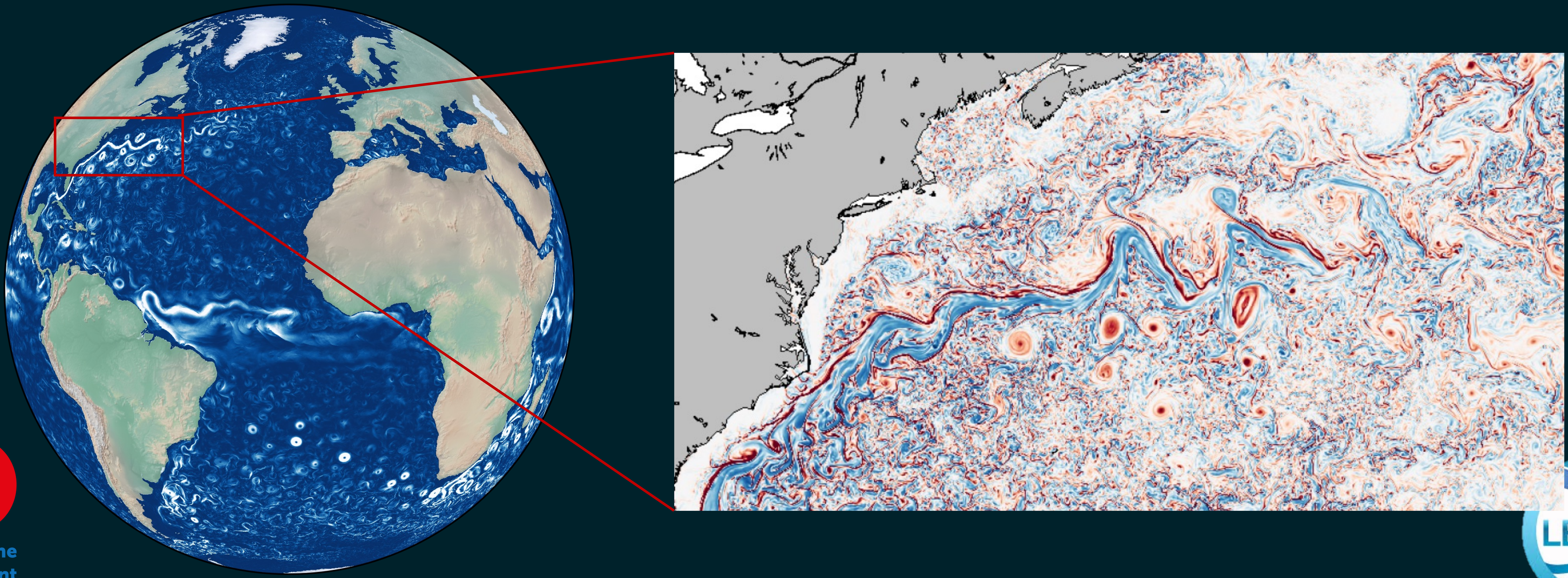
Modulation of Ocean Dynamics by (Sub)Mesoscale Ocean-Wave-Atmosphere Interactions: Current Knowledge and Limitations



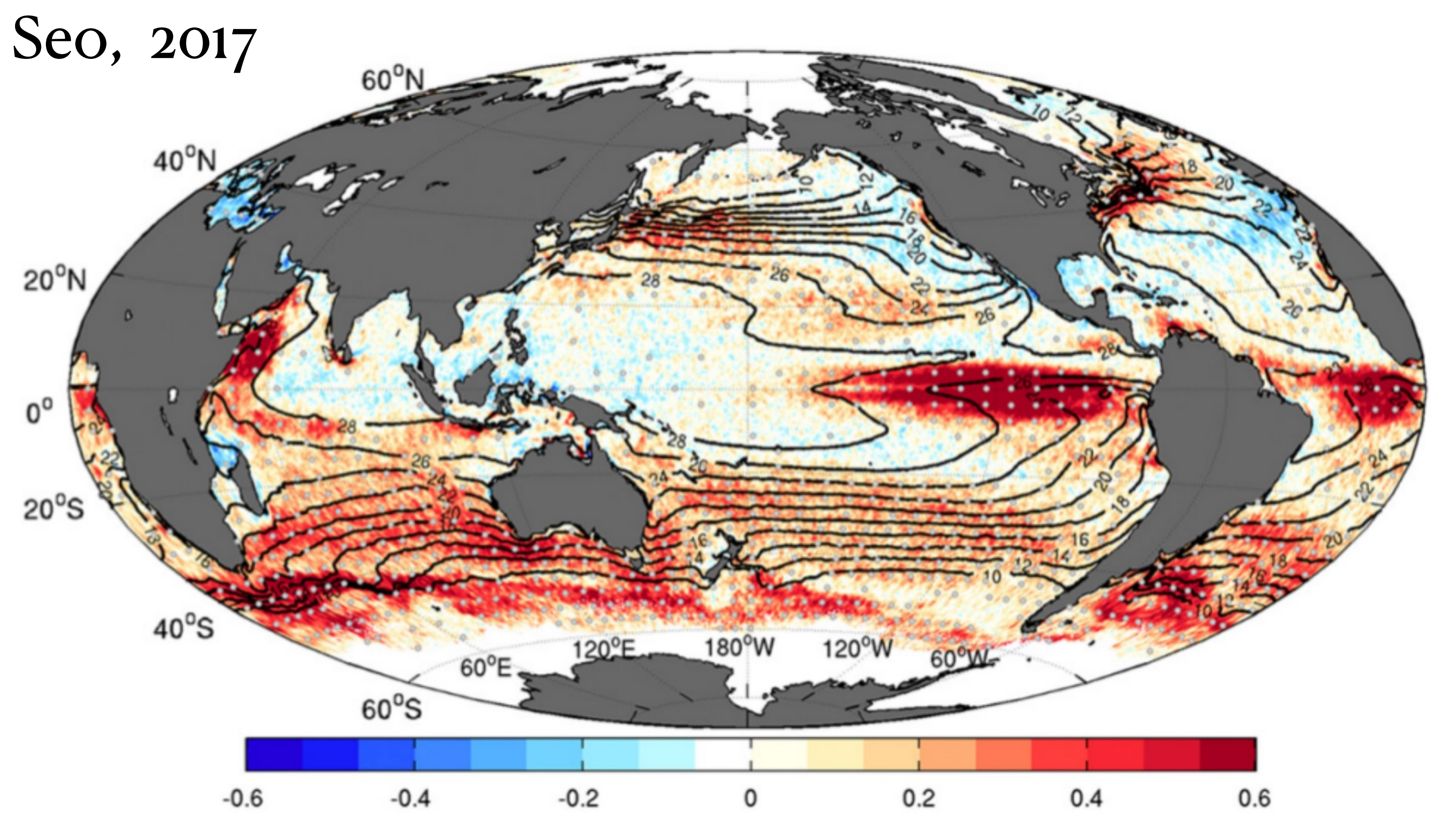
Institut de Recherche pour le Développement FRANCE

LEGOS

L. Renault, Mesoscale and Frontal-Scale Air-Sea Interactions Workshop, 06/03/2023

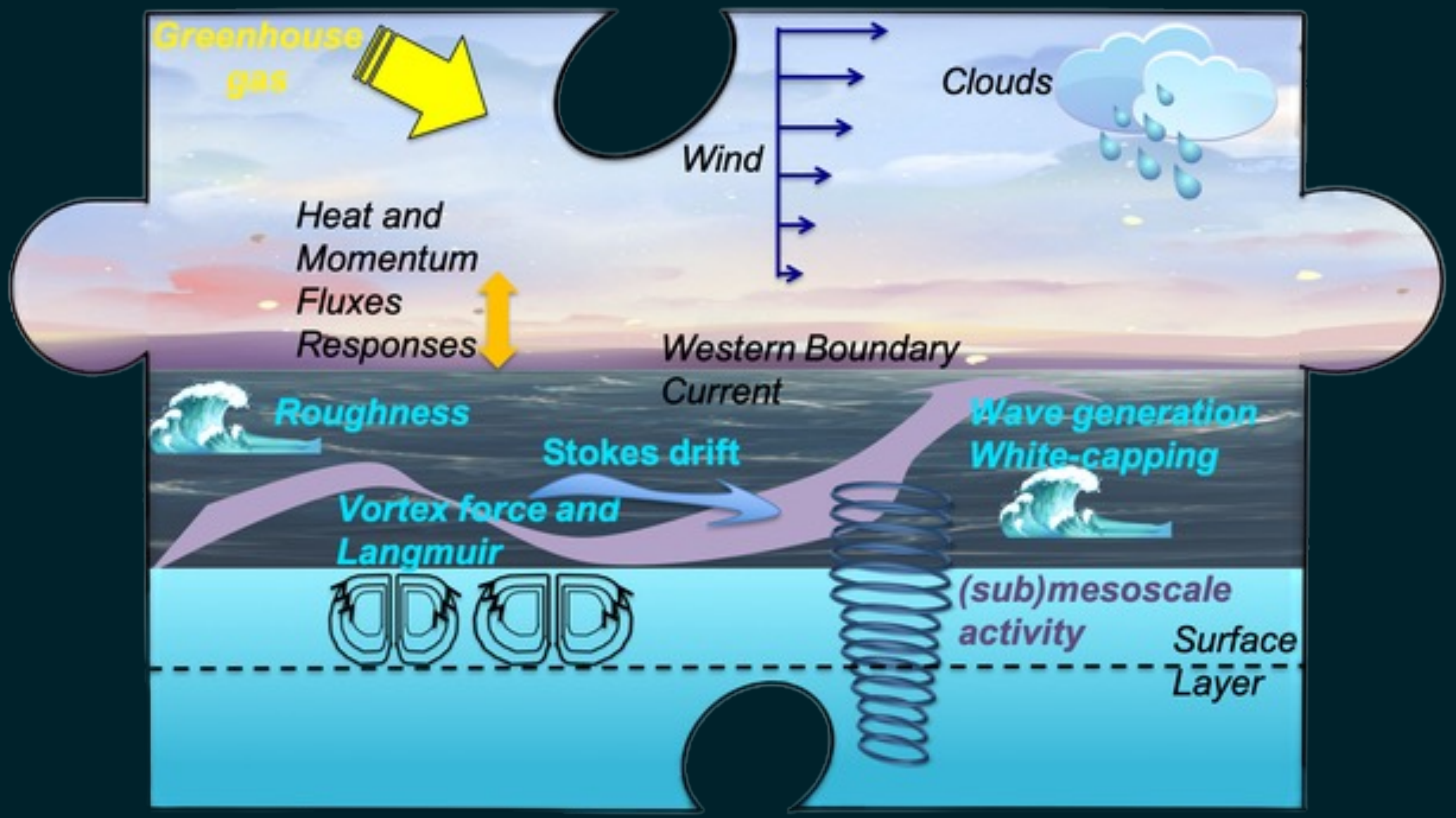
Strong Influence on the Atmosphere and the Ocean

Thermal Feedback, here correlation between wind speed and SST anomalies with spatial high-pass filtering (from radiometry and scatterometry)

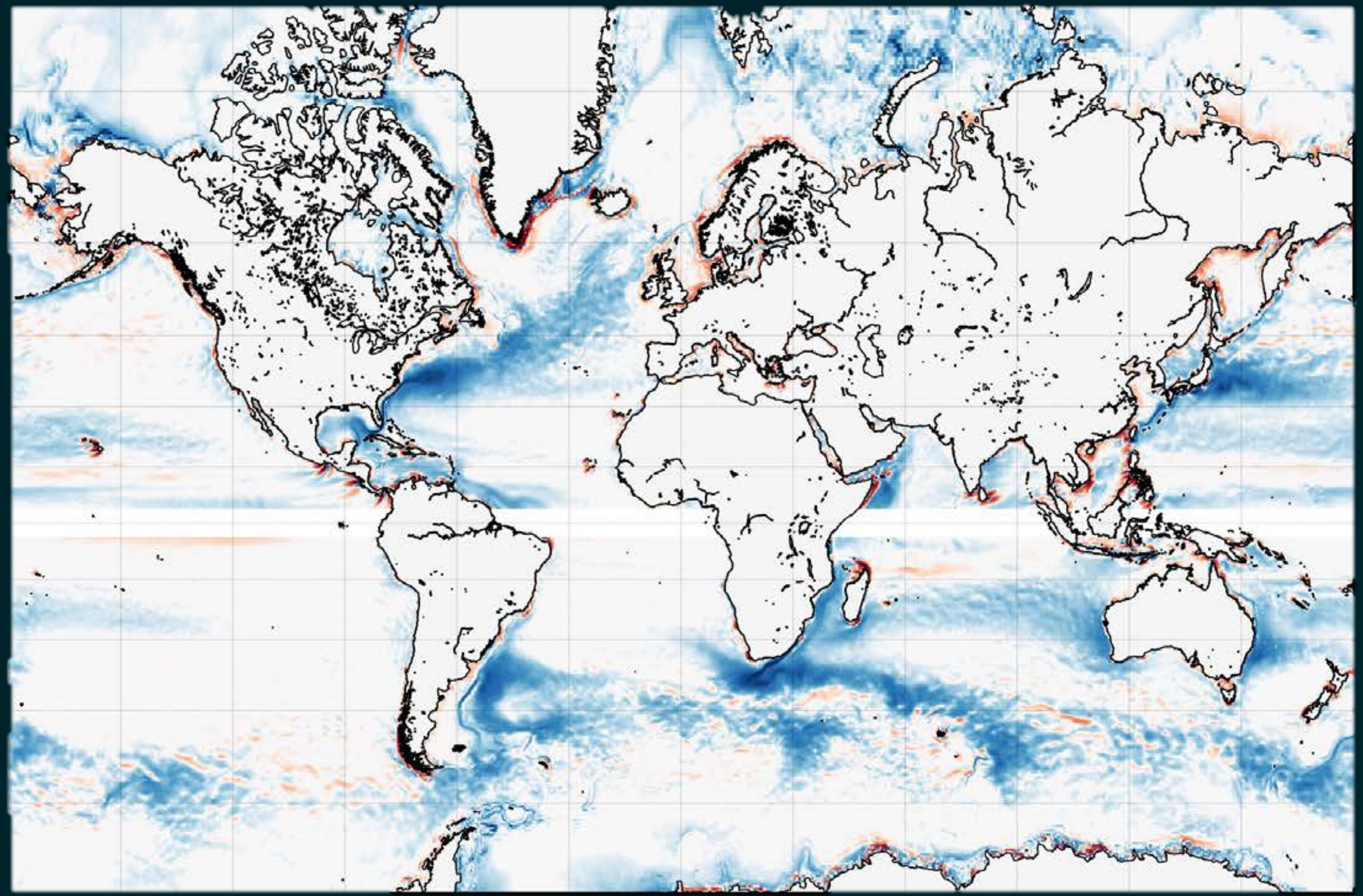


Seo, 2017

Wave Feedbacks, a missing piece ?

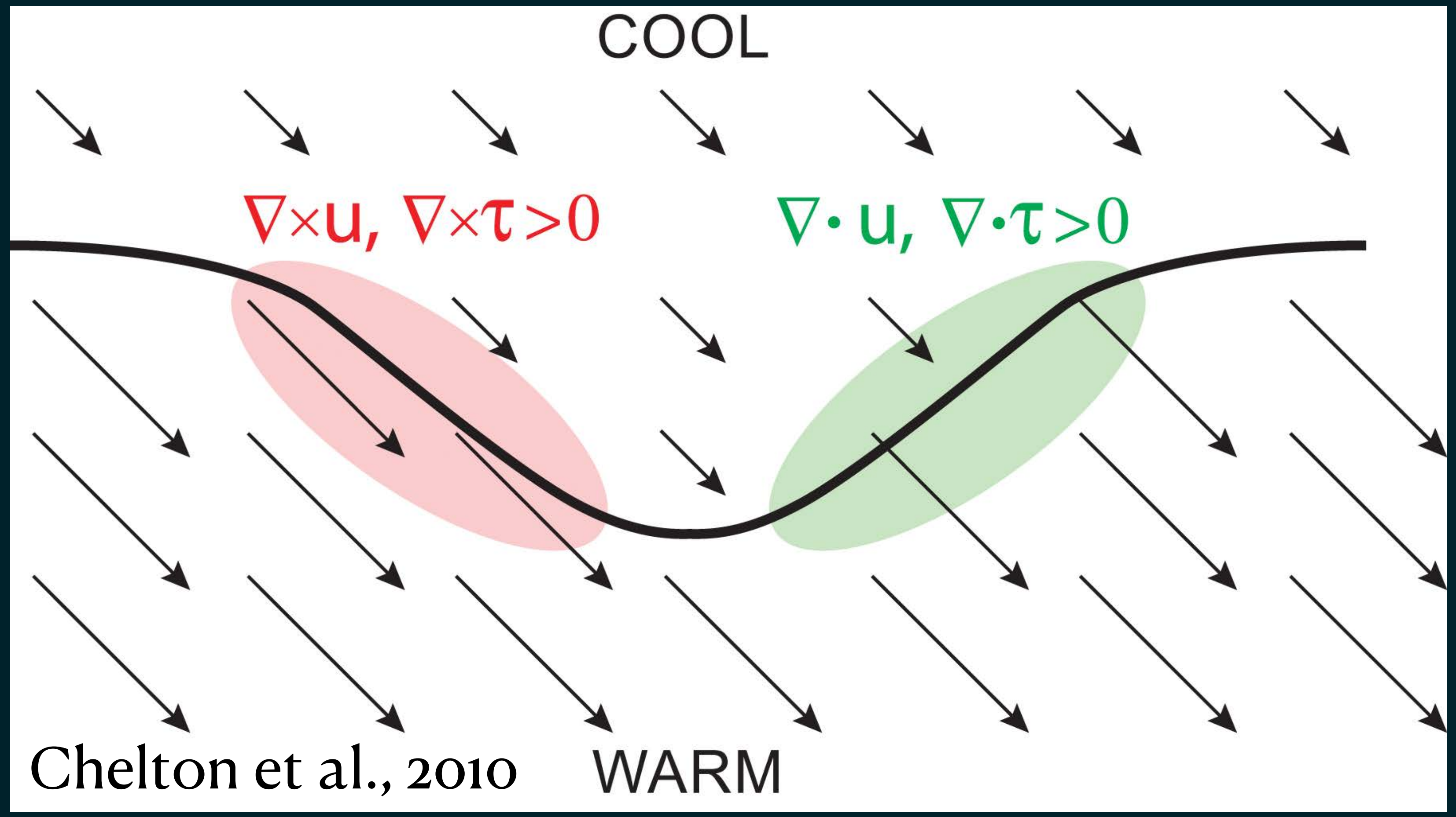


Current Feedback, here sinks of energy from mesoscale eddies to the atmosphere



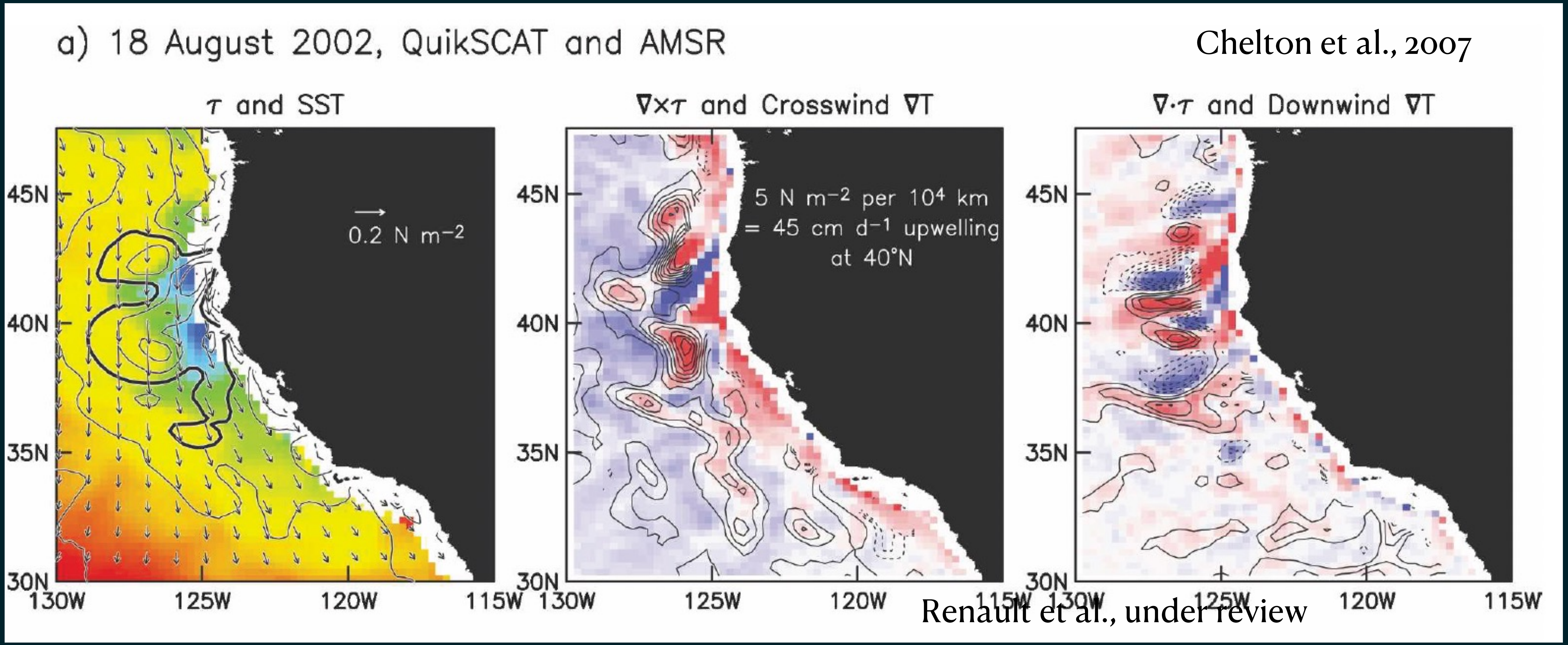
I won't focus on air-sea-land …

Mesoscale Thermal Feedback: First pathway via Wind Anomalies



Wind and Stress are modulated by SST anomalies and gradients

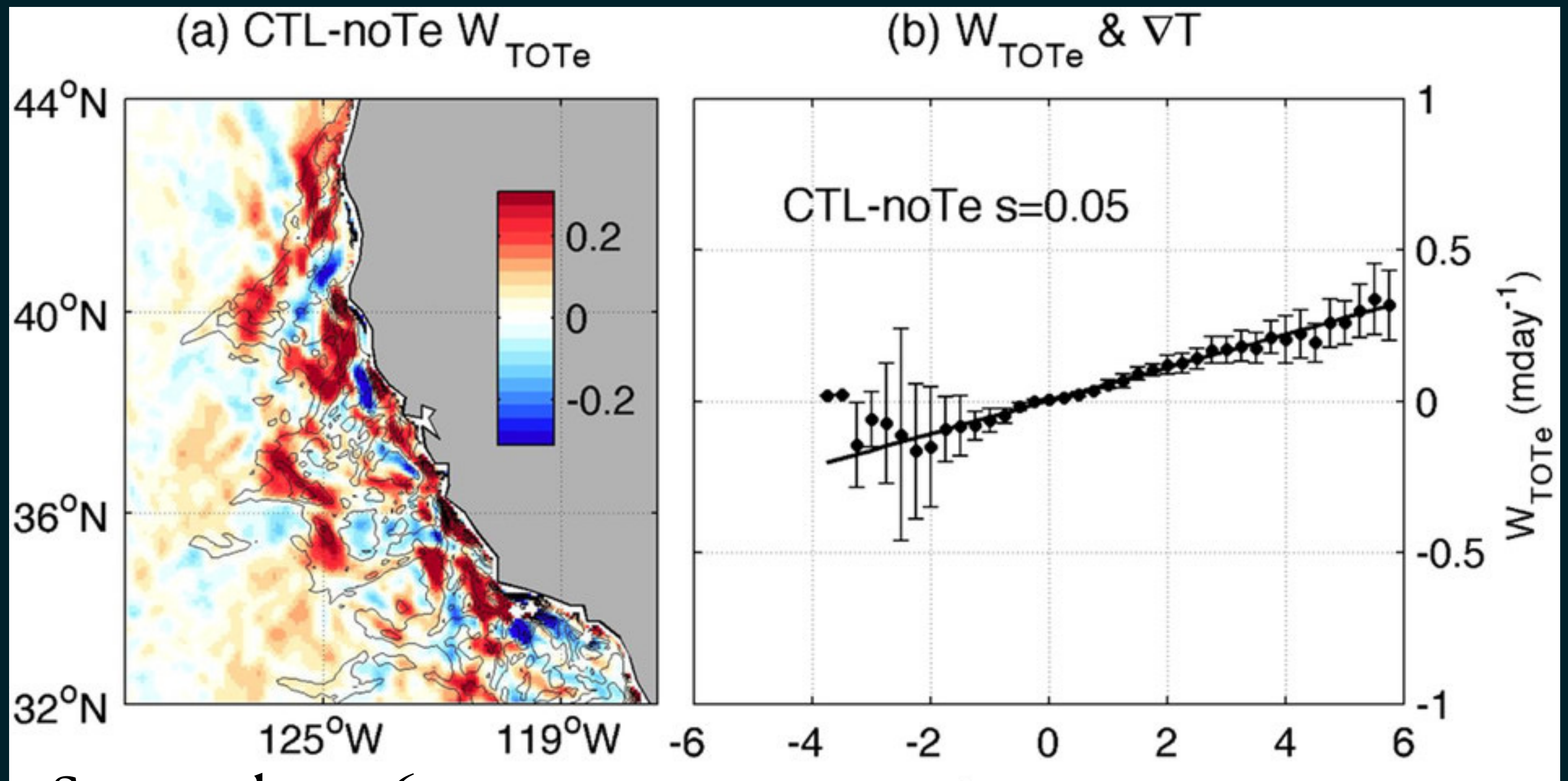
Modulation of wind and stress observed by satellite



Renault et al., under review

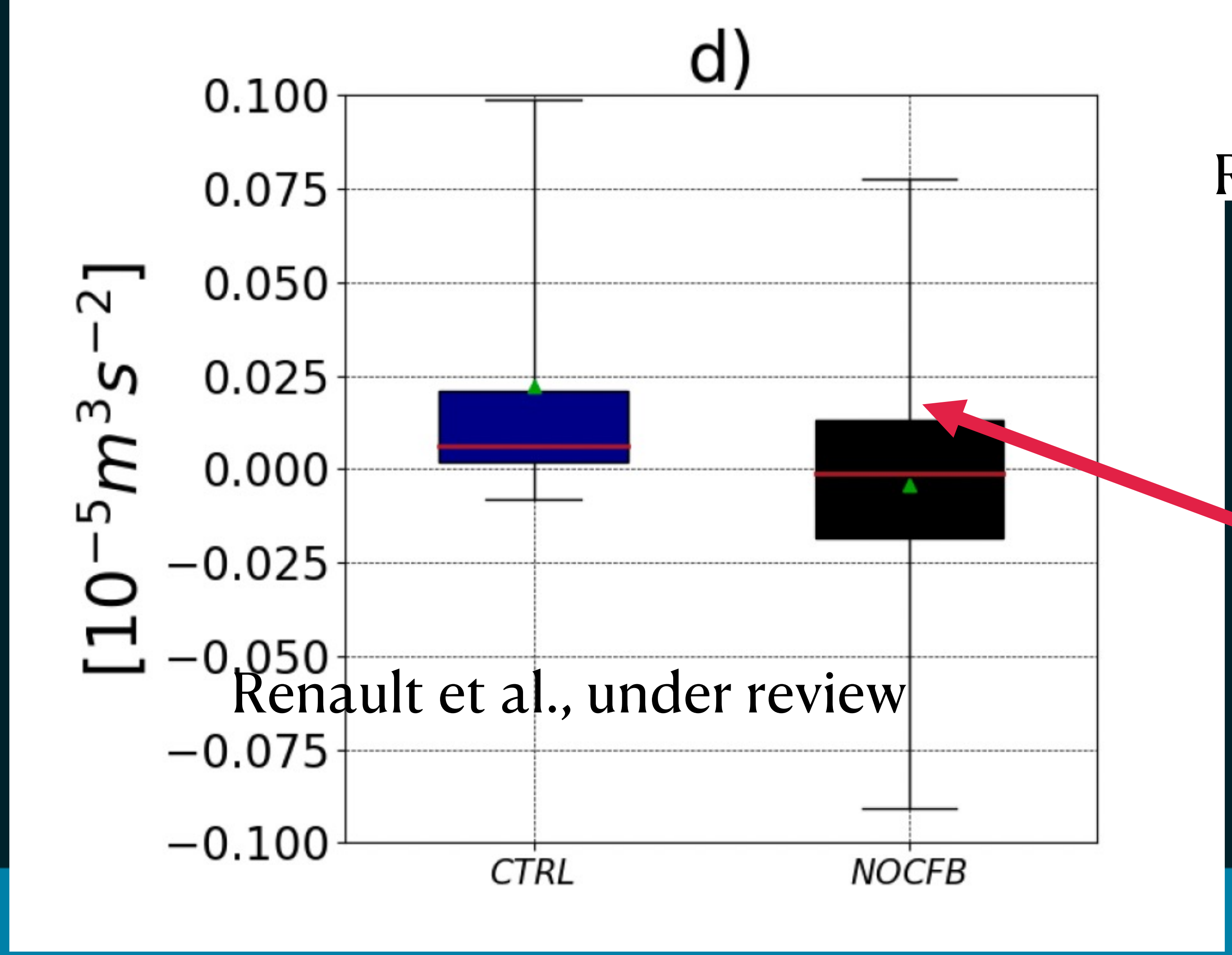
First Pathway via Wind Anomalies has a Weak Impact on the Ocean Dynamics

Ekman Pumping in the ocean that impact eddy propagation
But generally weak effect on the EKE
(Seo et al., 2016)



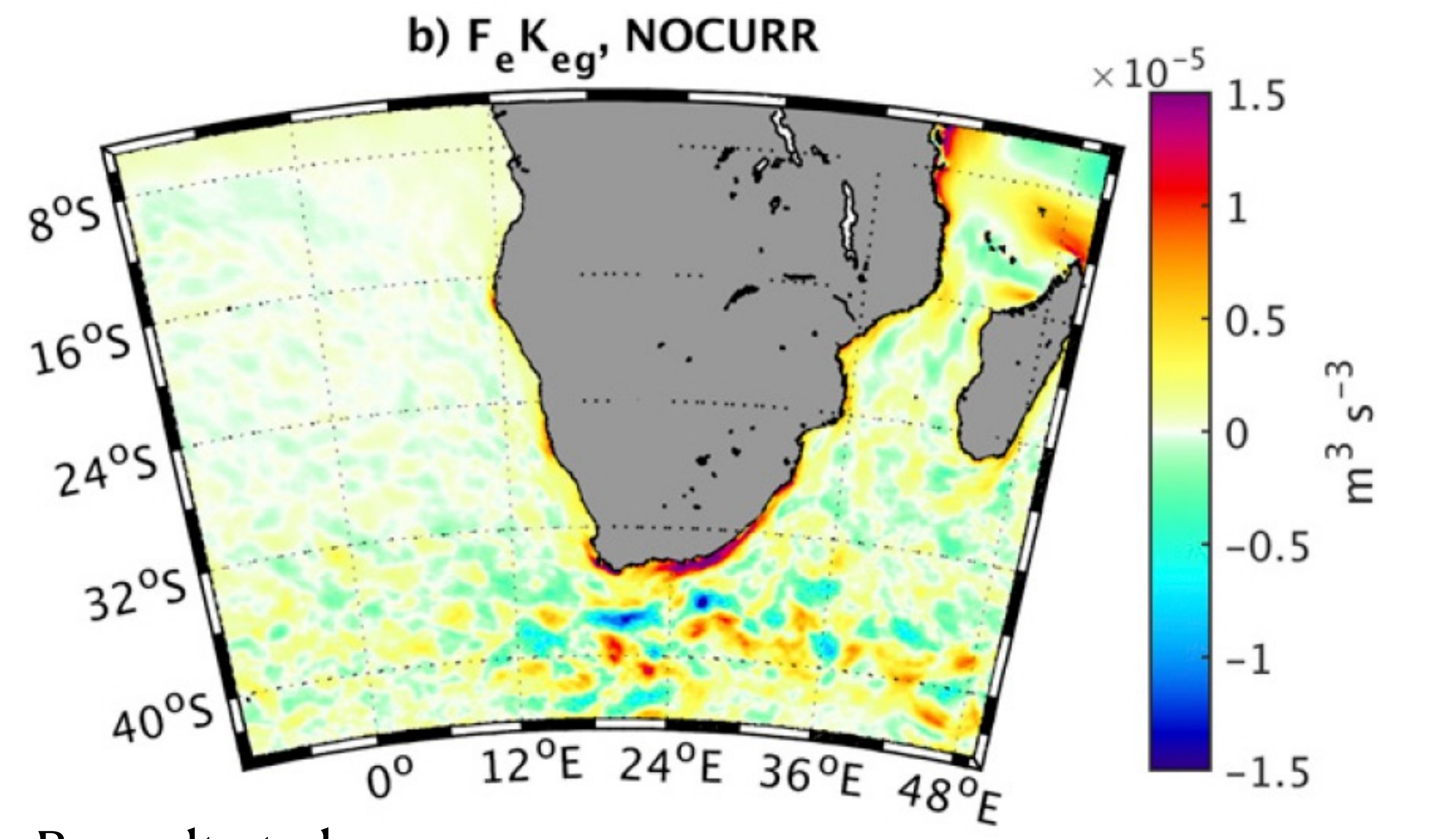
Seo et al., 2016

Confirmed by estimating the resulting baroclinic instability → no effect



Renault et al., under review

No significant effect on the exchange of energy between eddies and atmosphere

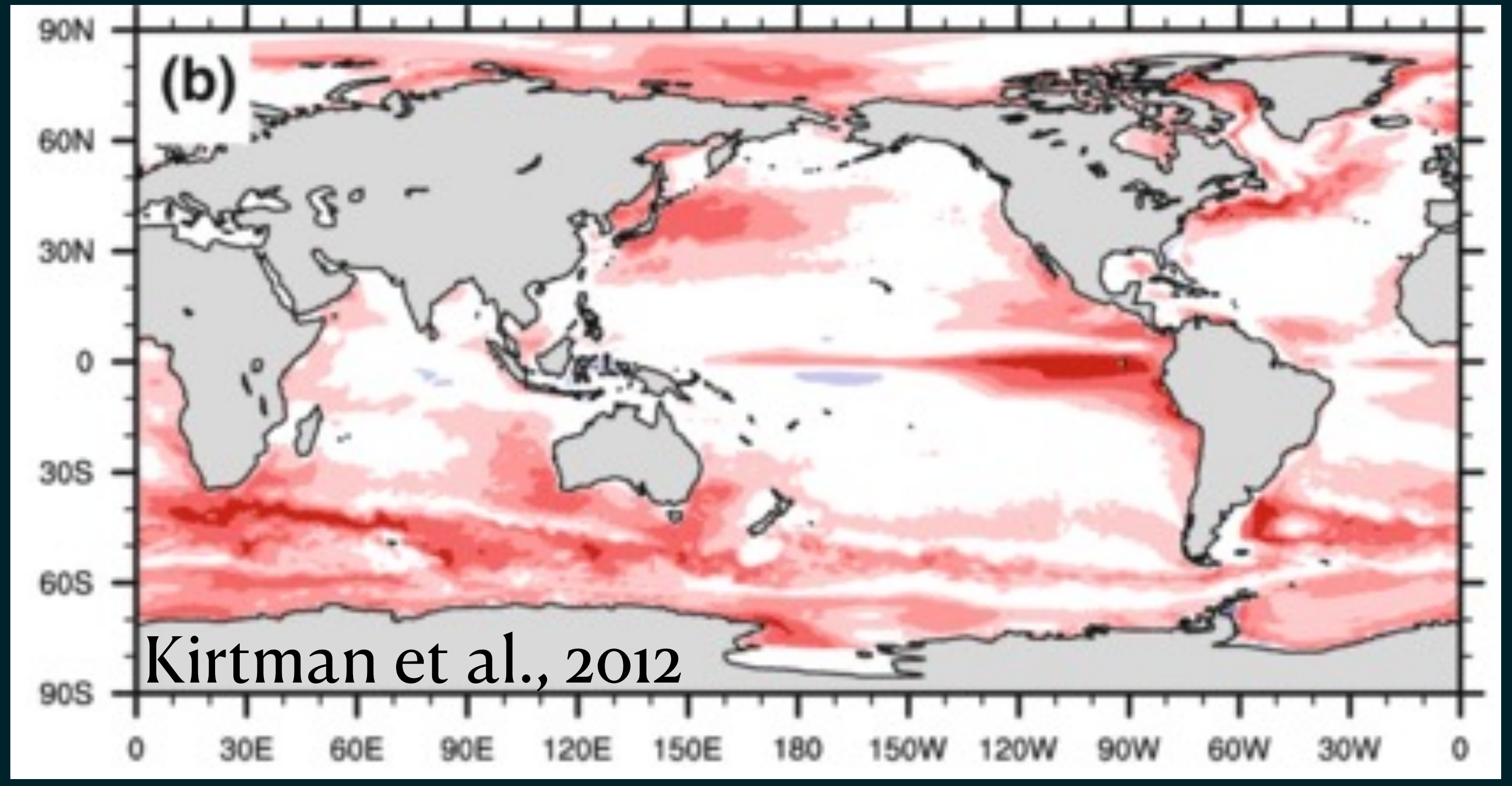


Renault et al., 2017

Only TFB
$\langle w'b' \rangle$~ 0 and $\langle \boldsymbol{u}'\boldsymbol{\tau}' \rangle$~0

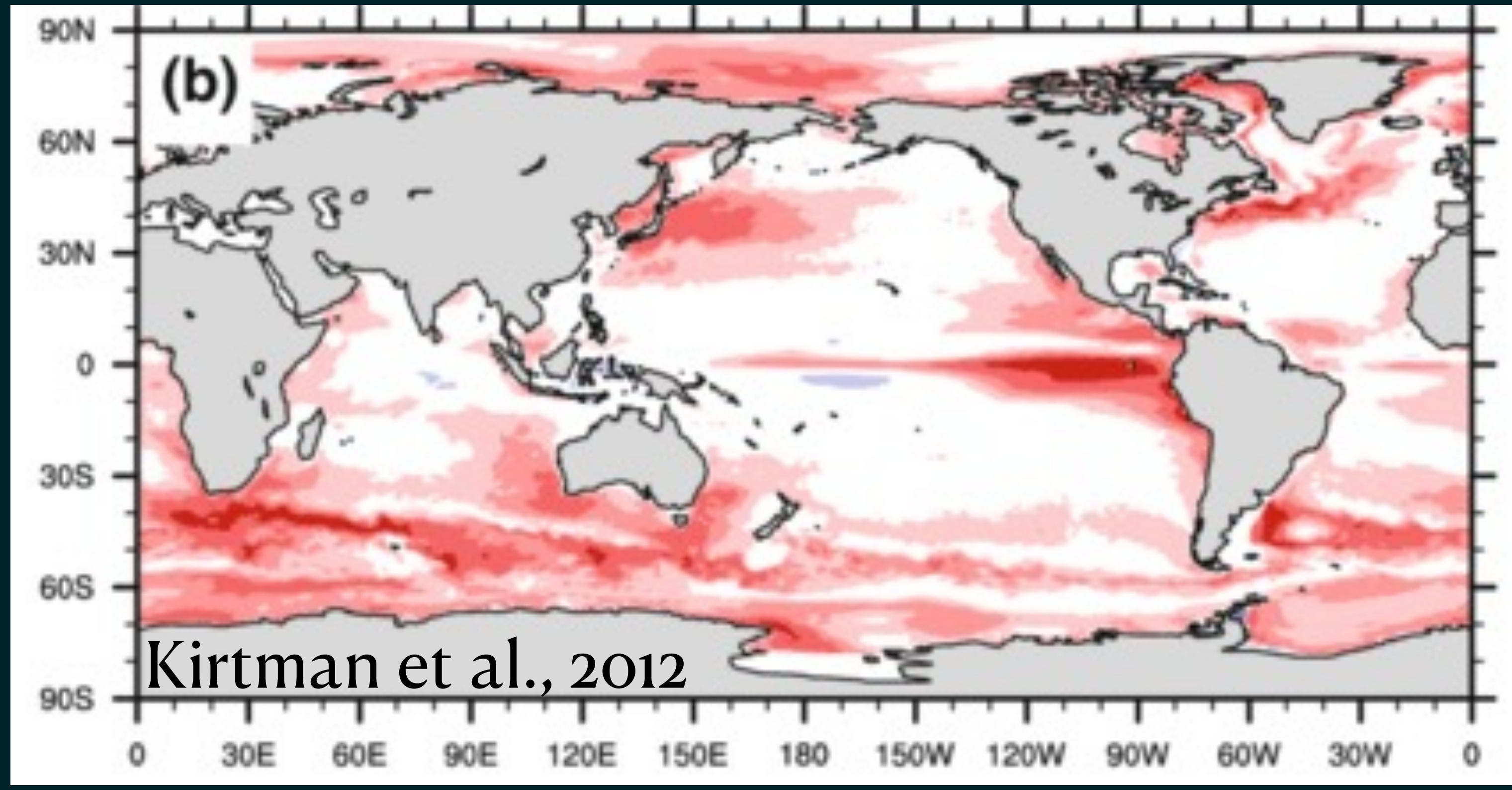
Mesoscale Thermal Feedback: Second pathway via Surface Heat Fluxes

Correlation between Turbulent Heat Flux and SST anomalies

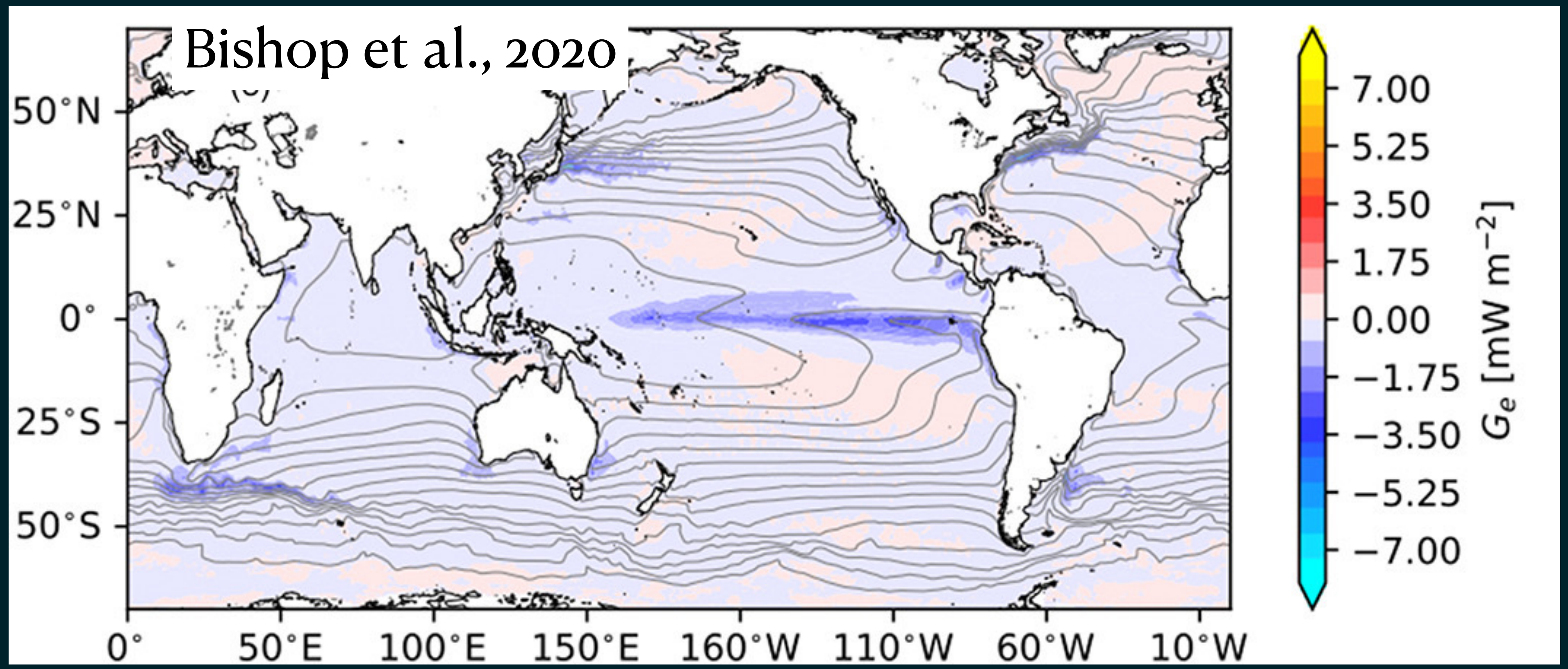


Mesoscale Thermal Feedback: Second pathway via Surface Heat Fluxes

Correlation between Turbulent Heat Flux and SST anomalies

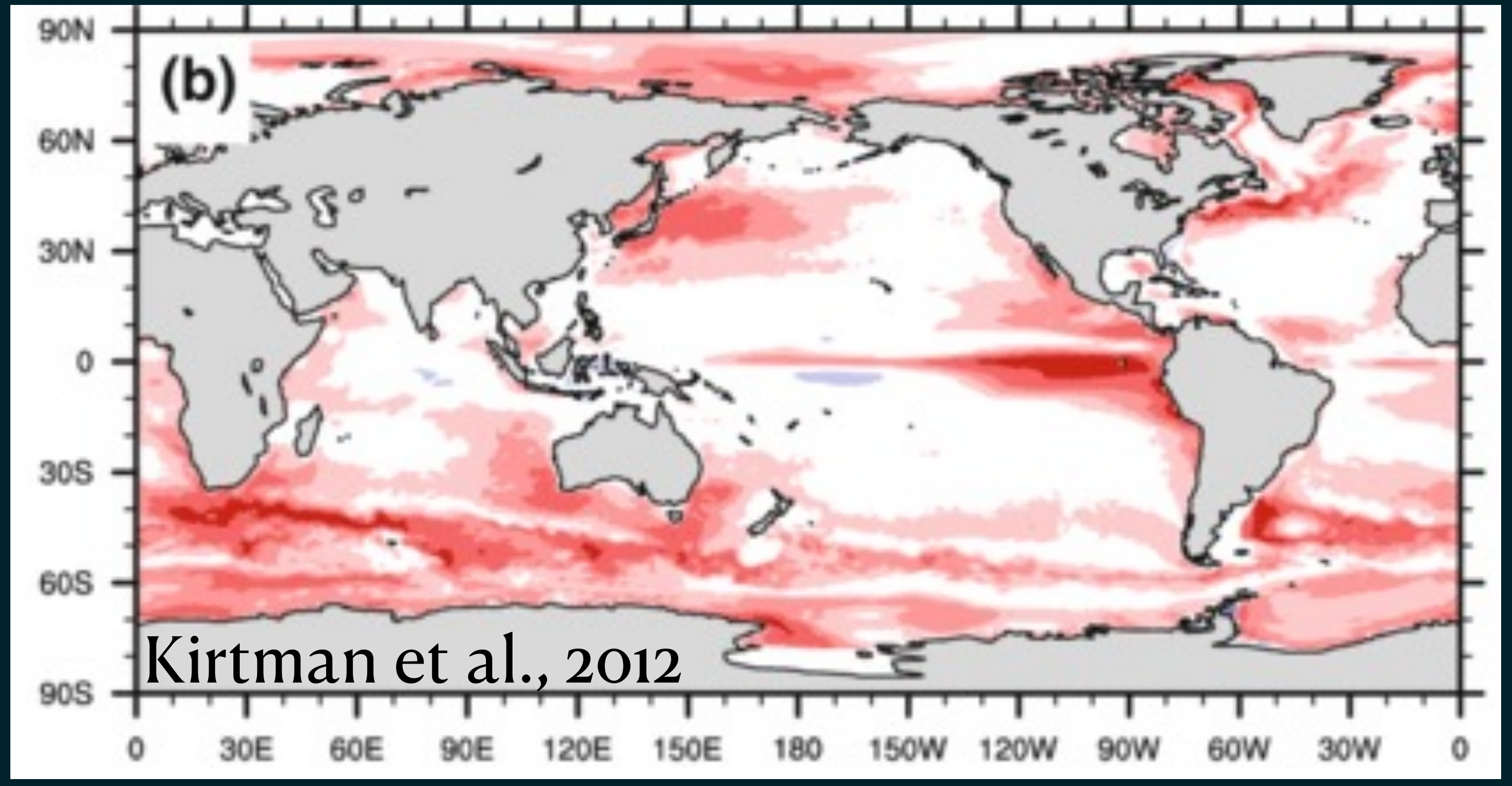


Transfer of Potential Energy from Mesoscale Eddies to the Atmosphere



TFB Induced Heat Fluxes can cause a Damping of the EKE

Correlation between Turbulent Heat Flux and SST anomalies



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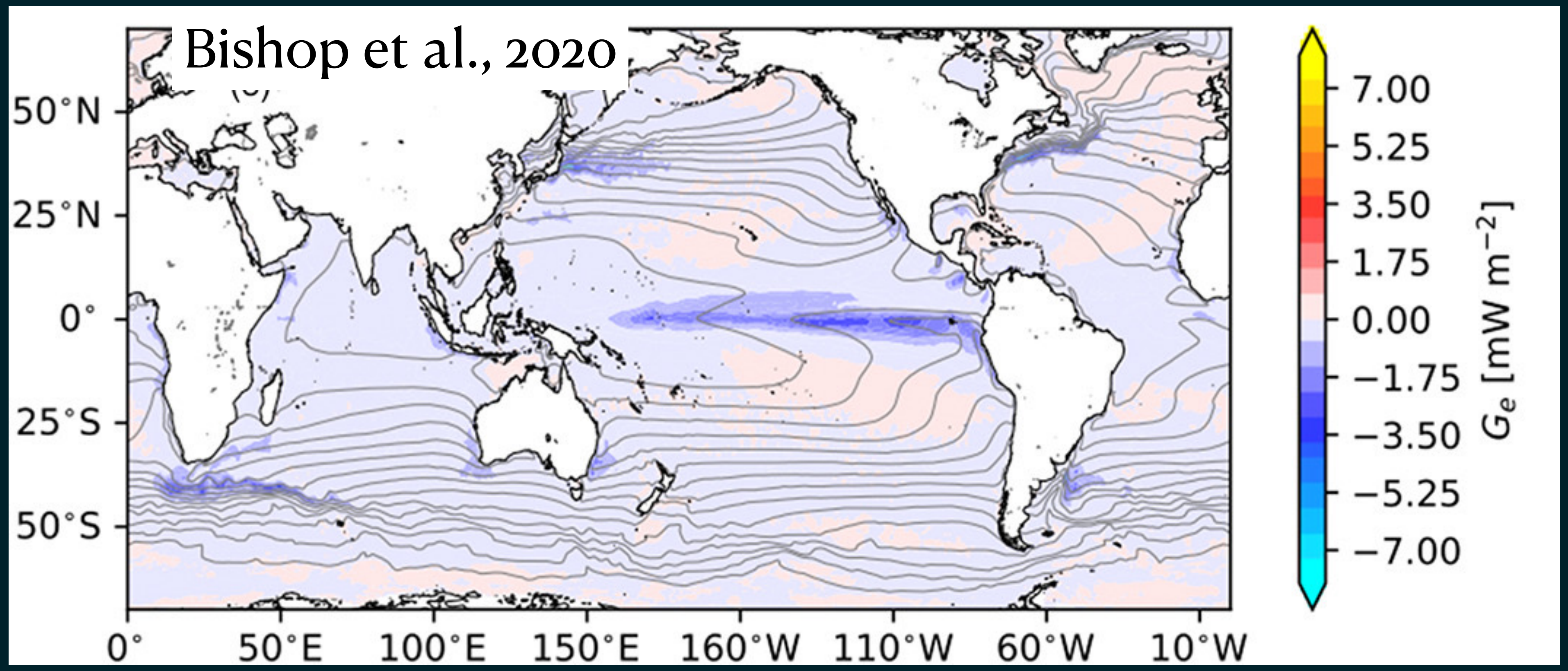
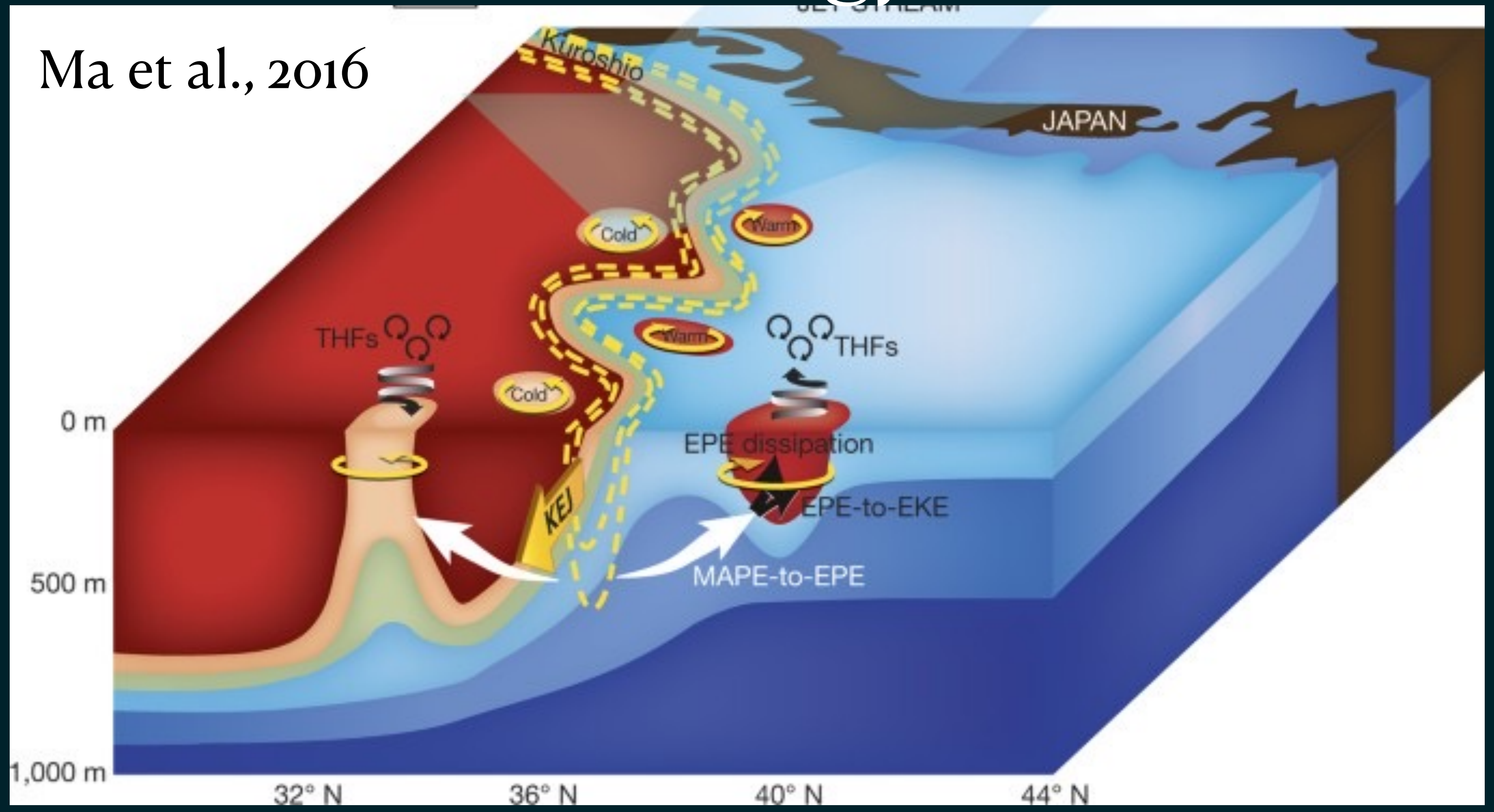


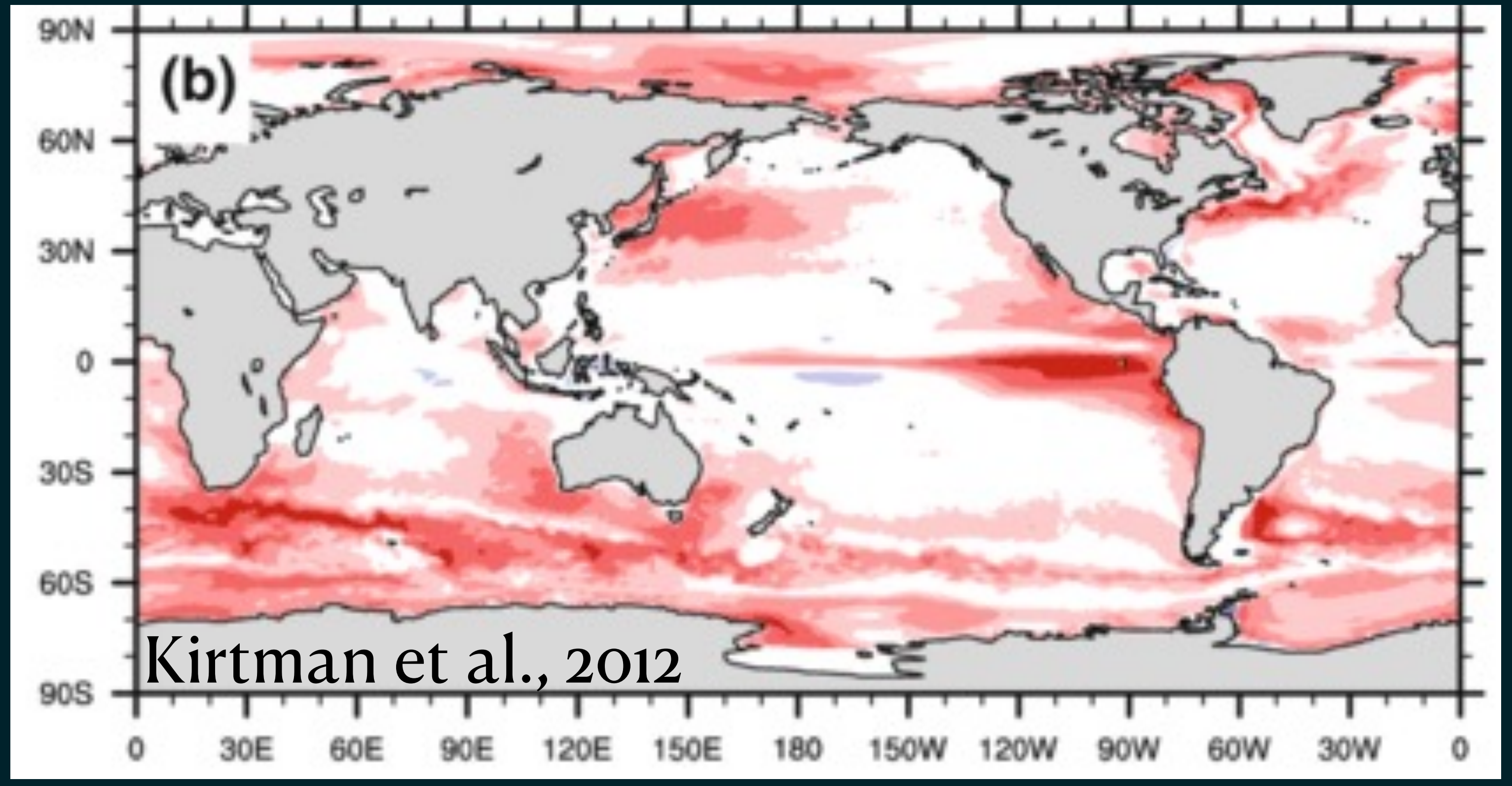
Reduction of baroclinic conversion of energy



- Ma et al. (2016): damping of EKE by ~10%
- Seo et al., (2016): no impact

TFB Induced Heat Fluxes can cause a Damping of the EKE

Correlation between Turbulent Heat Flux and SST anomalies



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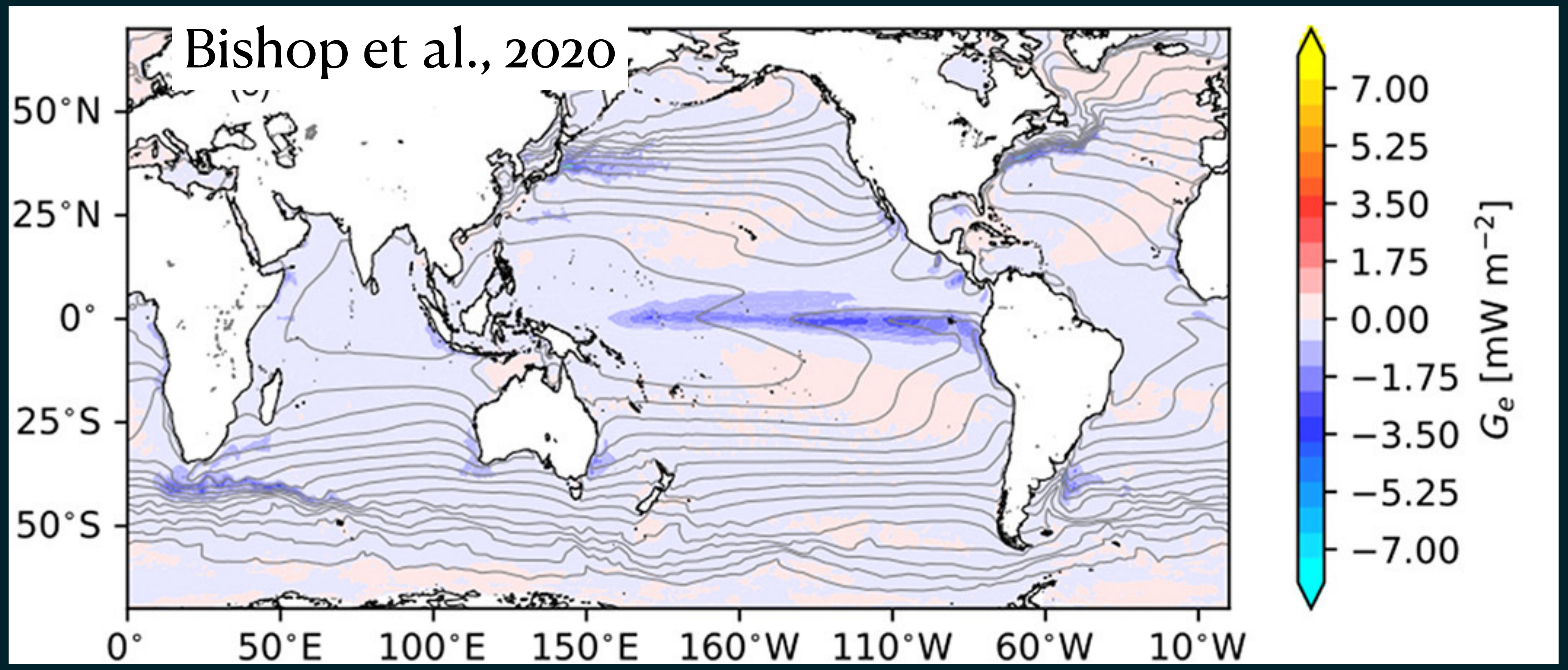

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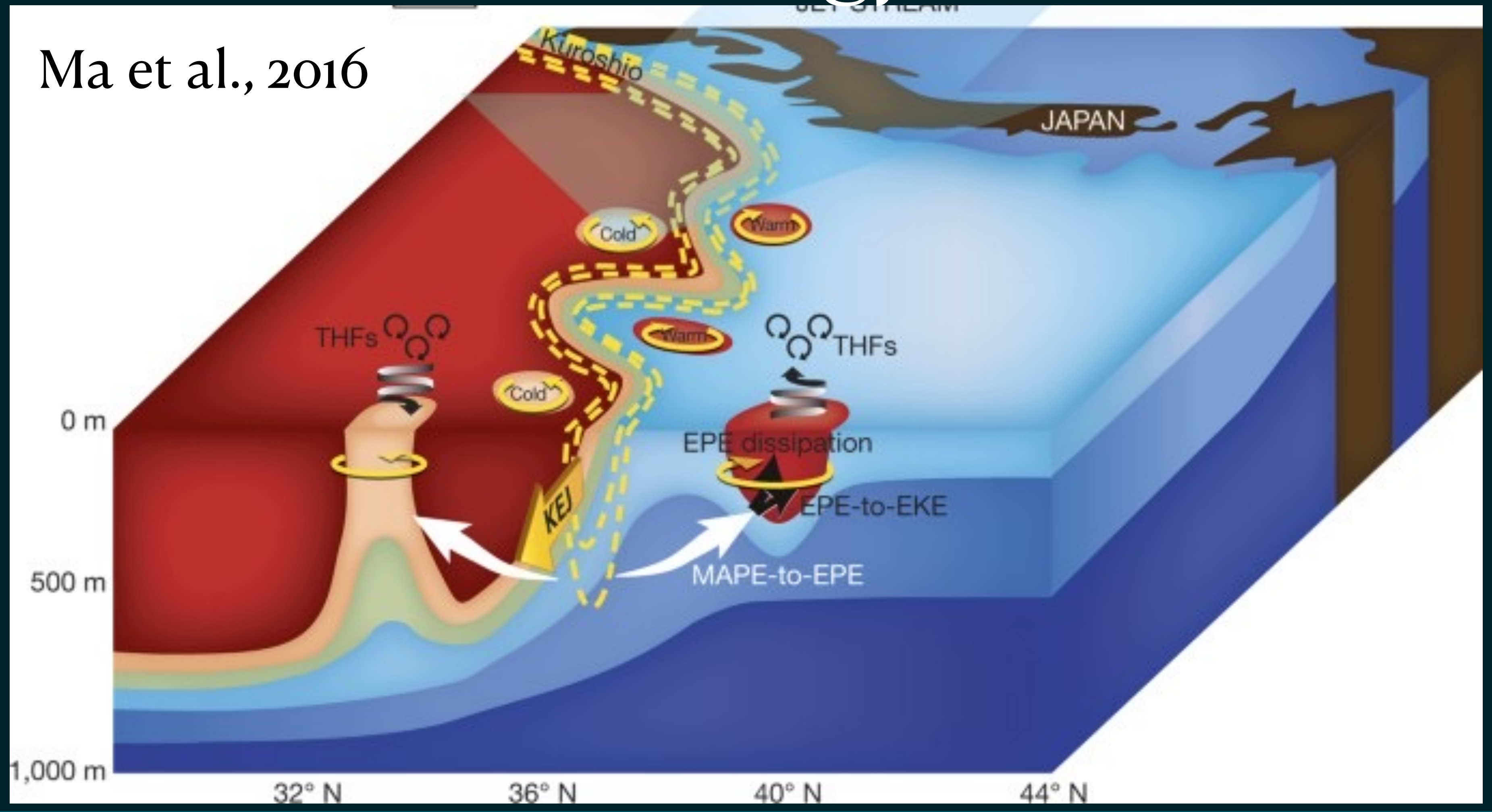
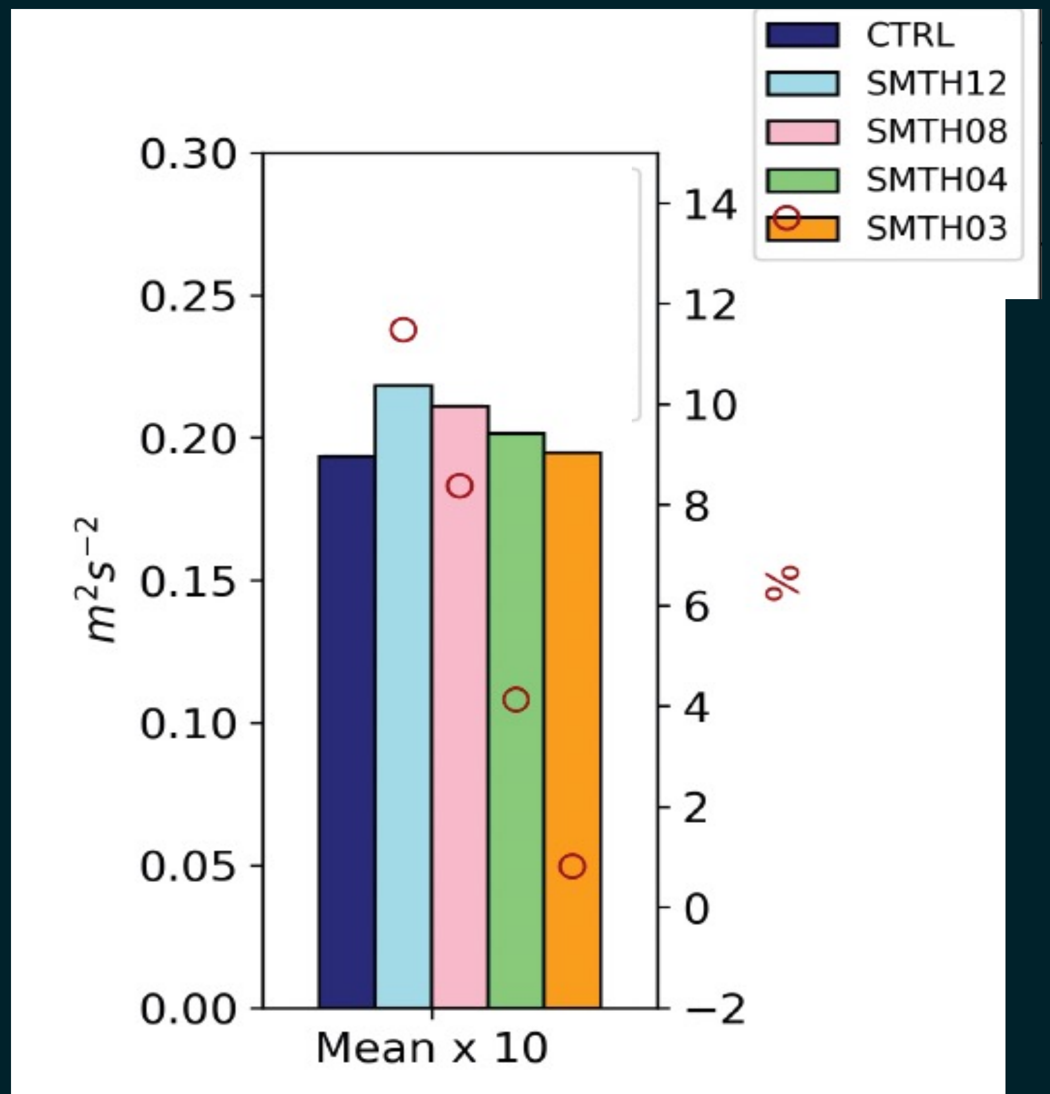


No Filter

~1000 km

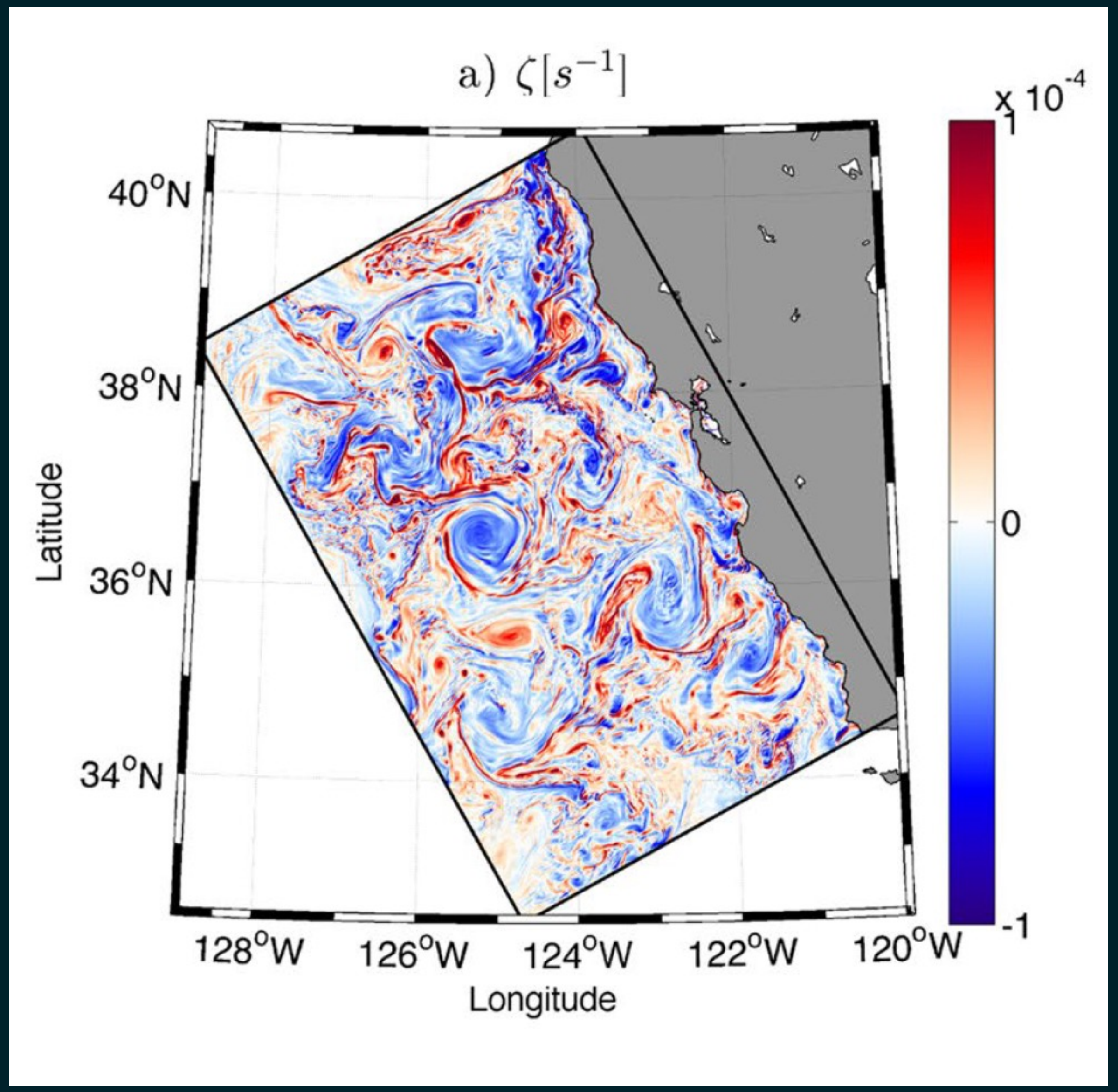
~300 km

Strong dependance on the spatial filter uses when sending the SST to the atmosphere

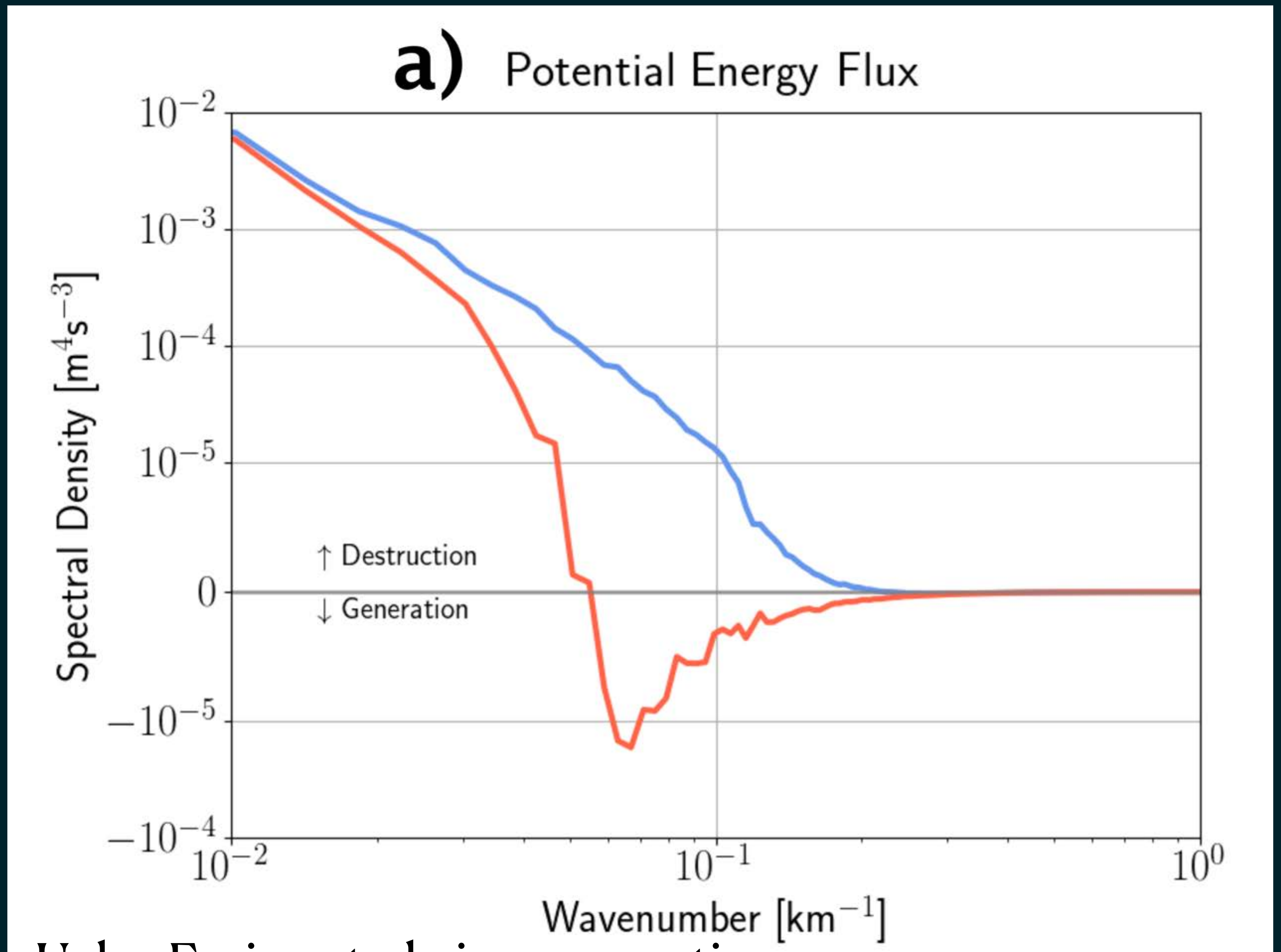


Renault et al., under review

Enhanced Process at Submesoscale but partly Balanced by Windwork

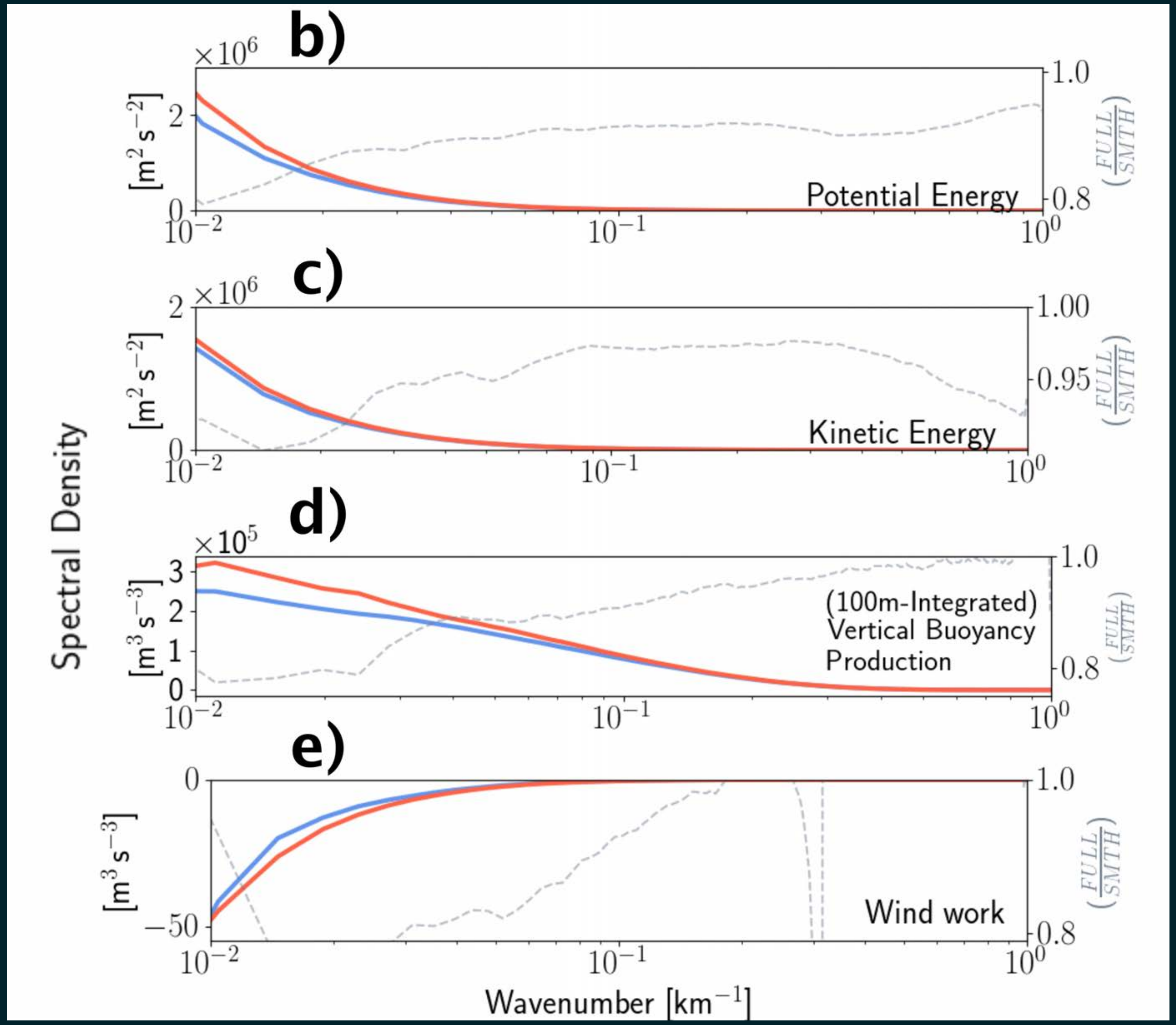


Snapshot of Surface Vorticity from a 500 m coupled simulation



Ucho Farias et al., in preparation

In Blue, simulation with submesoscale Thermal Feedback
In Red, without submesoscale Thermal Feedback



Observations are missing at those scales !

More information on Igor's Poster !

Main Effect of (sub)mesoscale Current Feedback is a Sink of Energy from Eddies to the Atmosphere

Bulk formula for surface wind stress:

$$\tau \;=\; \rho C_D |U_a - U_o|^2$$

usually approximated as

$$\tau \;\approx\; \tau_a \;=\; \rho C_D |U_a|^2$$

More generally, for $U_o \ll U_a$

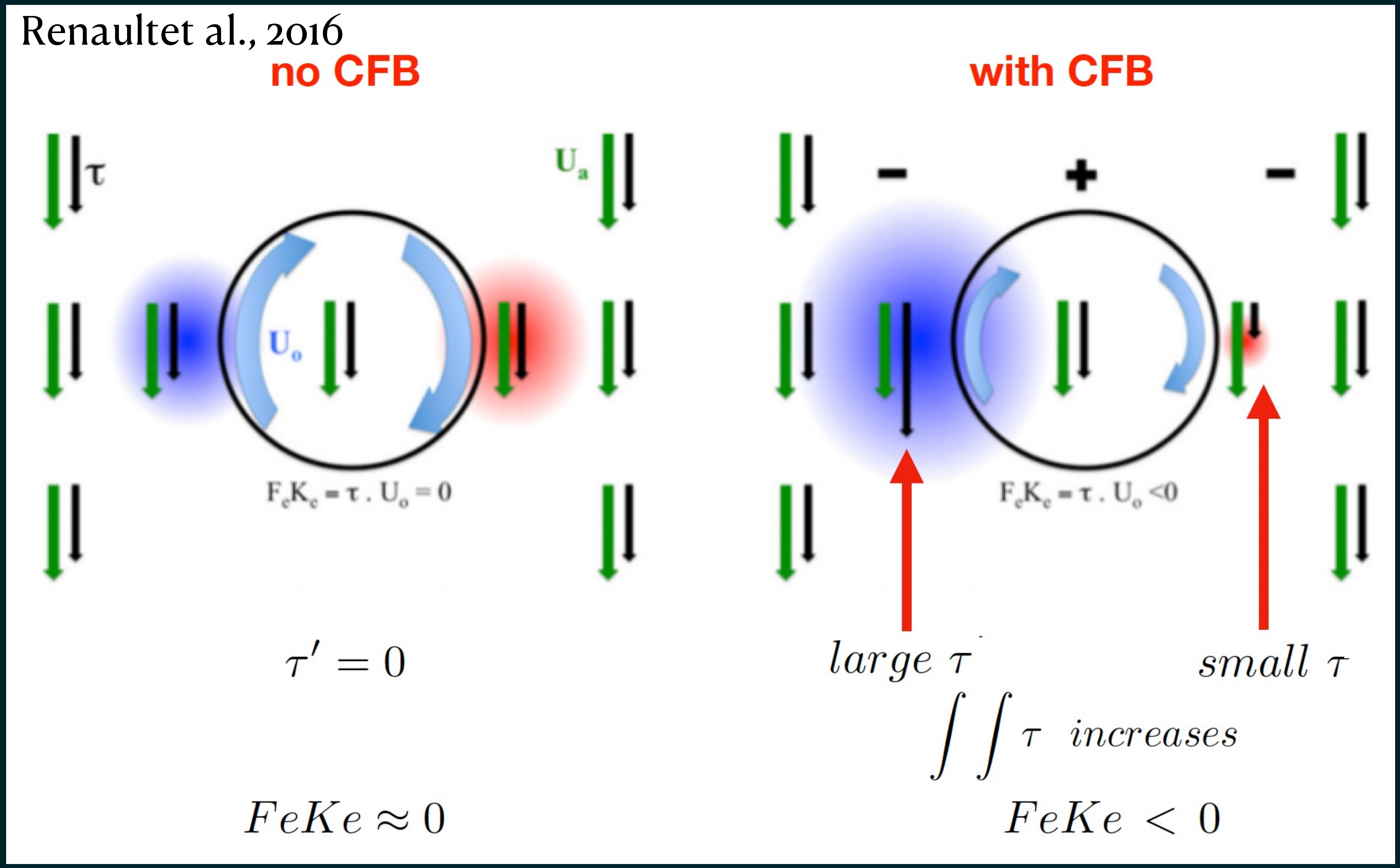
$$\tau = \tau_a + \tau'$$

$$\tau' \approx s_\tau U_o\,, \quad s_\tau \;\propto\; -\,|U_a|$$

Eddy wind work done the ocean:

$$FeKe = \langle \tau \cdot U_o \rangle \;\approx\; s_\tau U_o^2 \;\propto\; -|U_a| U_o^2 \;<\; 0$$

=> oceanic energy loss and atmospheric gain vis a vis a resting ocean.

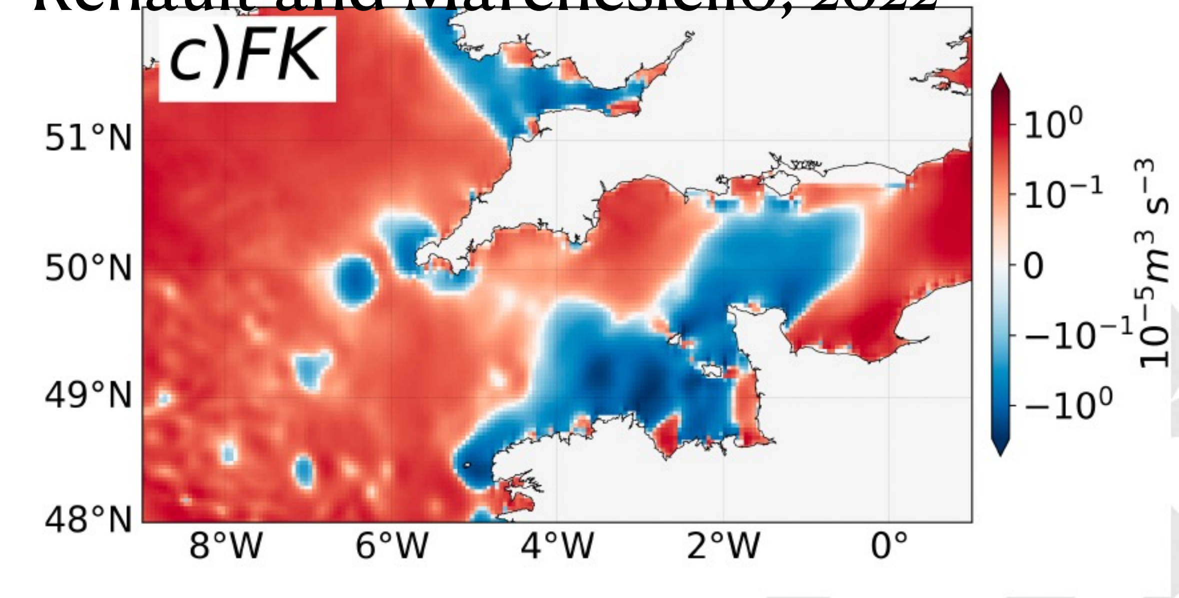


→Global Sinks of Energy
→The Ocean drags the Atmosphere

This Sink of Energy is Present at All Scales !

Tidal Scale

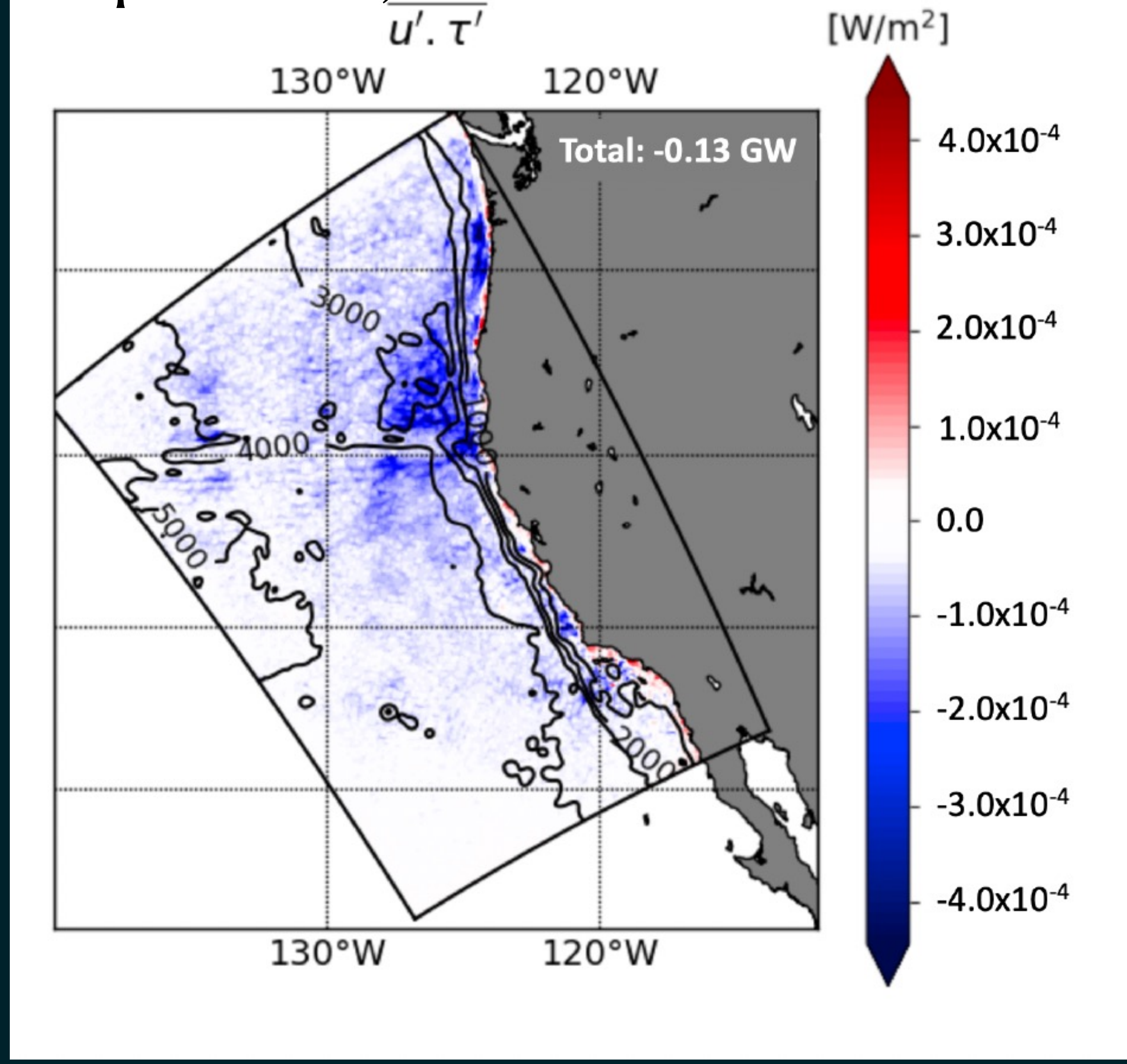
Renault and Marchesiello, 2022



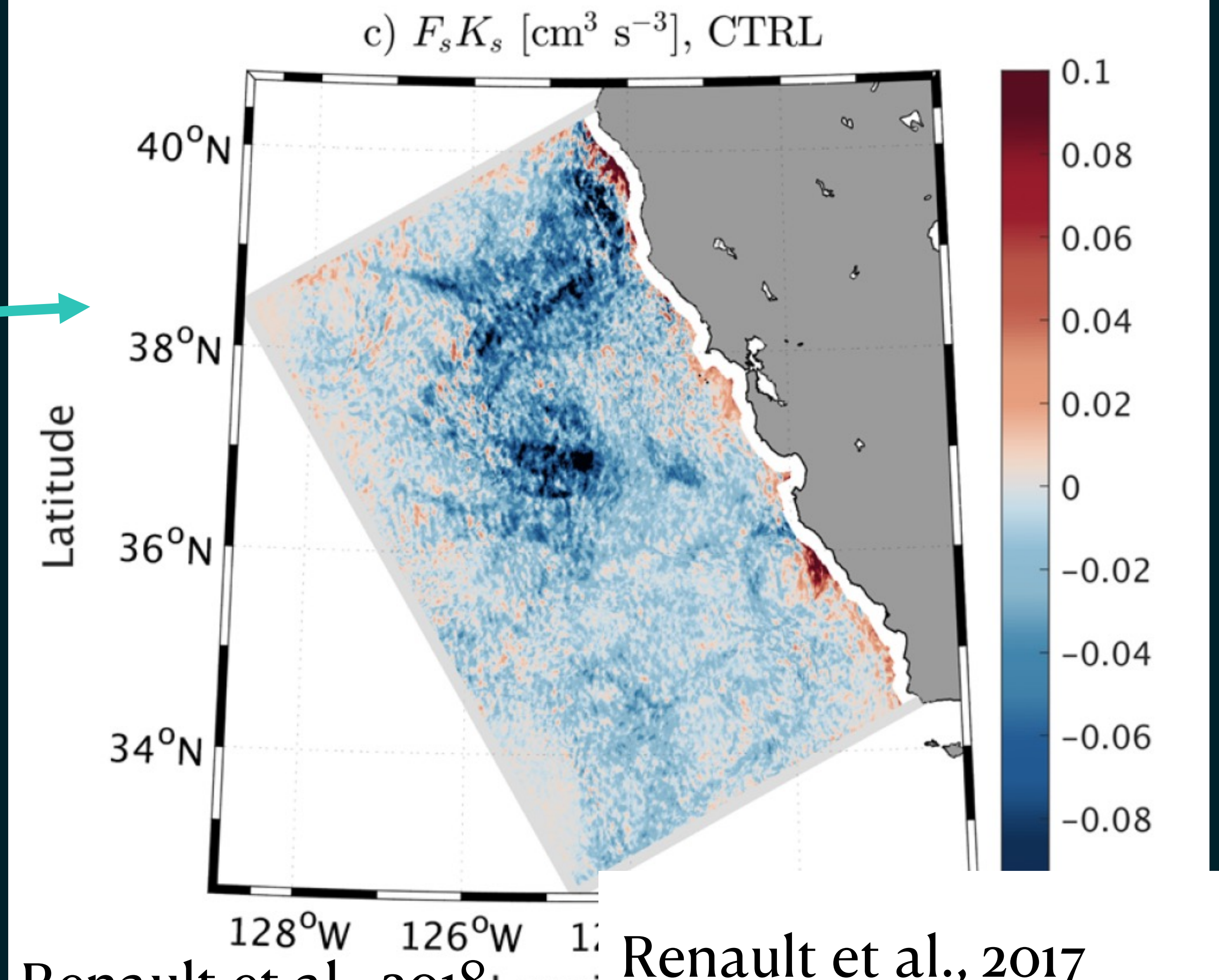
Not Observed !

Internal Tides Scale

Delpech et al., under revision



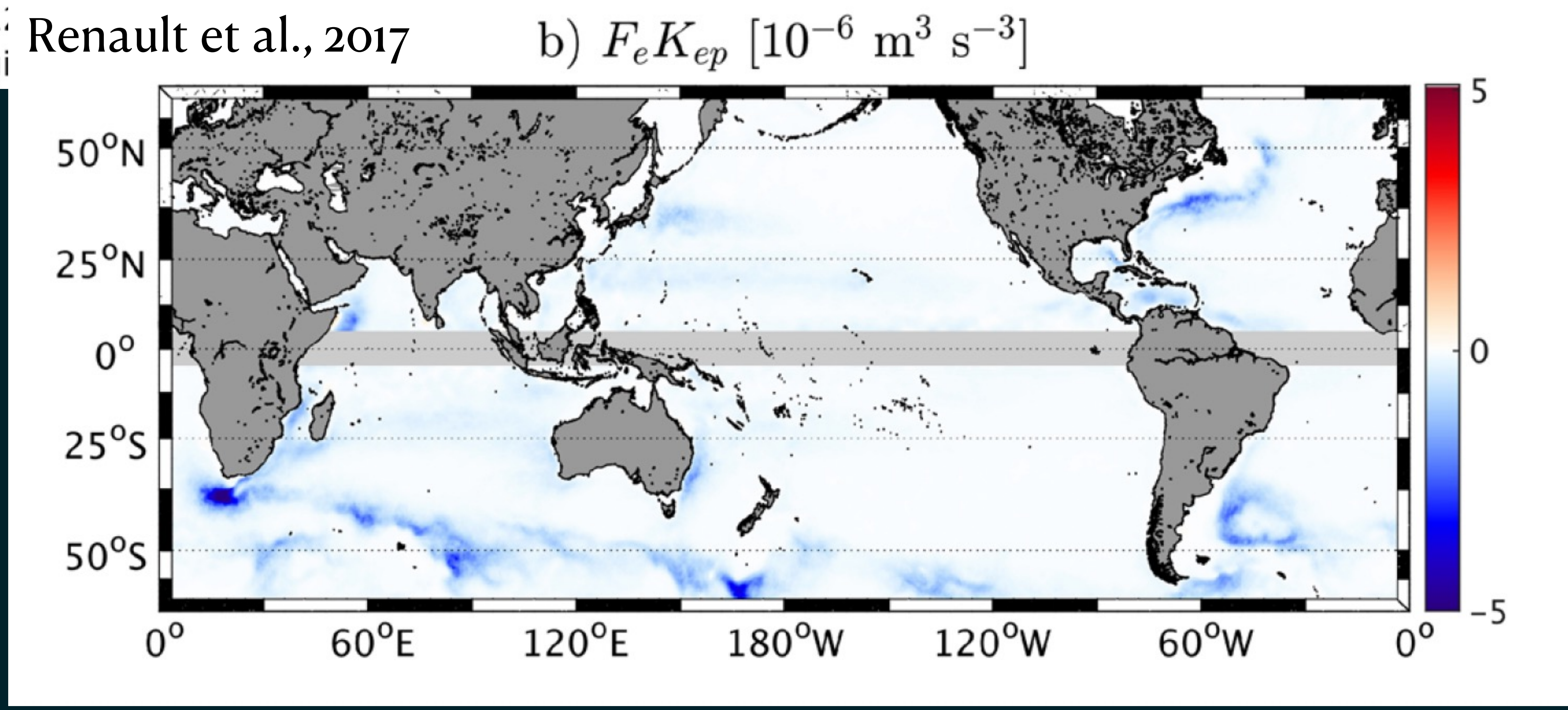
Submesoscale



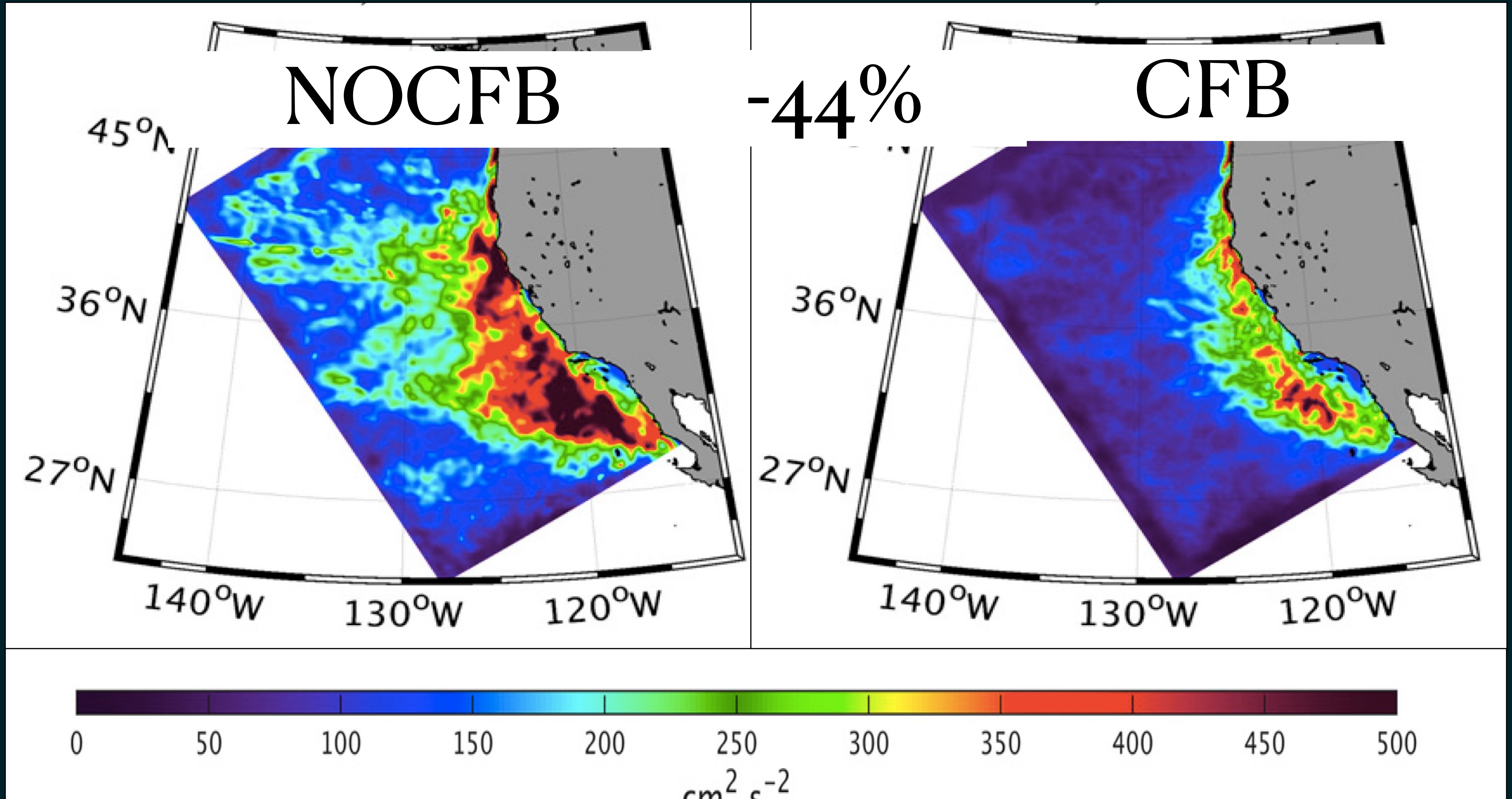
Renault et al., 2018

Mesoscale, **Partly Observed** (see also Rai et al., 2021) , but Large Uncertainties

Renault et al., 2017

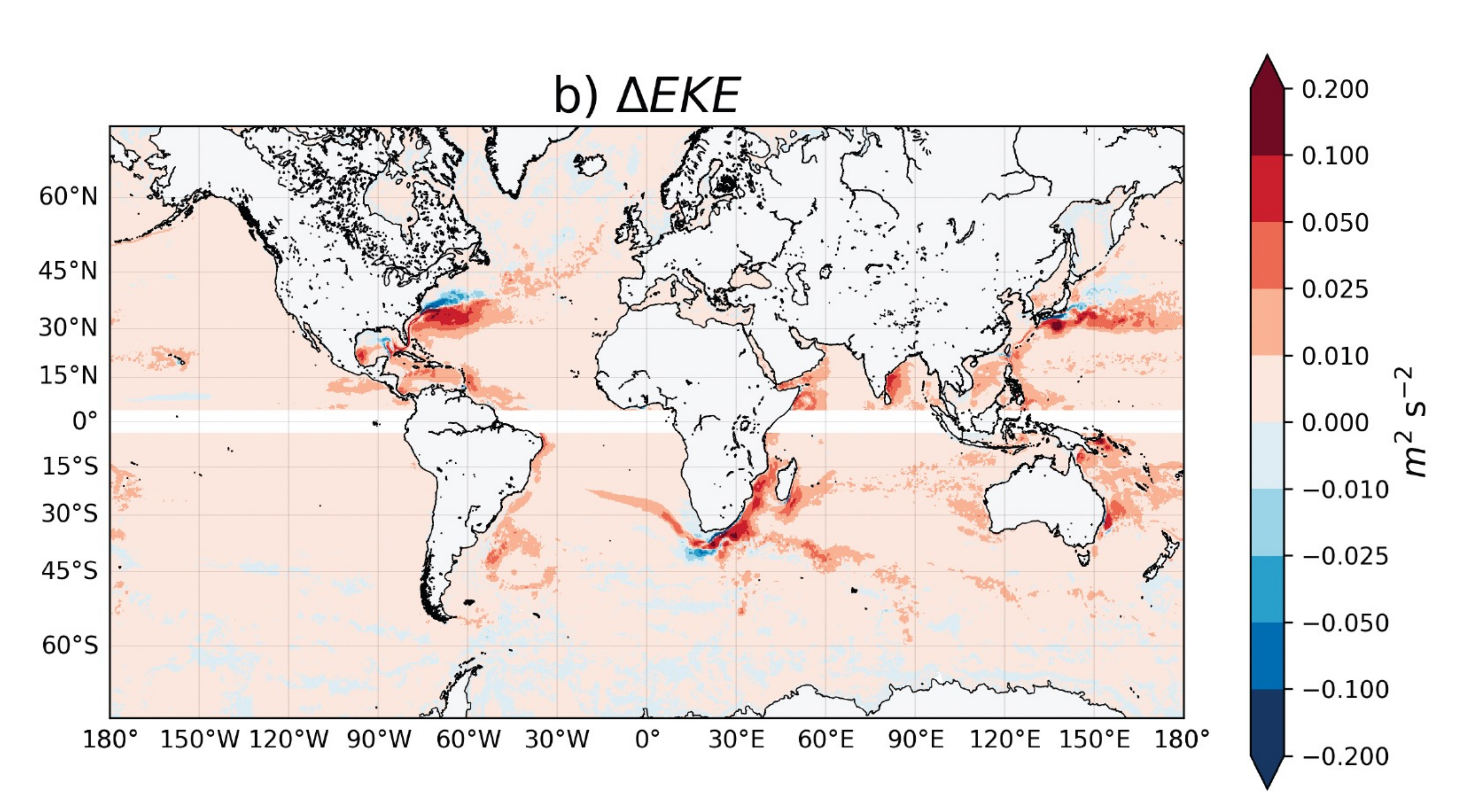


It causes the Eddy Killing Process a Damping of Mesoscale Eddies



Renaultet al., 2016

30% Global

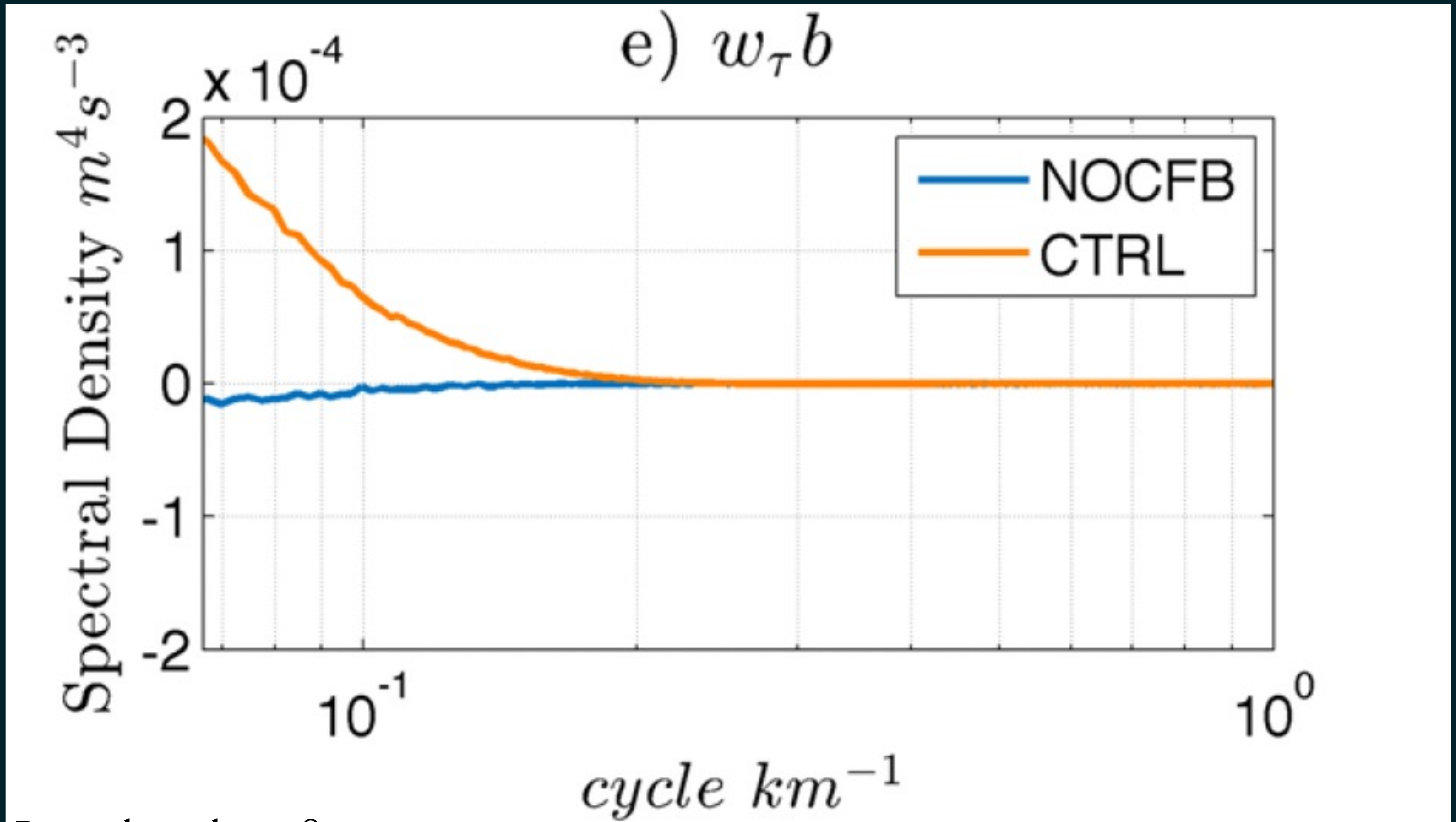


Seo et al., 2023; Renault et al., 2023

- 44% US West Coast *(Seo et al., 2016, Renault et al., 2016a)*
- 27% North Atlantic *(Renault et al., 2016b)*
- 25% Agulhas Current *(Renault et al., 2017a)*
- 40% South East Pacific *(Oerder et al. 2017)*
- 25% Gulf of Mexico (*Larrañaga et al., 2022*)

Also present at Submesoscale, but balanced by more Baroclinic Conversion caused by Ekman Pumping

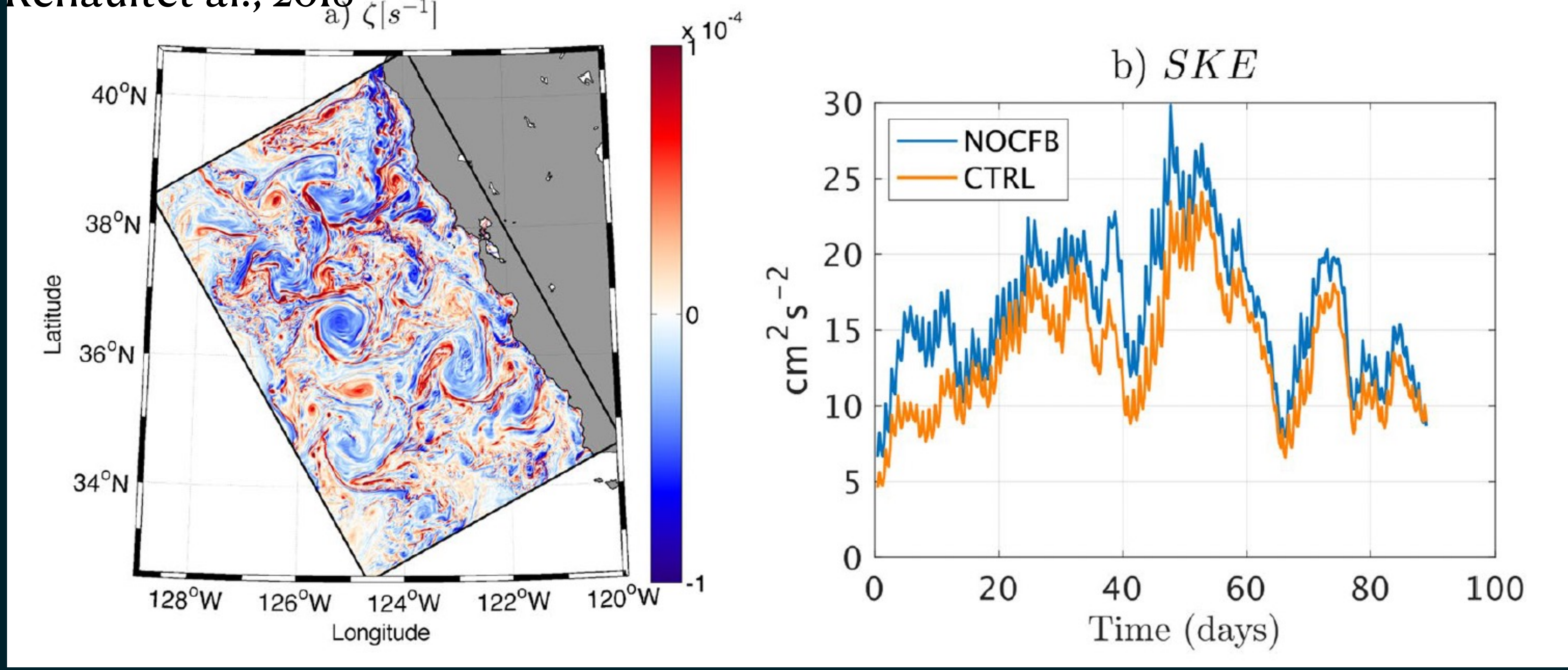
More Baroclinic Conversion



Renaultet al., 2018

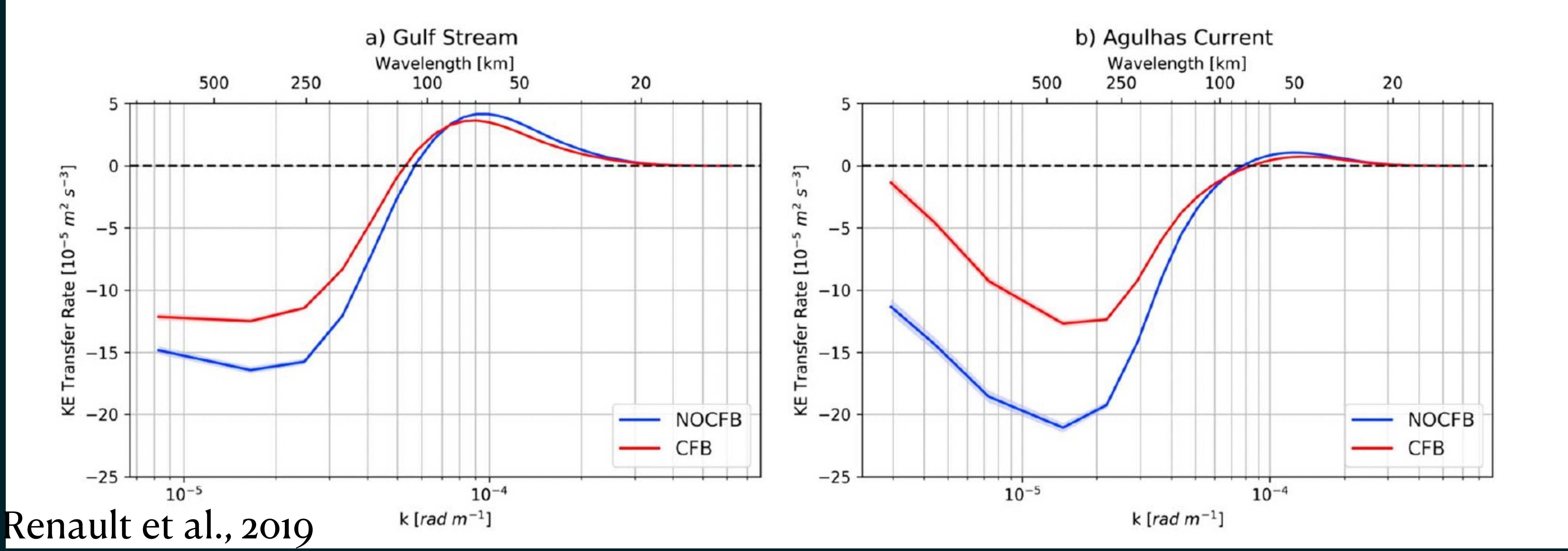
Reduction of SKE by ~15%

Renaultet al., 2018



An Upscaling Impact: Stabilization of Western Boundary Current

Reduction of the Eddy-Mean Flow Interaction
(the Inverse Cascade of Energy)



Renault et al., 2019

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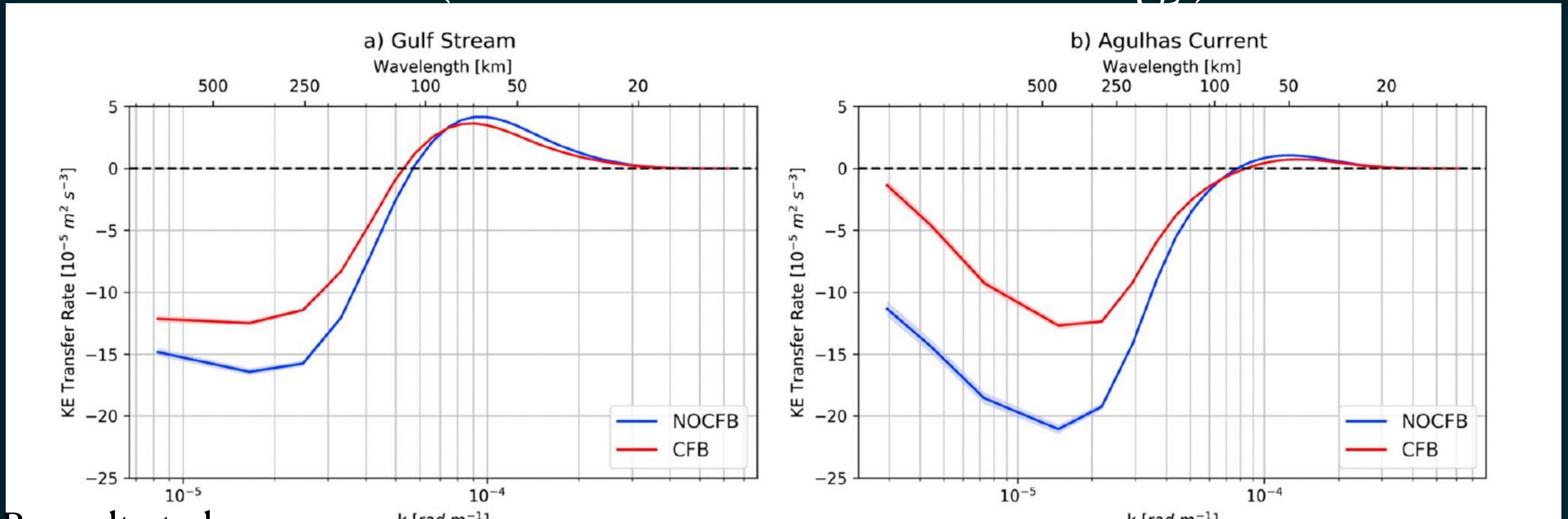
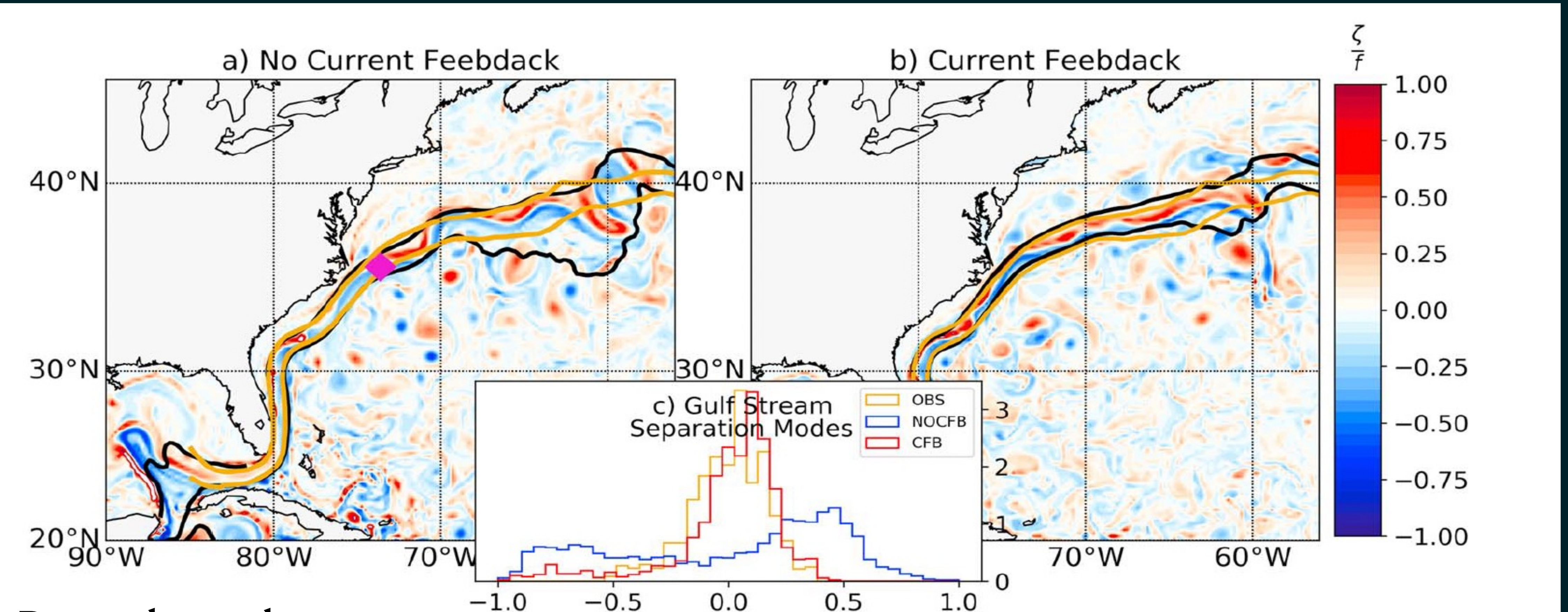


Renault et al., 2019

Path of the Gulf Stream



Renault et al., 2019

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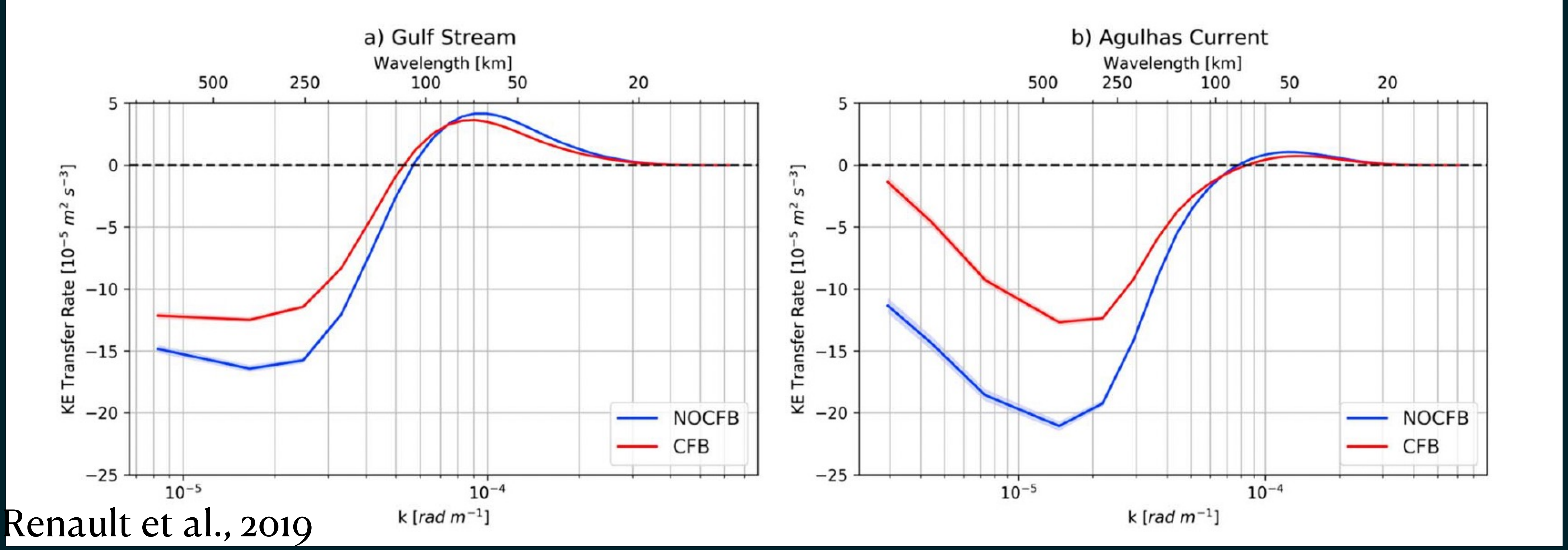

Renault et al., 2019

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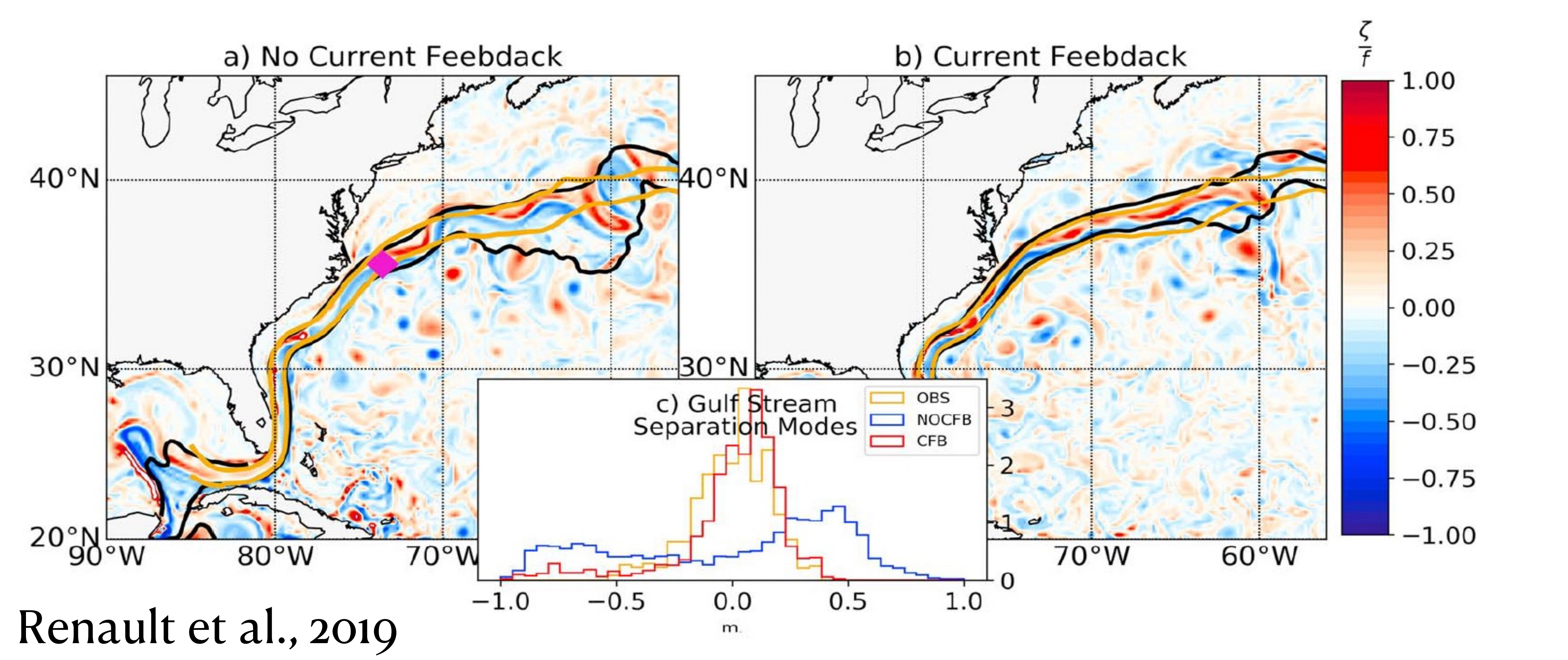
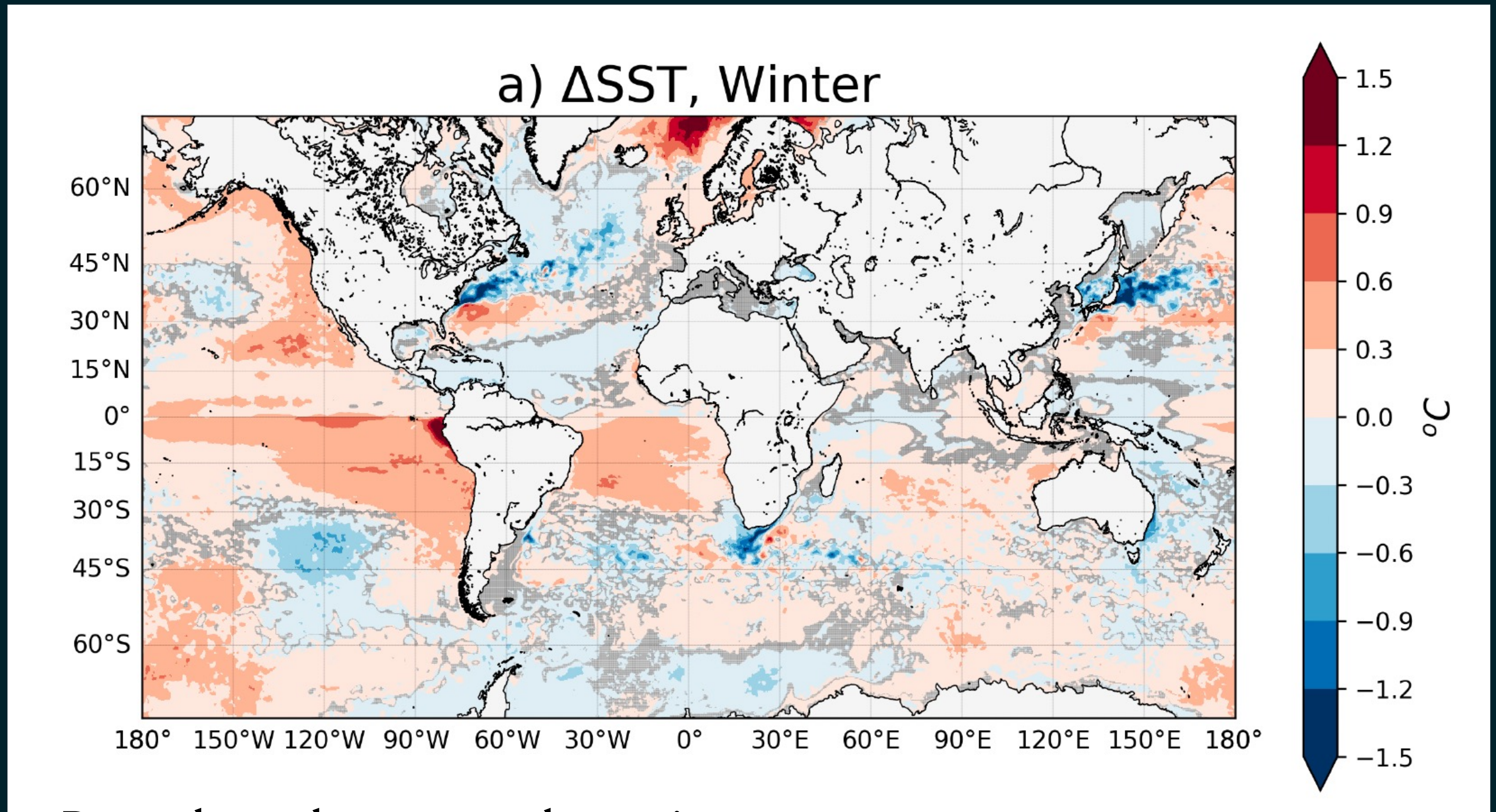


Renault et al., 2019

Difference of SST indirectly caused by Current Feedback



Renault et al., 2023, under review

See al Seo 2017, Renault et al., 2017, Seo et al., 2022

! Indirect Impact on atmosphere but not the focus of this talk

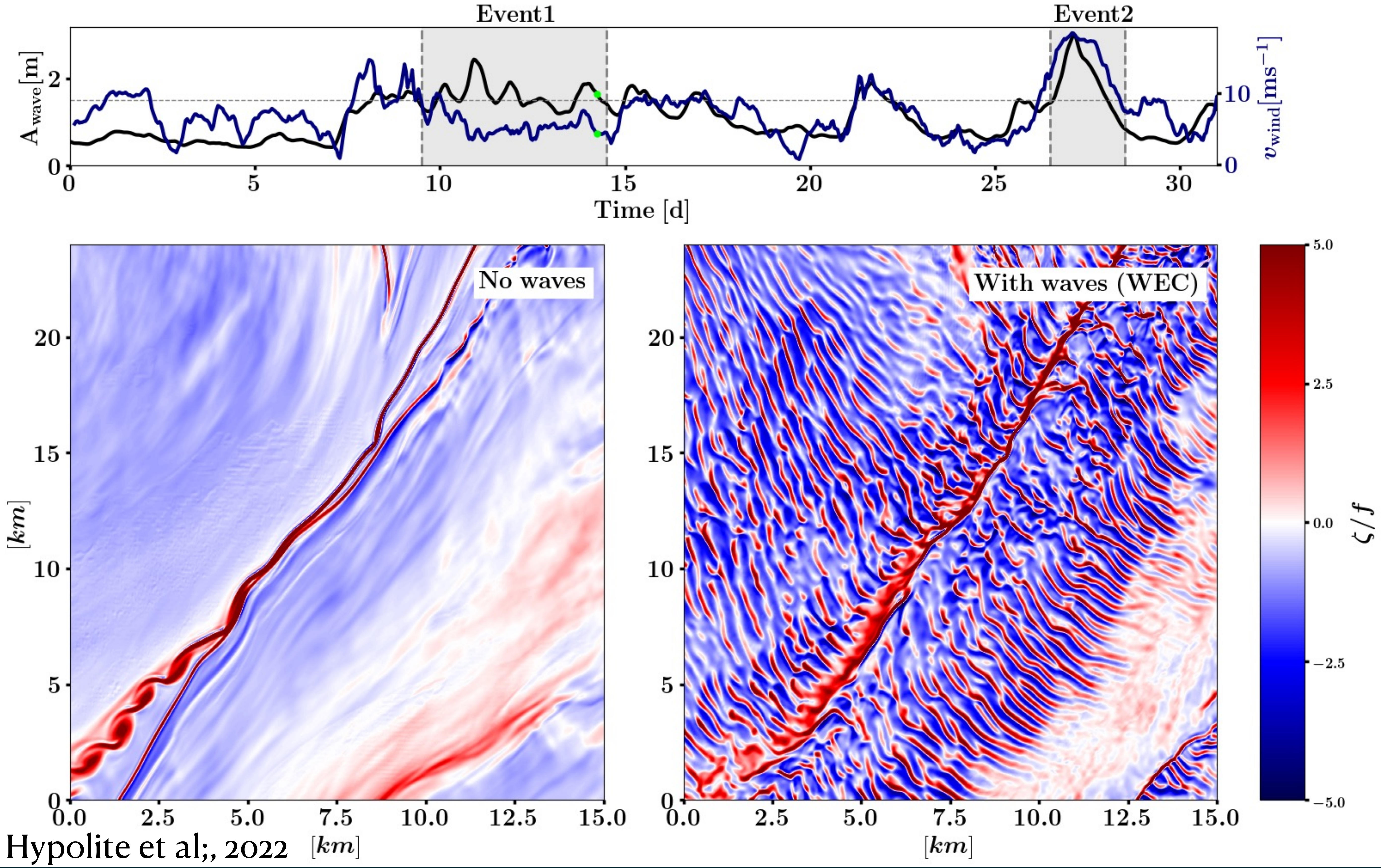
Role of the Surface Gravity Waves ?

Dx=30m, with and without wave forcing

Impact on submesoscale currents through vortex force

Impact on the atmosphere and retroaction on the Ocean ?

Impact at Mesoscale ?



Hypolite et al;, 2022

What are we Missing, What do We Need ?

- <u>Surface current, temperature, wind at the same time and same scales</u>

✓ Heat fluxes approximation without the knowledge of total surface current
✓ Windwork at submesoscale, tidal scale, mesoscale, etc
✓ Disentangle TFB and CFB effect
✓ EKE damping and subsequent reduction of cascade of energy
✓ Not only geostrophic current but also total and over the Equatorial region
Eddy Killing, Cascade of Energy, etc

- <u>Modeling :</u>

✓ Need to revisit bulk flux formula, validity at fine-scale/HF, waves?
✓ Coupled models often have an inconsistency between the atmosphere and wave models bulk formulas
✓ Submesoscale and Wave coupling need more studies
✓ Climate Impact

Need Surface Currents, and Surface Stress

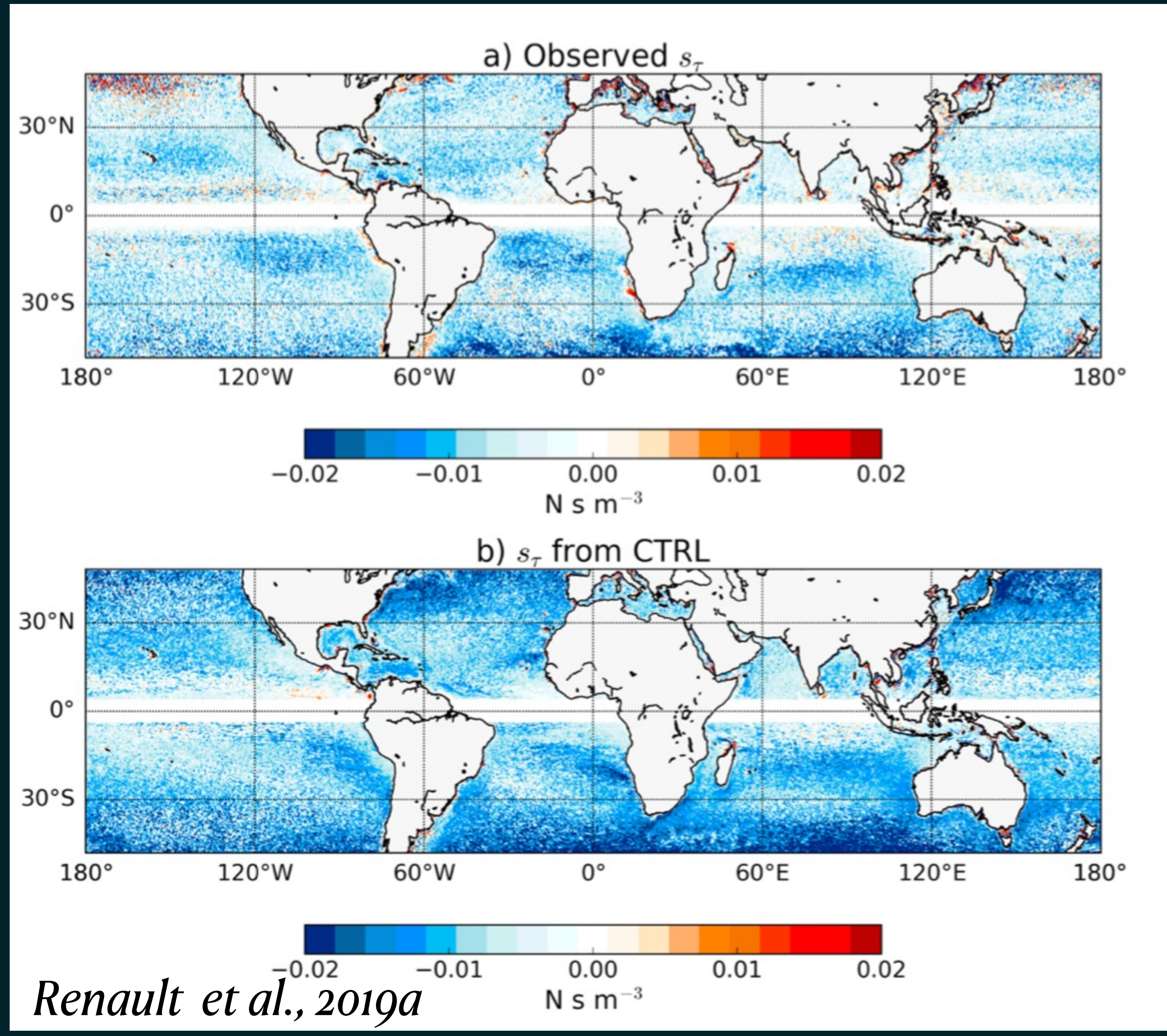
Large Uncertainties in the surface stress response because of smoothness and non-coherent observations (AVISO and QuikSCAT).

Surface Current Vorticity and Surface Stress Curl

Observations

Large Difference !

Models



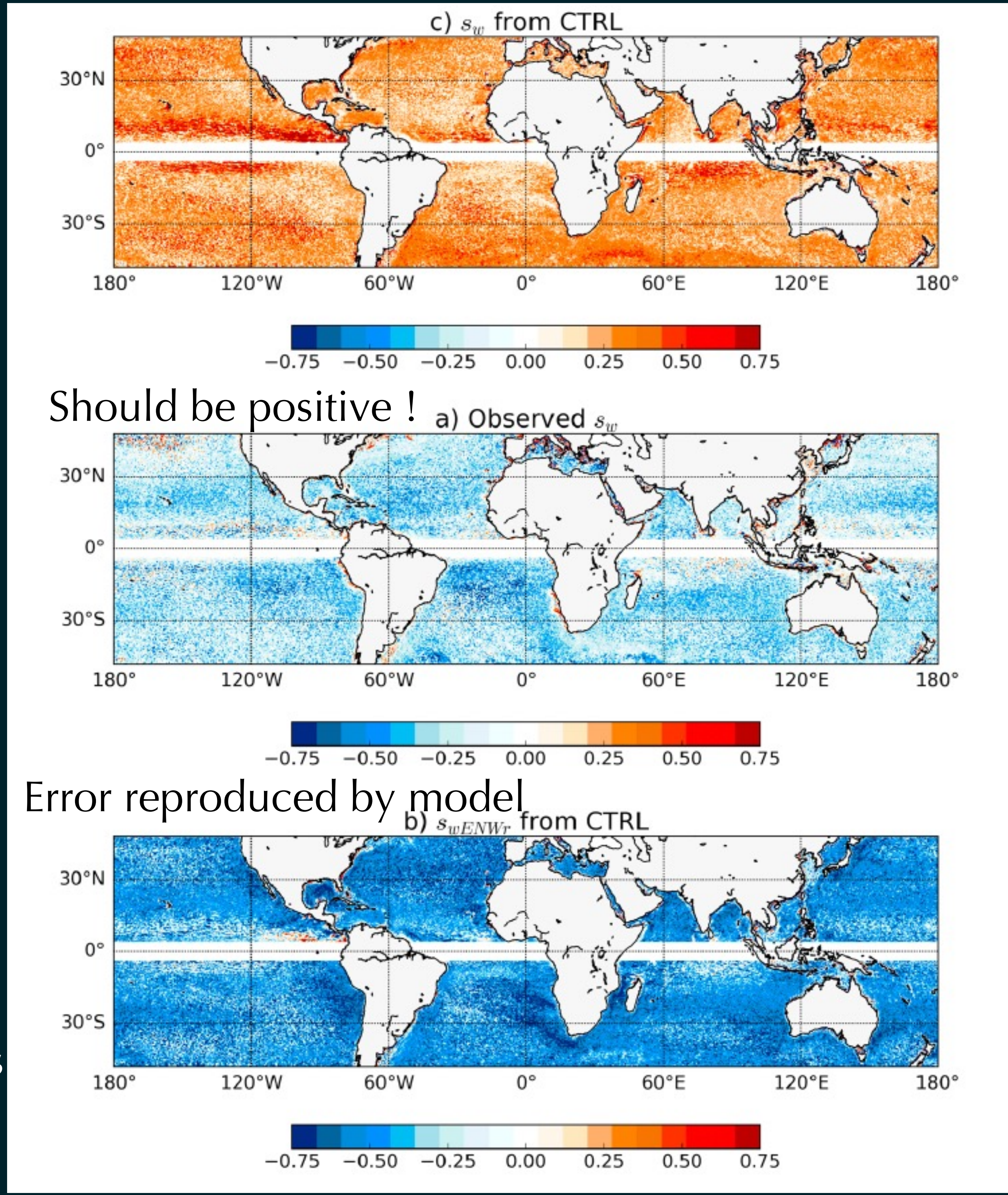
Wind Response is unknown from the obs., we need to know the surface current coherently with the stress

Surface Current Vorticity and 10-m Wind Curl

Models

Observations

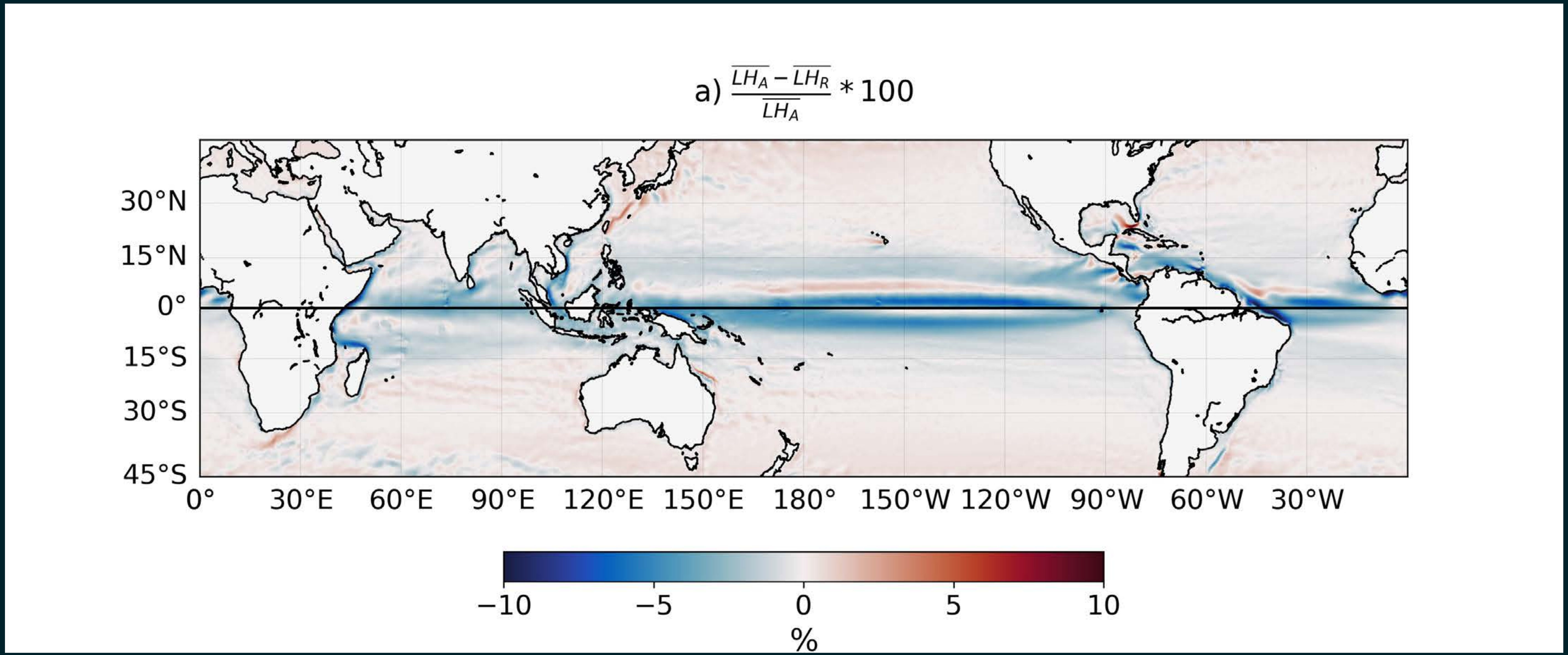
Fake Observations



Importance of having a good enough estimate:

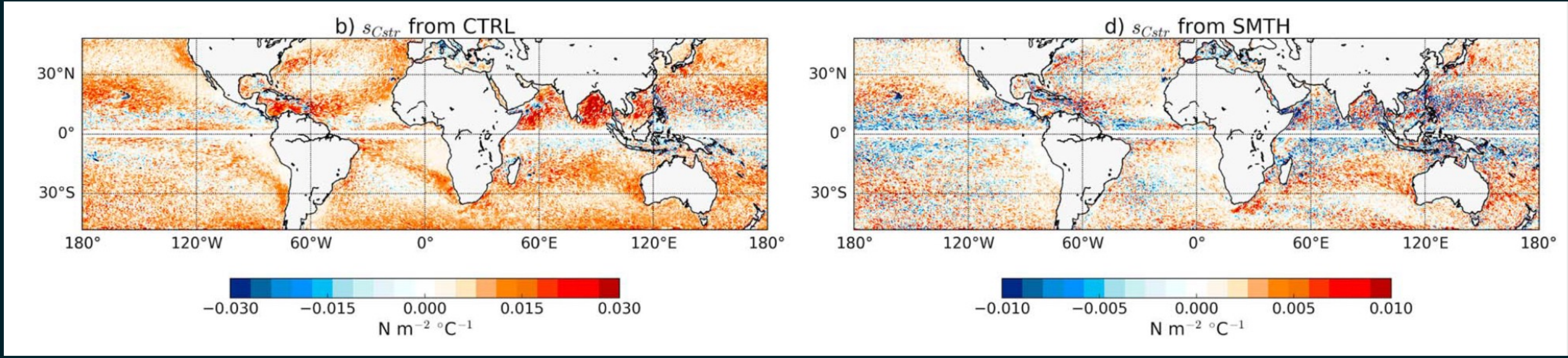
- Drive Windwork
- Force an Ocean Model (e.g., OMIP)
- Local to Large-Scale Impact
- No information over Equator

Need SST, Surface Currents, and Surface Stress

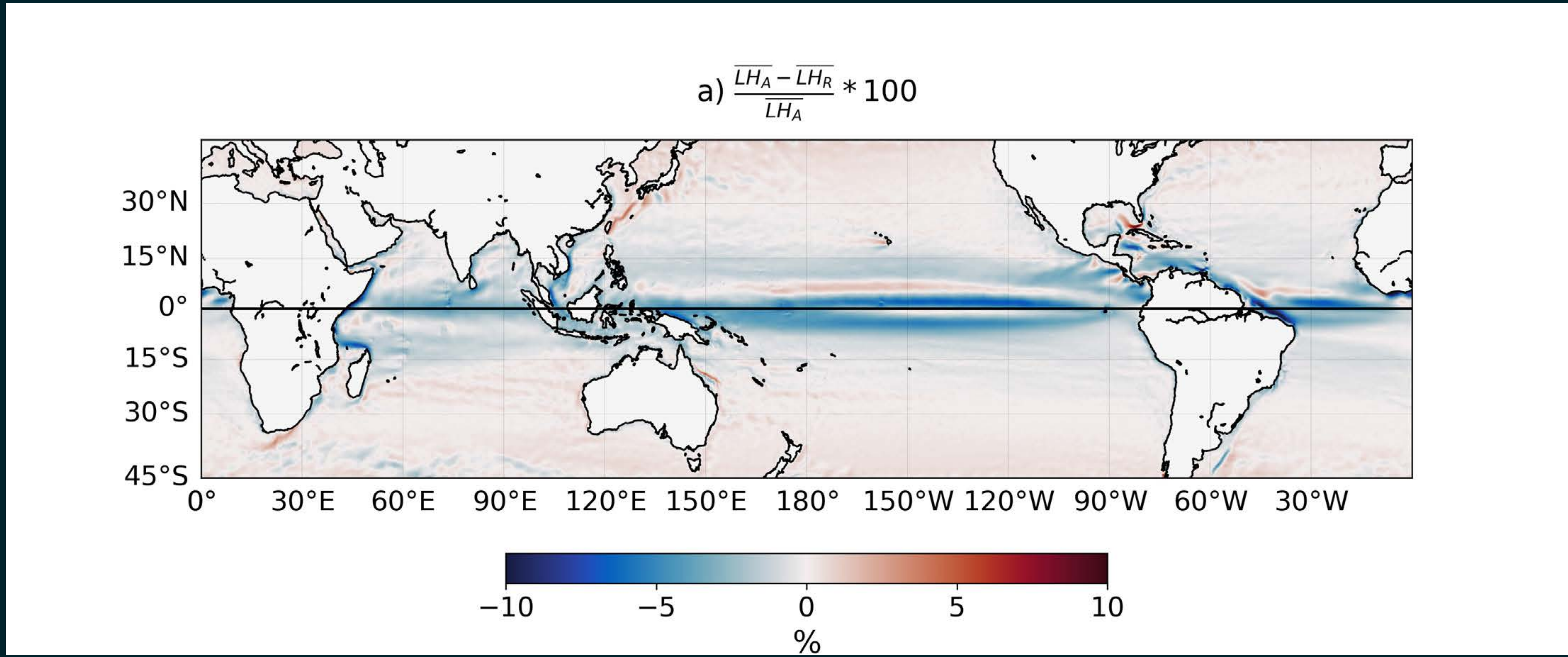


Error of 10-15% because we don't know the surface current

Coupling Coefficient TFB overestimated , see also Luna's poster



Thank you !



a) $\frac{\overline{LH_A} - \overline{LH_R}}{\overline{LH_A}} * 100$
30°N
15°N
0°
15°S
30°S
45°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
−10
−5
0
5
10
%