Submesoscale sea surface temperature variability as a sink of eddy energy in a coupled model

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Ocean Lunch Seminar Series

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Air-sea interaction across scales

Two fundamental regimes of ocean atmosphere coupling are well established (Seo et al. 2023):

1. Ocean's **large-scale response** to atmospheric variability;

Source: New Scientist

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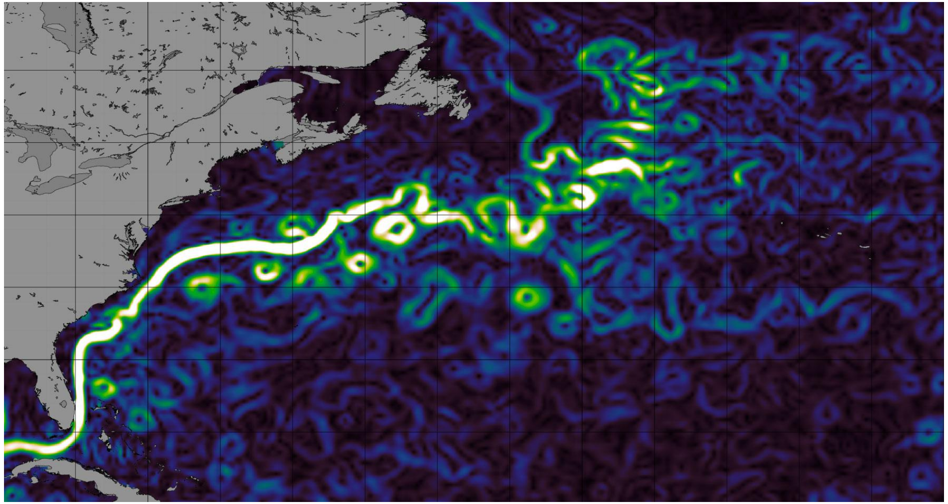
2. Atmospheric response driven by ocean **mesoscale eddy-induced** spatial SST and current variability;



Source: CMEMS/CLS

Submesoscale's role in air-sea interaction mechanisms

Two fundamental regimes of ocean atmosphere coupling are well established (Seo et al. 2023):

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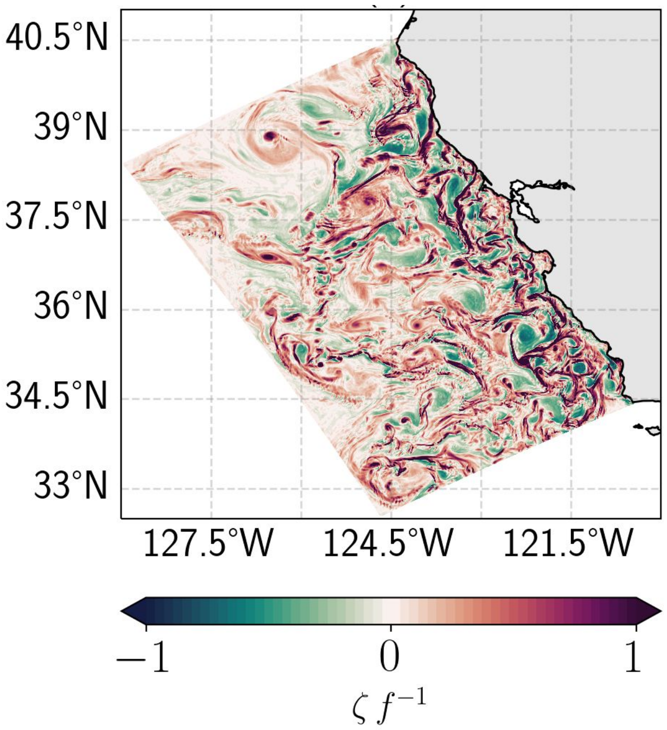
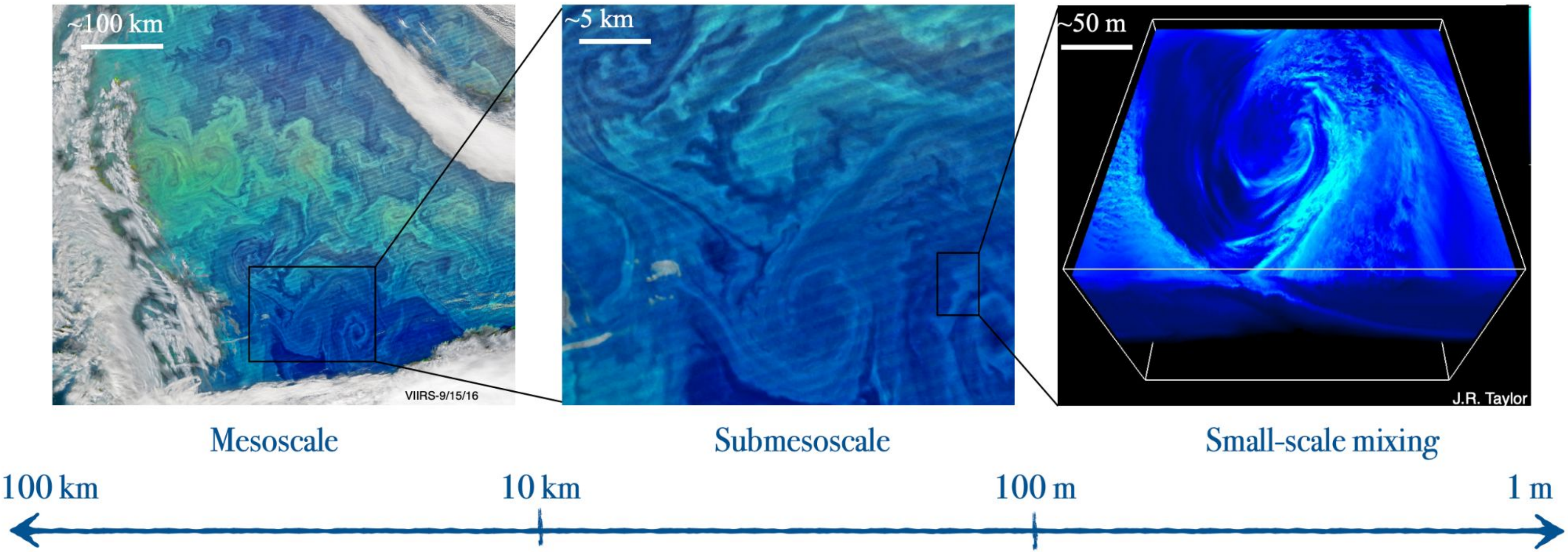


?. Air-sea interaction at submesoscale is less explored, but studies suggest an important role in the exchange of heat and momentum.

What is submesoscale ?



$$Ro \sim \frac{U}{fL};\, Ri \sim \frac{N^2}{(\frac{\partial u}{\partial z})^2}$$

* U: horizontal velocity scale; f: Coriolis frequency; L: horizontal length scale; N is the Brunt-Vaisala frequency

(Courtesy of Dr. Wenegrat)

Submesoscale influences on momentum exchange

- Renault et al. (2018) describe the impact of submesoscale dynamics on the momentum exchange with the atmosphere using a submesoscale-permitting model.

- The so-called “current feedback” mechanism arises from the referenced wind stress formulation:

$$\tau = \rho_a C_D |\mathbf{U}_a| \mathbf{U}_a$$

$$\downarrow$$

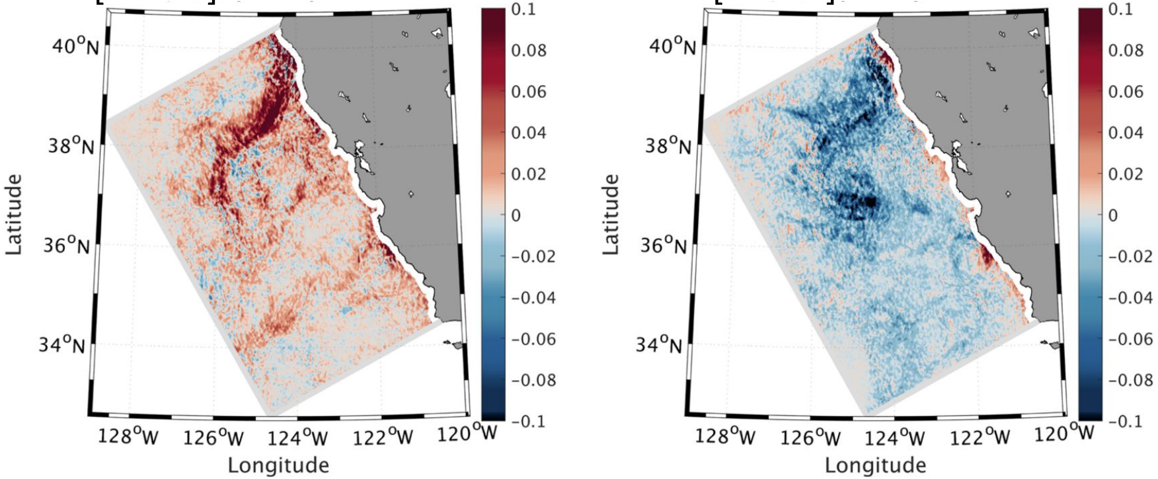
$$\tau = \rho_a C_D |\mathbf{U}_a - \mathbf{u}_o| (\mathbf{U}_a - \mathbf{u}_o)$$

Submesoscale influences on momentum exchange

Wind work or surface flux of eddy kinetic energy (EKE) is:

$$G(EKE) = \frac{\tau . \mathbf{u}_o}{\rho_o}$$

Wind work (no CFB) [cm^3s^{-3}] Wind work (CFB) [cm^3s^{-3}]



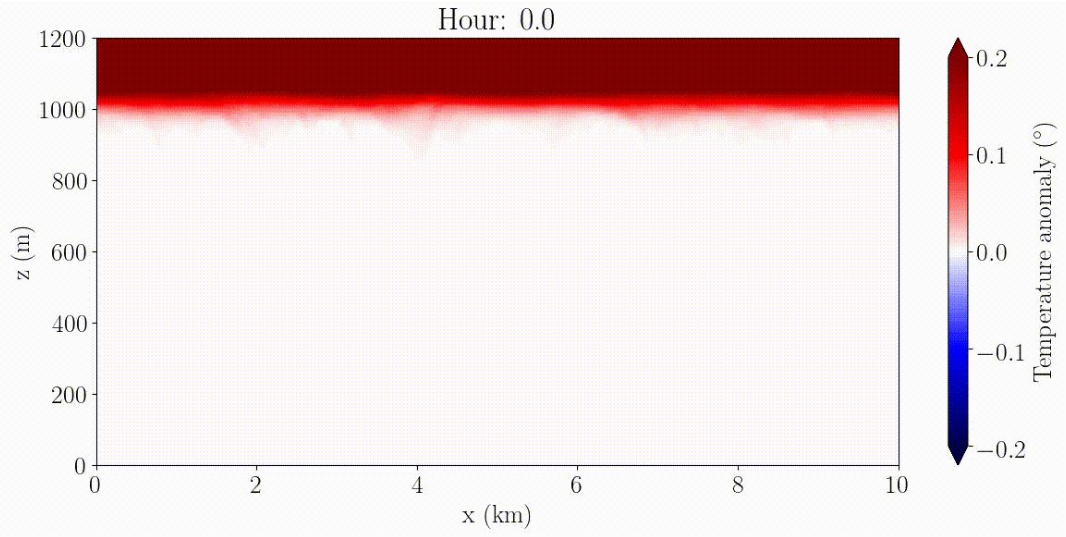
Adapted from Renault et al. (2018)

- Current feedback dampens submesoscale current variability by ~17%.

Thermal coupling mechanisms at submesoscale

- Using LES idealized simulations Wenegrat and Arthur (2018) show the impact of submesoscale fronts in PBL modulations;

- Winds blowing along sharp SST fronts are rapidly modified by changes in the vertical turbulent stress divergence (MABL modulations).



From Wenegrat & Arthur (2018)
(Courtesy of Dr. Wenegrat)

Exchange of EPE as a sink of energy in the upper ocean

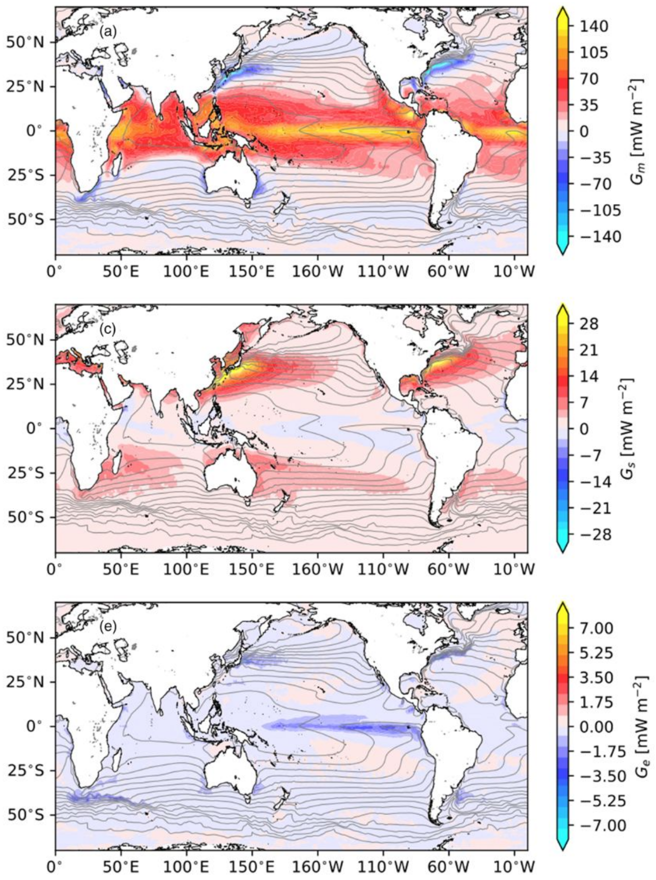
- Less is known about the influence of submesoscale SST variability on ocean energetics through its direct effect on the surface flux of eddy potential energy (EPE);

Exchange of EPE as a sink of energy in the upper ocean

- Less is known about the influence of submesoscale SST variability on ocean energetics through its direct effect on the surface flux of eddy potential energy (EPE);

- At mesoscale, EPE flux works as a sink of EPE to the atmosphere (Bishop et al., 2020);

- Simulations of submesoscale impact in the EPE flux are computationally costly and hence difficult to generate.



Adapted from Bishop et al. (2018)

EPE flux in the atmosphere-ocean system

$$G(EPE) = \frac{1}{N_r^2} \int_s \overline{b' Bo'} dS$$

where

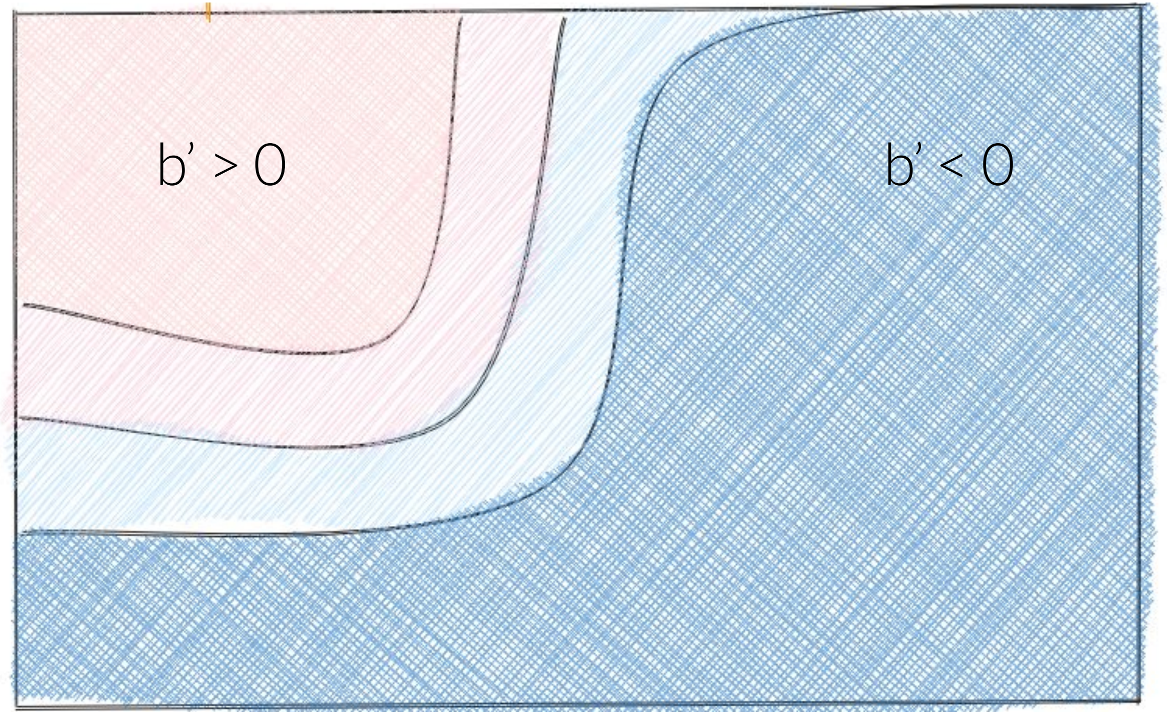
$$Bo' = \alpha g \frac{Q'_o}{\rho C_p} - \beta g (E' - P') S'$$

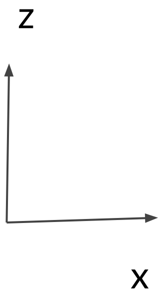
$$b' = \alpha g T' - \beta g S'$$

(Negative values of G(EPE) mean loss of EPE to the atmosphere).

Cronin & Sprintall (2001); Von Storch et al. (2012)

Exchange of EPE at air-sea interface





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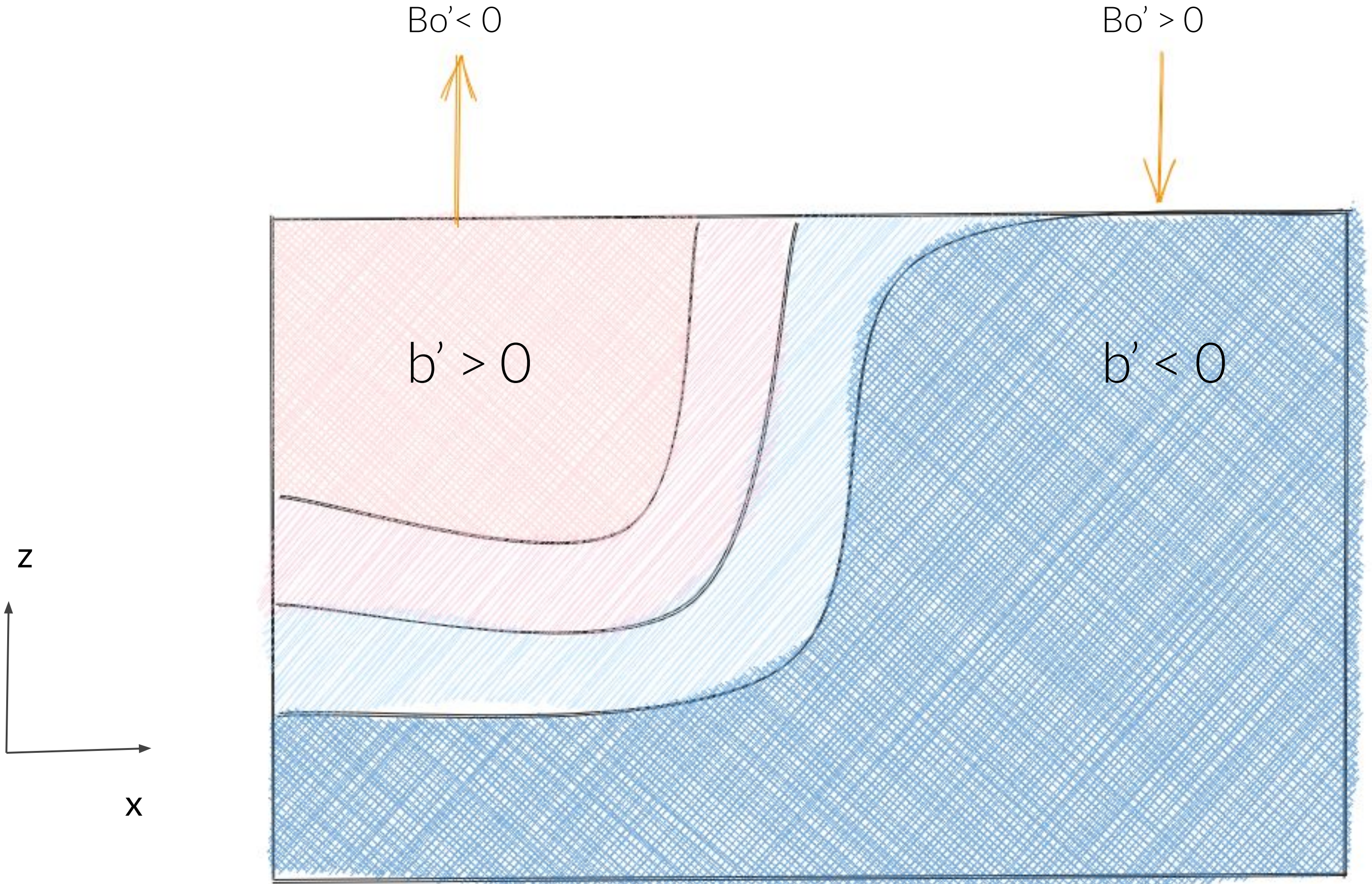

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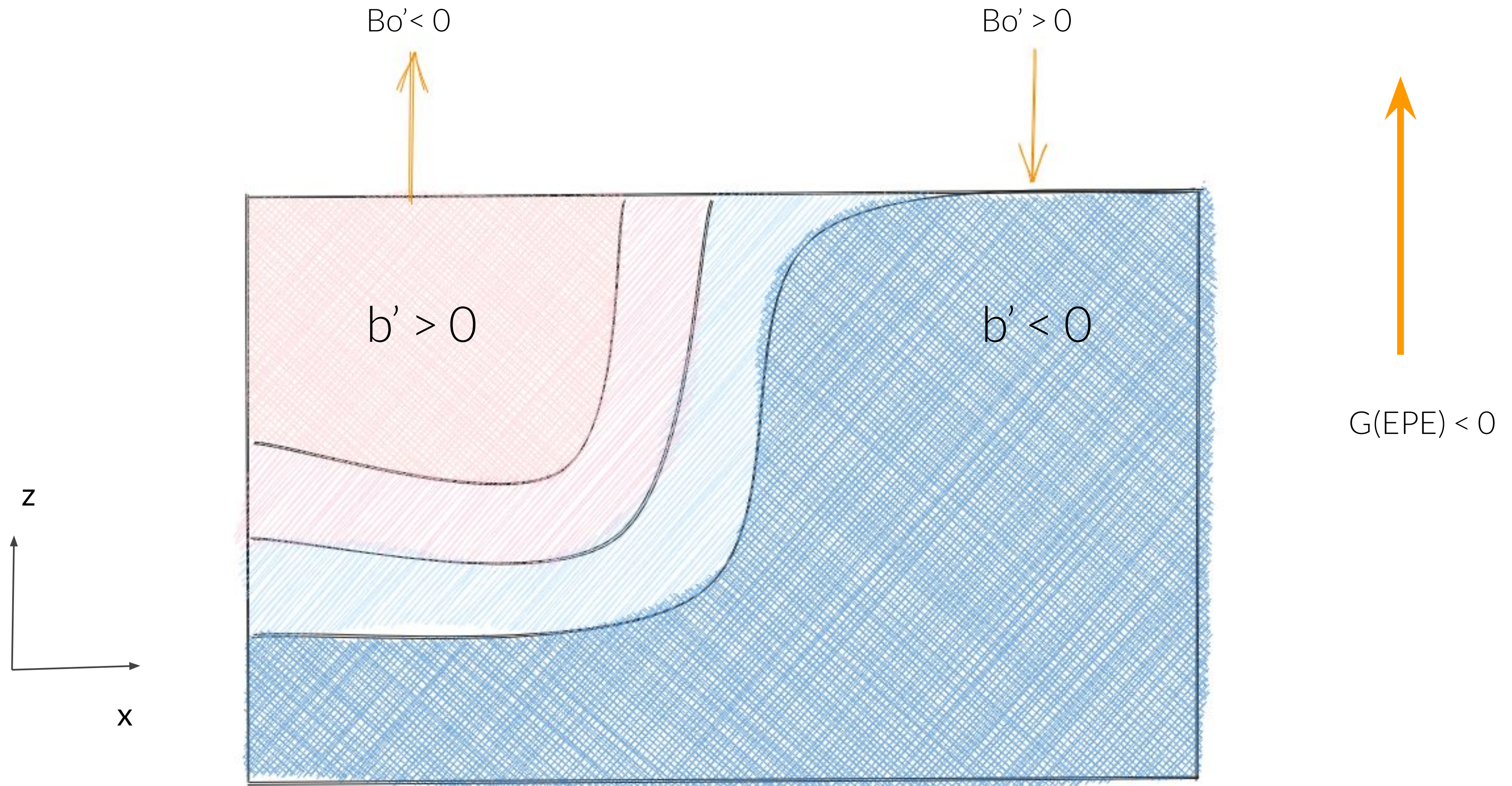

Objectives

- Understand the role of sea surface temperature (SST) variability in modifying the flux of EPE in the air-sea interface;

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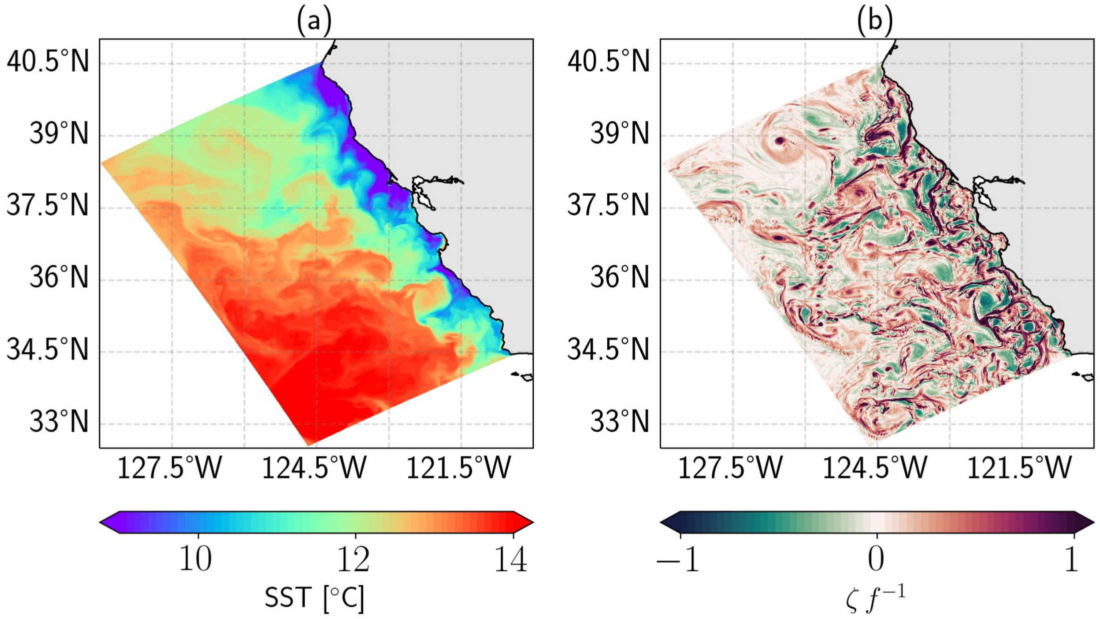
- Understand the role of sea surface temperature (SST) variability in modifying the flux of EPE in the air-sea interface;

- Assess the impact of upper-ocean energetics driven by heat and momentum exchange when SST variability at submesoscale is suppressed;

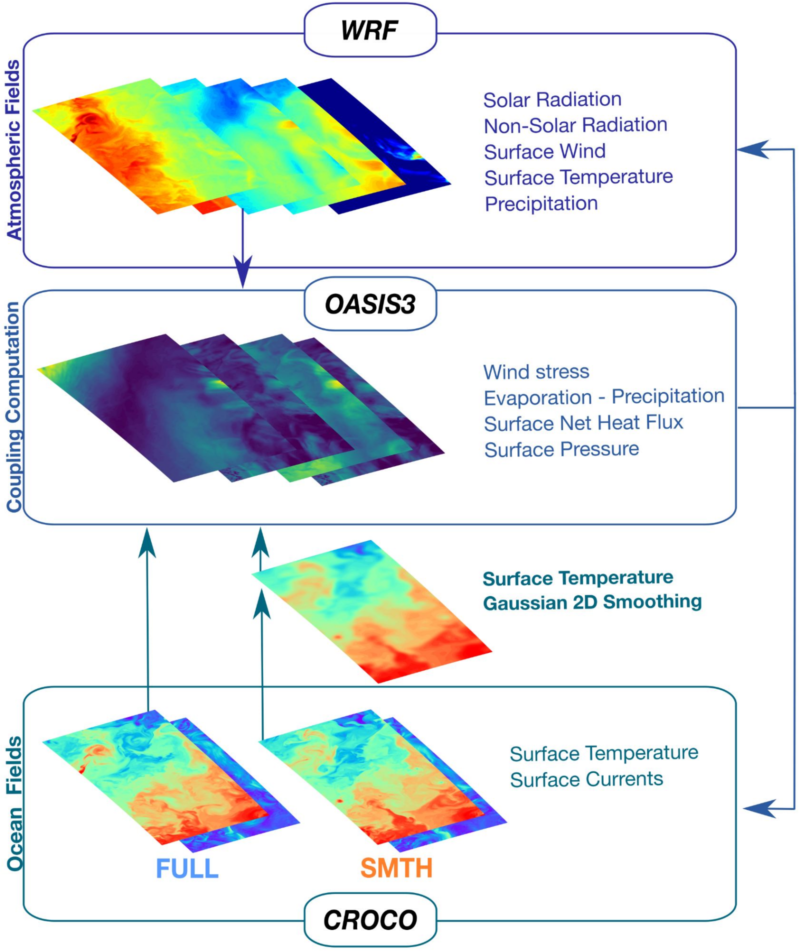
- Parameterize the EPE flux mechanism at submesoscale for ocean-only models.

Numerical simulations: Model description



- Fully-coupled regional model of the California Current System;
- **Ocean component**: Coastal and Regional Oceanic COmmunity (CROCO):
  - 500 m resolution (submesoscale-permitting);
  - 6-hour output.
- **Atmospheric component**: Weather Research and Forecast Model (WRF):
  - 2 km resolution;
  - hourly output.

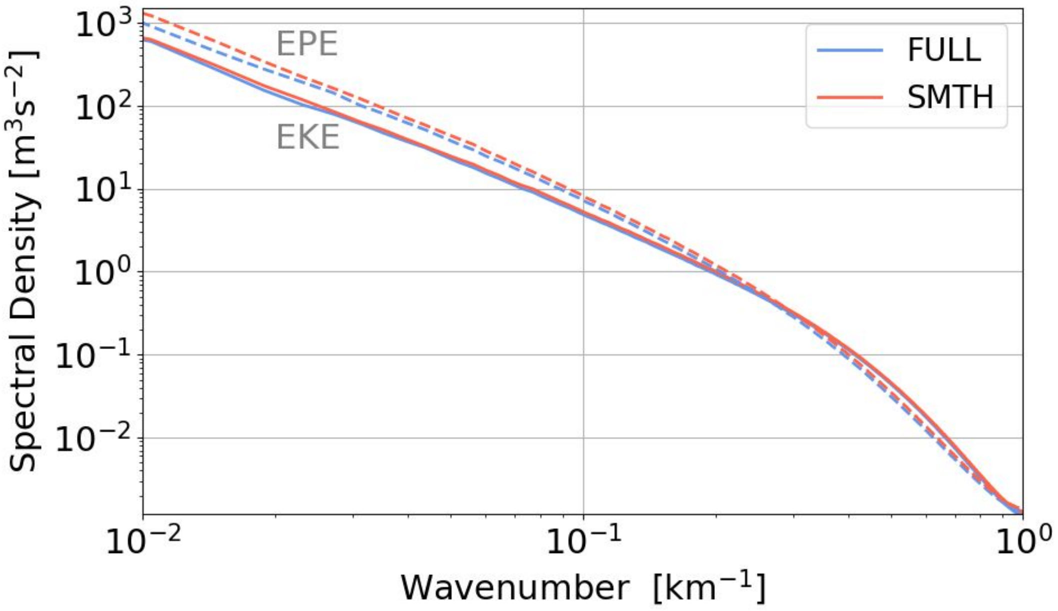
Two experimental setups for submesoscale heat exchange



- OASIS coupler: surface coupling interpolating software;
- Simulation setups: **FULL** and **SMTH**;
- For **SMTH**: Coupling SST fields are spatially smoothed for coupling exchange;
- Two different experiments with the same resolution.

SMTH experiments shows more surface eddy energy

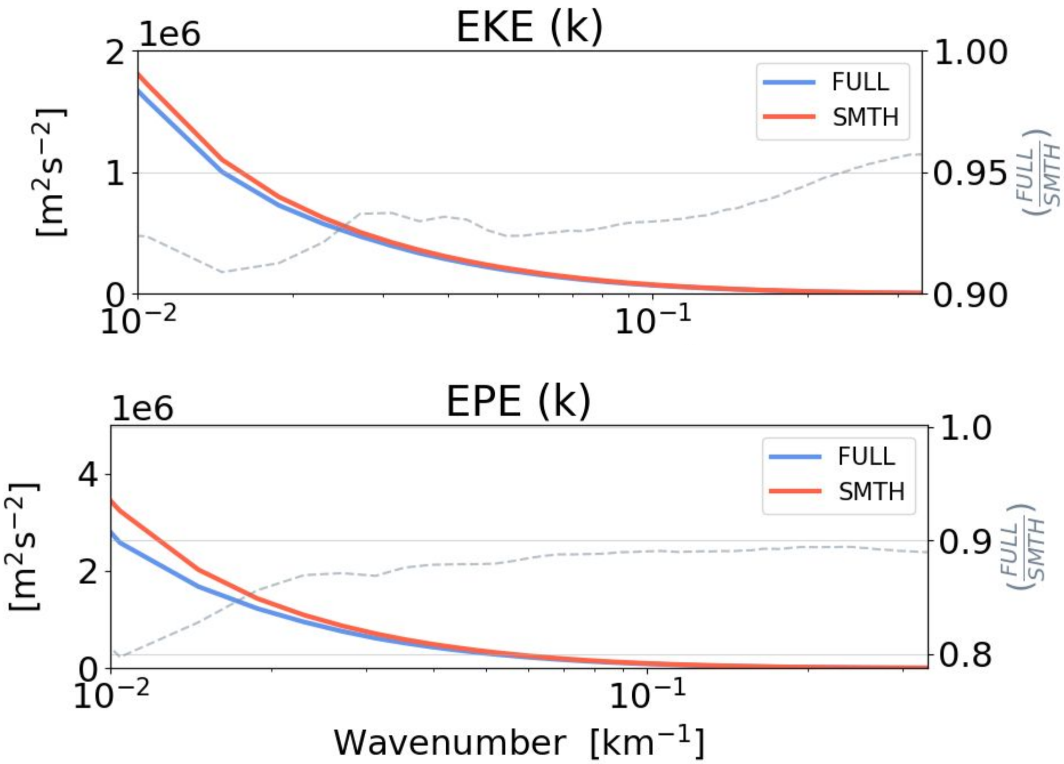
- Surface EKE and EPE spectra show more variability in the SMTH experiments.



Mesoscale ⟵ Submesoscale

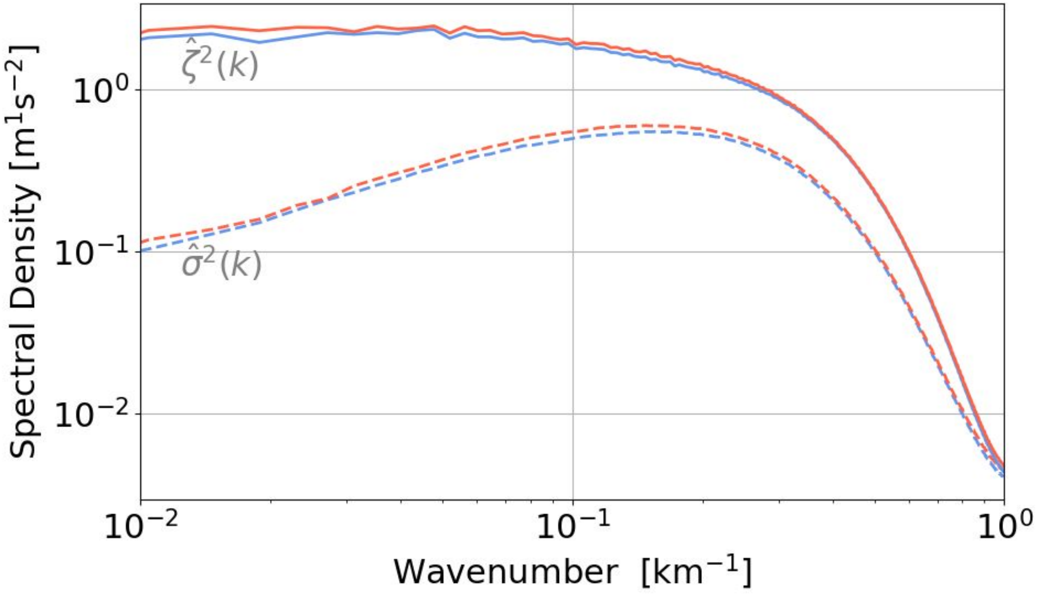
SMTH experiments shows more surface eddy energy

- This relative surplus of energy indicates more variability in velocity and buoyancy at submesoscale when heat exchange is suppressed;
- Cumulative change is similar to findings on EKE by current feedback (CFB) (Renault et al. 2018).



Vorticity and divergence are also larger in SMTH

- Similar patterns are found on vorticity and divergence power spectra which are larger in the SMTH experiment indicating a more dynamic submesoscale.



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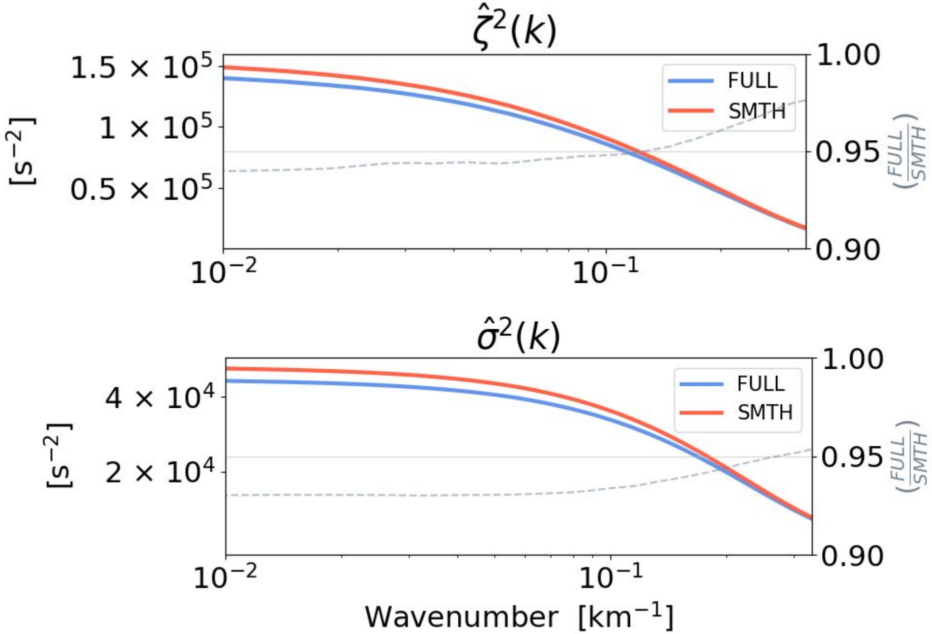
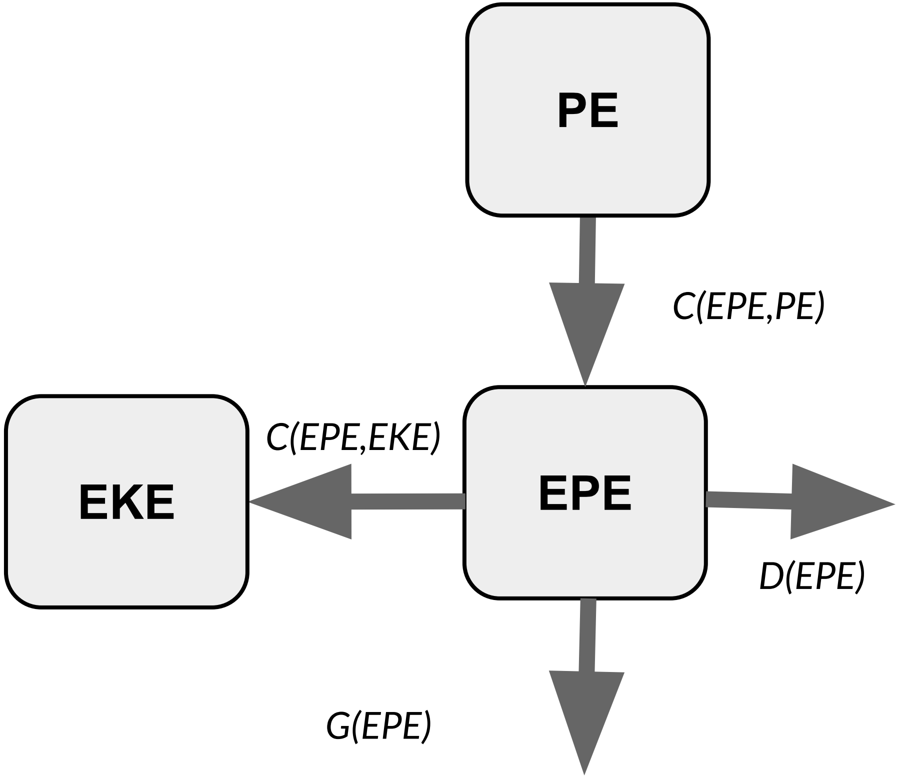


Describing the EPE diagnostics equation

$$\frac{d}{dt}EPE = C(EPE,PE) - C(EPE,EKE) + G(EPE) - D(EPE)$$



*
C = Conversion
D = Dissipation
G = Flux

Cronin & Sprintall (2001); Von Storch et al. (2012)

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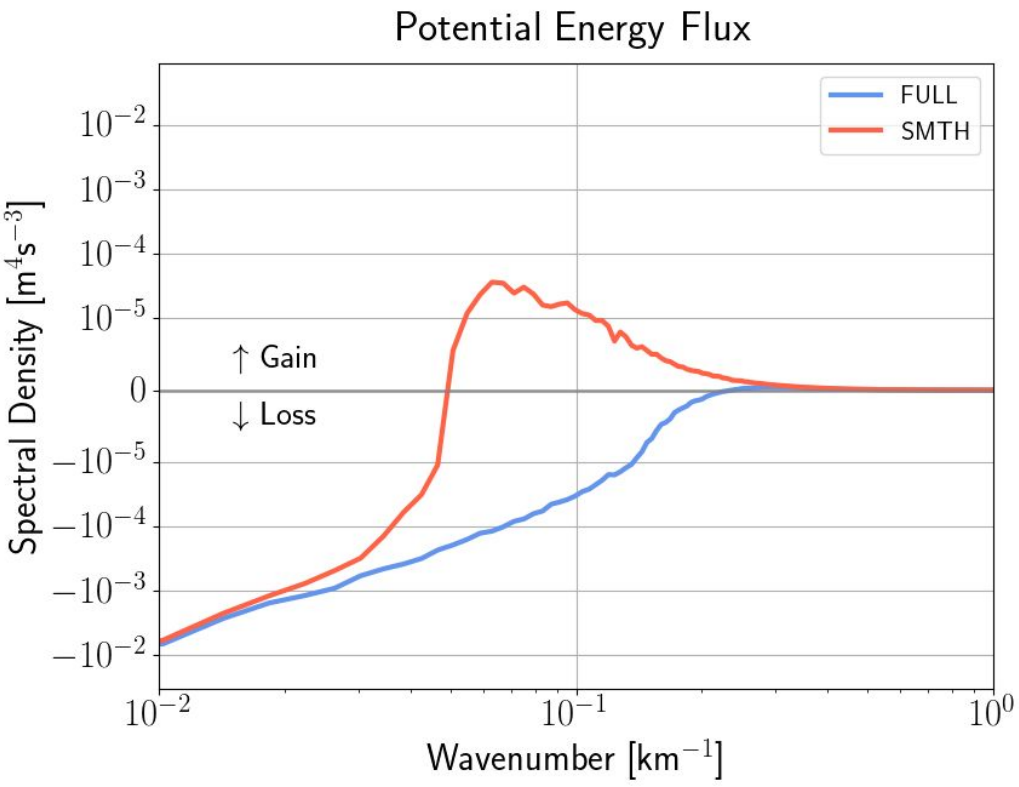
...or in spectral space ⟶ $G(EPE)(k) = \frac{1}{N_r^2} \mathbb{R}[\hat{b}^* \hat{B}_o]$

Cronin & Sprintall (2001); Von Storch et al. (2012)

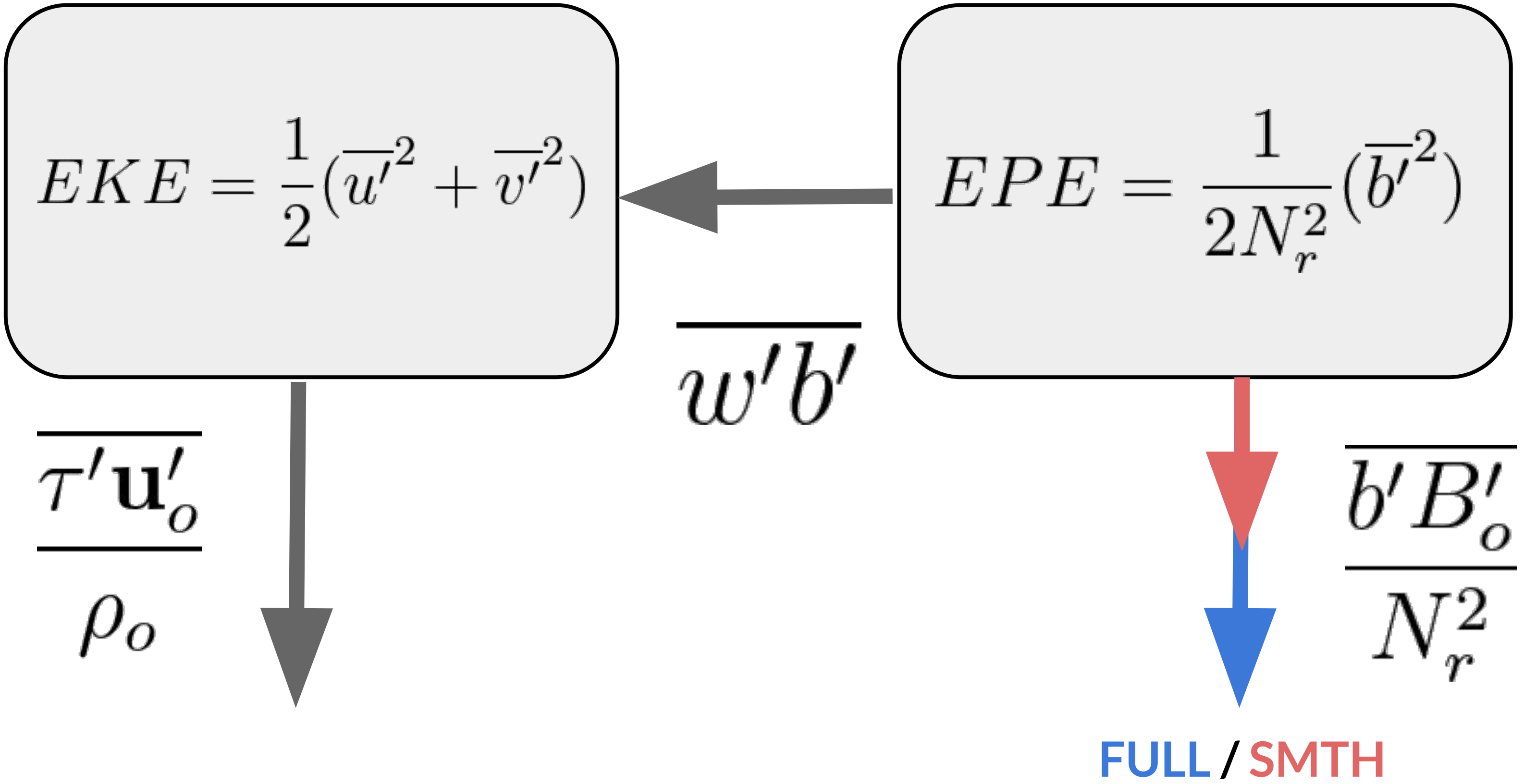
SST submesoscale actively drives loss of EPE in the ocean



- Submesoscale SST variability plays a role in altering the pathways and reservoirs of eddy energy in the ocean;

- In the **SMTH** case, EPE injection into the atmosphere (loss) is depleted and even of opposite sign (gain) in comparison with the **FULL** simulation.

Lorenz energy Diagram - Eddy Energy



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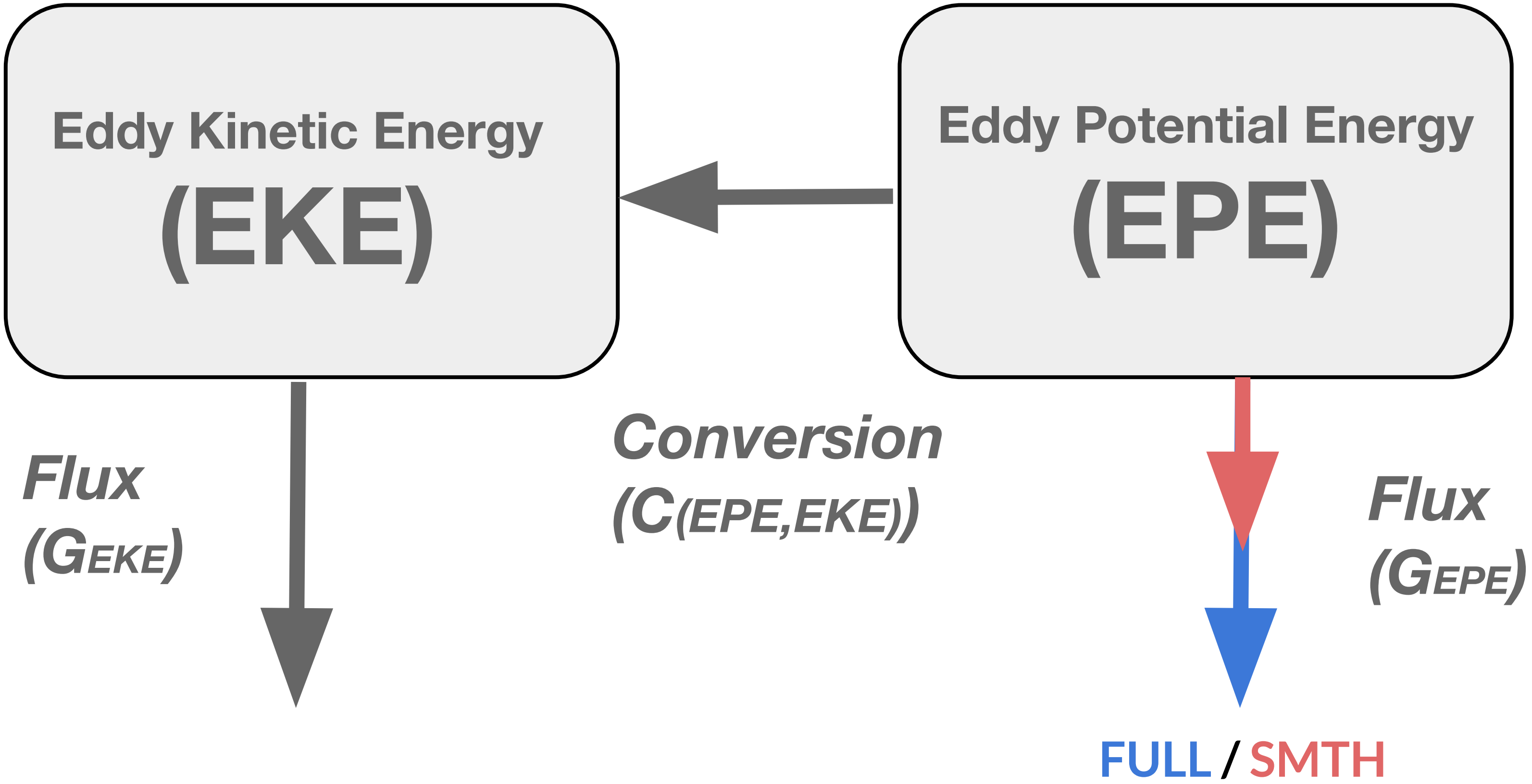
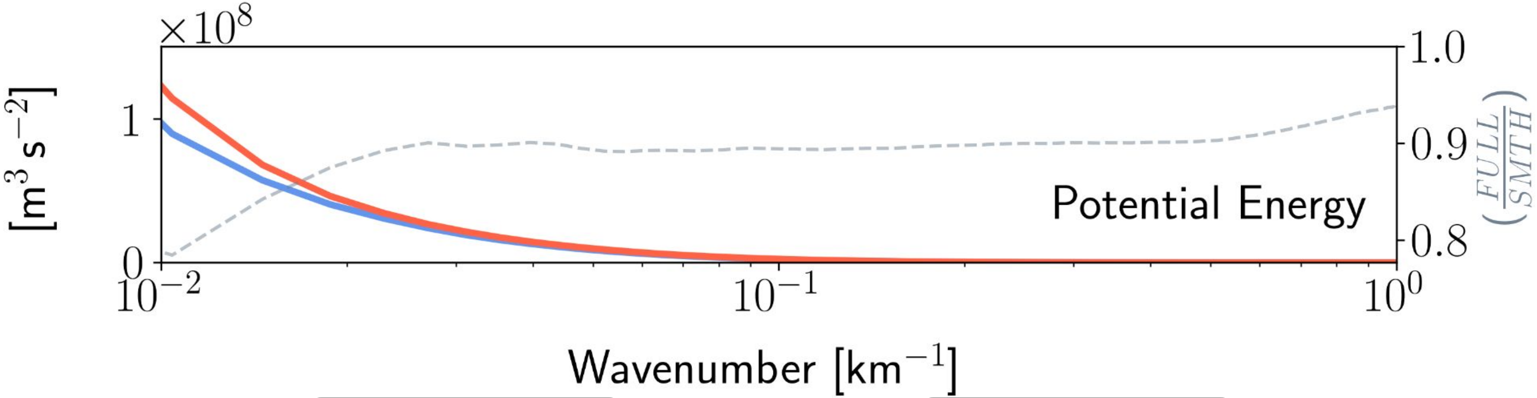
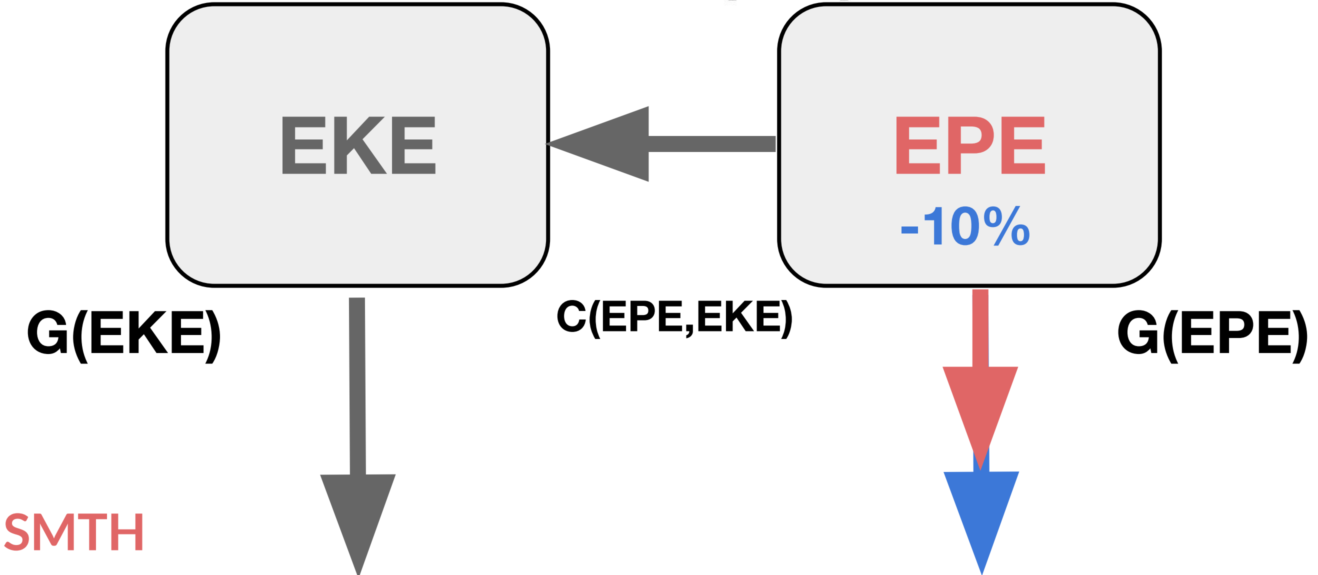


Eddy energy pathways and reservoirs are altered by this mechanism





FULL / SMTH

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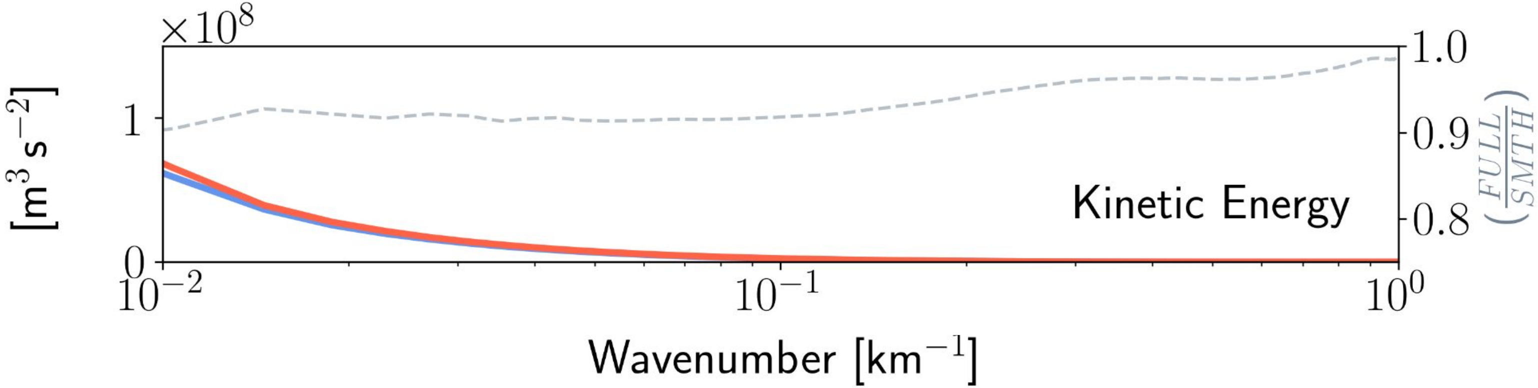

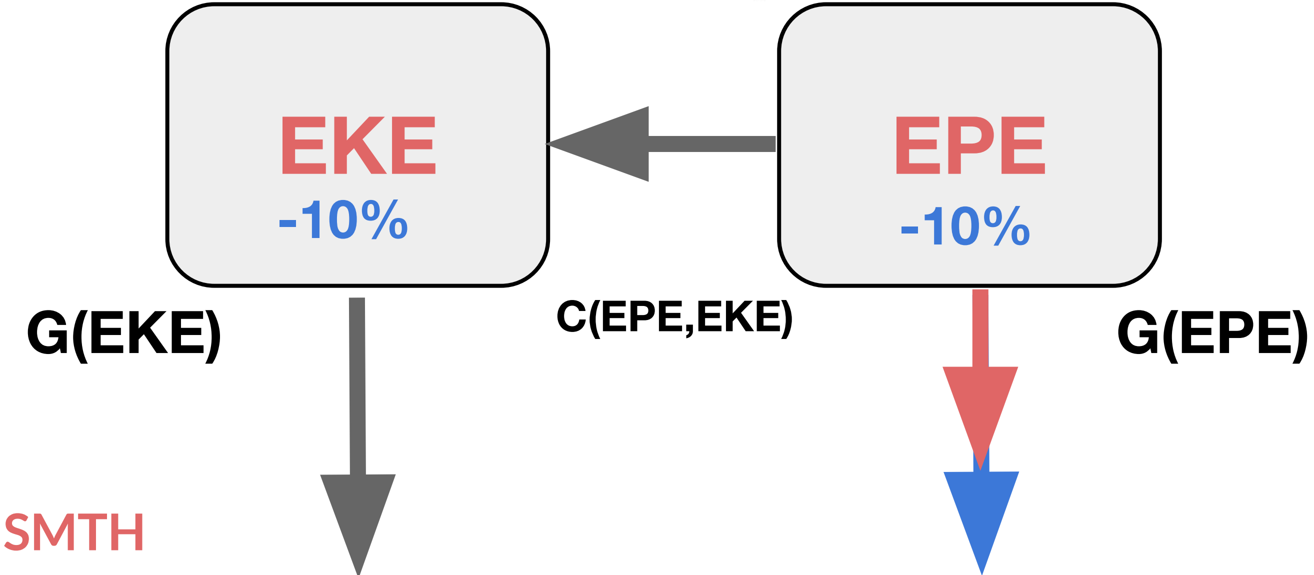

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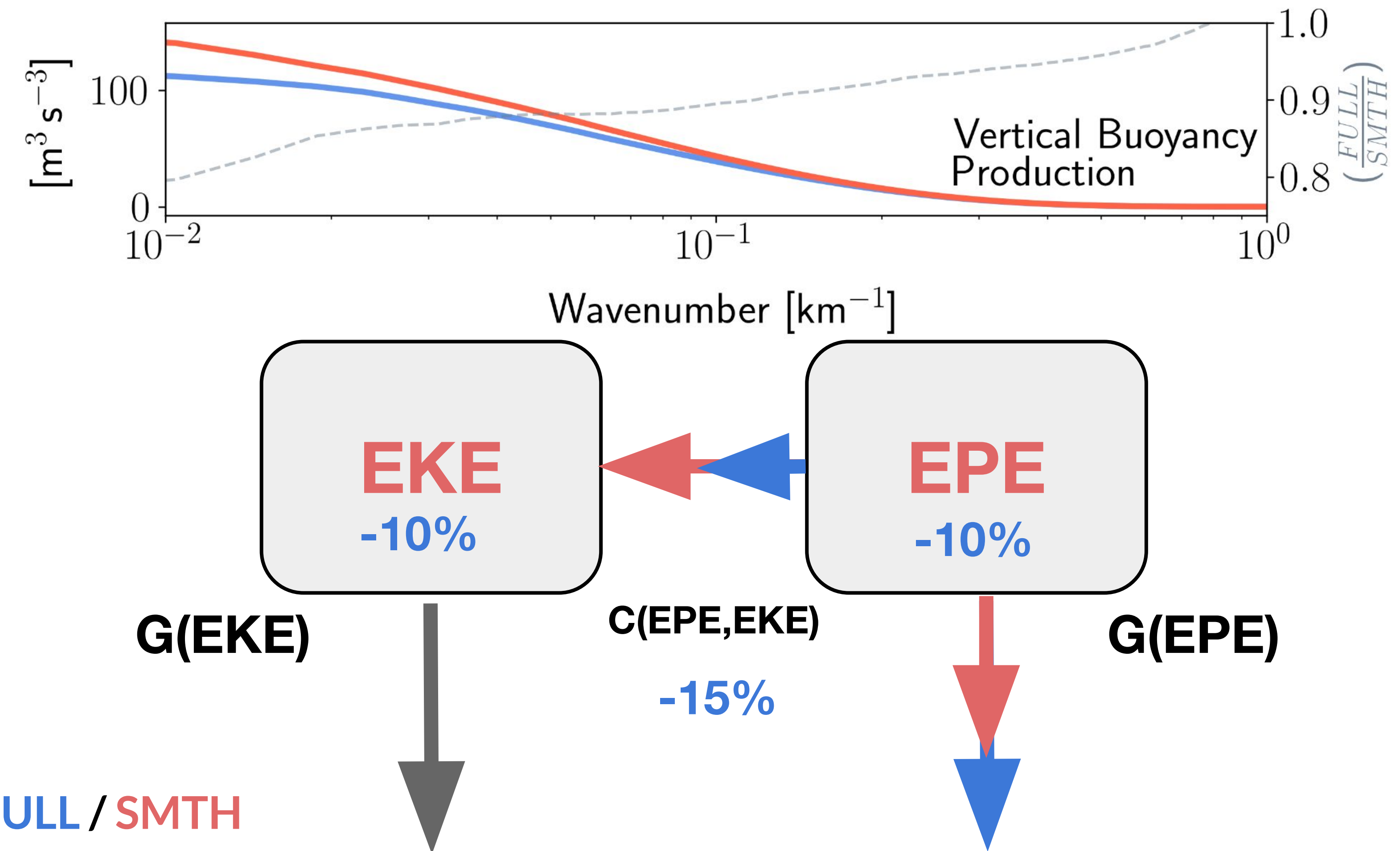

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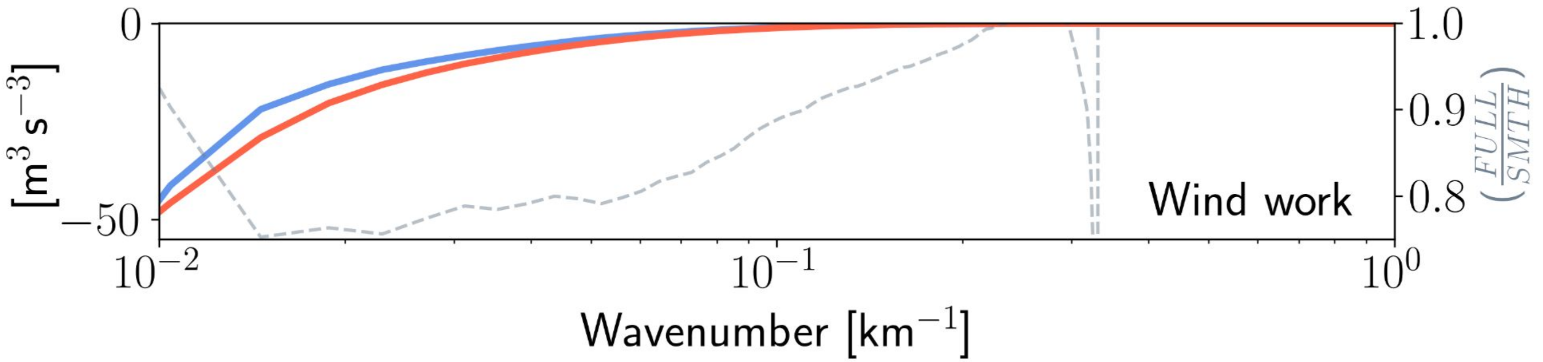
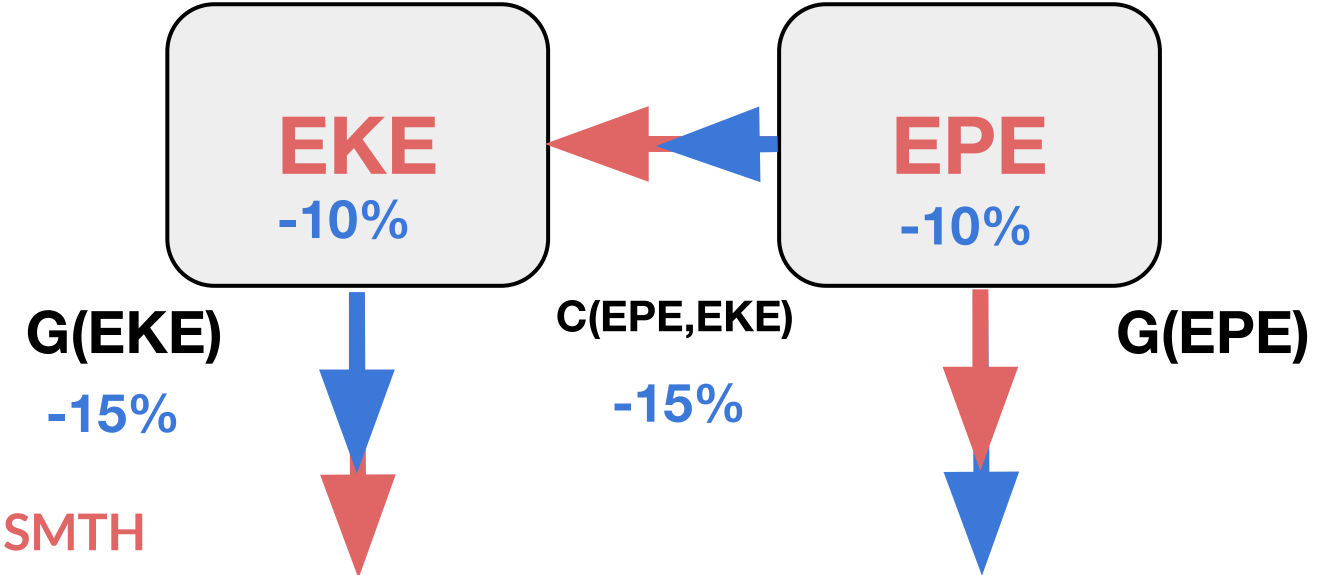
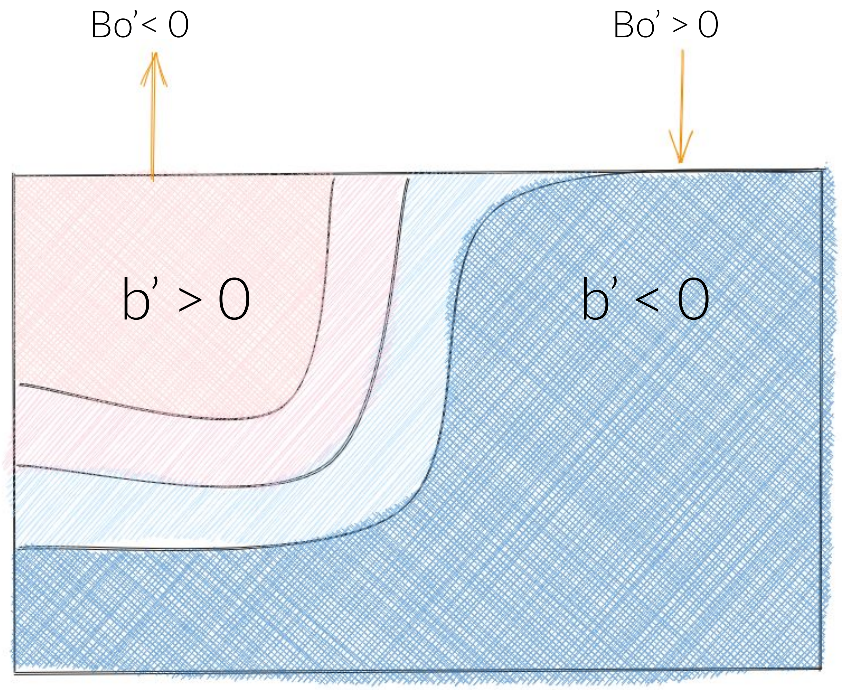




FULL / SMTH

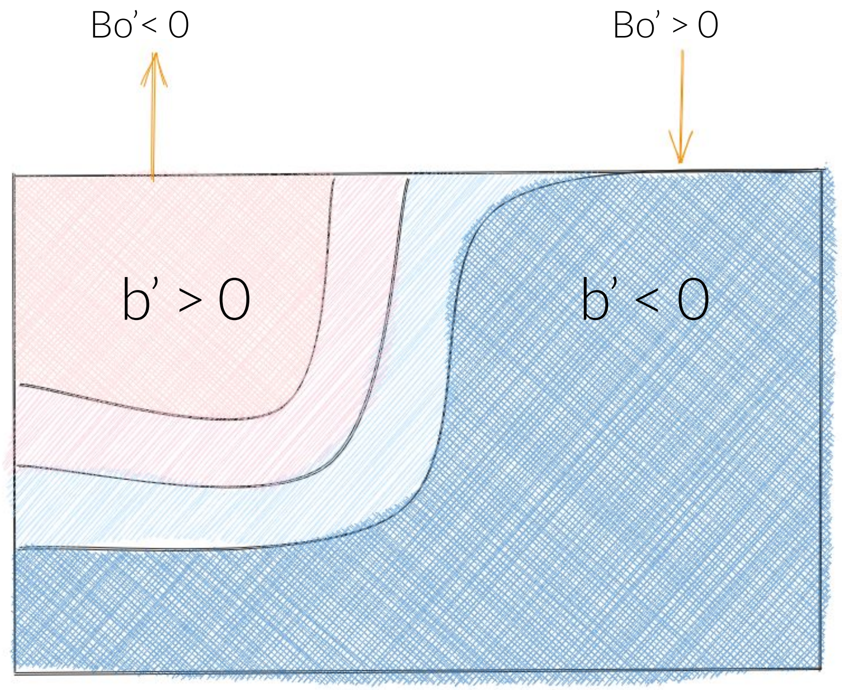
Assessing the mechanism in different coupling strategies

- The EPE flux at submesoscale is an active mechanism that modifies the energetics pathways and reservoirs;



Assessing the mechanism in different coupling strategies

- The EPE flux at submesoscale is an active mechanism that modifies the energetics pathways and reservoirs;
- When is this mechanism underestimated in numerical simulations ?
    - Bulk formulations
    - Fixed heat flux values (ocean-only models)



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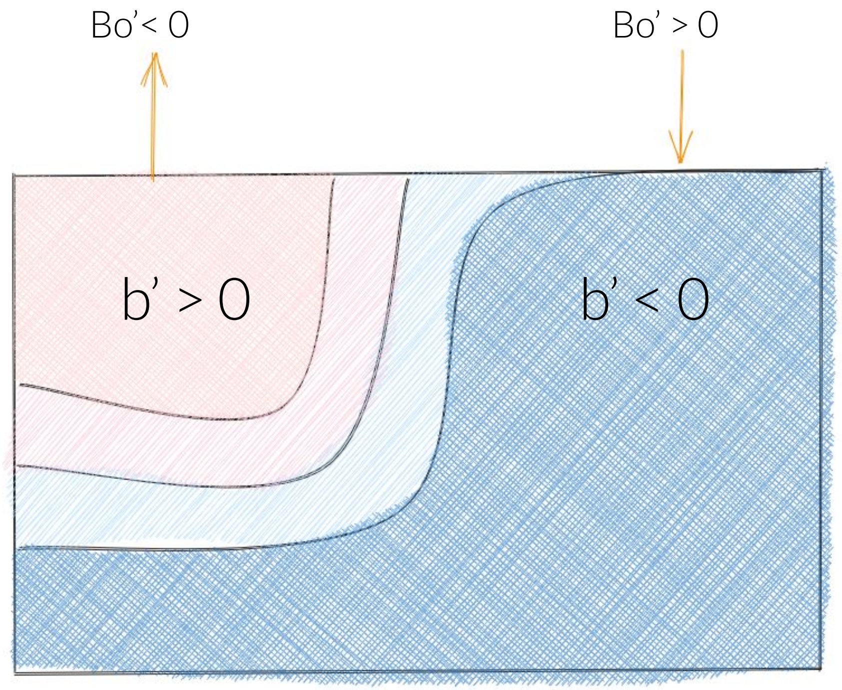
    - Fixed heat flux values (ocean-only models)

- Parameterizations may work as a guidance for future analysis.



What is the importance of each components of EPE flux ?

- Four components of the EPE flux can be computed to understand the influence of the thermal and salinity driven buoyancy and buoyancy flux;

- To simplify:

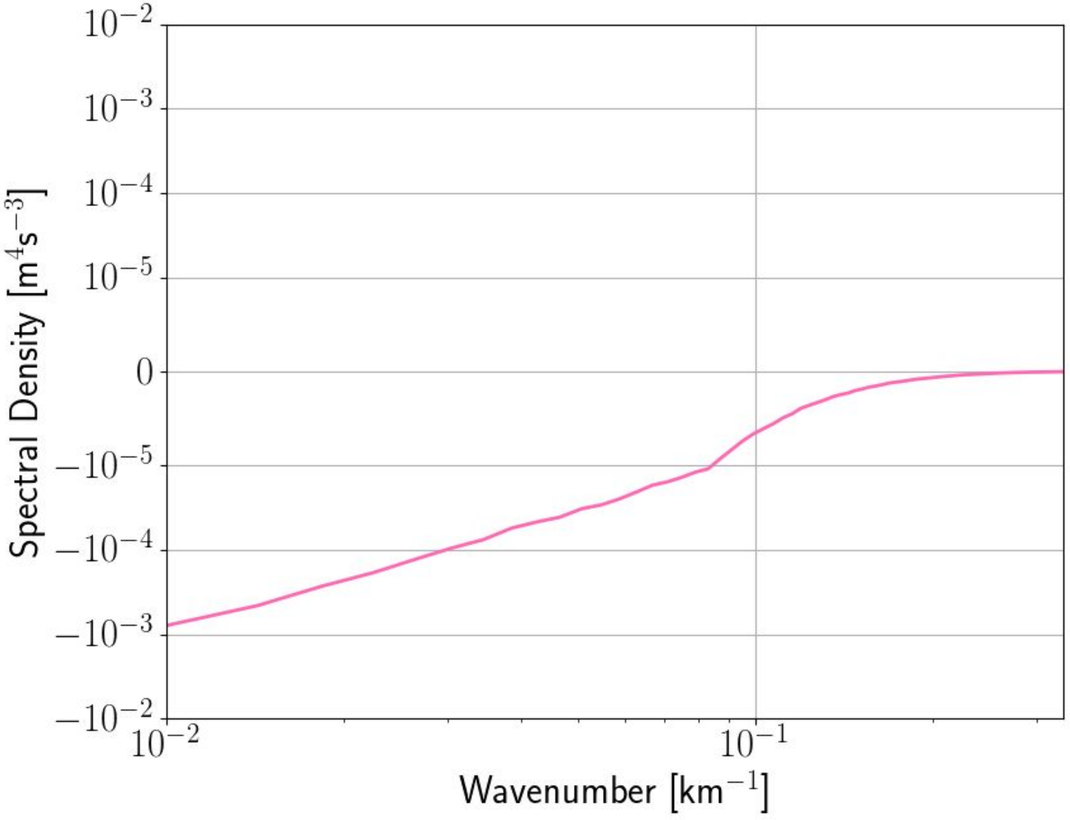
$$Bo' = \alpha g \frac{Q'_o}{\rho C_p} - \beta g (E' - P') S' \longrightarrow B'_o = B'_{oT} + B'_{oS}$$

$$b' = \alpha g T' - \beta g S' \longrightarrow b' = b'_T + b'_s$$

What is the importance of each components of EPE flux ?

$b_T B_{oS}$

EPE loss



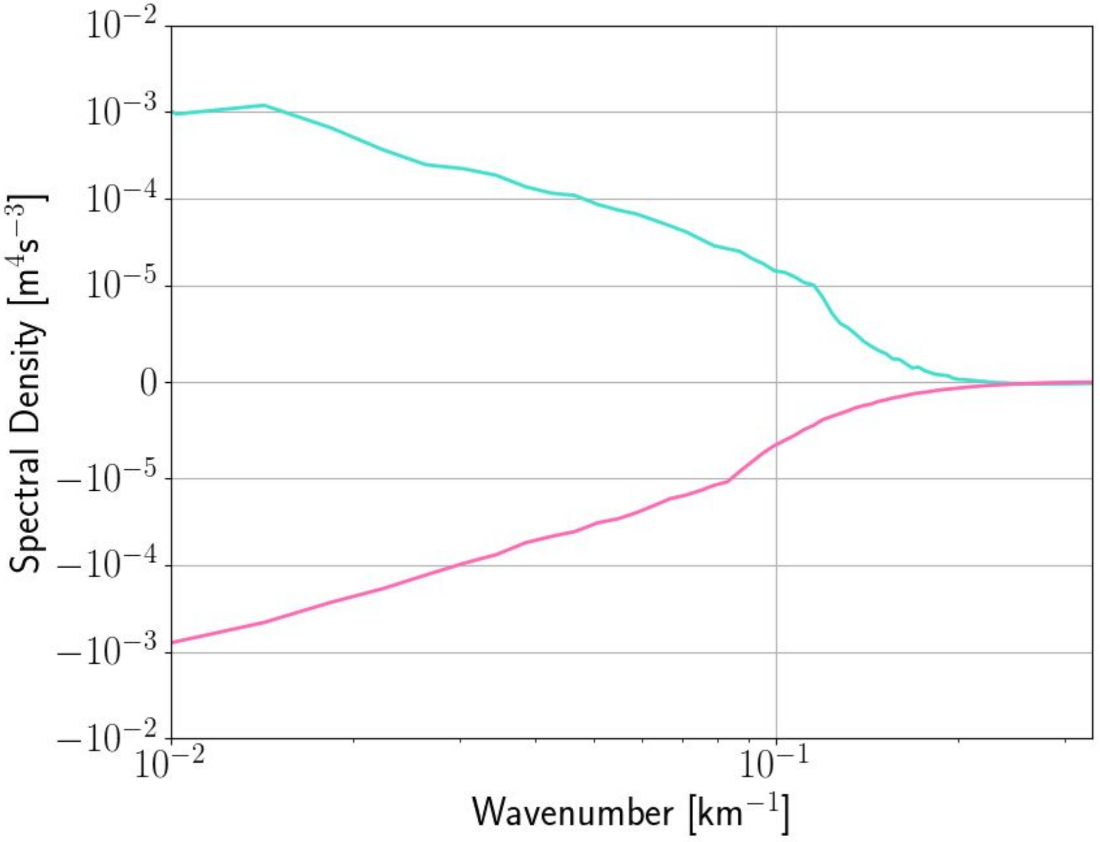
What is the importance of each components of EPE flux ?

$b_T B_{oS}$

EPE loss

$b_S B_{oT}$

EPE gain



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$b_T B_{oS}$

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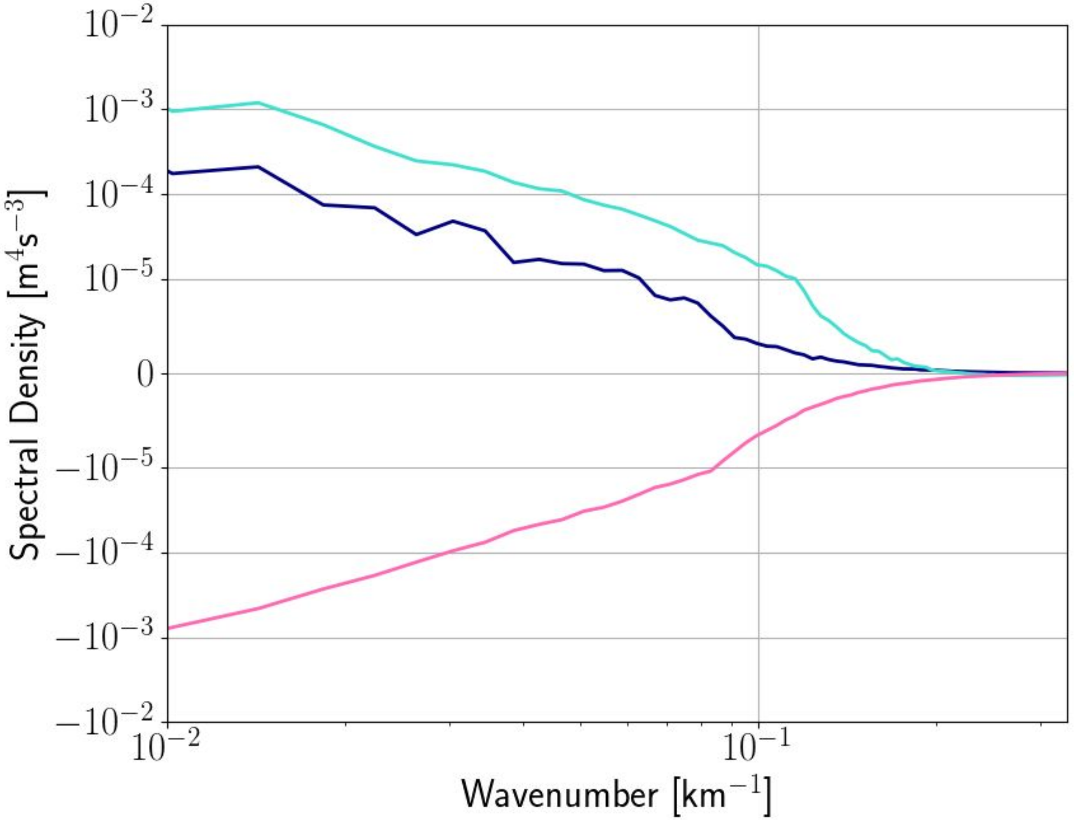
EPE gain

$b_S B_{oS}$

EPE gain (largest gain)



What is the importance of each components of EPE flux ?

$b_T B_{oS}$

EPE loss

$b_S B_{oT}$

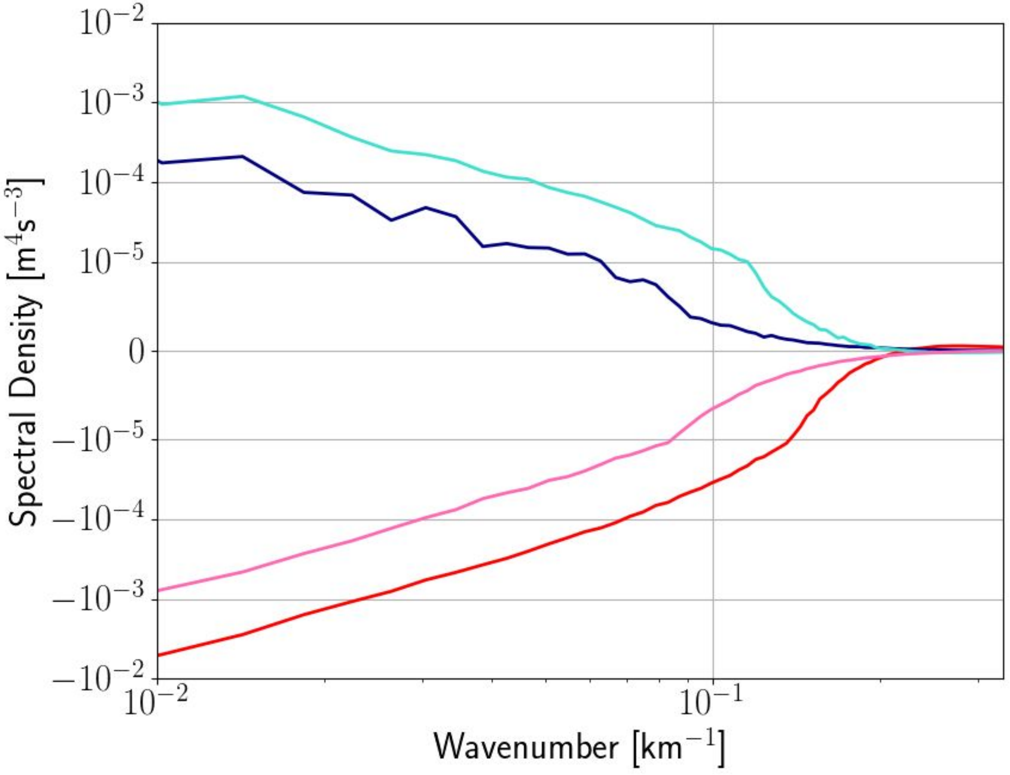
EPE gain

$b_S B_{oS}$

EPE gain (largest gain)

$b_T B_{oT}$

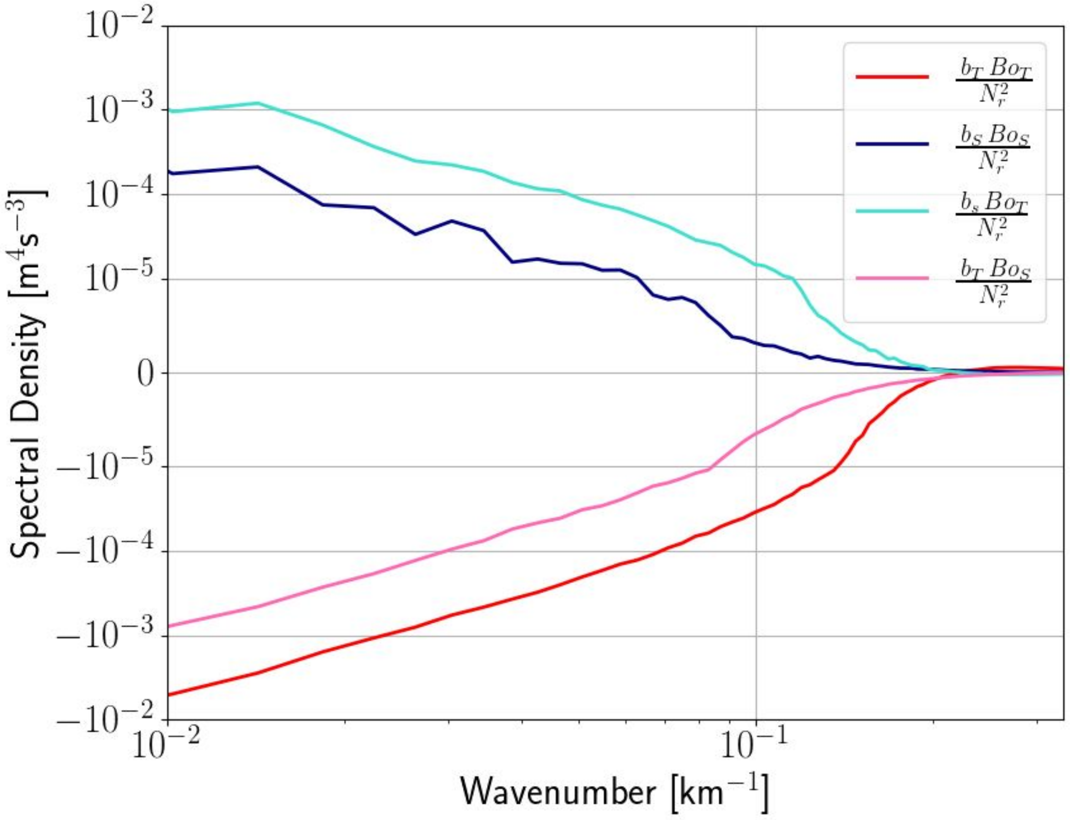
EPE loss (largest **component**)



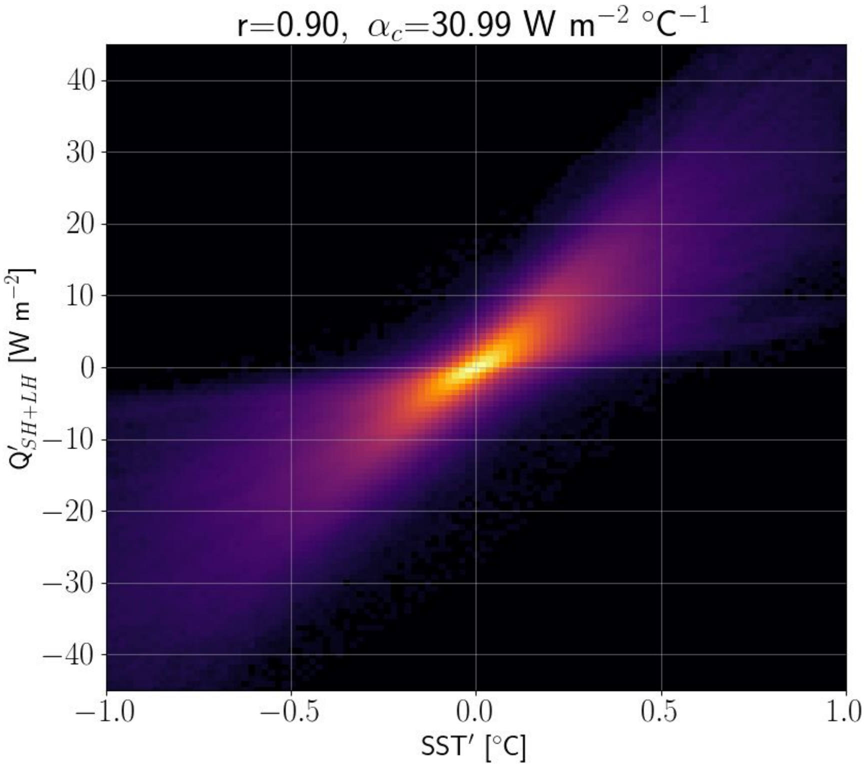
What is the importance of each components of EPE flux ?

- Four components of the EPE flux can be computed to understand the influence of the thermal and salinity driven buoyancy and buoyancy flux;

- Correlations between temperature and heat flux perturbation are the highest variability in the submesoscale and small mesoscale range.



Linearization of the heat flux anomalies



- Coupling coefficients for ocean-only and uncoupled models may be modified;

$$Q_o = \overline{Q_o} + Q'_o$$
$$Q_o = \overline{Q_o} + \alpha_c(SST')$$

Parameterization of the mechanism

- Using the approximation for heat flux perturbation, we obtain:

$$G(EPE) = 2\frac{s_b EPE_T}{\rho_o} \qquad s_b = \frac{\alpha_c}{C_p}$$

- Which is similar to the parameterization of the current feedback (Renault et al. 2018):

$$G(EKE) = 2\frac{s_c EKE}{\rho_o} \qquad s_c = \frac{3}{2}\rho_a C_D |U_a|$$

Parameterizations of the mechanism

- The EPE flux at submesoscale is proportional to the current feedback effect:

$$R = \frac{G(EKE)}{G(EPE)} = \frac{s_c EKE}{s_b EPE_T}$$

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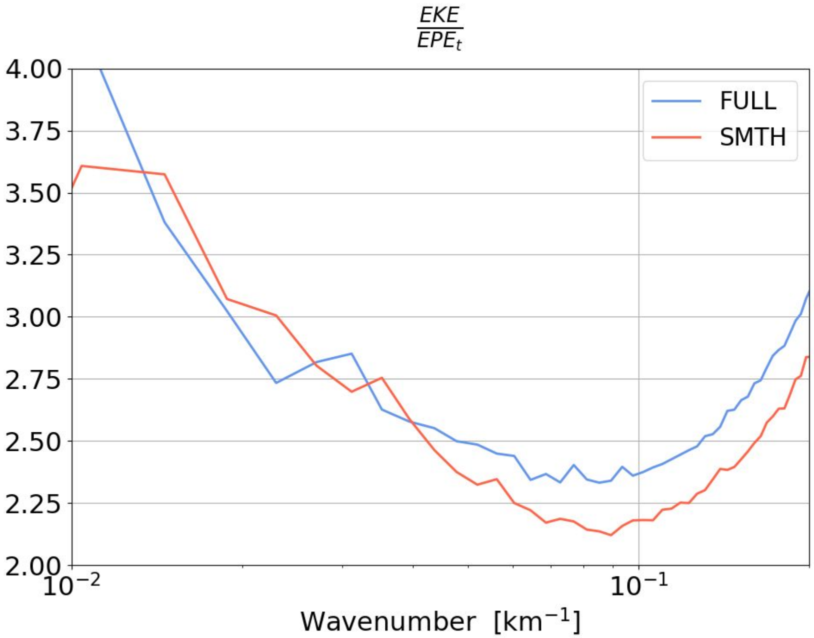
- Since the Sc and Sb are order 1, the ratio is proportional to the ratio between the EKE and EPE



Conclusions

- Submesoscale SST variability drives EPE flux from ocean to the atmosphere, reducing eddy energy of the ocean;

- Changes in submesoscale energy dissipation/conversion due to eddy potential energy fluxes are on the same order of magnitude as the kinetic energy fluxes;

- Understanding the effect of SST submesoscale variability in the EPE flux may be important for uncoupled model air-sea coupling strategies.

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Thank you for your time!