Signature of mesoscale eddies on air-sea heat fluxes

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Introduction: air-sea interaction

SU

What does interaction mean in the physical world?

In the physical world, interaction refers to the way that different objects or systems affect each other through various forces and fields. These interactions can be described in terms of the exchange of energy, momentum, and other physical quantities.

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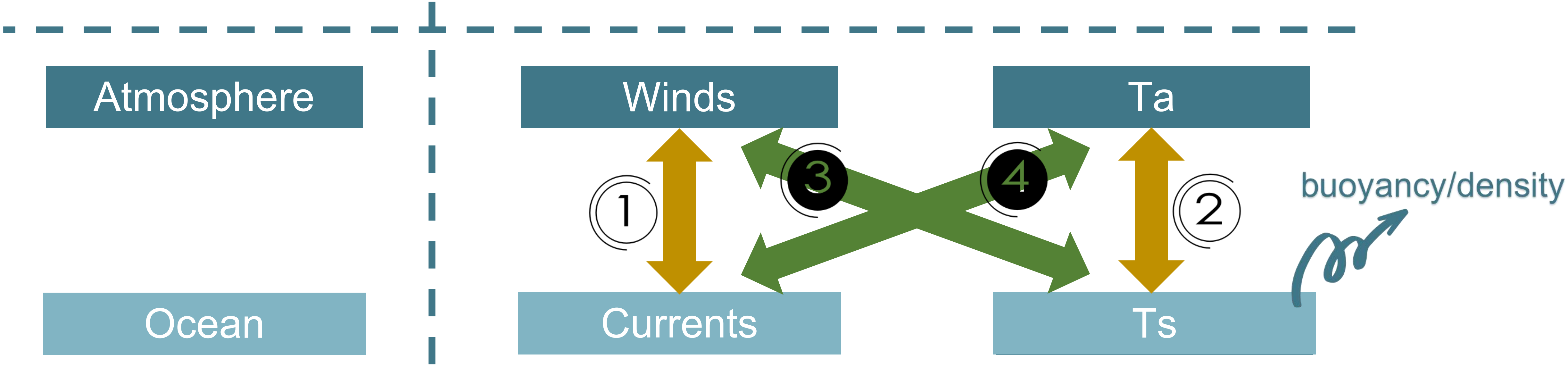
Introduction: air-sea interaction



(1) Winds and currents: current feedback to wind stress (e.g., eddy killing), nonlinear Ekman dynamics etc ...

(2) Ta and Ts: heat exchange (water mass formation or destruction etc) ...

(3) Winds and Ts: thermal feedback to wind ...

(4) Ta and currents: ???

Heat flux

Momentum flux

Part 1: wind-current interaction

a. Current feedback

How ocean eddies lose/gain energy to/from the atmosphere.

$$\boldsymbol{\tau} = \rho c_d \boldsymbol{u_a}|\boldsymbol{u_a}|$$

$$\boldsymbol{\tau} = \rho c_d (\boldsymbol{u_a} - \boldsymbol{u_o})|\boldsymbol{u_a} - \boldsymbol{u_o}|$$

b. Nonlinear Ekman theory

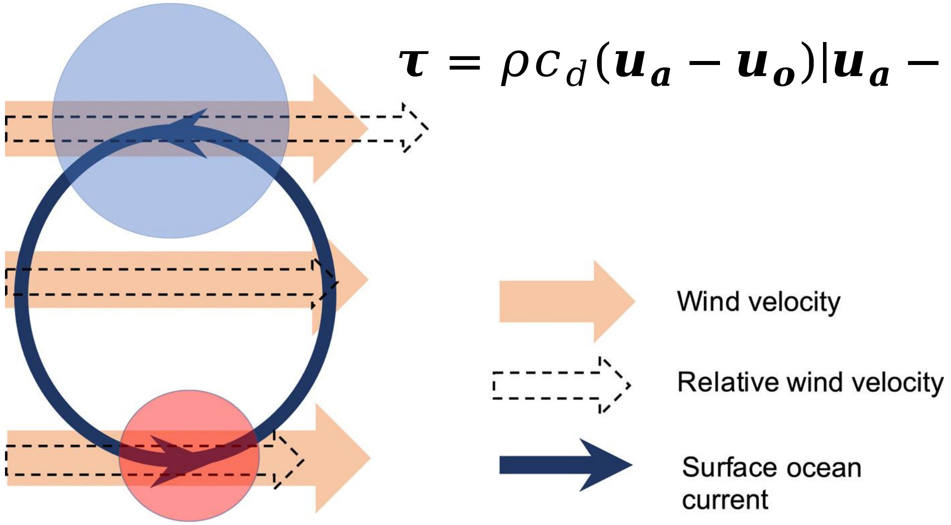
$$\boldsymbol{U_{Ek}} \cdot \nabla \boldsymbol{u} + \boldsymbol{u} \cdot \nabla \boldsymbol{U_{Ek}} + \boldsymbol{U_{Ek}} \cdot \nabla \boldsymbol{U_{Ek}} + f\hat{\boldsymbol{z}} \times \boldsymbol{U_{Ek}} = \boldsymbol{\tau}/\rho$$

ocean current   Ekman flow

Or simply: $w_{Ek} = \frac{1}{\rho} \times \frac{\tau}{f+\zeta}$ **Basically, what matters is ζ.**

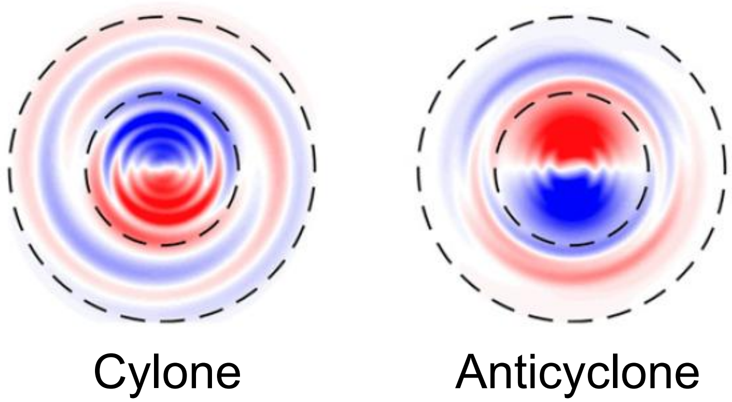
Regime of eddy killing

$$\boldsymbol{\tau} = \rho c_d (\boldsymbol{u_a} - \boldsymbol{u_o})|\boldsymbol{u_a} - \boldsymbol{u_o}|$$



Rai et al., 2021

Vortex-induced Ekman pumping



Chen et al., 2021

Part 2: air-sea temperature interaction

Bulk formulae

$$Q_s = \rho c_p c_s w(T_s - T_a)$$
$$Q_l = \rho L_e c_l w(q_s - q_a)$$

- proportional to wind speed, air-sea temperature and humidity contrast

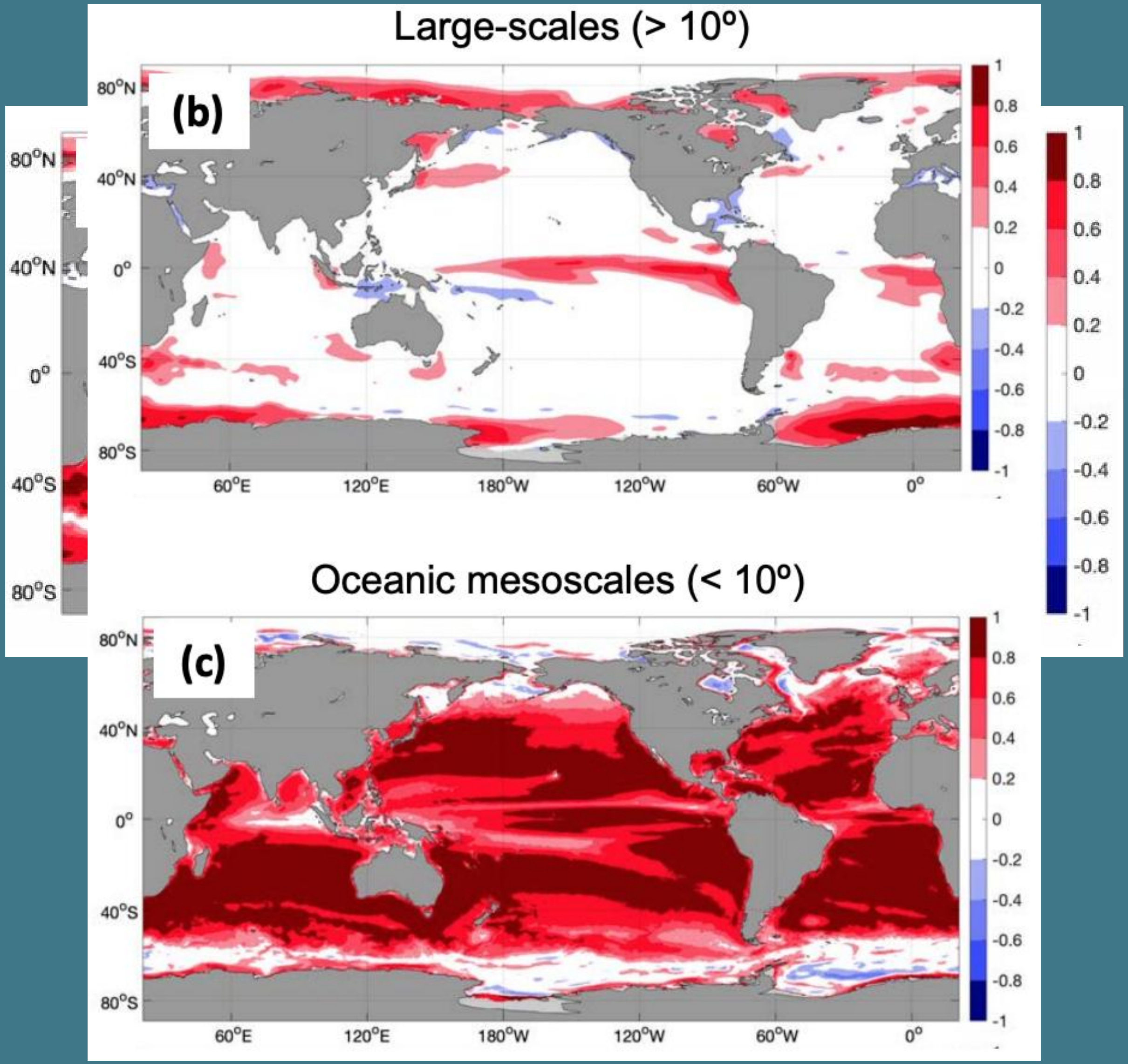
Large scale

The atmosphere drives the SST and turbulent heat flux (THF) variabilities.

Meso scale

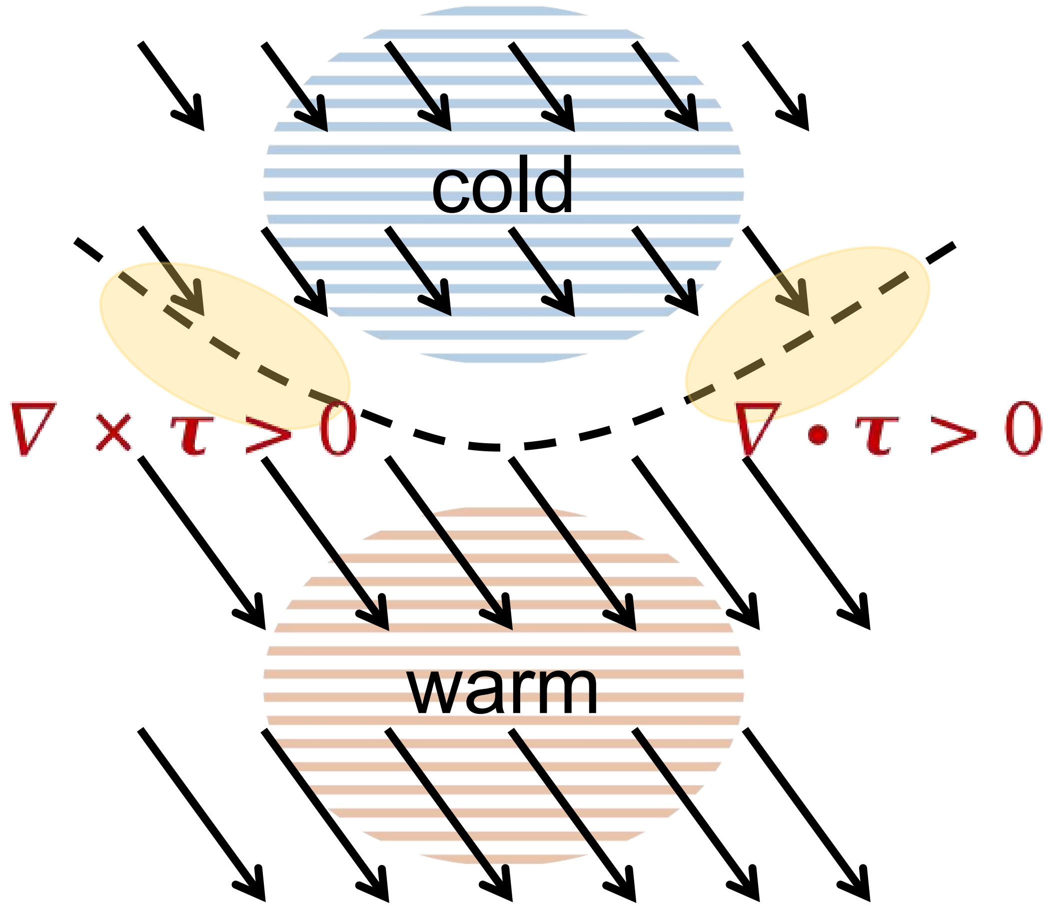
Ocean processes dominate the variability.

SST and THF correlation



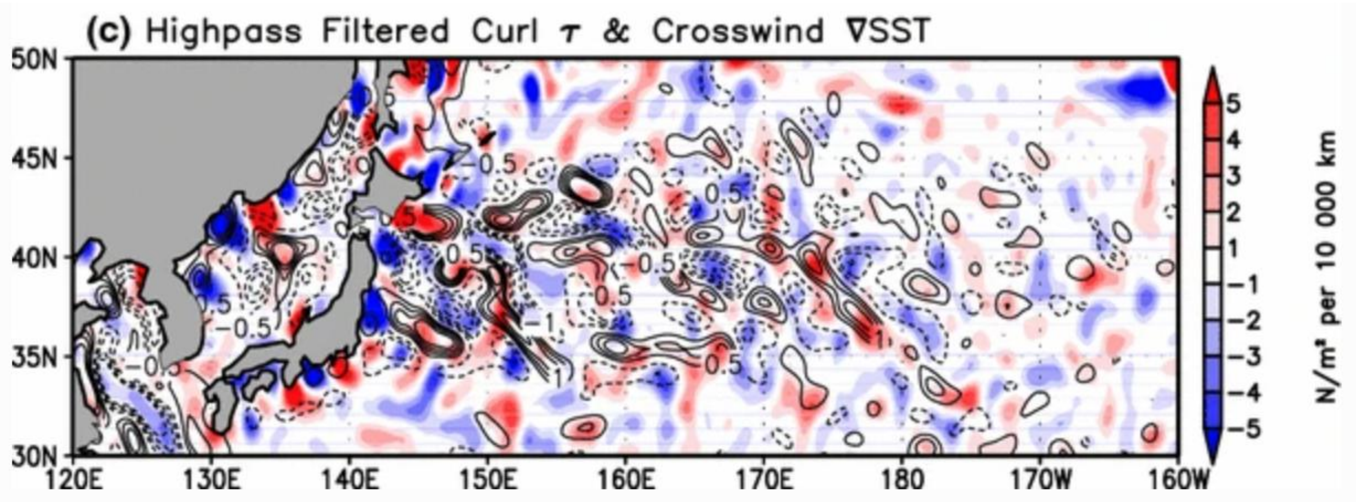
Part 3: SST-wind interaction

Oceanic thermal feedback to wind stress

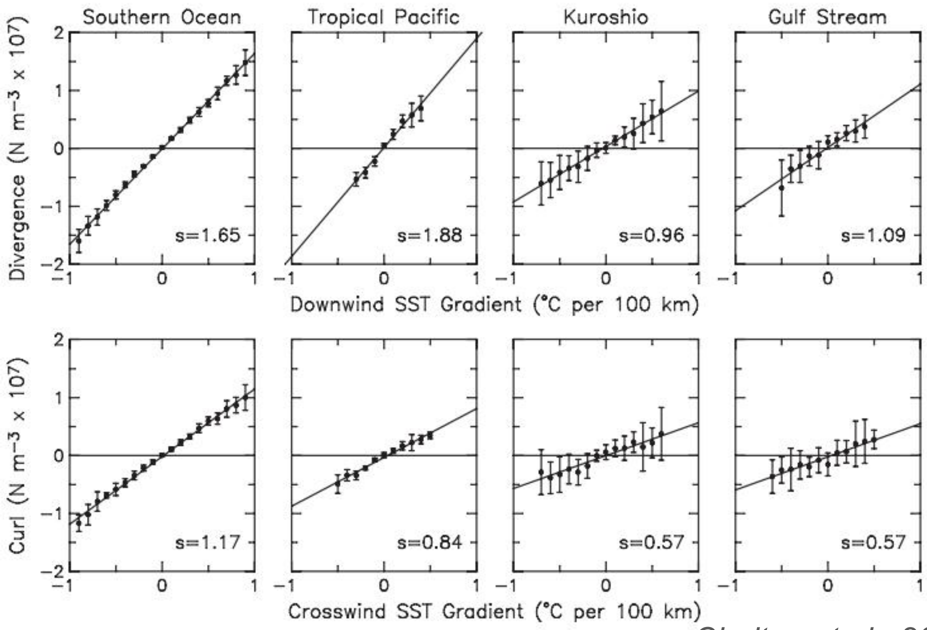


Crosswind SST gradient: stress vorticity
Downwind SST gradient: stress divergence

revised from Chelton et al., 2010

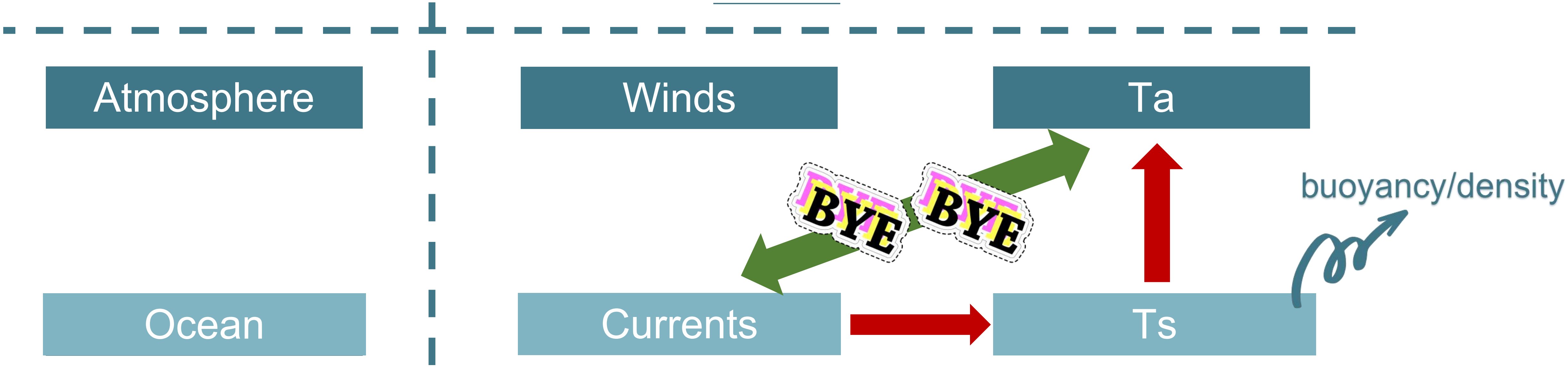


Wei et al., 2017

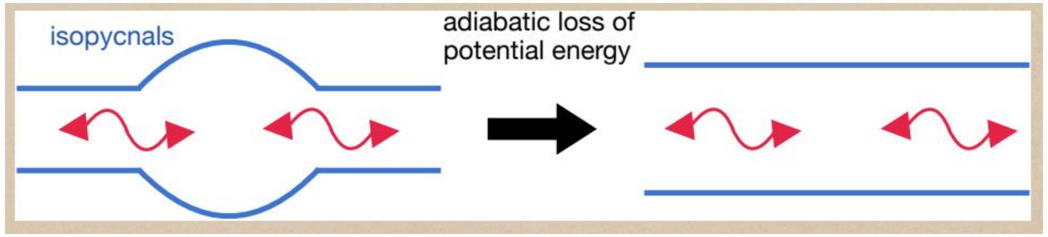


Chelton et al., 2004

Part 4: how do currents impact Ta?



1) Takaya's talk on eddy tensor

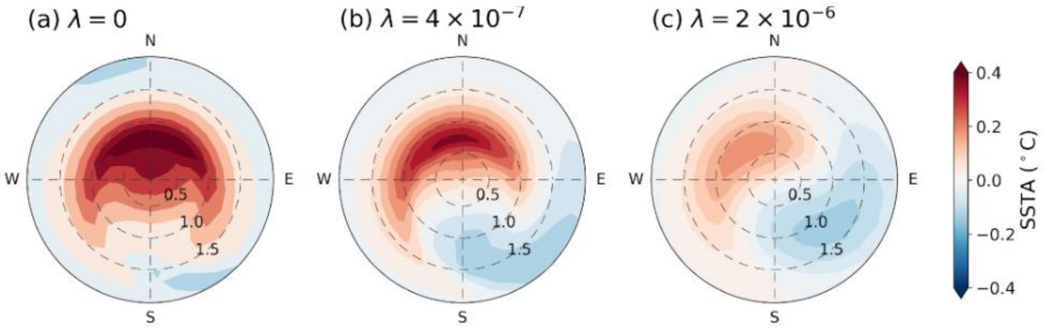


$$\overline{u'b'} = -\kappa_{GM}\nabla\bar{b}$$

$$\overline{u'C'} = -\kappa_{Redi}\nabla\bar{C}$$

2) Roger's talk on SSH-SST center incoherence

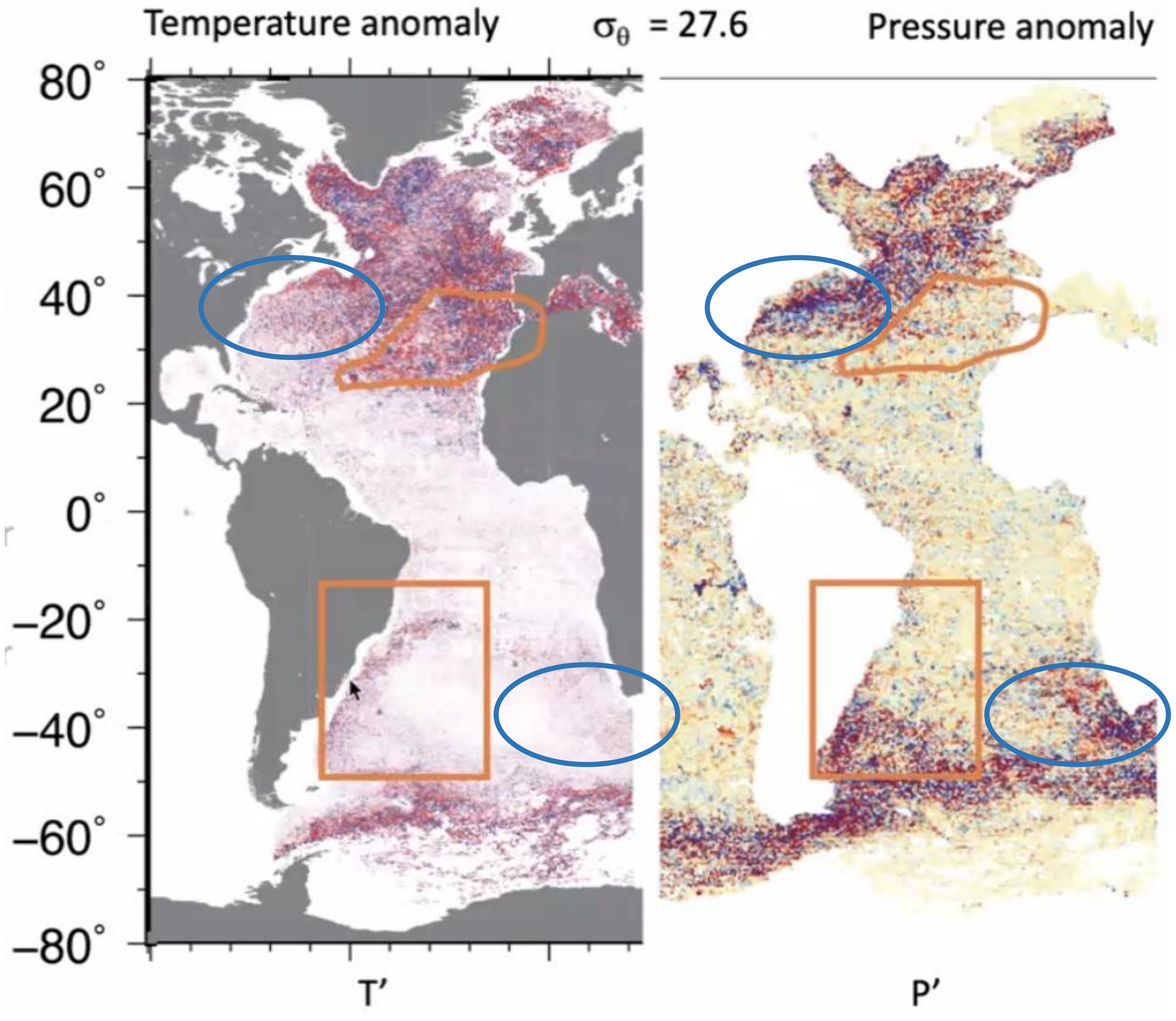
$$\frac{\partial T'}{\partial t} = -\tilde{u}'\cdot\nabla T' - v'\frac{dT_b}{dy} - \lambda T'$$



a. Flux only at the air-sea interface.
b. Eddy velocity is prescribed.

Part 4: how do currents impact Ta?

3) Lynne's talk on T' and P' incoherence



Along same isopycnal:

- ❖ Identical P', various T'
  water mass formation (mixing)
- ❖ Identical T', various P'
  water mass subduction

Another way of how ocean currents might affect air-sea heat flux

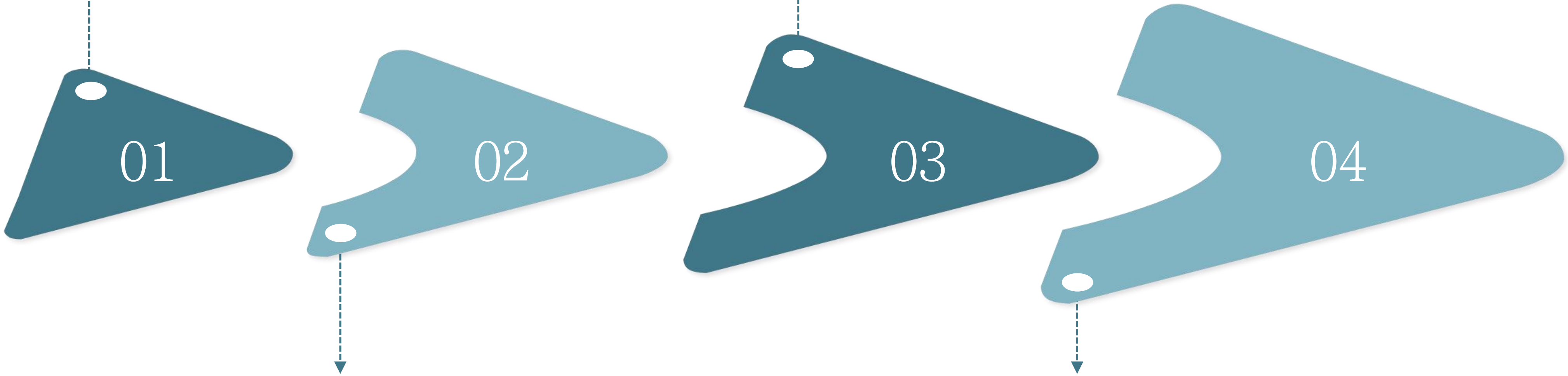
NIO study: scientific question and methods

OAFlux2 (Yu, 2023)

The second generation of OAFlux sponsored by NASA’s MEaSUREs program. (Yu, 2023)

META3.2 eddy atlas

Derived from the altimetric absolute dynamic topography (ADT) (Pegliasco et al., 2022)



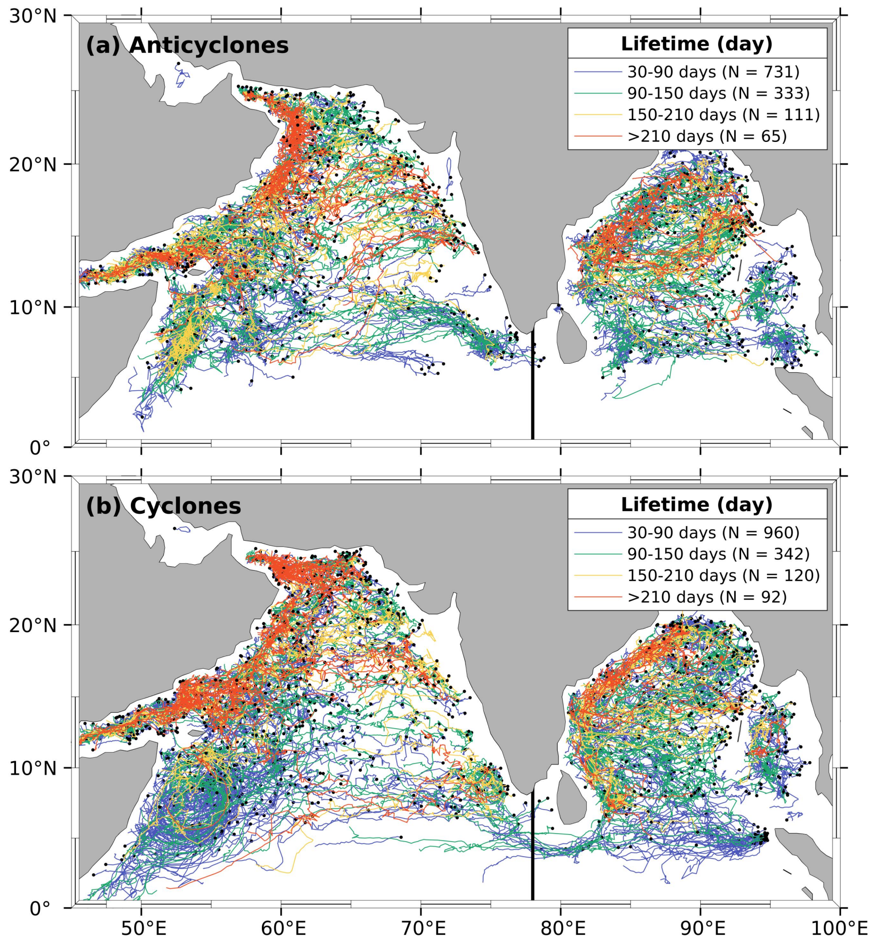
Filtering processes

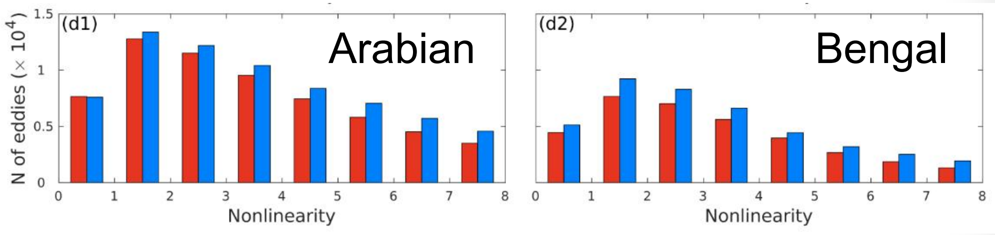
1) Time: bandpass Butterworth window to preserve 7-90 days;
2) Space: moving average Hann window to remove scales larger than 600 km.

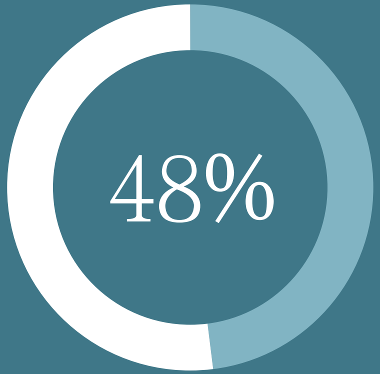
Co-location

1) Extract air-sea variables within eddy contours;
2) We focus on the North Indian Ocean at the moment.

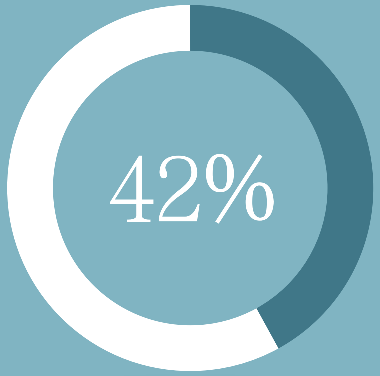
SSH-SST coherent and incoherent eddies







coherent eddies

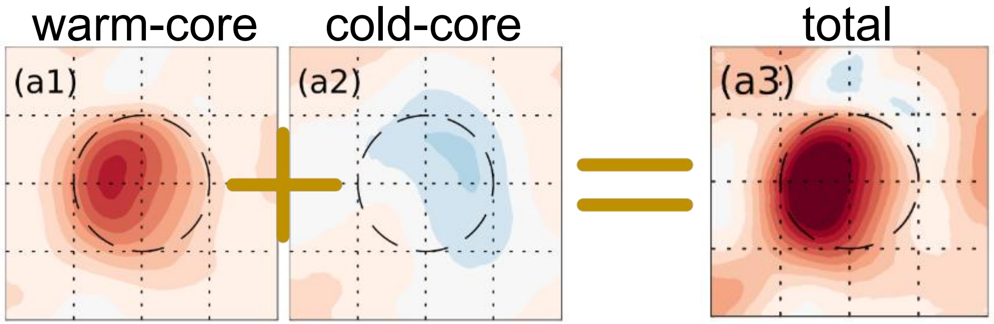


incoherent edddies

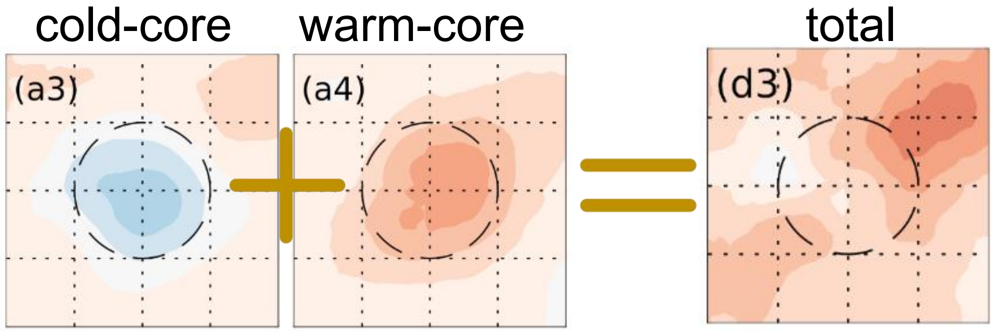
Coherent: AEs ---> SSHA+ ---> SSTA+
CEs ---> SSHA- ---> SSTA-

Incoherent: AEs ---> SSHA+ ---> SSTA-
CEs ---> SSHA- ---> SSTA+

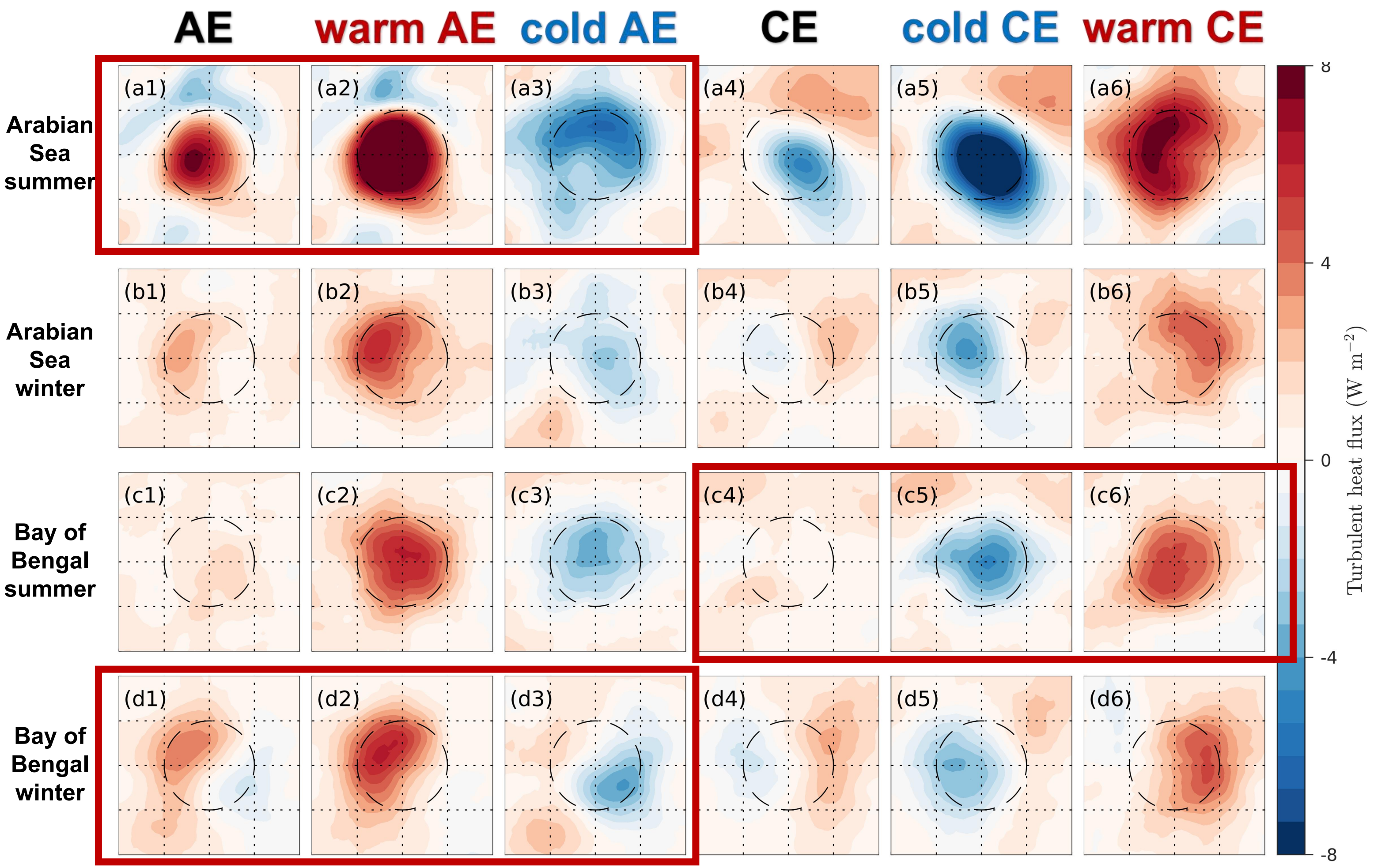
Example 1: Arabian Sea AEs



Example 2: Bay of Bengal CEs



Seasonal variability of eddy-induced THF



Monopole (shifted)

Coherent eddies dominate the total pattern. (**eddy-trapping effect**)

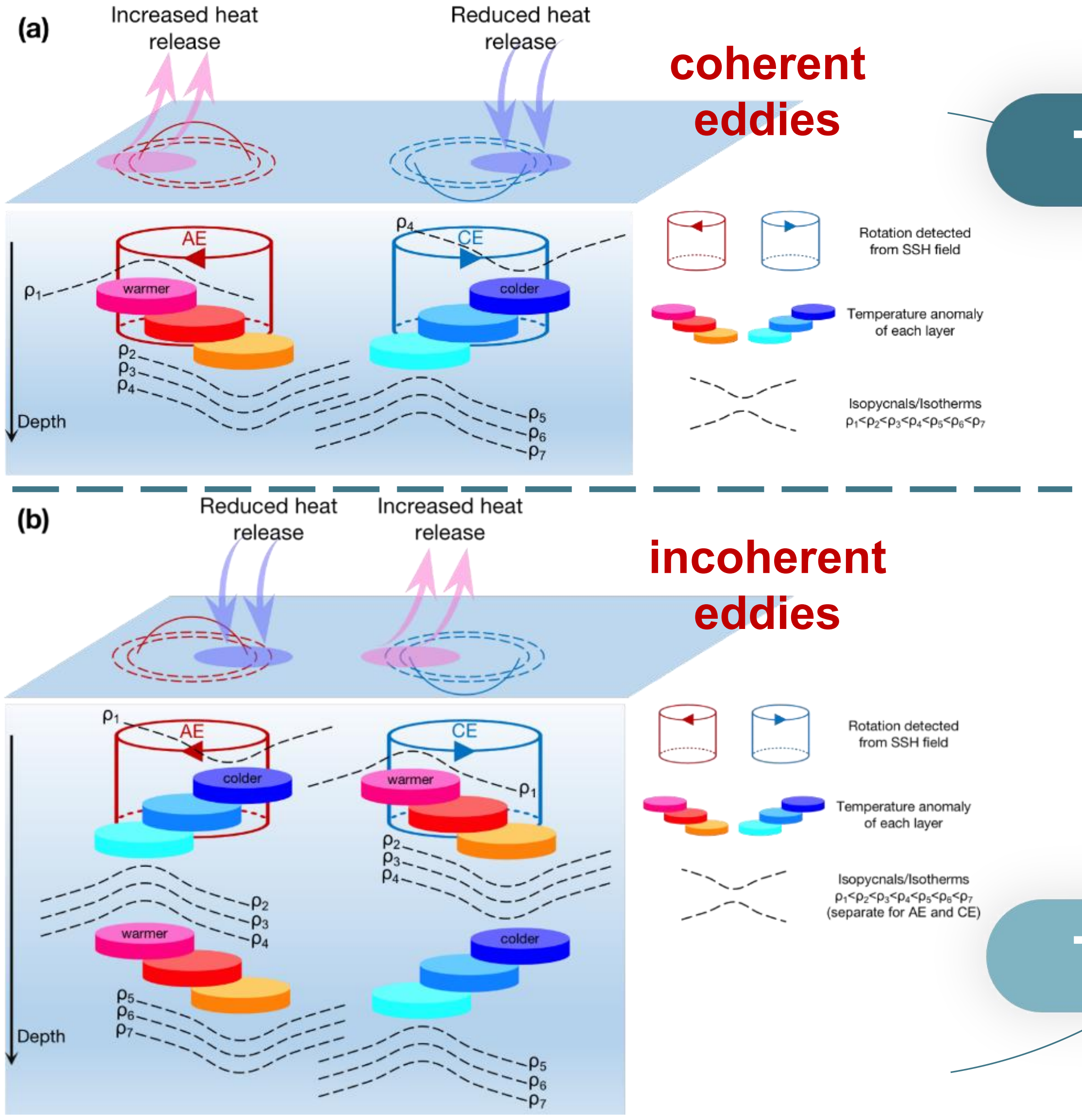
Cancellation

Coherent and incoherent eddies have inseparable magnitudes.

Dipole

Incoherent eddies shift in an opposite direction from coherent eddies. (**eddy-stirring effect**)

Paradigms of eddy-flux interaction



THM 1

Eddy-induced SST-THF coefficients could go up to 30 W/m2/K (in contrast with the large-scale 1 W/m2/k).

THM 2

The combination of SSH-SST coherent and incoherent eddies leads to monopoles, dipoles and cancellation.

THM 3

Mechanisms of incoherent eddies: heat exchange at the air-sea interface or at the ML base, or subduction along trajectories (e.g., creation of mode waters).

Thanks!