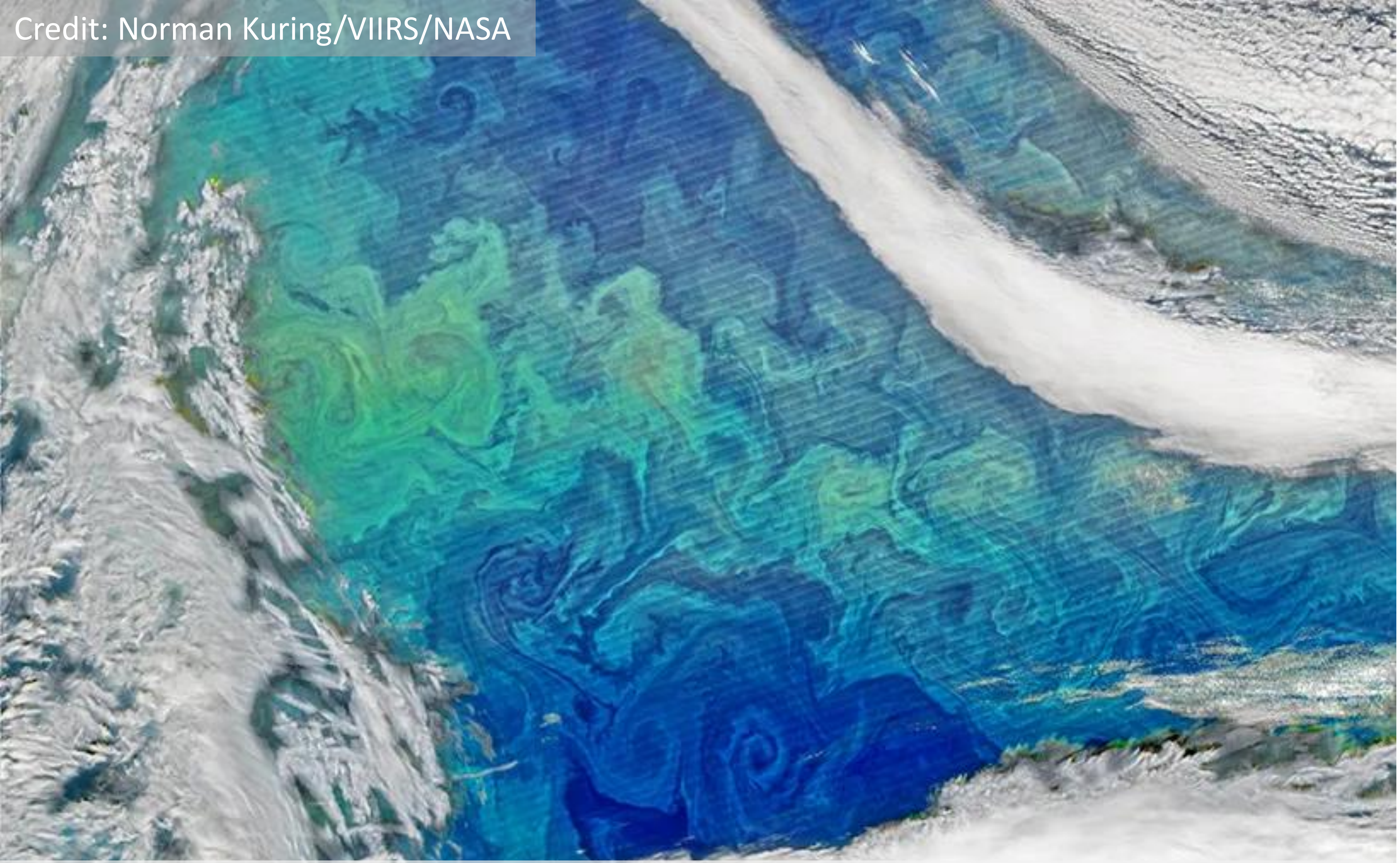

Credit: Norman Kuring/VIIRS/NASA

Subgrid momentum closure: how to link kinetic and potential energy backscatter?

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March 29, 2023
Ingolstadt

Global energy spectrum of the general oceanic circulation

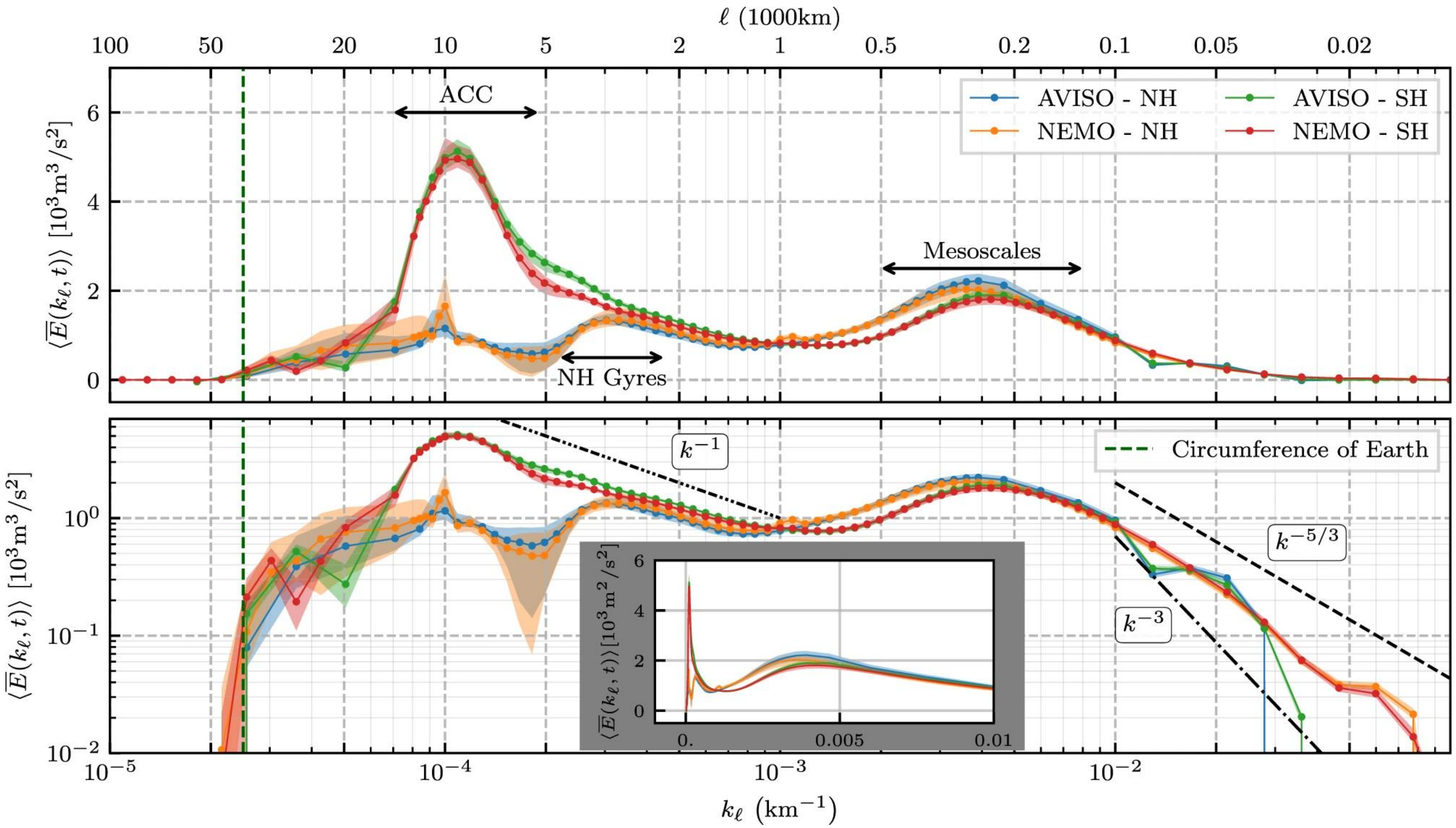


Figure 1. Power spectral density. Adapted from Storer, B.A., Buzzicotti, M., Khatri, H. et al. Global energy spectrum of the general oceanic circulation, 2022

Global energy spectrum of the general oceanic circulation

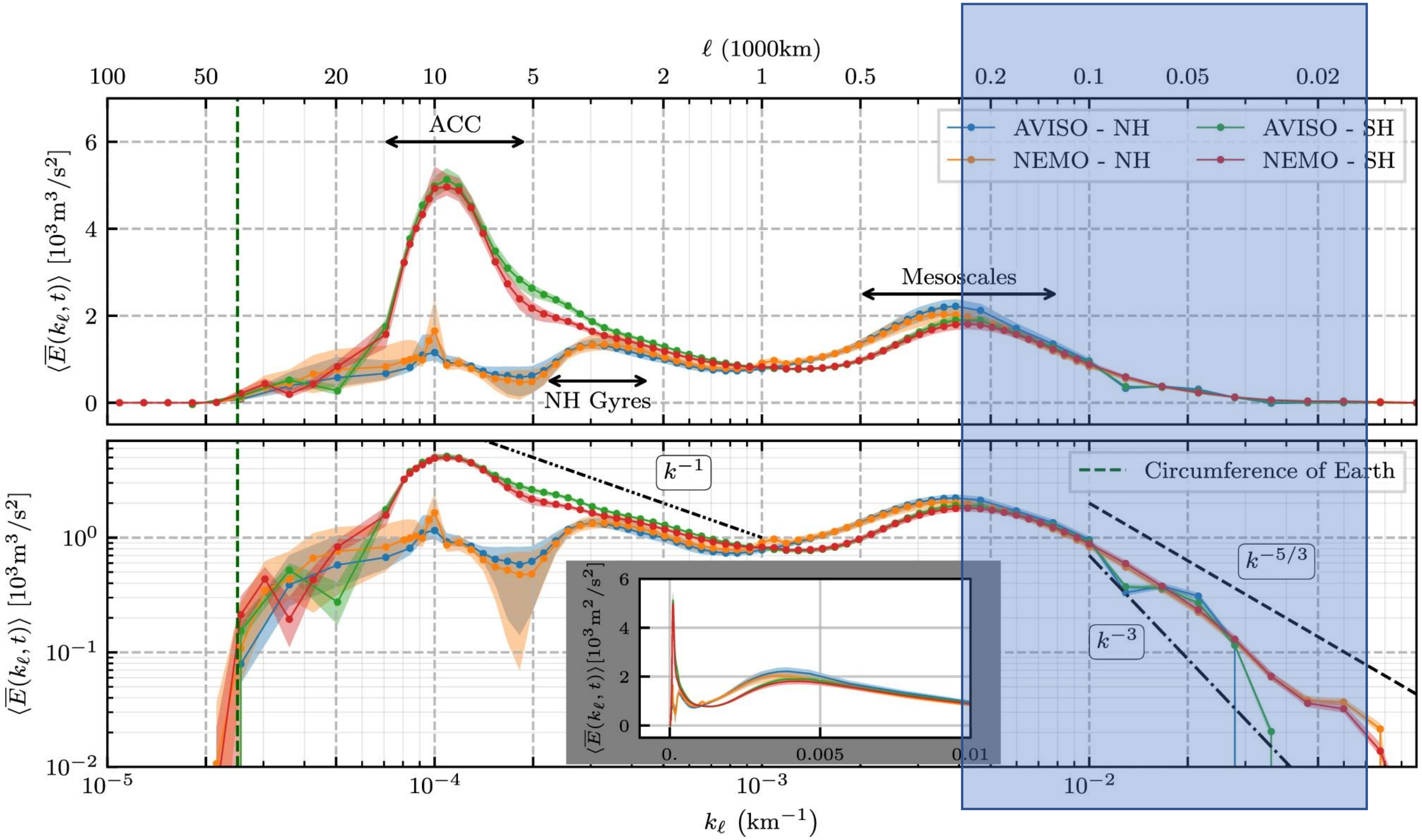
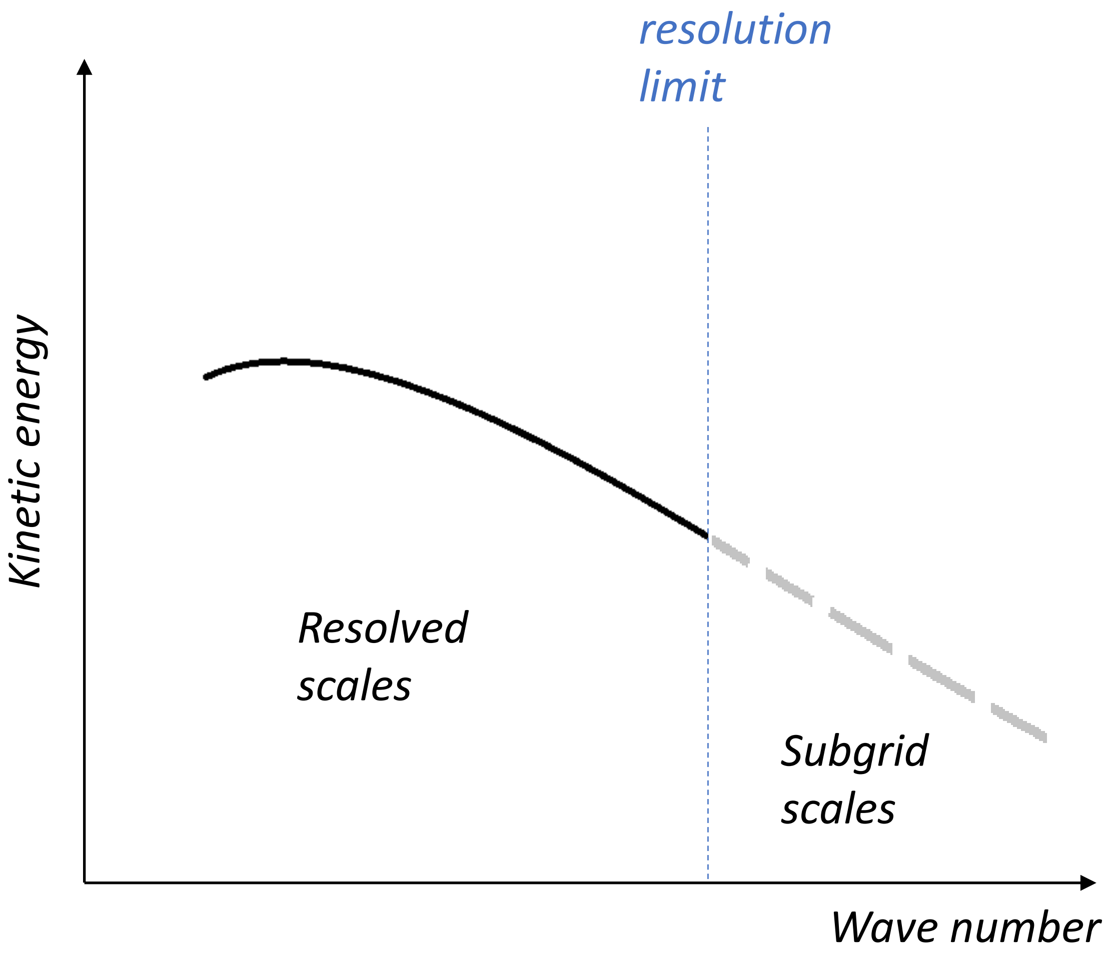


Figure 1. Power spectral density. Adapted from Storer, B.A., Buzzicotti, M., Khatri, H. et al. Global energy spectrum of the general oceanic circulation, 2022

Set of primitive equations

Spectral perspective



Numerical perspective (FESOM2)

$$\partial_t \mathbf{u} + \mathbf{u} \cdot \nabla \mathbf{u} + w \partial_z \mathbf{u} + f \mathbf{u}^{\perp} + \frac{1}{\rho_0} \nabla P = \partial_z (A_v \partial_z \mathbf{u})$$

(Momentum equation)

$\partial_z p = -g\rho$ (Hydrostatic equation)

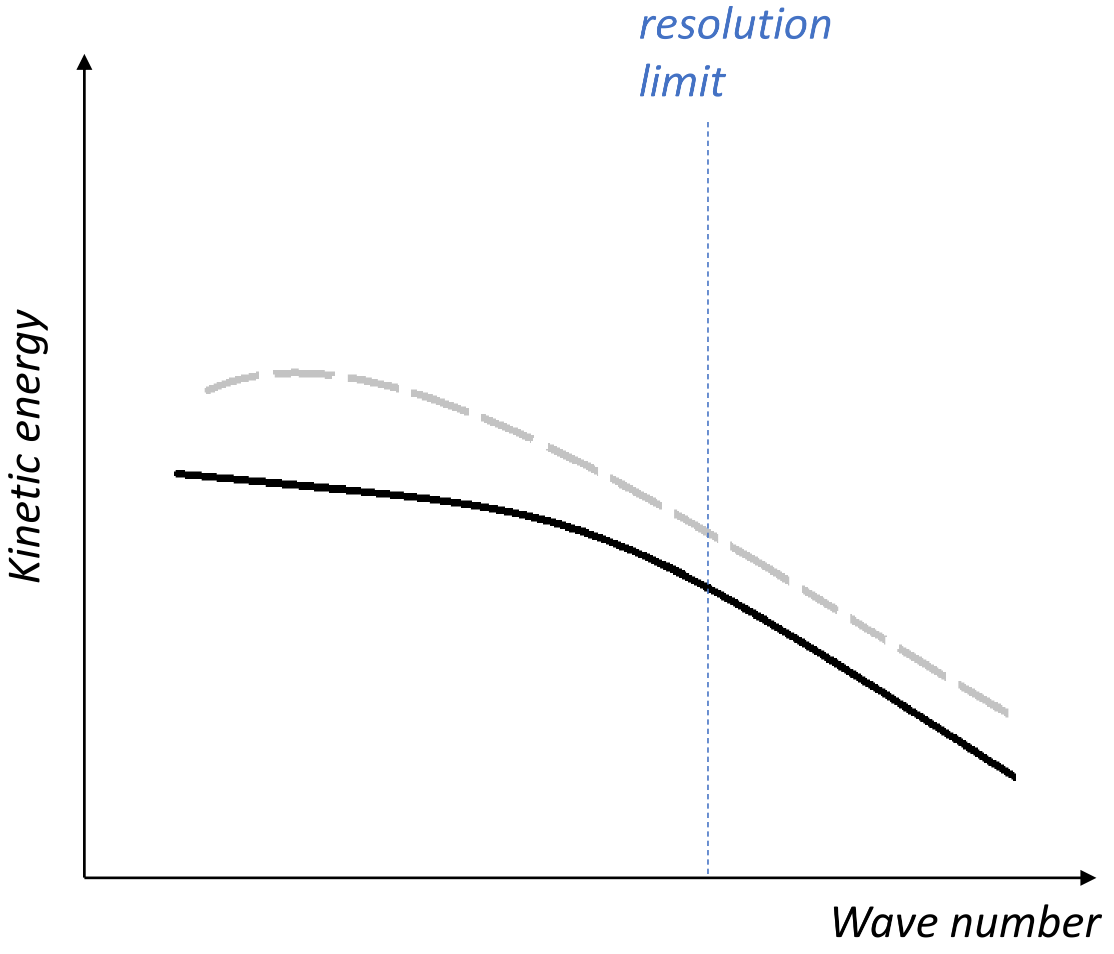
$\nabla \cdot \mathbf{u} + \partial_z w = 0$ (Continuity equation)

$$\partial_t T + \nabla \cdot (\mathbf{u}T) + \partial_z (wT) = \nabla \cdot \mathbf{K} \nabla T$$

$\partial_t S + \nabla \cdot (\mathbf{u}S) + \partial_z (wS) = \nabla \cdot \mathbf{K} \nabla S$ (Tracer equations)

Viscous operator in the momentum equation

Spectral perspective



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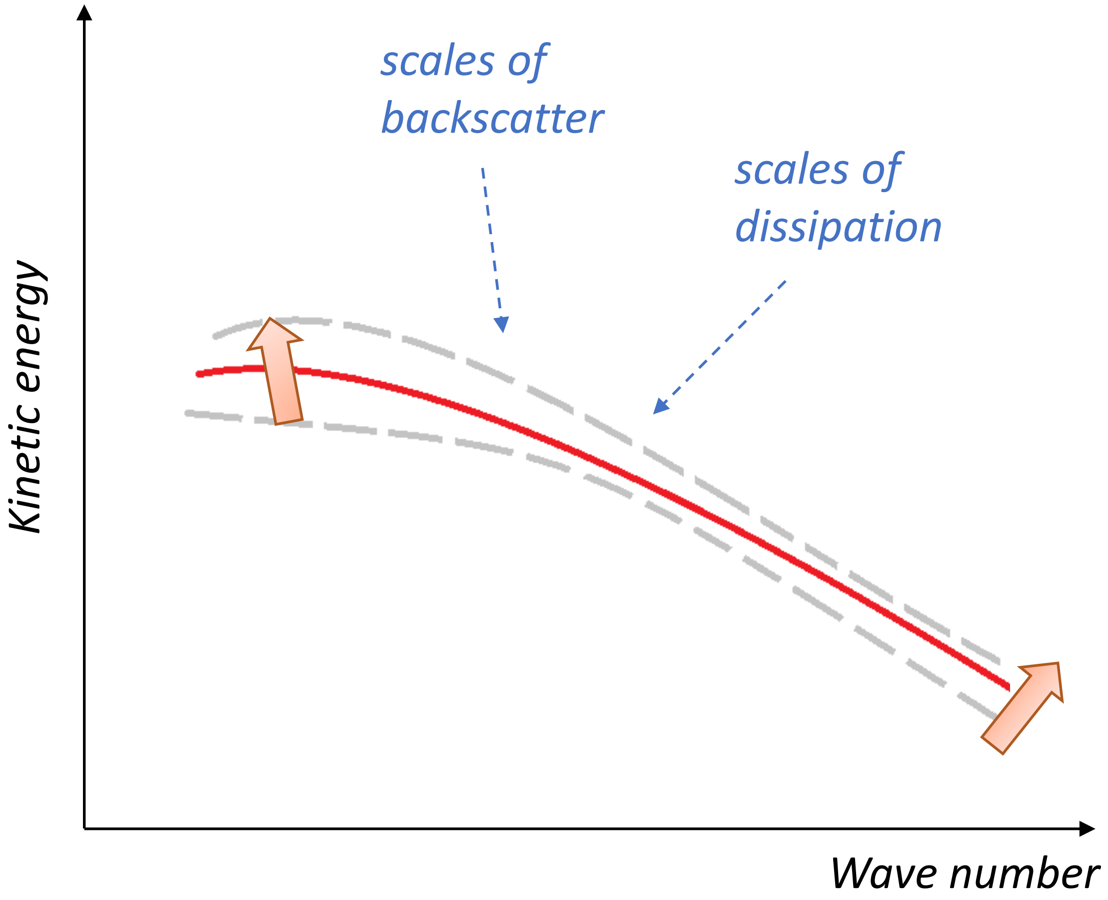
$$+ \mathbf{V}(\mathbf{u})$$

Viscous operator in the momentum equation

Spectral perspective



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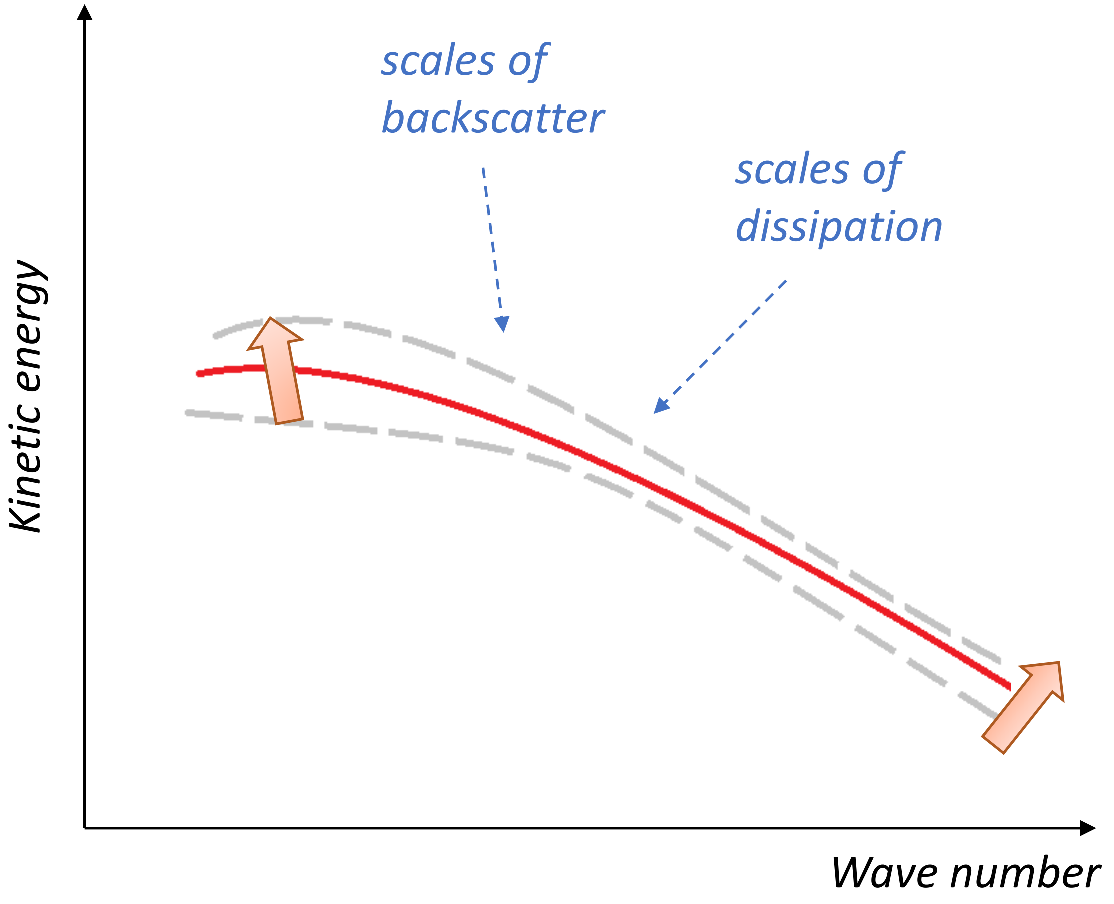
$$+ \mathbf{V}(\mathbf{u})$$

$$+ \mathbf{B}(\mathbf{u})$$

Viscous operator in the momentum equation

Spectral perspective



Numerical perspective

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$$+ \mathbf{V}(\mathbf{u})$$

$$+ \mathbf{B}(\mathbf{u})$$

How to define the amplitude of $\mathbf{B}(\mathbf{u})$?

Subgrid energy equation

diffusion term

KE source

KE sink

$$\partial_t e = -c_{dis}\dot{E}_{dis} - \dot{E}_{back} - \nabla \cdot (\nu^C \nabla e)$$

Dissipation rate from the resolved flow to subgrid

Backscatter rate from subgrid to the resolved flow

Juricke, at al. Ocean kinetic energy backscatter parametrizations on unstructured grids: Impact on mesoscale turbulence in a channel, 2019

New terms in subgrid equation

diffusion term

KE source

KE sink

$$\partial_t e = -c_{dis}\dot{E}_{dis} - \dot{E}_{back} - \nabla \cdot (\nu^C \nabla e)$$

Dissipation rate from the resolved flow to subgrid

Backscatter rate from subgrid to the resolved flow

new advection term:

$$-\mathbf{u} \cdot \nabla \mathrm{e}$$

new stochastic term:

$$+Ae\sum_i EOF_i(x)PC_{fitted,i}(t)$$

Stochastic term design

Postprocessing

Kinetic energy data from the reference high-resolution simulation (coarse grained)

EOF analysis of this data to get the first N EOFs and PCs to explain the fixed percentage of variability

Fit each PC with the AR1 process, get an array of coefficients

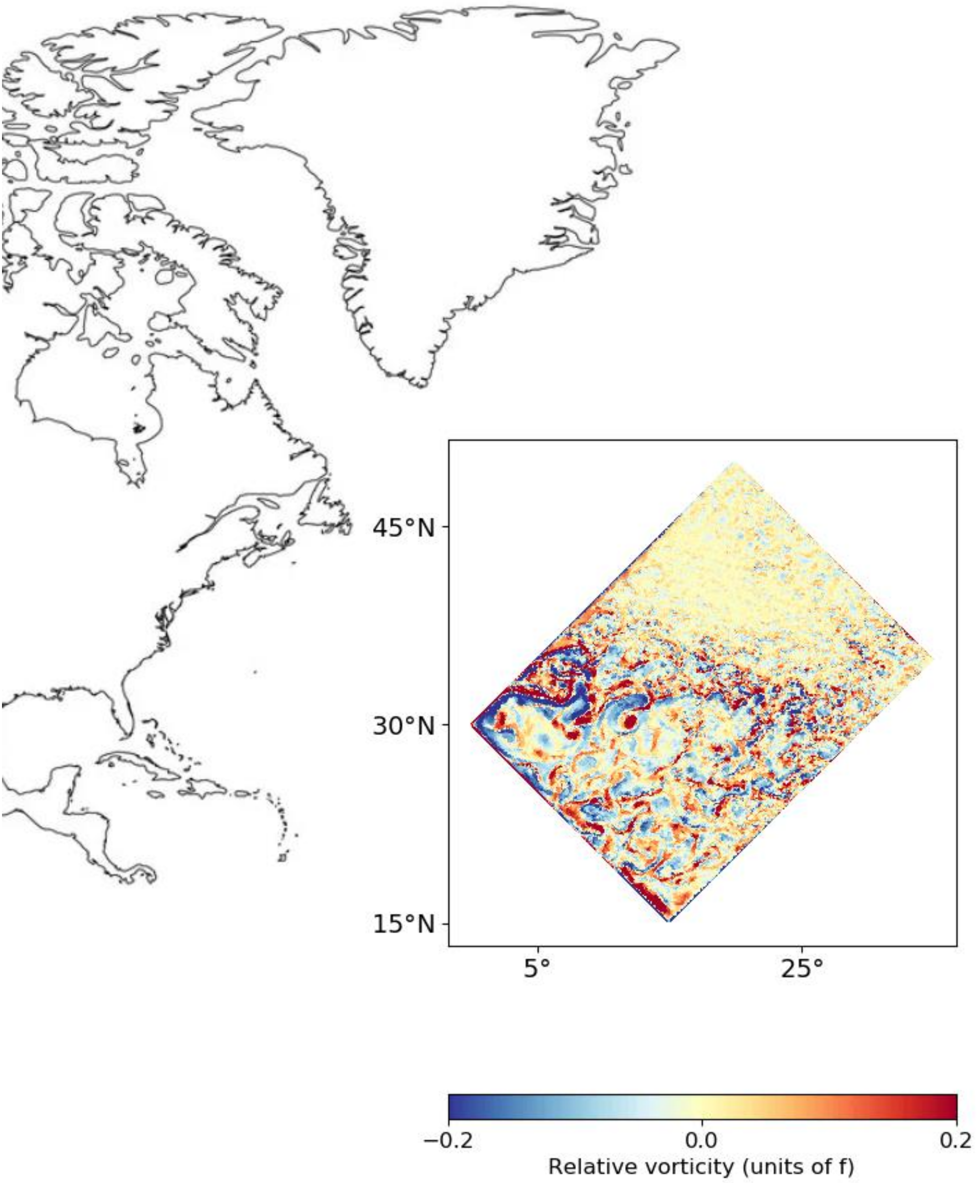
Simulation

Make PC-amplitude correction and generate every time step realization of each PC

Add the product of stochastic PC and deterministic EOF to the subgrid energy budget

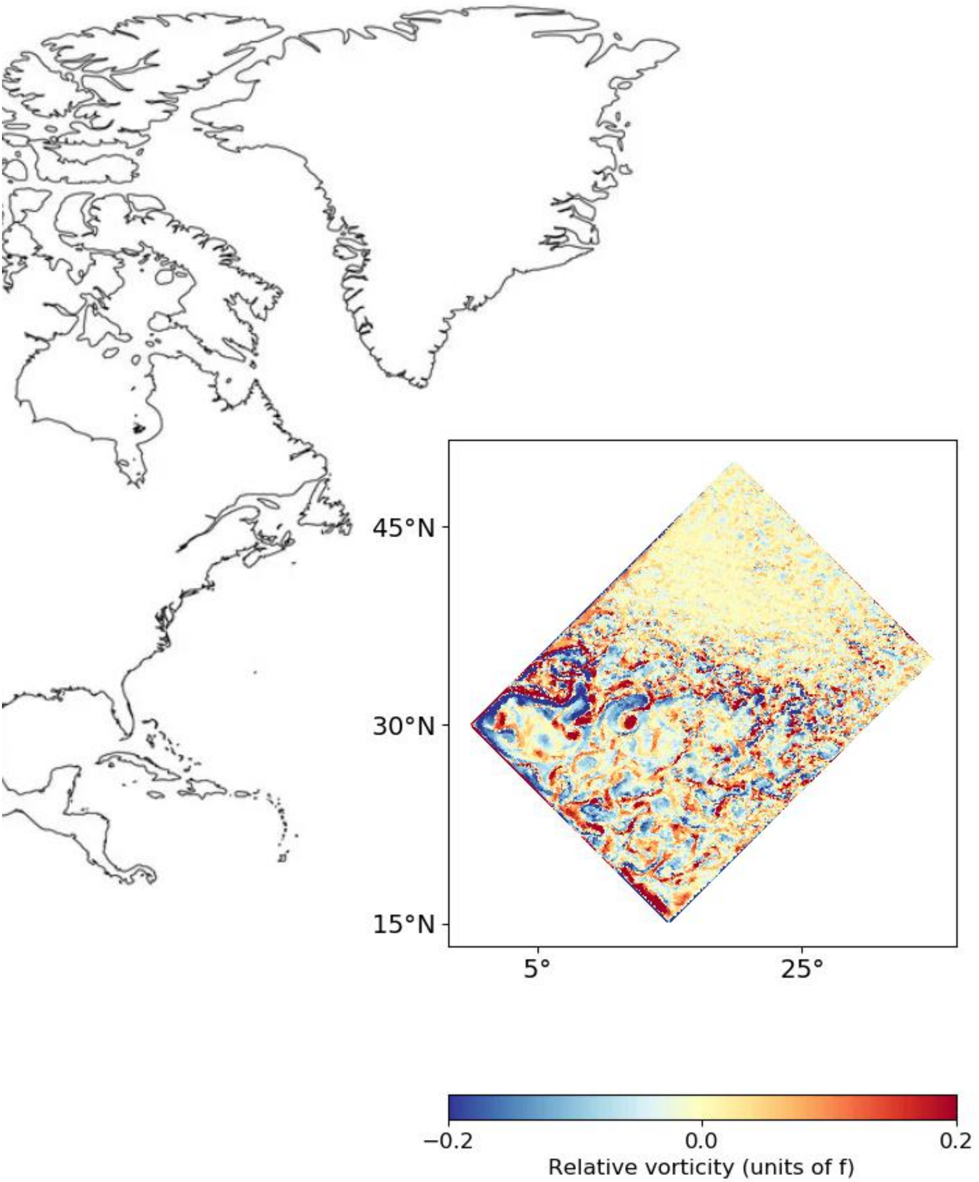
Run different amplitudes of the stochastic term

Testing setup: double-gyre domain



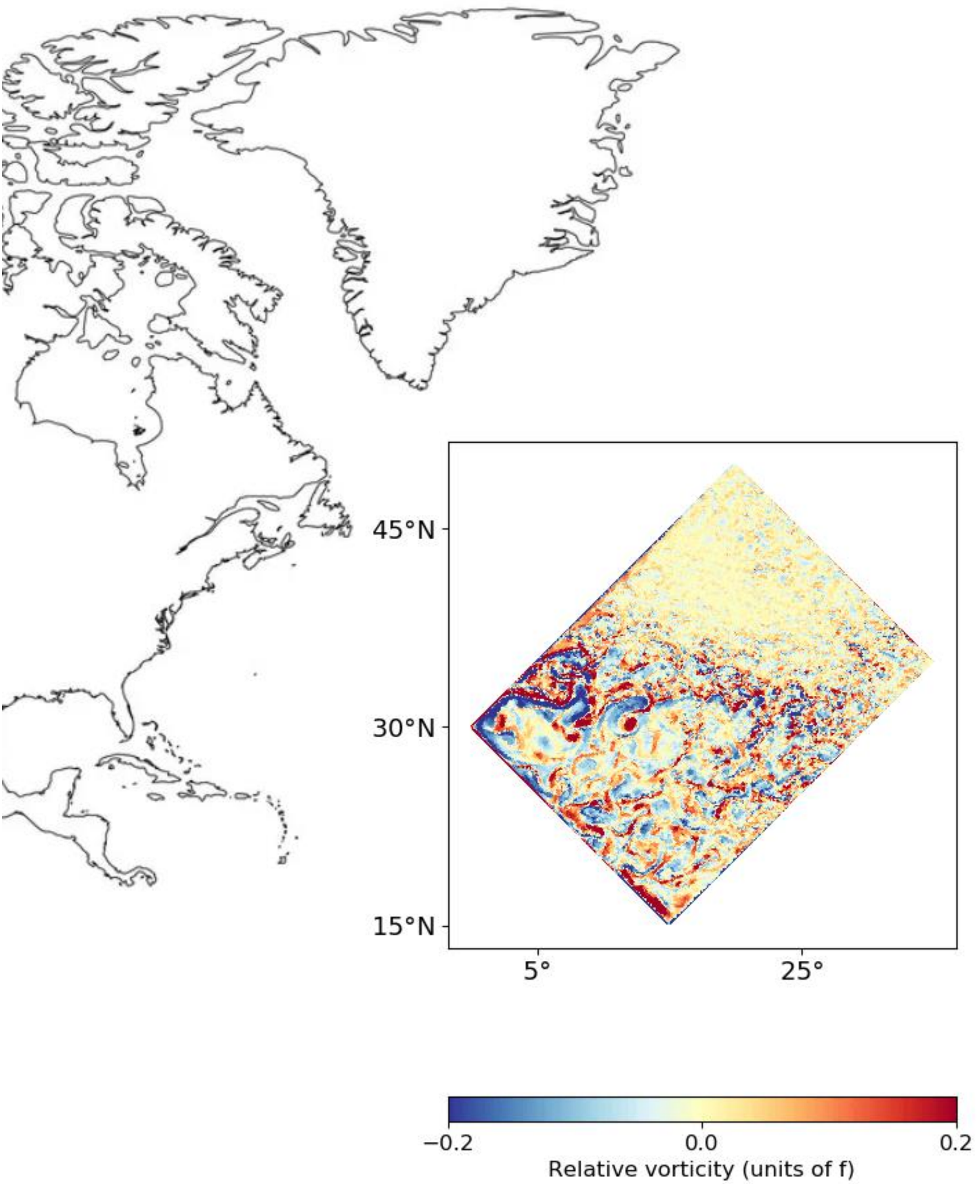
Credit: M. Lévy, at al. Modifications of gyre circulation by sub-mesoscale physics, 2010

Testing setup: double-gyre domain

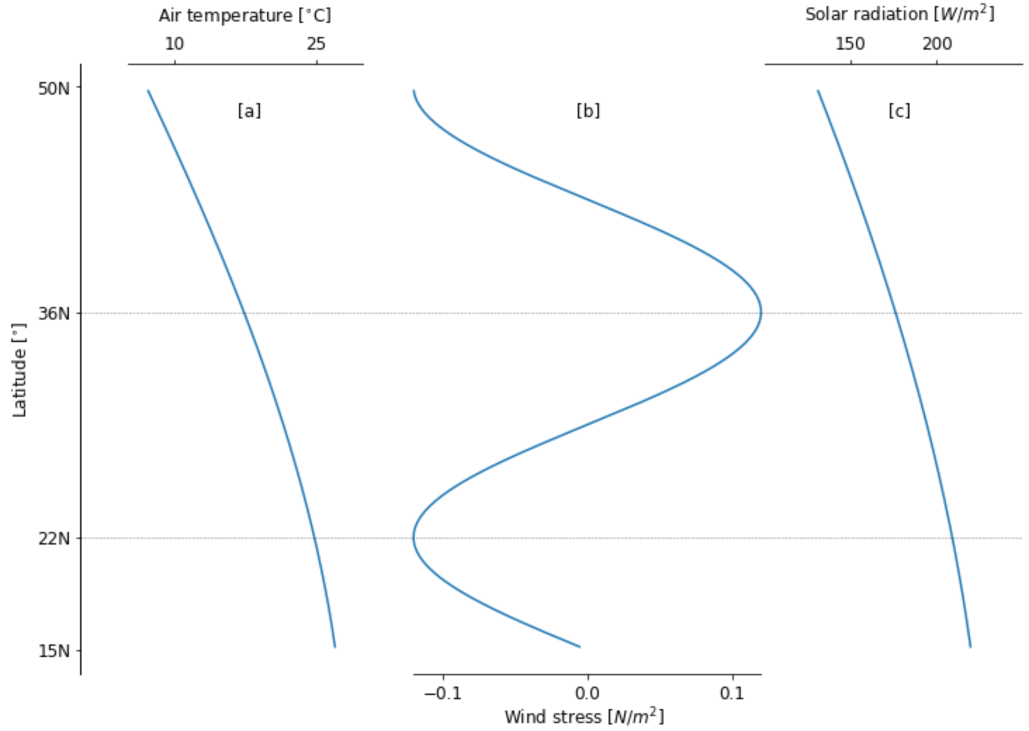


Wind forcing

Testing setup: double-gyre domain



Analytical profiles of double-gyre dynamics



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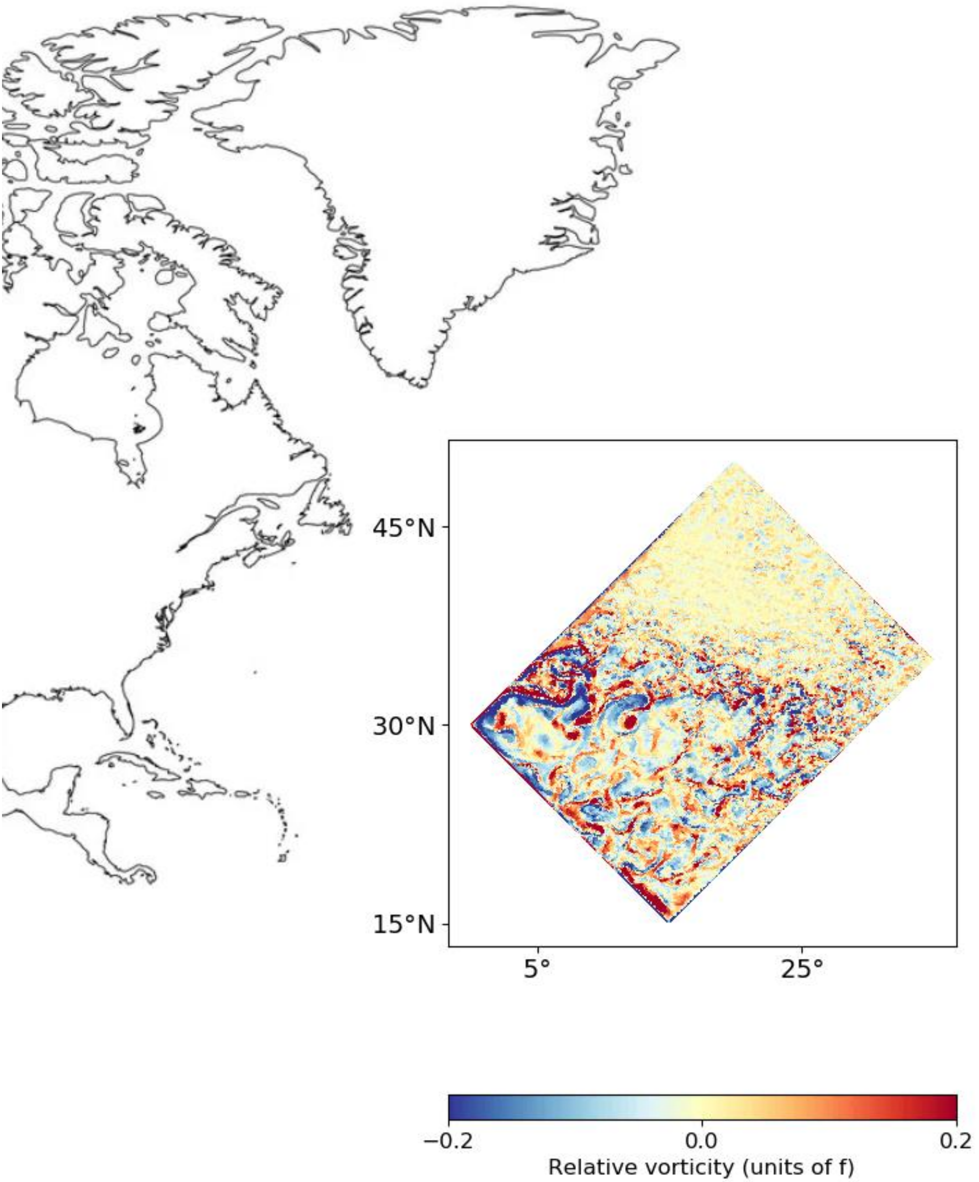

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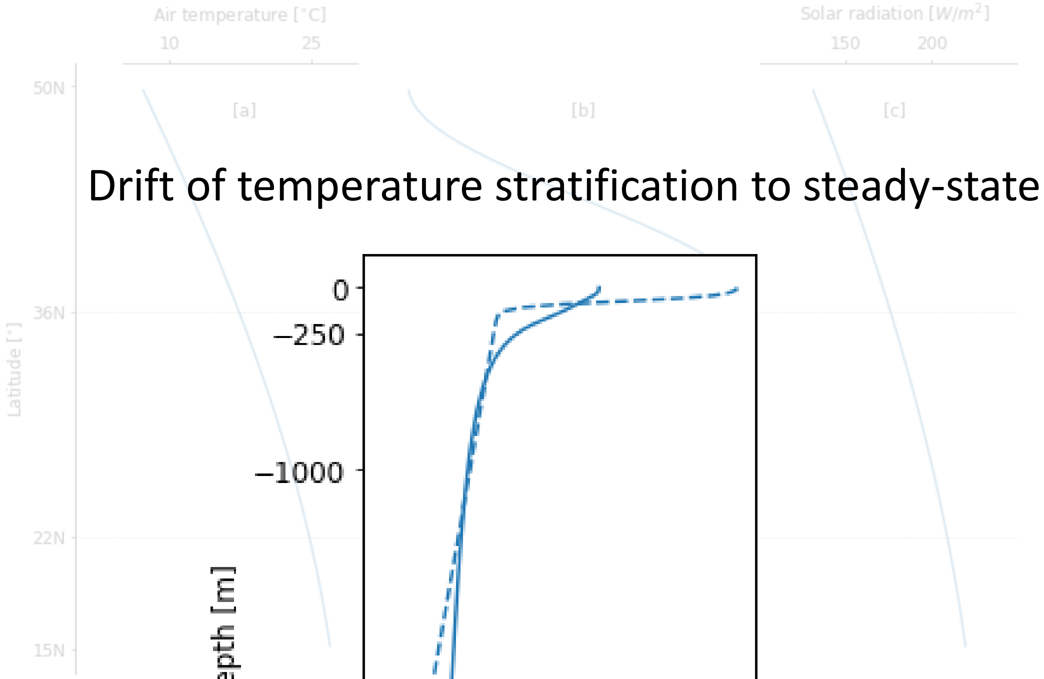
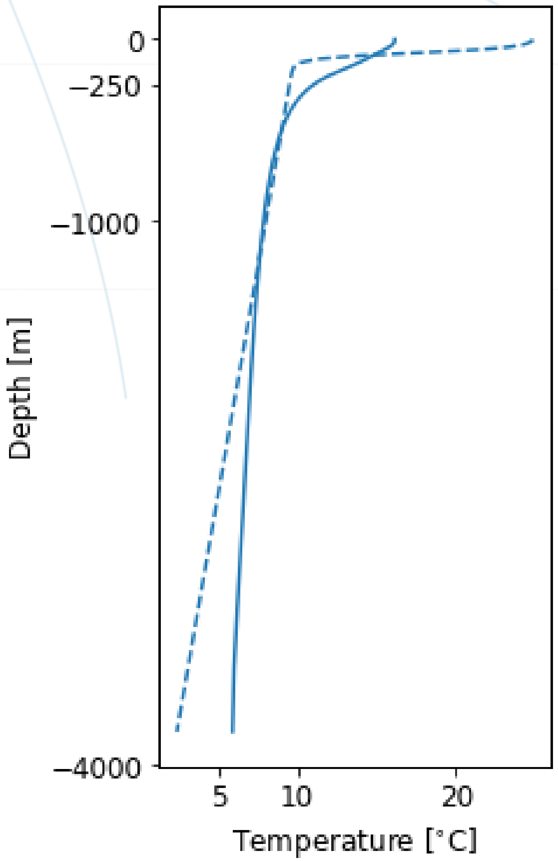


Drift of temperature stratification to steady-state



Description of simulations

- 2 setups: new double-setup and doubly-periodic channel (mean flow maintained by temperature relaxation)

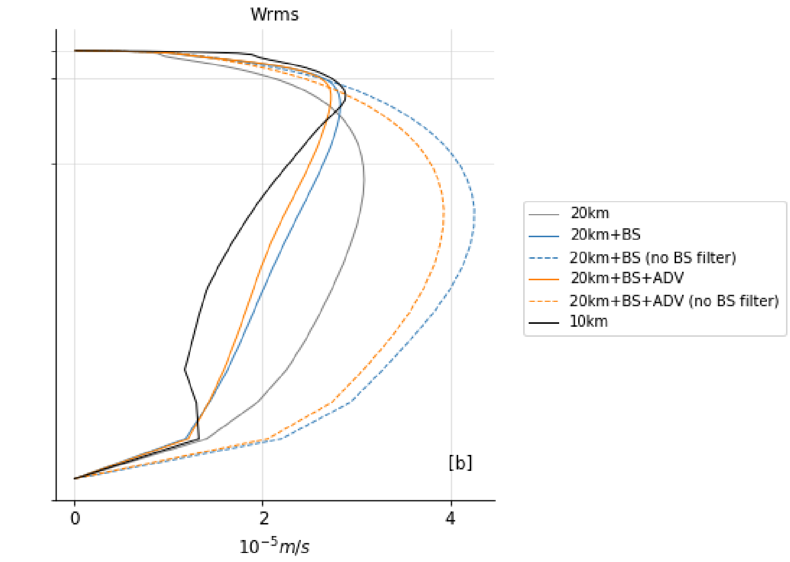
- 6 simulations for each setup to test the advection component:

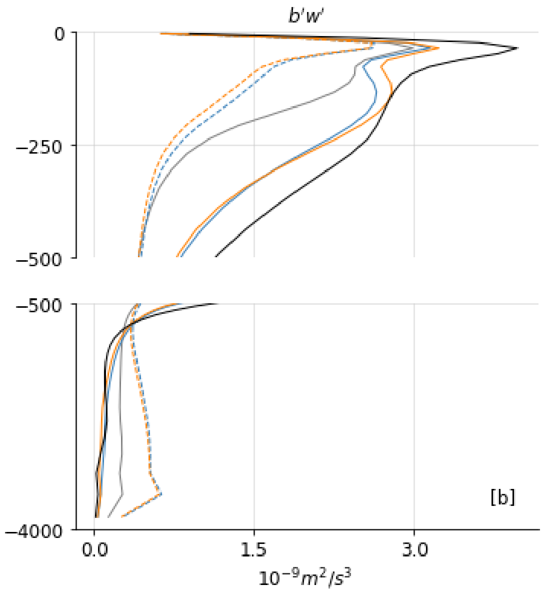
- Low resolution (LR) without backscatter
- LR with backscatter
- LR with backscatter and advection
- LR with insufficient space filtering
- LR with insufficient space filtering and advection
- High reference resolution

- 3 simulations for each setup with different intensities of the stochastic component

- 2 combined (advection+stochastic) simulations for each setup

Advection component. Highlights

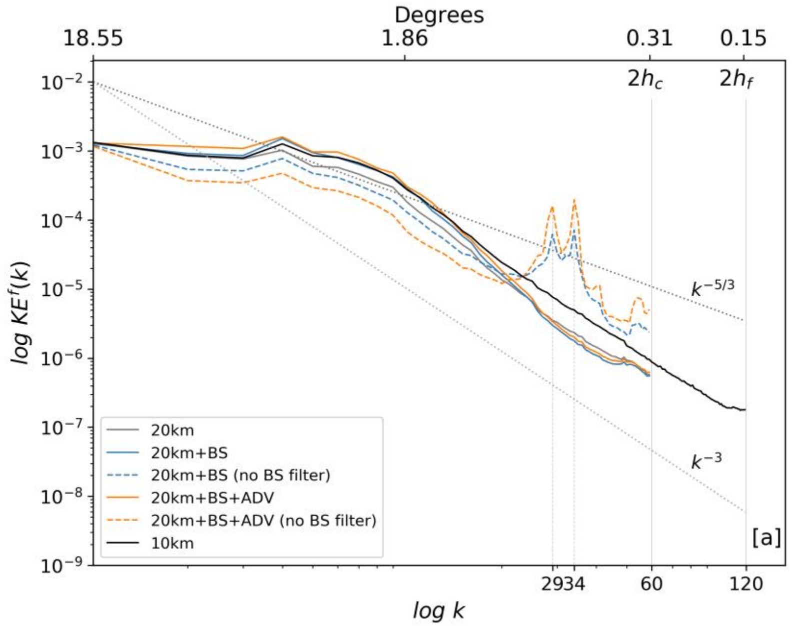


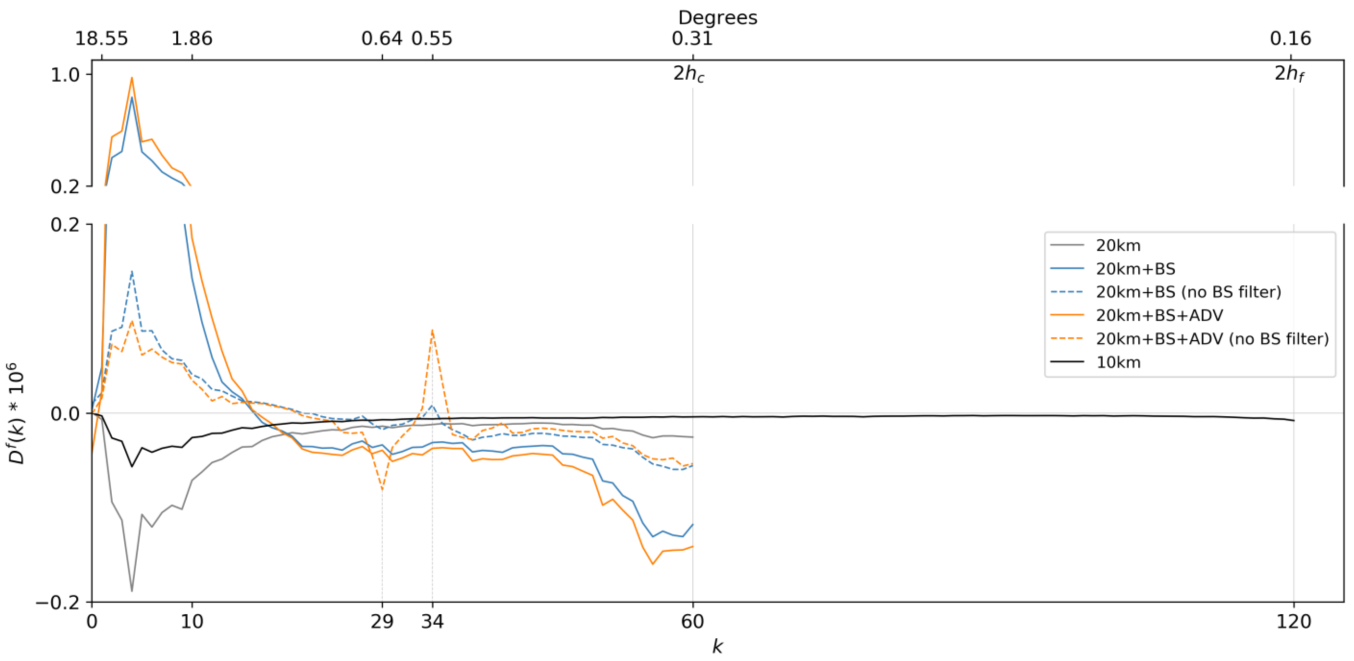


- The advection component shows the increase in buoyancy flux while decreasing vertical velocity variability

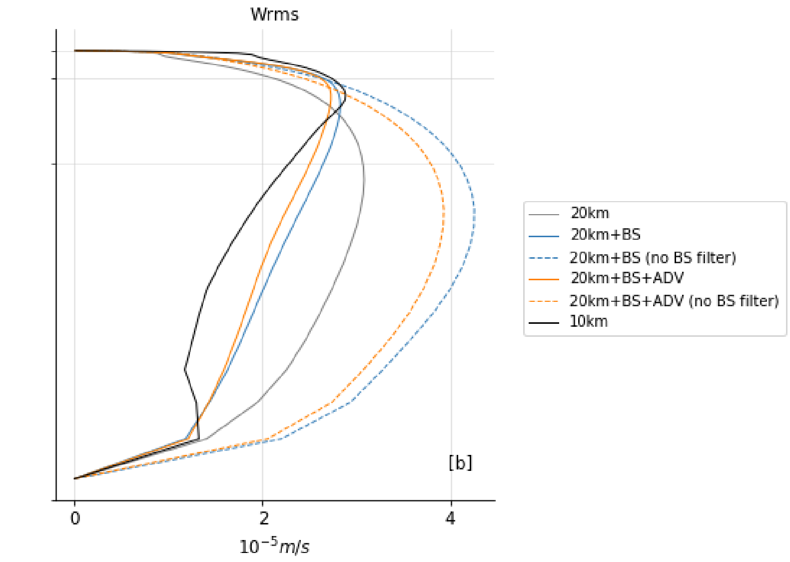
Advection component. Hightlights

- The advection component shows the increase in buoyancy flux while decreasing vertical velocity variability
- Catalyzing: more energy and more dissipation along the whole spectra
- Overall, the vertical profiles of KE and EKE shift closer to the reference simulation





Advection component. Hightlights



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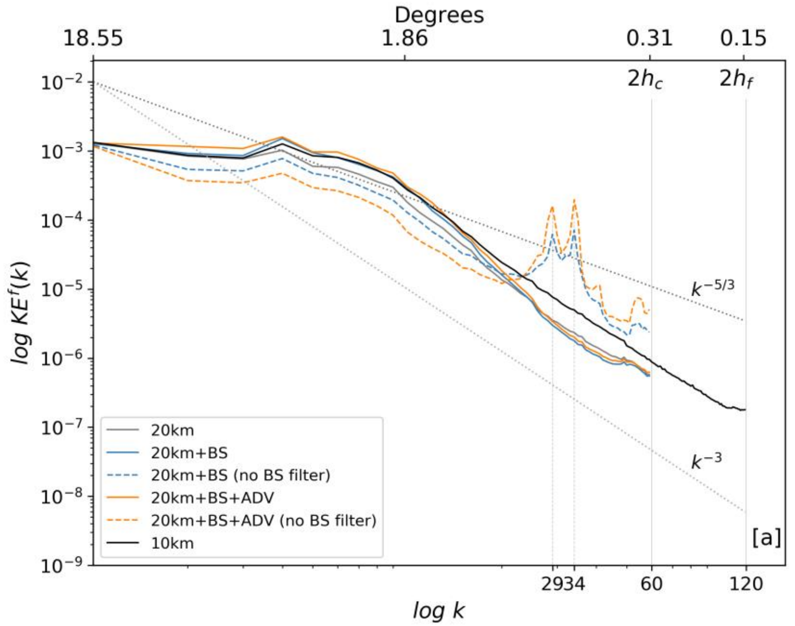
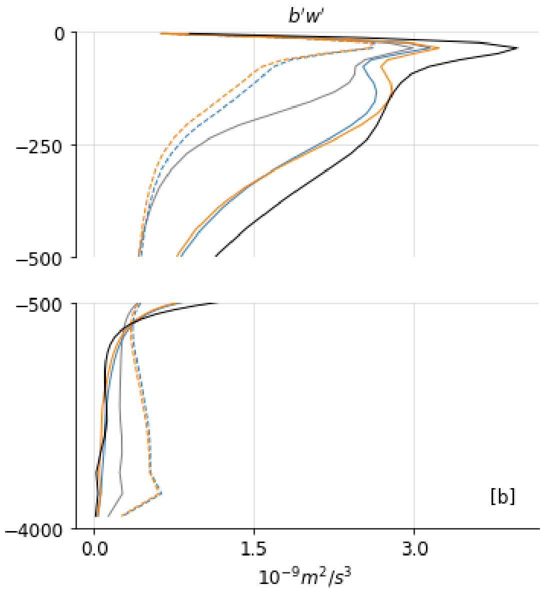
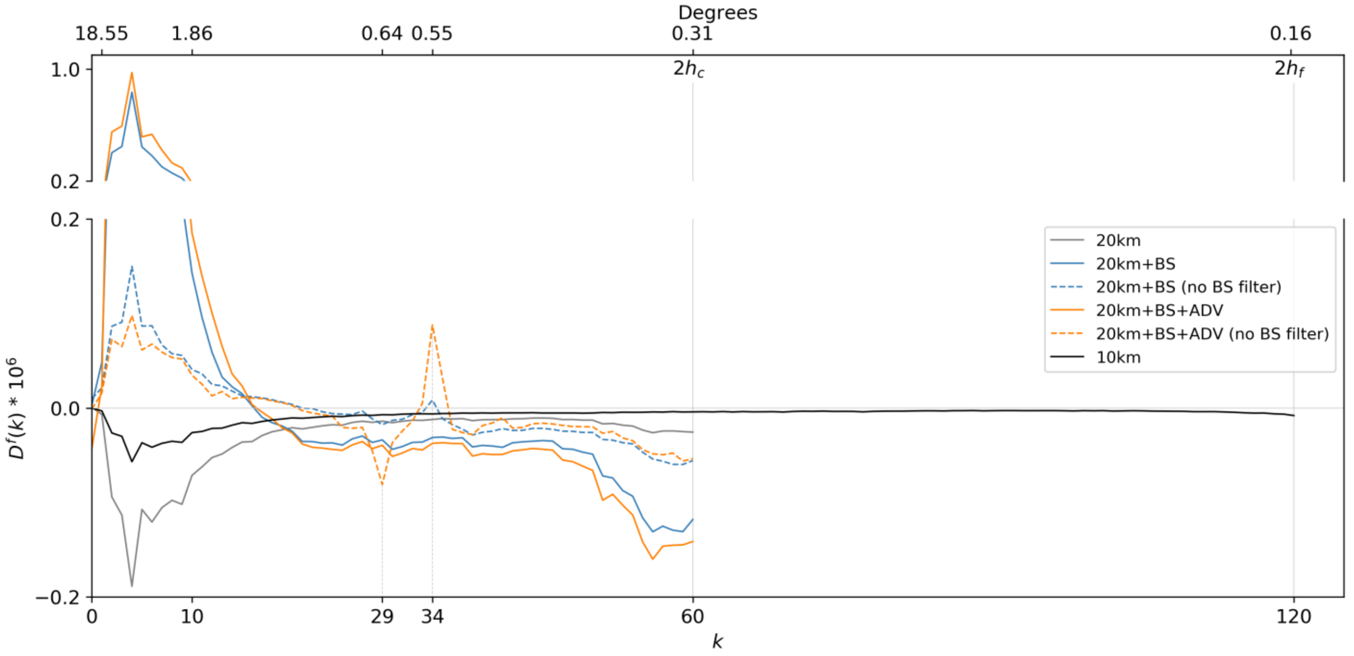


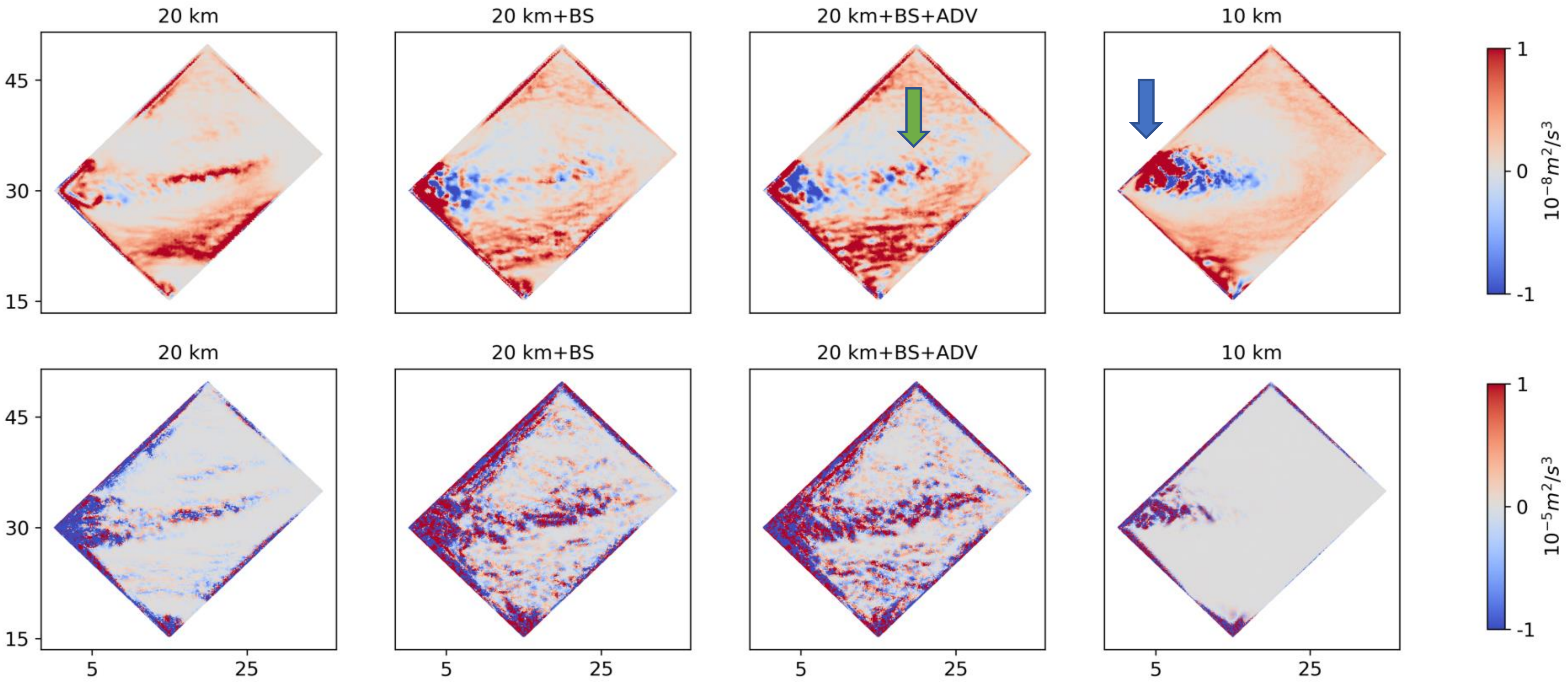


- Importance of spatial filtering: art-effects on the spectral diagnostics, distortion of vertical profiles



Advection component. Hightlights

2D buoyancy flux

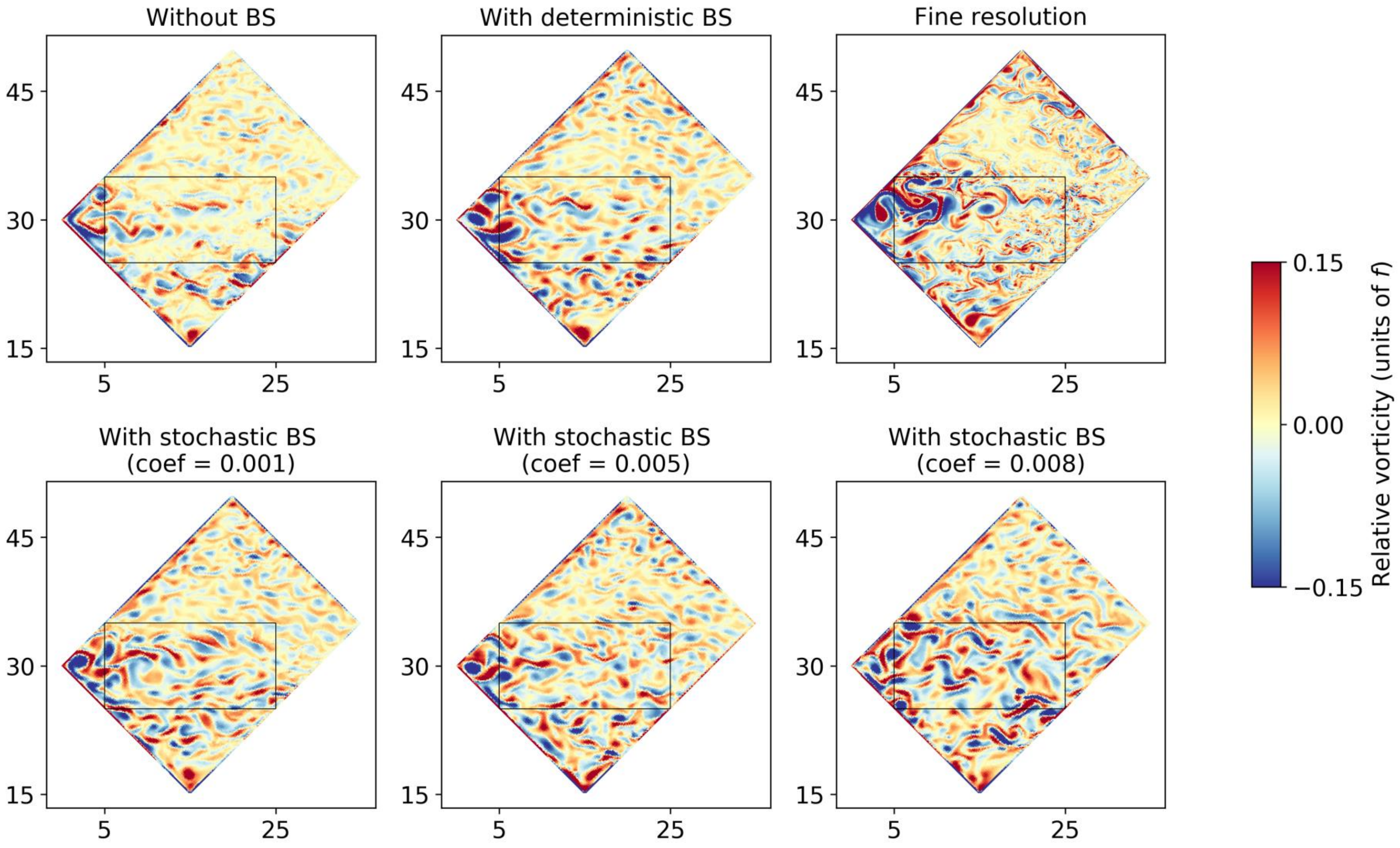


Dissipation power

Simulations with BS and BS+ADV do not produce enough energy, but as compensation, we have a prolongated pattern of excitation and degeneration along the jet.

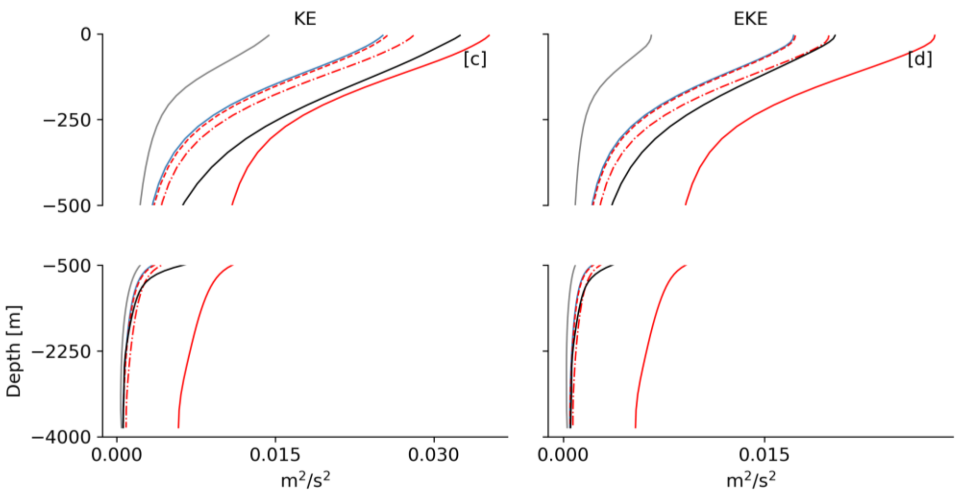
That should be there to compensate for the dissipation losses.

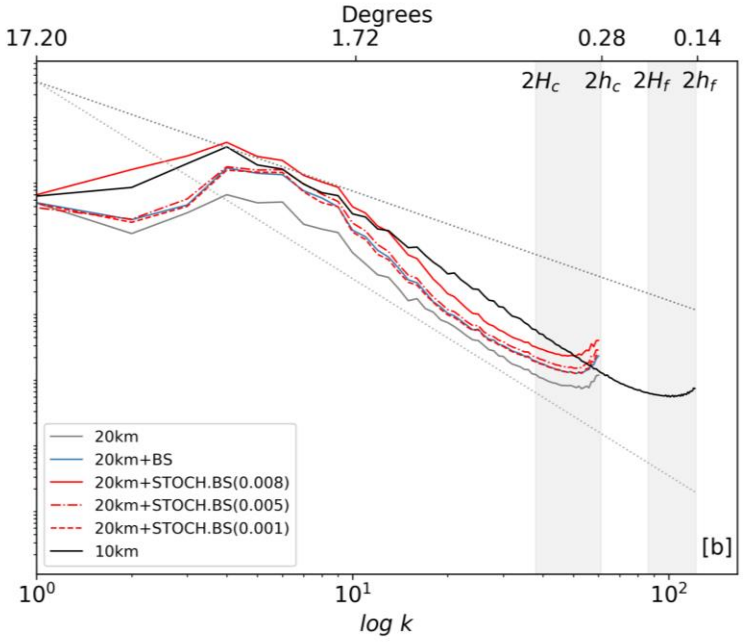
Stochastic component. Vorticity field



- Correctly filtered backscatter can «adopt» strong stochastic component
  - BS overperforming below the jet (situation getting better with the middle-intensity stochastic term)
  - With middle-intensity stochastic component jet tends to align along the reference position

Stochastic component. Highlights



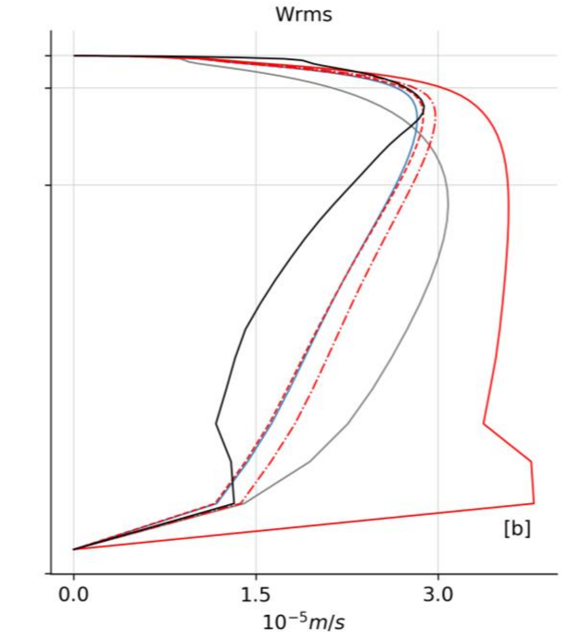


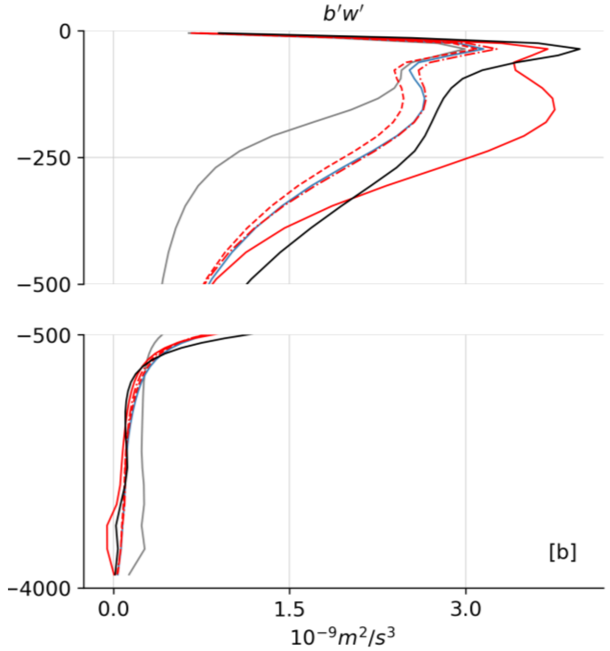
- Importance of complete diagnostics: an example with the high-intensity stochastic component

- Middle-intensity stochastic component aligns towards reference simulation

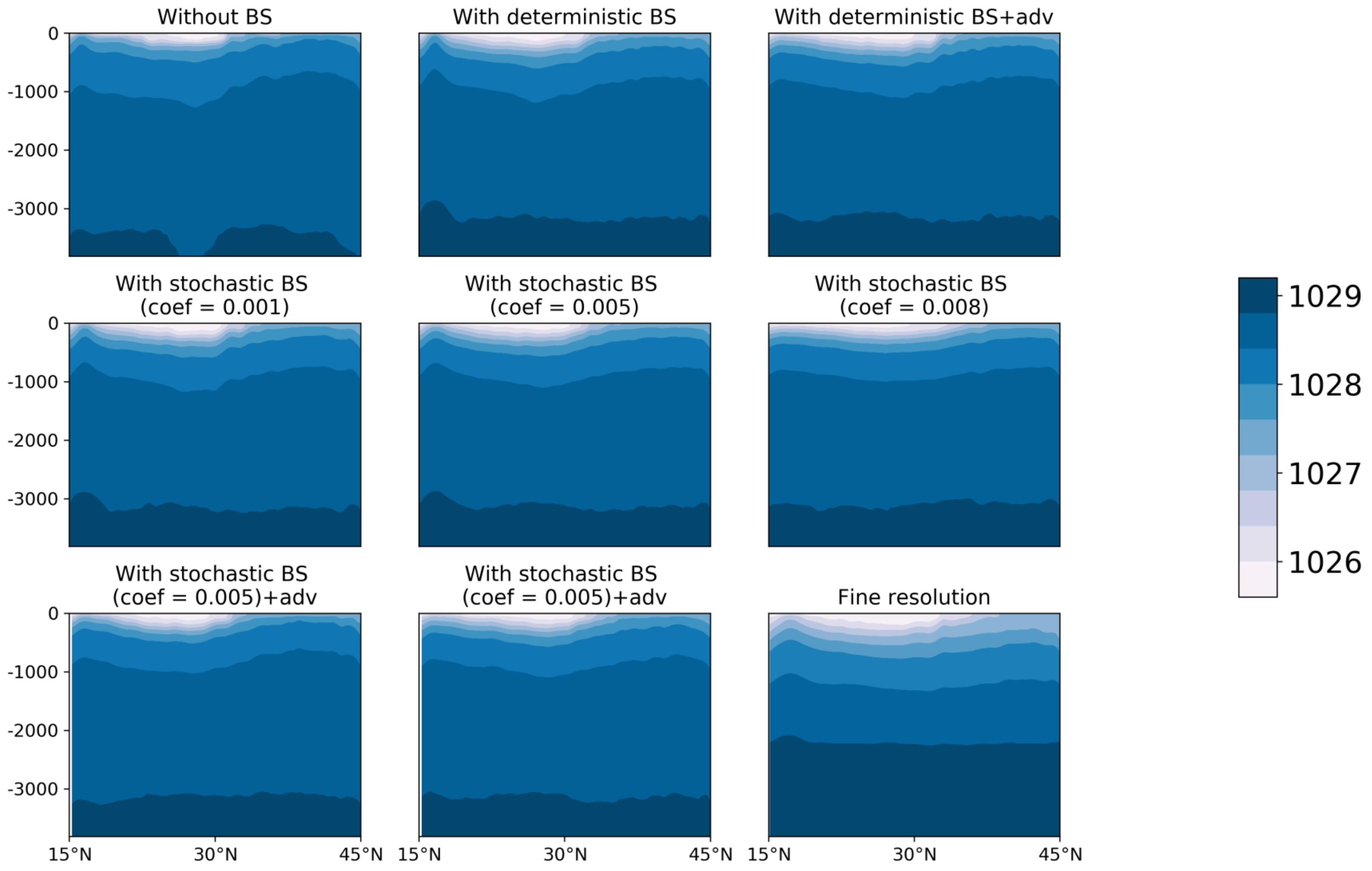
Stochastic component. Highlights

- Importance of complete diagnostics: an example with the high-intensity stochastic component
- Middle-intensity stochastic component aligns towards reference simulation
- Strong anomalies of the large-amplitude noise in the vertical profiles





Combined simulations (subgrid advection + stochastics)



- The potential drawback of backscatter as a source of diapycnal mixing was not confirmed
- Steady-state stratification of high resolution is different in its shape from low-resolution simulation
- Similar flattening of isopycnals both with advection and stochastic components

Conclusion

- Subgrid advection shows an improvement in vertical profile diagnostic and spectral diagnostic, mostly as a catalyst in the right direction

- Insufficient smoothed backscatter could be used for the detailed diagnostics of VISC and BS operators

- The efficiency of the stochastic component should be considered only as a complex diagnostics (to avoid anomalies)

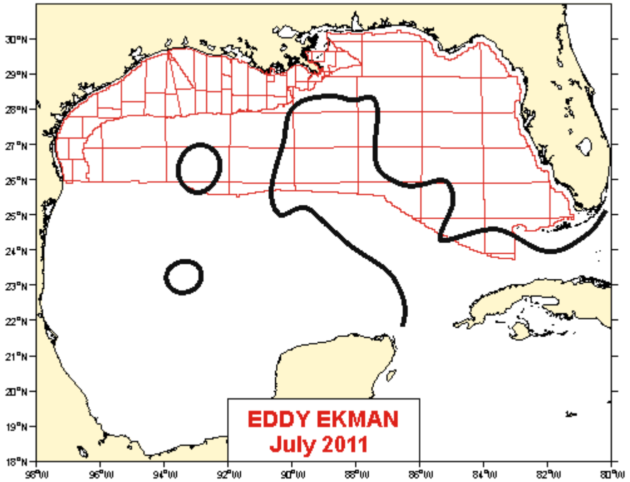
- The recommended amplitude of stochastic term might be given as a range and depends on the number of EOFs (the more small-scale EOFs, the more noise is potentially excited)

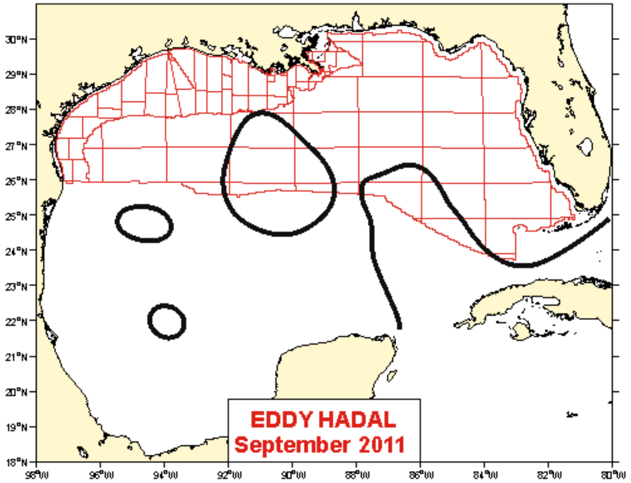
Link with the GM-parametrization (current work):

- Interconnections between the diffusivity coefficient of GM and backscatter scales/intensity in the double-gyre setup

Thank you for your attention

Horizon Marine, the oceanographic company, provides an eddy-tracking in the Gulf of Mexico and gives the names to big/middle-size eddies





Eddy Name	Size	Year
Wilde II	Small	01/22 - present
Wilde	Medium	09/21 - present
Verne	Large	08/21 - 12/21