# Generation of lee waves and submesoscale vortices in the wake of the Charleston Bump

**Ocean Sciences Meeting**
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# What is the Charleston Bump?

- The Charleston Bump is a prominent topographic feature along the U.S, eastern seaboard (100 km x 200 km) with rough small-scale topography,
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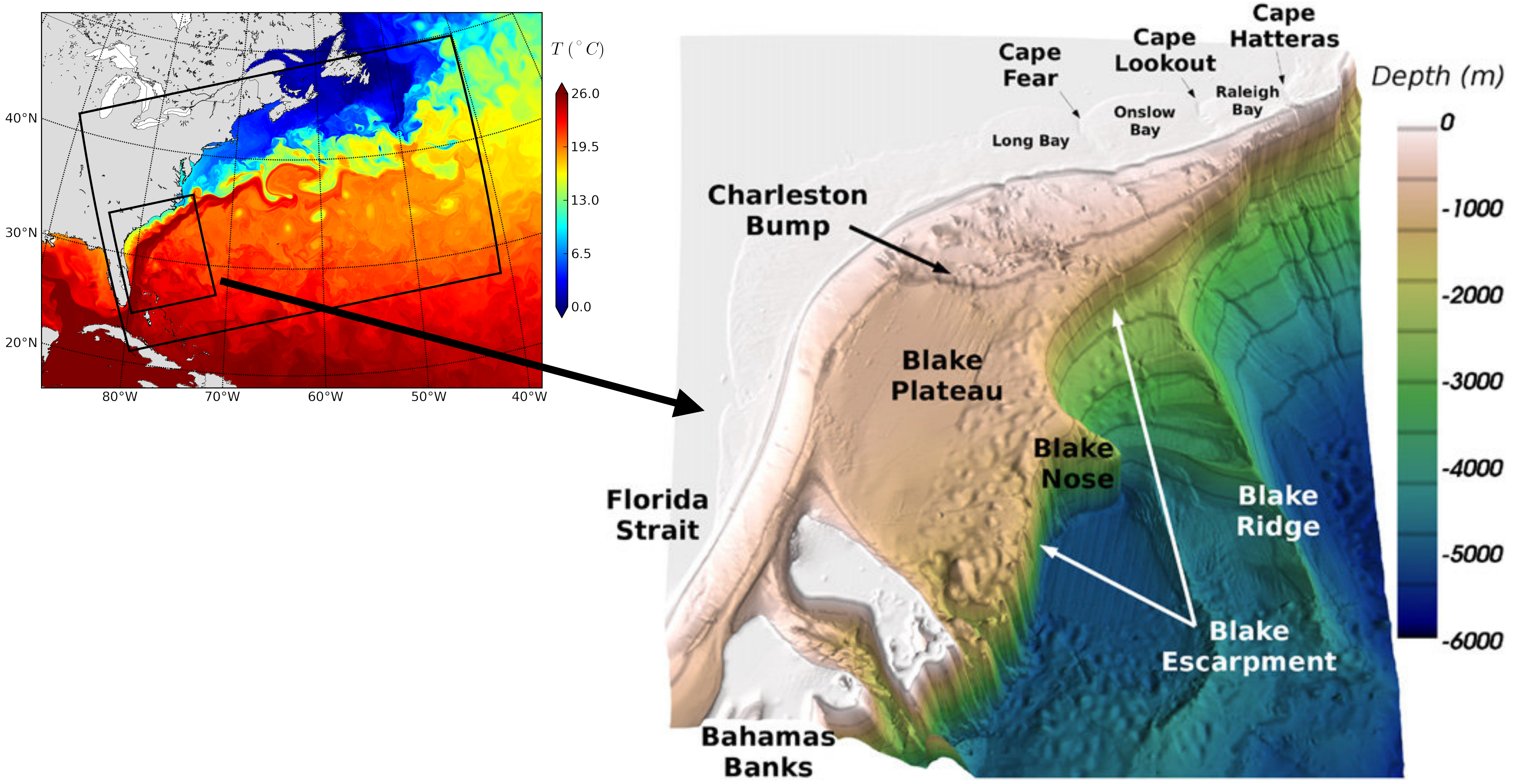
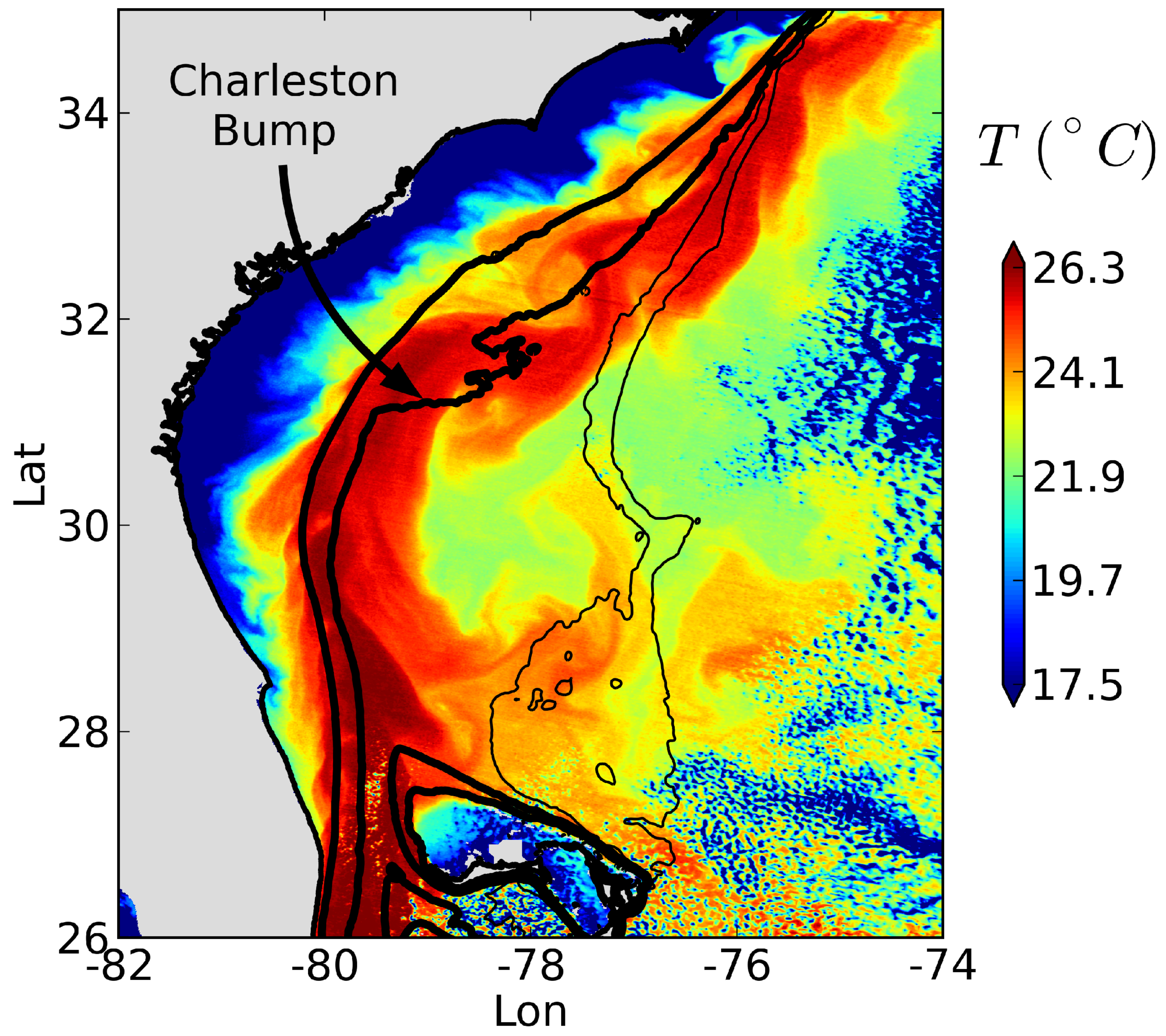



Topography from SRTM30

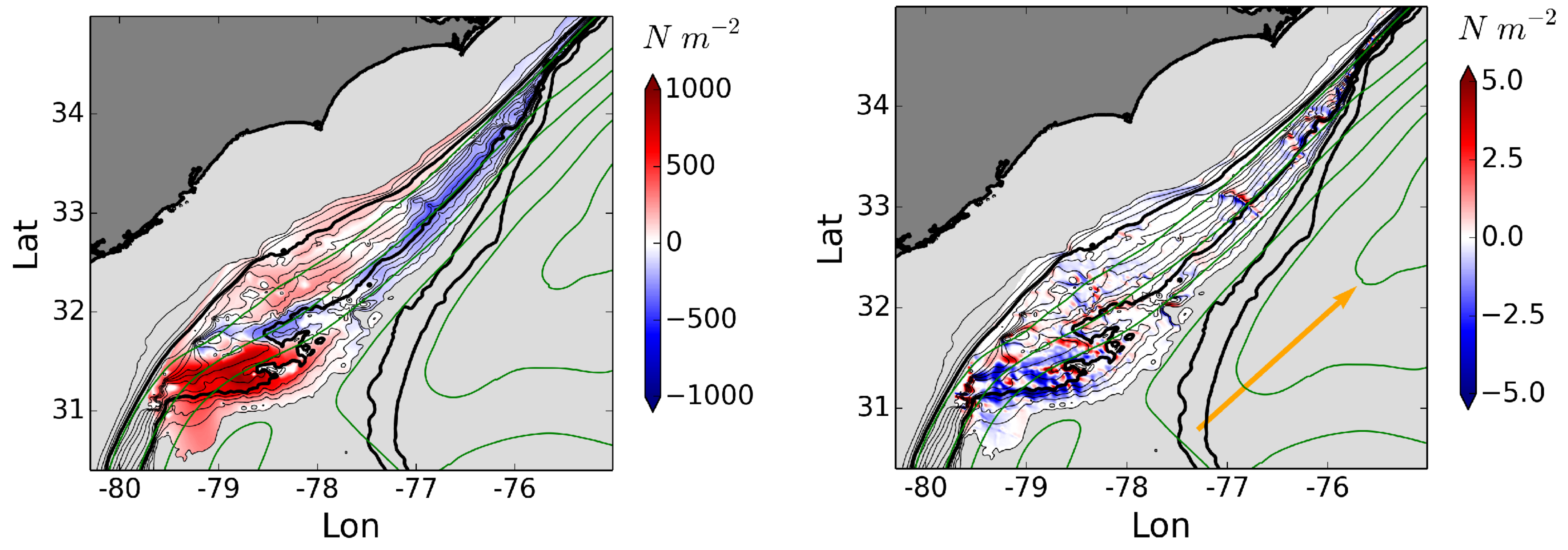
- Right on the Gulf Stream path.




Observed Sea Surface Temperature (SST) of the Gulf Stream. Data from MODIS-AQUA.

# Large scale Impacts of the Bump

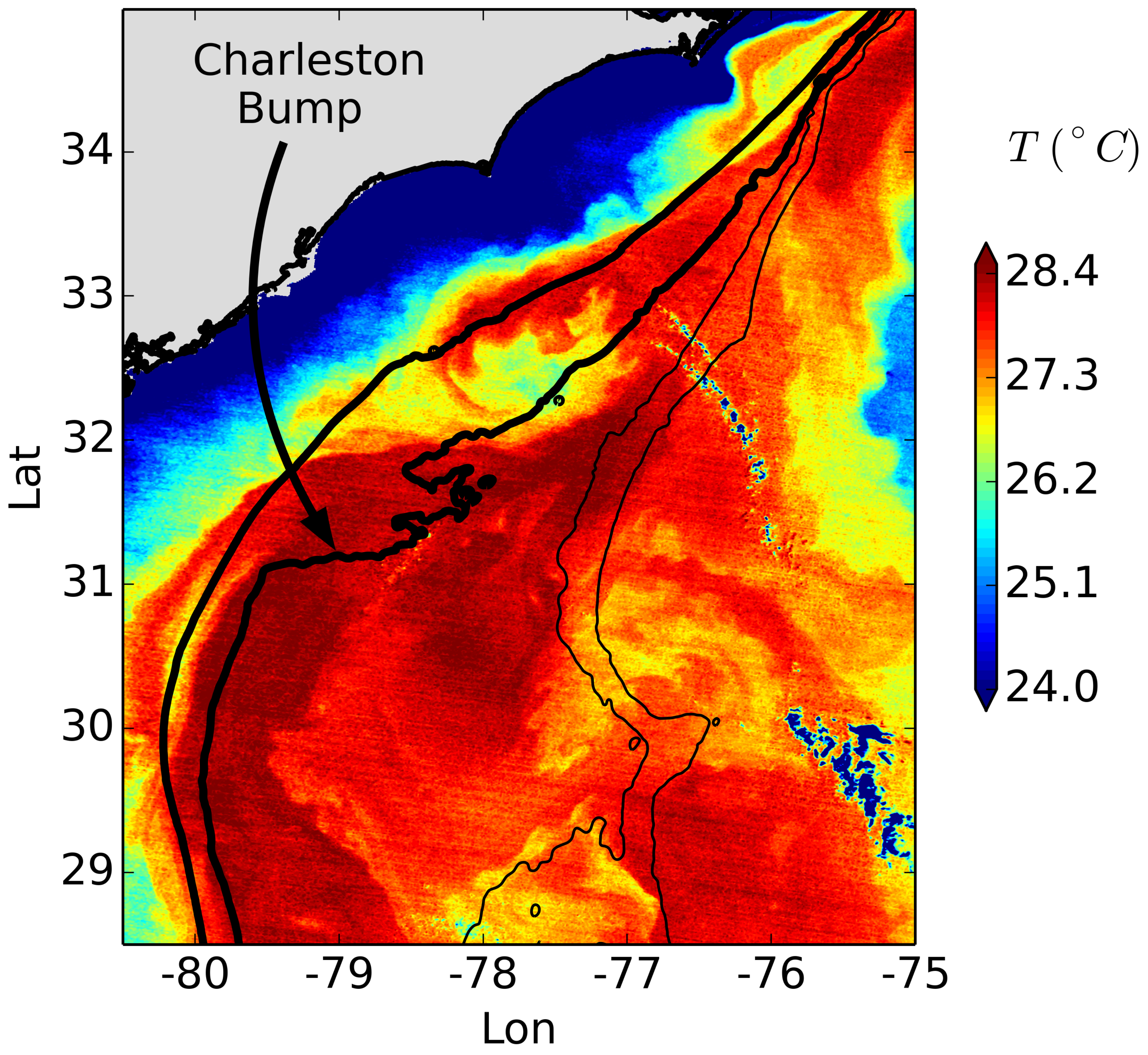
- **Significant local pressure anomalies and topographic form drag** exerted by the Bump steer the mean current pathway seaward.




Mean bottom pressure anomaly (left) and form drag (right) from a ROMS dx=750 m simulation

- Form drag : $1.5\,10^{10}\mathrm{N}$
- Also a hot spot for the viscous drag ( $0.5\,10^{10}\mathrm{N}$ )

- Strong amplification of meanders and generation of frontal eddies

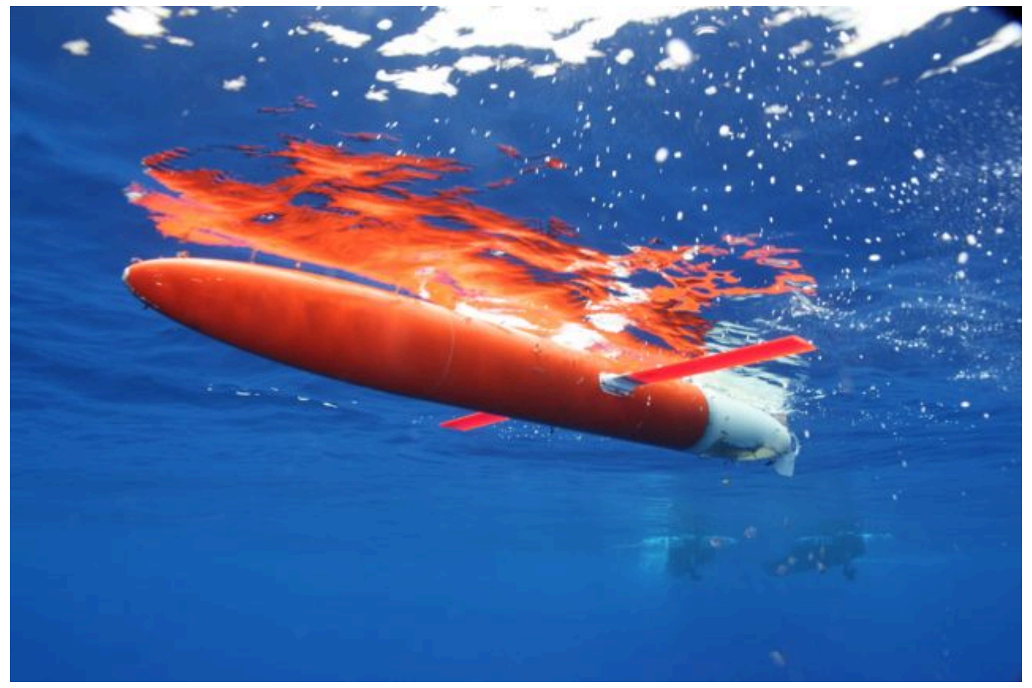


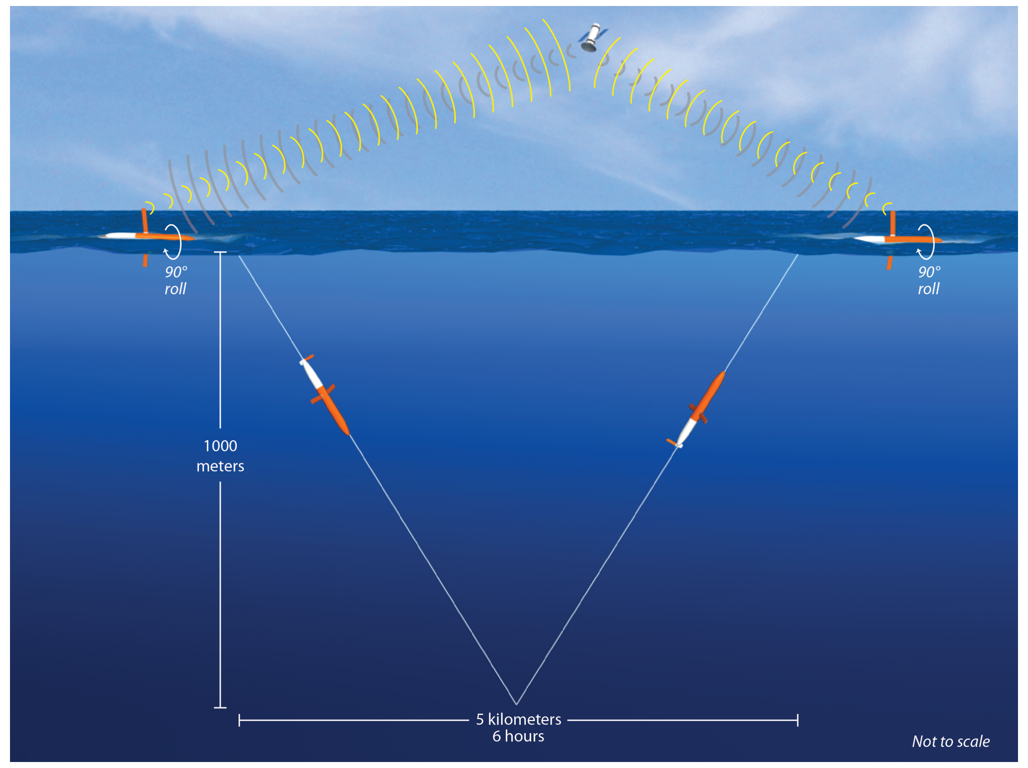

Observed Sea Surface Temperature (SST) of the Gulf Stream. Data from MODIS-AQUA.

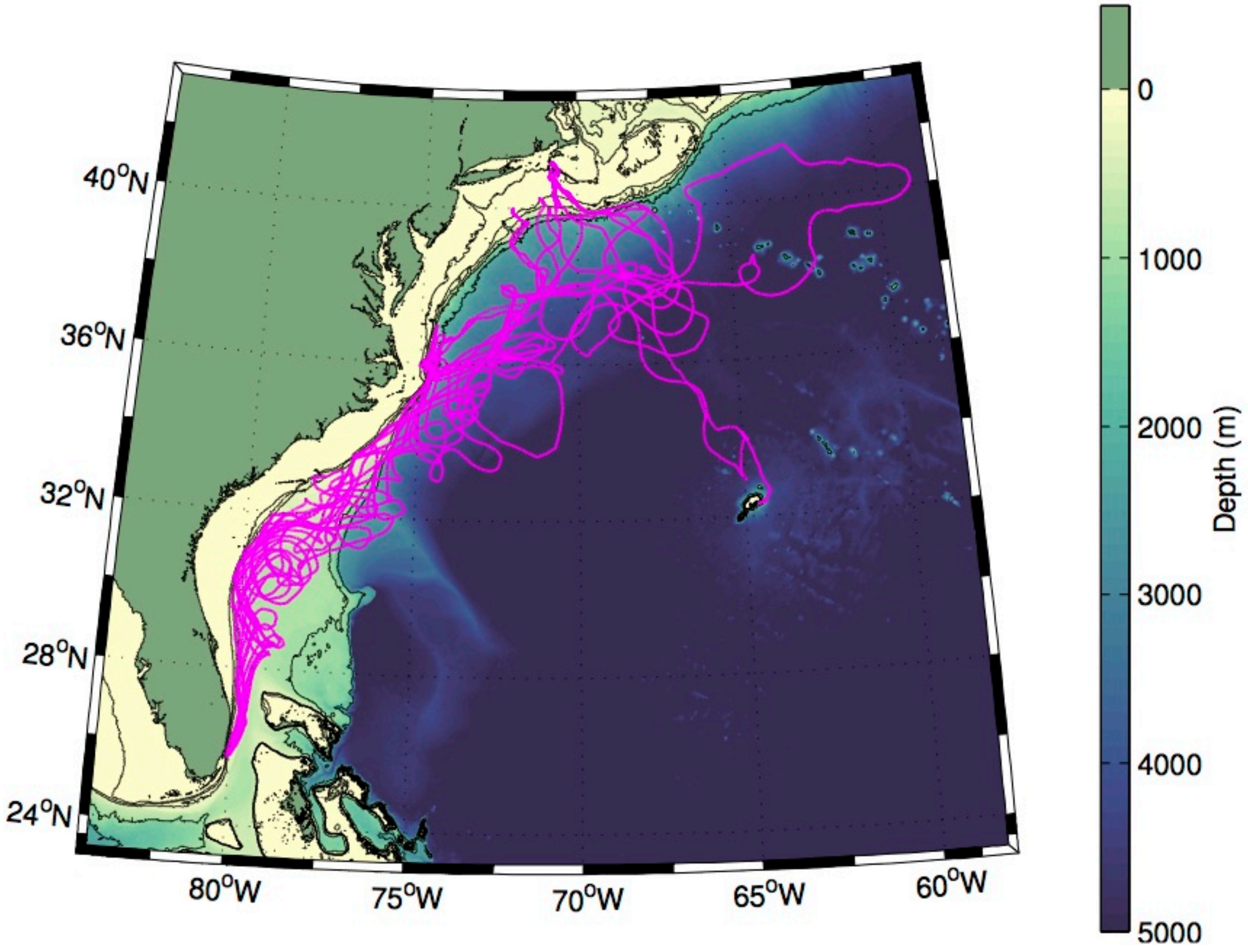
[Gula, Molemaker & McWilliams, JPO, 2015]

# Thick bottom boundary layer

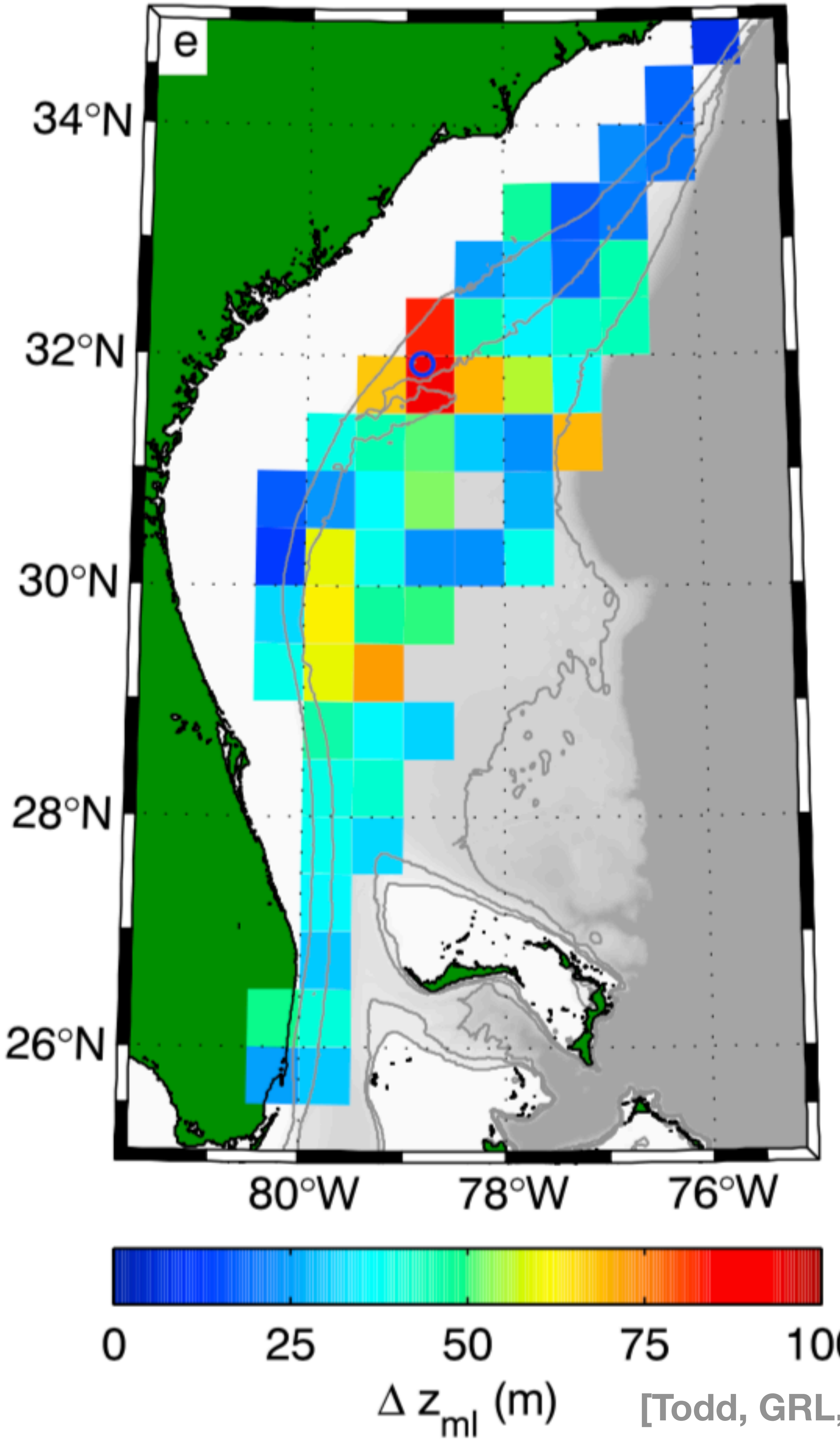
- Thick O(100 m) bottom mixed layers are generated in the lee of topography, likely due to enhanced turbulence generated by O(1) m s-1 near-bottom flows.





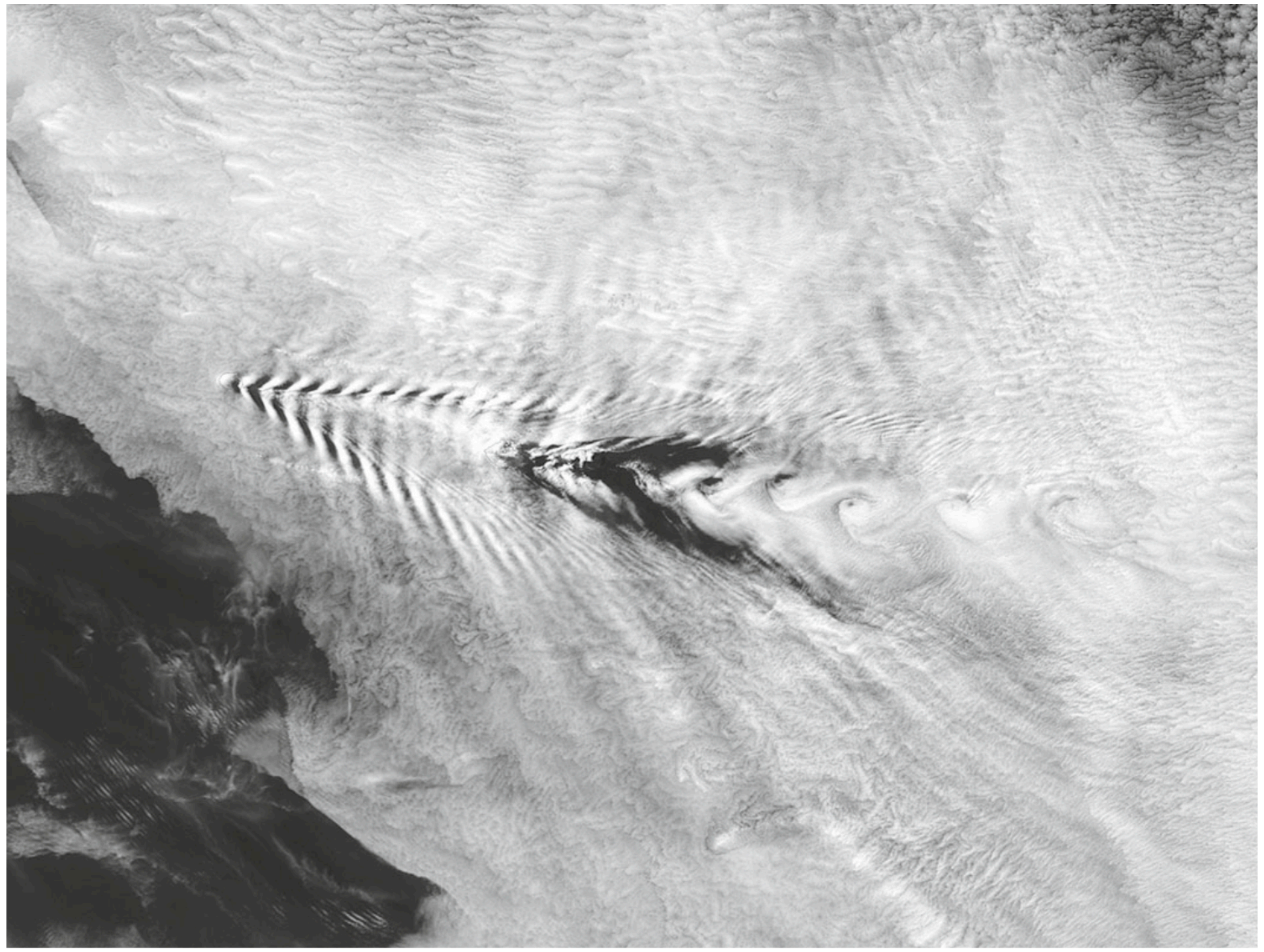




Glider Data [Todd & Owens, 16]
publicly available: https://spraydata.ucsd.edu/projects/GS




[Todd, GRL, 17]

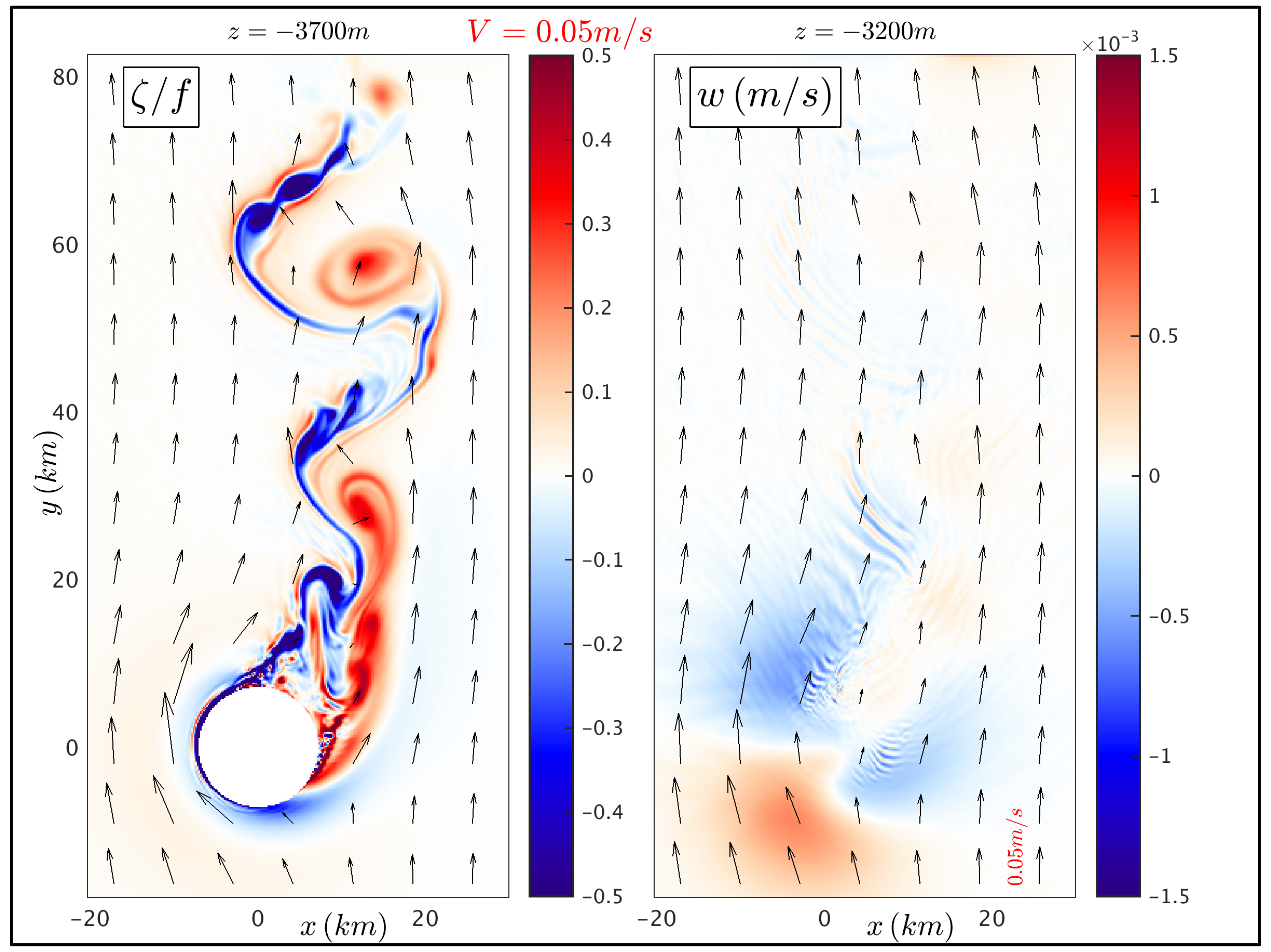
# Flow-topography interactions over the Bump?



MODIS satellite image in the wake of the Crozet Islands in the southern Indian Ocean on November 2nd, 2004. [Nunalee & Basu, 14]

1. **Vortical wake** in the lee of the Bump?

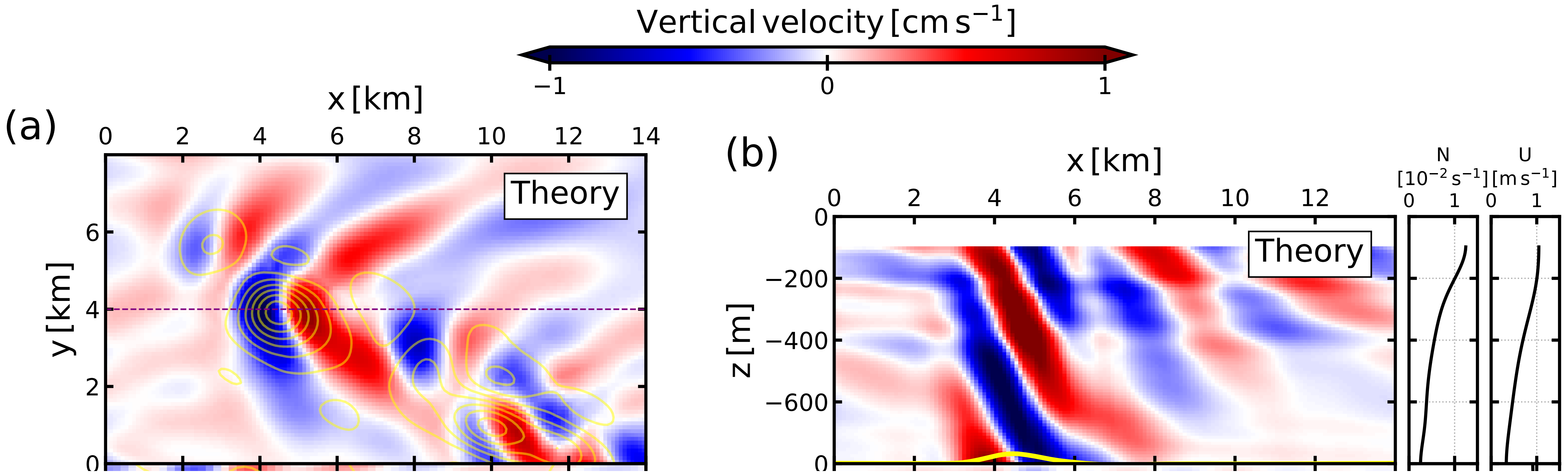
*= instabilities, energy dissipation, and formation of submesoscale coherent vortices*




[Srinivasan et al, JPO, 2019]

2. Generation of **Lee waves**?

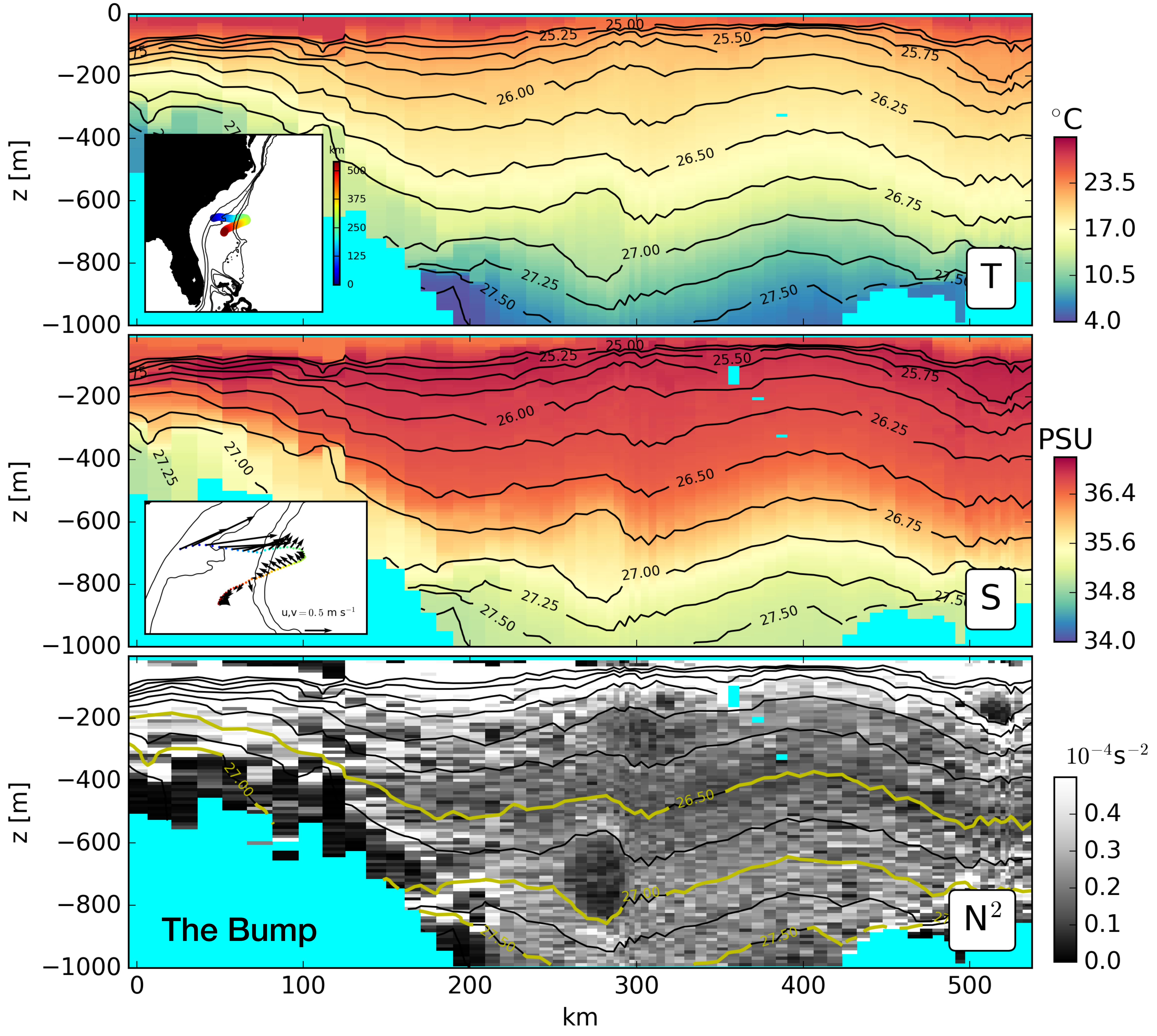
*= extraction of momentum, energy and dissipation*



# Observation of submesoscale coherent vortices (SCVs)

- Anticyclonic submesoscale lenses of well-mixed water are observed in glider sections of the Gulf Stream in the lee of the Bump

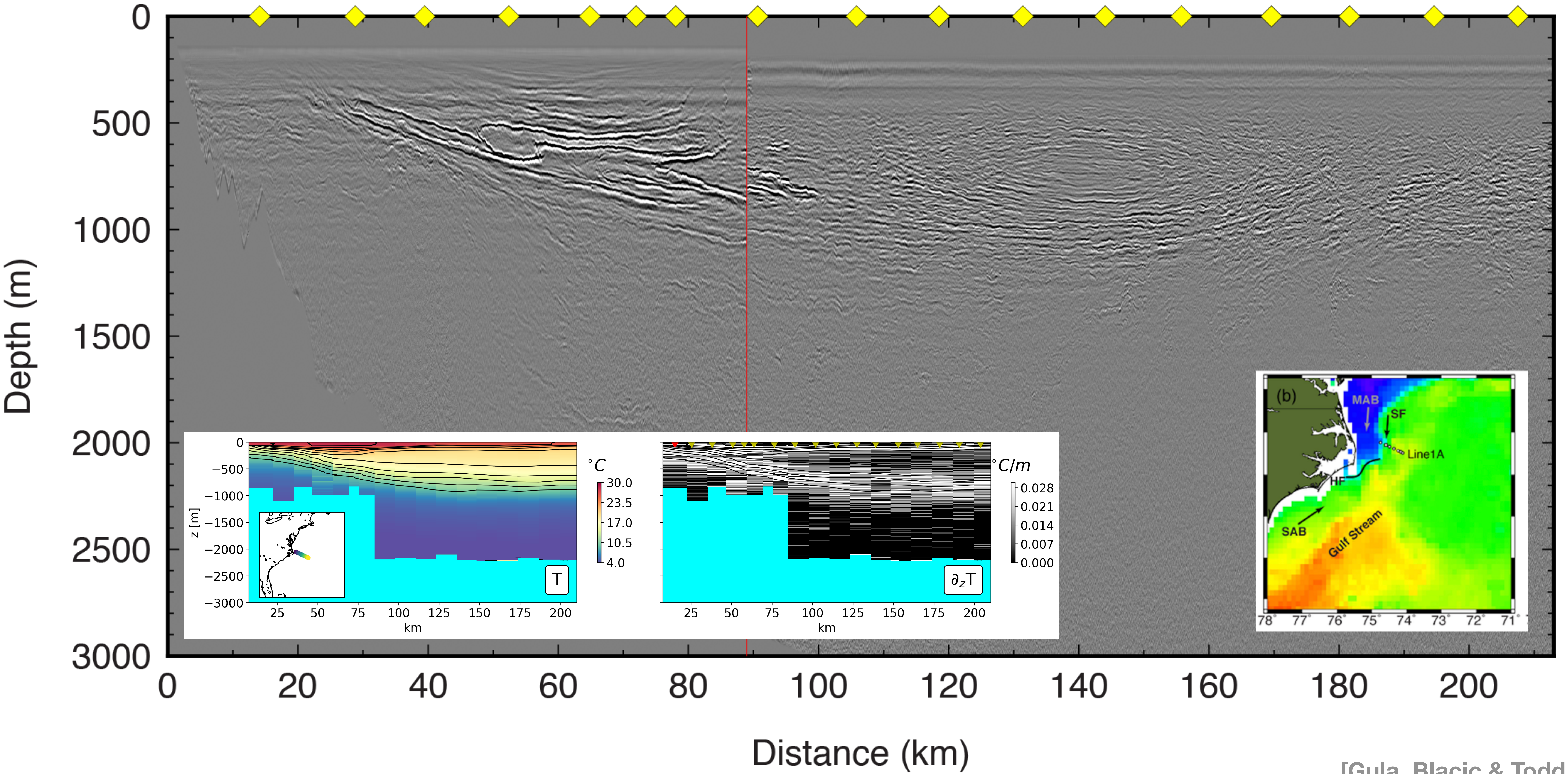
**Glider data**




[Gula, Blacic & Todd, GRL, 2019]

# Observations of SCVs in the Gulf Stream

**Seismic Data from the Eastern North America Margin Community Seismic Experiment in Sep. 2014**




[Gula, Blacic & Todd, GRL, 2019]

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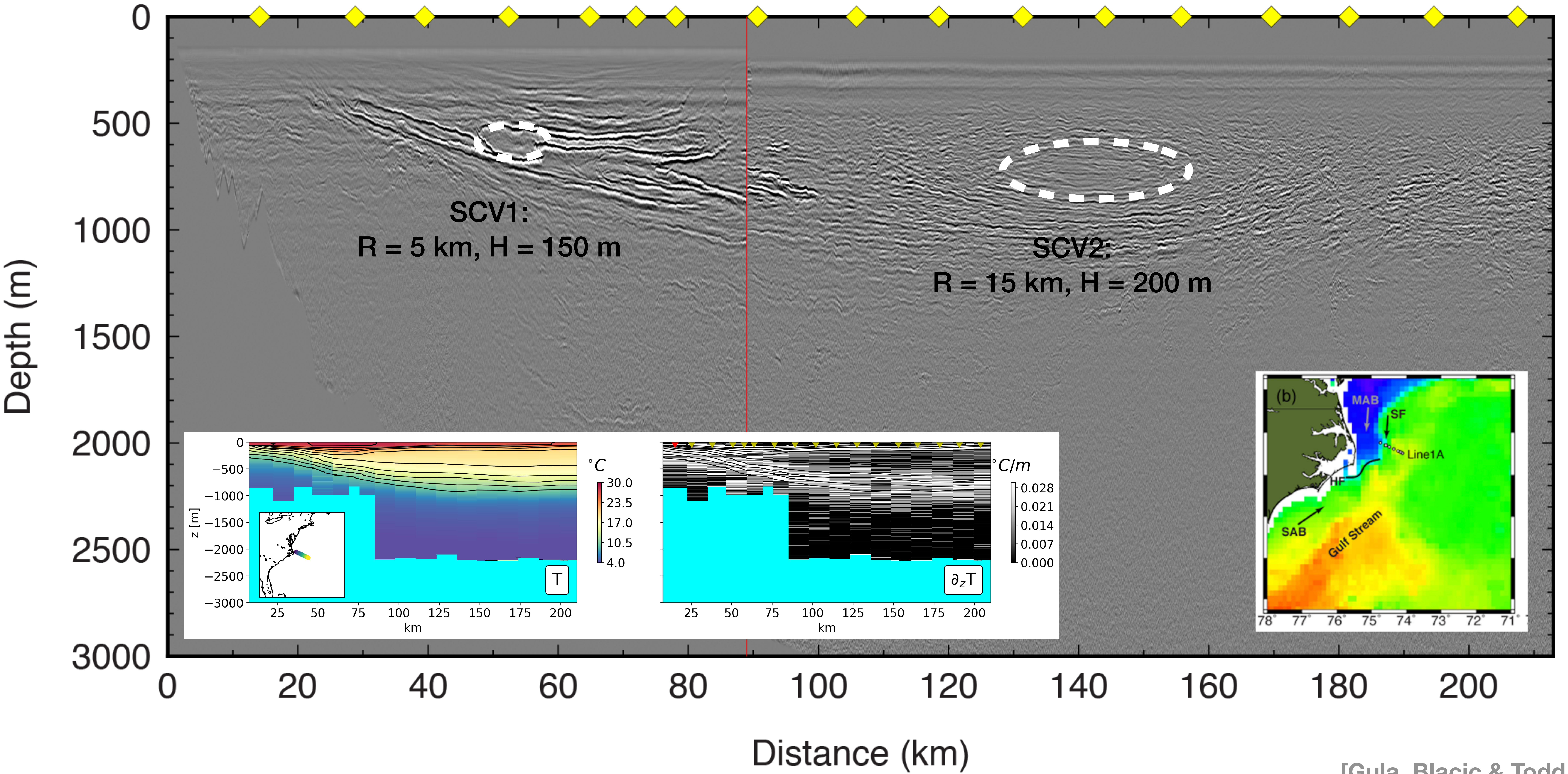
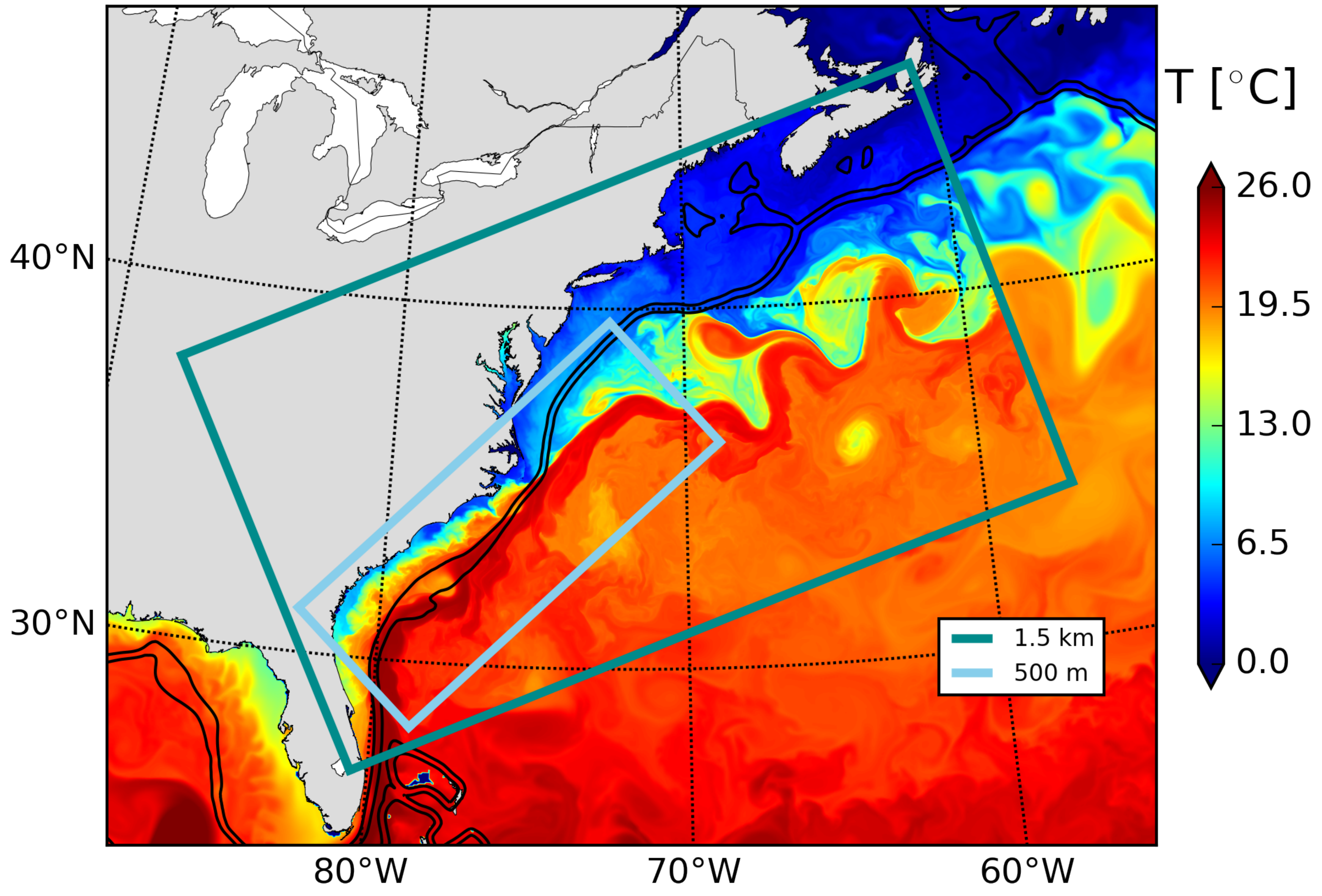
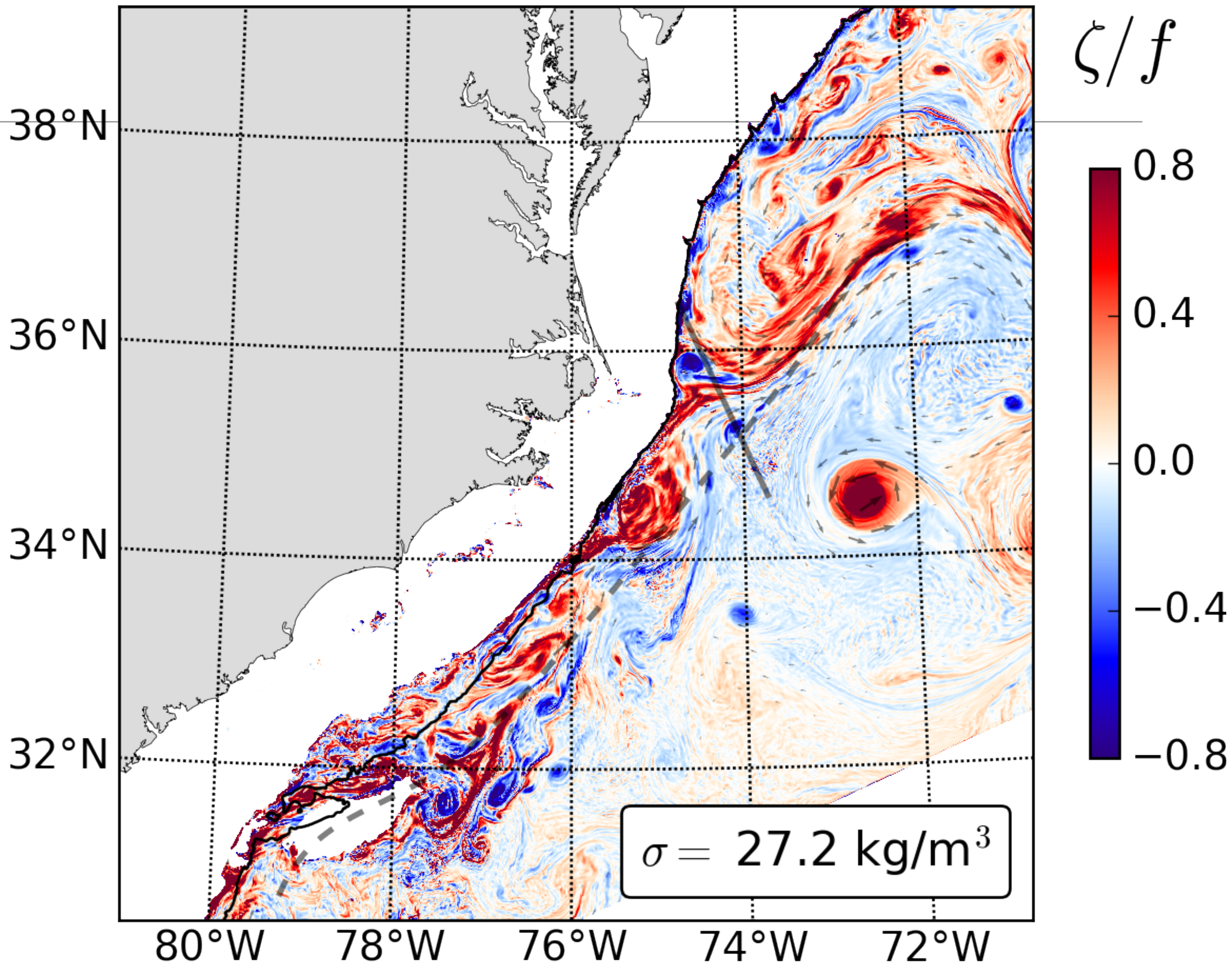



[Gula, Blacic & Todd, GRL, 2019]

# Modeling SCV's in the Gulf Stream

- Successive down-scale nested grids with the ROMS/CROCO model, from Atlantic (dx = 6 km) to local subdomain (dx = 500 m, 100 lev.).




- **The model typically exhibit SCVs at the location of the glider and seismic data with similar radius and thickness.**

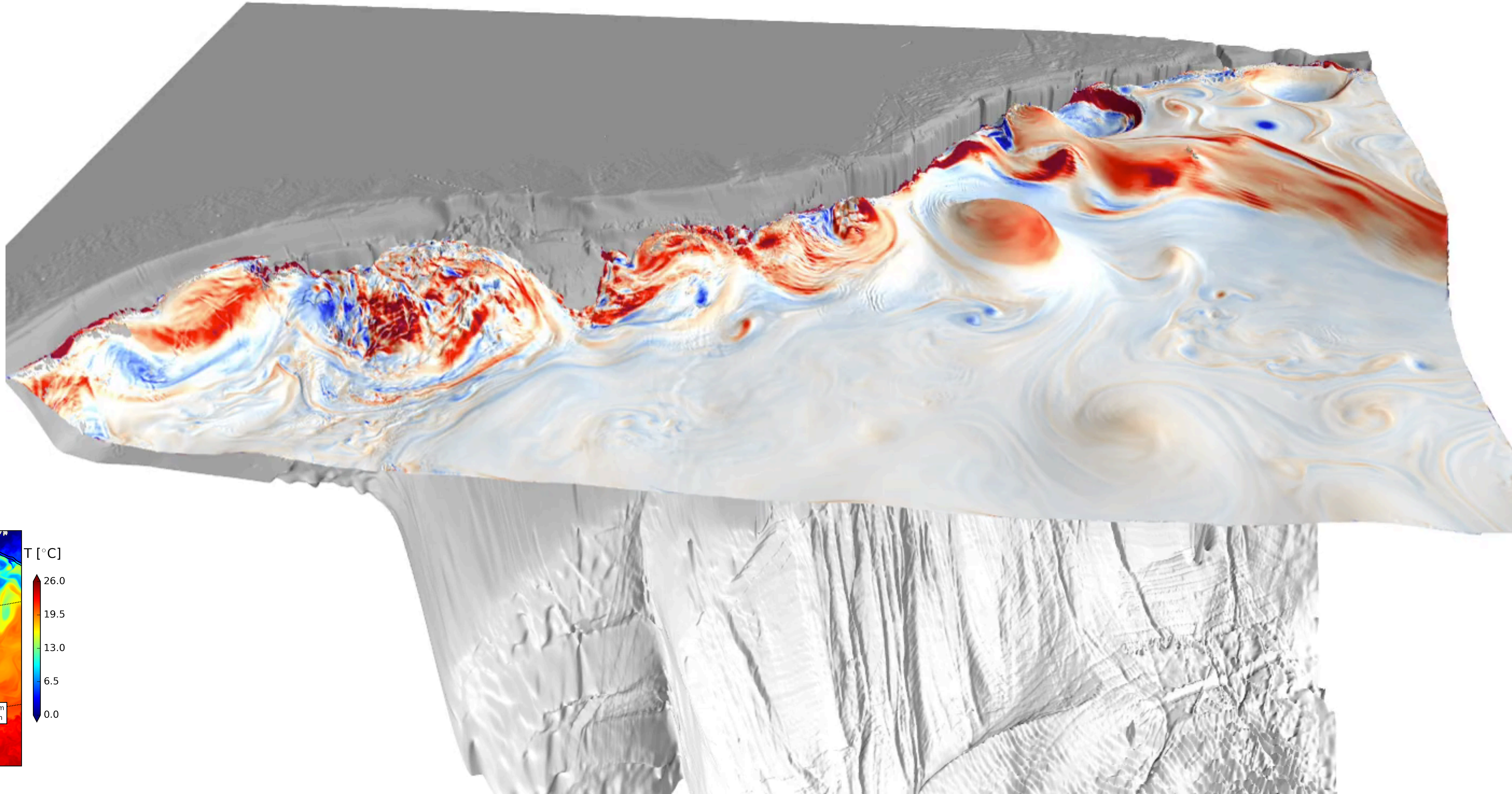
- **The SCVs originate from the Charleston Bump, where there is a strong generation of vorticity due to frictional effects**

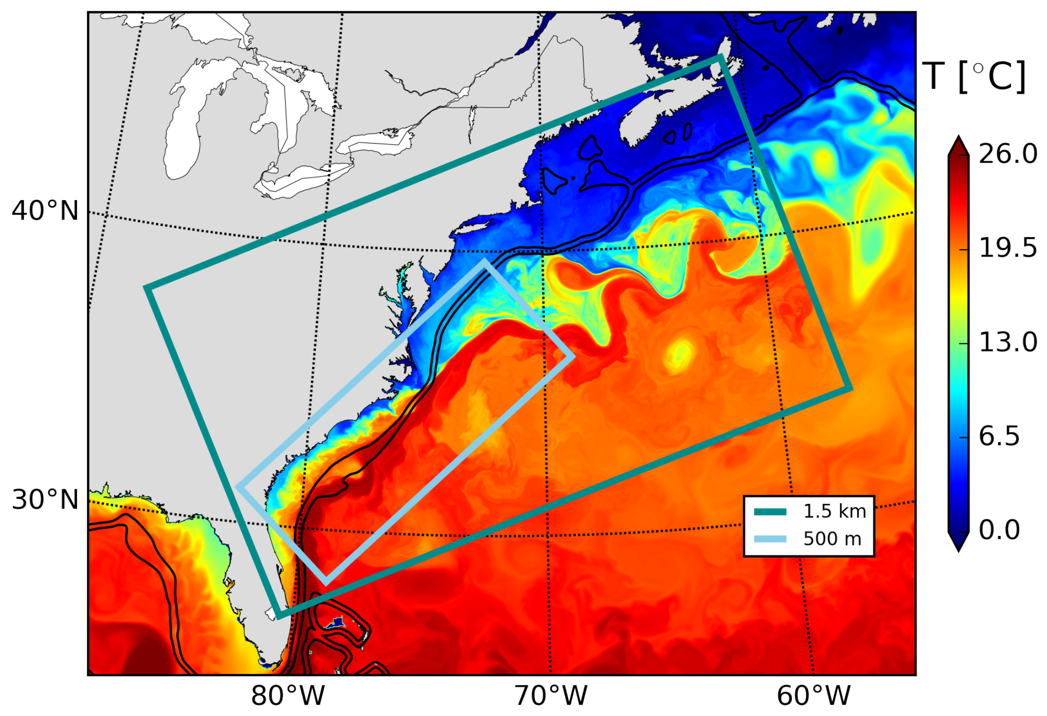
[Gula, Blacic & Todd, GRL, 2019]

# Modeling SCV's in the Gulf Stream

Relative vorticity on the isopycnal .

$$\sigma = 27\,\mathrm{kg\,m^{-3}}$$

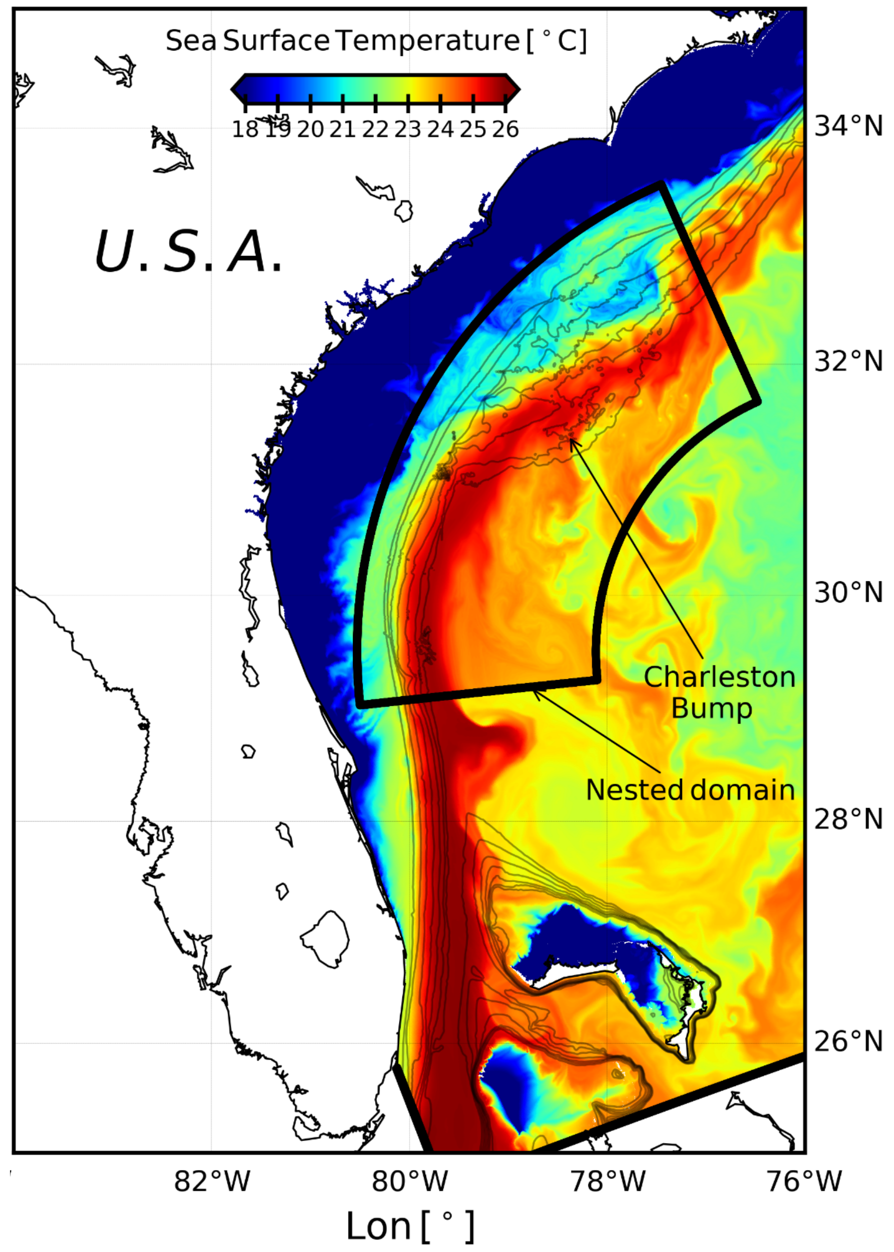




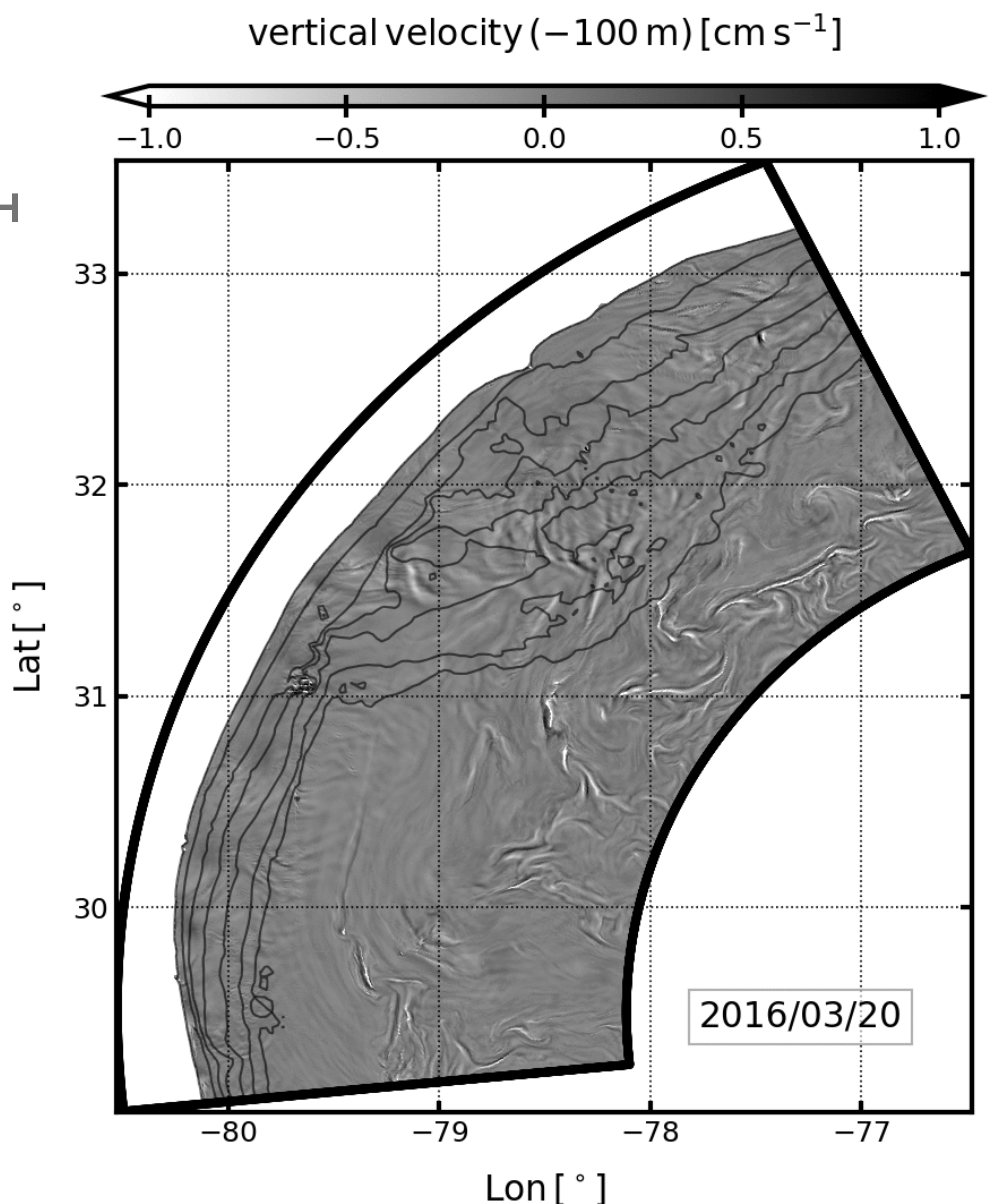
## 2. Generation of **Lee waves**?

# Simulation of Lee waves in the Gulf Stream

- We performed a nest at **dx = 150- 300 m** with **CROCO-NH**




- Climatological forcings (monthly winds, no tides)




[De Marez, Lahaye & Gula, Sci. Rep., 2020]

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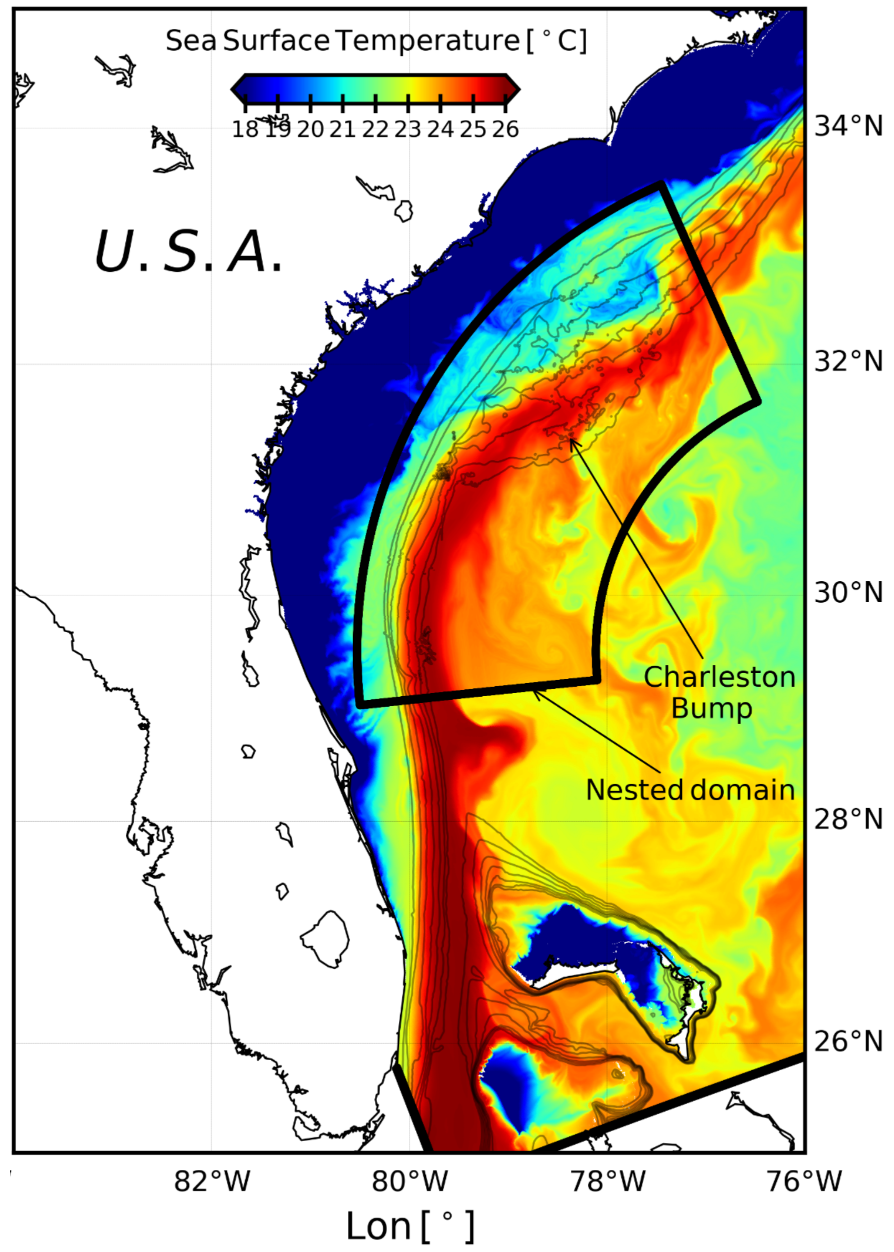


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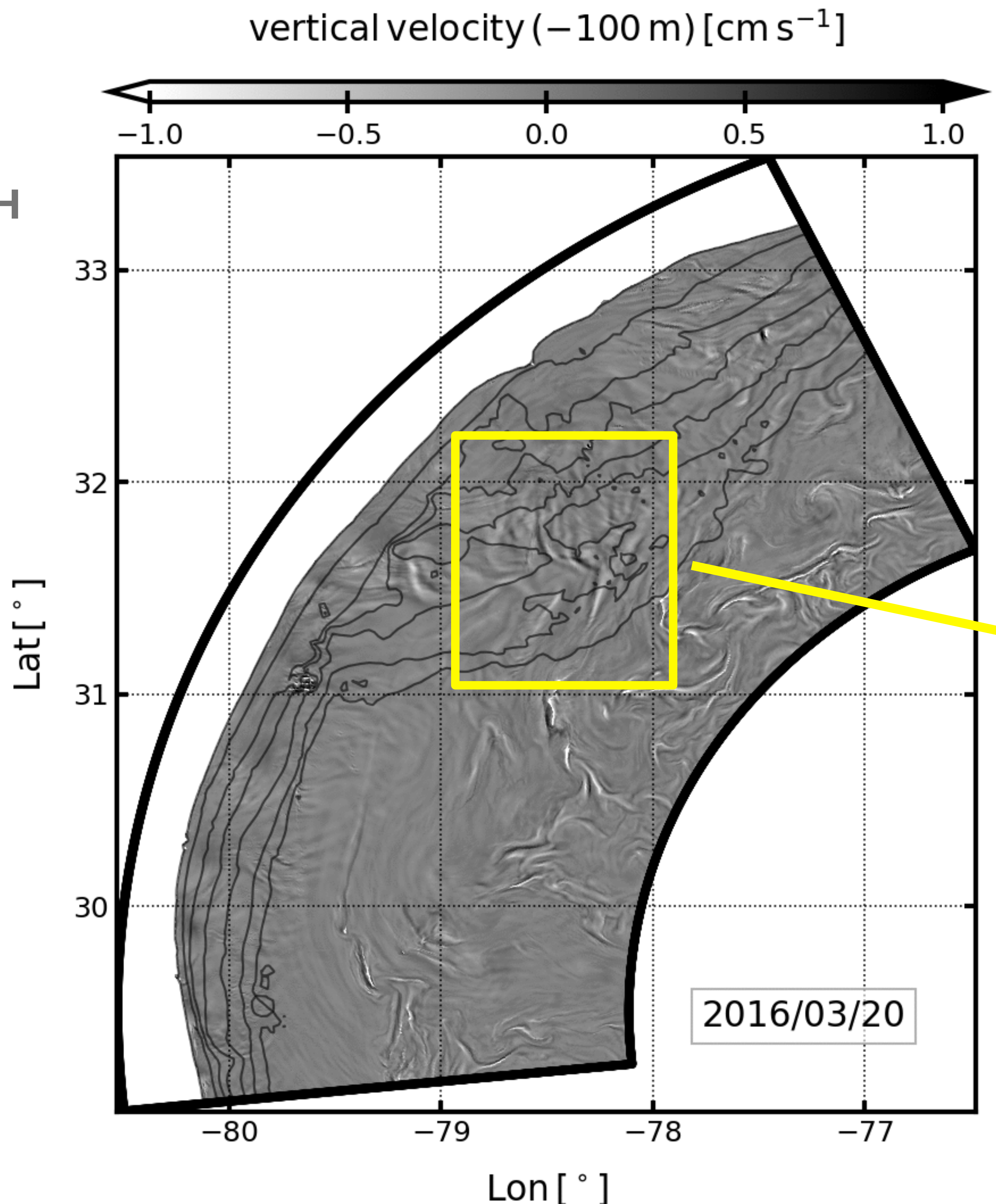
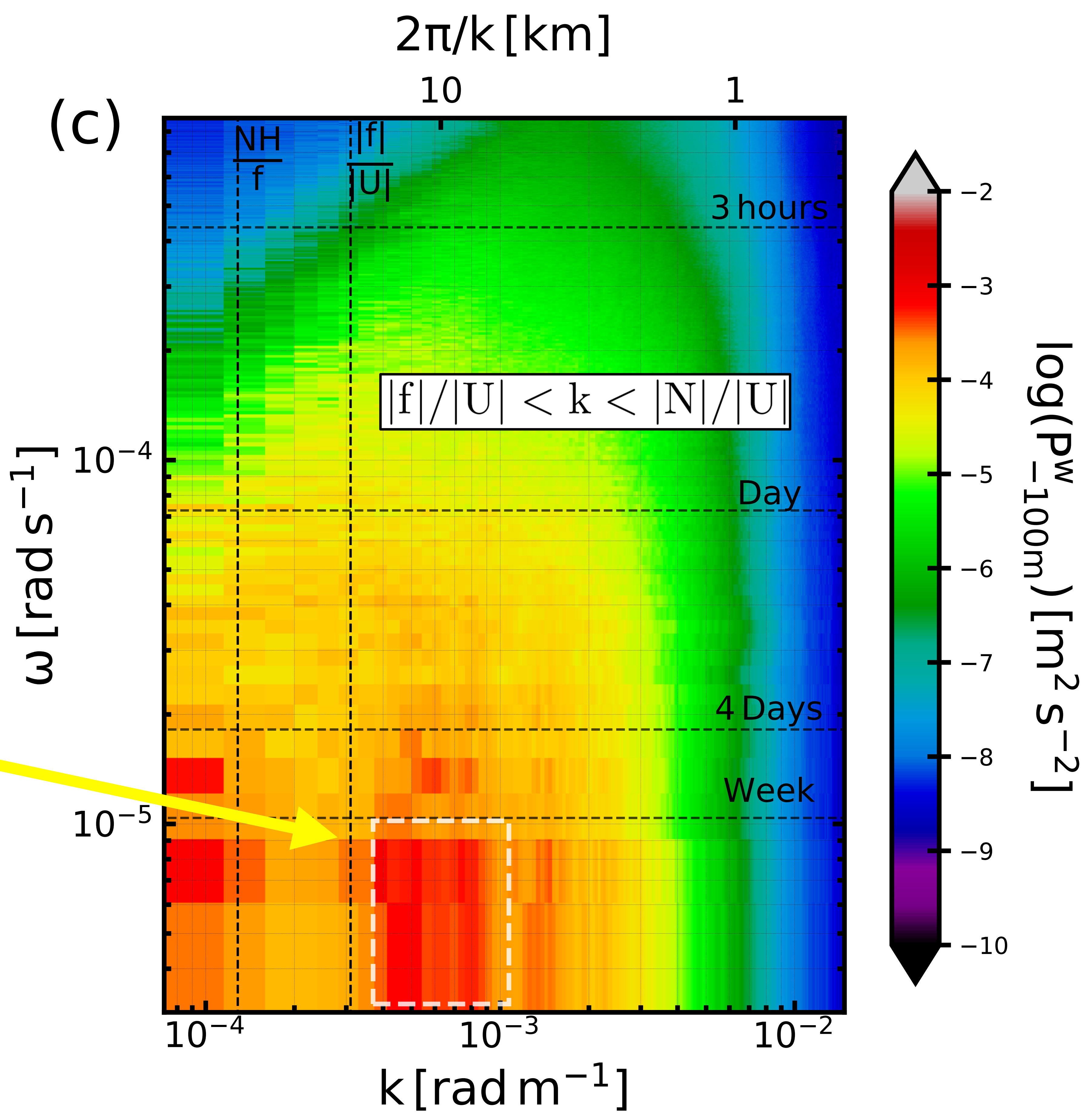



**Power spectra of vertical velocity**




- **Strong signature of lee waves over the Bump**

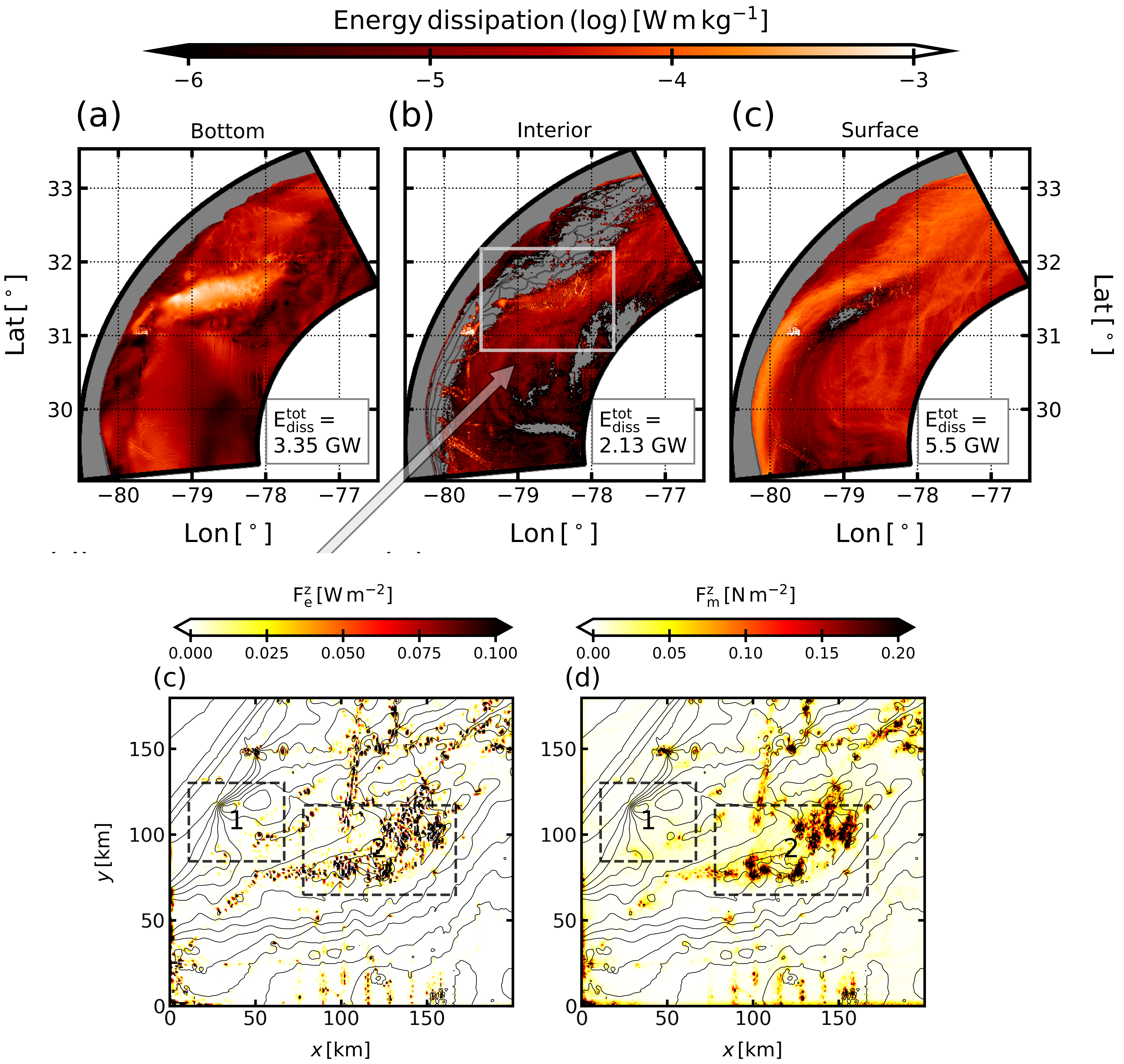
[De Marez, Lahaye & Gula, Sci. Rep., 2020]

# Energy and momentum fluxes due to the Lee Waves

A significant amount of energy (O(1) GW) is being dissipated in the interior of the fluid, in regions with strong lee waves generation

The lee wave energy flux ( $\mathrm{Fe^z = p'w}$ ) computed in the simulation yields a total conversion of O(0.3) GW. *[same than the analytical formula of Nikurashin & Ferrari, 2010]*

The wave drag amounts to O(1) GN and represents about 20% of the form drag exerted by the whole Charleston Bump.

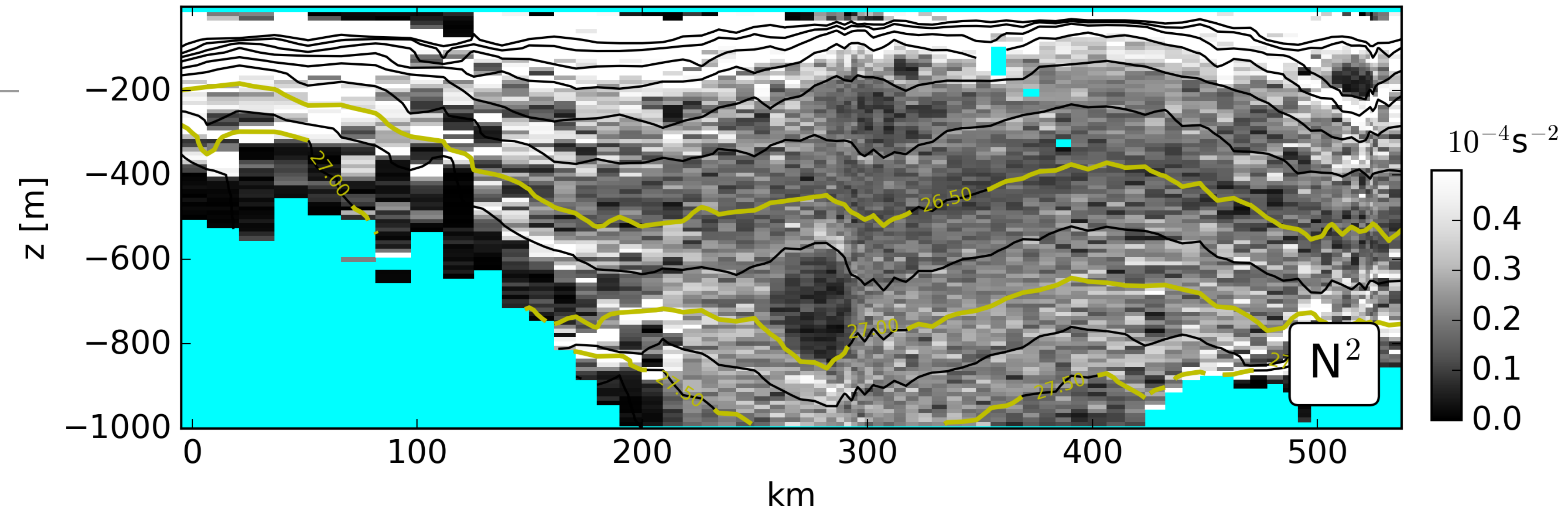



**Vertical energy and momentum fluxes due to lee waves**

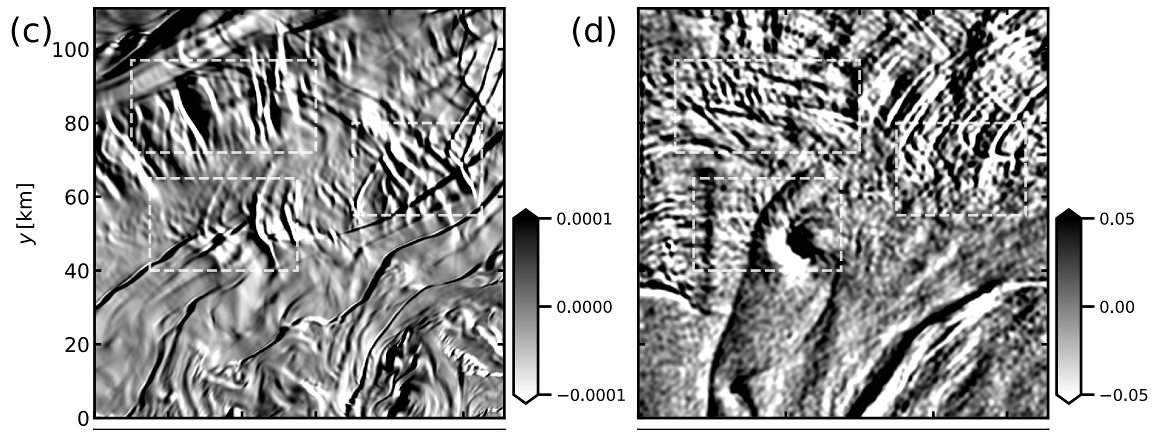
[De Marez, Lahaye & Gula, Sci. Rep., 2020]

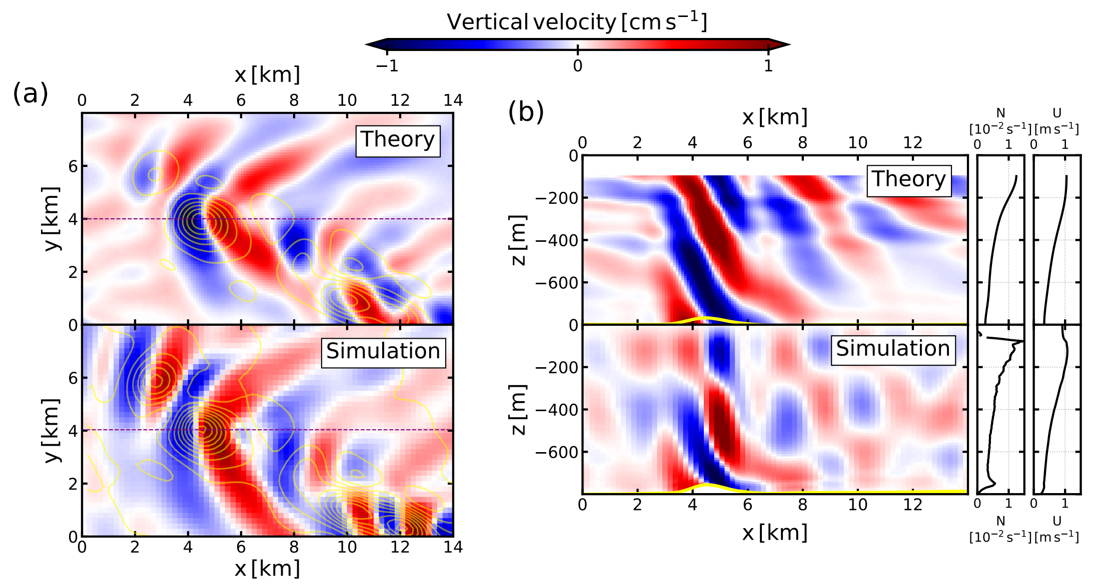
# Summary

1. Submesoscale lenses of well-mixed water are observed in seismic images and glider sections in the lee of the Bump
2. They are anticyclonic SCVs generated due to the frictional effects and intense mixing in the wake of the topography.
3. They can transport waters from the Bump's bottom mixed layer over long distances and spread them within the gyre.




Gula, J., T. Blacic, & R.E. Todd, 2019 : Submesoscale coherent vortices in the Gulf Stream, *Geophys. Res. Lett.*, 46, 2704-2714.



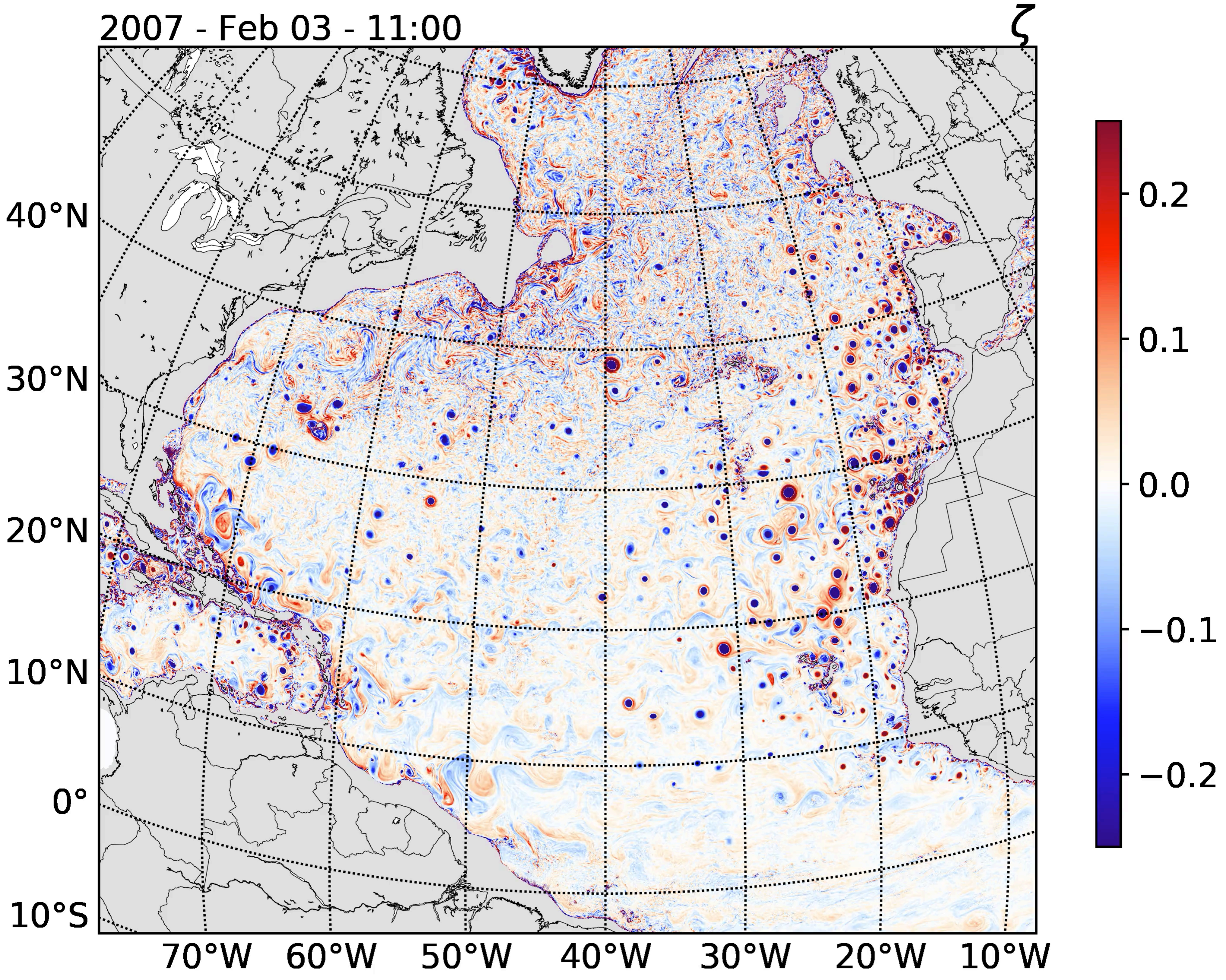



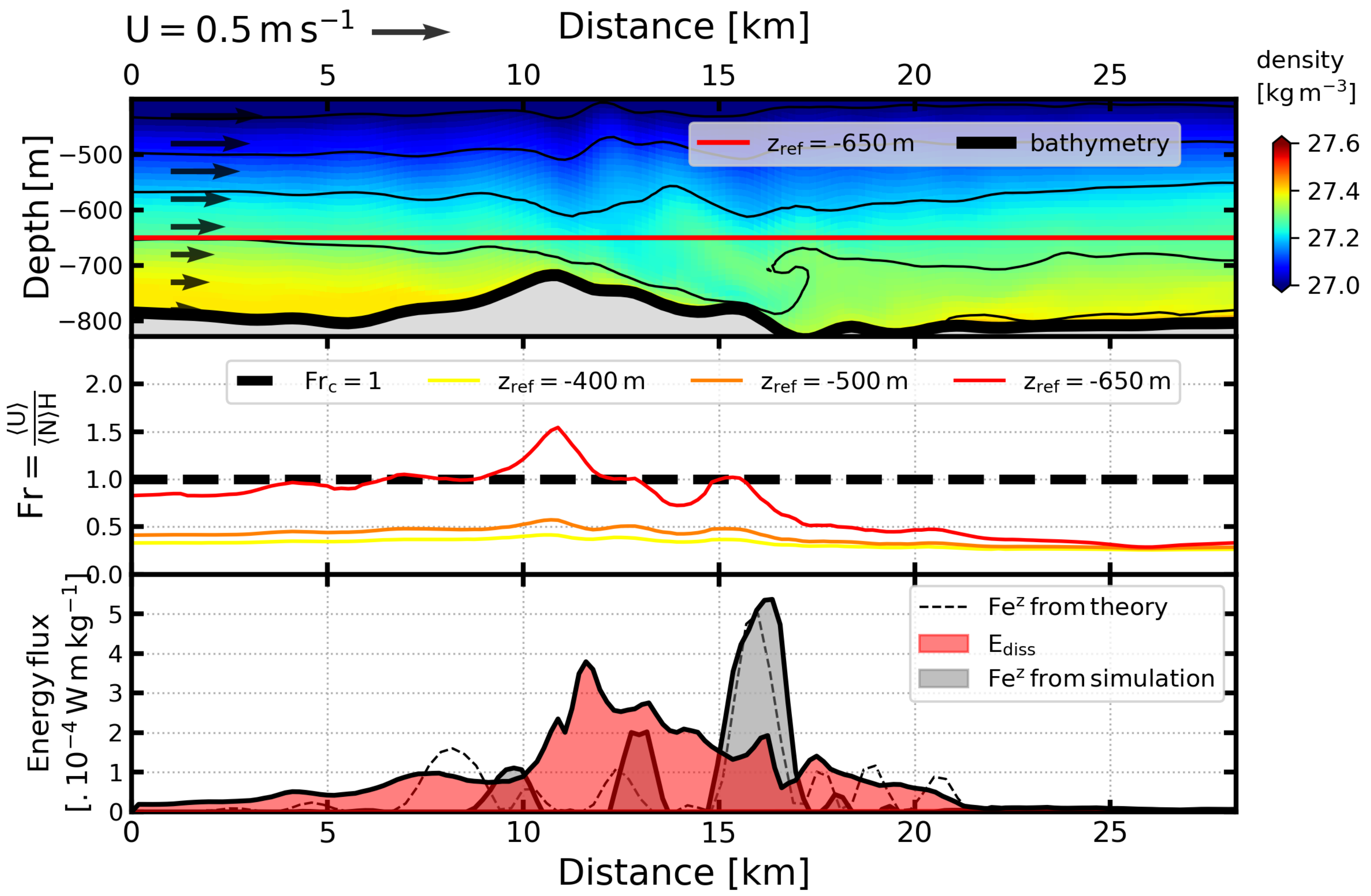

4. Signatures of lee waves are observed over the Bump in satellite sun-glitter images and reproduced using a realistic simulation (and linear theory)
5. Lee waves radiate energy and promote dissipation (O(1 GW) over the Bump) and modify the flow through the wave drag (O(1 GN)).

De Marez, C., N. Lahaye & J. Gula, 2020 : Interaction of the Gulf Stream with small scale topography : a focus on lee waves, *Scientific Reports*, 10, 2332.

# Prospective

Do the SCVs generated here (and elsewhere in the gyre) have large-scale impacts?




Disentangle the role of lee waves and other processes (evanescent waves, hydraulic jump) on local energy dissipation and mixing.