New Views of the Gulf Stream

Spray Glider Observations along the U.S. East Coast

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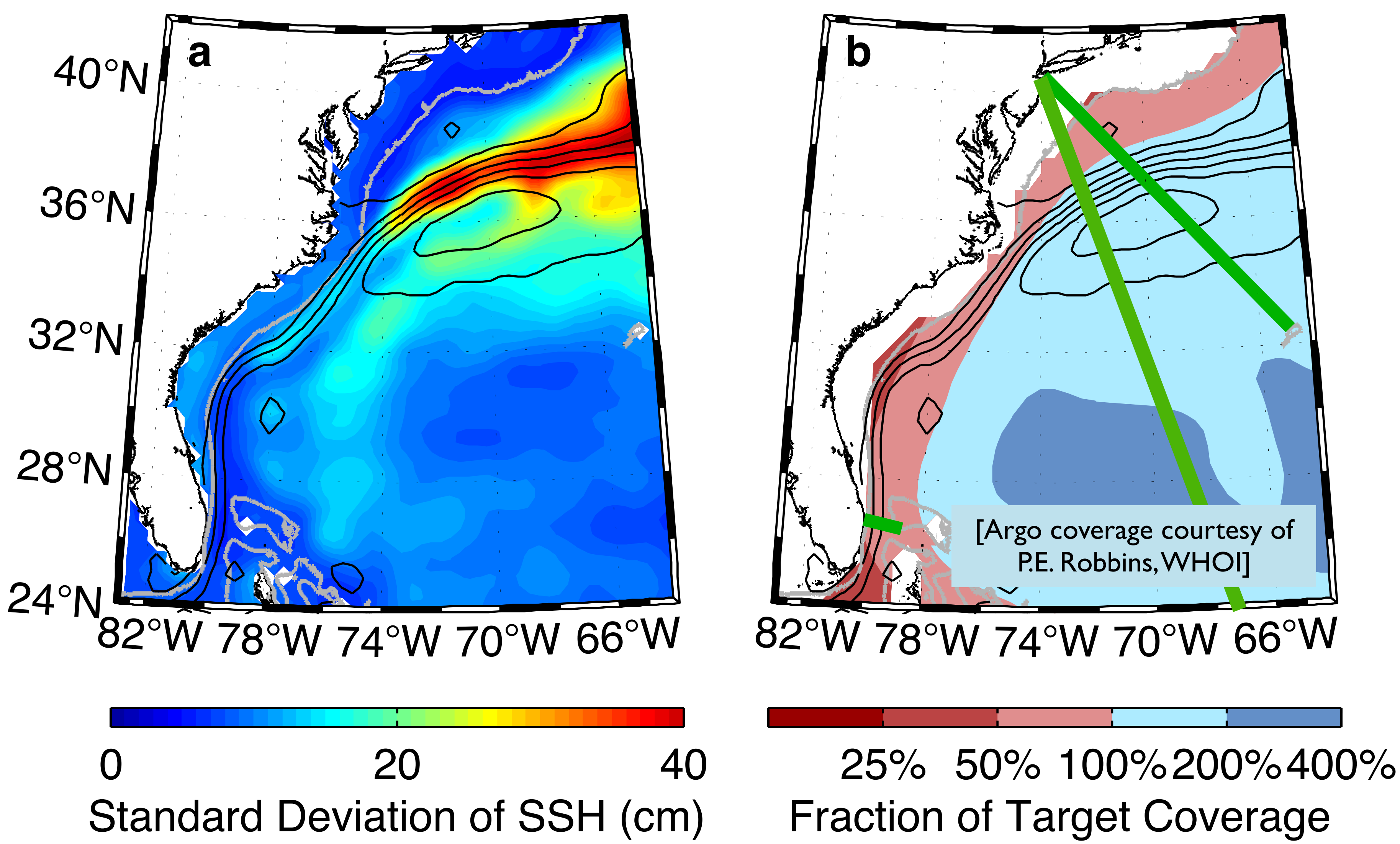
An Under-Observed Gulf Stream

Existing routine <u>subsurface</u> measurements:

- Florida Straits: cable and surveys
- M/V *Oleander*: XBT and ADCP
- AX10: Repeat XBT line
- Low Argo density

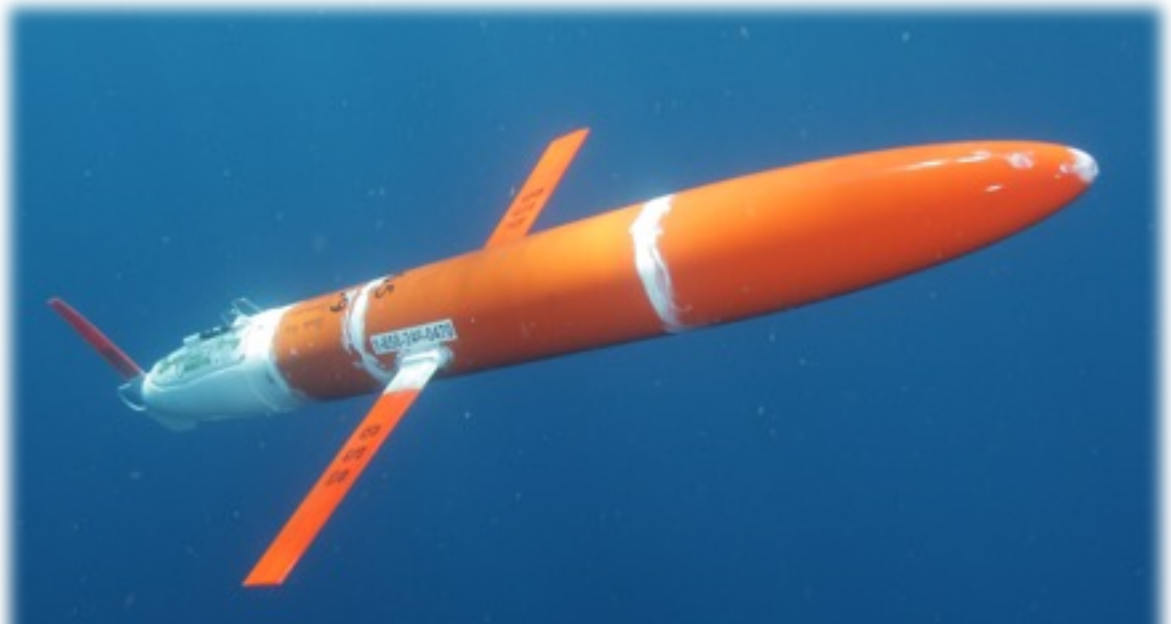
What about the 1500 km between Florida and the *Oleander* line??



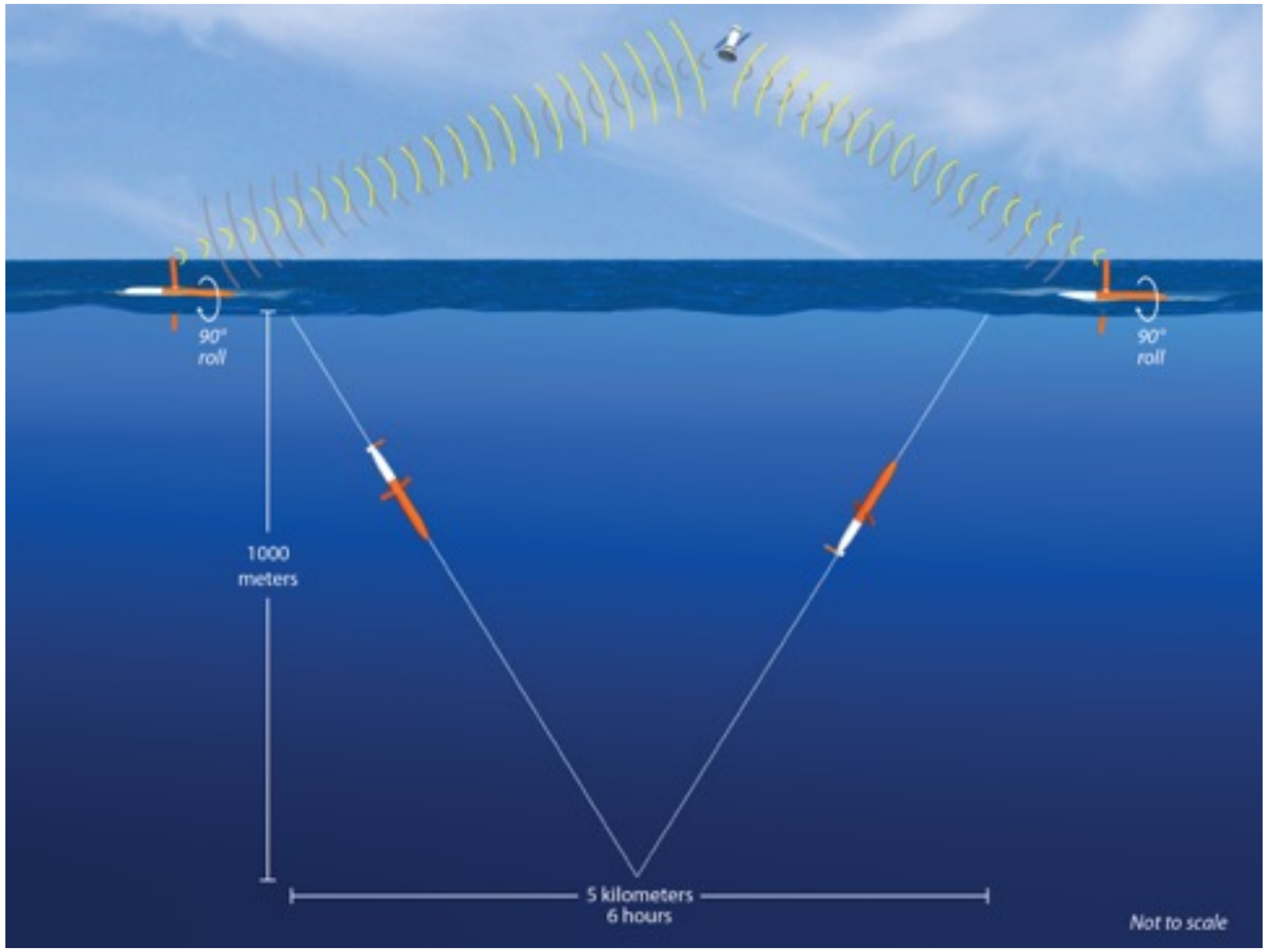
Gliders to Fill the Observational Gap

Spray is a buoyancy-driven glider with:

- Long duration (100+ days)
- 1000-m depth limit
- Automatic current-crossing navigation
- ~0.25 m s^{-1} horizontal speed



Spray #65 in the Gulf Stream off Miami, October 2015



Typical Sensors:

- Pumped CTD
- Doppler Current Profiler
- Chlorophyll Fluorescence
- 1-MHz Acoustic Backscatter

Glider Missions to Date

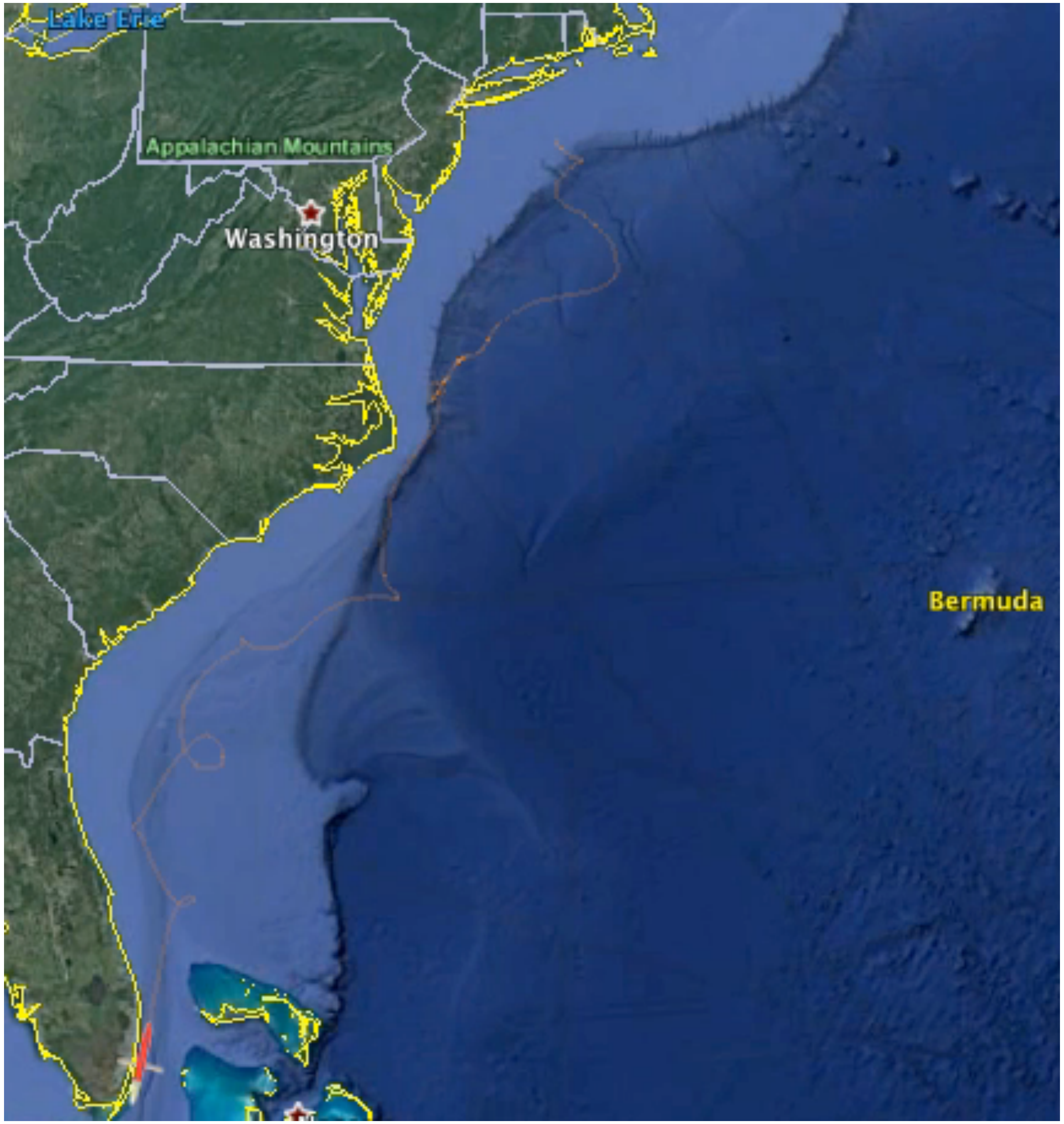
Mission Plan:

- deploy off Miami
- zig-zag downstream
- recover on New England shelf

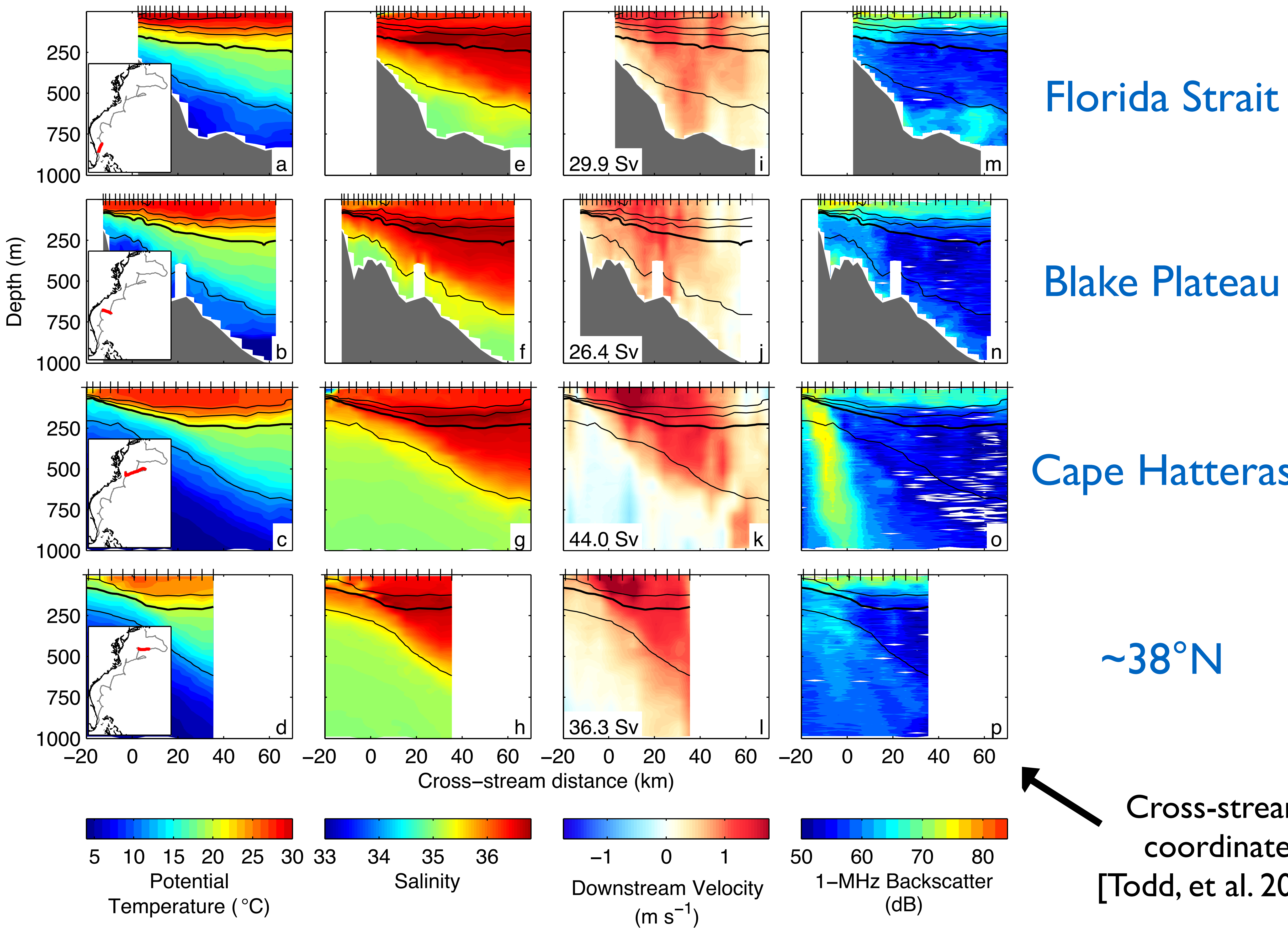
Statistics to Date:

- 4 complete missions
- 1 underway mission
- 338 glider-days
- >3,300 profiles
- >15,000 km over ground
- >35 Gulf Stream crossings

- 1 Iridium outage (5 wks)
- 1 major shark attack



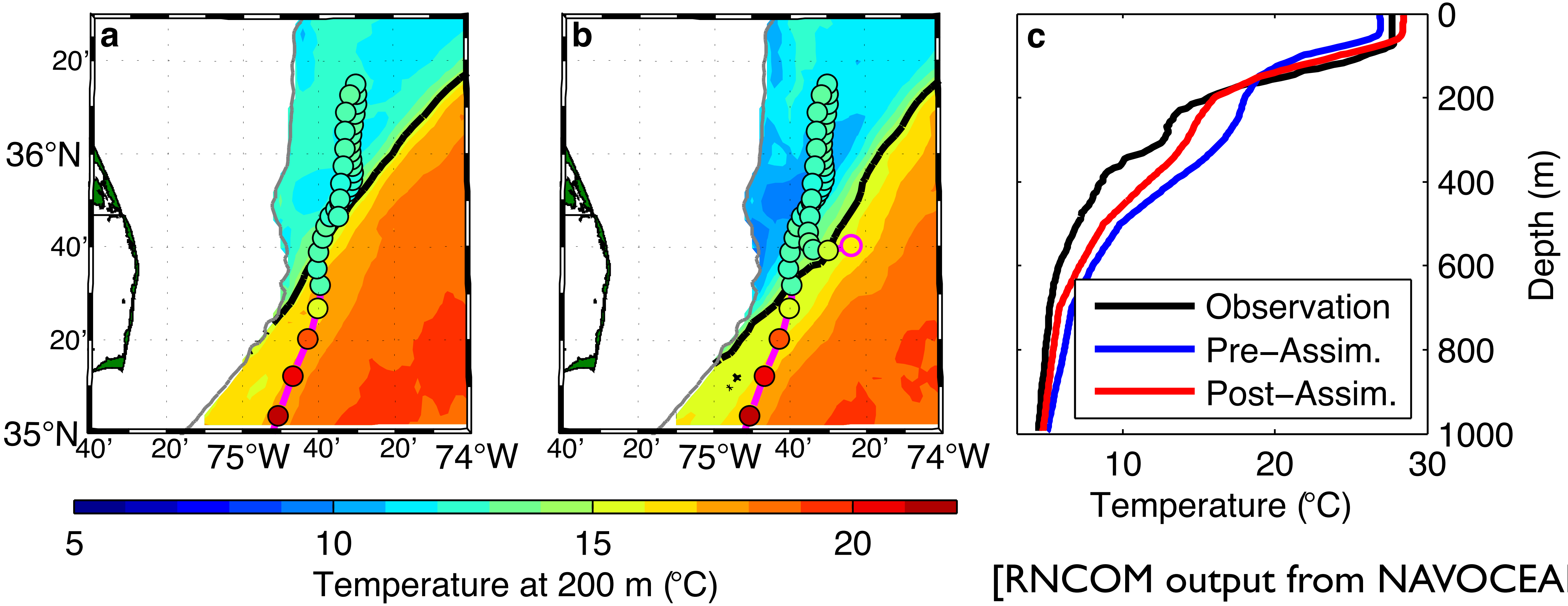
Example Gulf Stream Crossings



Cross-stream coordinate
[Todd, et al. 2016]

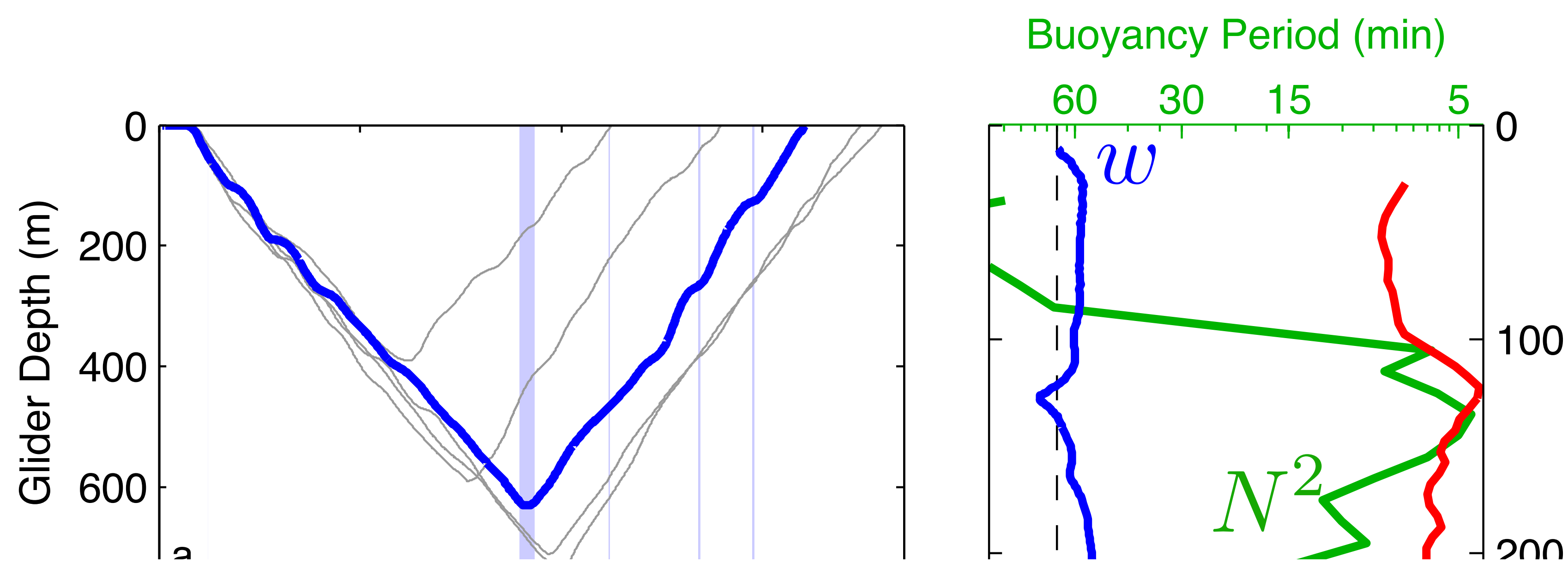
Impact on Operational Models

- Gliders returned decimated data via Iridium after each dive.
- Temperature and salinity data transmitted to:
  - NAVOCEANO (email)
  - IOOS NGDAC, GTS (via NOAA SWFSC)
- Assimilated glider observations qualitatively affect Gulf Stream representation.

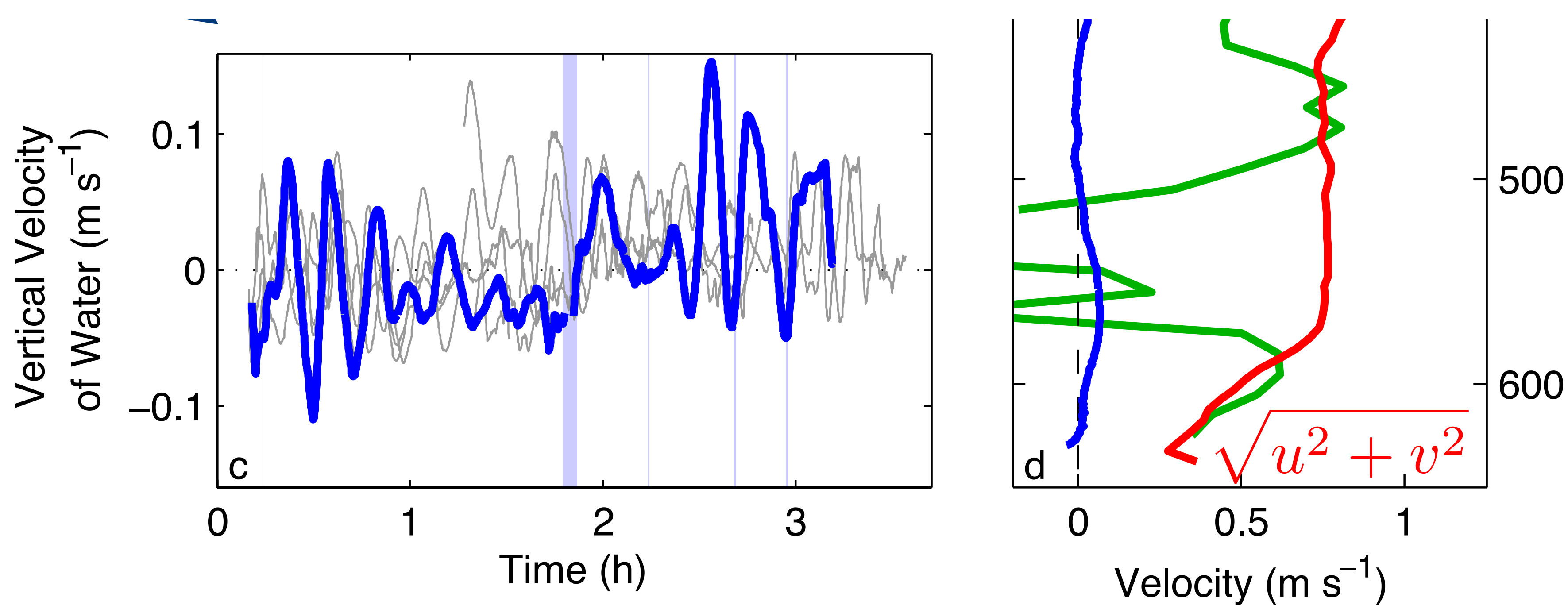


[RNCOM output from NAVOCEANO]

Identifying High-Frequency Internal Waves

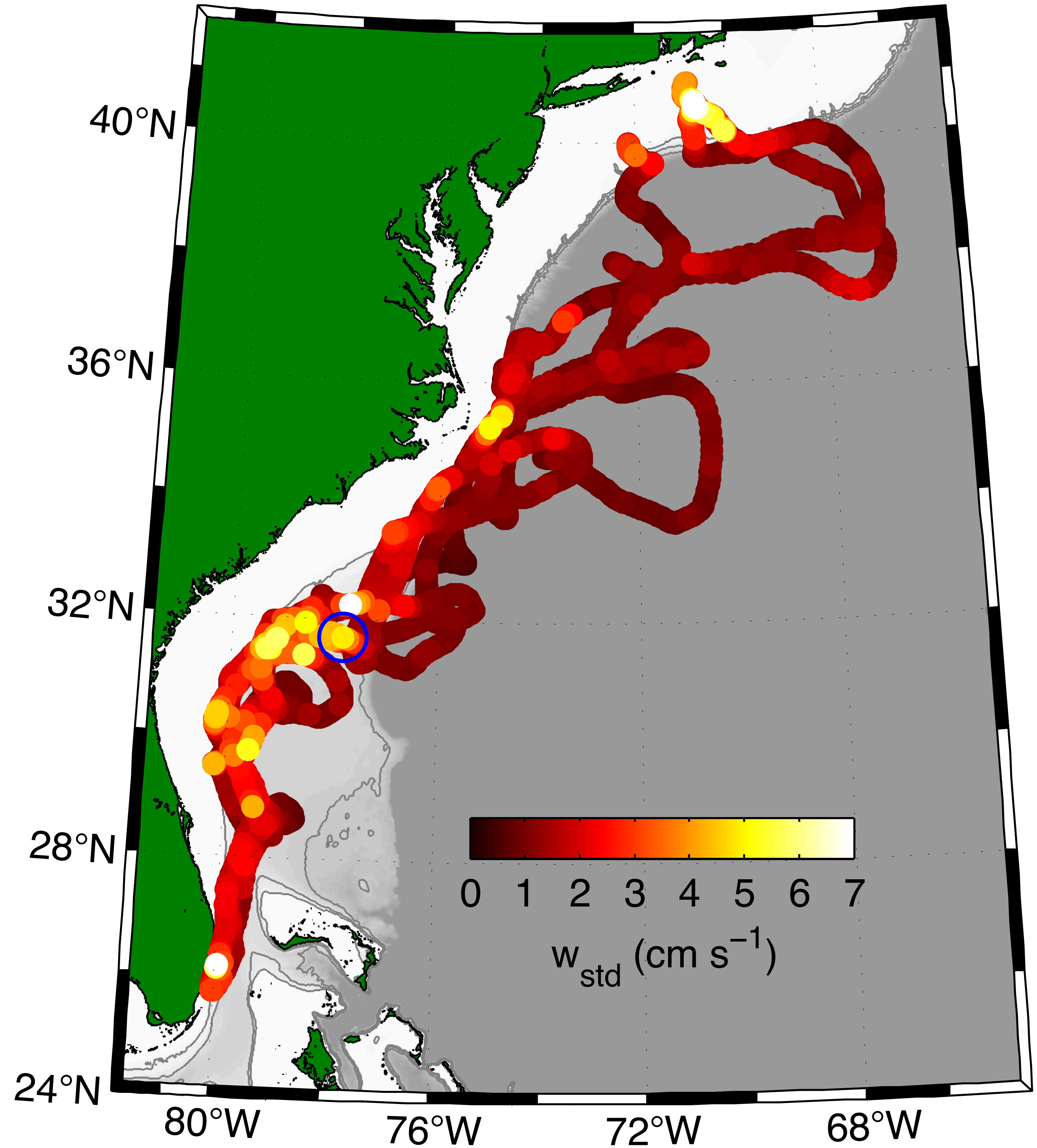


Strong, high-frequency internal waves near the buoyancy frequency within the Gulf Stream



Internal Waves in the Gulf Stream

- Large-amplitude, high-frequency internal waves prevalent in the Gulf Stream when bottom depth is less than ~1000 m.
- Largest waves near the Charleston Bump.



Topographic Froude Number and Lee Waves

- Topographic Froude number key to flow behavior over topography:

$$F_{\text{topo}} = \frac{U}{NH}$$

- Estimates of topographic Froude number for Gulf Stream flowing over Blake Plateau:

$$0.4 < F_{\text{topo}} < 2.5$$

- Likely to form nonlinear internal lee waves and hydraulic jumps when topographic Froude number less than unity.

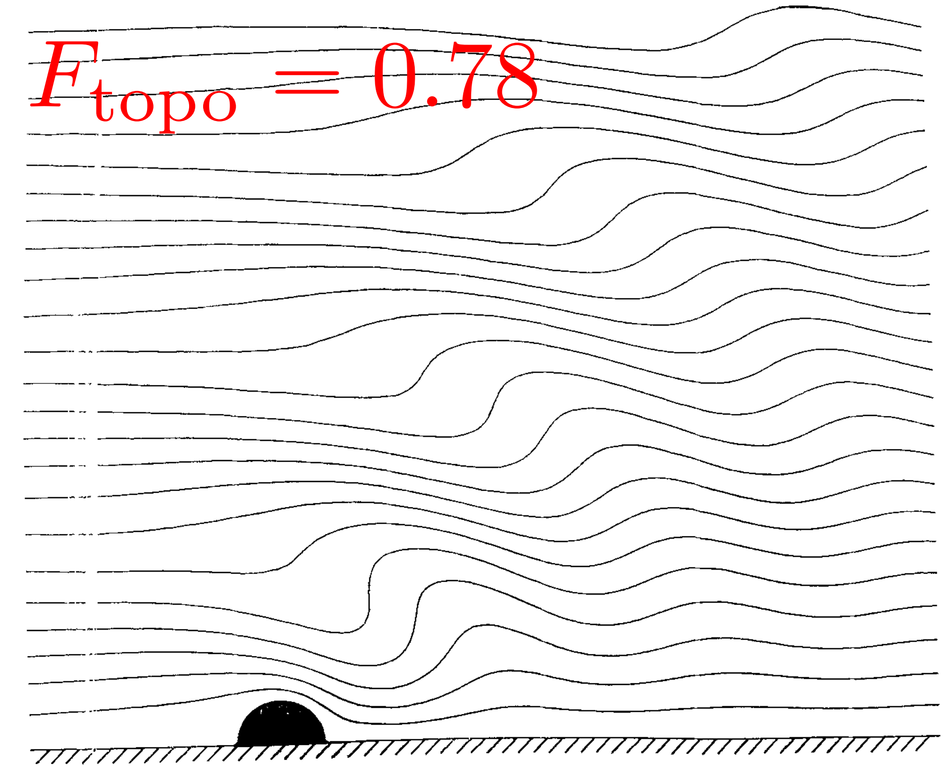


FIGURE A3. Stratified shear flow over a semi-circular obstacle for $k = k_c = 1{\cdot}27$.

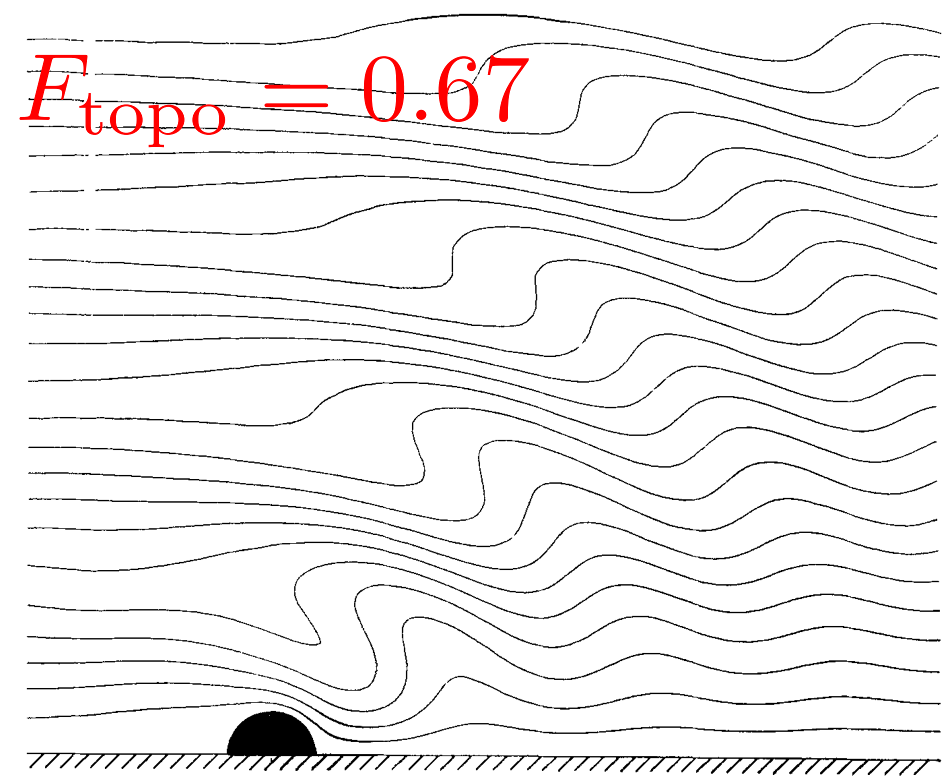
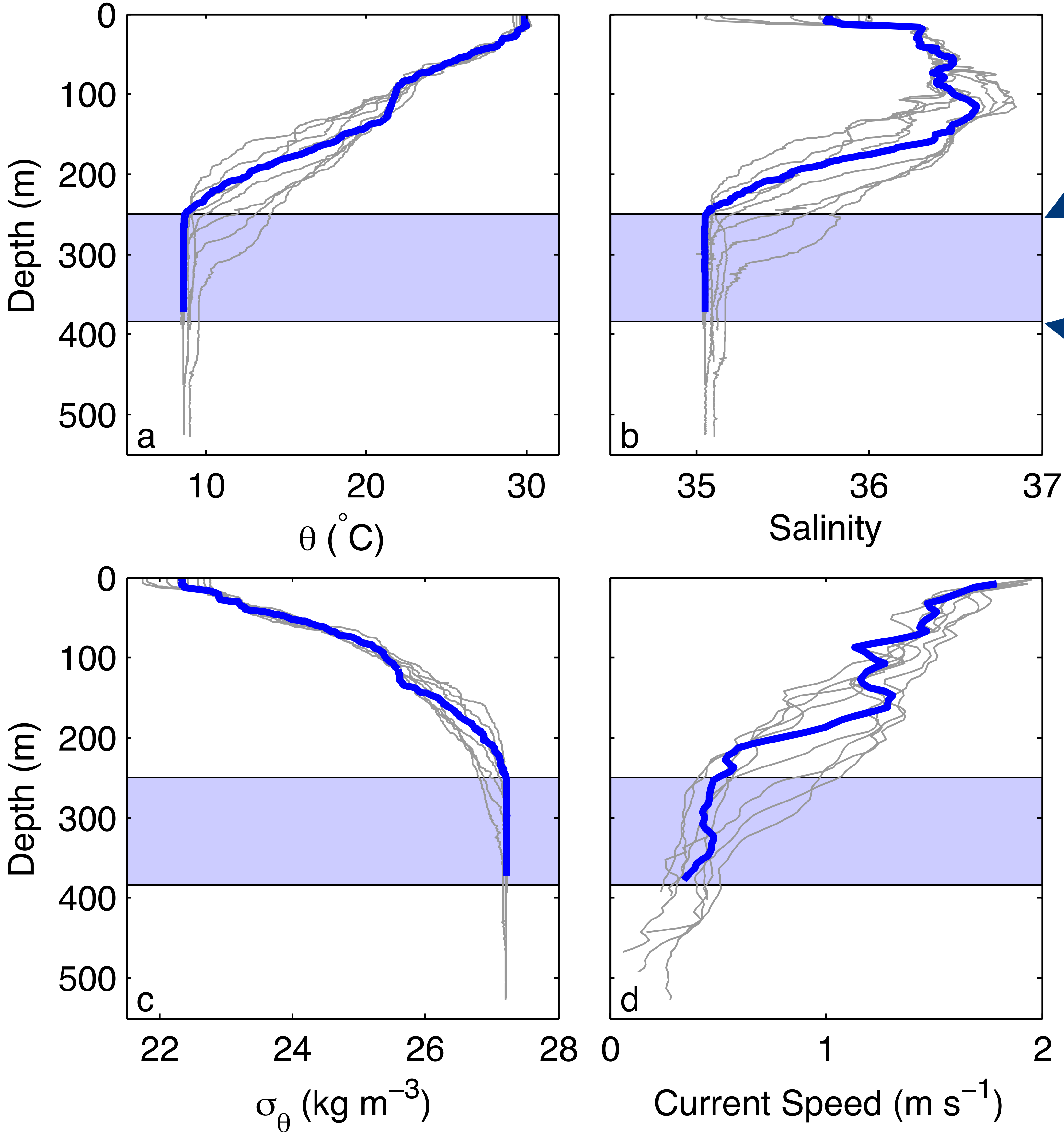


FIGURE A4. Stratified shear flow over a semi-circular obstacle for $k = 1{\cdot}5$.

[Miles & Huppert, 1968]

Bottom Mixed Layers

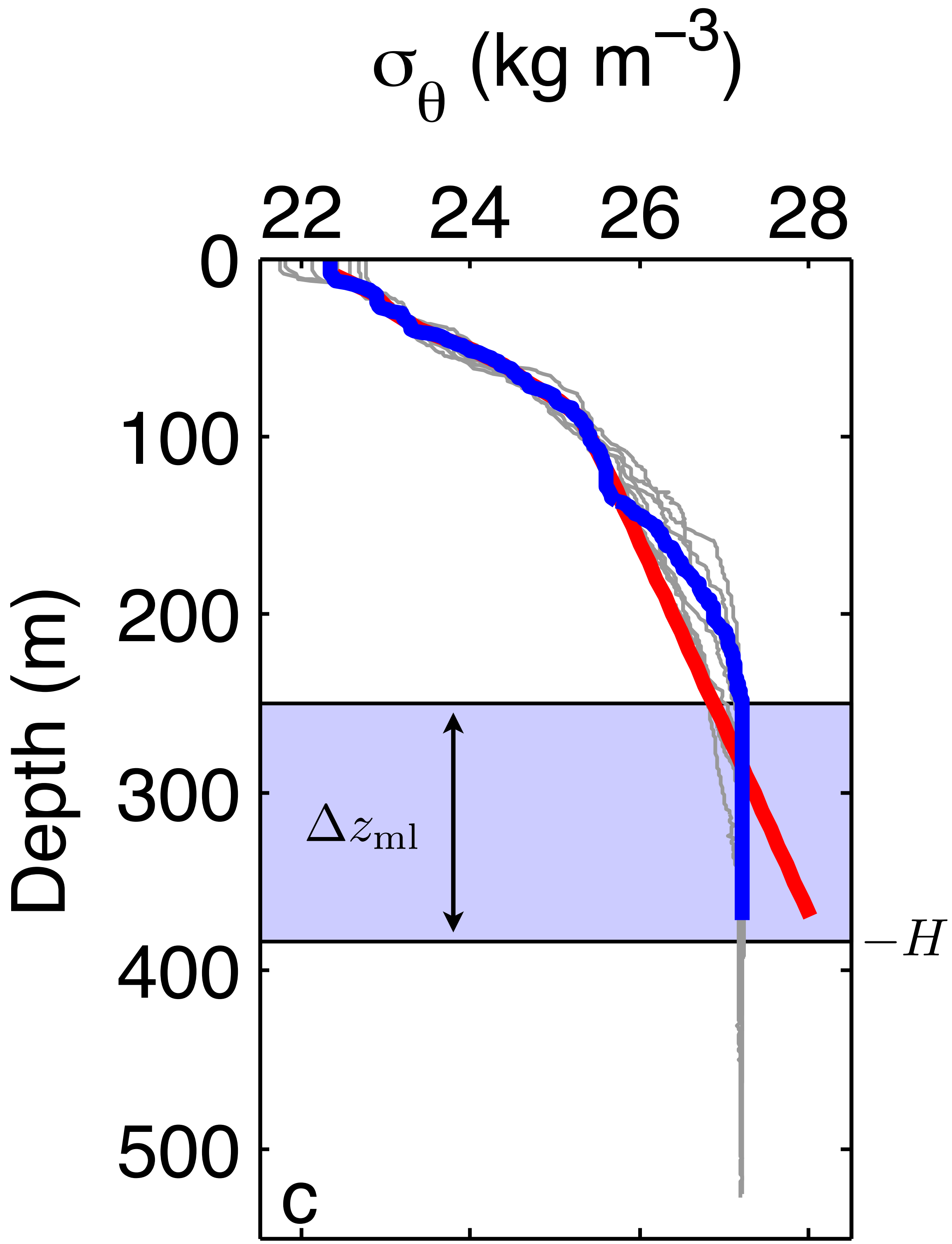


Top of mixed layer ($\Delta\sigma = 10^{-2}$ kg m^{-3})

Altimeter-based bottom depth

Well-mixed in temperature, salinity, and density over 134 m with ~0.5 m s^{-1} velocity

Energy to Form Bottom Mixed Layers



- Construct linear 'pre-mixed' profile.
- Estimate change in potential energy as:

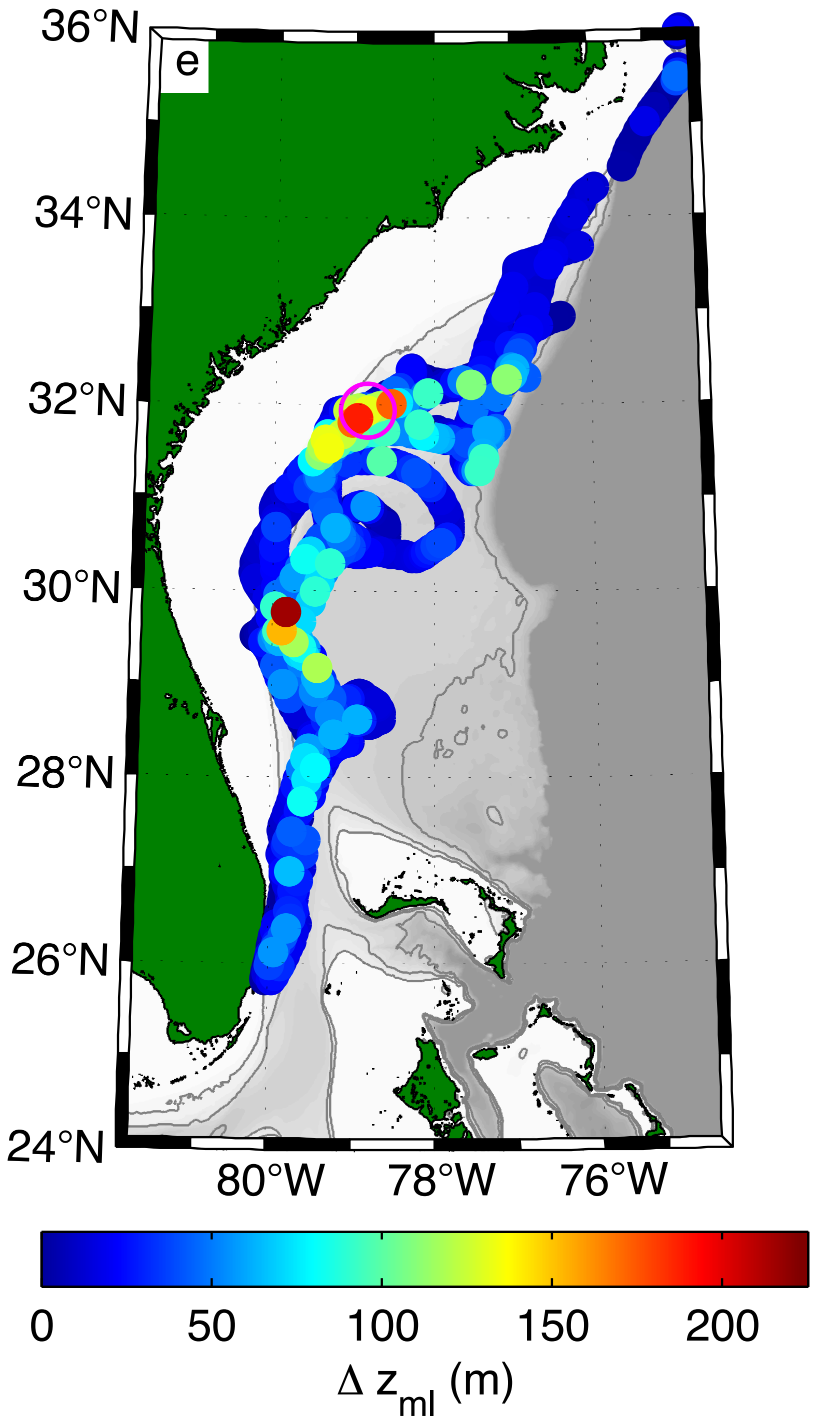
$$\Delta PE = \int_{-H}^{-H+2\Delta z_{\mathrm{ml}}} \Delta\sigma_\theta g z \, dz$$

- Compare to fraction of work done by quadratic bottom drag that goes toward mixing,

$$\Gamma c_D \rho u^3$$

which, for typical local values, can convert about 3×10^3 J m^{-2} of kinetic energy to potential energy.

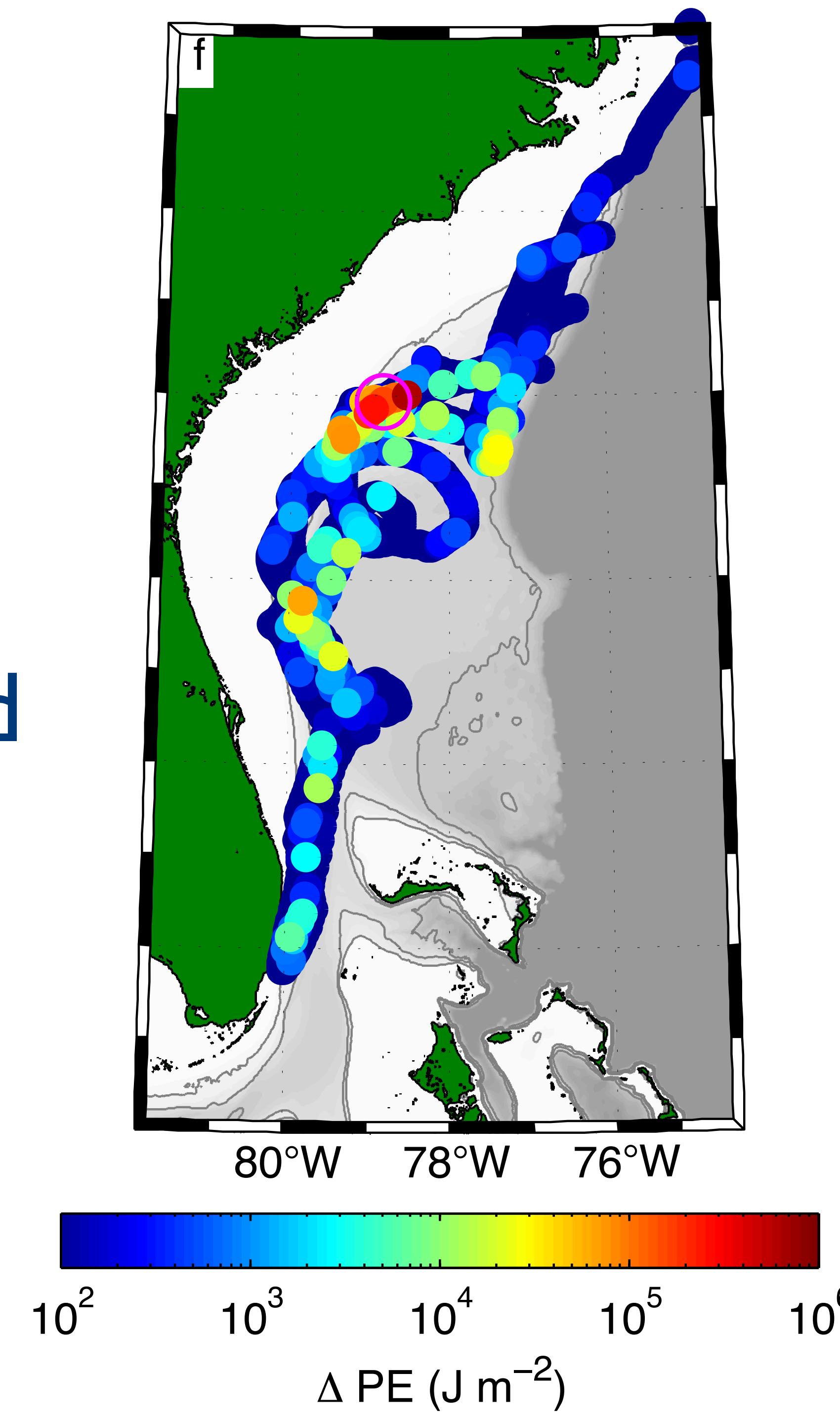
Bottom Mixed Layers



O(100 m)-thick bottom mixed layers are prevalent over Blake Plateau and near the Charleston Bump.

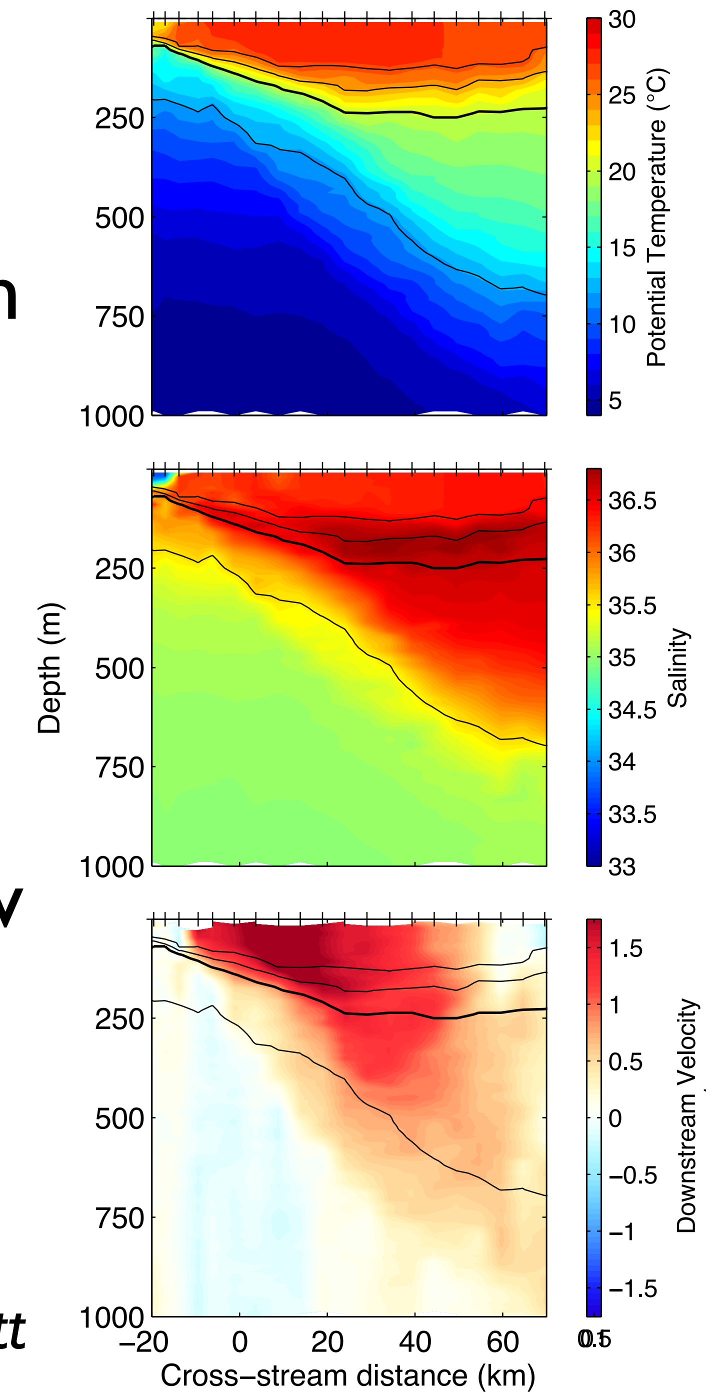
Energy required is much too large for bottom drag alone.

Hydraulic jumps and resultant mixing likely given topographic Froude number.



Summary

- Spray gliders repeatedly surveyed across the Gulf Stream between Florida and New England.
- Continued glider operations can fill the existing gap in subsurface observations of the Gulf Stream.
- Glider observations improve representation of the Gulf Stream in operational models.
- Nonlinear lee waves and thick bottom mixed layers are sinks for energy from large-scale Gulf Stream flow over bathymetry.



Reference:

Todd, RE (2016), High-frequency internal waves and thick bottom mixed layers observed by gliders in the Gulf Stream, submitted to *Geophsy. Res. Lett*

Thanks:

- Scripps: Dan Rudnick, Jeff Sherman, Ben Reineman, Kyle Grindley, Evan Randall-Goodwin
- WHOI: Breck Owens, Carol Anne Clayson, Larry George, Patrick Deane, Ben Hodges
- NOAA AOML: Gustavo Goni, Molly Baringer, Francis Bringas
- UNC Institute for Marine Studies, NCSU Center for Marine Sciences and Technology, Discovery Diving Co.