High-Resolution North Atlantic Ocean Modeling: Impact of bathymetry and atmospheric forcing

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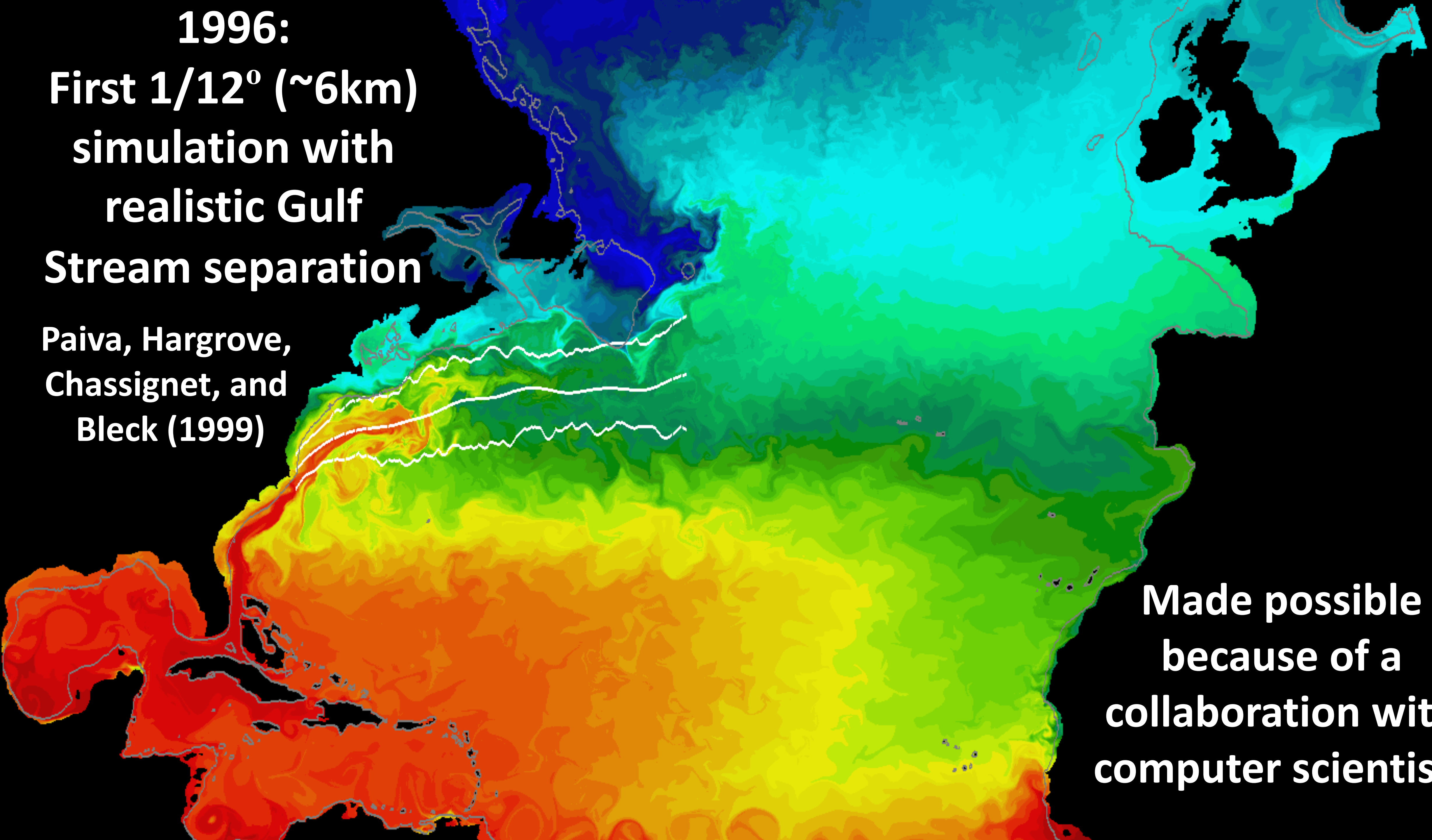
1996:
First 1/12º (~6km) simulation with realistic Gulf Stream separation

Paiva, Hargrove, Chassignet, and Bleck (1999)



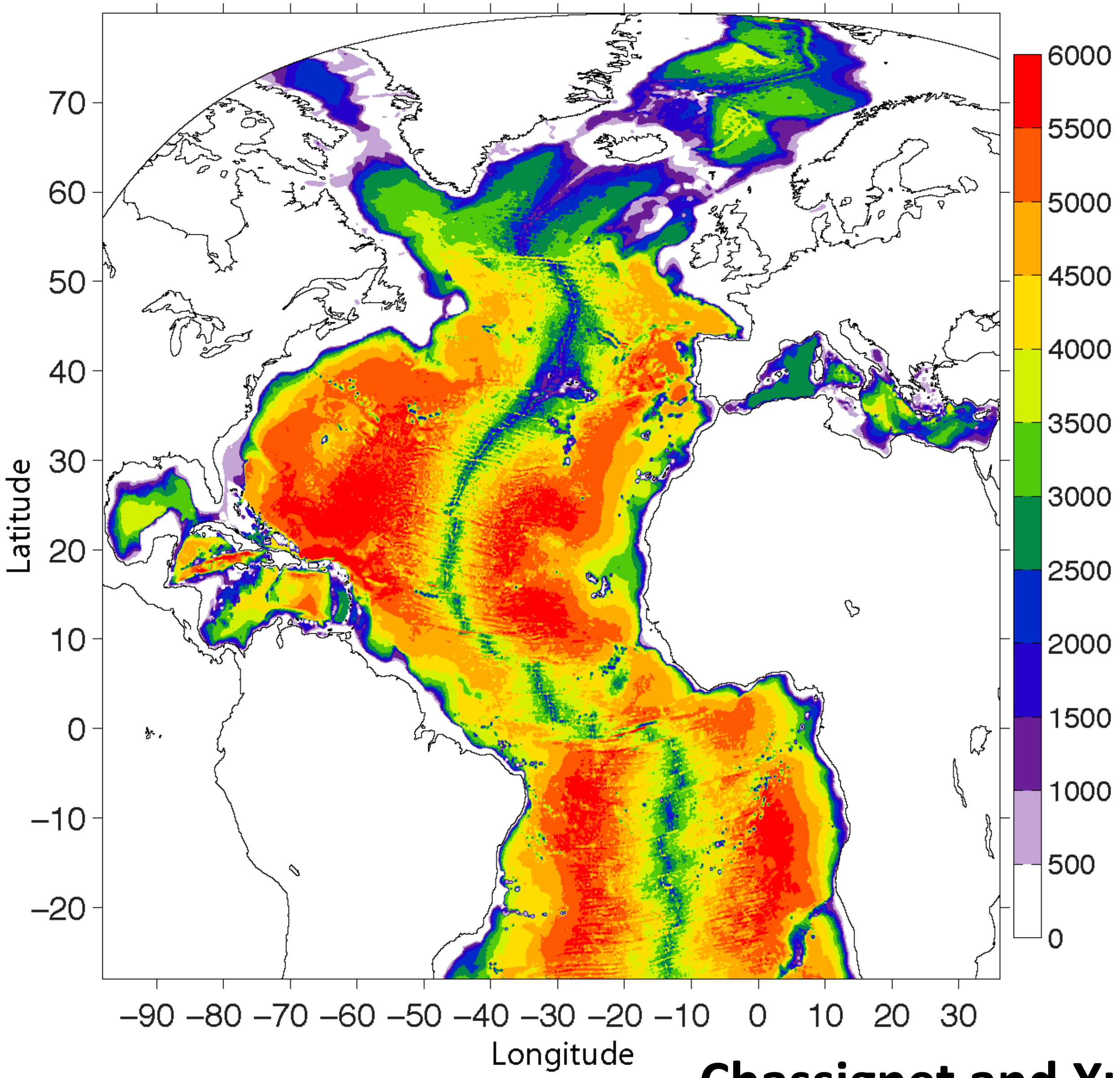
Made possible because of a collaboration with computer scientists

- Why the improvement at $\Delta x > 1/10°$?
  - First baroclinic Rossby radius of deformation is mostly resolved => good representation of baroclinic instability processes
  - Flows may exceed a critical Reynolds number (Özgökmen, Chassignet, and Paiva, 1997)
- However, identifying the dynamics responsible for western boundary current separation and penetration continues to be a challenge
- Does not work equally well in all models

Should we keep increasing the horizontal resolution?

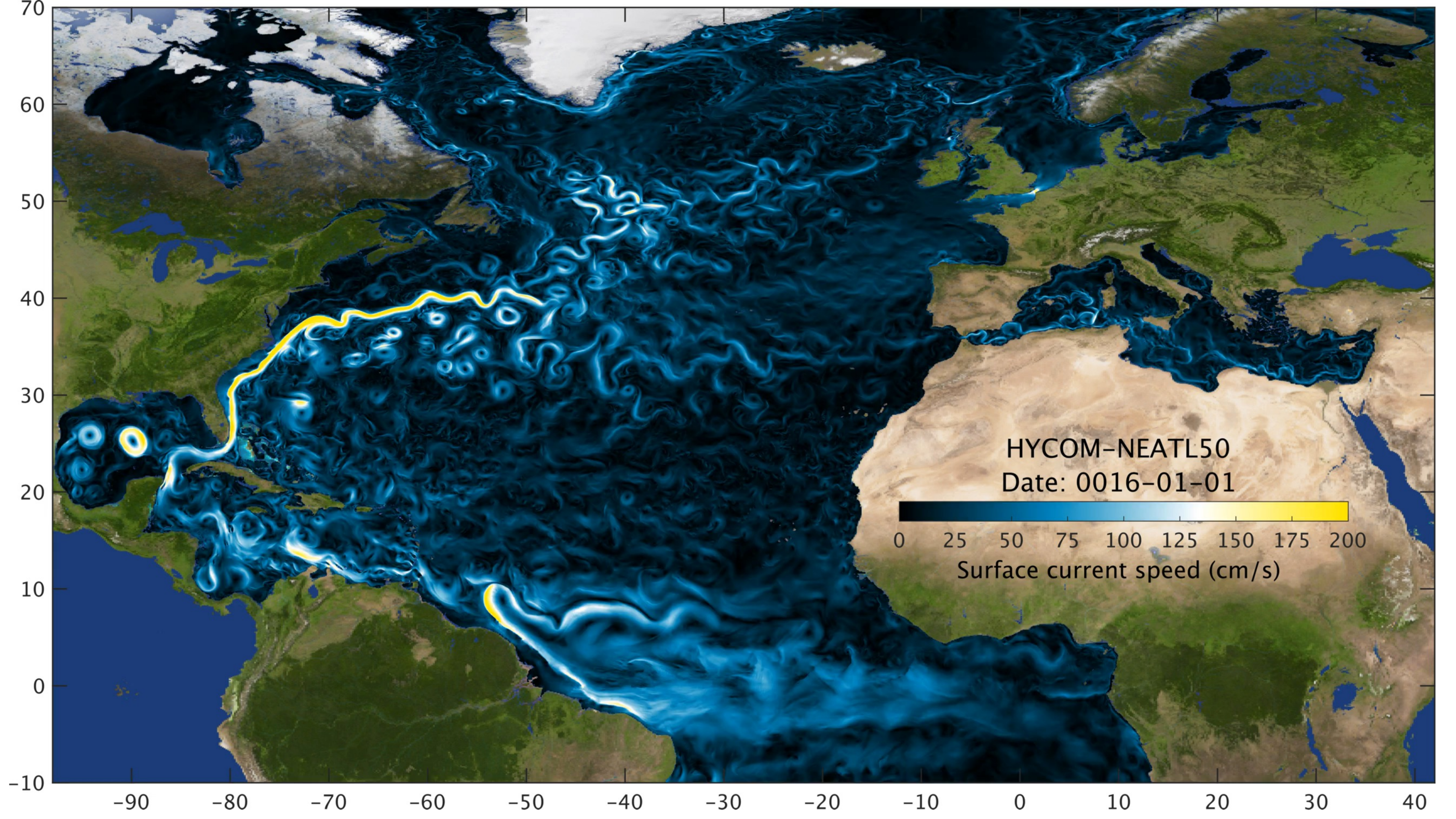
- **1/12°, 1/25°, 1/50°?**
- **What is the added value?**

- **North Atlantic HYCOM configuration**
- **Closed boundaries**
- **Climatological forcing with daily variability**
- **Viscosity as a function of grid spacing (1/12° and 1/25°)**
- **Same viscosity for 1/25° and 1/50°**



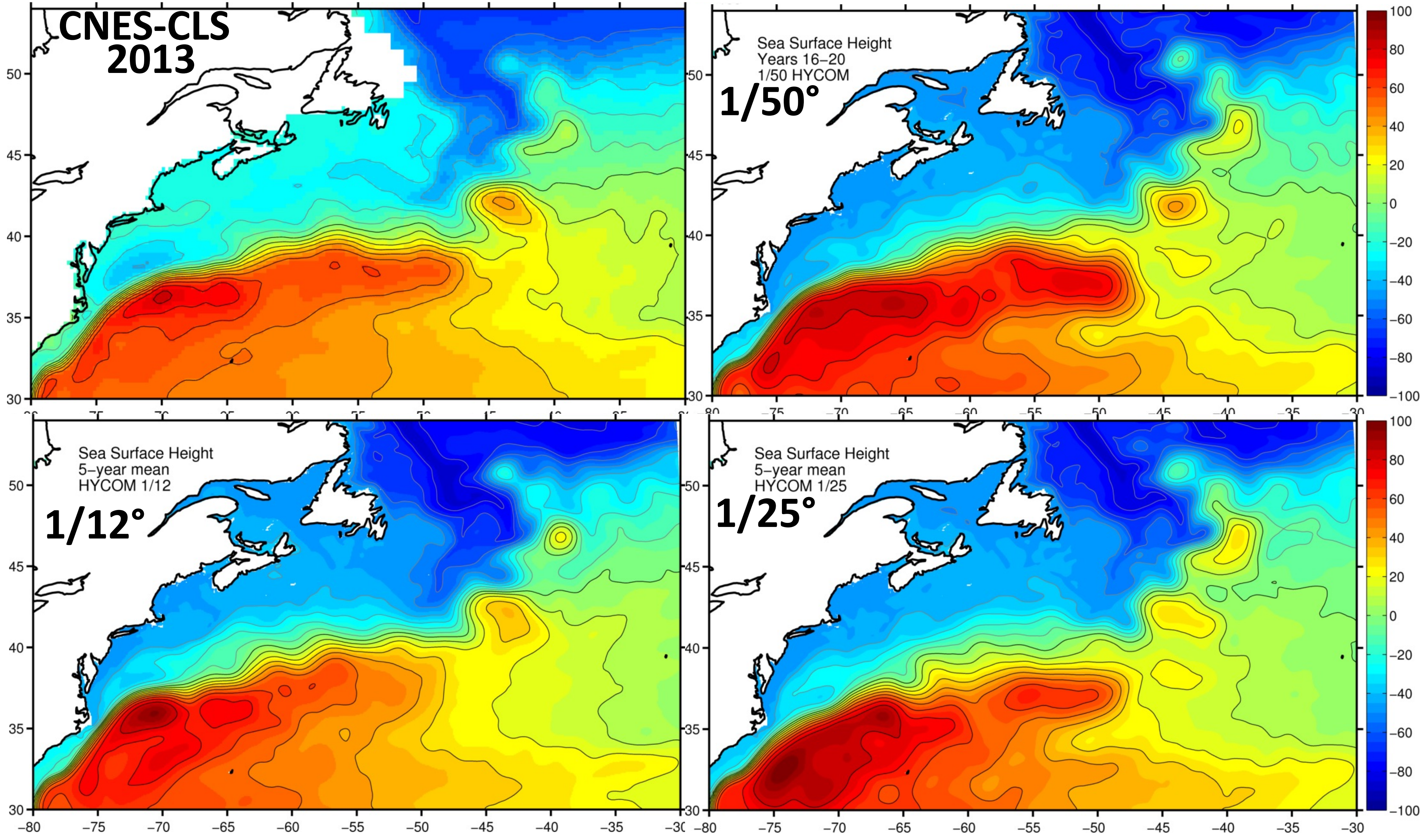
Chassignet and Xu (2017, JPO)

500k CPU-hours per model year for the 1/50°

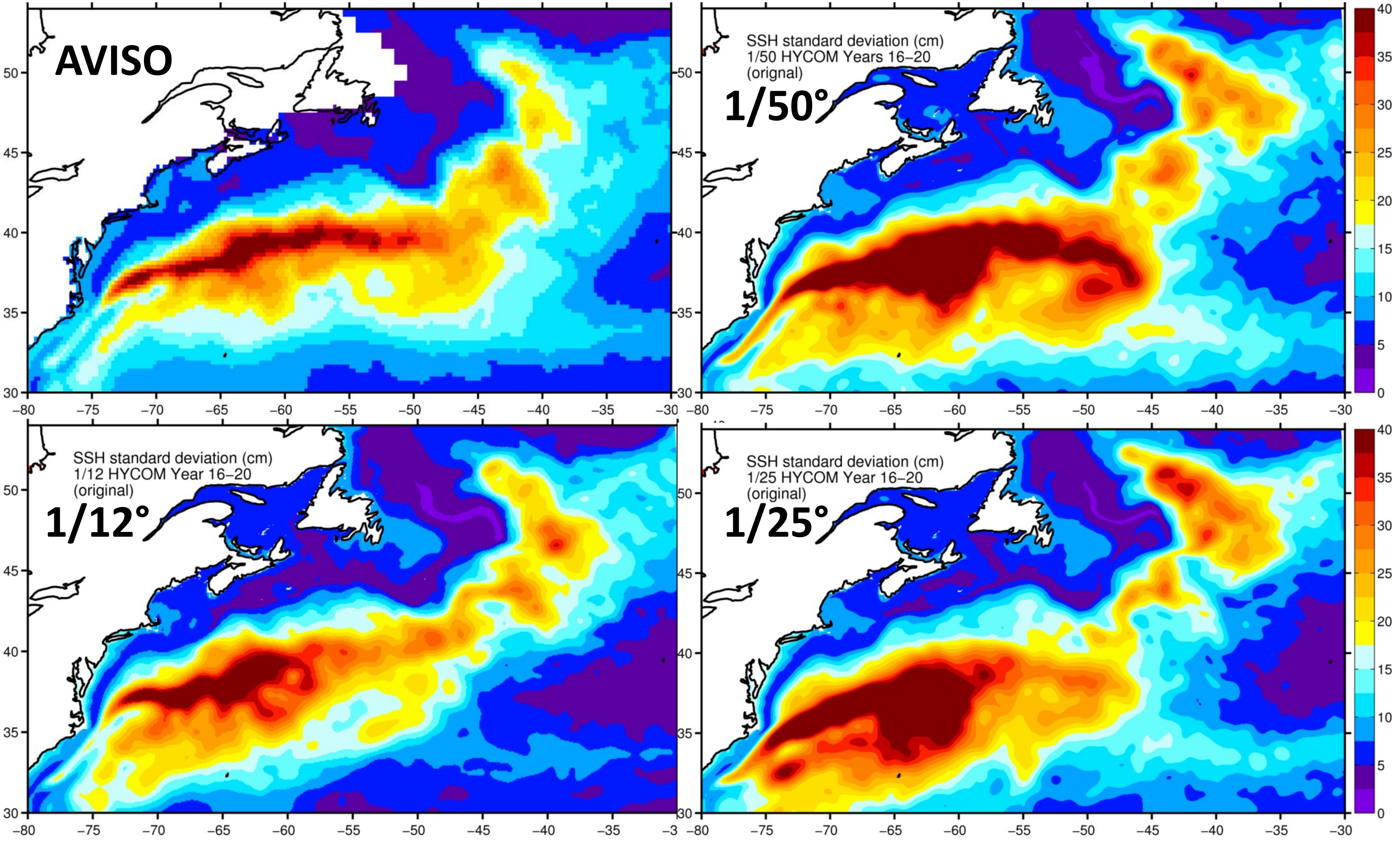


HYCOM-NEATL50
Date: 0016-01-01
0 25 50 75 100 125 150 175 200
Surface current speed (cm/s)
70
60
50
40
30
20
10
0
−10
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40

Mean SSH (Years 16-20)



SSH variability (Years 16-20)



Increased horizontal resolution

⇒ **Horizontal resolution of ~1/10^{o} led to a significant improvement in western boundary current separation (Smith et al., 2000)**

⇒ **Possible regime shift at 1/50^{o} when the submesoscale (~10 km) is resolved and the nonlinear effects of the submesoscale eddies intensifies the midlatitude jet and increases its penetration eastward**

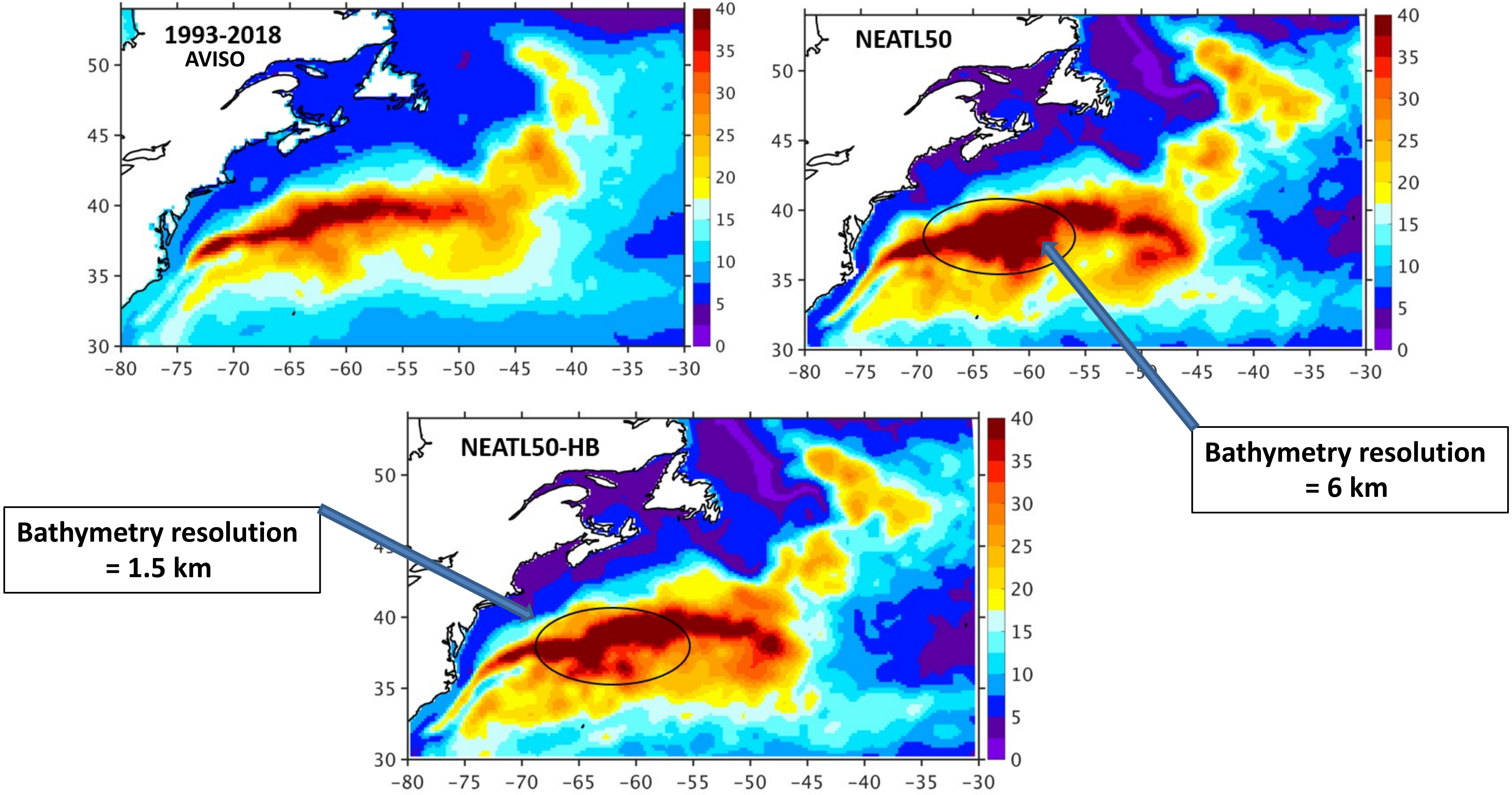
Chassignet and Xu (2017, JPO)

Major discrepancies when comparing to observations

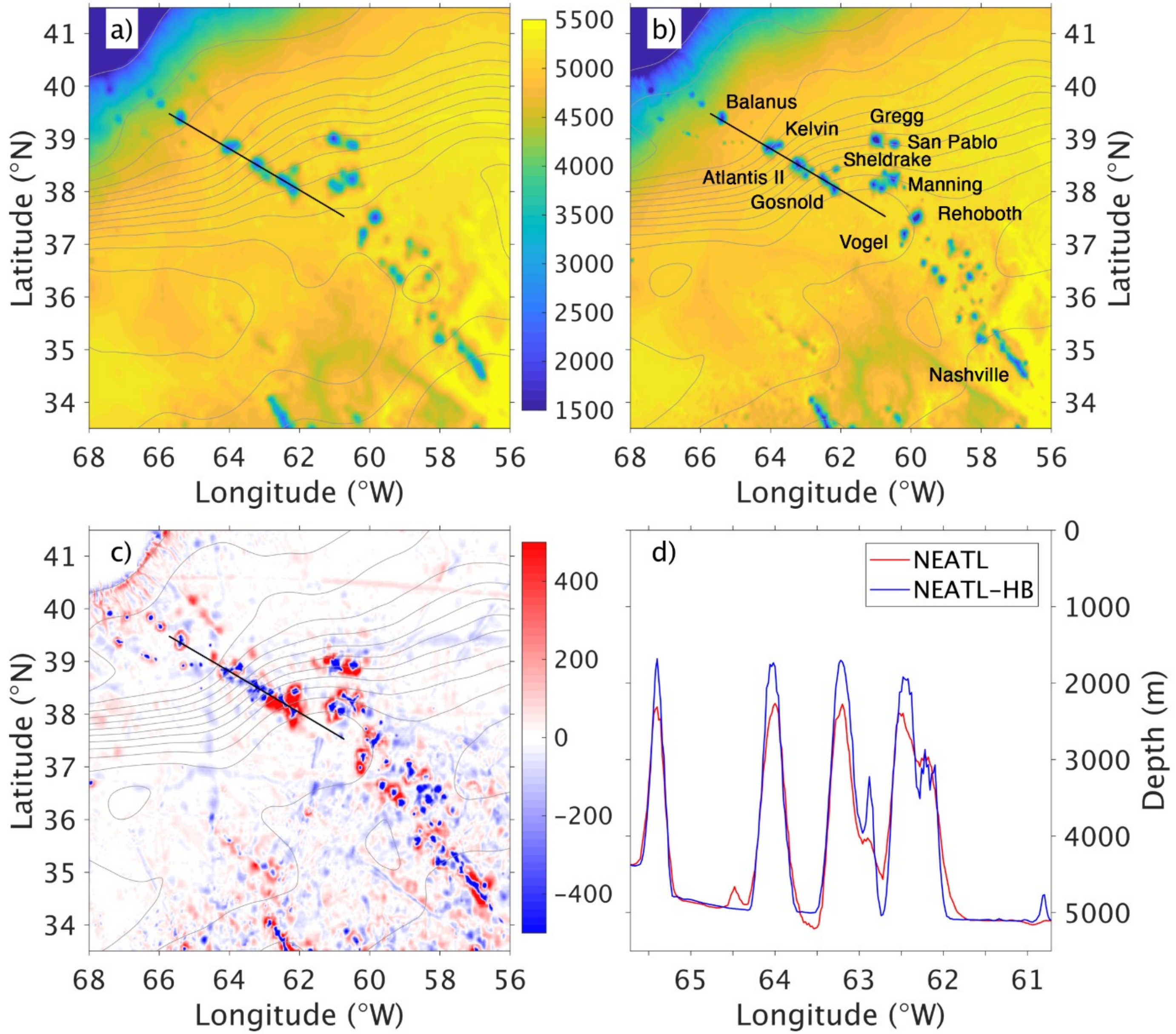
#1: High EKE around the New England Seamount Chain

#2: High EKE upstream the New England Seamount Chain

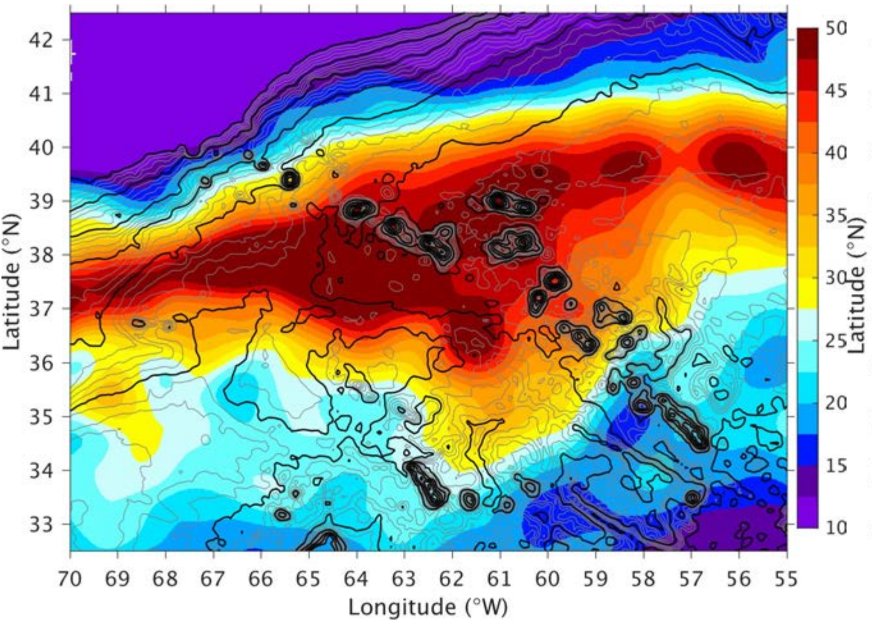
Discrepancy # 1: Higher EKE around the NESMC



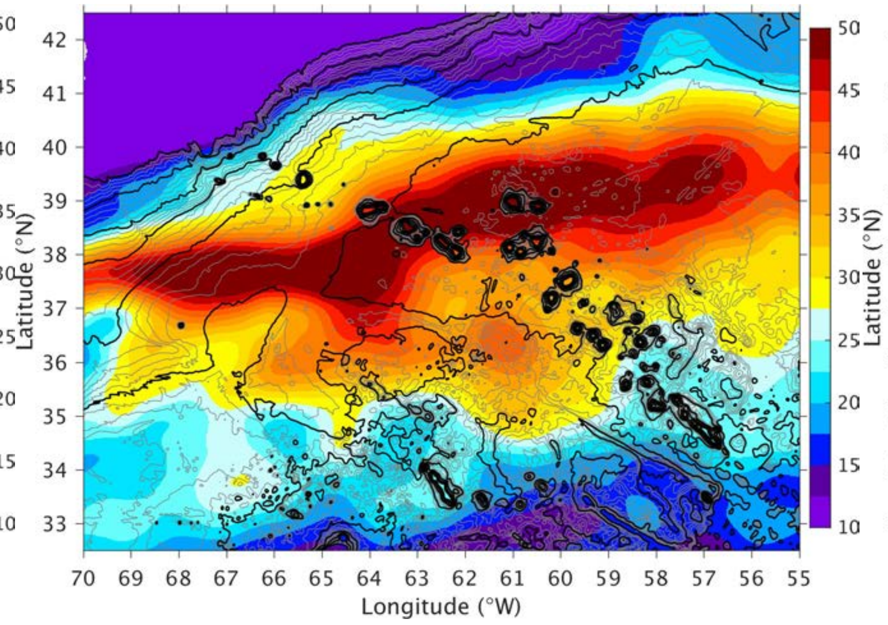
Difference in bathymetry



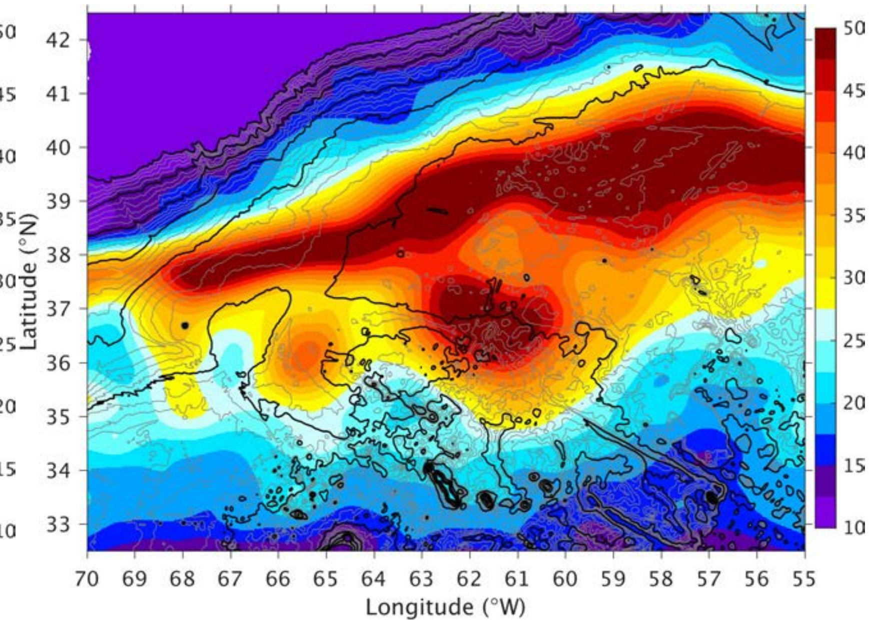
Eddy Kinetic Energy



Coarse bathymetry



Fine bathymetry

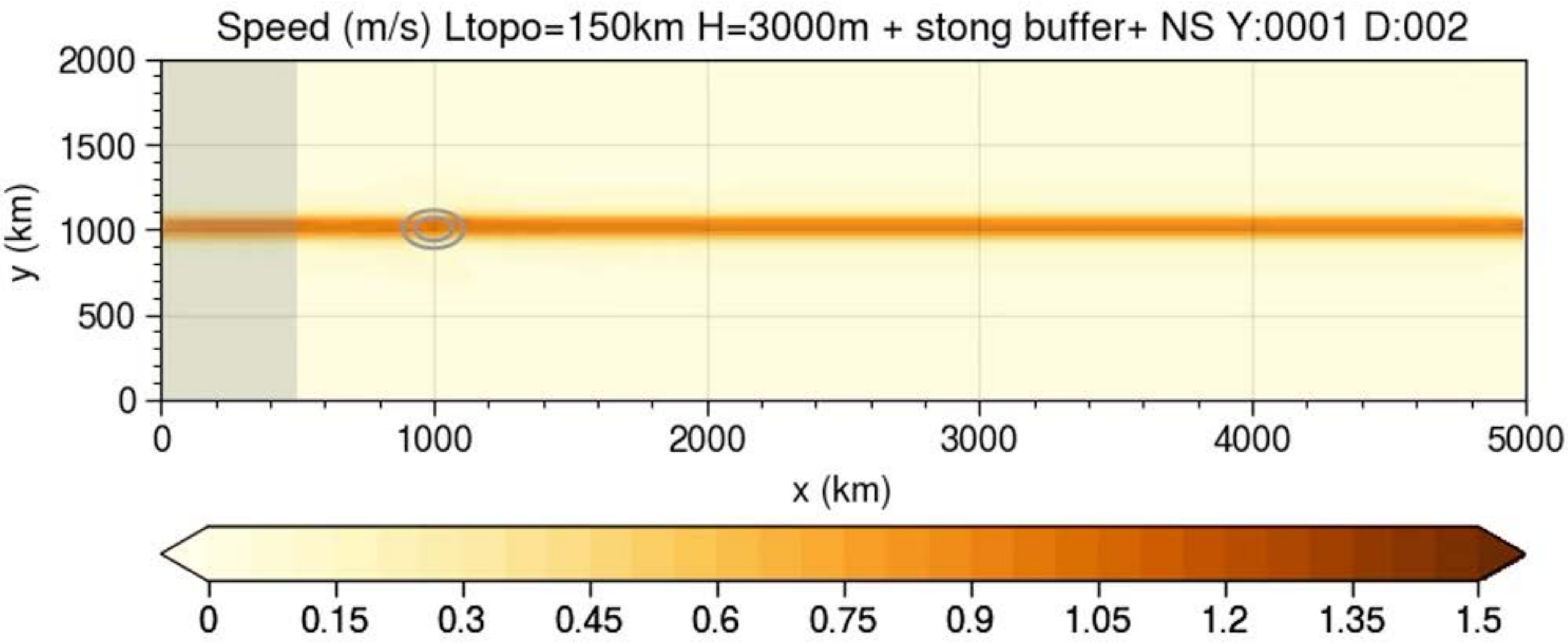


No NESC

- **Clear impact of the New England Seamount Chain on the Gulf Stream pathway and variability**
- **Can we quantify/document this impact? => Idealized studies**

Idealized HYCOM channel configuration

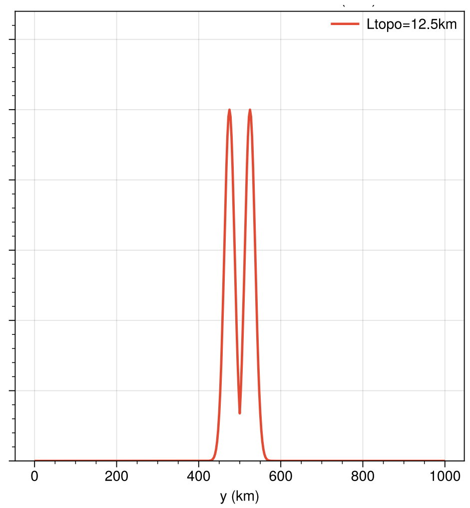
$H = h_{max}\, e^{(x-x_0)/2W^2}$

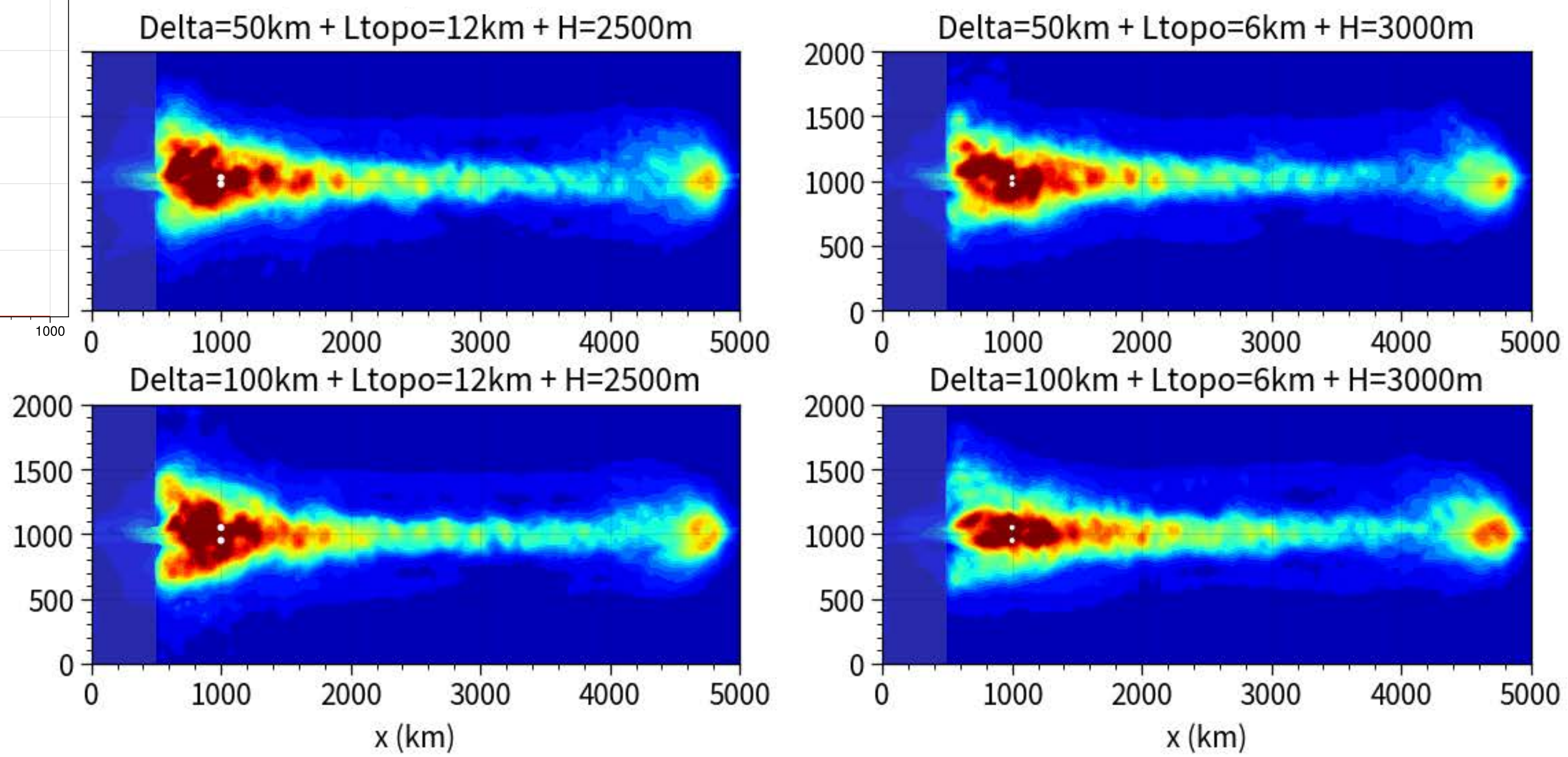


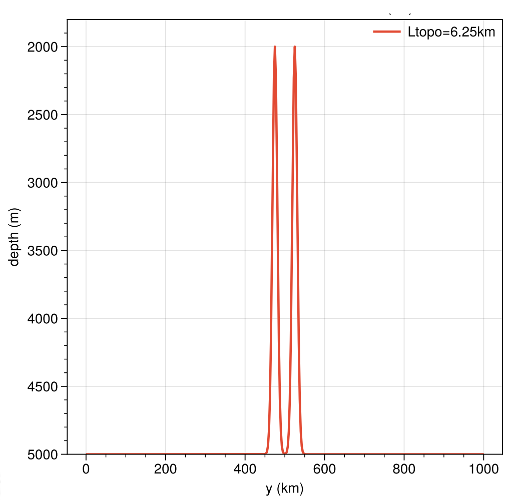
2 layers (1000 m and 4000 m); 800 m interface displacement, .8 m/s jet

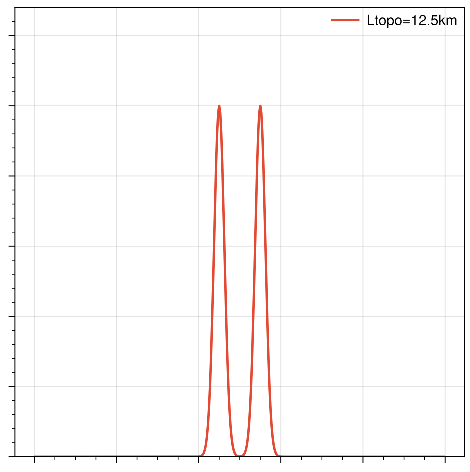
Δx=10km

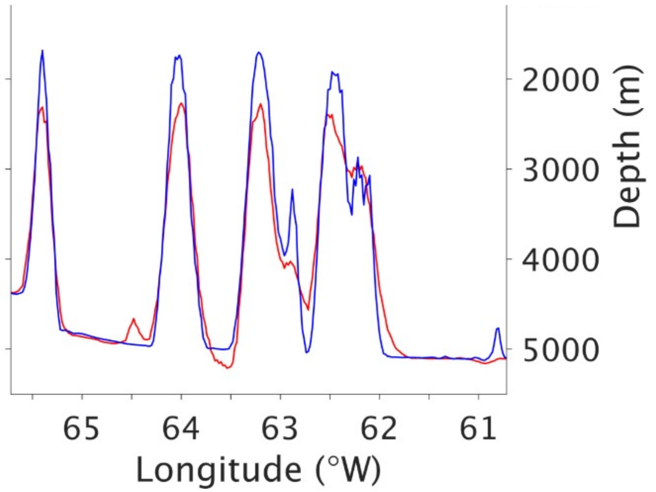
Reduced EKE with narrow seamounts



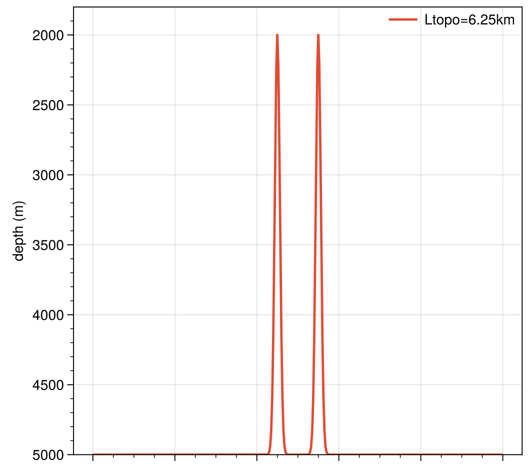




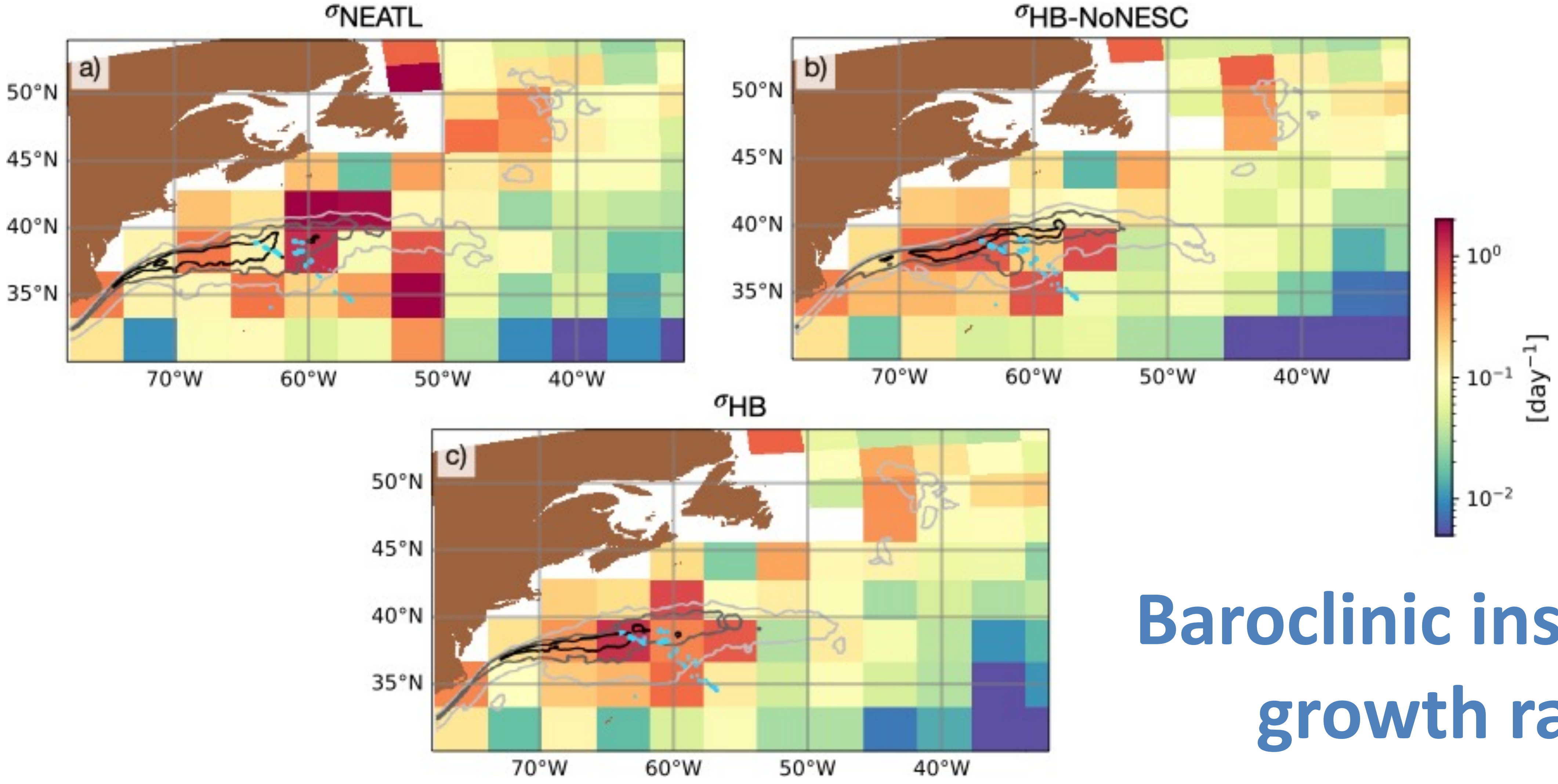




Δx=1km



Hypothesis: Narrow seamounts => less impact on the upper layer jet => increased stability



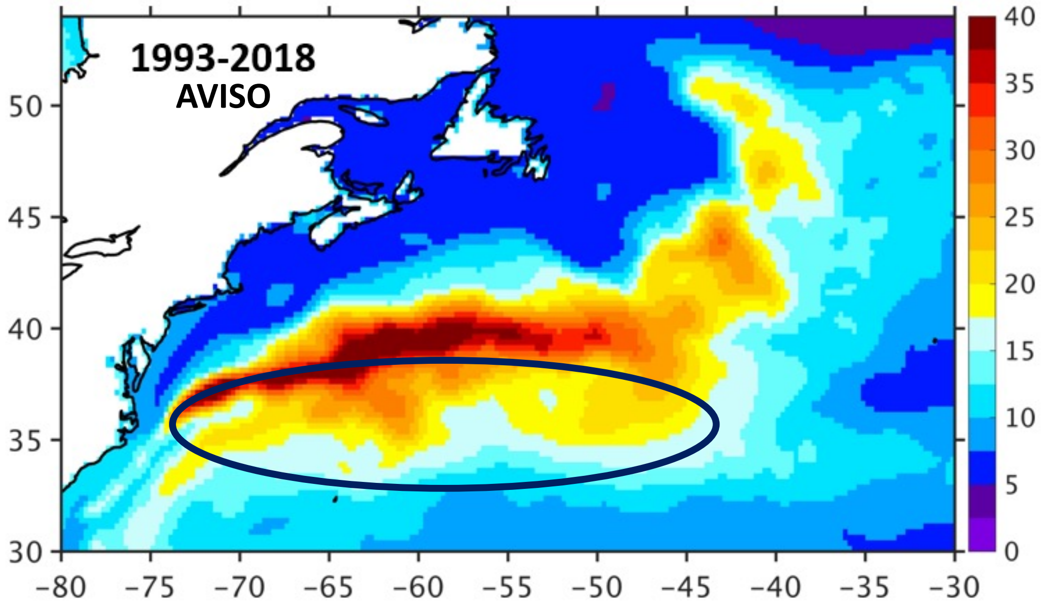
Baroclinic instability growth rates

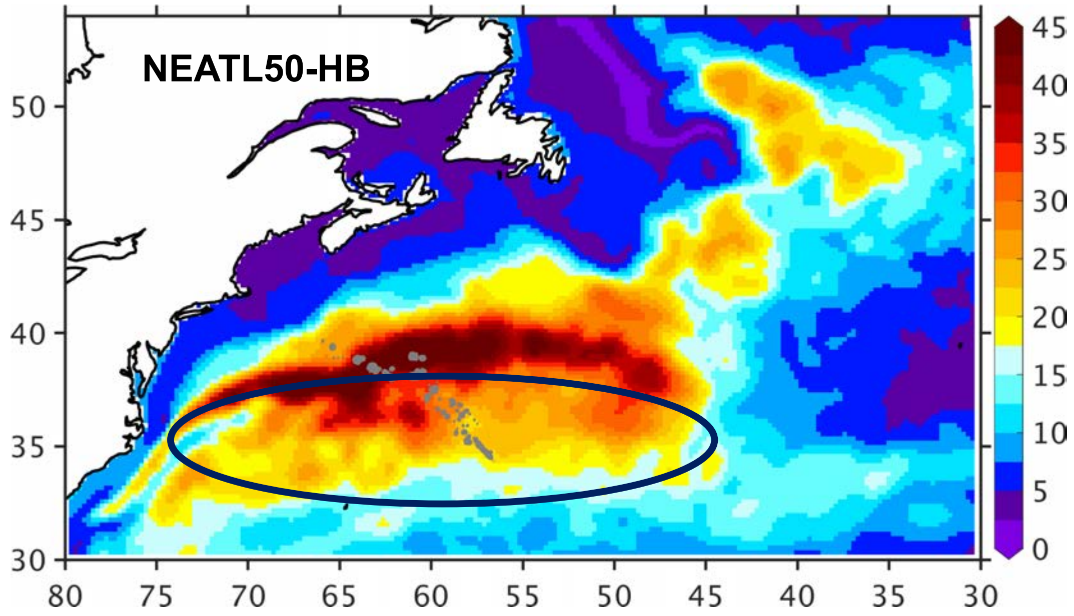
Linear quasi-geostrophic eigenvalue problem on a β-plane (background flow: 5-year temporal mean, 4°x4°)

Conclusion #1: Bathymetry

A proper representation of the fine scale structure of the New England Seamount Chain has a much more profound impact on the Gulf Stream pathway and variability than one would have a priori anticipated (Chassignet et al., 2023, JPO).

Discrepancy # 2: Higher EKE upstream of the NESC and south of Gulf Stream





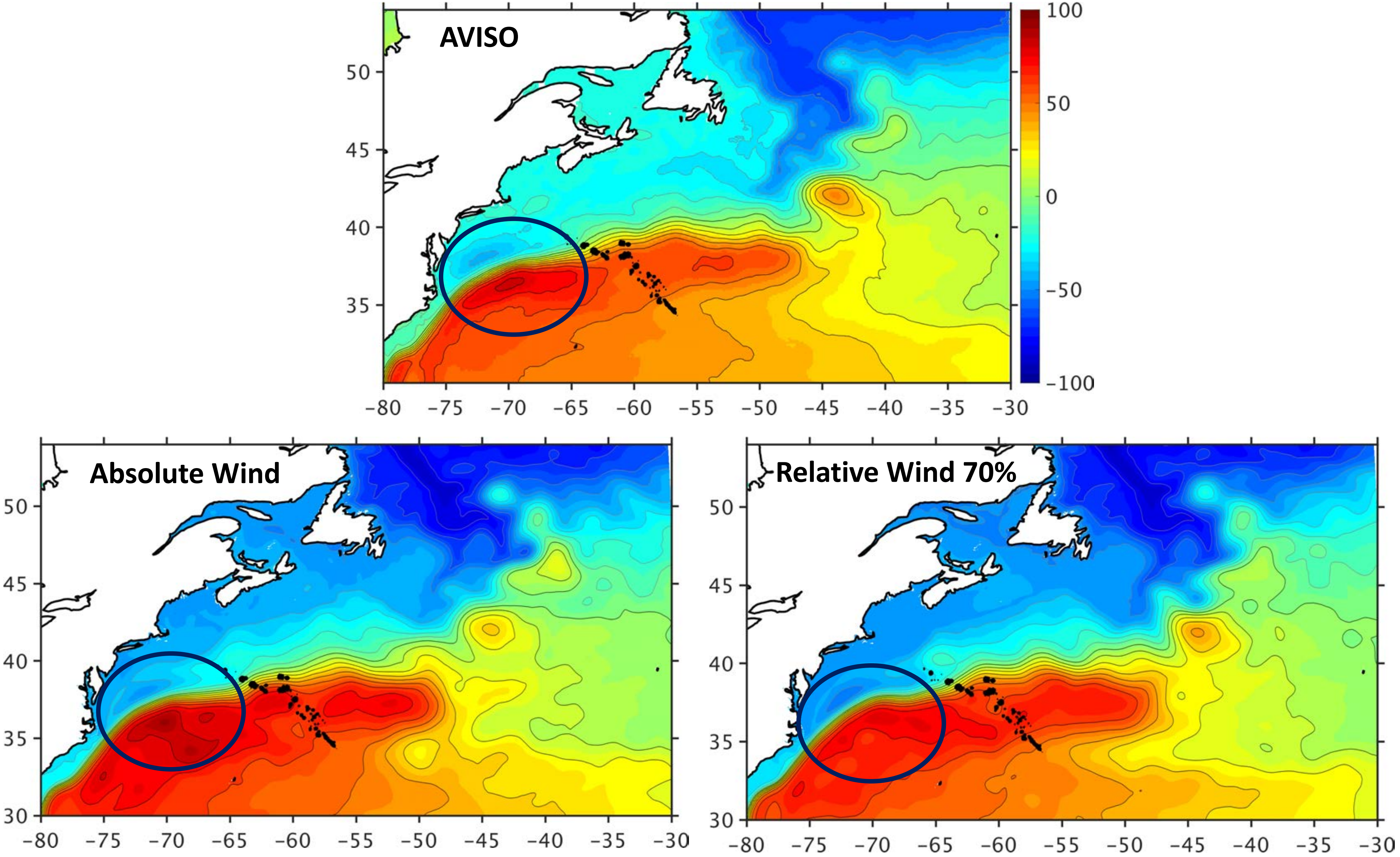
- Viscosity as a function of grid spacing (1/12° and 1/25°)
- Same viscosity for 1/25° and 1/50°

Absolute versus relative wind forcing

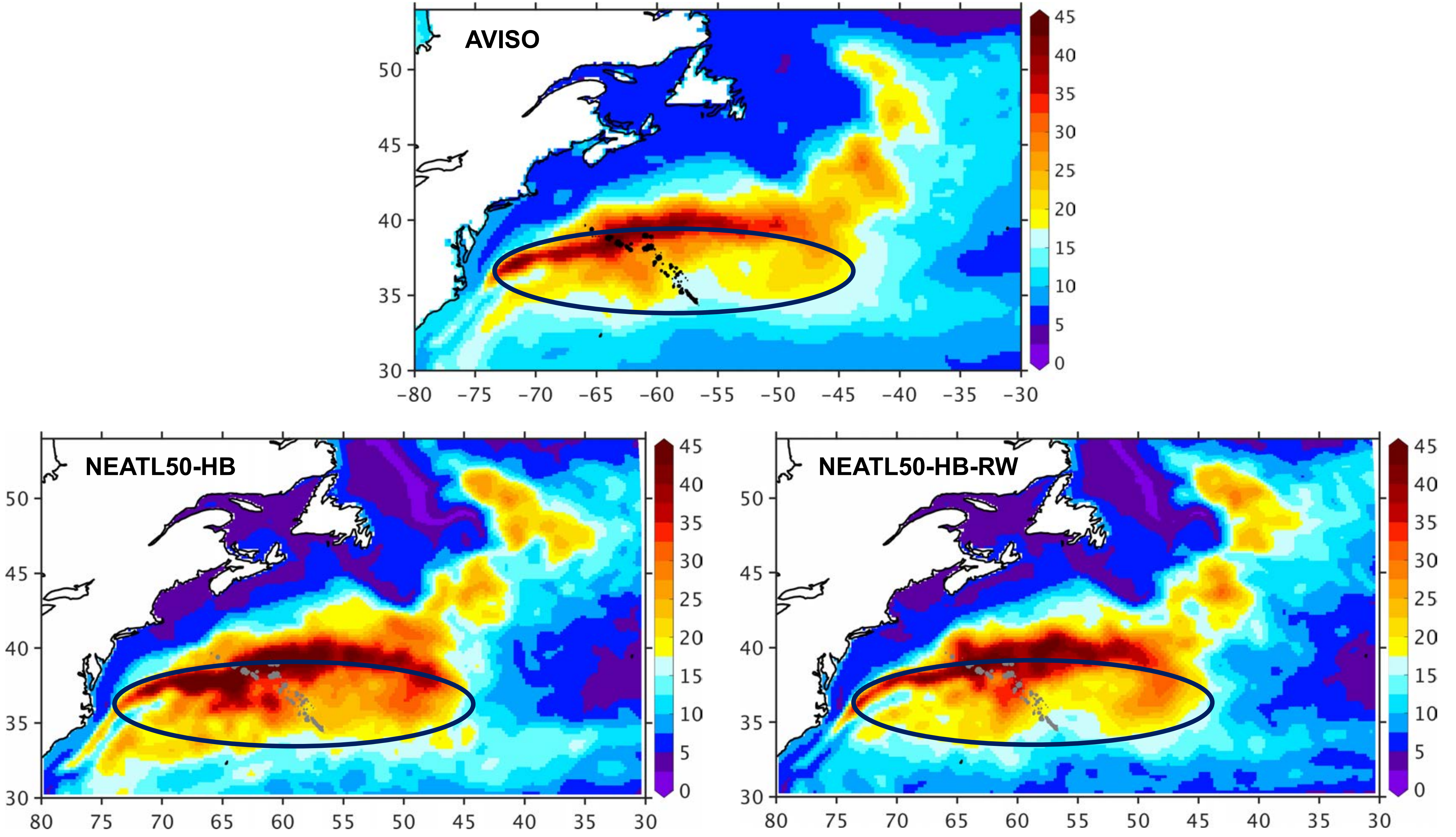
- All the simulations described so far use absolute wind forcing (no shear between wind and ocean currents) in the wind stress formulation.
- Relative wind induces a severe "eddy killing effect" (30% reduction in KE).
- Renault et al. (2019) proposed a 70% relative wind stress formulation to take into account ocean-atmospheric feedback.
- Less eddies also allows for a reduction of the viscosity as a function of the grid spacing.

Viscosity Parameter	Absolution Wind (E026)	Relative Wind (E037)
Laplacian coefficient A	10 m2/s	5
Biharmonic diff vel. for momentum	4 cm/s	1cm/s <40N
Biharmonic diff vel. for layer thickness	4 cm/s	1cm/s <40N
Laplacian diff vel. for tracer	1 cm/s	0.5 cm/s

Relative wind impact on mean sea surface height



Relative wind impact on surface EKE



Conclusion #2: Relative wind

Reducing the viscosity together with implementing the 70% relative wind as in Renault et al. (2019) not only maintains the overall kinetic energy, but it also reduce the excessive EKE south of the Gulf Stream (Chassignet and Xu, GRL, in prep).

Summary

- ✓ **A proper representation of the fine scale structure of the New England Seamount Chain has a much more profound impact on the Gulf Stream pathway and variability than one would have a priori anticipated (Chassignet et al., 2023, JPO).**
- ✓ **Reducing the viscosity together with implementing the 70% relative wind as in Renault et al. (2019) not only maintains the overall kinetic energy, but it also reduce the excessive EKE south of the Gulf Stream (Chassignet and Xu, GRL, in prep).**

Questions?