Gulf Stream Influence on the Extratropical Transition of North Atlantic Tropical Cyclones

More Information (publication in prep):

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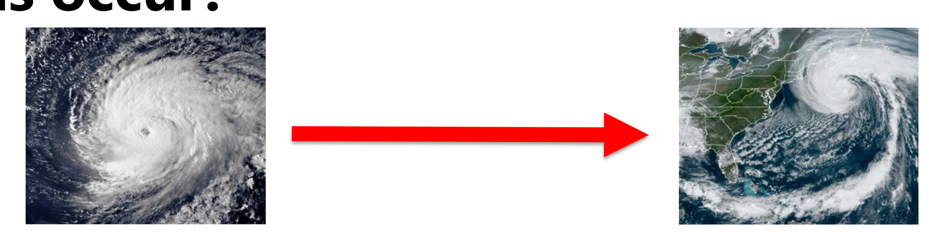
Motivation

- **North Atlantic**: favored region for **extratropical transition** (ET) of tropical cyclones (TCs)[1] → cold and warm fronts
- Gulf Stream (GS) influences:
  - midlatitude winter cyclones[2,3]
  - **climatology of atmospheric fronts**[4]
- Mechanisms debated:
  - SST vs. SST ∇, latent vs. sensible HF[2]
  - Regional **preconditioning** vs. direct?
  - Diabatic frontogenesis[5] (**baroclinicity** ⬆)

Objectives

Does the **Gulf Stream play a role** in the **extratropical transition** of tropical cyclones in the region and **how might this occur?**

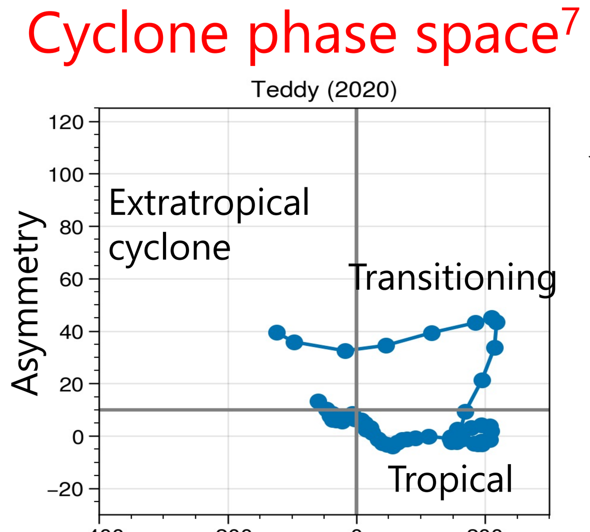


Data

- ERA5 reanalysis
- 0.25° resolution
- TempestExtremes[6]
- 1980-2018

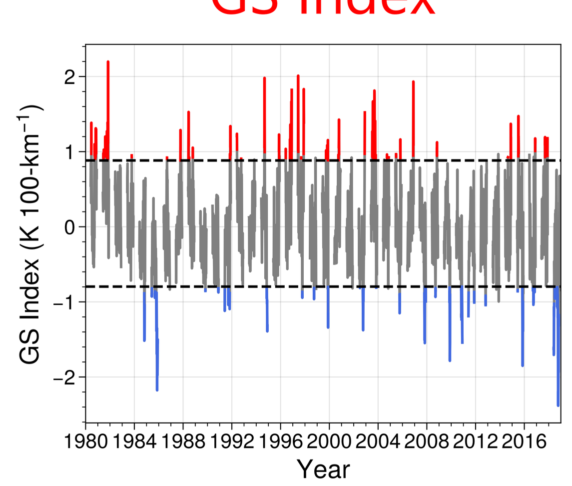
Methods

Cyclone phase space[7]



Cyclone phase space for Hurricane Teddy in ERA5 during the 2020 North Atlantic hurricane season.

GS Index



Time series of Gulf Stream SST ∇ index based on 4 points associated with the topographically-bound GS between June 1 – November 30.
Red: Above 95%
Blue: Below 5%

Frontogenesis

$$F_{ad} = \frac{1}{2}|\nabla\theta||D\cos(2\beta) - \delta|$$

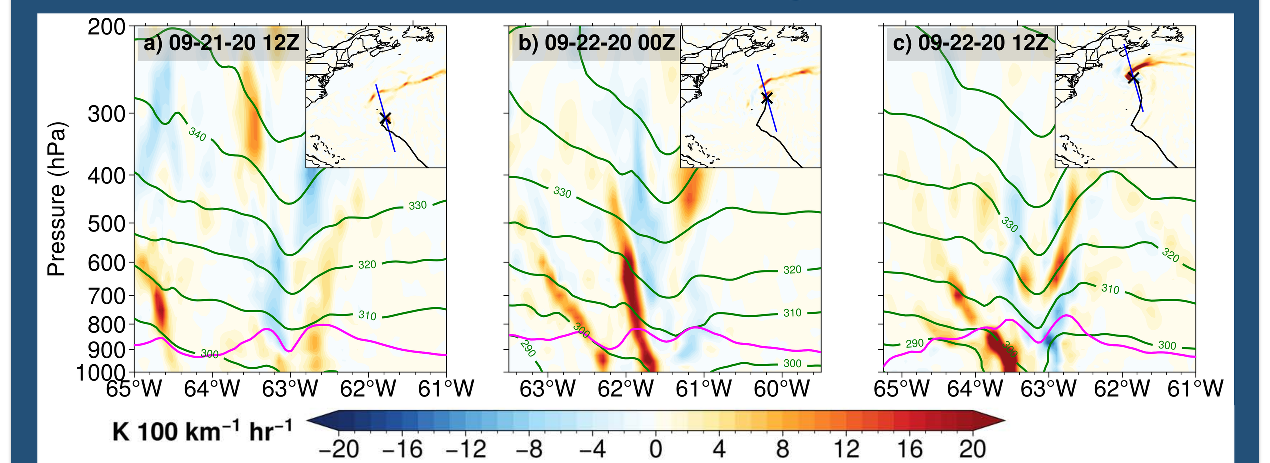
$$F_{di} = n \cdot \nabla\dot{\theta}$$

Sensible Heat Flux ∇

$$SHF\,\nabla = n \cdot \nabla SST$$

RESULTS

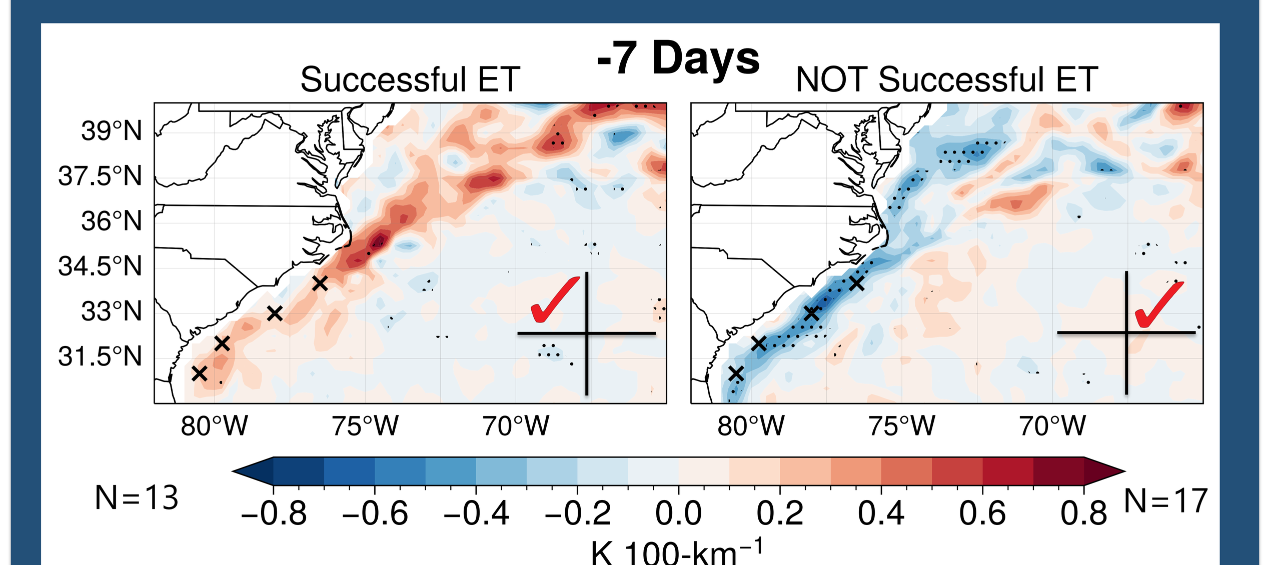
Hurricane Teddy (2020)



Vertical cross section of adiabatic frontogenesis (shaded), isentropes (green contours), boundary layer height (magenta). Inset: 925hPa adiabatic frontogenesis associated with the ET of Hurricane Teddy (shaded), center of Teddy at each time (X marker) and cross section region (blue line).

- Teddy approaches a **quasi-stationary front**, adiabatic frontogenesis develops.
- Anecdotal evidence of **surface-based** frontal development during ET **near GS**.

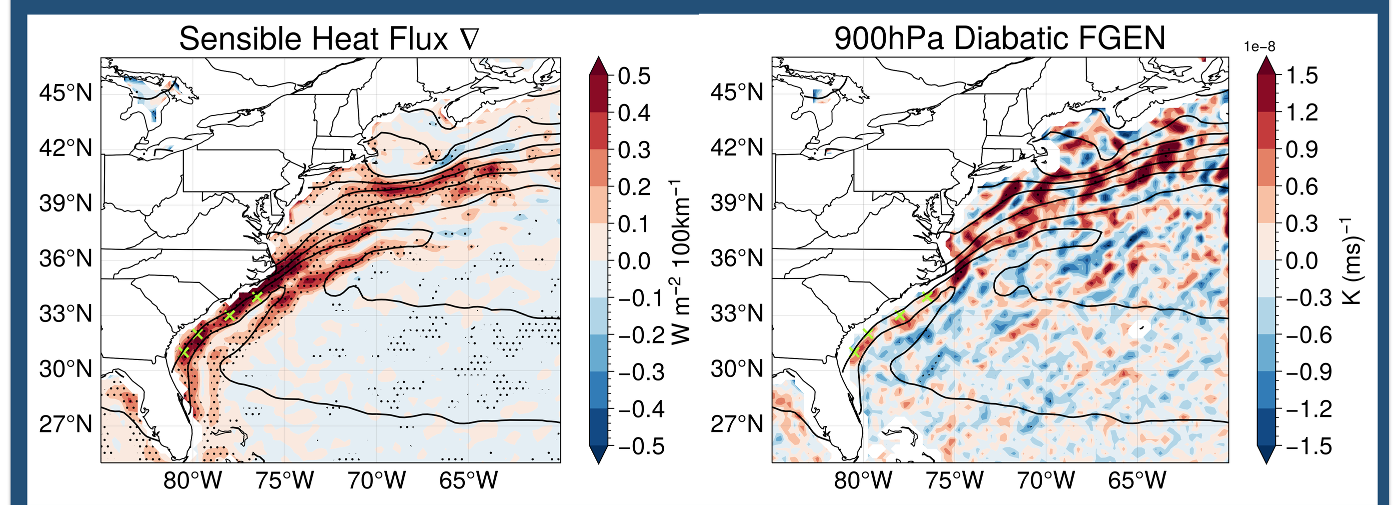
Evidence for a relationship between ET fate & SST ∇ strength



Composites of anomalies from climatological daily mean SST gradient at a 7-day lead for times averaged by storm when TCs successfully transition (left) and do NOT successfully transition (right). Hatching indicates statistical significance for p < 0.1.

- **Diminished** SST ∇ anomalies for unsuccessful ET and vice-versa.
- **Persistent signal** in days/weeks leading up to ET times contributes to **baroclinicity** for enhanced/diminished ET.
- **Persistence** implies **predictability.**

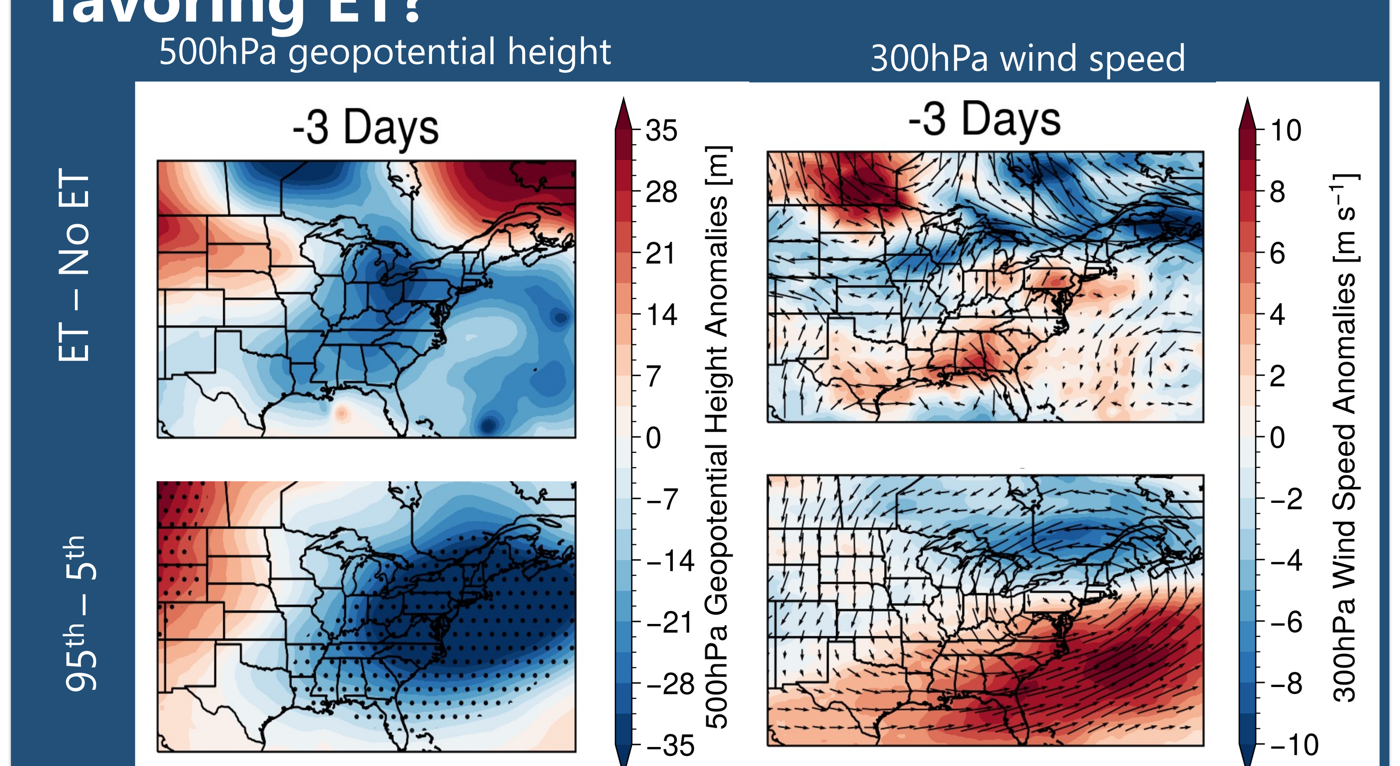
Gulf Stream SST ∇ and Baroclinicity



Left: Sensible heat flux gradient composites based on the difference between the 95th and 5th percentiles of the GS index. Right: Same but for 900hPa diabatic frontogenesis.

- Composite differences between extremes in GS Index show **enhanced surface baroclinicity** when GS index is higher.
- Mechanism: SHF ∇ scales with **diabatic frontogenesis** by influencing near-surface temperatures (noisier signal).
- Region more **conducive for influence on ET.**

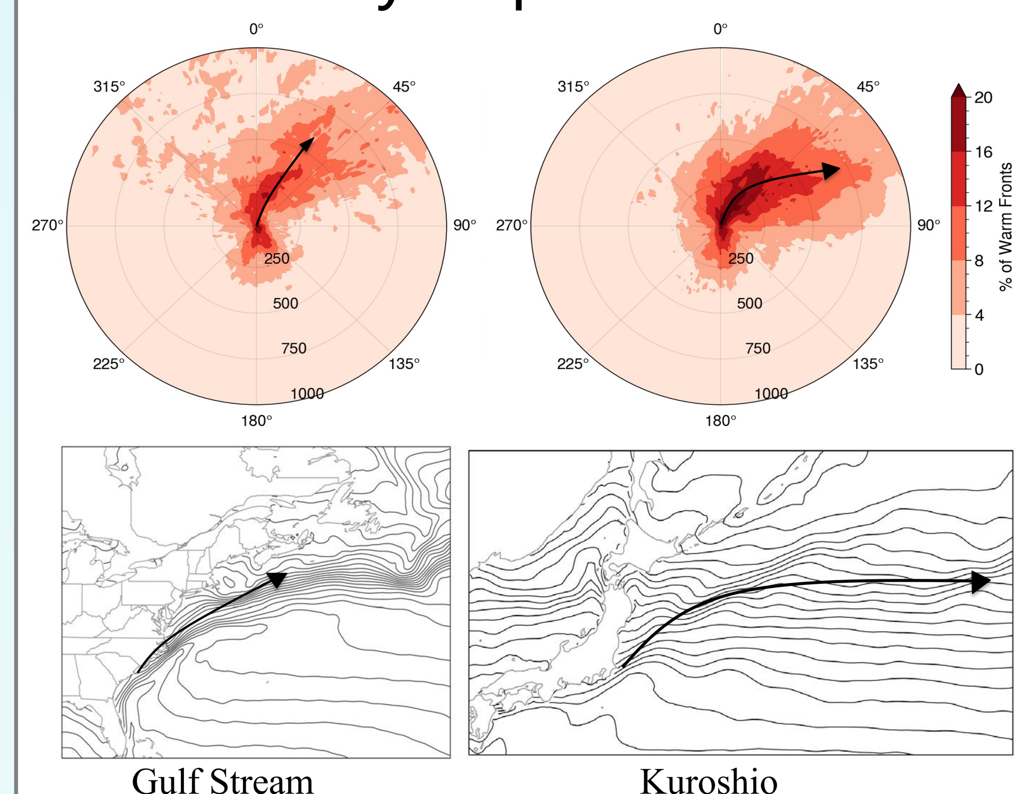
Is the ocean signature for ET completion an artifact of atmospheric conditions favoring ET?



Left: Lead composites of 500hPa geopotential height anomalies differences between successful and not successful ET (top) and 95th-5th percentiles of GS Index (bottom). Right: Same but for 300hPa wind speed (shaded) and vectors.

- **Large-scale atmospheric setup** associated with extrema of Gulf Stream strength is **NOT the same** as for different **ET phases**.
- Suggests GS role in ET completion.

Bonus: Warm frontal structure in transitioned TCs appears to reflect WBC orientations – baroclinicity imprint?



Top: TC-centered composites of 900hPa F diagnostic relative frequencies of warm fronts at ET completion for NATL (left) and WPAC (right). Bottom: Climatological mean SST contours for GS and Kuroshio.

$$F = \frac{\zeta_P|\nabla T_P|}{\zeta_O|\nabla T_O|}$$

Results consistent with Tochimoto and Niino (2021)

Conclusions

1) **Diminished SST gradient** strength with **unsuccessful ET** (and vice-versa)
2) **Enhanced baroclinicity** associated with **stronger GS** SST ∇
3) GS strength appears to **not** be an artifact of **atmospheric conditions** conducive to ET
4) **WBC orientation** imprints on **warm frontal structure** at ET completion

Takeaway: GS is important for ET, likely from regional preconditioning!

References

1 Jones, S. C. *et al. Weather Forecast.* 18, 1052–1092 (2003); **2** Booth, J. F. *et al. Mon. Weather Rev.* 140, 1241–1256 (2012); **3** Jacobs, N. A. *et al. Int. J. Remote Sens.* 29, 6145–6174 (2008); **4** Parfitt, R. *et al. Geophys. Res. Lett.* 43, 2299–2306 (2016); **5** Reeder, M. J. *et al. J. Atmos. Sci.* 78, 1753–1771 (2021); **6** Hart, R. E. *Mon. Weather Rev.* 131, 585–616 (2003); **7** Zarzycki, C. M. *et al. J. Appl. Meteorol. Climatol.* (2021)