Dialogues towards

Integrated observing and forecasting Ocean Boundary Systems

An initiative led by the Boundary Systems Task Team under the umbrella of the OOPC panel

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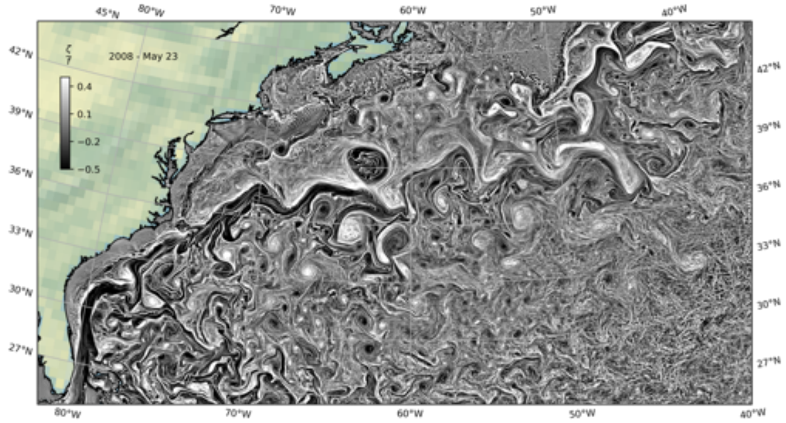
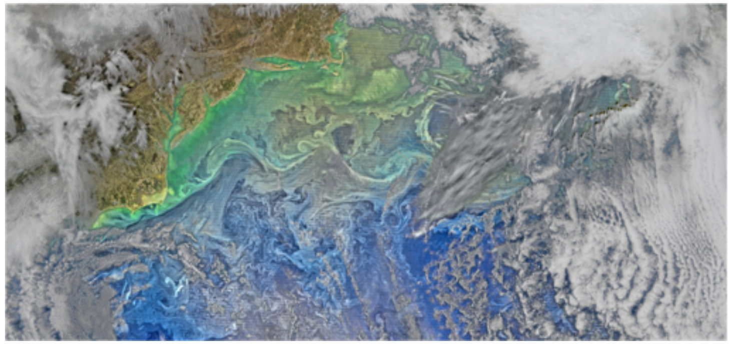
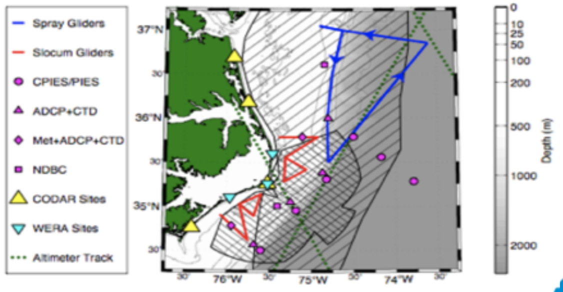
Dialogues towards Integrated observing and forecasting Ocean Boundary Systems

- Guide observing system requirements for **ocean physics** at ocean boundaries to link the ***global*** observing system to ***regional*** coastal systems.
- Promote conversations & collaborations between modelling and observing communities towards better observing system designs.
- Derive knowledge from historically well-observed boundary current systems and mature observing systems.







Gulf Stream System: Part 2- Modeling

Presenter: Jonathan Gula

University of Brest, Laboratory for Ocean Physics and remote Sensing (LOPS)

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Outline

- The Gulf Stream
- Modeling The Gulf Stream
- Confronting models with observations
- Data assimilation and regional forecasting
- Conclusion

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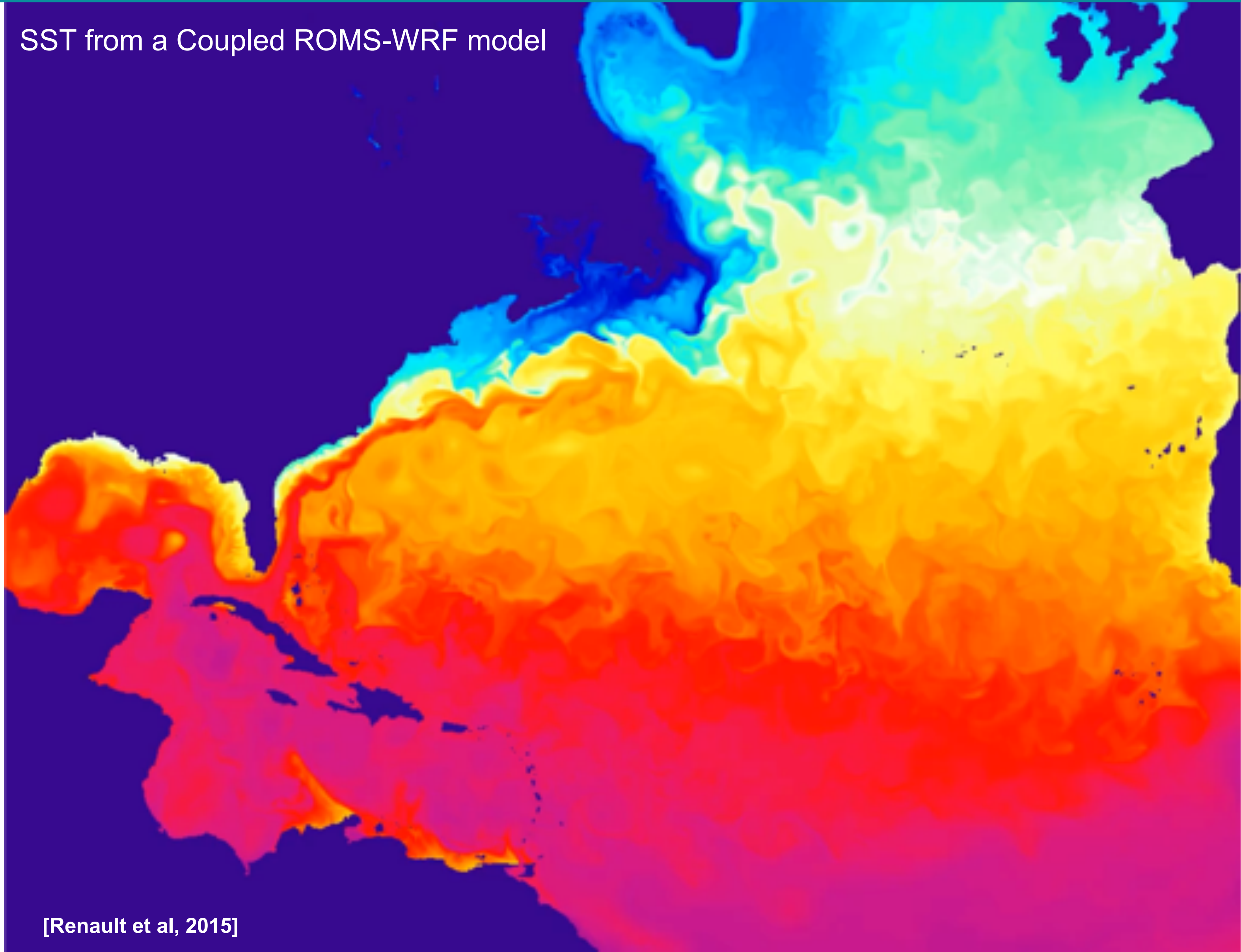
A. The Gulf Stream

An important component of the ocean / climate

- Meridional heat transport with impacts on the global ocean circulation (AMOC)
- Large impacts on biogeochemistry (fluxes of CO_2, oxygen, nutrients, etc.)
- Impacts on the atmosphere
- Etc.



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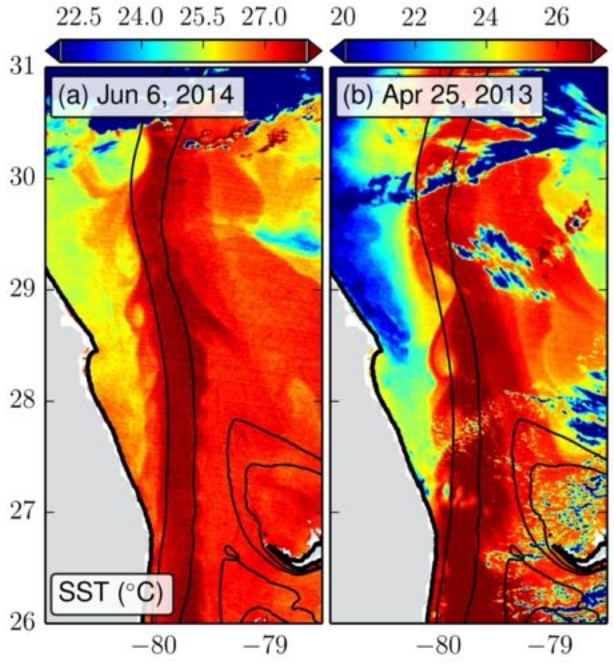
A. The Gulf Stream

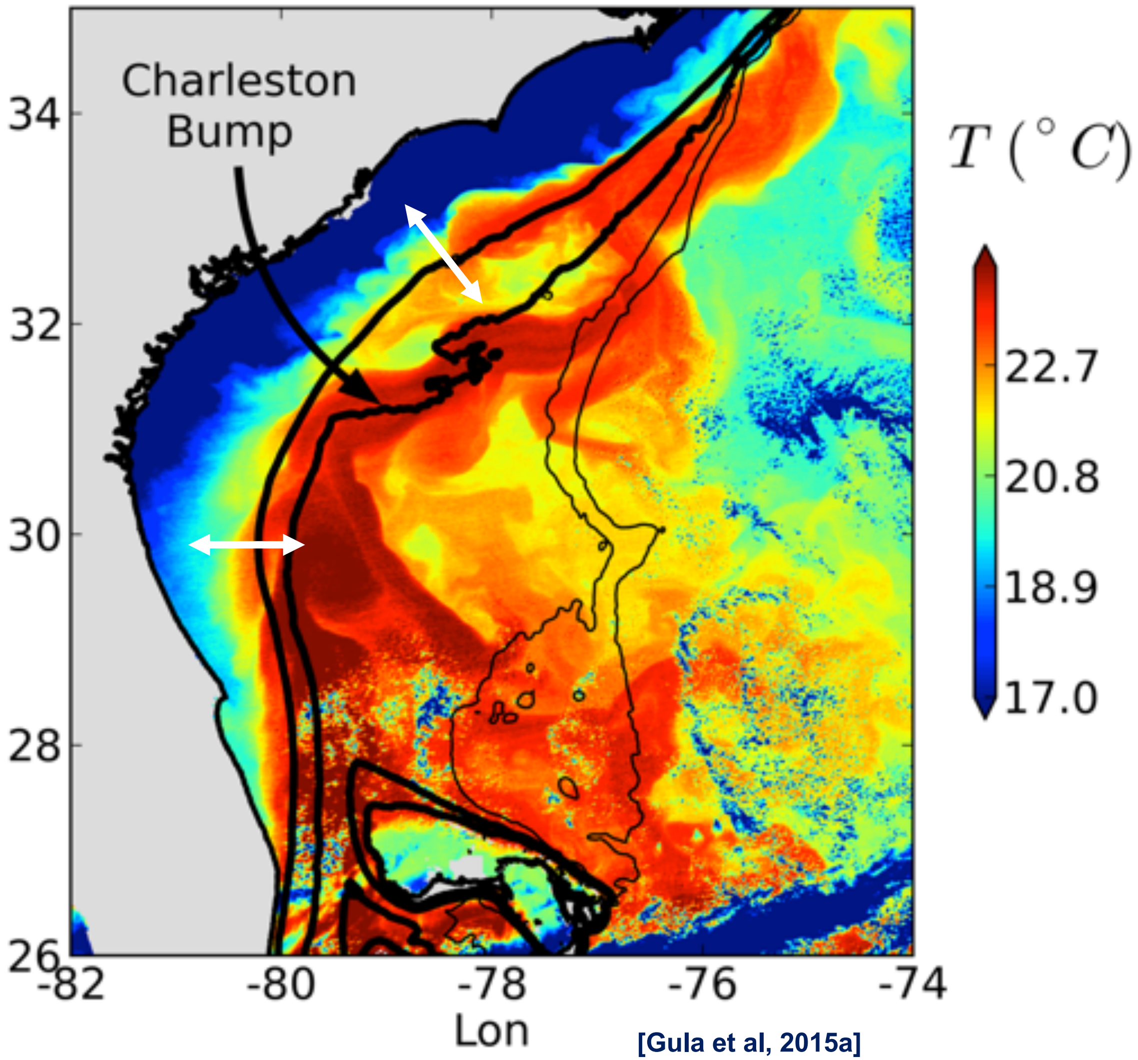
(sub)mesoscale variability along the slope:

- cross-shelf exchanges and impacts biological production
- Dissipation of eddy energy
- Mixing and water-mass transformations



[Gula et al, 2015b]

Observed Sea Surface Temperature (SST) from MODIS.



[Gula et al, 2015a]

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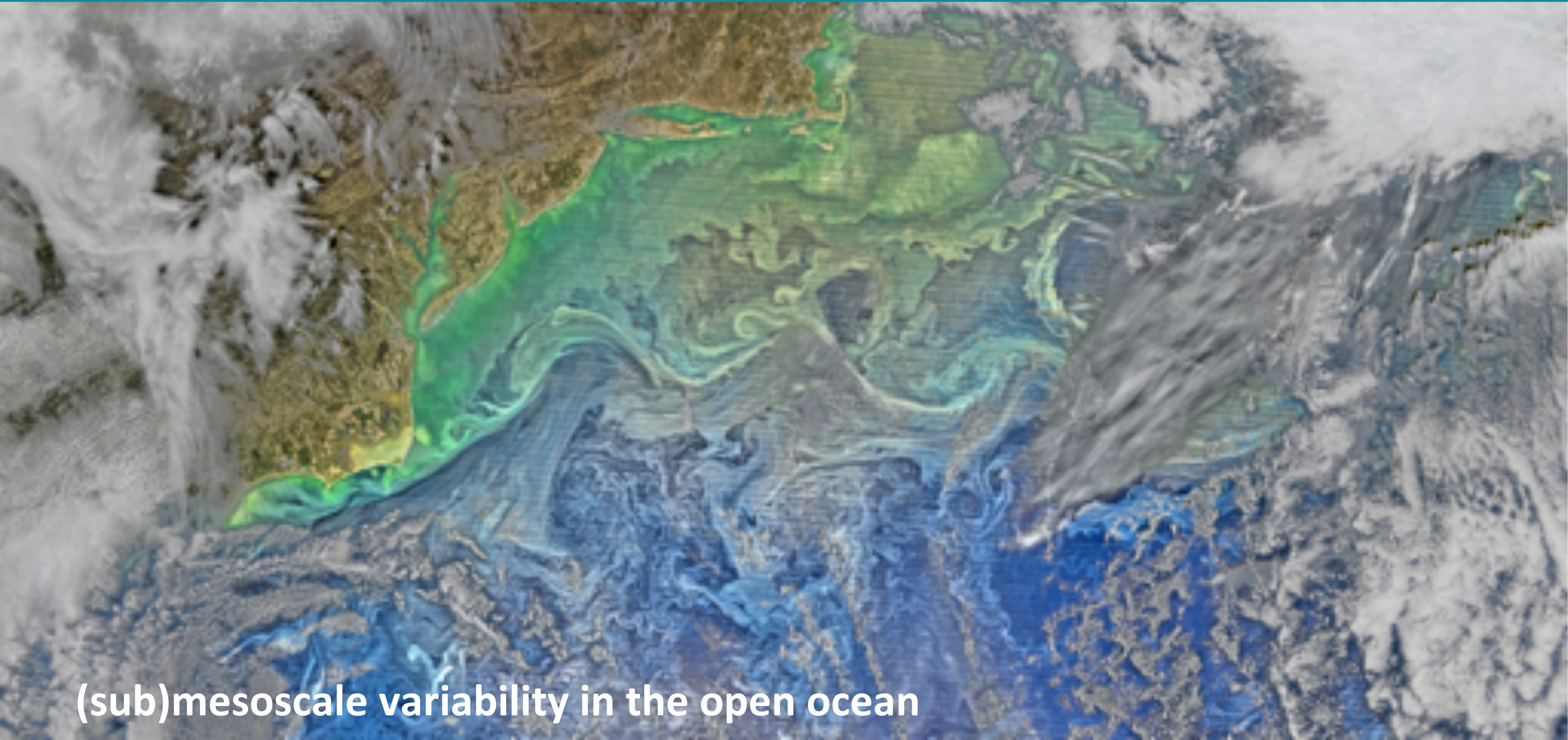
A. The Gulf Stream

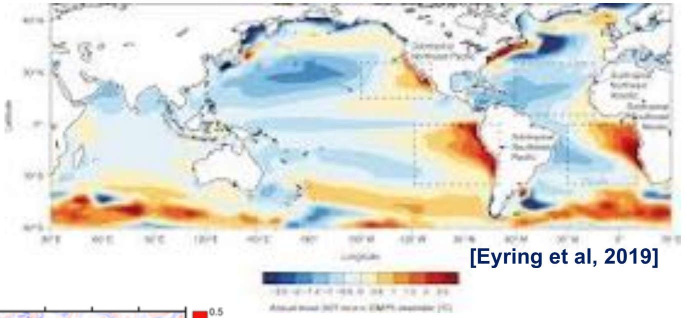
ocean colour (VIIRS – 03/09/16)



(sub)mesoscale variability in the open ocean

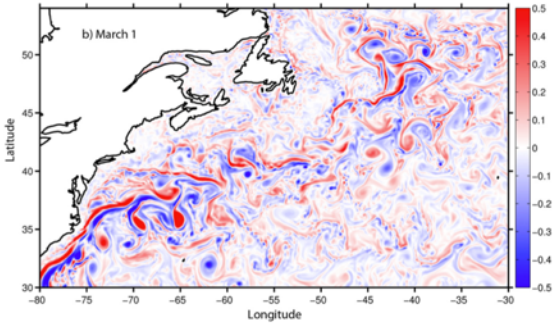
B. Modeling The Gulf Stream

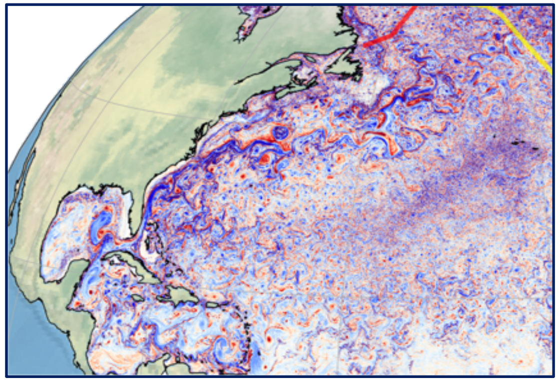
- CMIP models (typically **1 – 0.25 deg**) for climate applications *[decades to centuries]*
- Eddying ocean models (typically **10 km**) for ocean circulation, including forecast – reanalysis *[years to decades]*
- Submesoscale permitting models (typically **1 km**) for regional – basin-scale applications *[years]*
- Submesoscale resolving models (typically **100 m**) for regional applications – process studies *[weeks - months]*

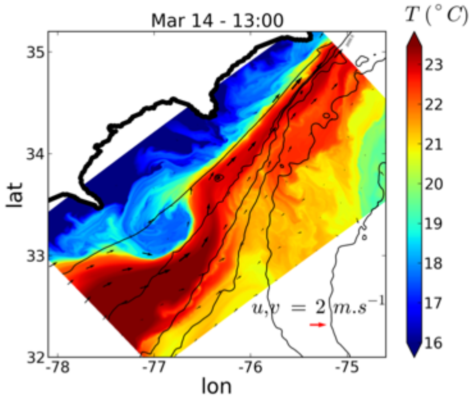


[Eyring et al, 2019]

[Chassignet and Xu, 2017]







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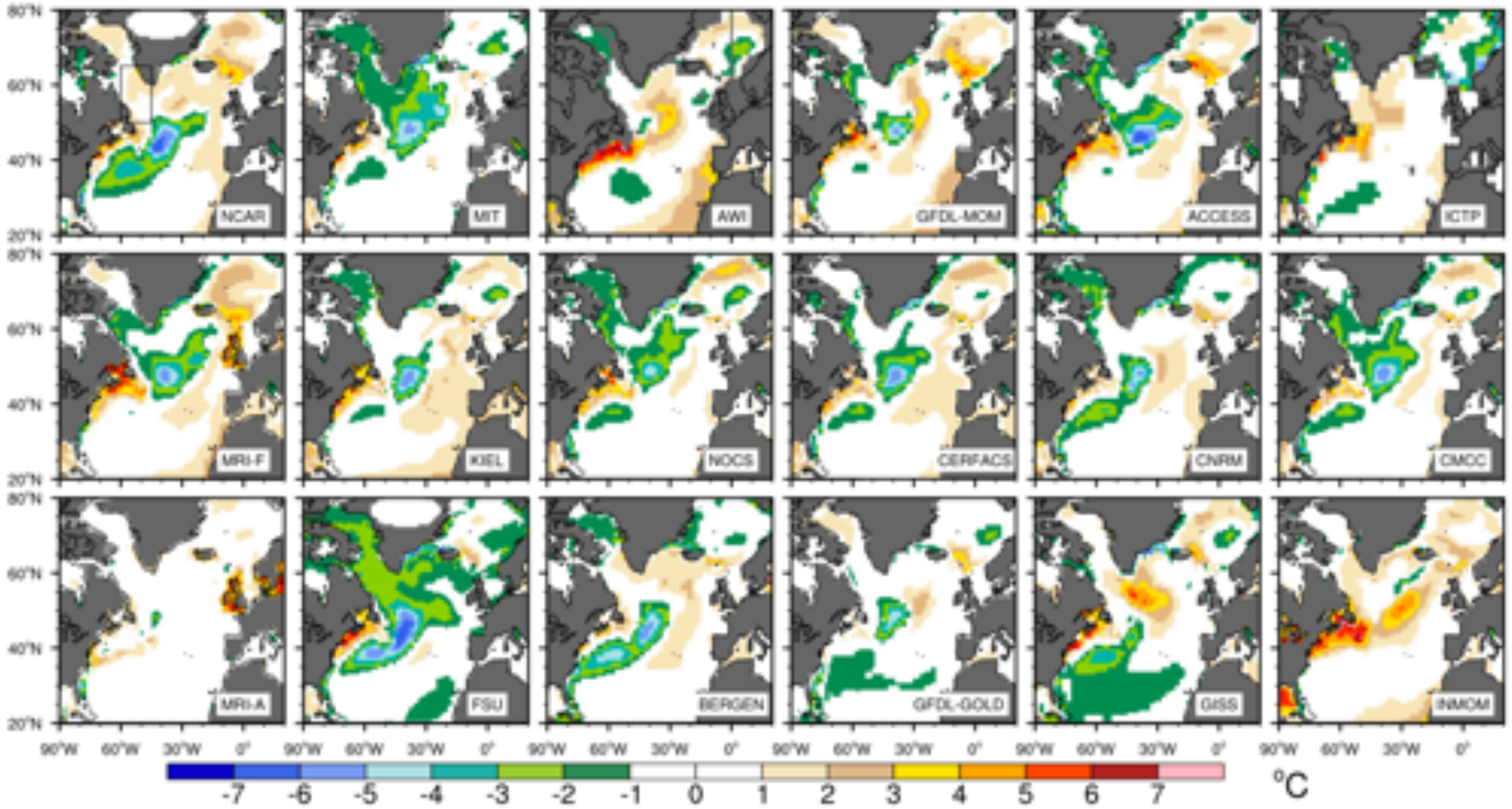
B. Modeling The Gulf Stream

- From climate scale models:

Common issues related to **“overshooting”** of the Gulf Stream: a too-far-north penetration of the Gulf Stream and a too-zonal NAC path

Mean SST bias in CORE-II experiments (1 deg. Res)

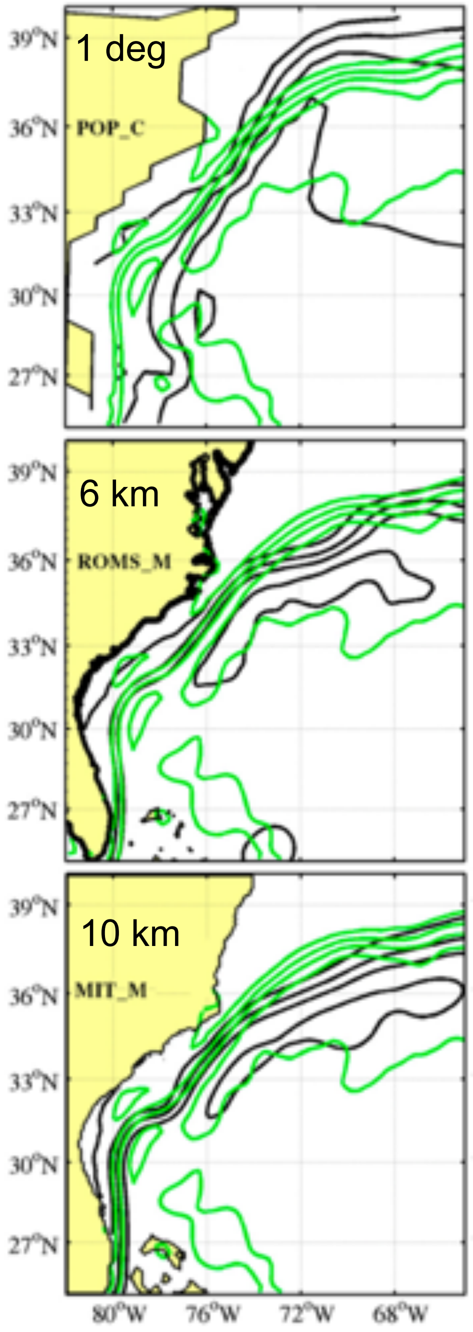


[Danabasoglou et al, 2014]

B. Modeling The Gulf Stream

- Eddying models (with more inertia) usually gets a better separation.

- Though, too strong eddying may induce other biases (*e.g.*, a permanent meander following separation)



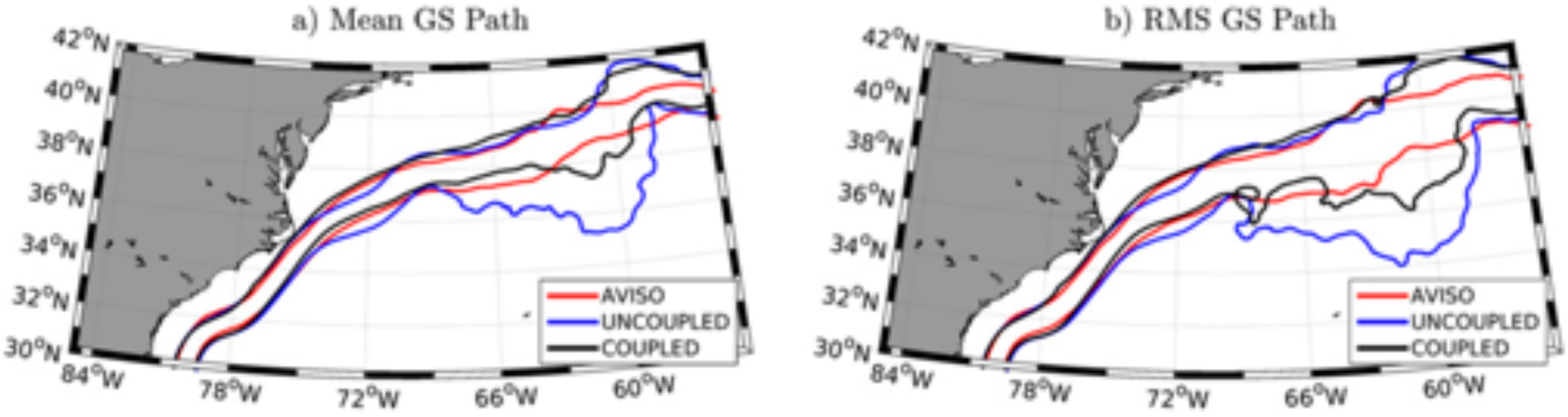
AVISO obs in green

[Schoonover et al, 2015]

B. Modeling The Gulf Stream

- Too strongly eddying may be tempered by, *e.g.*, including atmosphere coupling or at least considering relative winds ($U_{atm} – U_{ocean}$), which induce an eddy-killing effect **[Renault et al, 2020]**

Gulf Stream path from obs (AVISO), and ROMS simulations (6 km) with or without coupling with the atmosphere.

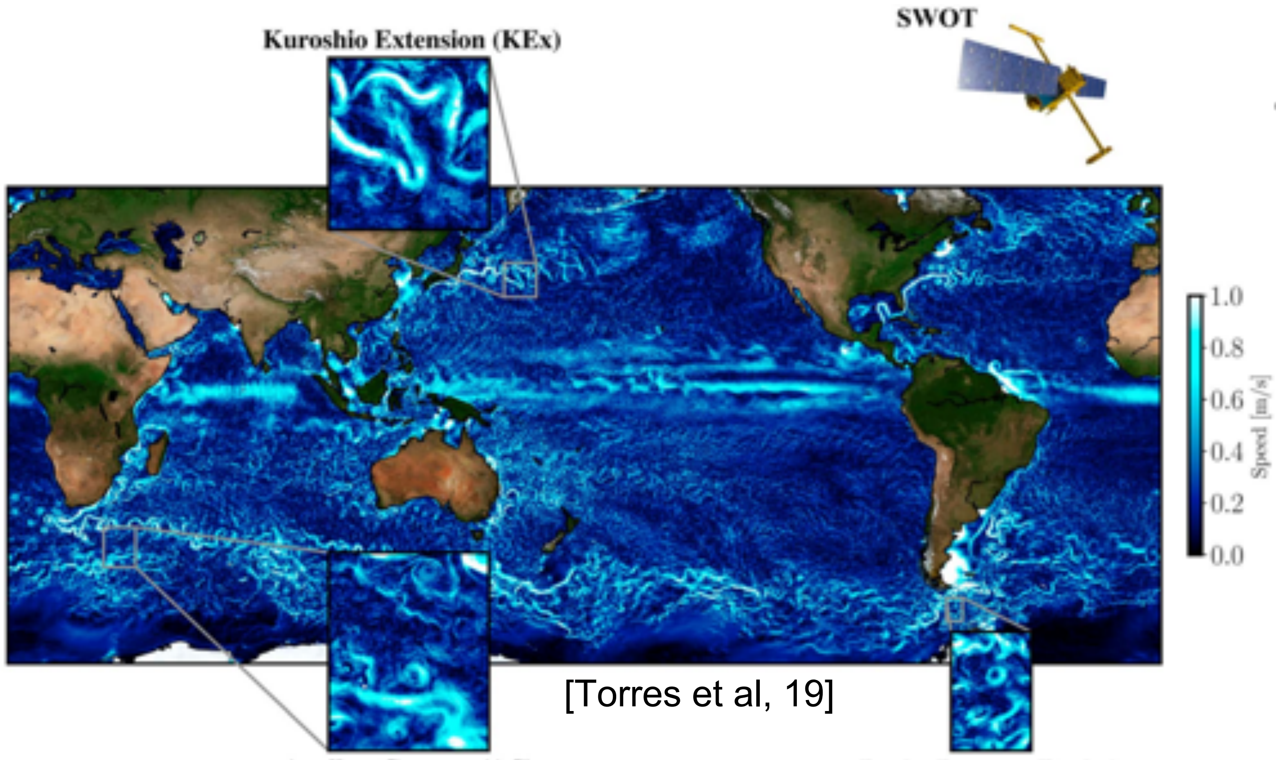


[Renault et al 2015]

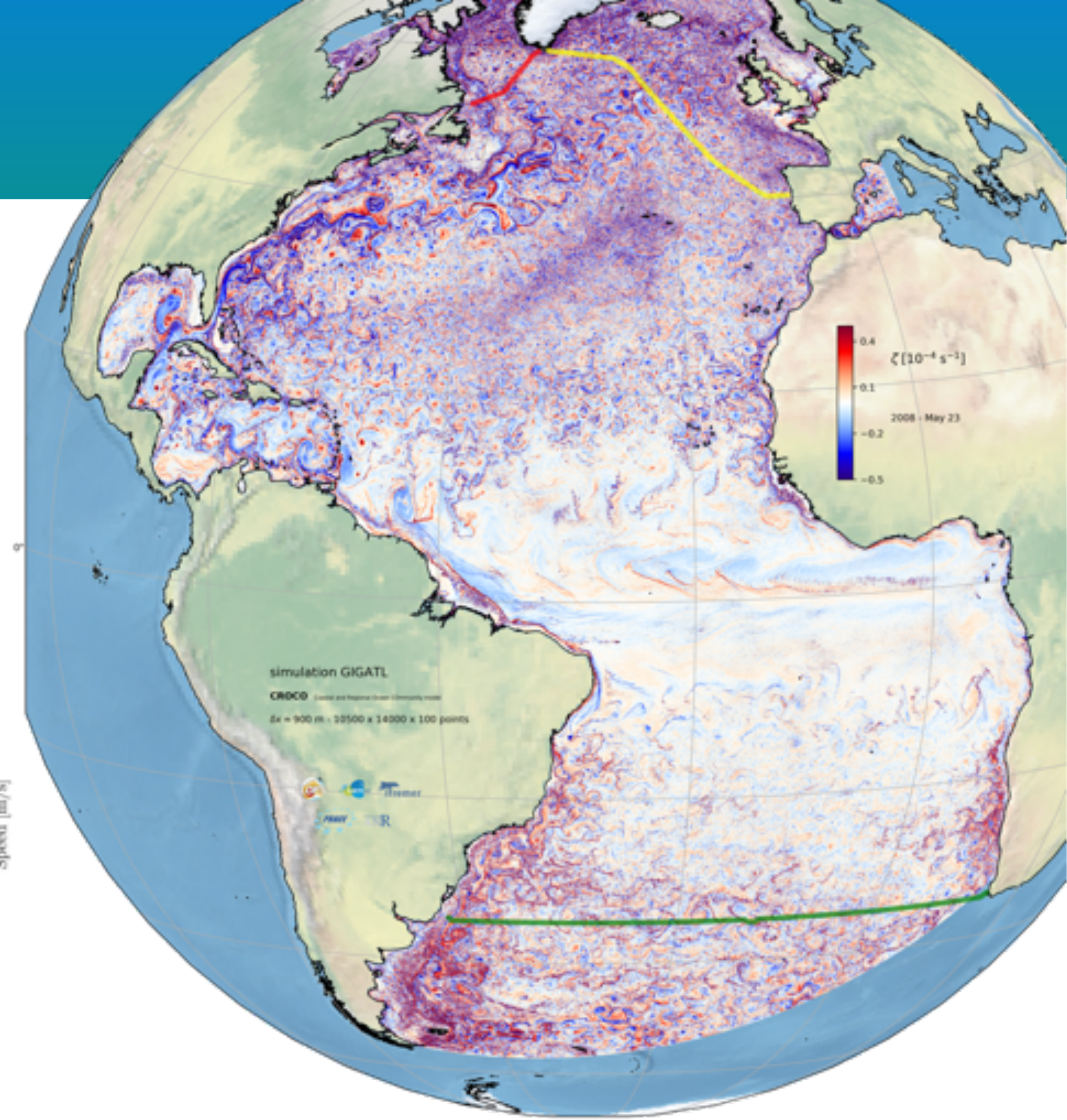
B. Modeling The Gulf Stream

A new generation of submesoscale-permitting global or basin-scale models

[most of them including tides]



Global configuration LLC4320 (MITgcm at 1/48)



Atlantic configuration GIGATL (ROMS/CROCO at 1 km)

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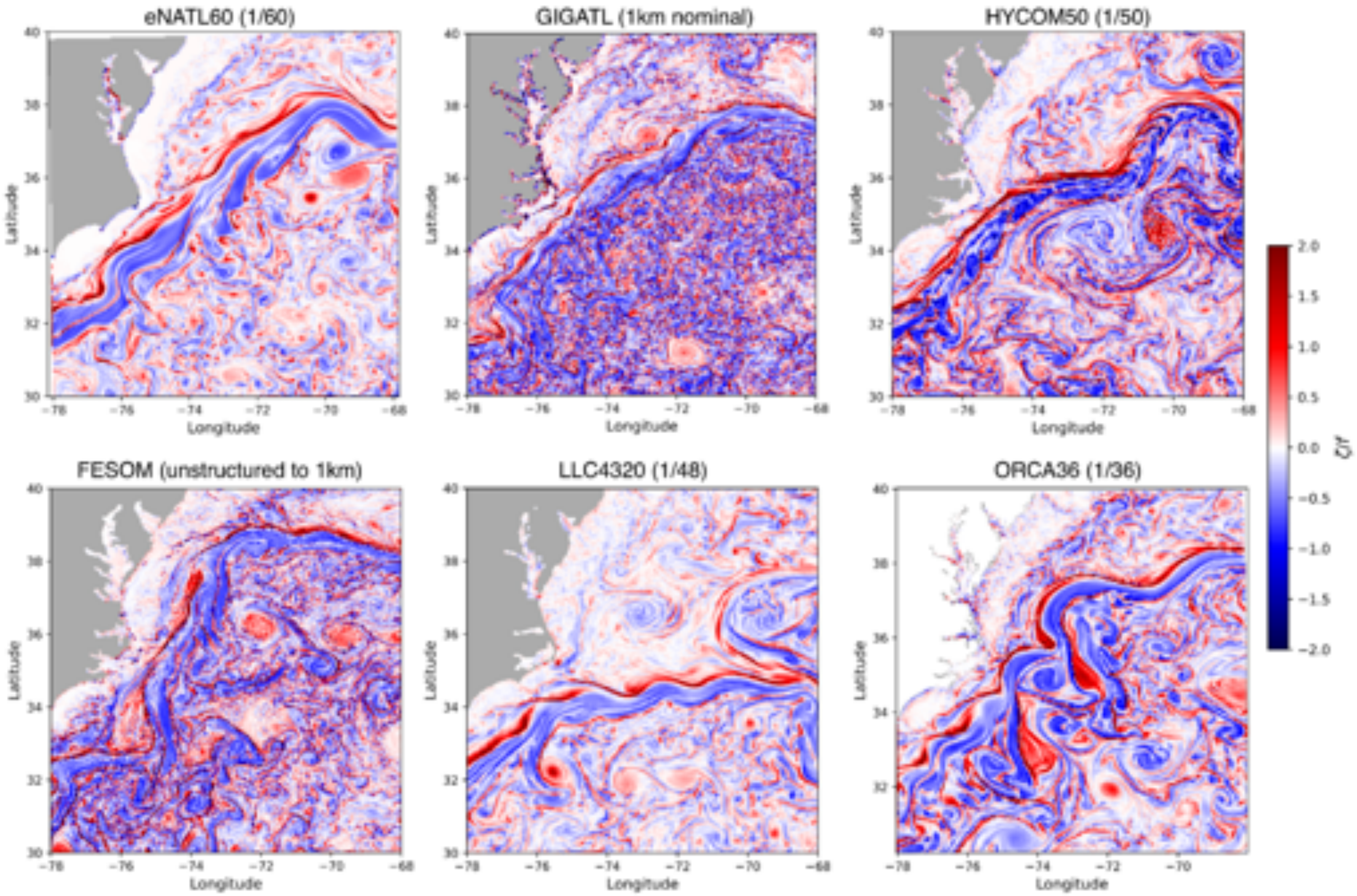
B. Modeling The Gulf Stream

A new generation of submesoscale-permitting global or basin-scale models [most of them including tides]

A lot of intercomparisons are underway.

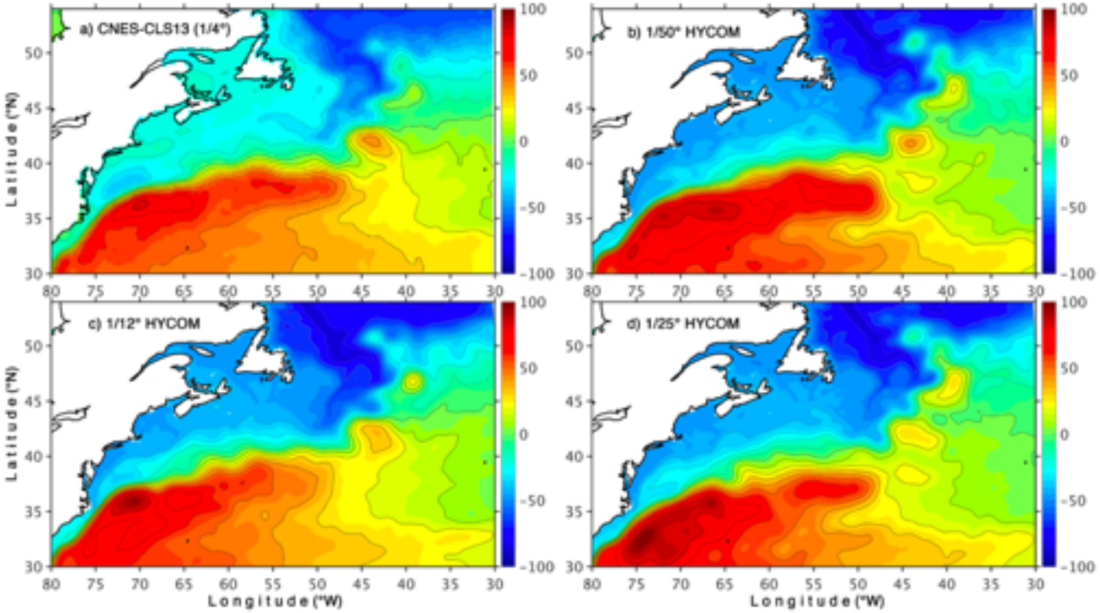


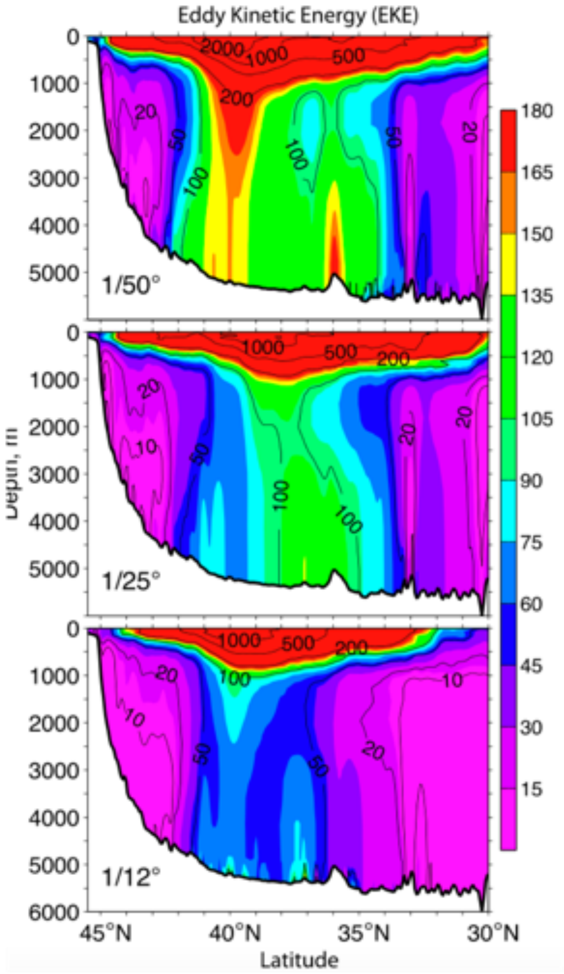
[Uchida et al]. https://github.com/roxyboy/SWOT-AdAC-ocean-model-intercomparison

B. Modeling The Gulf Stream

The transition to submesoscale-permitting seems to improve:

- the representation of mesoscale variability (levels of energy)
- the Gulf Stream eastward penetration
- the GS vertical structure

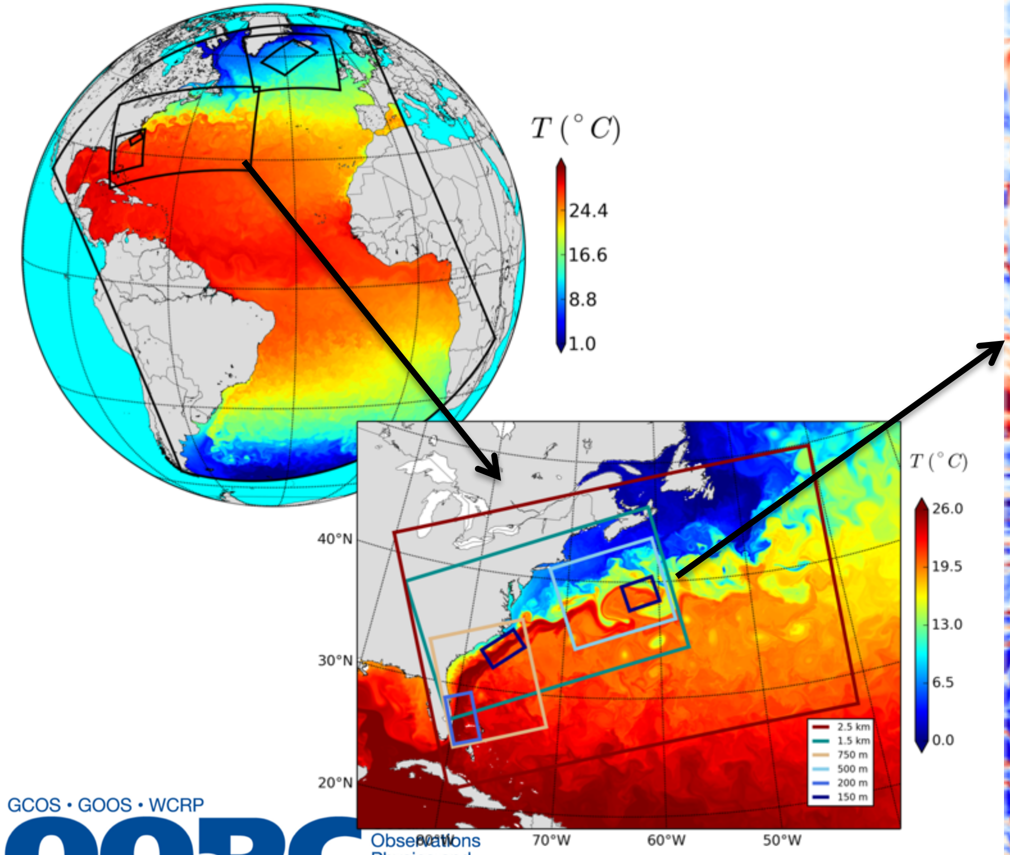


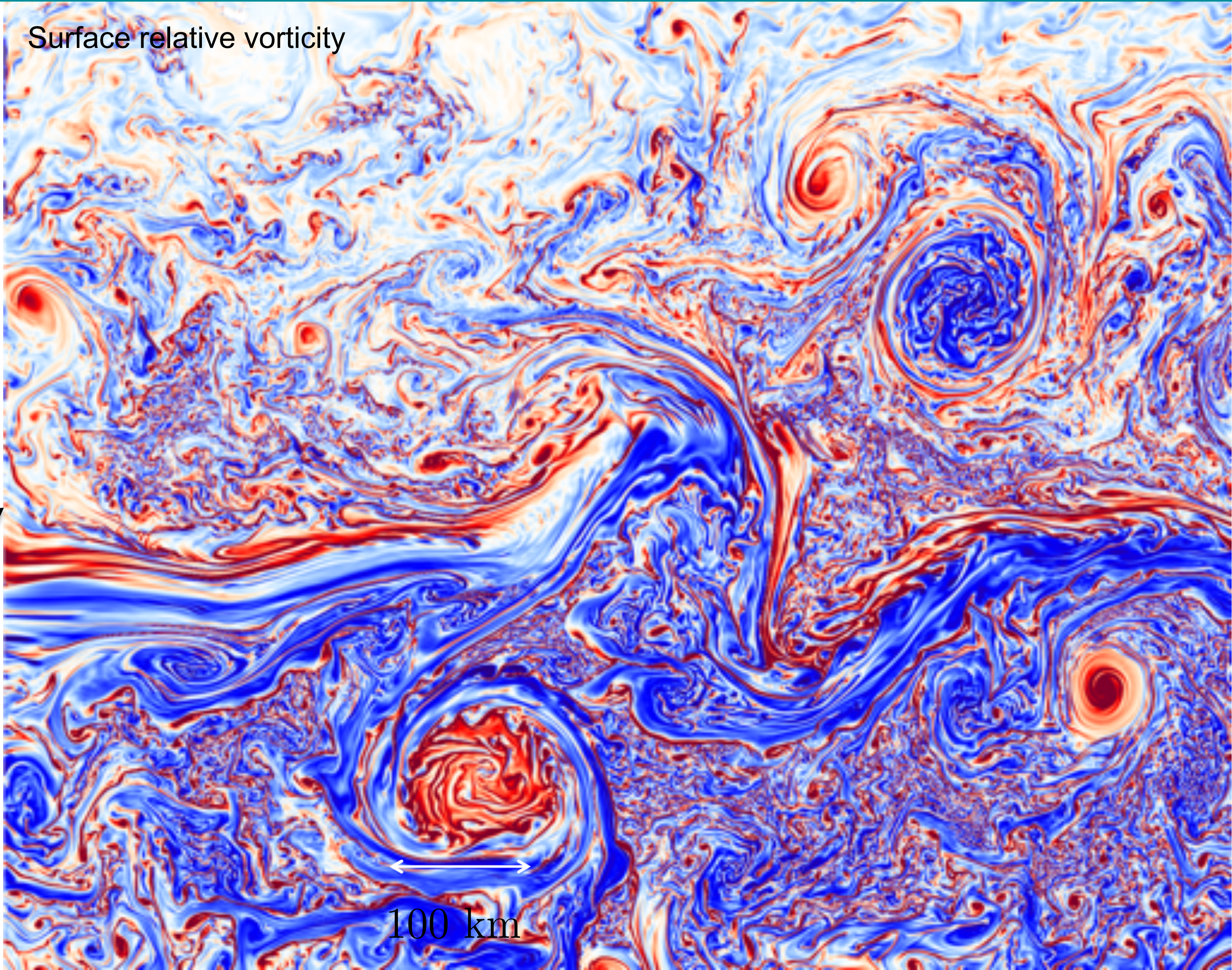


[Chassignet & Xu, 2017]

B. Modeling The Gulf Stream

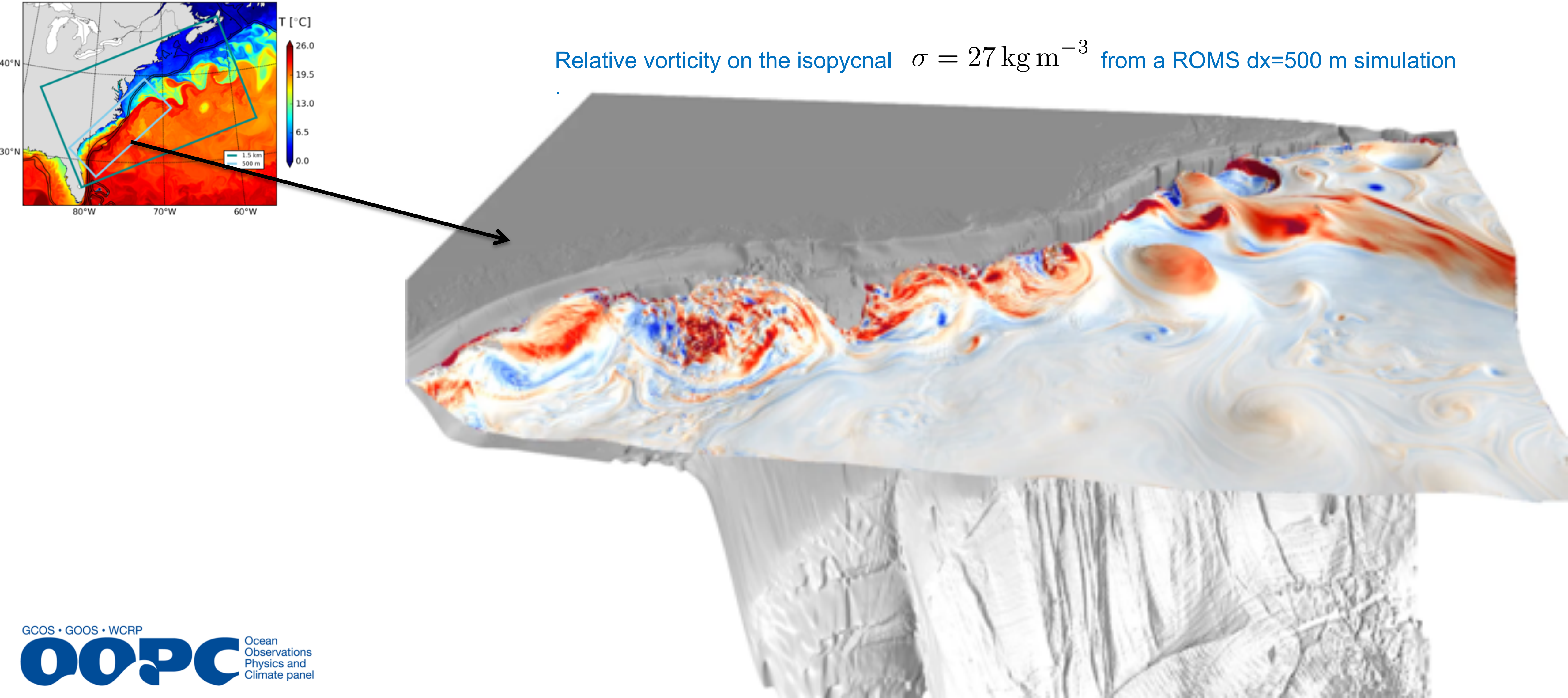
- Regional submesoscale-resolving models:





B. Modeling The Gulf Stream

Relative vorticity on the isopycnal $\sigma = 27\,\mathrm{kg\,m^{-3}}$ from a ROMS dx=500 m simulation
.



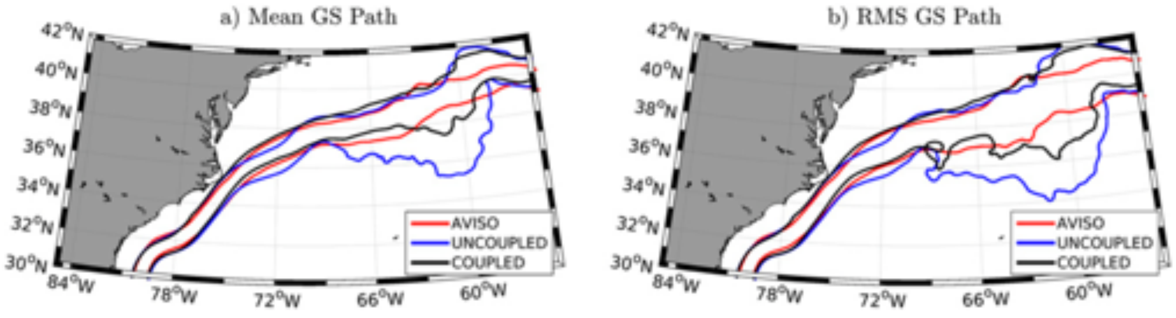
C. Confronting models with observations

- Mean structure of the currents / stratification
- Mesoscale variability
- Submesoscale dynamics
- High-frequency variability [tides / internal waves]
- Small scale turbulence [Mixing / dissipation] including BBL or air-sea turbulent fluxes
- Etc.

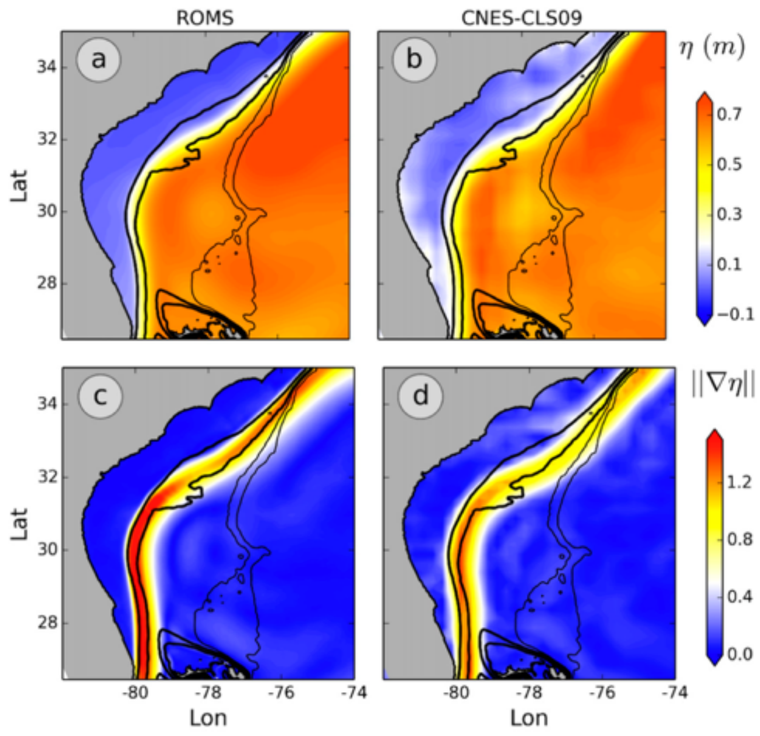
C. Confronting models with observations

Mean surface currents :

- From ***altimetry, surface drifters***



[Renault et al 2015]

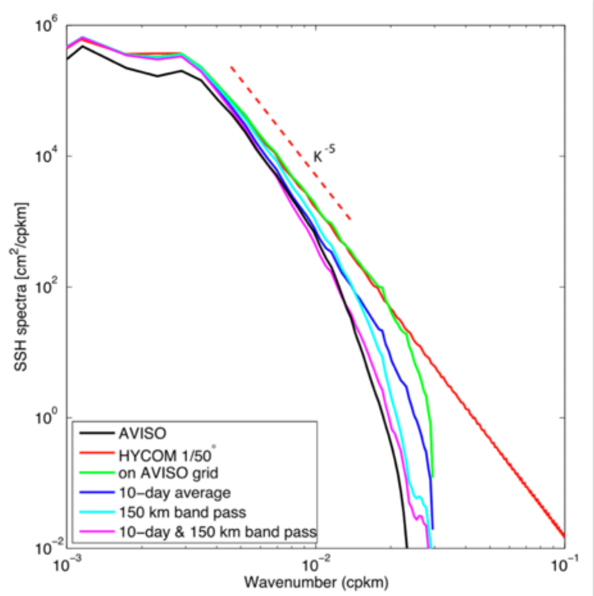


Model [Gula et al 2015] **Obs**

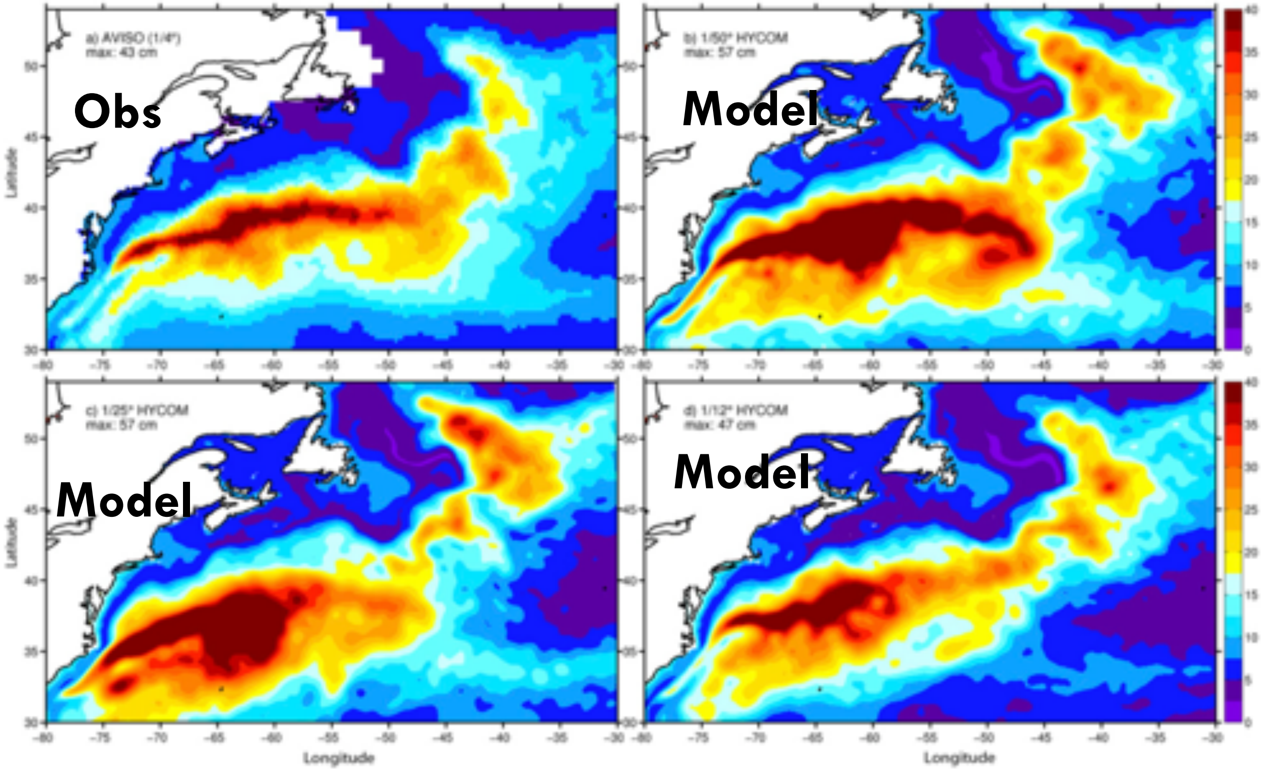
C. Confronting models with observations

Surface mesoscale variability:

- SSH / geostrophic EKE from ***altimetry***
- EKE from ***surface drifters***



[Chassignet & Xu, 2017]



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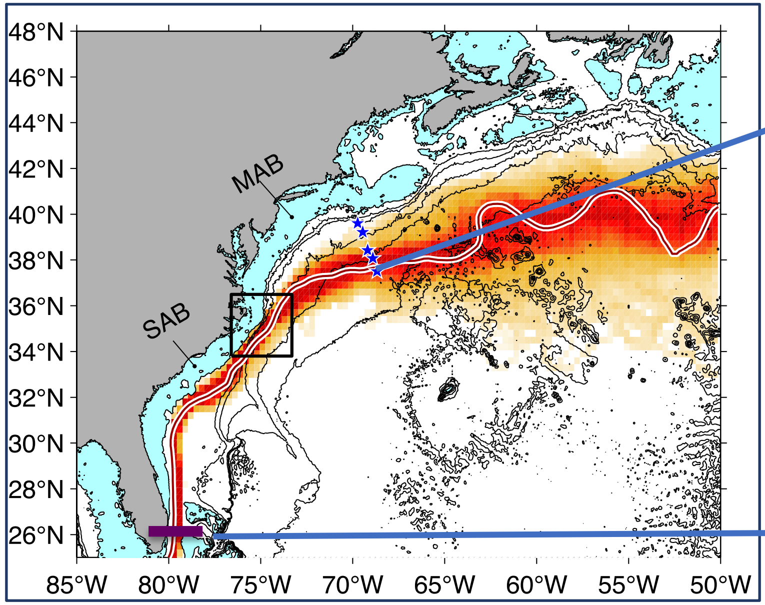
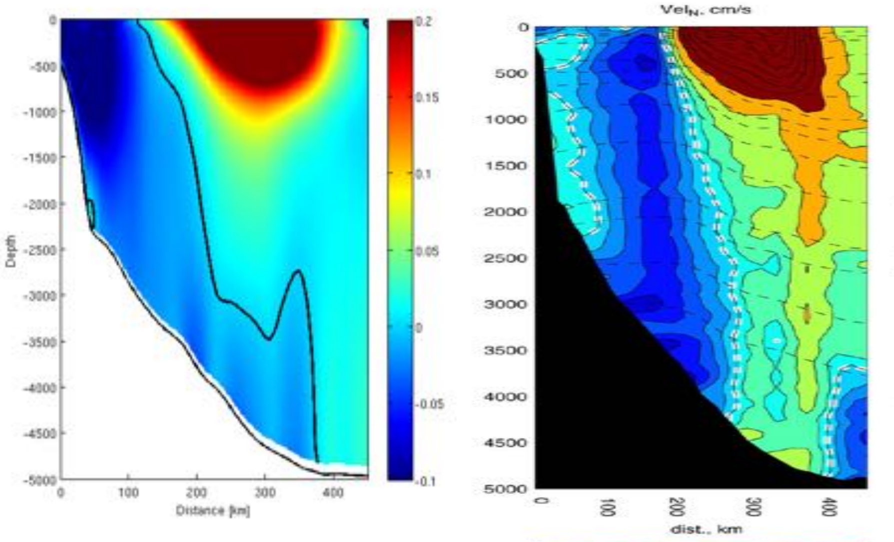
C. Confronting models with observations

Mean vertical structure:

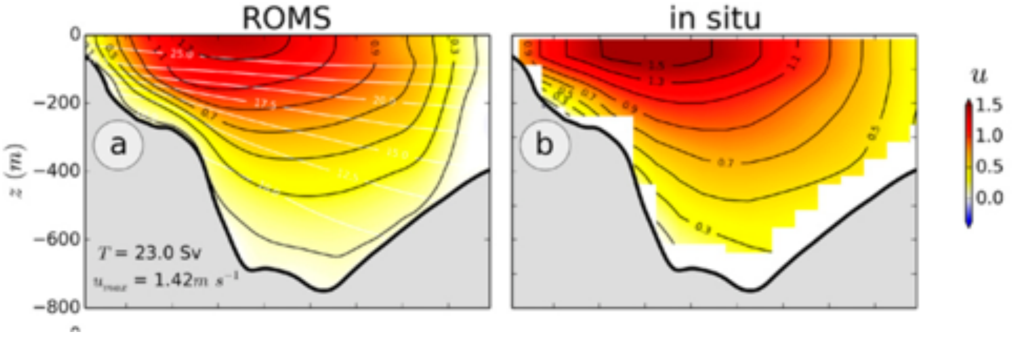
- Repeated sections (Florida Strait, Oleander) and mooring arrays (line W)



[Figure M. Andres]



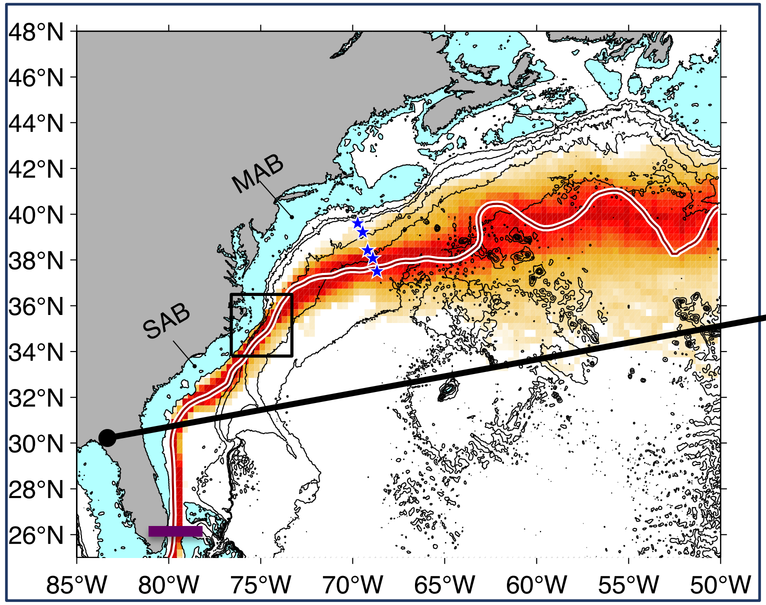
Model **Obs**



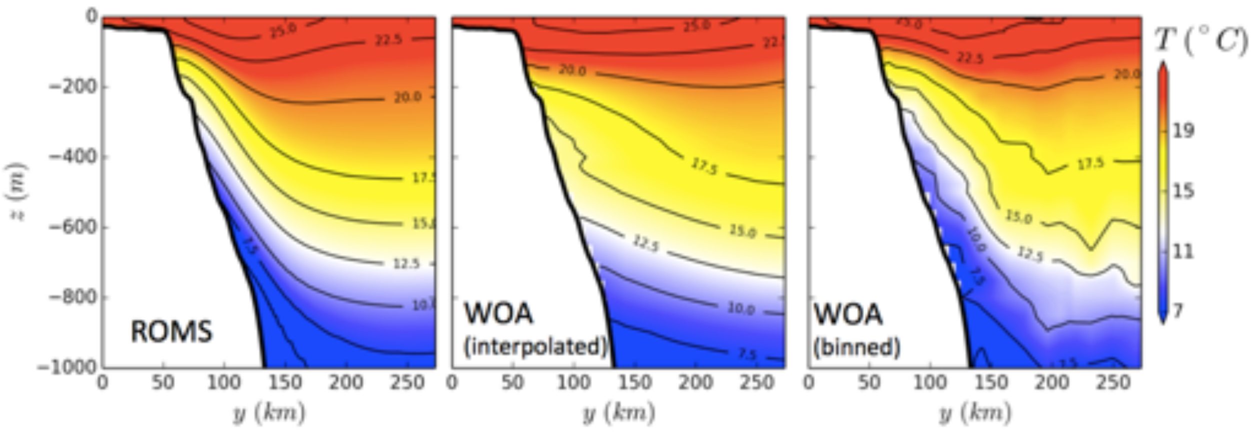
C. Confronting models with observations

Mean vertical structure:

- Repeated sections (Florida Strait, Oleander) and mooring arrays (line W)



[Figure M. Andres]



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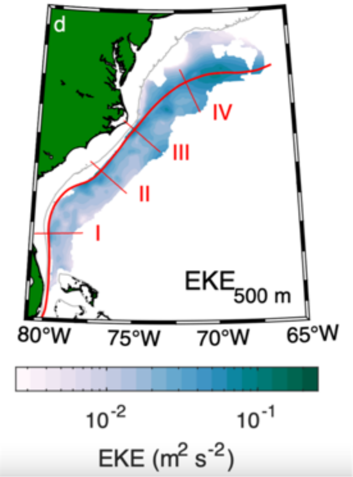
C. Confronting models with observations

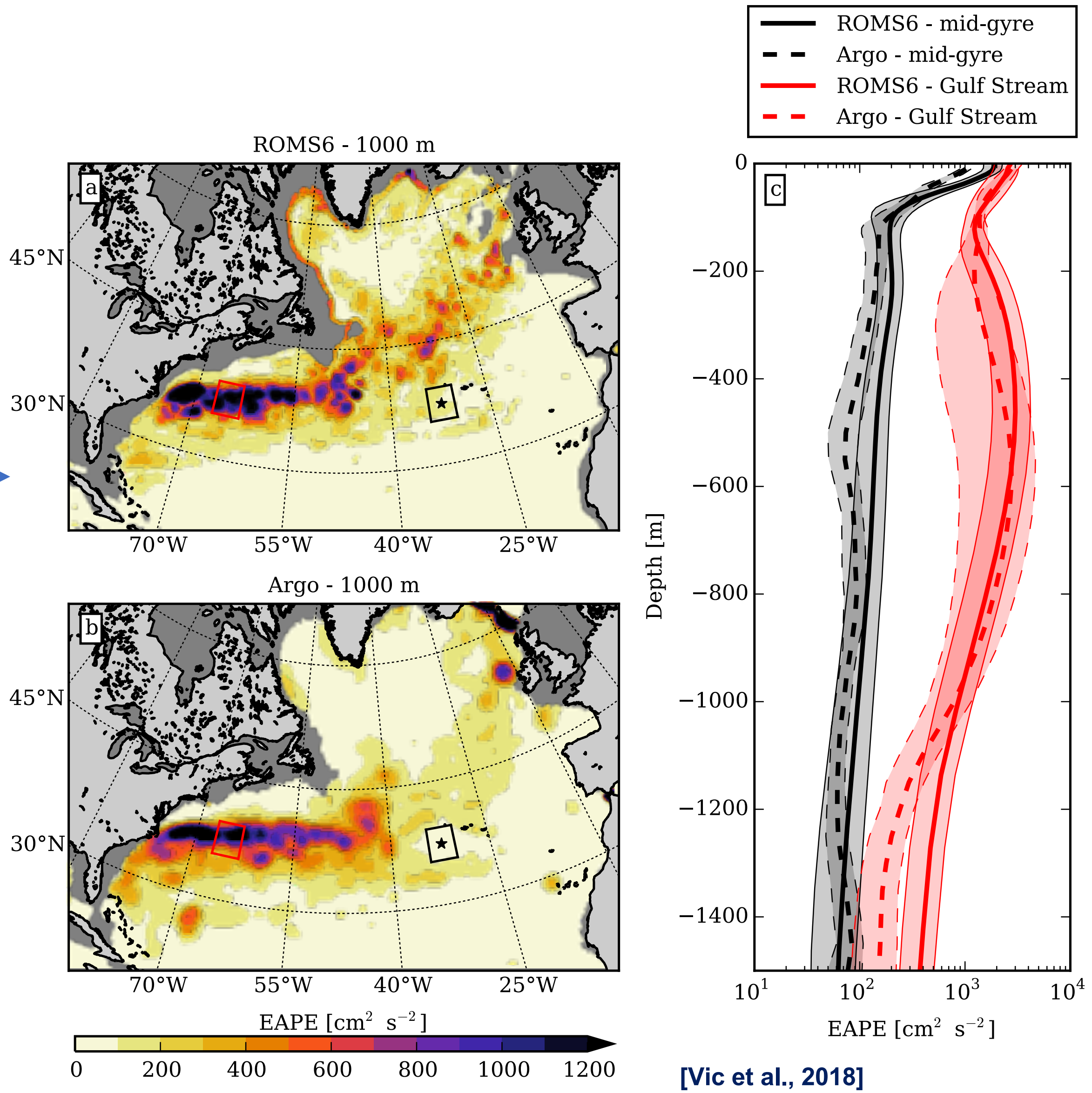
Mesoscale variability in the interior:

- Mesoscale turbulence in the interior from **Argo** using Eddy Available Potential Energy (EAPE) *[Roullet et al., 2013]* – down to 2000 m

- 3D EKE from **gliders** using about 20000 profiles in the GS region *[Todd, 2021]* – down to 1000 m



[Todd, 2021]



[Vic et al., 2018]

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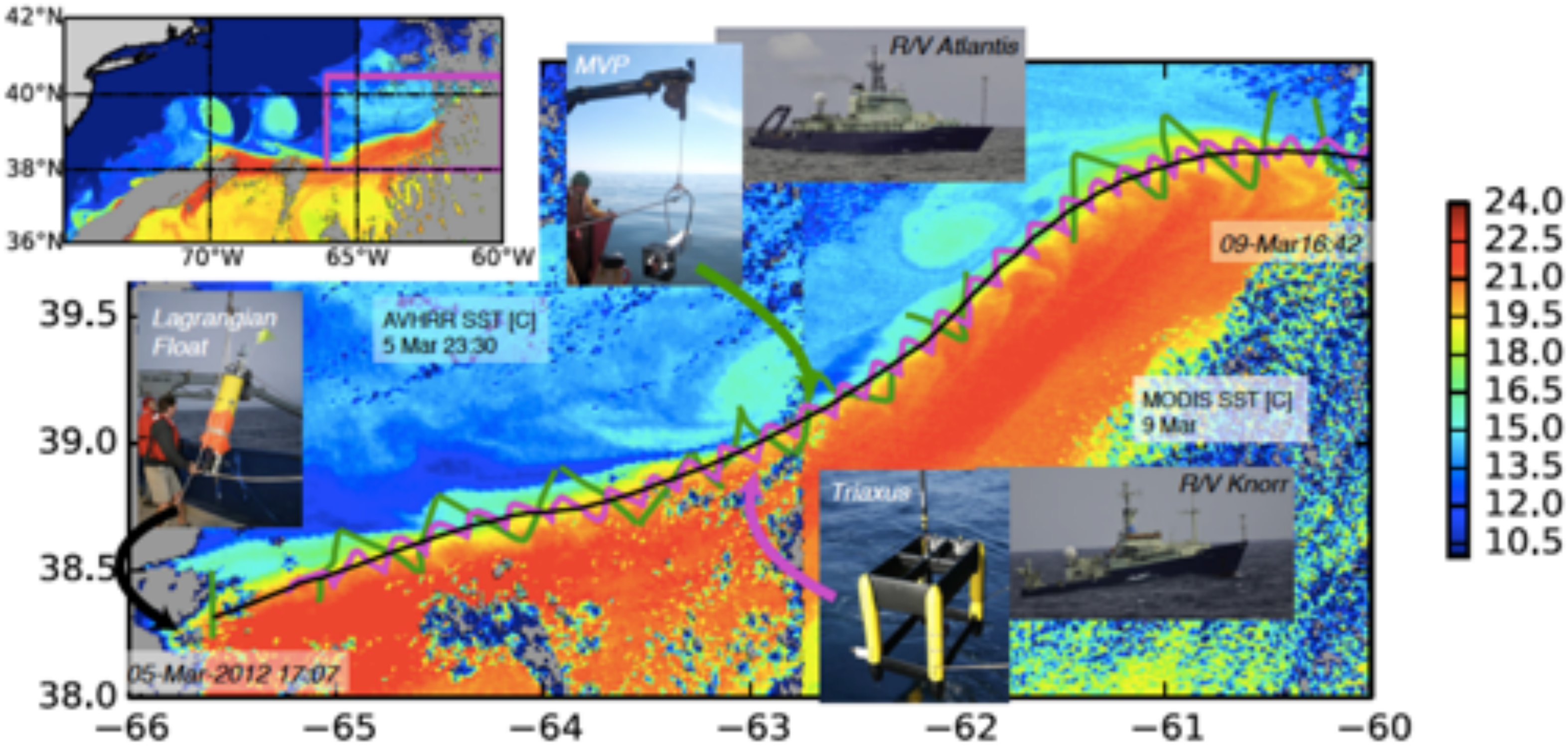
C. Confronting models with observations

Submesoscale dynamics (in the surface layer):

- SST / ocean color images
- Targeted field observations such as LATMIX



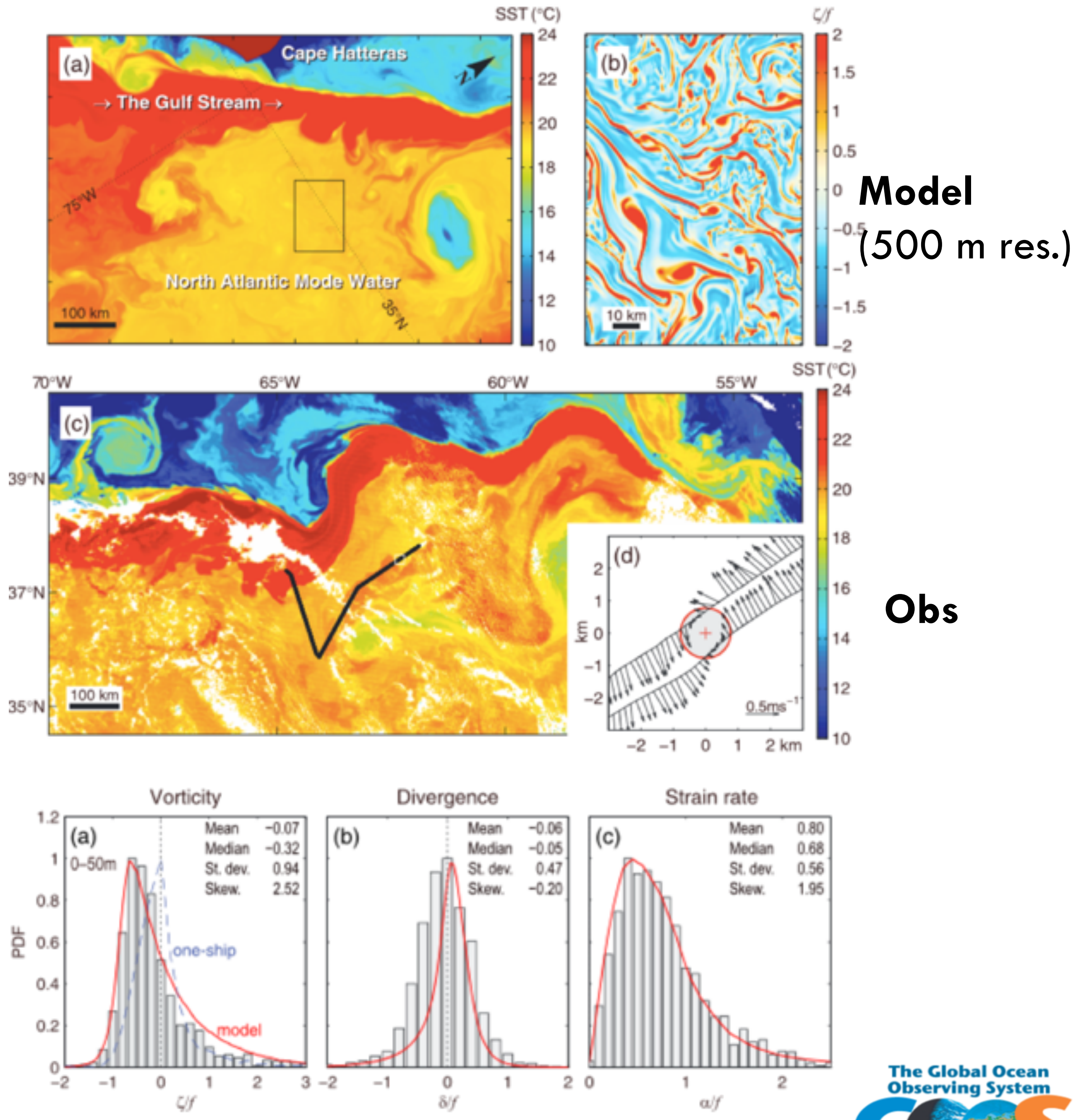
LATMIX 2012 cruise track superimposed on SST images

[Klymak et al., 2016]

C. Confronting models with observations

Submesoscale dynamics (in the surface layer):

- More quantitative assesment of the levels of submesoscale turbulence using velocity measurements allong parallel ship tracks during LATMIX.



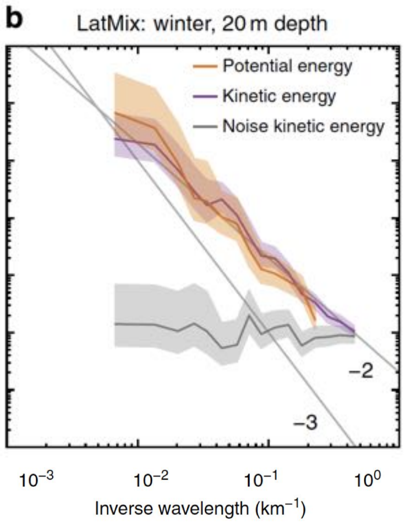
[Shcherbina et al, 2015]

C. Confronting models with observations

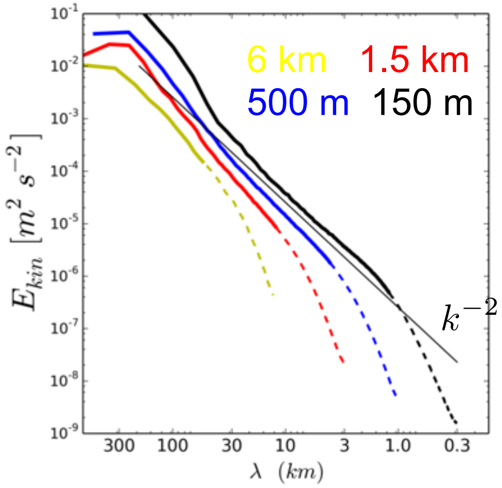
Submesoscale dynamics (in the surface layer):

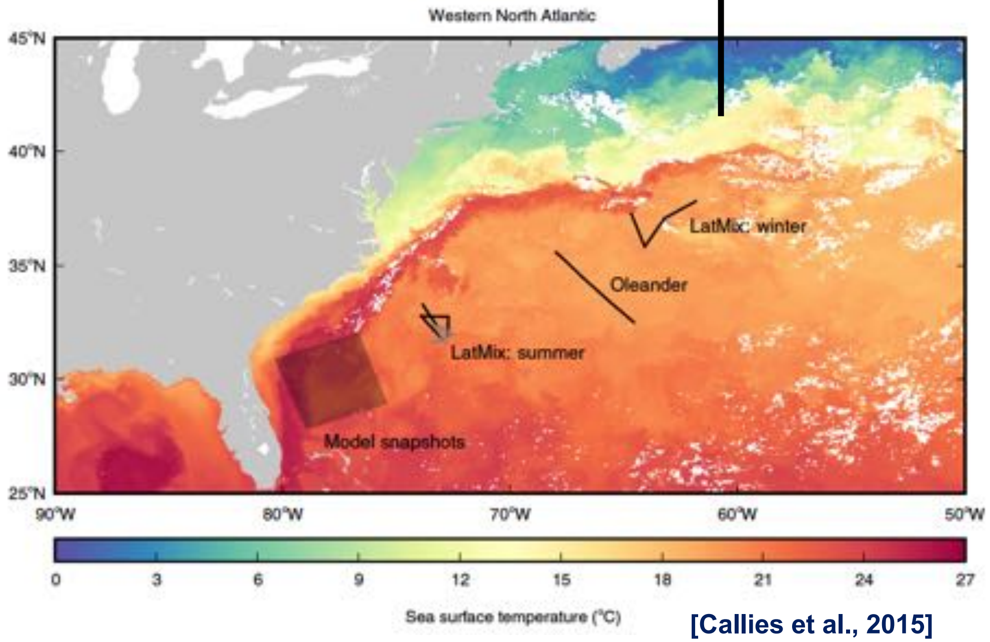
- More quantitative evaluation of the levels of submesoscale turbulence using energy spectra (based on 1D hydrographic sections):

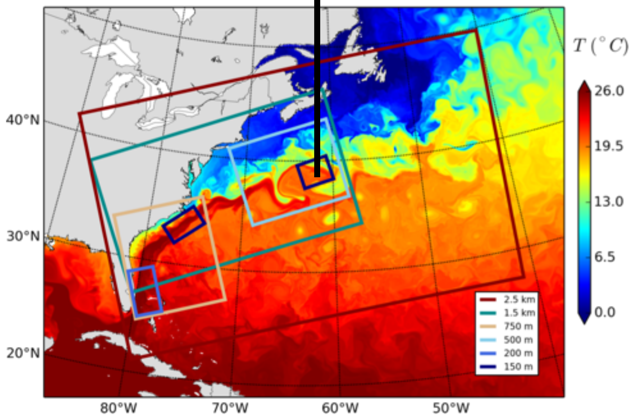
In-situ observations:



Model





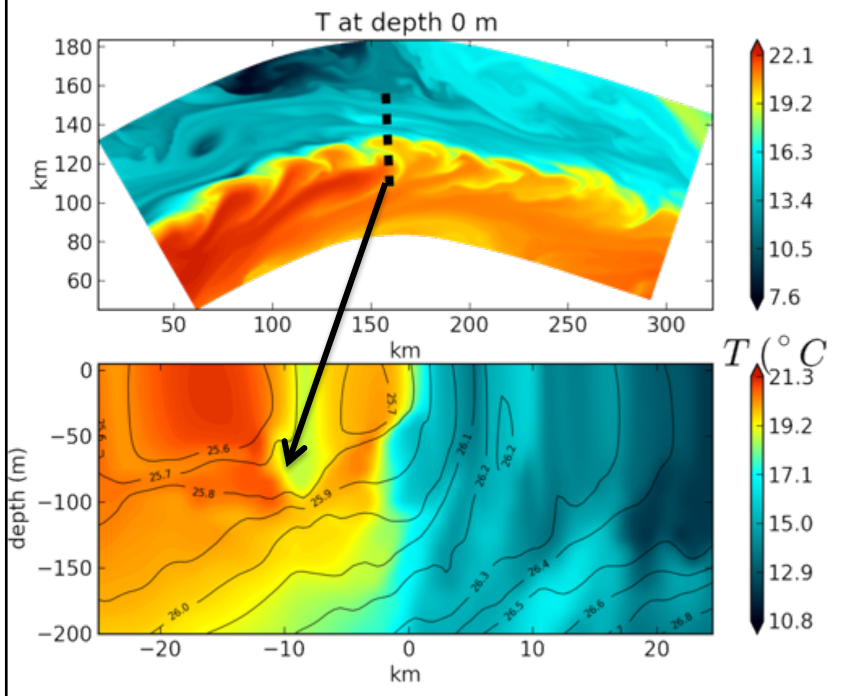


[Callies et al., 2015]

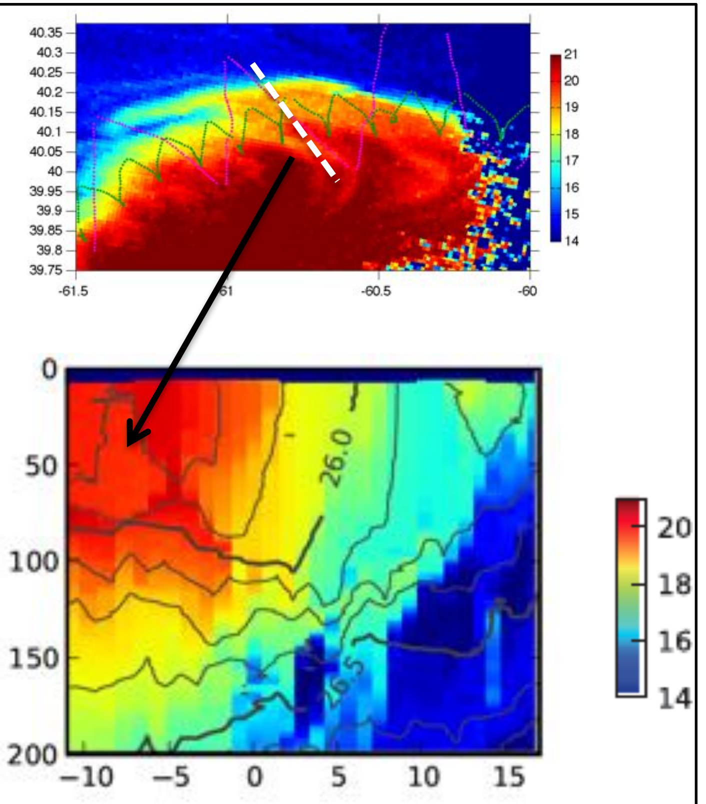
C. Confronting models with observations

Submesoscale dynamics (in the surface layer):

- Process studies (e.g., mixed-layer baroclinic instability, symmetrical instability.)



Model

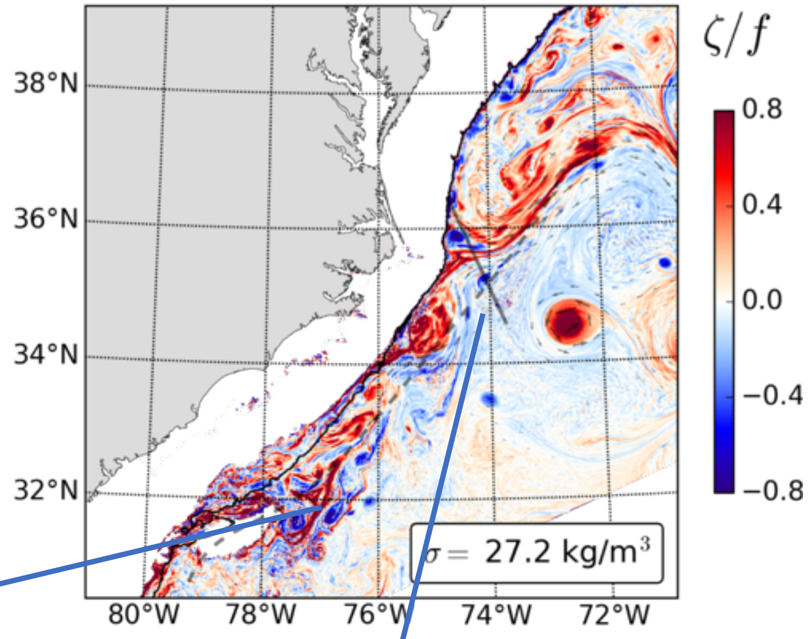


Observed temperature LatMix 2012

C. Confronting models with observations

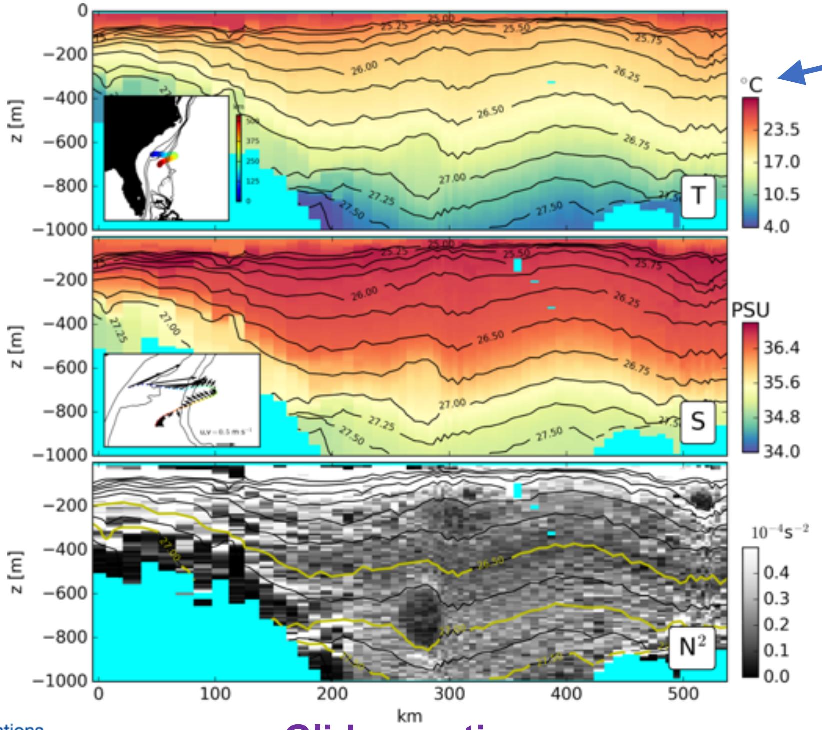
Submesoscale dynamics (at the bottom / in the interior):

- Mostly qualitative comparisons from opportunistic observations (gliders/ sismic, etc.)

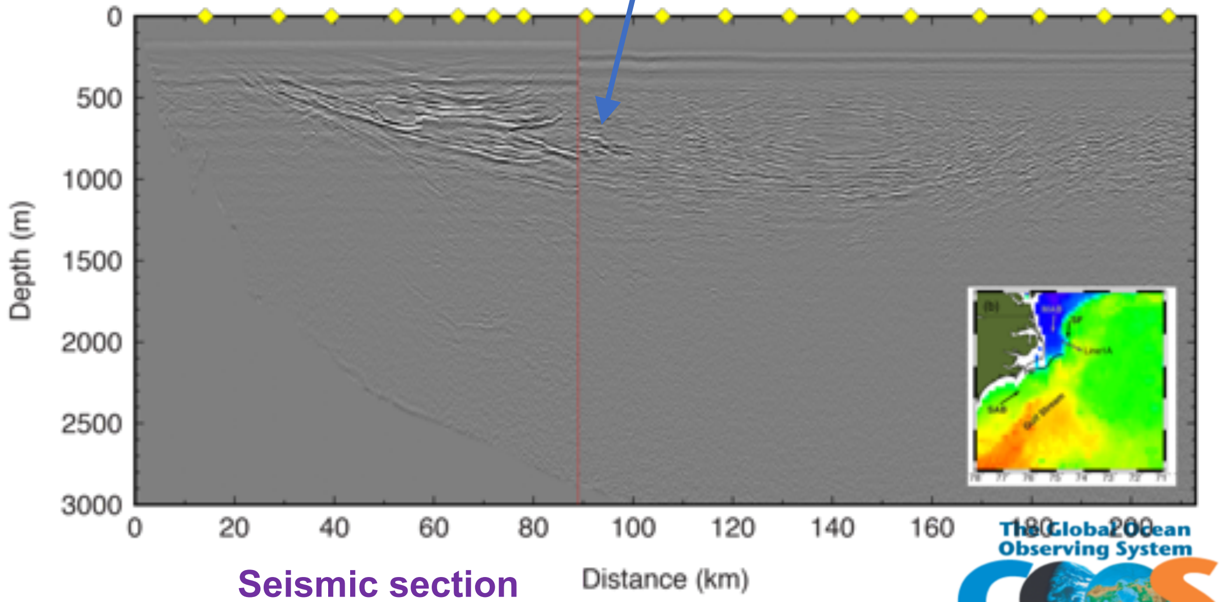


Model

[Gula et al., 2019]



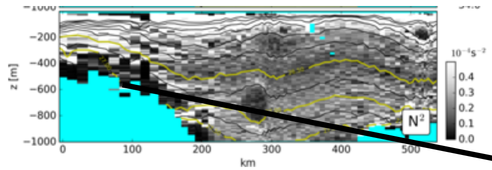
Glider section



Seismic section

C. Confronting models with observations

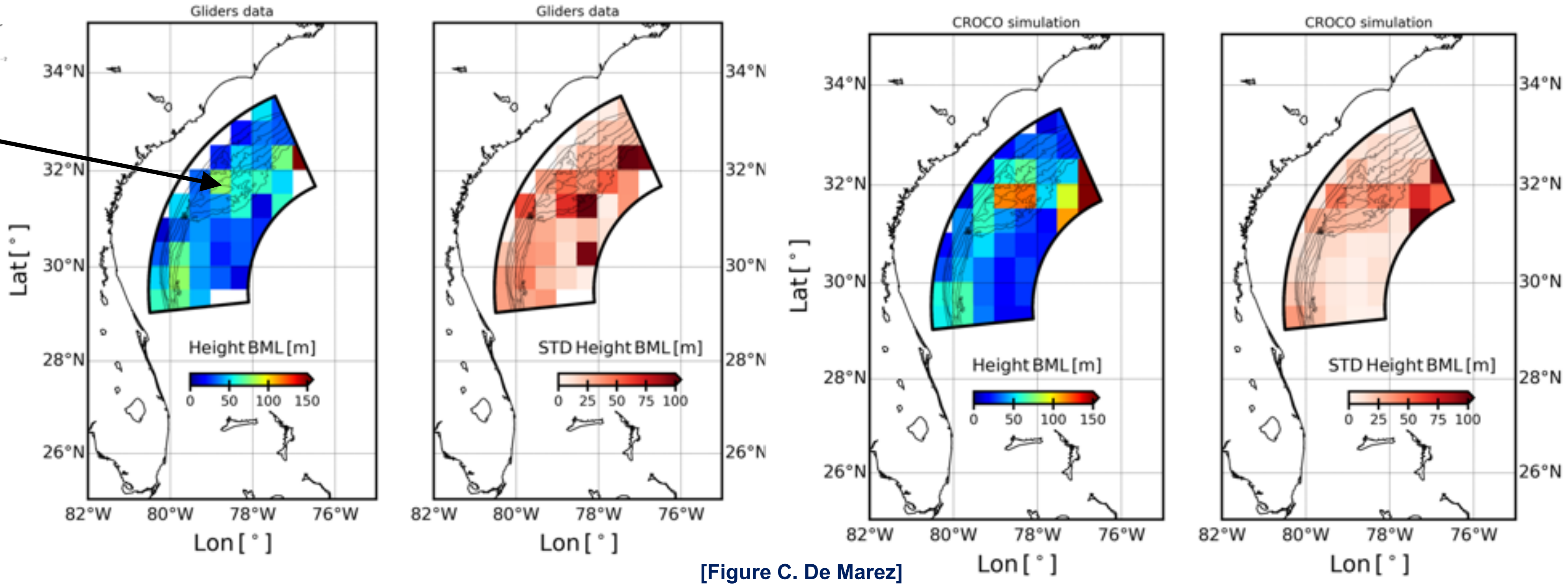
Mixing and water-mass transformations:



Thick bottom mixed layers observed by gliders in the Gulf Stream **[Todd, 2017]**

Gliders

Model (ROMS/CROCO at 150 m res.)



[Figure C. De Marez]

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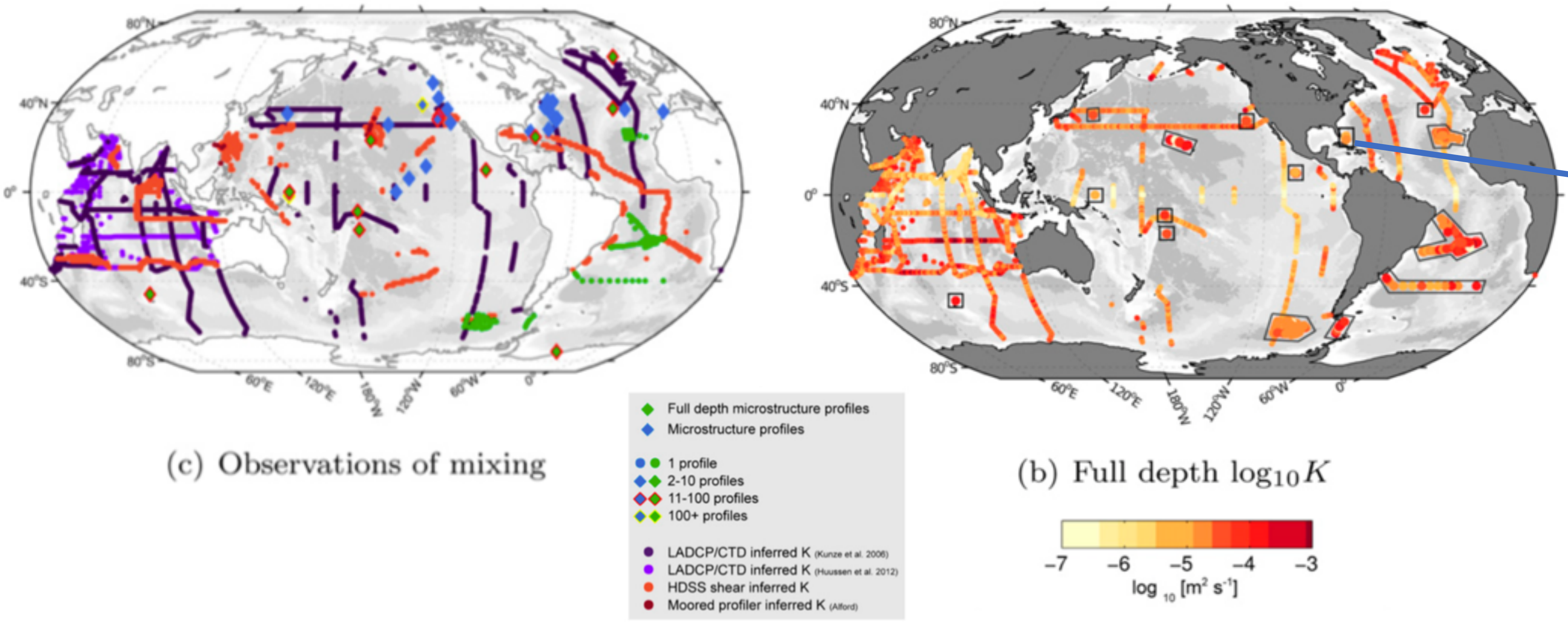
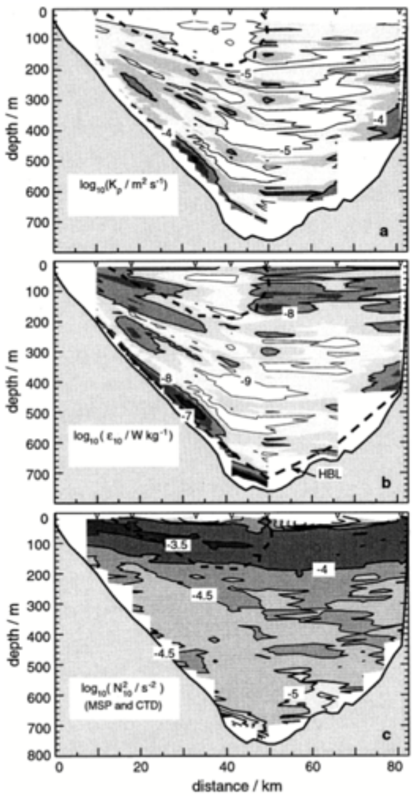
C. Confronting models with observations

Mixing and water-mass transformations:



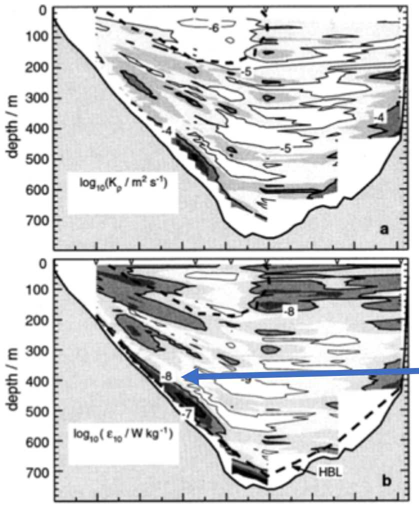
[Waterhouse et al, 2014]



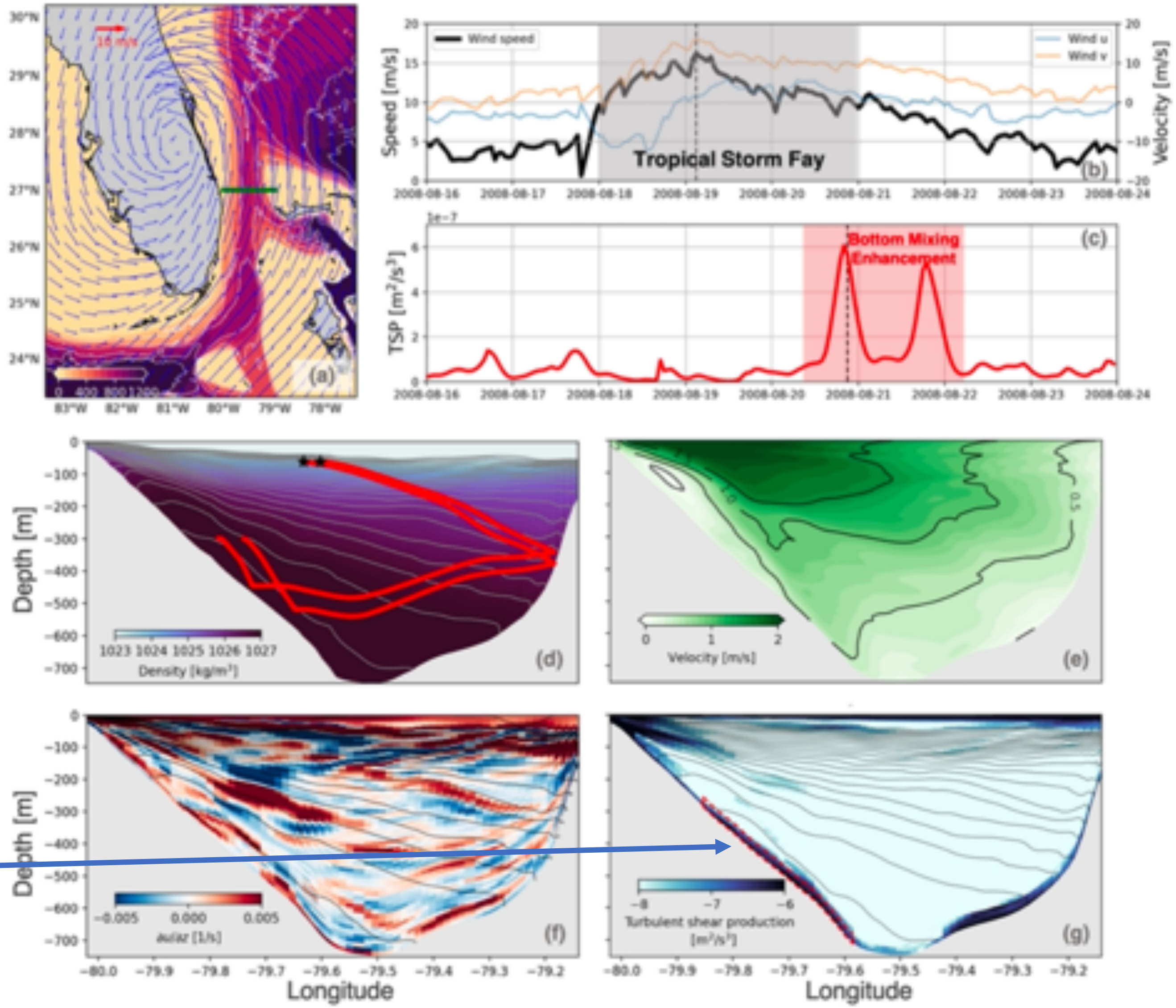
[Winkel et al, 2002]

C. Confronting models with observations

- Bottom Mixing Enhanced by Tropical Storm Generated Near-Inertial Waves Entering Critical Layers in the Straits of Florida



Microstructure [Winkel et al, 2002]



Model results [Qu et al, 2021]

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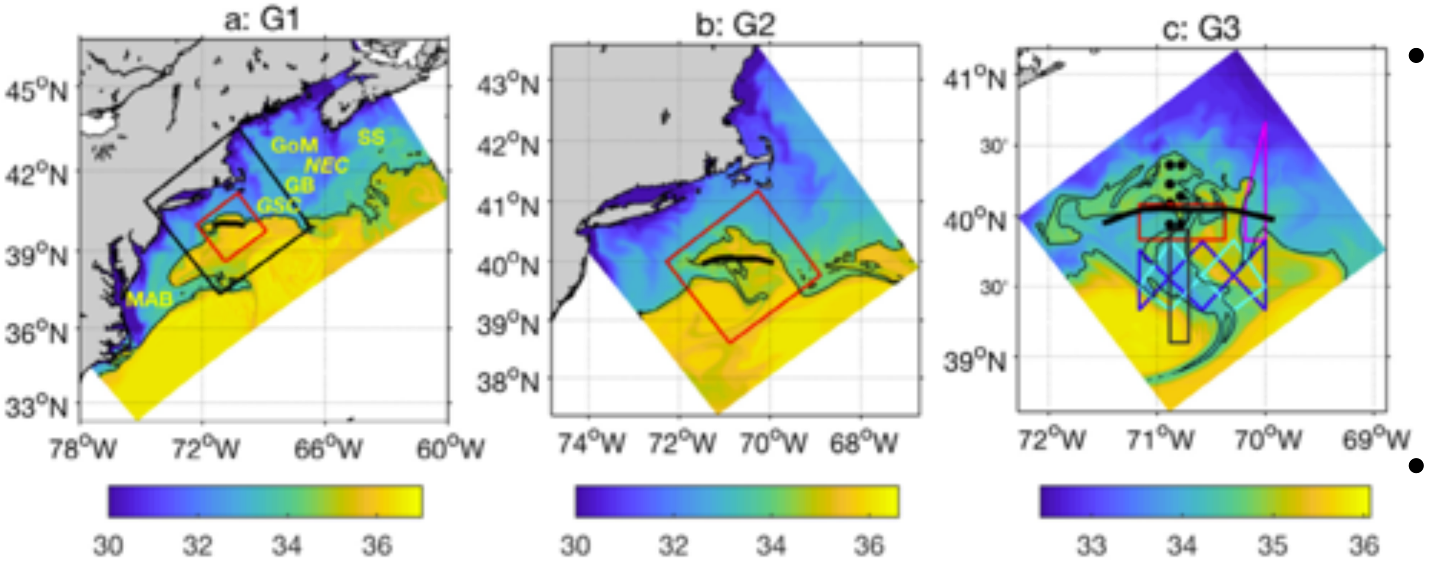
D. Data assimilation and regional forecasting

Requirements are even more challenging for **data assimilation**.

- An adequate representation of (sub)mesoscale dynamics requires some knowledge of 3d variables with high enough spatial and temporal density.



[Levin et al, 2021a,b]

- Nested models *(with grid-scale down to 800 m)* used in conjunction with a 4D-Var data assimilation system using extensive obs from remote sensing, in situ, and mobile platforms can perform well to reproduce the (sub)mesoscale circulation on the MAB [Levin et al, 2021a,b]

- In particular velocity data from the Pioneer Array play a critical role to reduce uncertainties

E. Conclusion

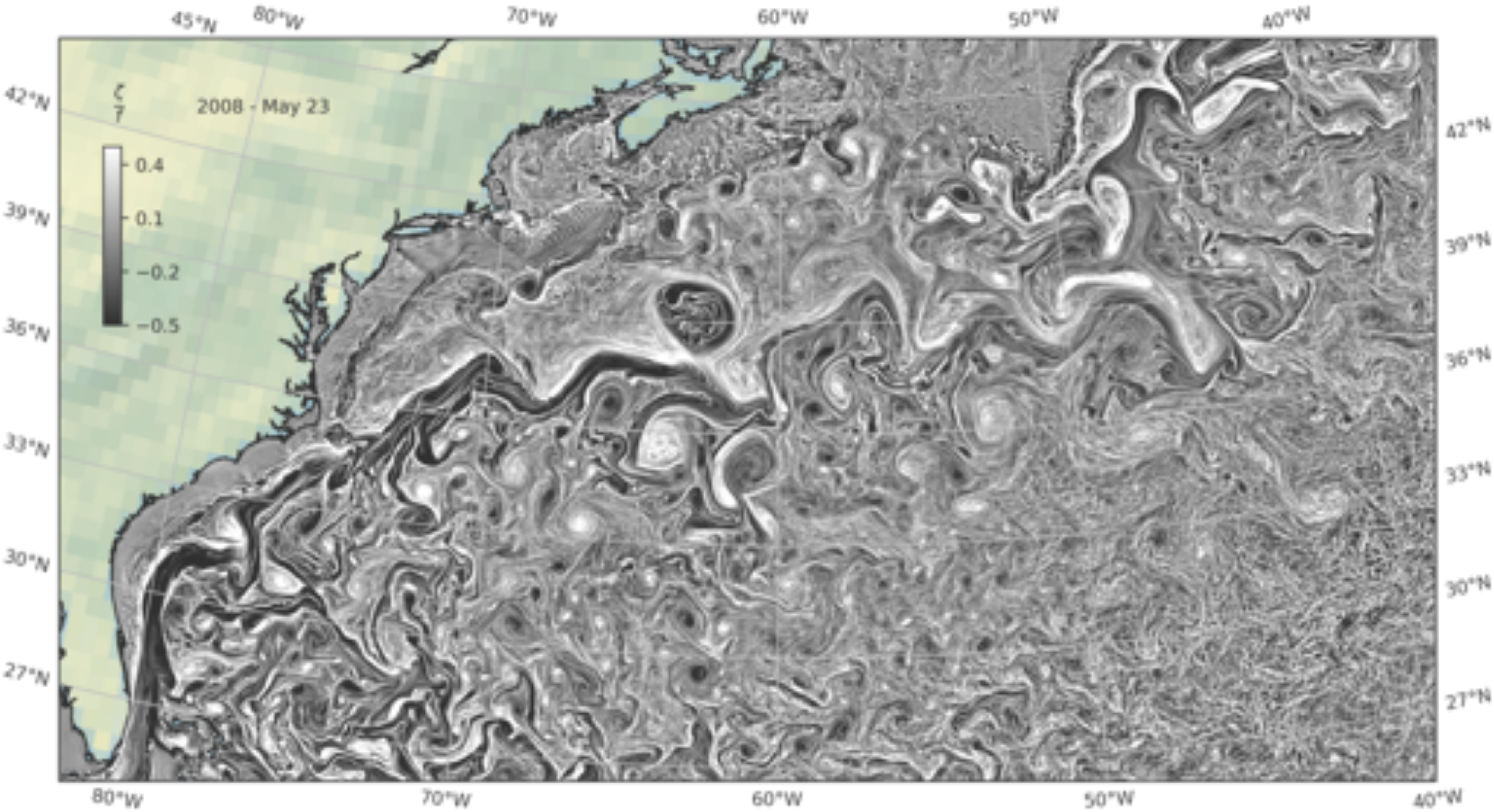
Sustained ocean observations from satellites and in situ networks are critical for assessing the skills and limitations of ocean models.

- Needs to acquire more high-horizontal resolution, **directly-measured velocity sections** across the Gulf Stream (more frequent sADCP sections)

- Dedicated experiments **to measure velocity gradients** (*e.g.,* array of moorings, swarm of gliders) at the surface and bottom to validate (sub)mesoscale dynamics in models and perform assimilation in regional systems.

- Increase **measurements in the deep ocean** (below 2000 m). *Models are not well tested / constrained there.*

- New measurements of **small-scale turbulence** in the interior and at the bottom – *missing important processes for mixing and water-mass transformations.*



45°N
80°W
70°W
60°W
50°W
40°W
42°N
39°N
36°N
33°N
30°N
27°N
$\frac{\zeta}{f}$
2008 - May 23
0.4
0.1
−0.2
−0.5