Wind-Current Coupling in the Context of Mesoscale and Frontal-Scale Air-Sea Interaction

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Ocean Mesoscale and Frontal-Scale Ocean–Atmosphere Interactions and Influence on Large-Scale Climate: A Review

Hyodae Seo, Larry W. O'Neill, Mark A. Bourassa, Arnaud Czaja, Kyla Drushka, James B. Edson, Baylor Fox-Kemper, Ivy Frenger, Sarah T. Gille, Benjamin P. Kirtman, Shoshiro Minobe, Angeline G. Pendergrass, Lionel Renault, Malcolm J. Roberts, Niklas Schneider, R. Justin Small, Ad Stoffelen, and Qing Wang

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Hyodae Seo (hseo@whoi.edu)
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Francis E. Fowler IV Center for Ocean and Climate

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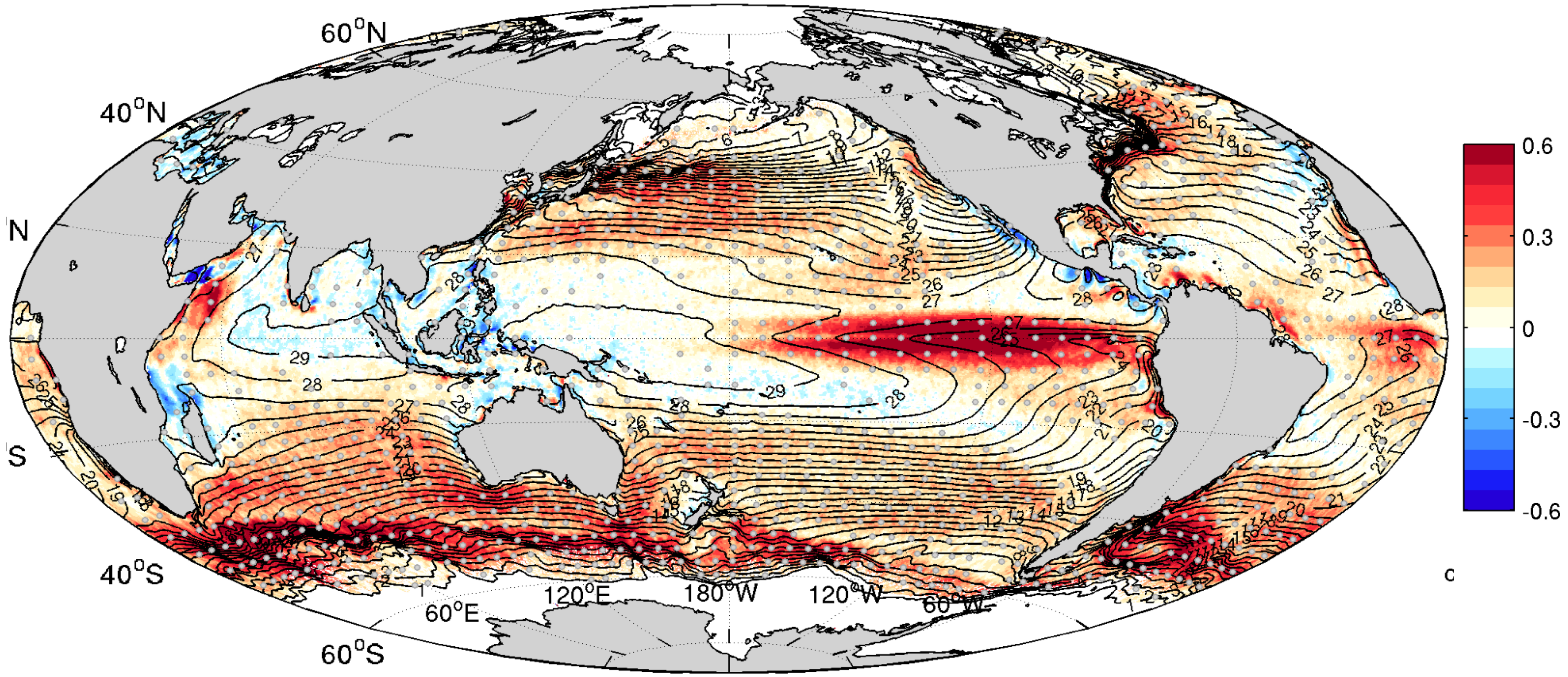
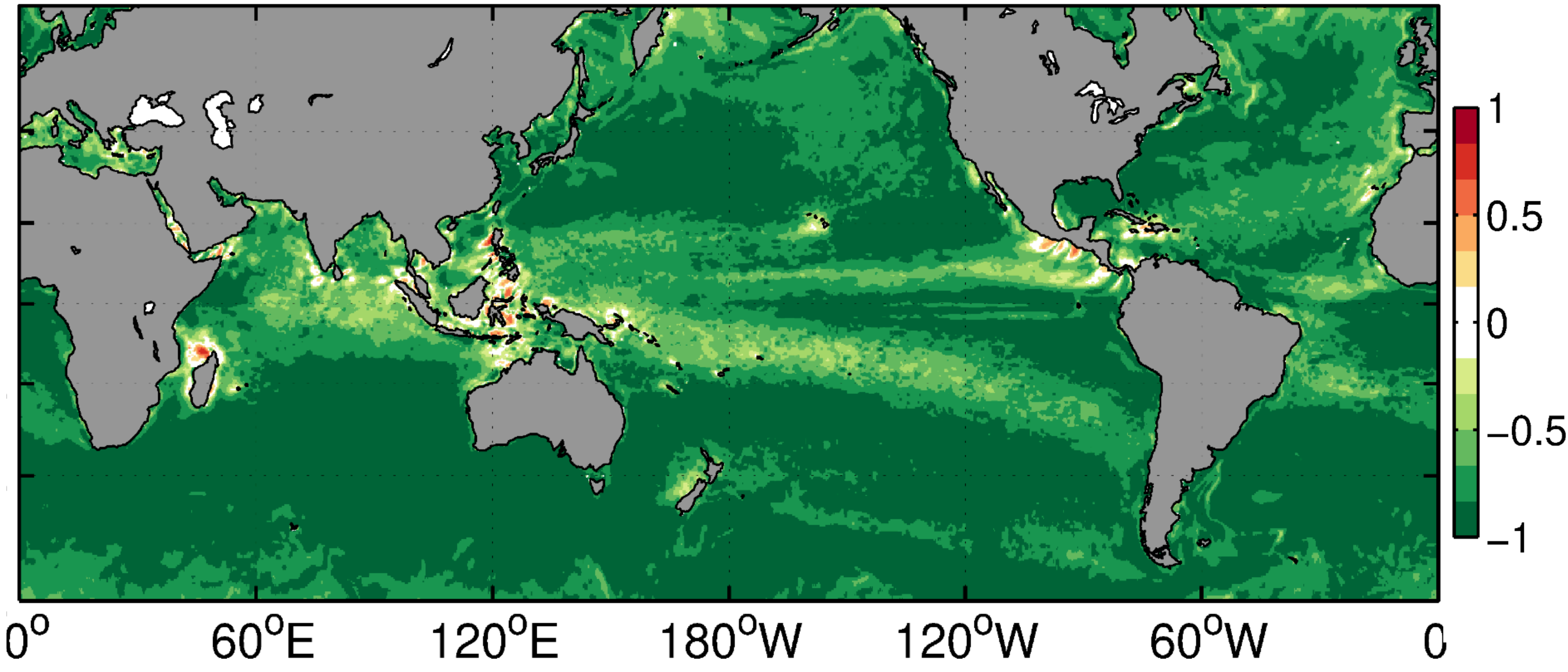
At mesoscale, ocean-driven atmospheric variability.
Via air-sea heat flux

Satellite daily correlation
bet'n SST and wind speed



ERA5 correlation
bet'n SST and latent heat flux



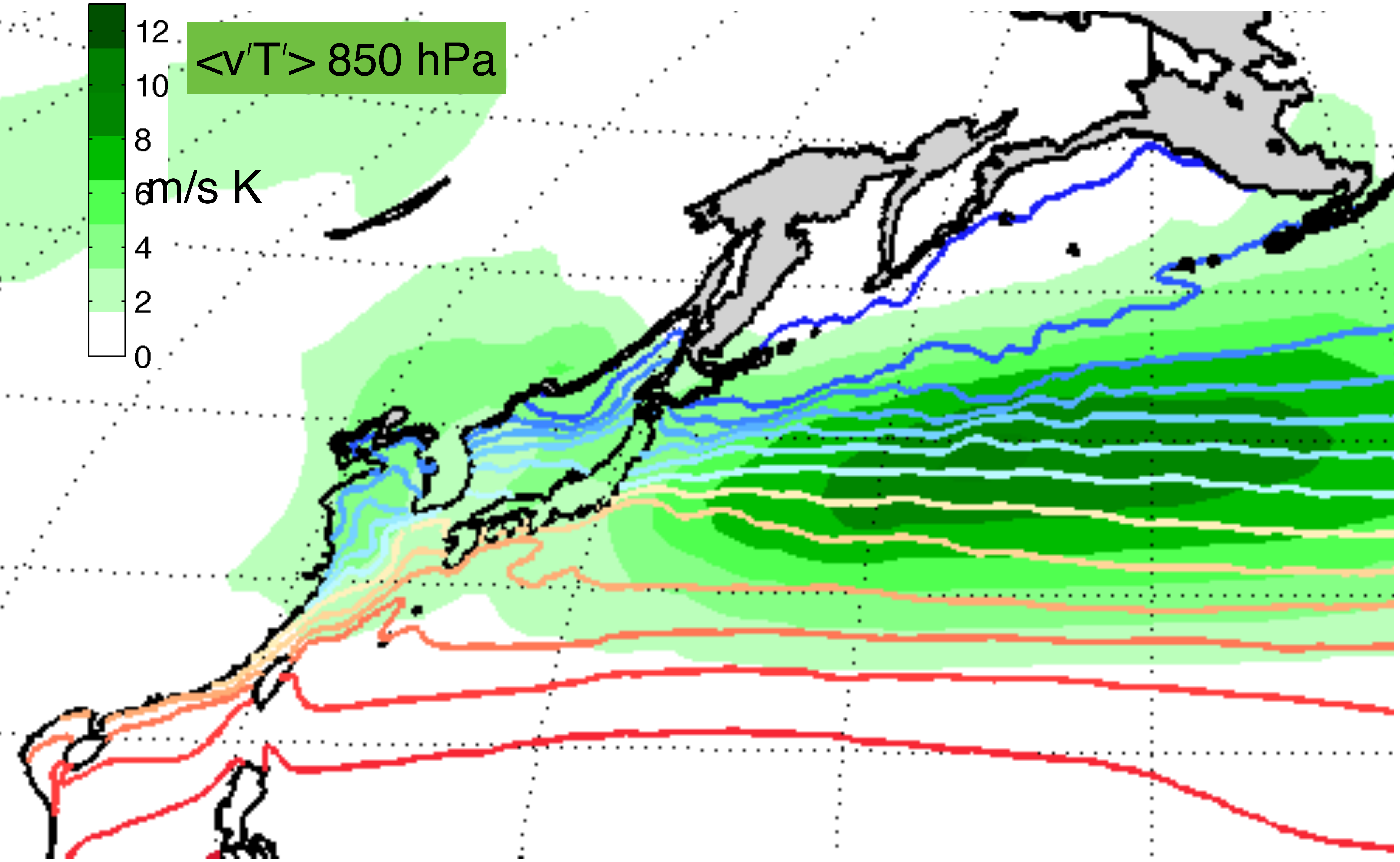
A positive wind-SST correlation indicates where the ocean influences the atmosphere.
The O→A influence is via turbulent heat flux response.
Yet, no satellite-based heat flux estimates exist.

QuikSCAT wind and NOAA OI SST (AVHRR, 2000-2009)
10 degree zonal filtering: Seo (2017), Gentemann et al. (2020); Small et al. (2008)

ERA5 (1991-2020), 1000 km zonal filtering
Seo, O'Neill et al. (2023)

Atmospheric baroclinicity maintained by SST fronts

Seo et al. (2023)

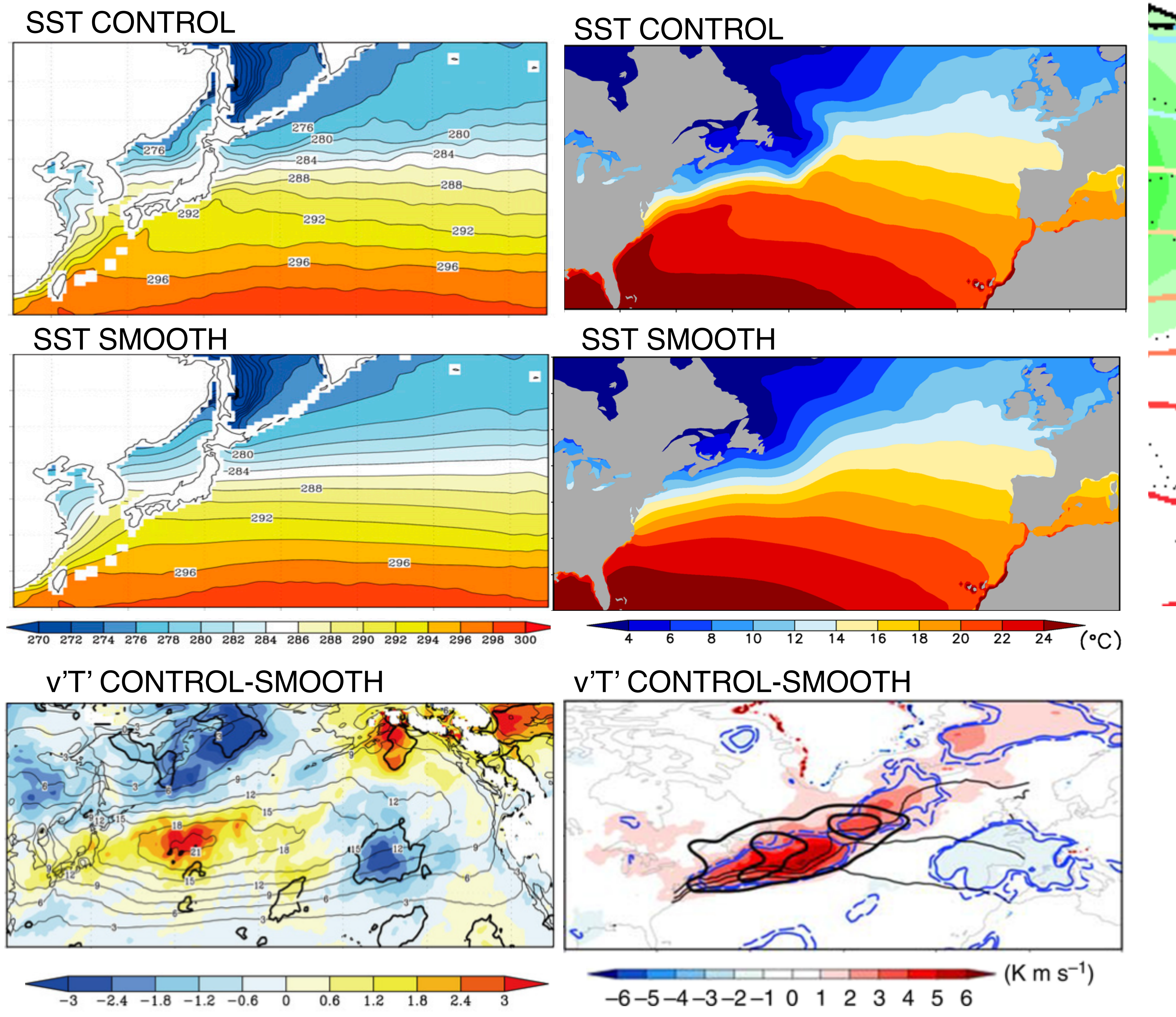


The growth rate of the extratropical cyclones scales with low-level baroclinicity

$$|\boldsymbol{\sigma}_{\mathrm{BI}}| = 0.31\left(\frac{g}{N\theta}\right)\left|-\frac{\partial\theta}{\partial y}, \frac{\partial\theta}{\partial x}\right|$$

Hoskins and Valdes (1990); Nakamura and Shimpo (2004)

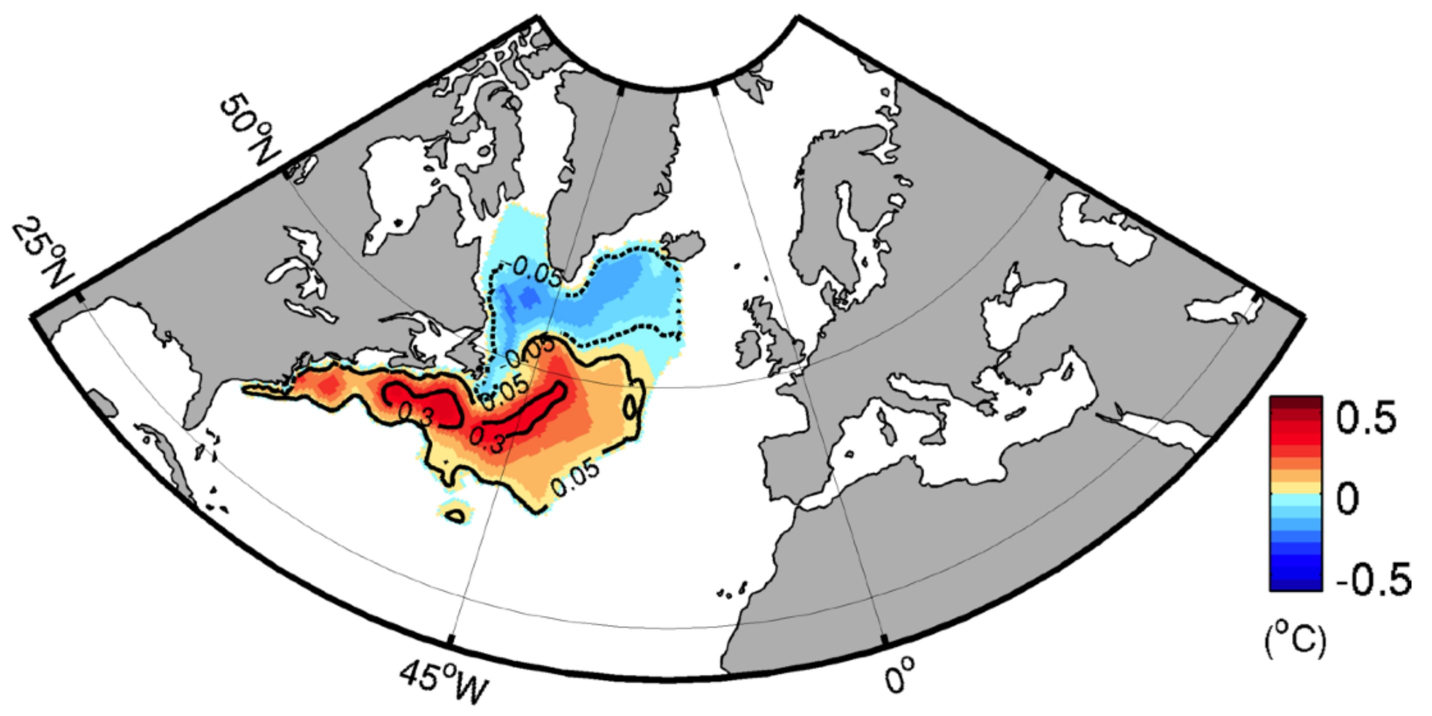
AGCM simulations



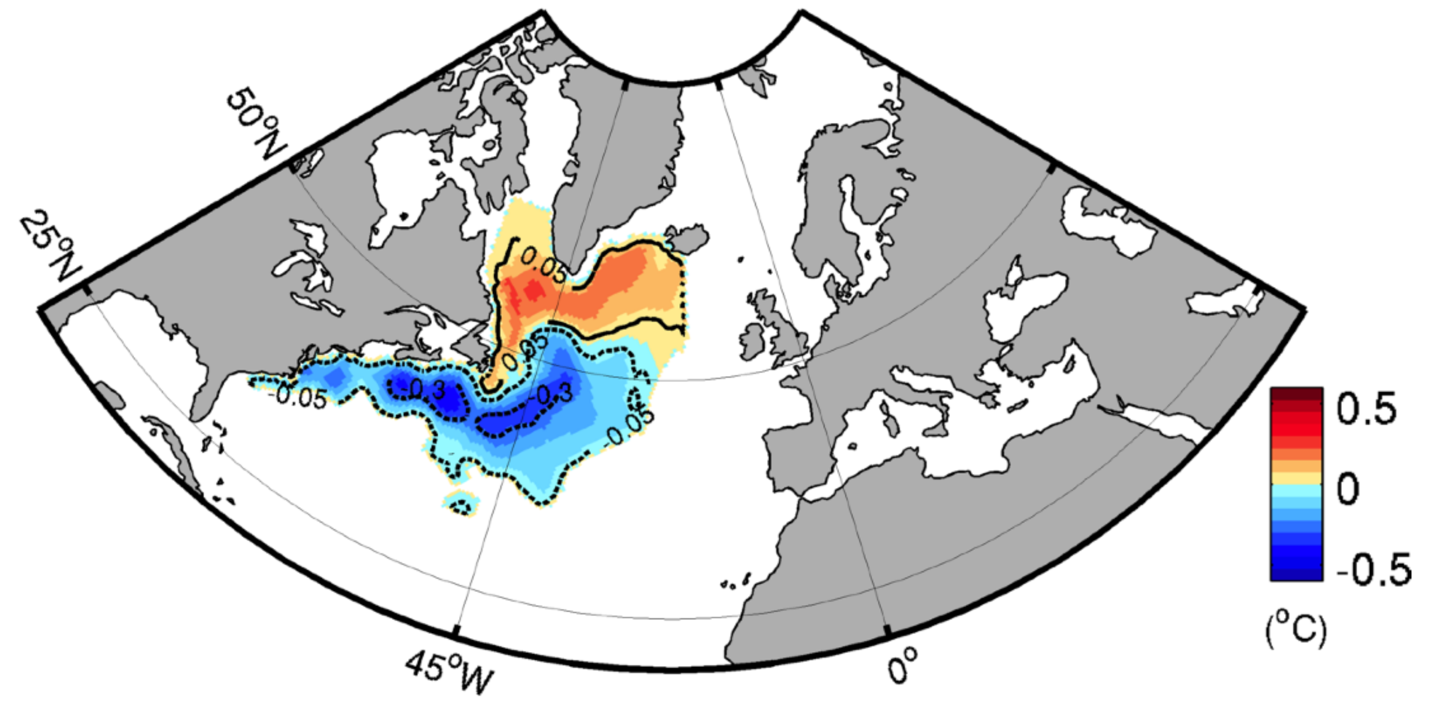
Not so simple: extratropical atmospheric dynamics are highly nonlinear

Atmospheric model forced with

northward GS SSTA (POS)



Southward GS SSTA (NEG)

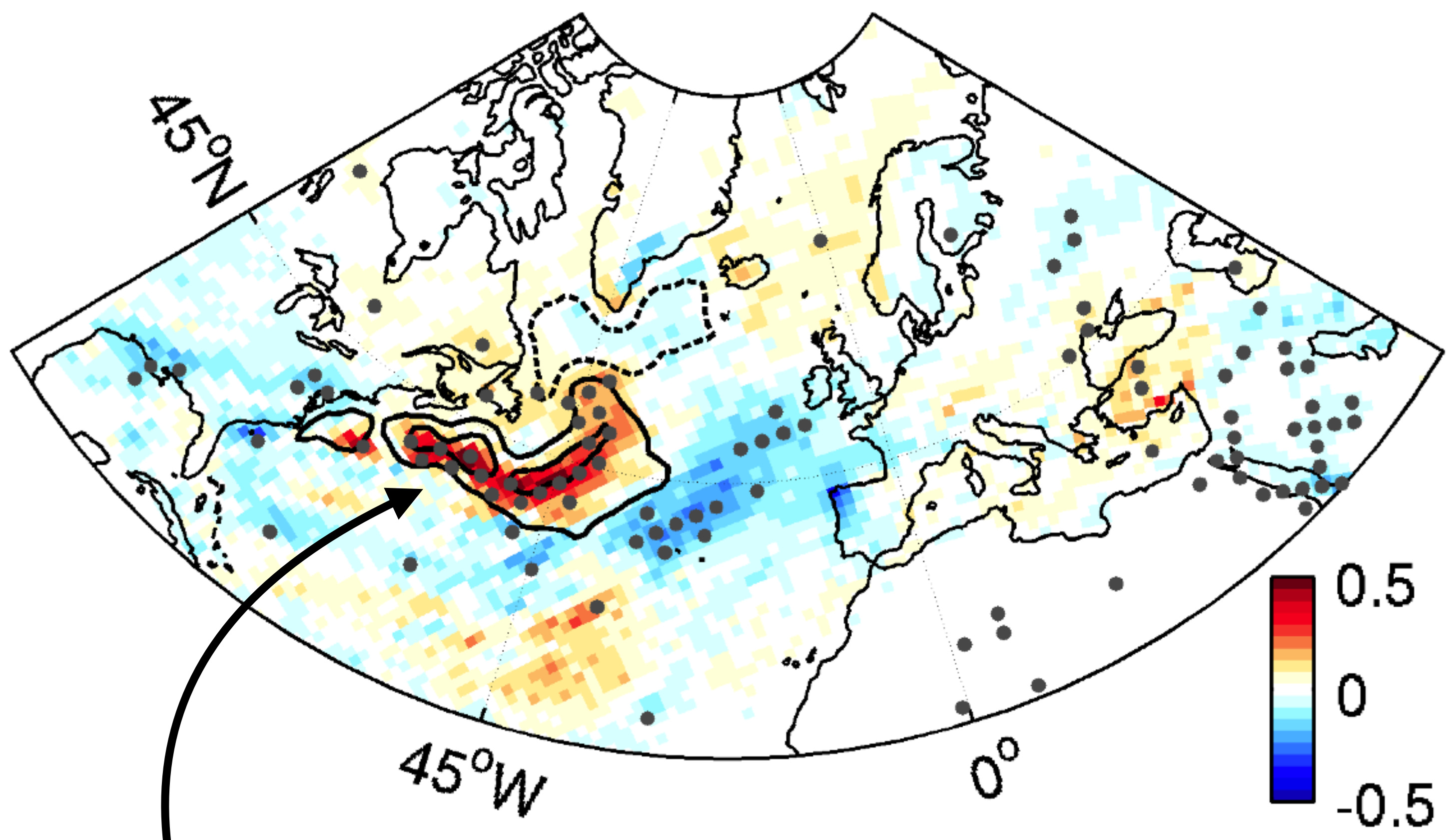


Seo et al. (2017)

Precipitation

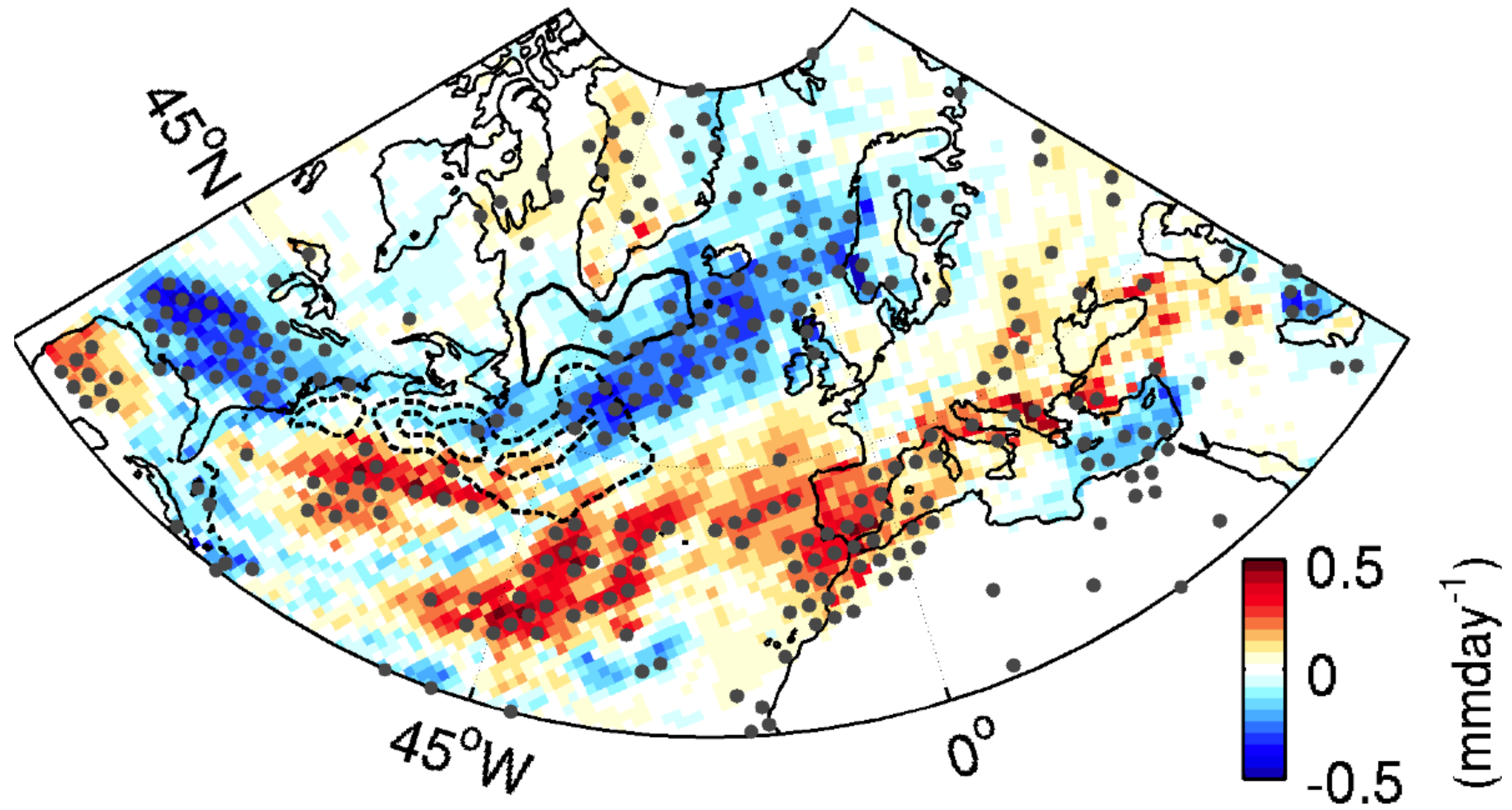
Symmetric (linear) response

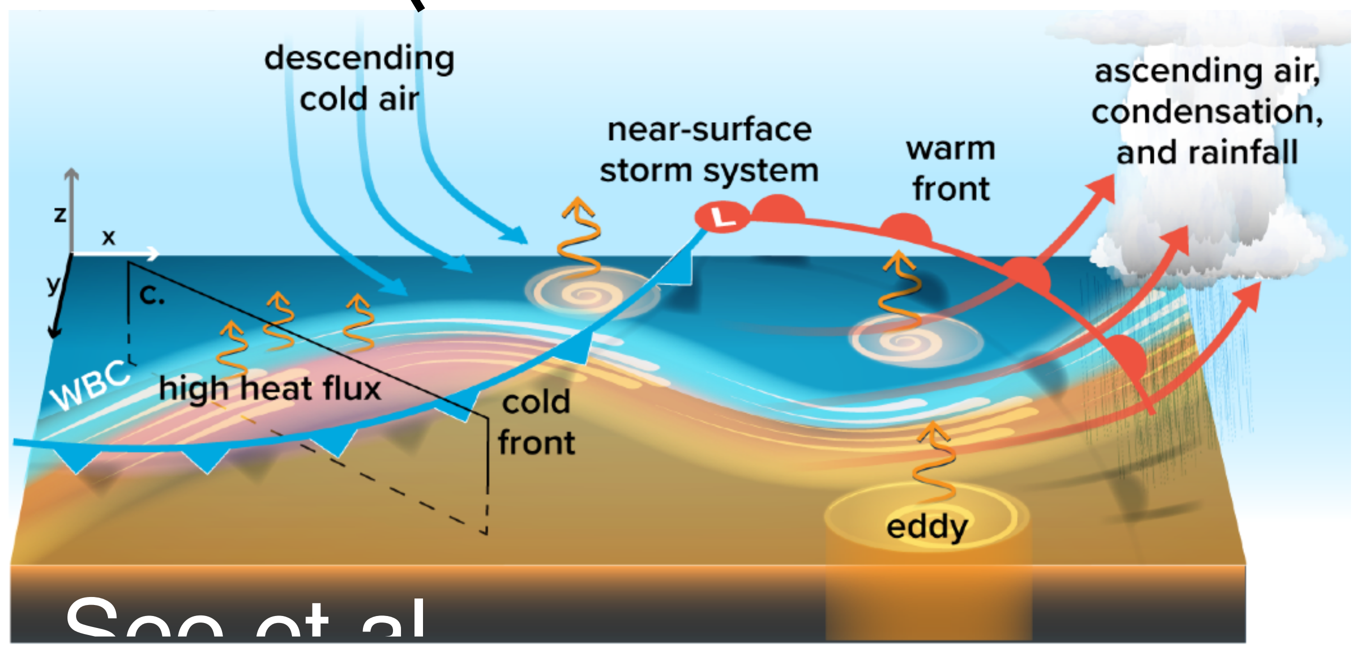
= ½ × (POS - NEG)



Asymmetric (nonlinear) response

= ½ × [(POS - CLIM) + (NEG - CLIM)]





Symmetric response: direct and local response to diabatic forcing

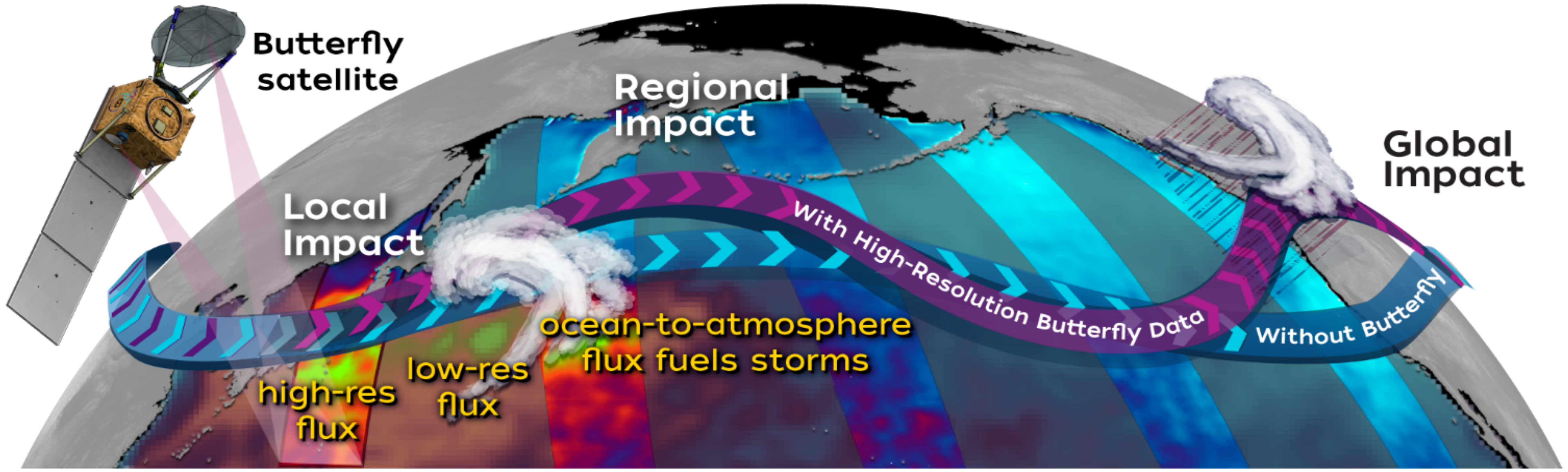
Asymmetric response: nonlinear eddy-mean flow interactions in the upper levels

→ Climate impacts of the GS variability remains difficult due to the fundamental stochastic character (Czaja et al. 2019; “the Quantum Cafe”).

The Butterfly concept

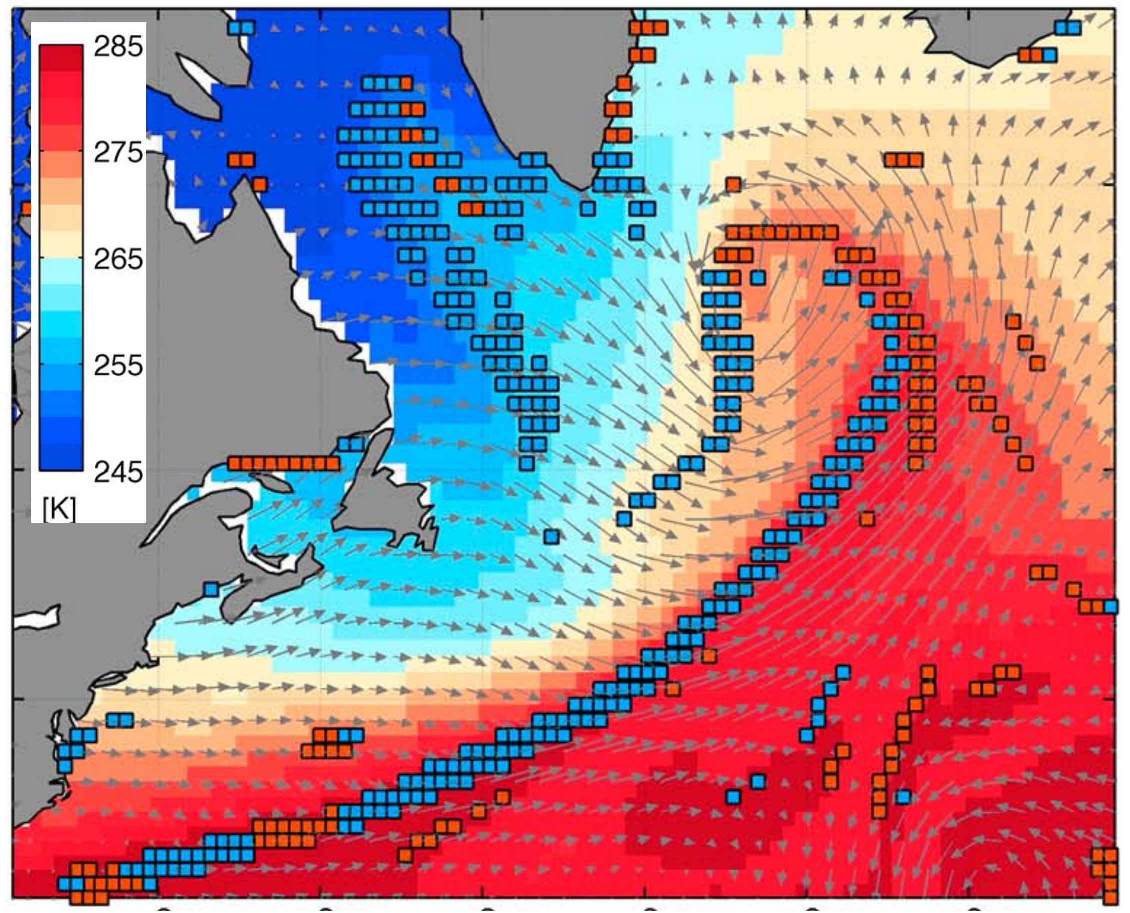
BUTTERFLY

revealing the oceans' impact on weather & climate



WHAT

Butterfly is the first satellite mission to **simultaneously** measure sea surface temperature, wind, & near-surface air temperature & humidity in order to estimate air–sea turbulent heat and moisture fluxes at a spatial resolution and accuracy sufficient to resolve the impact of small-scale ocean features on large-scale weather and climate.



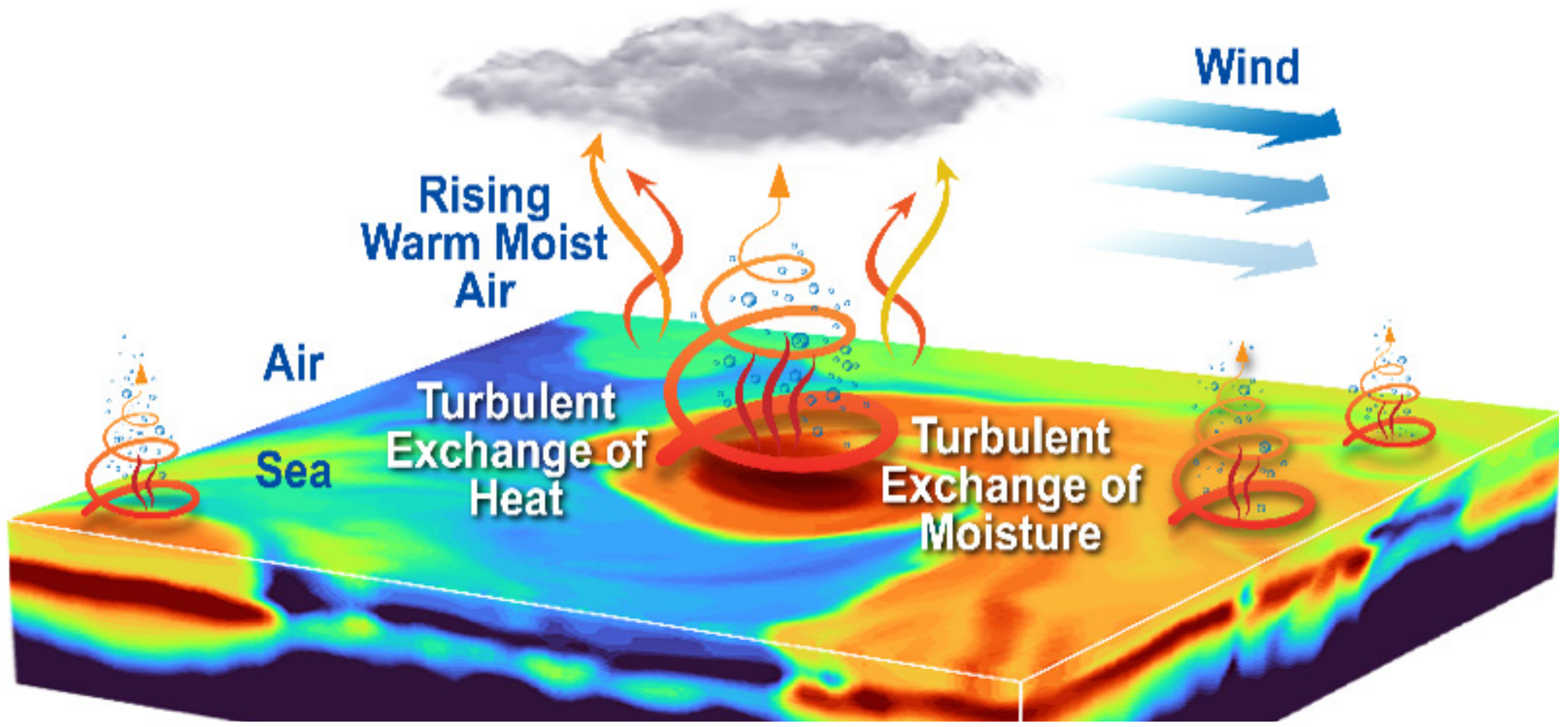
Parfitt & Seo 2018

WHY

The ocean supplies the atmosphere with heat and moisture, dominating the global water and energy cycles while fueling weather and climate variability. Butterfly measures this air–sea exchange at spatial scales never before observed to unlock how the small-scale ocean "drives" the large-scale atmosphere, transforming predictability from mere days to weeks.

HOW

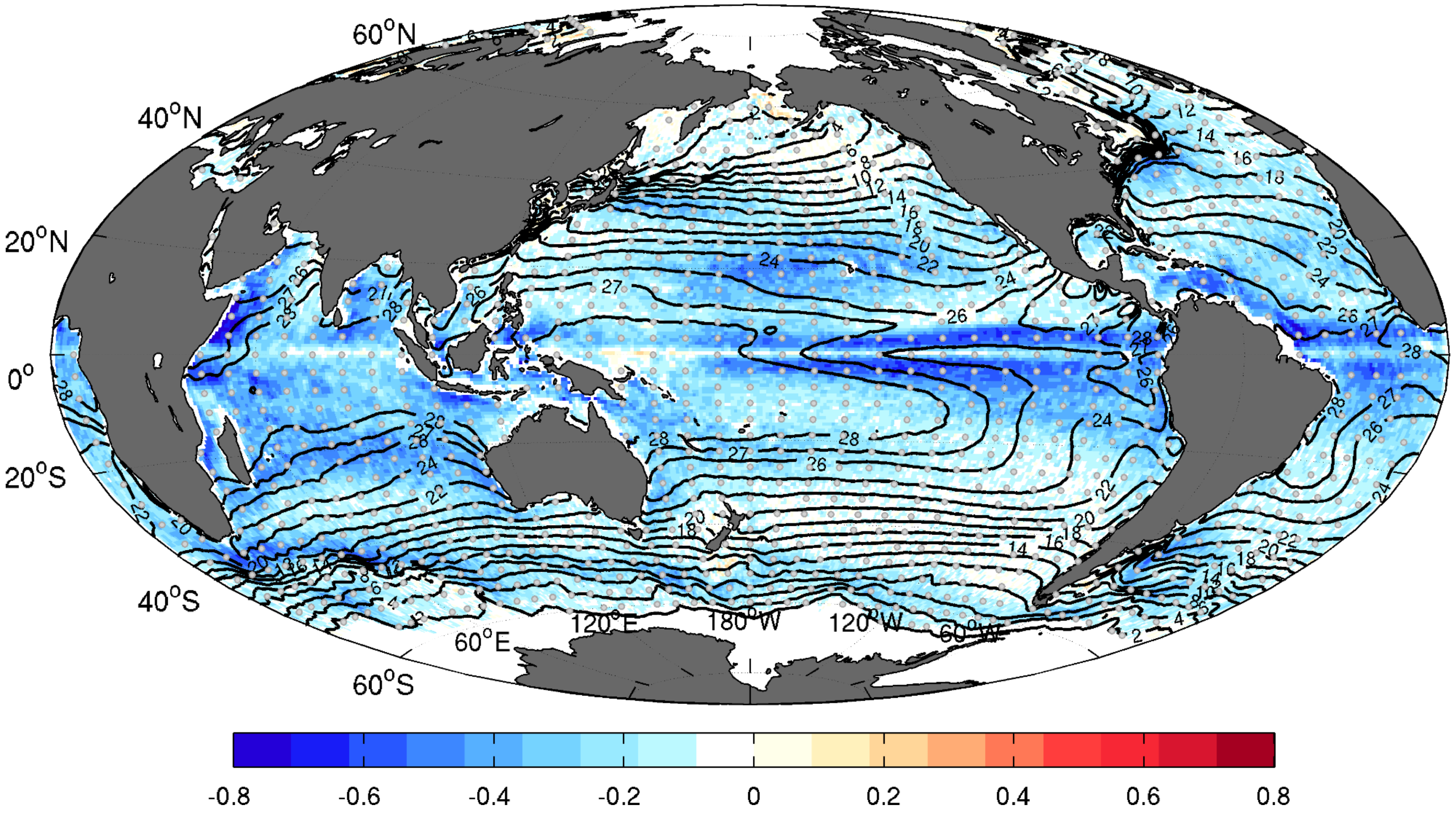
Butterfly's passive microwave instrument is specially designed to measure air-sea turbulent heat and moisture flux at <25-km resolution.

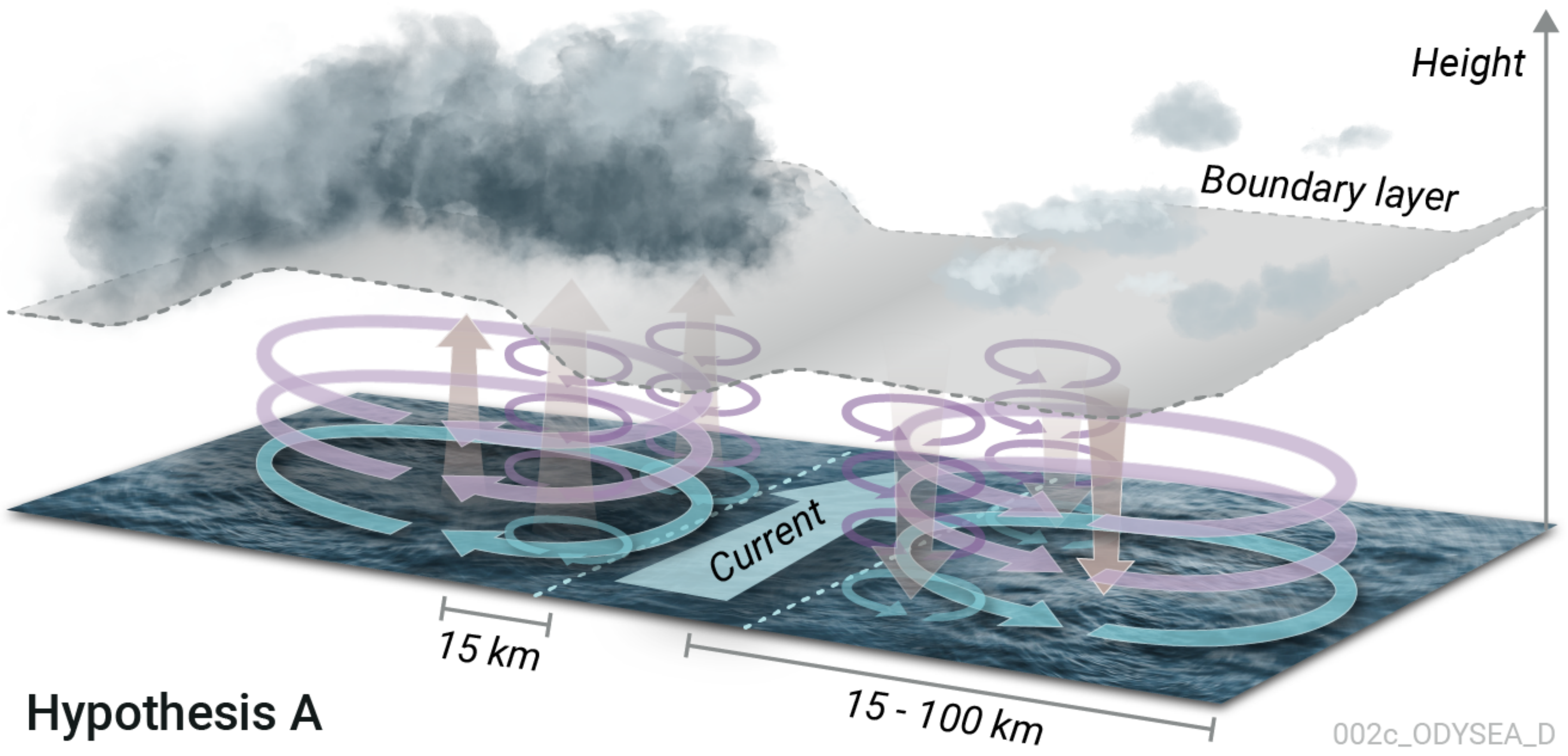


Winds and currents: The ODYSEA concept

odysea.ucsd.edu

Daily correlation of wind stress curl w/ surface vorticity





Surface current is reversely manifested in the wind stress

AVISO current and ERA-interim relative wind stress (1993-2015 JJAS)

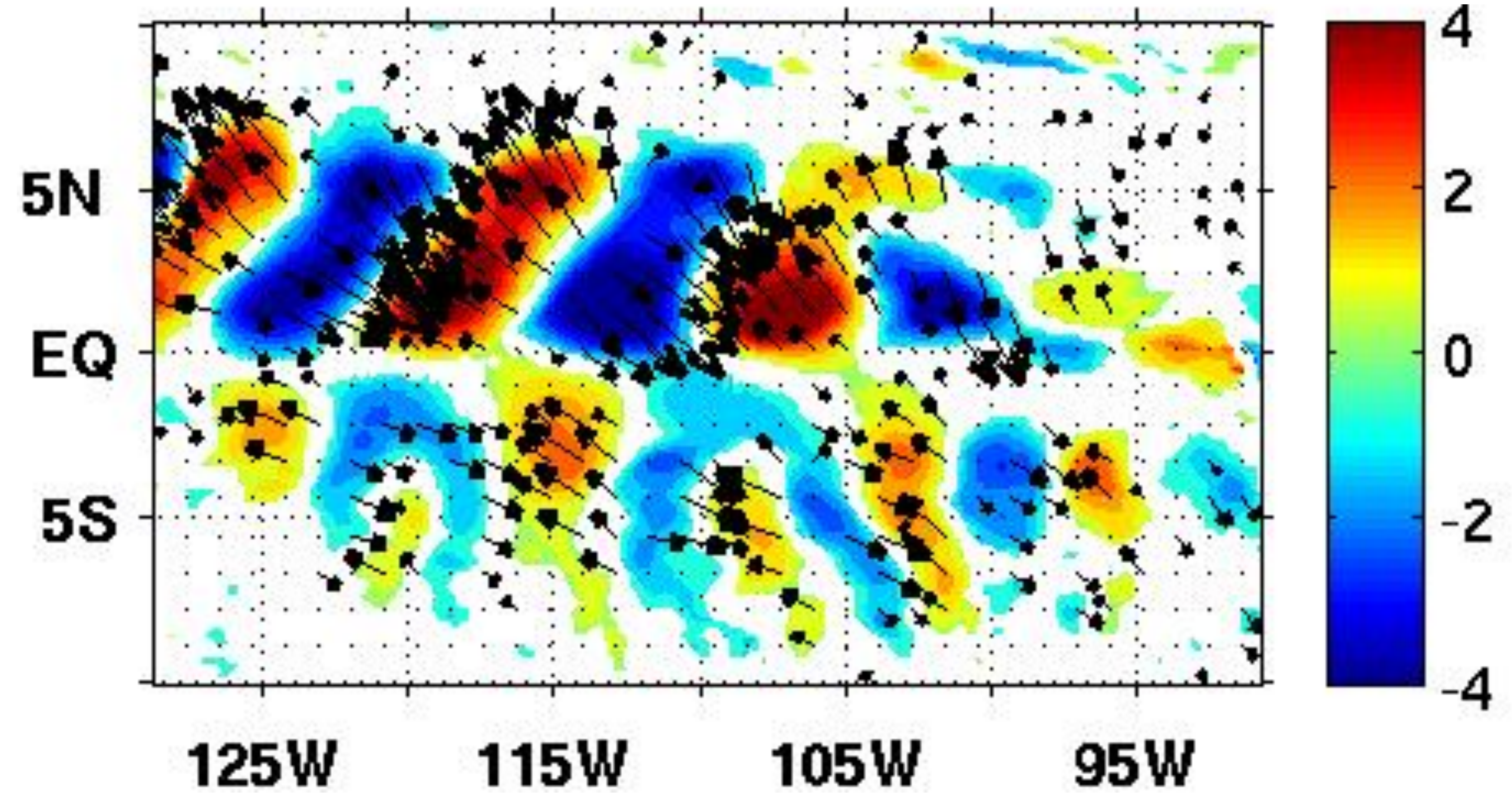
Odysea will advance the understanding of air-sea momentum flux and ocean currents at fine spatial scales.

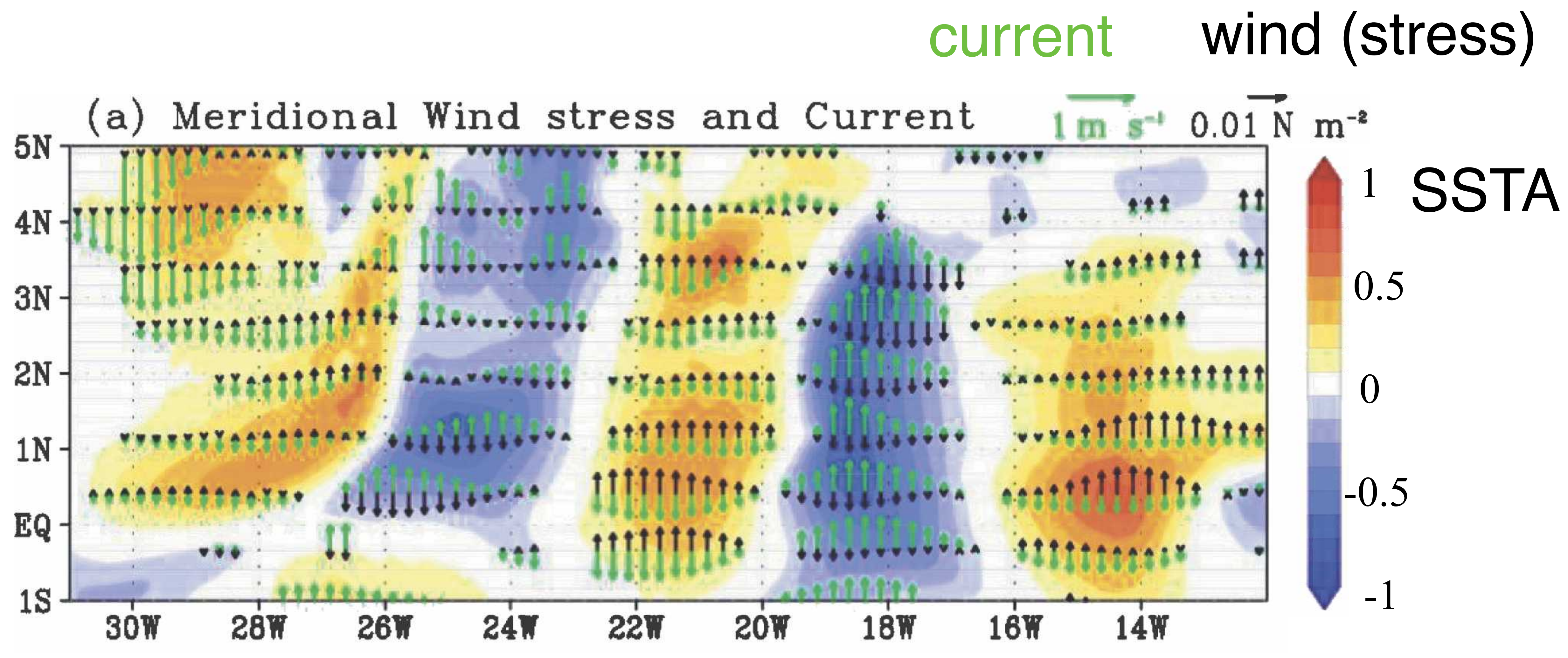
Can it *alone* help better understand the surface current impacts on the atmosphere?

Thermal and mechanical coupling inherently intertwined at mesoscale

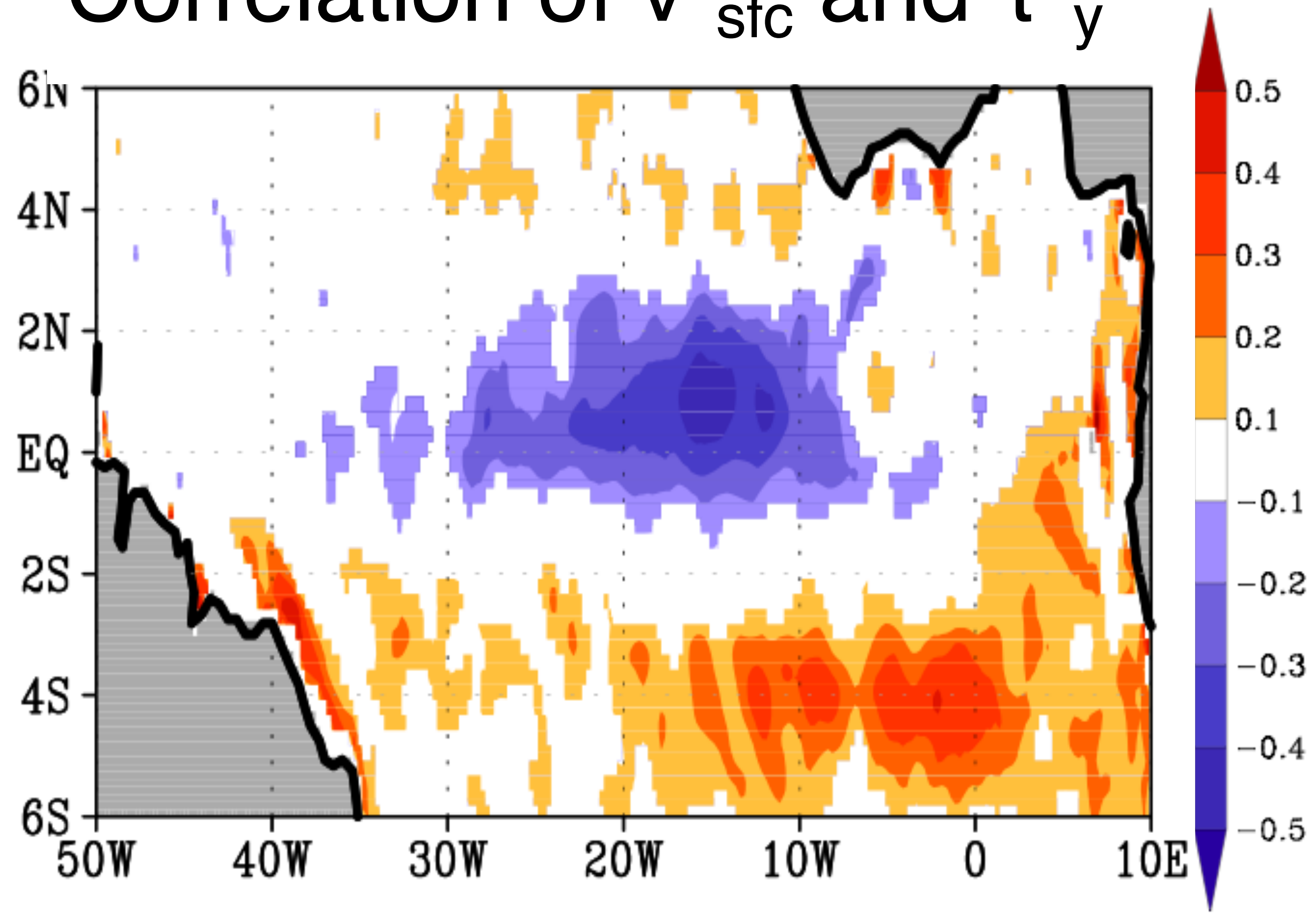
Tropical Instability Waves

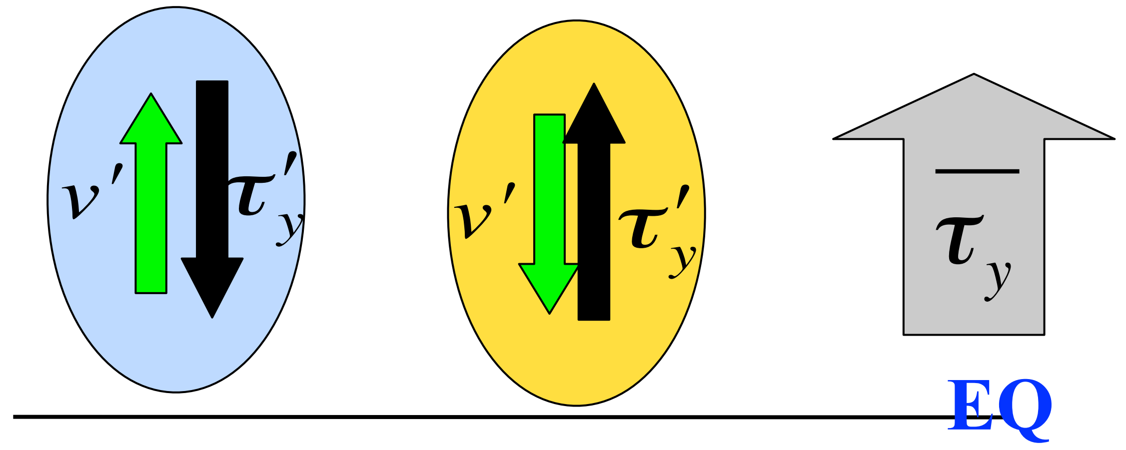
Combined EOF1 SST and Wind stress (WS)





Correlation of v'_{sfc} and τ'_y





Warm TIW SSTA accelerates wind via upward surface heat flux.
The resulting wind anomaly is in the opposite direction to TIW currents.

→ Negative wind work via current-wind coupling is enhanced by SST-wind coupling

Seo et al. (2007a,b)

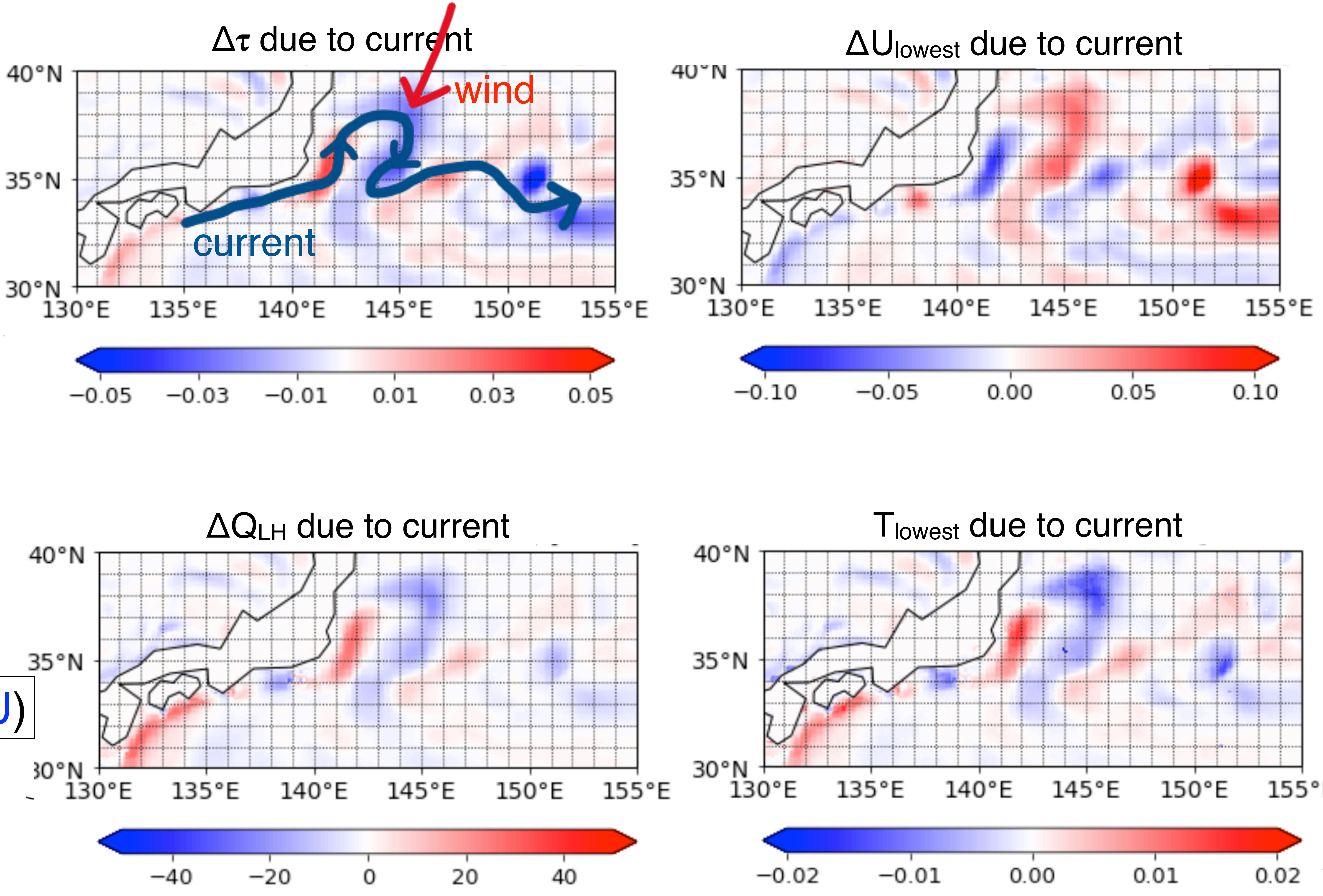
Ocean currents affect both the momentum and turbulent heat flux

Current feedback on wind stress

$$\tau = \rho_a C_D (W - U)^2$$

Current feedback on heat flux

$$Q_{LH} = \rho_a L_e C_E \Delta q (W - U)$$

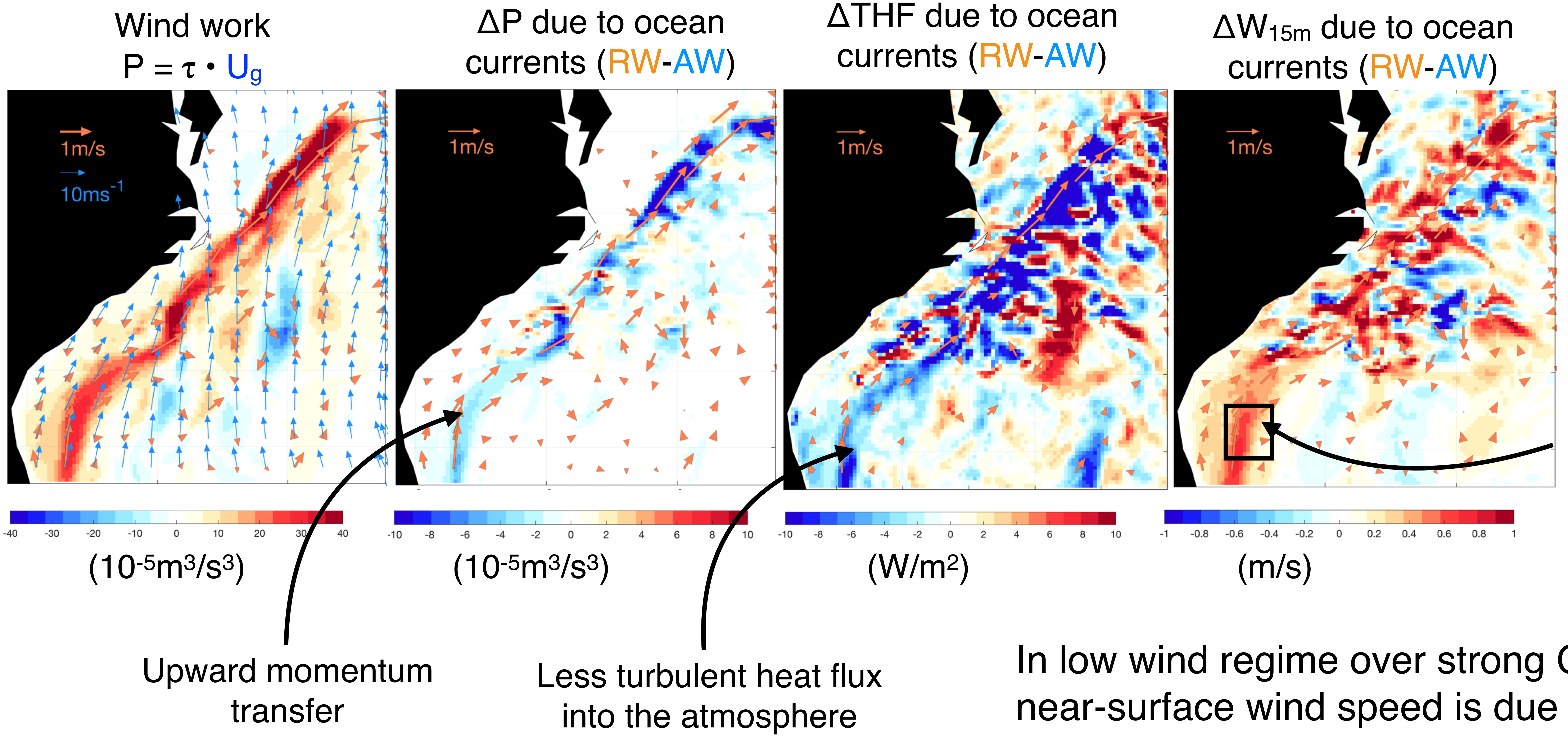


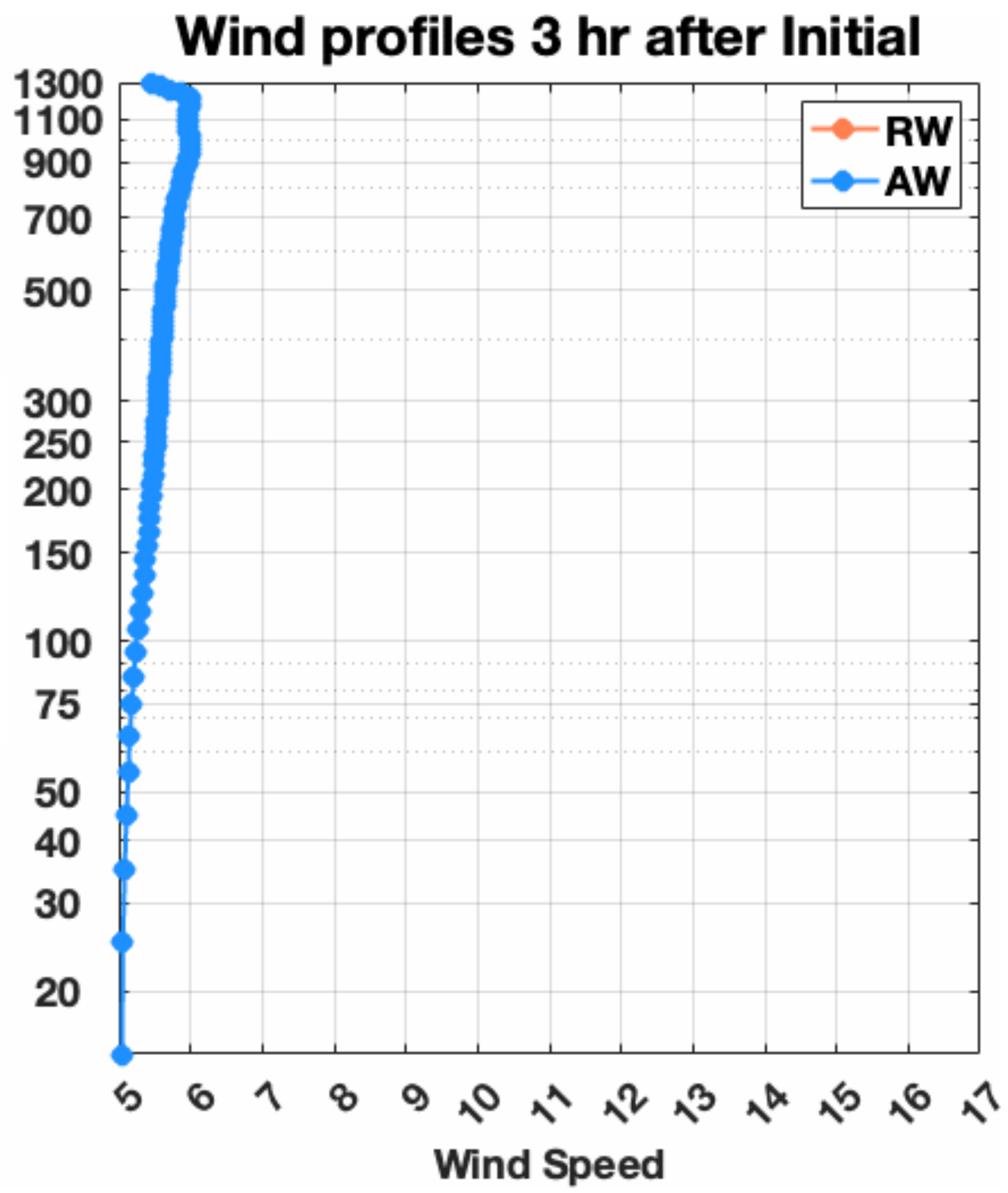
Ajin Cho et al. (in prep)

Understanding the impacts of ocean current on wind

High-resolution SCOAR regional coupled model simulations: RW vs. AW

Snapshots @ 12 hours after the initialization





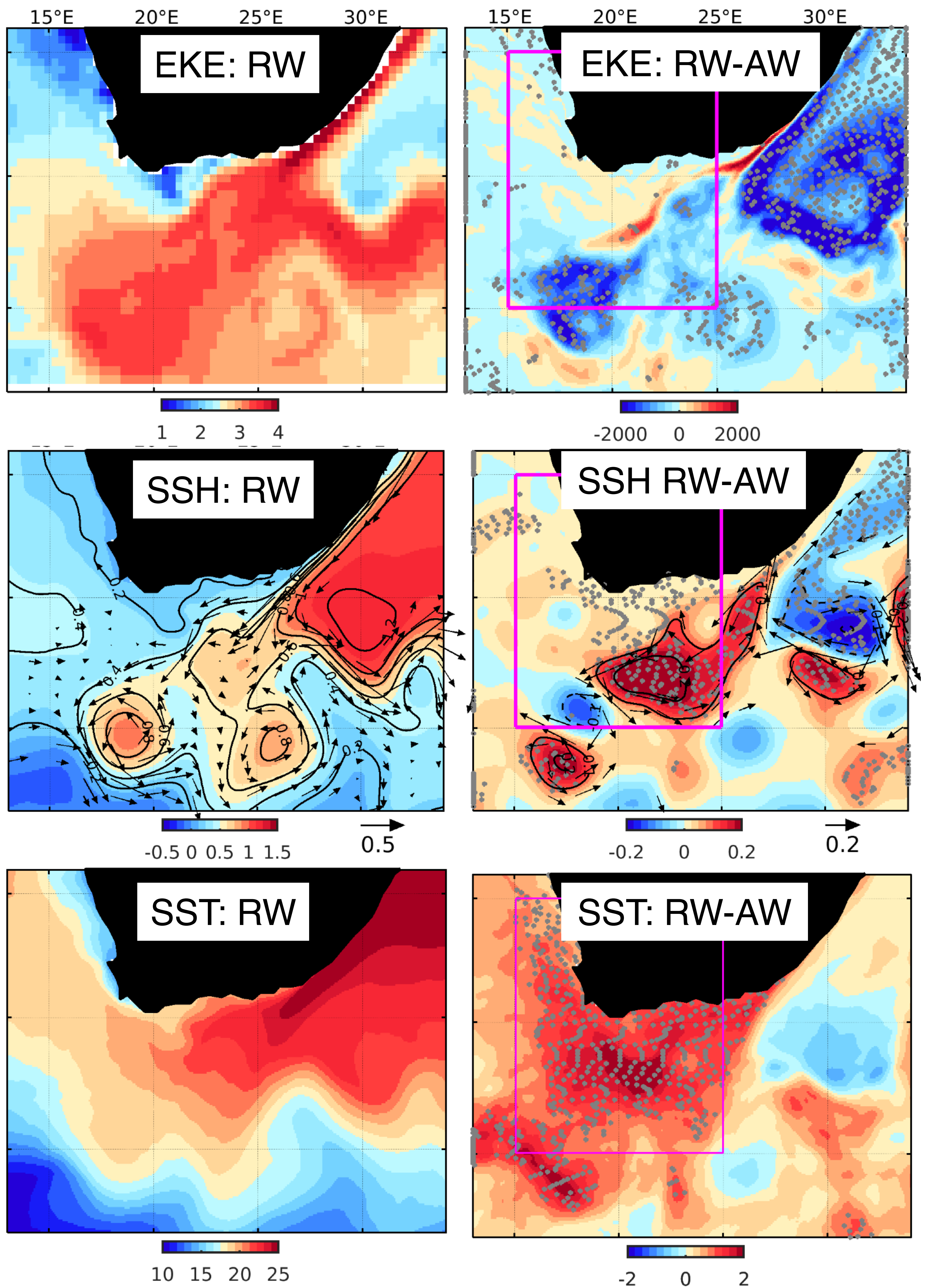
In low wind regime over strong GS current, the increase in near-surface wind speed is due to upward momentum transfer.

High wind or convective regime, the wind response becomes chaotic (~hrs), where the spatial variability of high flux response is likely be important.

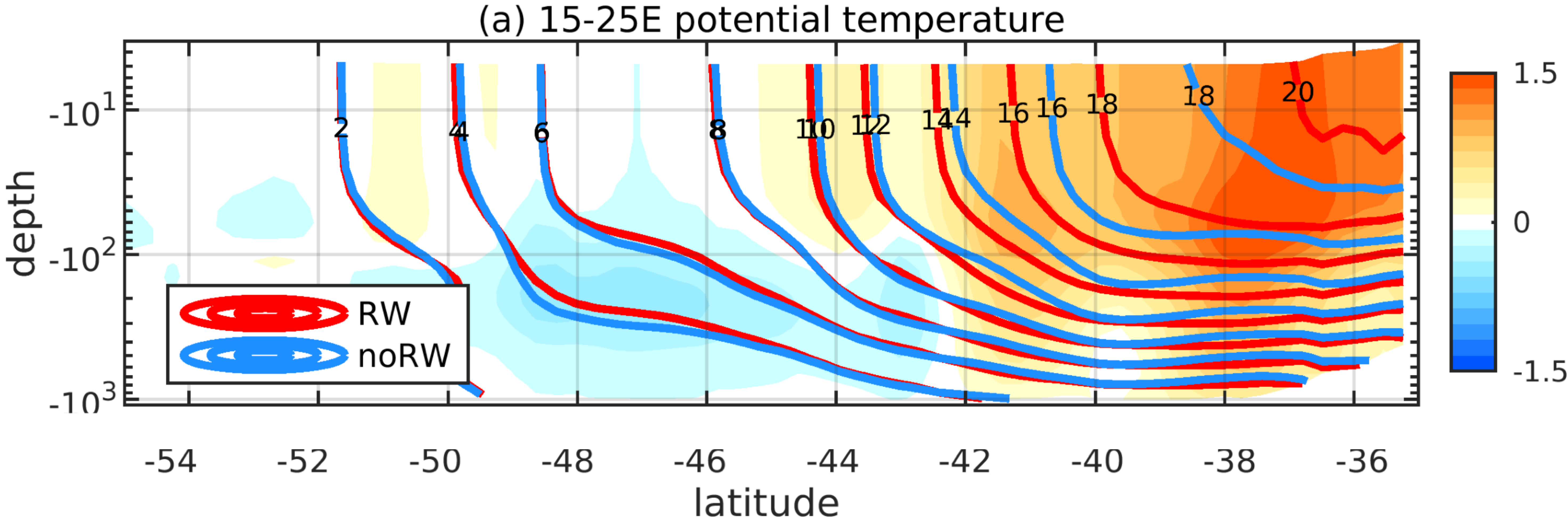
Seo et al. (in prep)


Seo et al. (2021)
RW effect damps the eddy energy and mean currents
The storm storm are influenced by their thermal interaction with oceans
Big question:
Can the relative wind effect influence the storm track in the western boundary current regions?
Agulhas Current
westerly wind
storm track (v'T' 850hPa)
RW: relative wind
$\tau = \rho_a C_D (U_a - U_o)^2$
AW: absolute wind
$\tau = \rho_a C_D (U_a)^2$
VS
WRF
ROMS
τ^a, Q_{NET}, Q_{FW}
SST, U_{sfc}
WRF
ROMS
τ^a, Q_{NET}, Q_{FW}
SST

Ocean circulation changes relevant to atmospheric baroclinicity



Southward shifted subtropical front

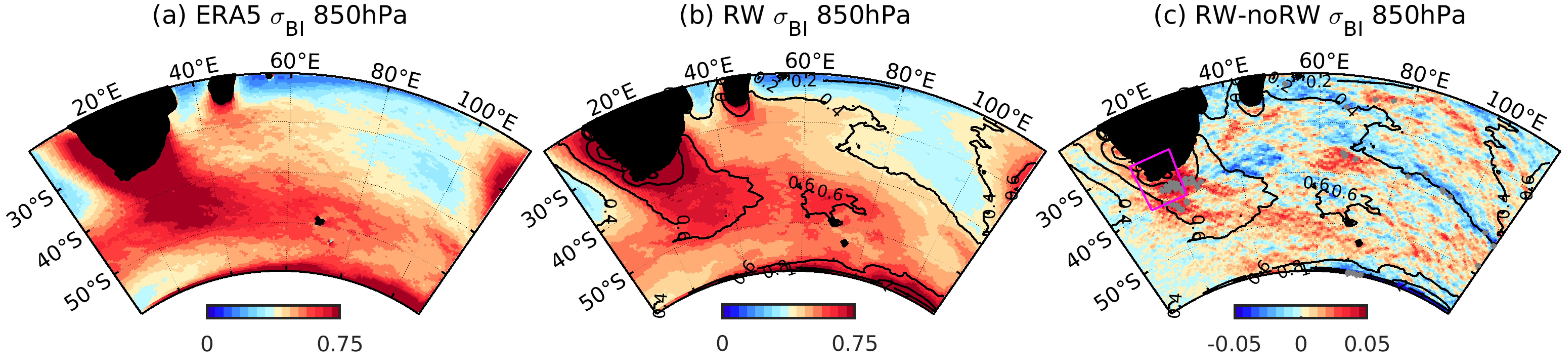


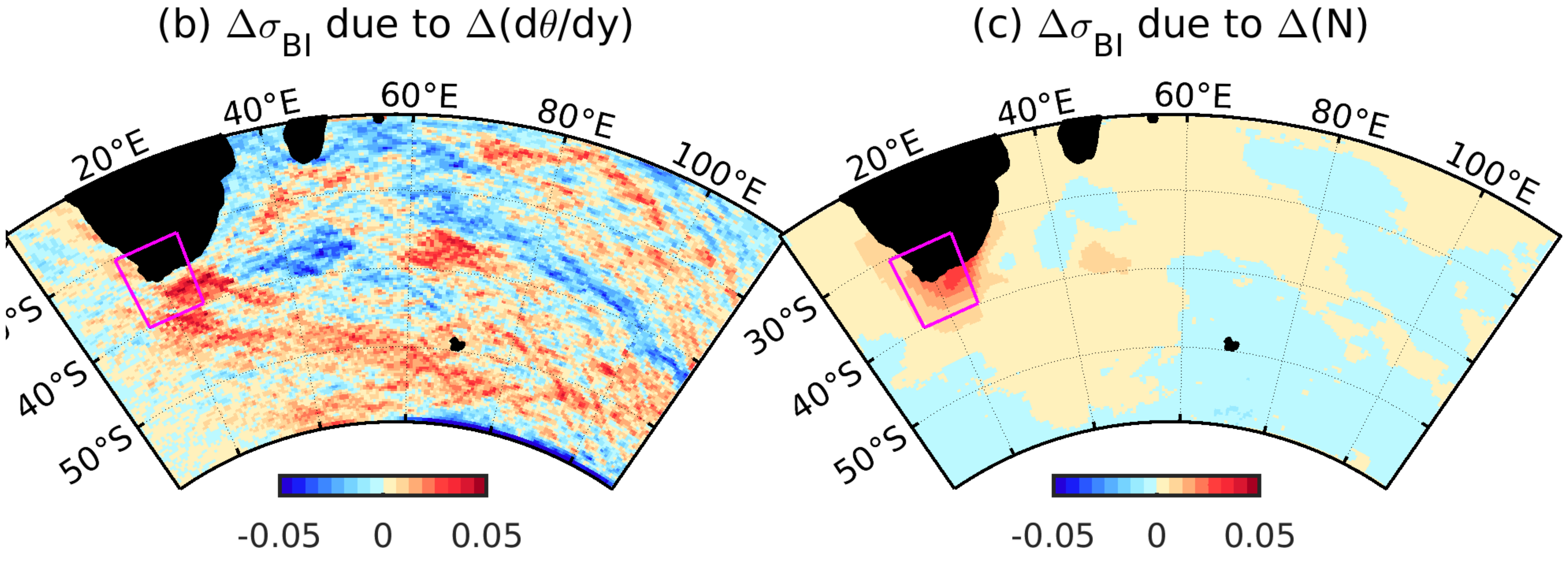
$$|\boldsymbol{\sigma}_{\mathrm{BI}}| = 0.31\left(\frac{g}{N\theta}\right)\left|-\frac{\partial\theta}{\partial y},\frac{\partial\theta}{\partial x}\right|$$

SST warming and strengthening of the SST front
→ enhance baroclinic wave activity

Changes in low-tropospheric baroclinicity

$$|\boldsymbol{\sigma}_{BI}| = 0.31\left(\frac{g}{N\theta}\right)\left|-\frac{\partial\theta}{\partial y}, \frac{\partial\theta}{\partial x}\right|$$





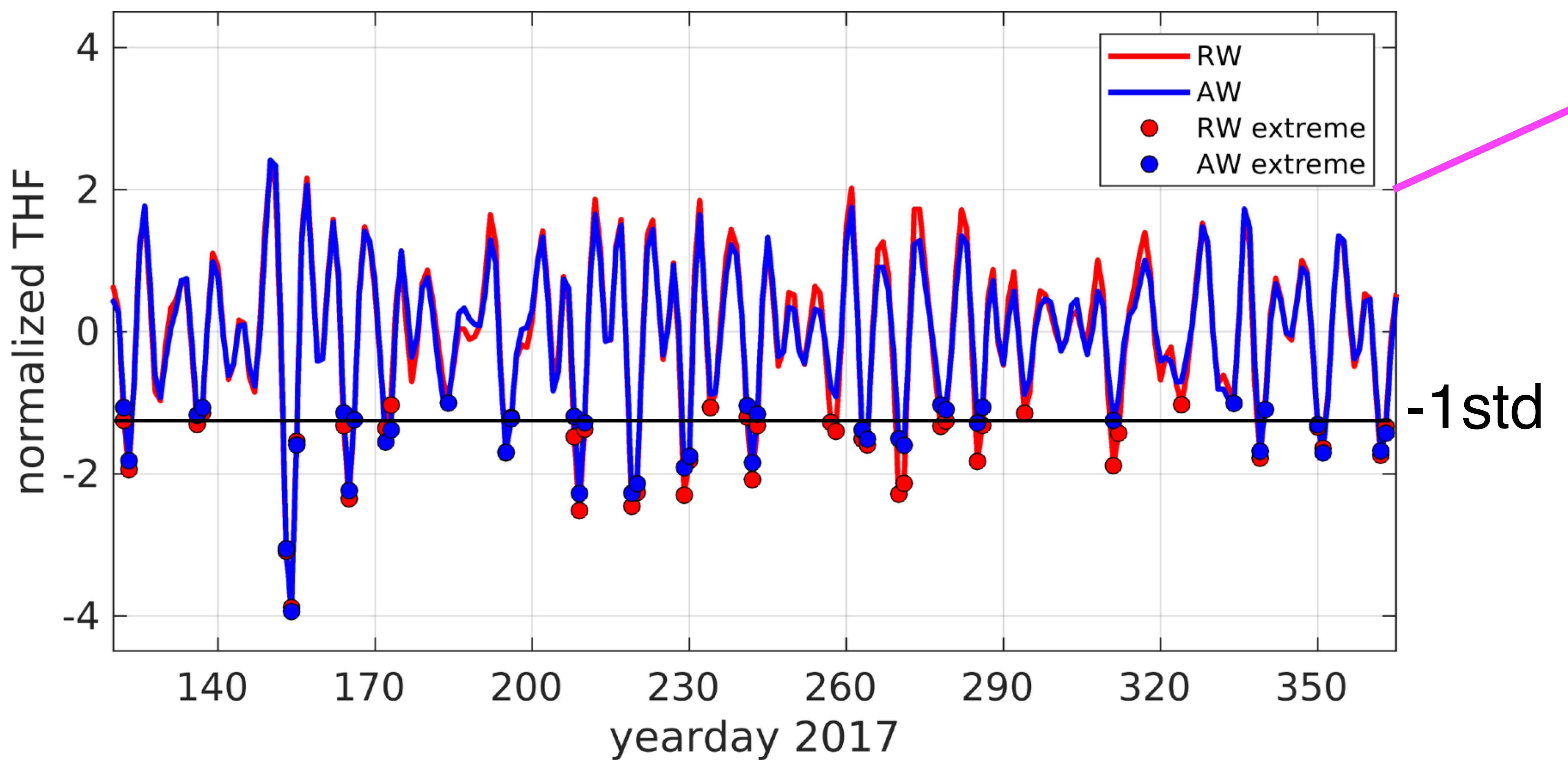
- Increased baroclinicity over the AC retroflection region.
- The downstream response is NOT significant.
- Nearly equal contribution from temperature gradient and static stability

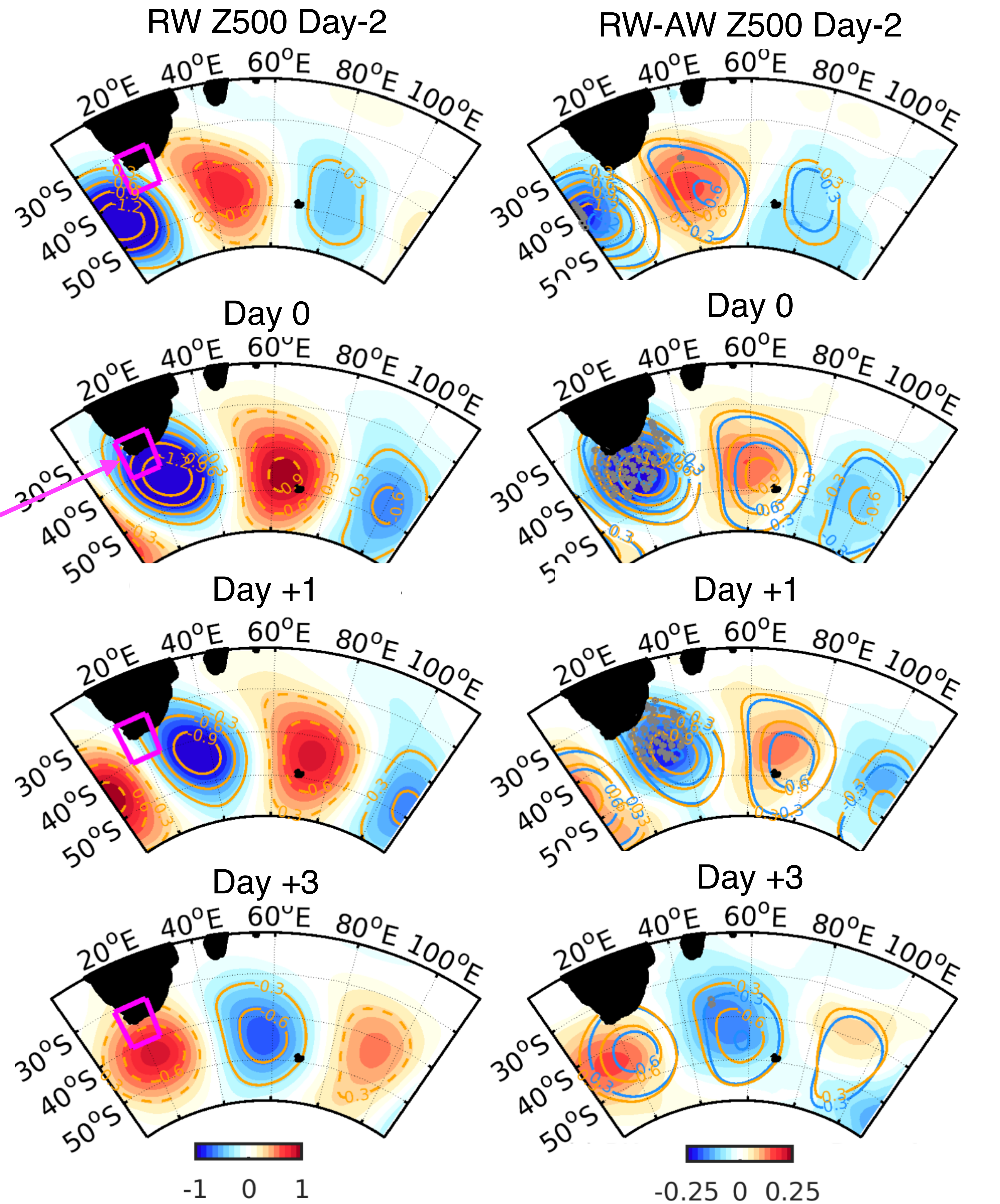
Seo et al. (2021)

Assessing storm track impacts

Composite evolution of 2-8 day bandpass filtered Z_{500} when the 2-8 day THF over the retroflection exceeds < -1 std.

82 (87) events in RW (AW) for 5 years





Enhanced baroclinic wave amplitude by 10-25%

The magnitudes here are all normalized by the values at Day-2.

Seo et al. (2021)

Thermal and mechanical coupling inherently intertwined at small-scales

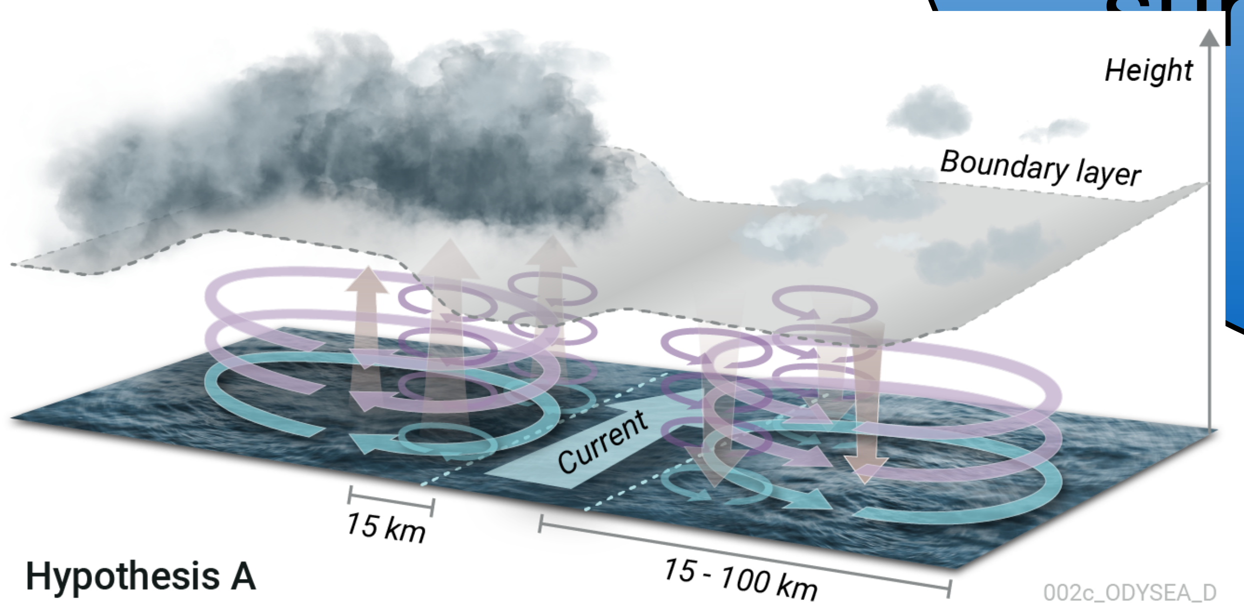
Two highly complementary and synergistic satellite mission concepts
will help understand this coupling better.

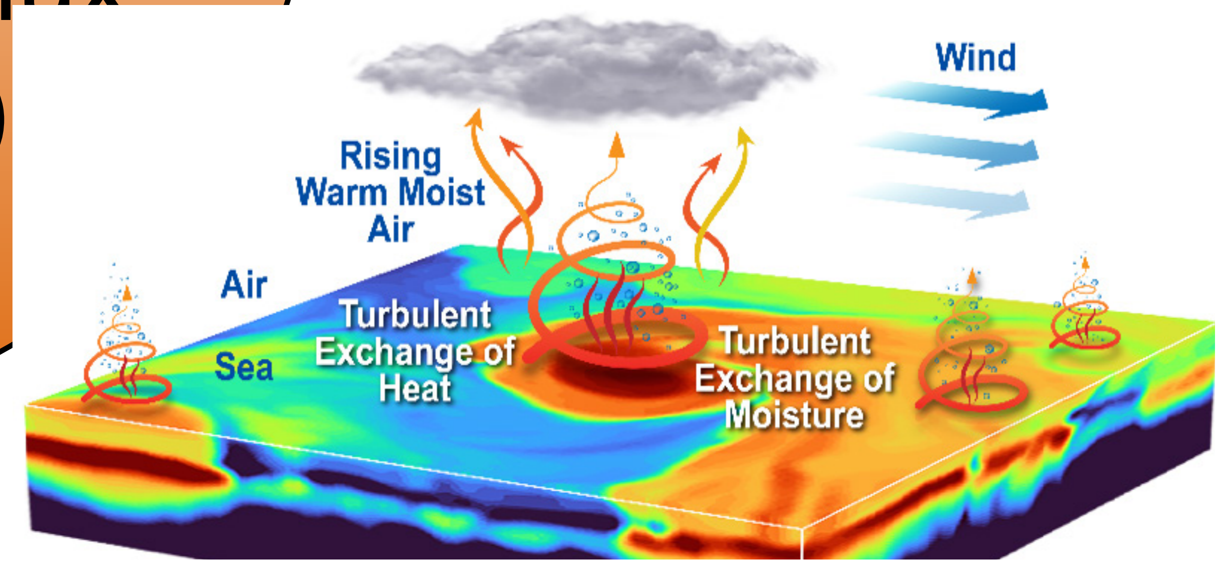
Butterfly

Accurate turbulent heat flux estimates require surface currents.

Odysea

Accurate momentum flux estimates require turbulent heat flux (and waves!)





- These two satellites together will likely stimulate a new pulse in research on surface momentum and heat fluxes at fine spatial scales
- Further understanding of the multi-scale nature of the ocean current impacts in the climate system requires dedicated and process-oriented high-resolution coupled model simulations.

Thanks!

hseo@whoi.edu