NC STATE UNIVERSITY

CVCWG, CESM Workshop 2024

Hemisphere-dependent Response of Hadley Circulation to ENSO and Eddy Forcing

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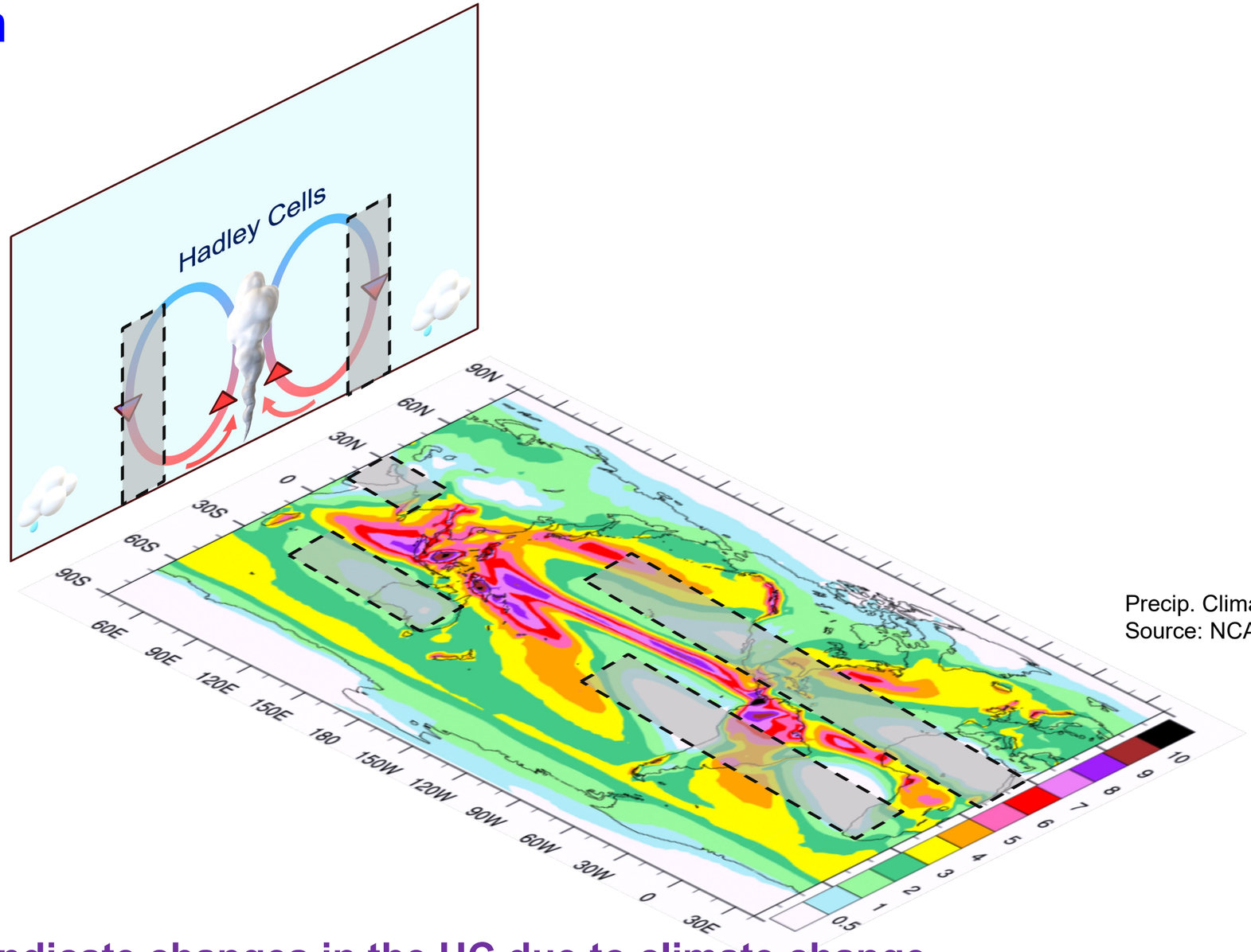
Hadley Circulation

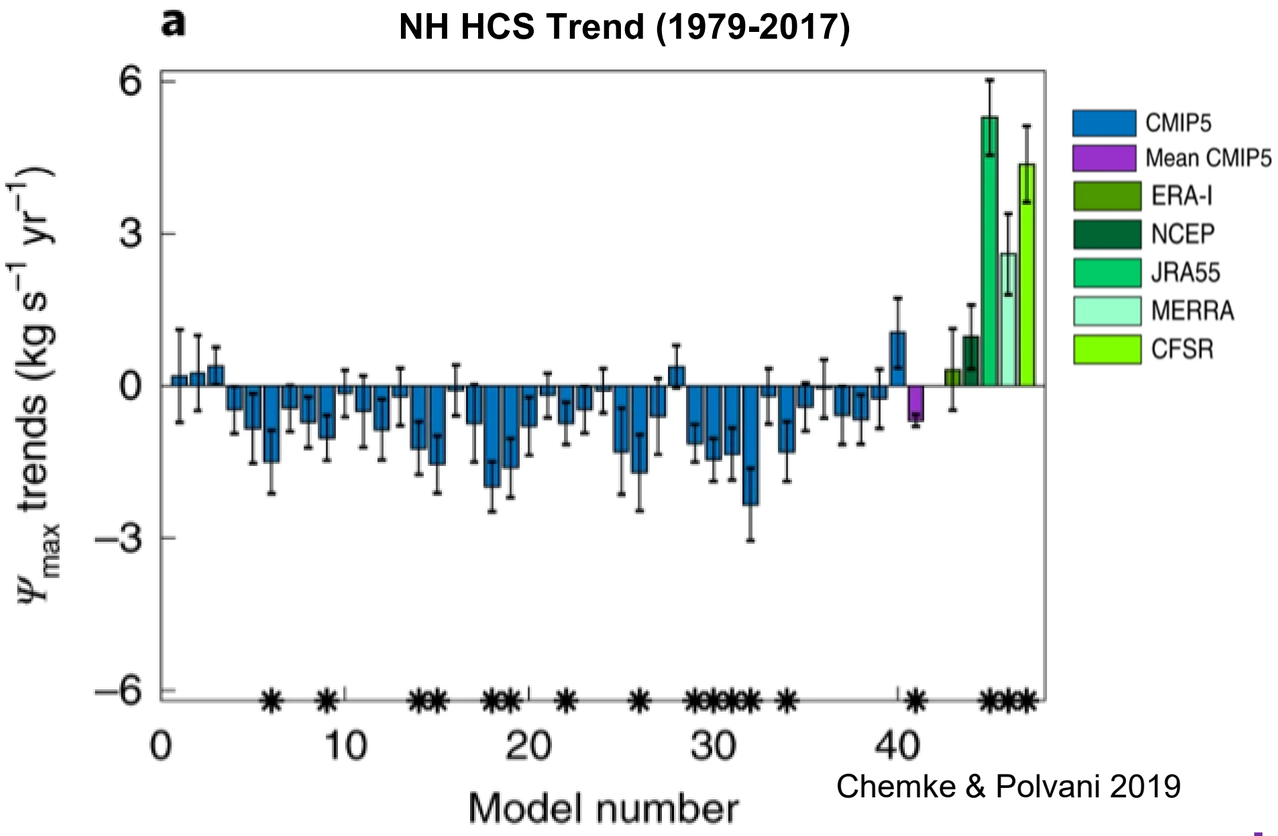


Precip. Climatology (1979-2010)
Source: NCAR Climate Data Guide

- **Recent observations indicate changes in the HC due to climate change**
  (Mitas and Clement 2006; Stachnik and Schumacher 2011; Nguyen et al. 2013)

Hadley Circulation Strength (HCS)

- A warmer climate theoretically implies a weaker Hadley circulation strength (HCS) (Held & Soden 2006)



Chemke & Polvani 2019

- Climate models mostly show a weakening of HCS in NH and SH (Nguyen et al. 2013, Mitas & Clement 2006)

- Recent observational reanalyses show a strengthening of HCS in NH (Chemke & Polvani 2019)

Historical trend in HCS has high uncertainty!

Motivation

- Internal climate variability contributes to uncertainty in the recent HCS trend (Nguyen et al. 2013; Zaplotnik et al. 2022).

Internal Atmospheric Variability

Primarily Eddy driven internal atmospheric variability (Walker & Schneider 2006; Caballero 2007; Zurita Gotor & Alvarez-Zapatero 2018)

Coupled Variability

Anomalous wind-stress (τ') driven tropical ocean circulation variability (e.g., ENSO, Upwelling) (Oort & Yiegner 1997; Seager et al. 2003; Chemke 2022)

Atmospheric Eddy → **Interannual HCS Variability** ← τ'-driven ocean circulation

Science Questions

- What is the relative importance of eddy-driven atmospheric variability versus dynamically coupled modes, including ENSO on HCS variability?
    - How much does ENSO contribute alone?

- Do the potential drivers of HCS variability operate in one or both hemispheres?

We answer these questions using unique NCAR Community Earth System Model CESM2 (1° resolution) model experiments under pre-industrial settings.

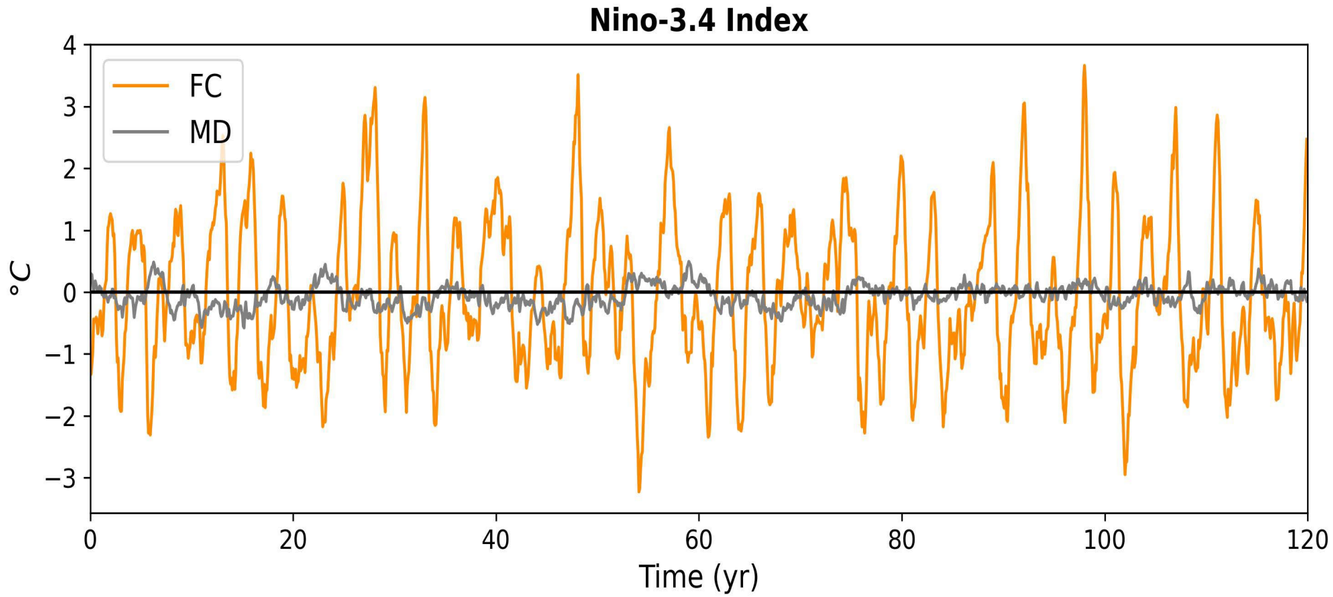
CESM2 Model Experiments

Fully Coupled (FC): State-of-the-art model, include leading climate variabilities like ENSO, IOD, Atlantic Niño.

Mechanically Decoupled (MD): Global ocean lacks the τ'-driven ocean variability (Larson et al. 2024, JCLI).

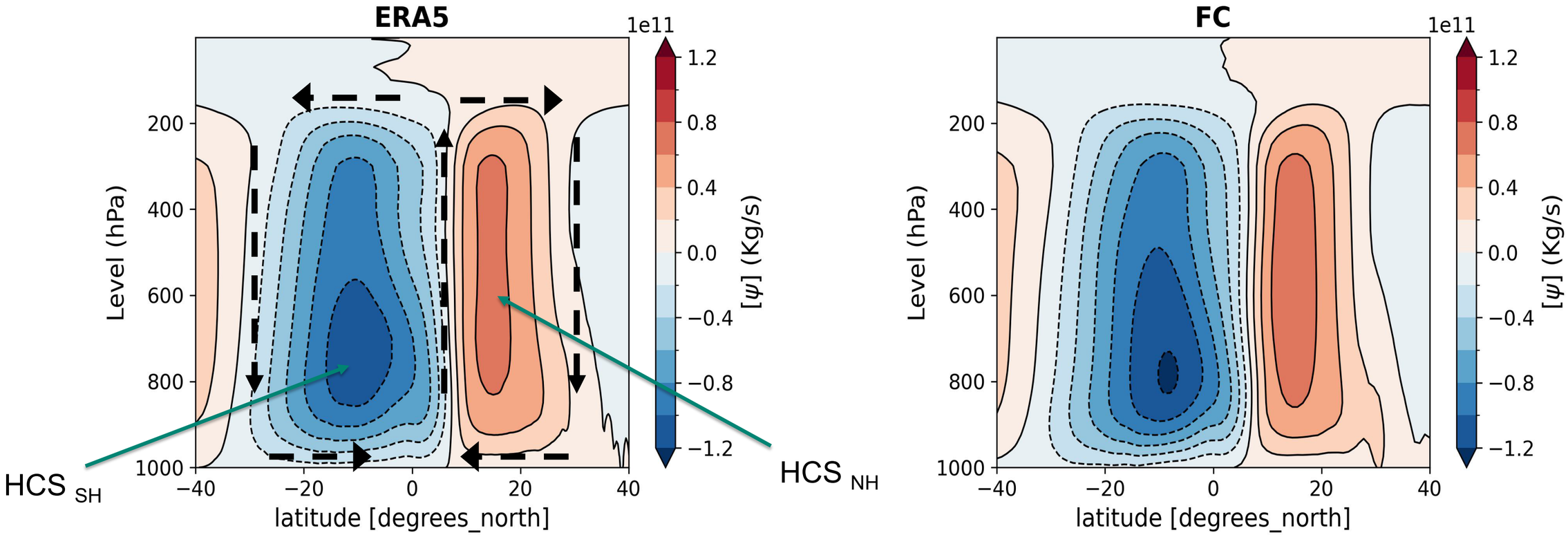
- Lacks τ'-driven ocean modes including ENSO.
- Retains buoyancy coupling

FC – MD:
Impact of τ'- driven ocean circulation variability



FC and MD model datasets are freely available in Climate Data Gateway !

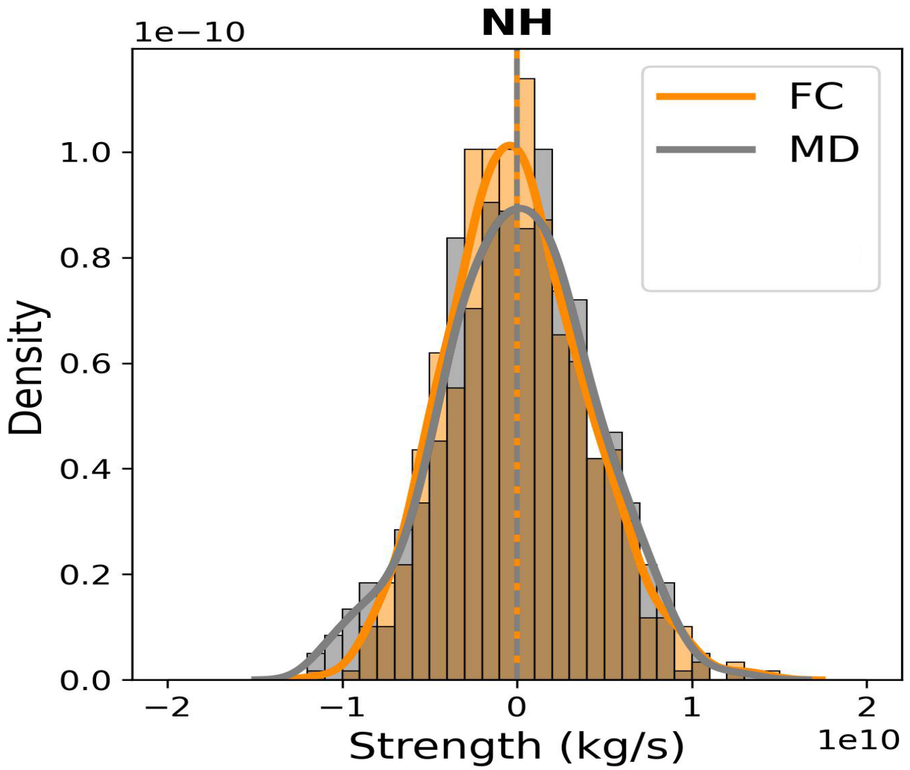
Mean HC

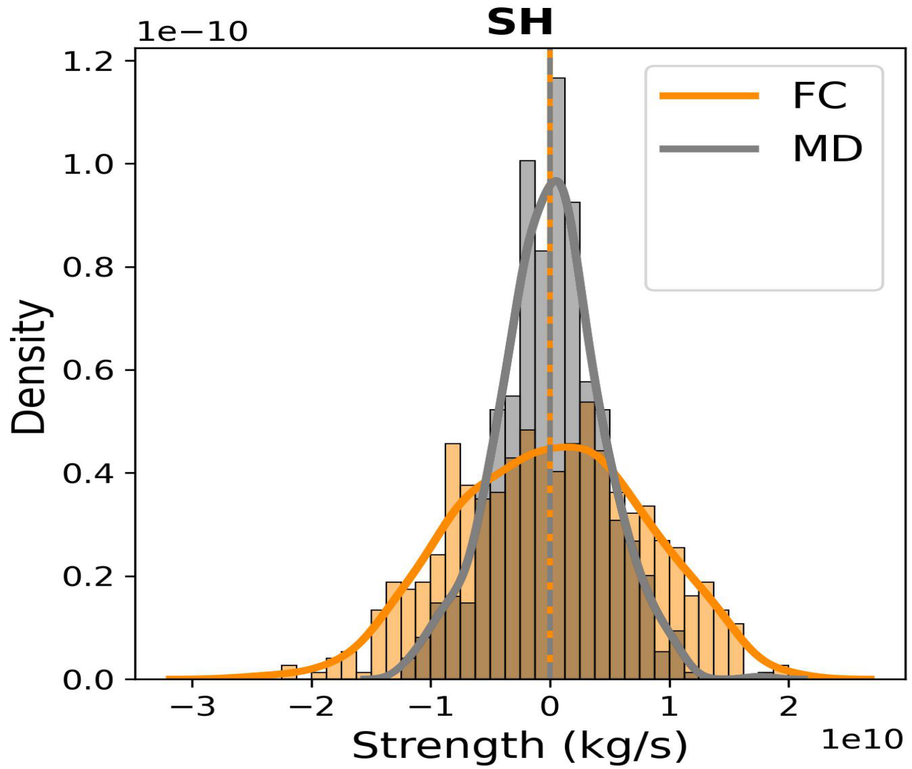


- Mean HC in the CESM2 FC shows similar characteristics to the ERA5 reanalysis.

Interannual HCS Variability

FC – MD:
Impact of τ'- driven ocean circulation variability

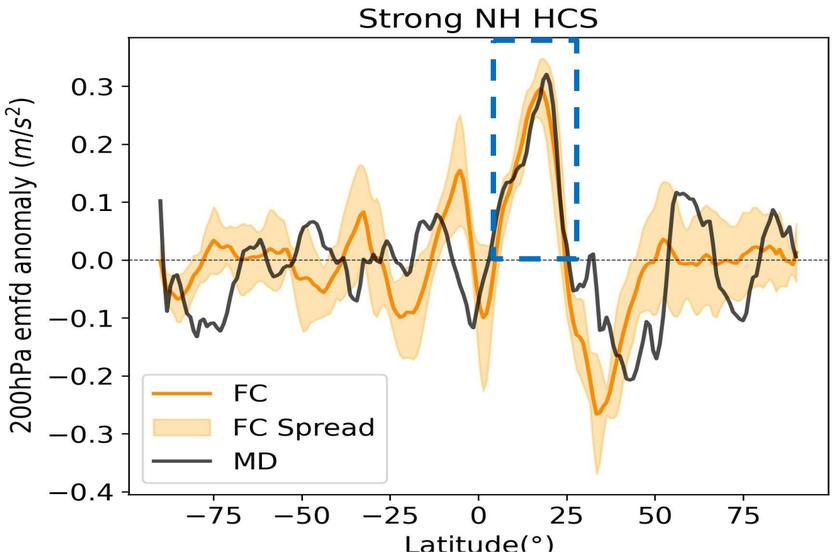


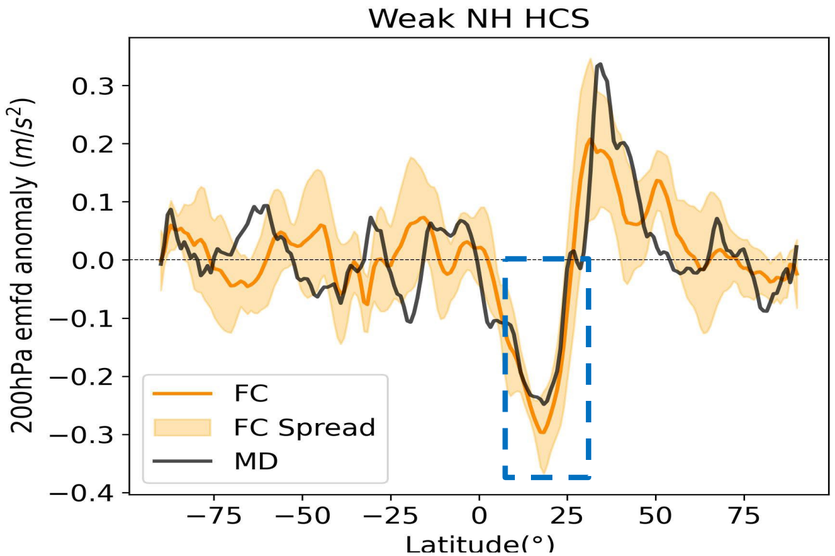


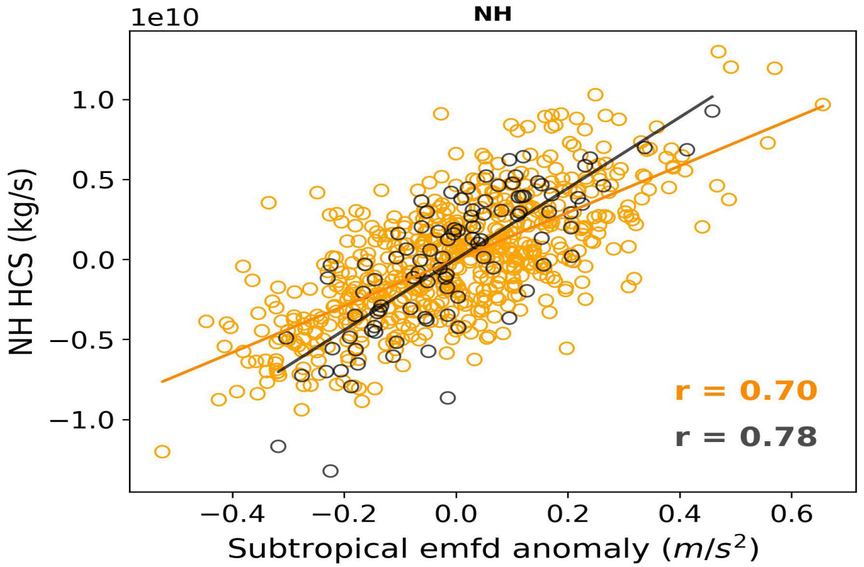
- τ'- driven ocean circulation variability significantly increases HCS variability in the SH, not in the NH.

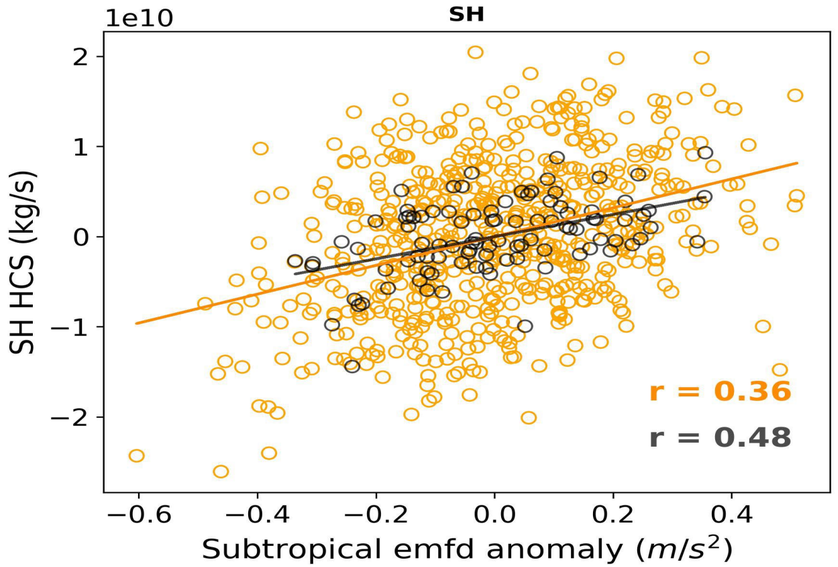
NH HCS Variability

❑ τ'- driven ocean circulation variability has an insignificant contribution to the NH HCS variability.









Role of upper-atmospheric eddies:

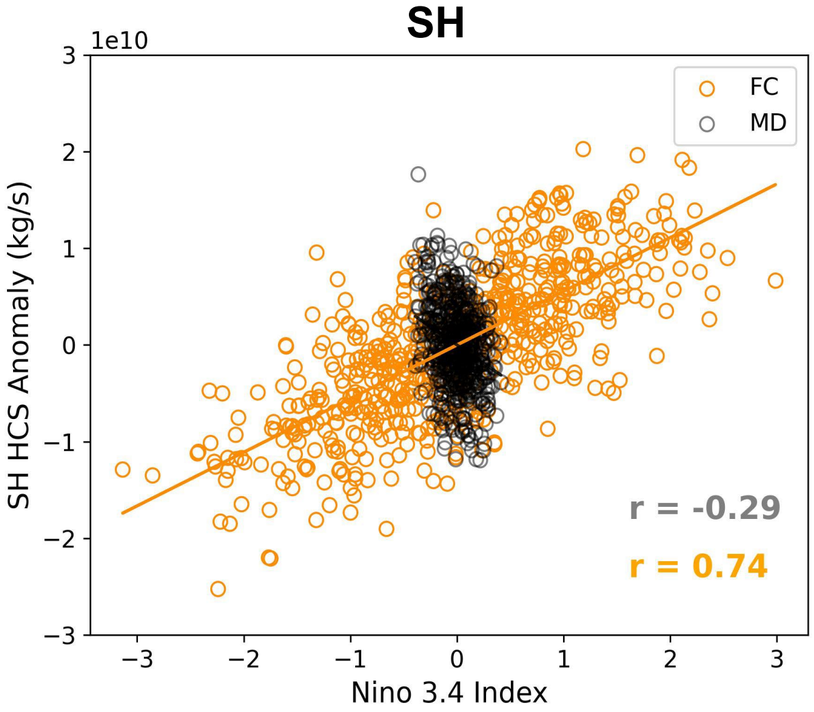
Strong NH HC: Divergence of anomalous EMF in subtropics.

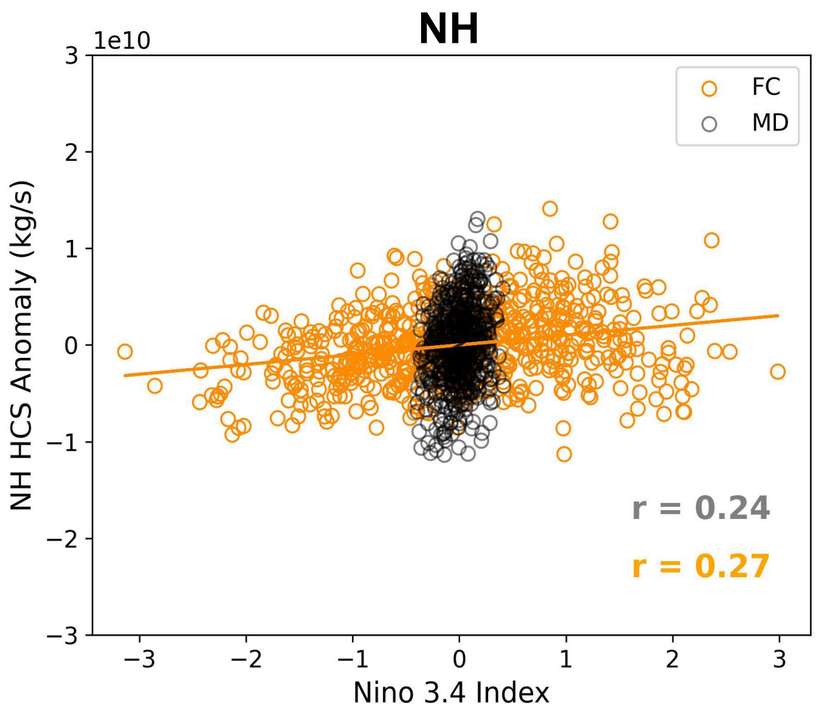
Weak NH HC: Convergence of anomalous EMF in subtropics.

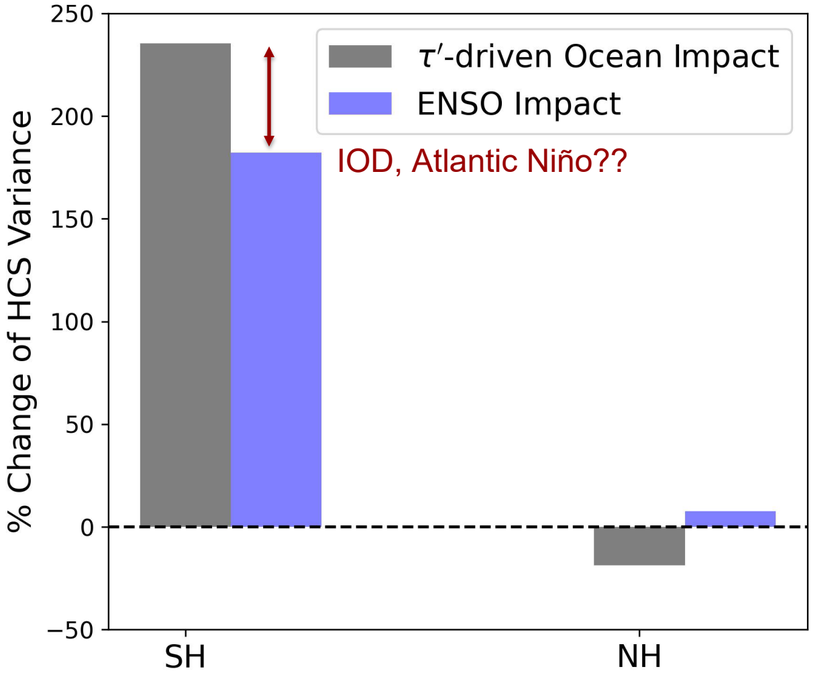
Eddies influence HCS in NH and SH.
-Strong in NH

SH HCS Variability

❑ τ'- driven ocean circulation variability significantly contributes to the SH HCS variability.



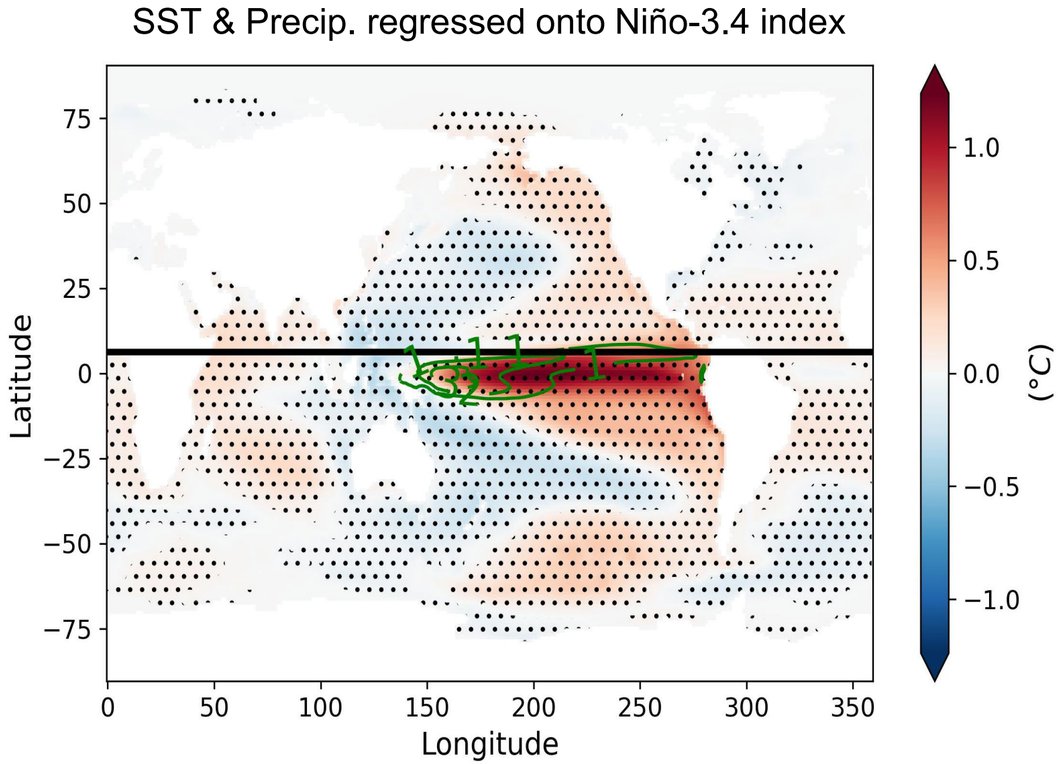




- ENSO is highly correlated with the HCS variability in SH.
- ENSO doesn't modulate NH HCS variability.
- ENSO dominates over all the coupled modes in driving HCS variability.

Summary

- ❑ Eddy-driven internal atmospheric variability impacts the HCS variability in both hemispheres.
  - A strong influence in the NH.
- ❑ ENSO-driven coupled variability impacts the HCS variability in SH.
  - ENSO-related heating is concentrated in the SH.



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