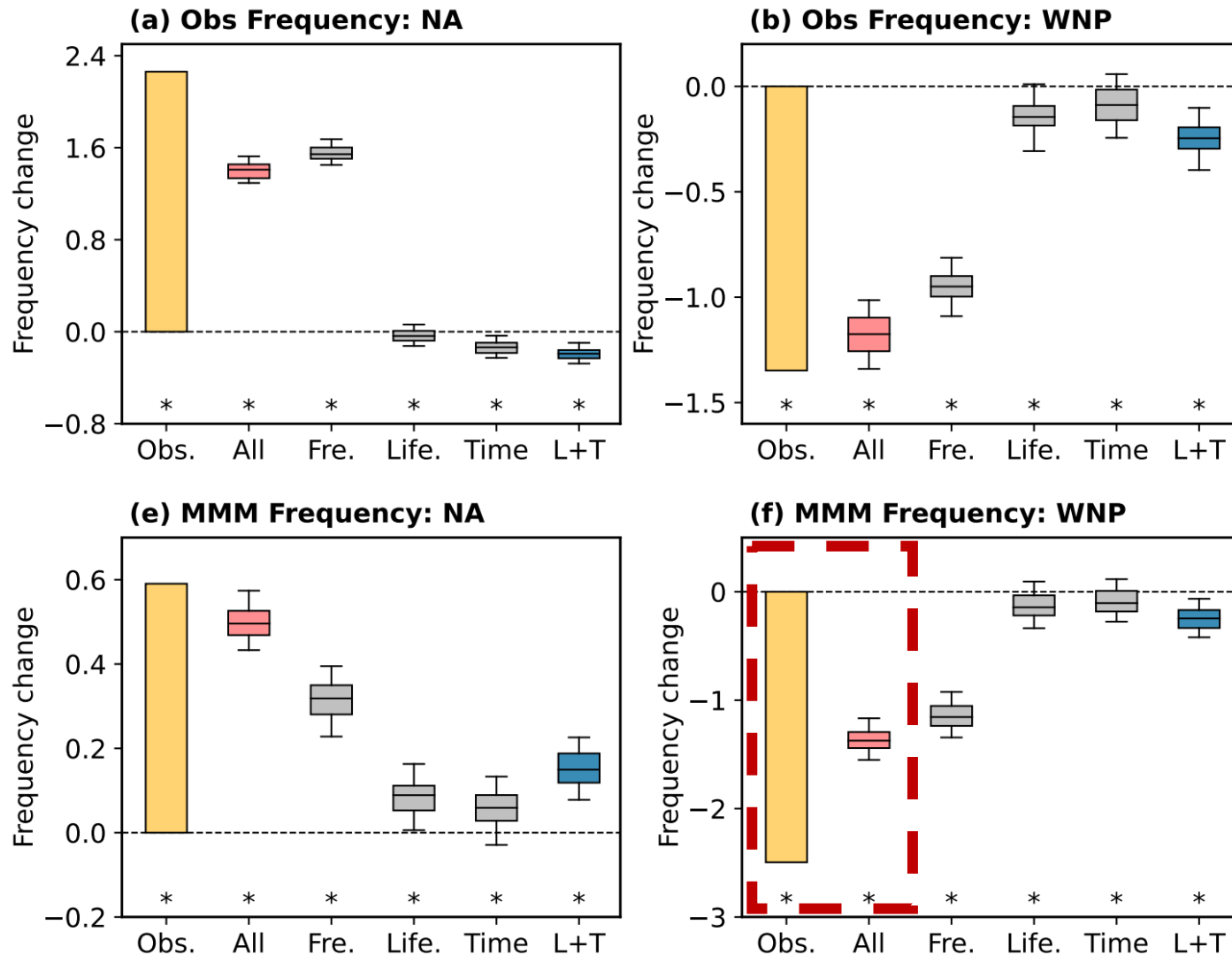


- ✓ Annual TC frequency
- ✓ TC seasonal cycle
- ✓ TC lifespan

The Probabilistic Model:

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

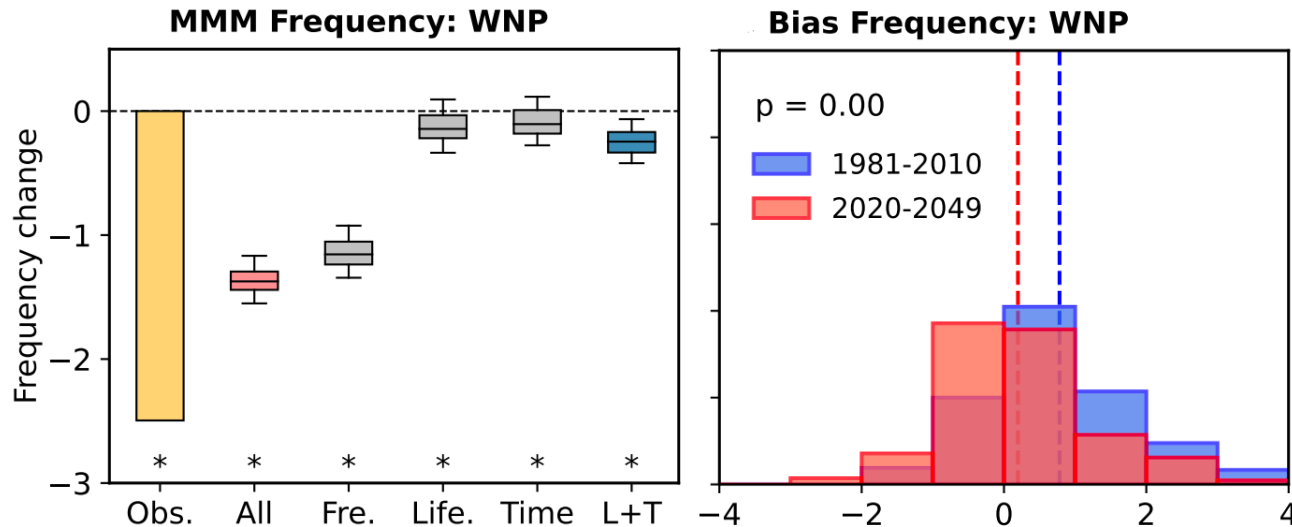
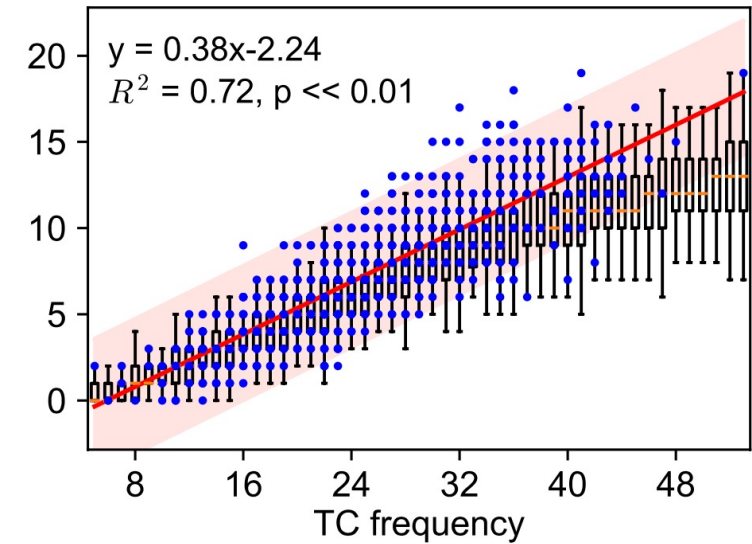
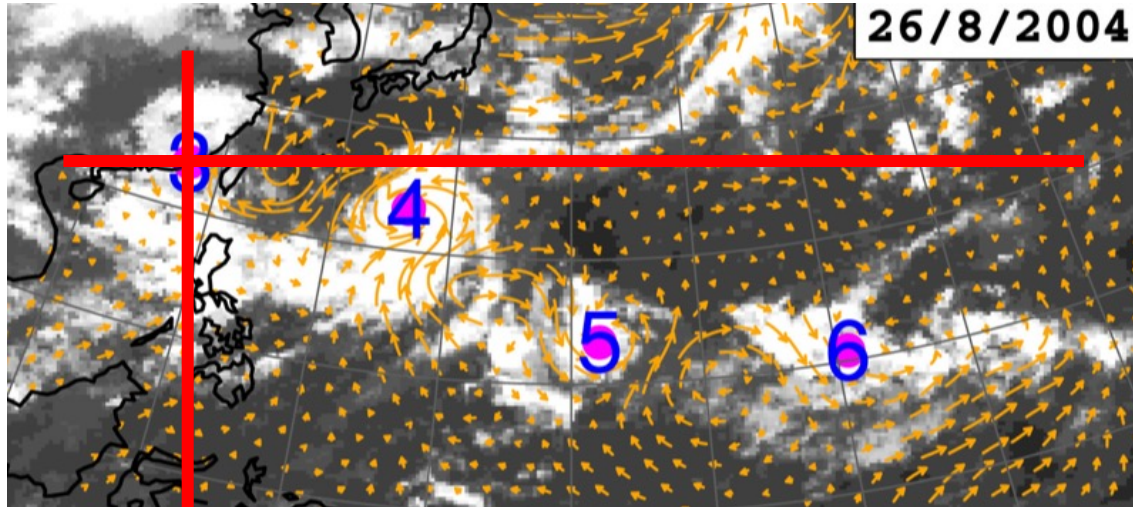
Statistical perspective: What controls TC cluster changes?



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

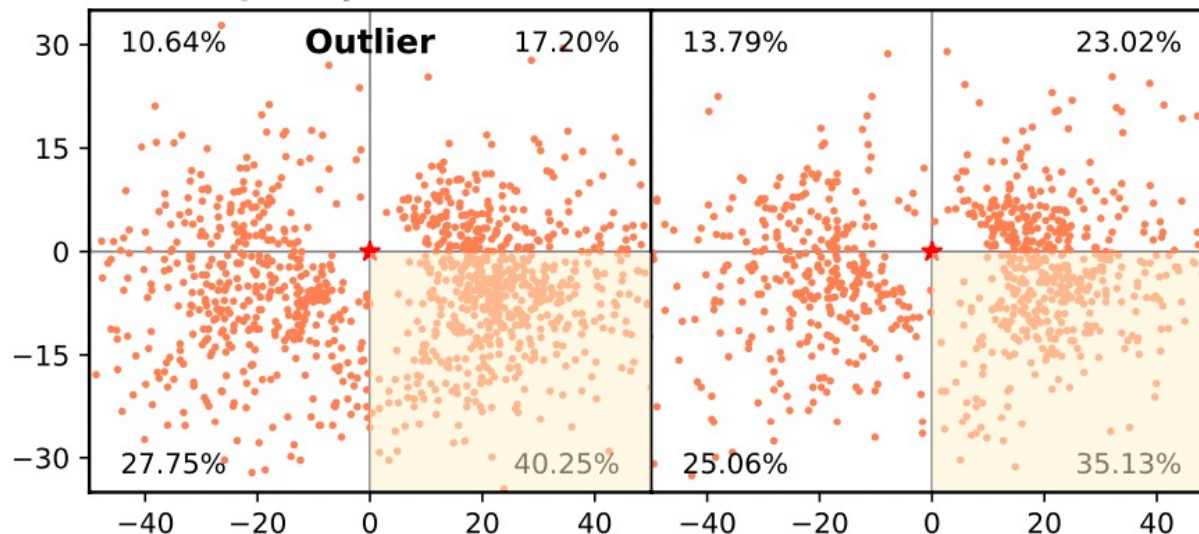
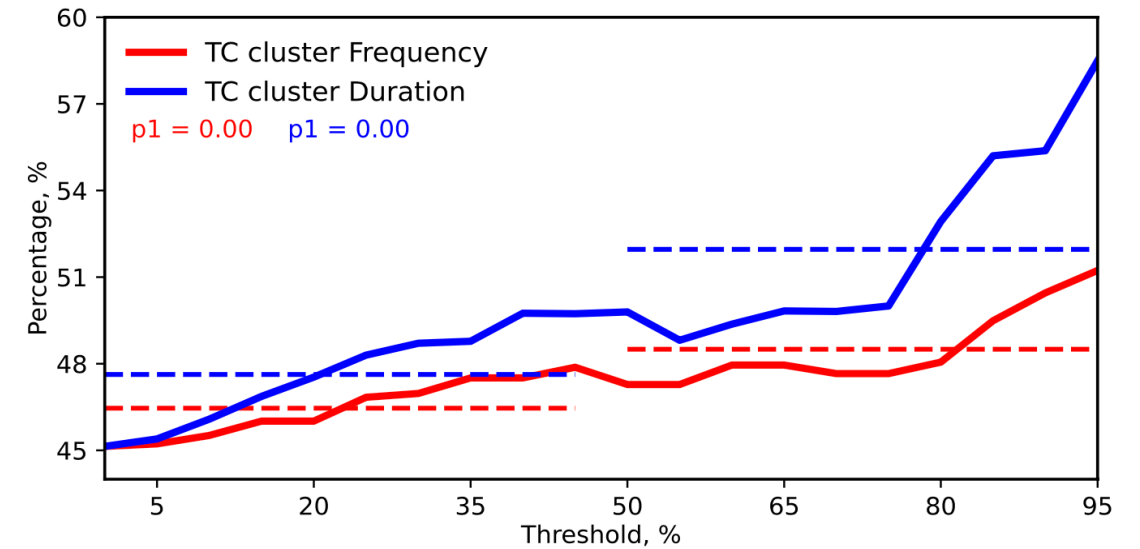
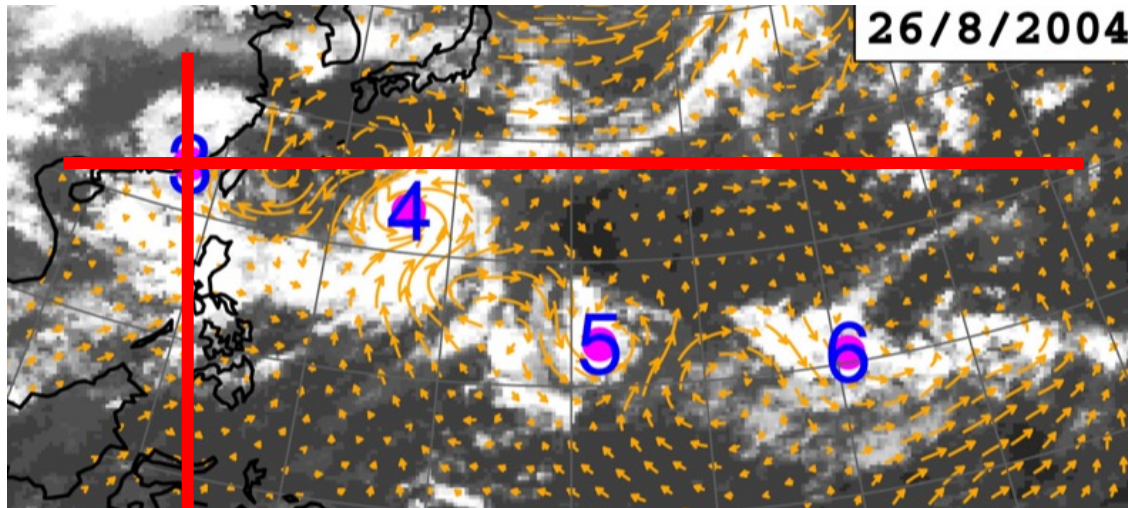


Outliers: years of TC cluster frequency beyond explanation of the probabilistic model.

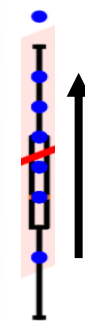
Independent Assumption

Dependency -> Dynamic linkage

Statistical perspective: Identifying dynamically-linked TC clusters



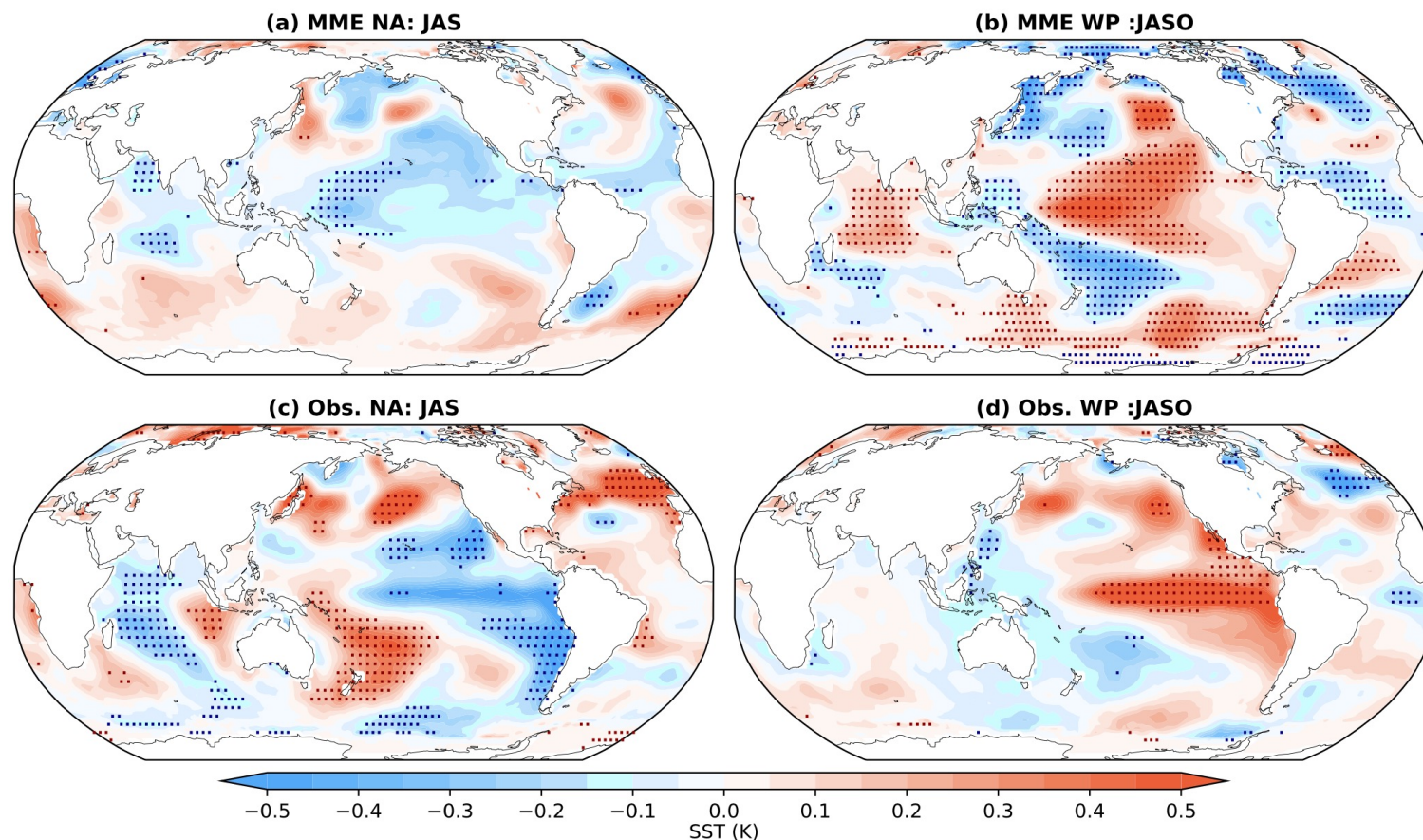
Outlier



- 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

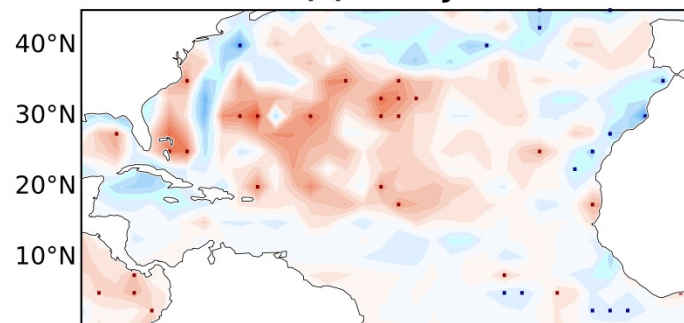
Physical perspective: Favorable Large-Scale Condition for TC cluster



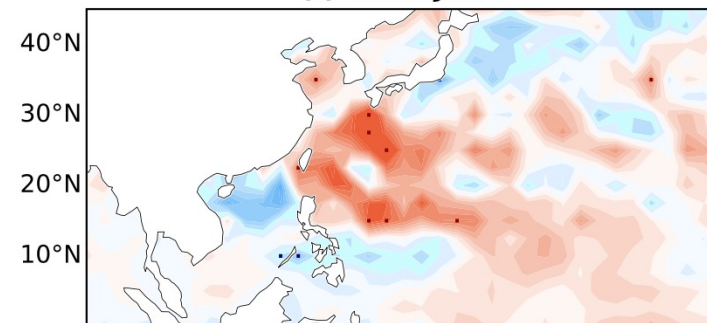
- The enhanced dynamical connections between TCs over the WNP and NA are associated with El Niño and La Niña conditions, respectively.
- Strengthened synoptic-scale wave activity intensities.

SST (↑) and synoptic-scale wave activity (→) differences between years with high TC cluster dynamic connections and years with low TC cluster dynamic connections.

(e) Obs.: JAS



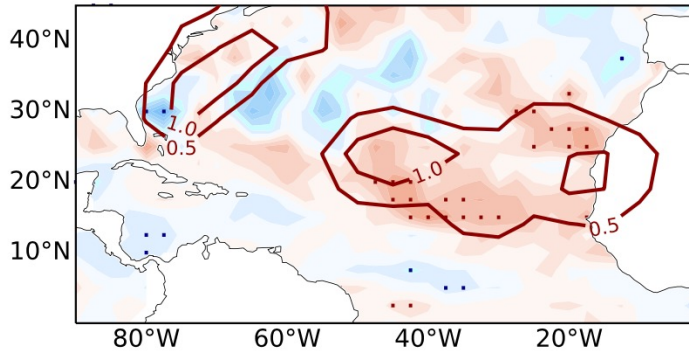
(f) Obs.: JASO



Physical perspective: Role of synoptic-scale waves

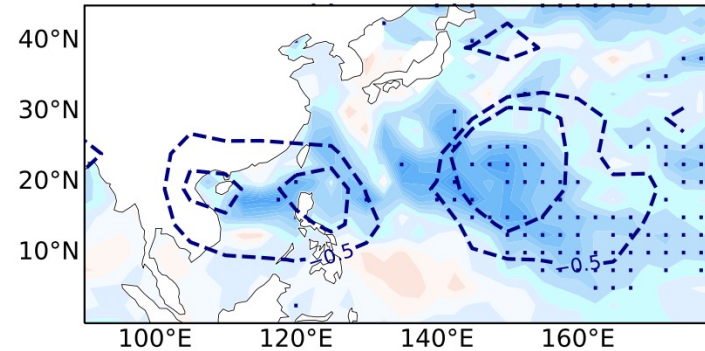
NA

(g) MRI-H: JAS



WNP

(h) MRI-H: JASO

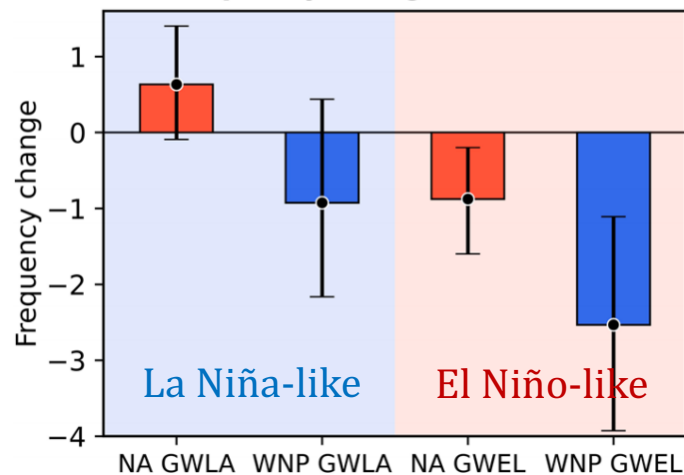


Two synergistic effects

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

MRI-H Climate model: La Niña-like warming pattern

(a) Frequency change



- Forced with the observed La Niña-like global warming pattern: the hotspot for TC clusters shifts from the WNP to the NA.
- Forced with the projected El Niño-like warming: the TC cluster activities are suppressed in both basins, with a larger decrease occurring over the WNP.

HIRAM: Different warming patterns

Conclusion

1. We develop a **probabilistic model** assuming that TCs are mutually independent and occur randomly.
2. **Against this baseline**, we identify outliers as clusters with dynamic interactions between TCs.
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** modulates dynamically connected TC clusters through synoptic-scale wave activity changes.

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, 850–858.

Thank you

Zheng-Hang Fu

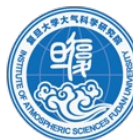
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