Warming and lateral shift of the Gulf Stream

from in situ observations since 2001

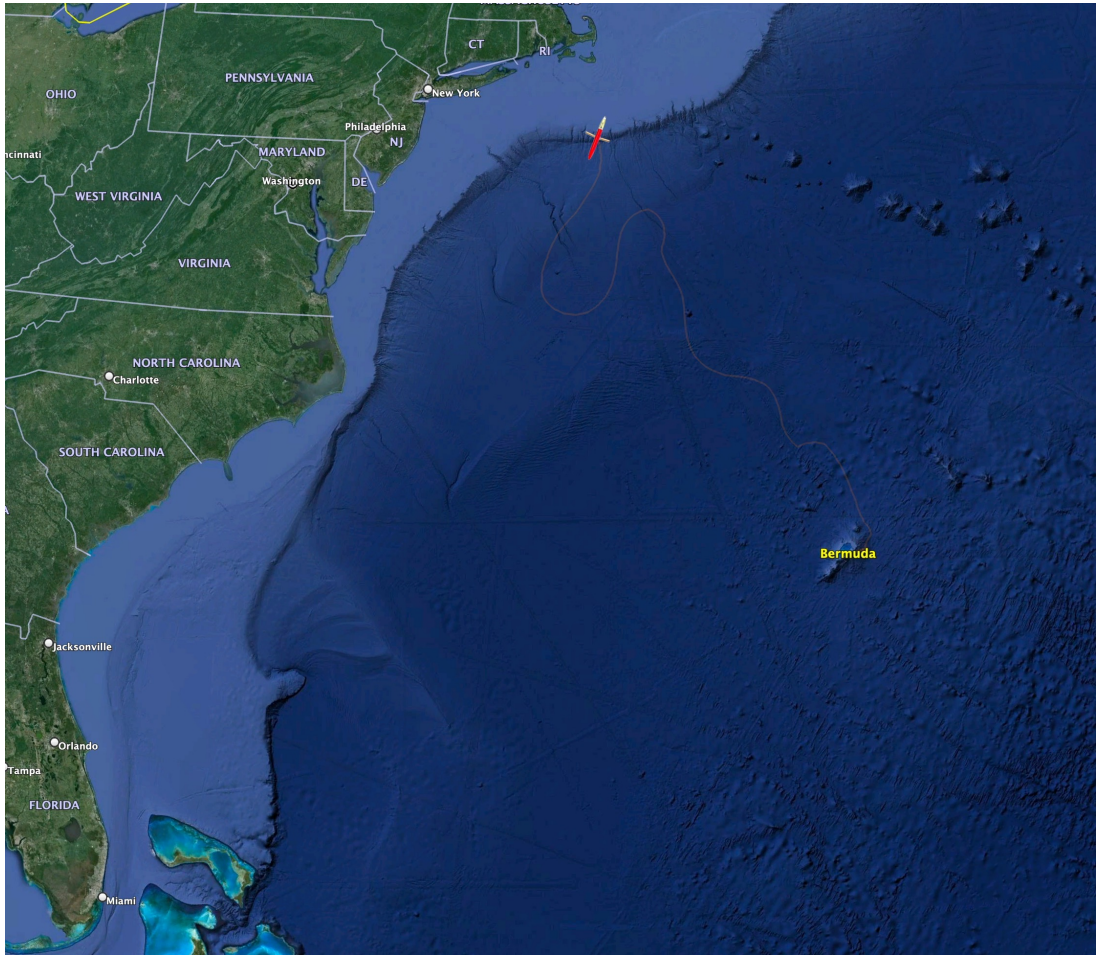
WOODS HOLE OCEANOGRAPHIC INSTITUTION

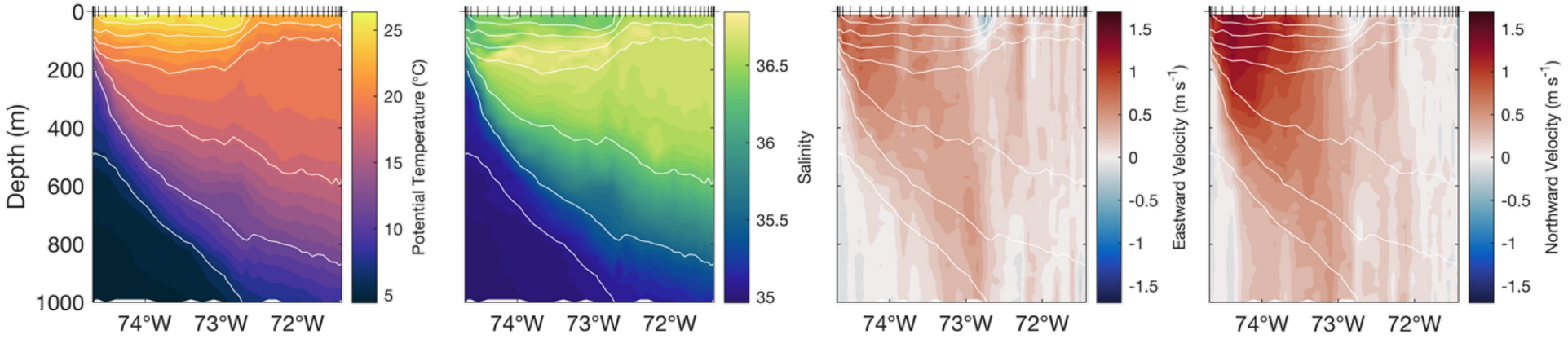
Robert E. Todd
Alice S. Ren

Source: The New York Times

Since 2004, Spray gliders in and near the Gulf Stream have completed:

- **61** glider missions
- **>4,700** glider-days (~13 years at sea)
- **>36,000** profiles
- **~435** Gulf Stream crossings

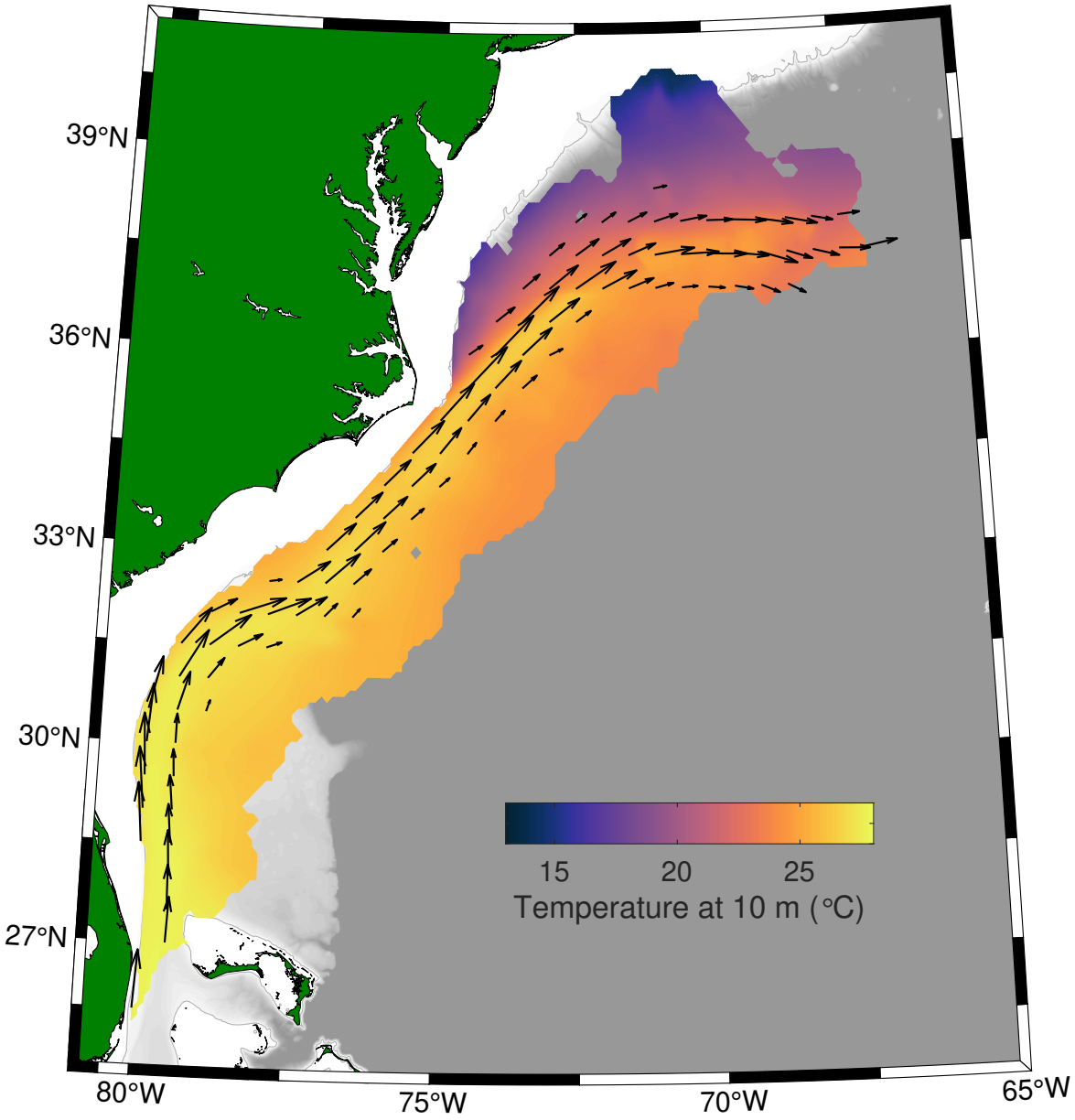




The observing system for the Gulf Stream

Challenges:

- Strong currents
- Sharp gradients
- Large scale



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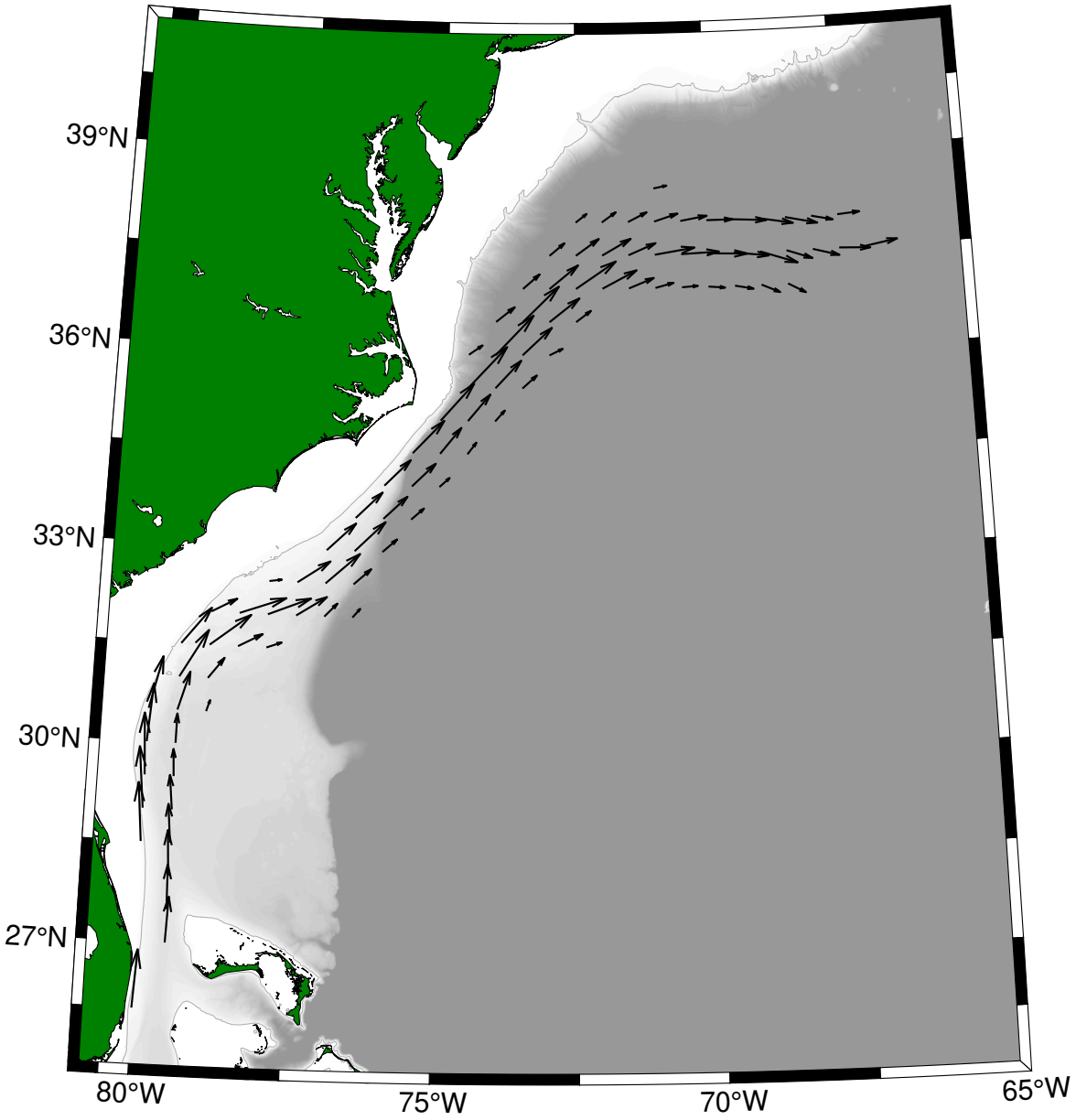

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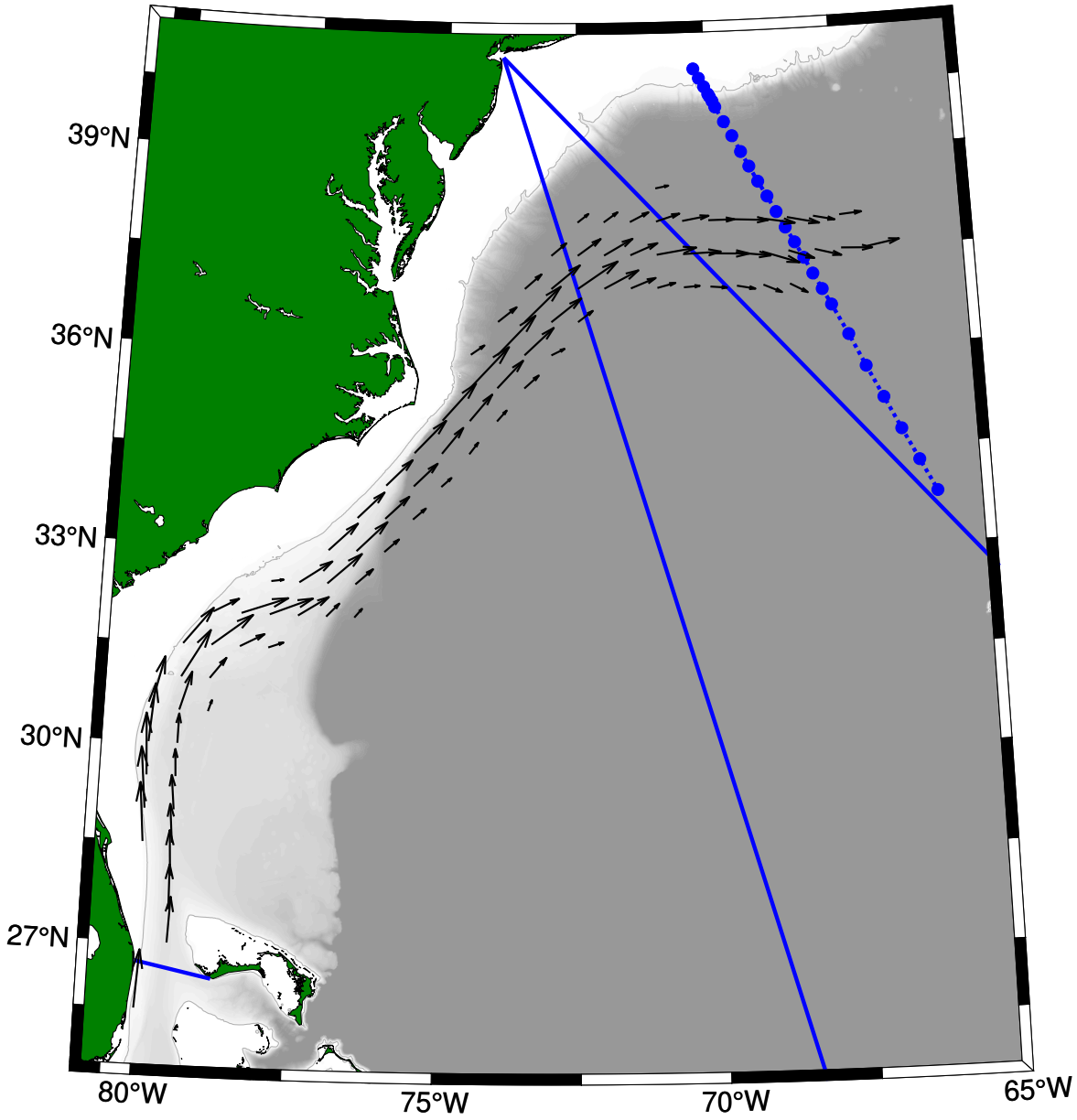

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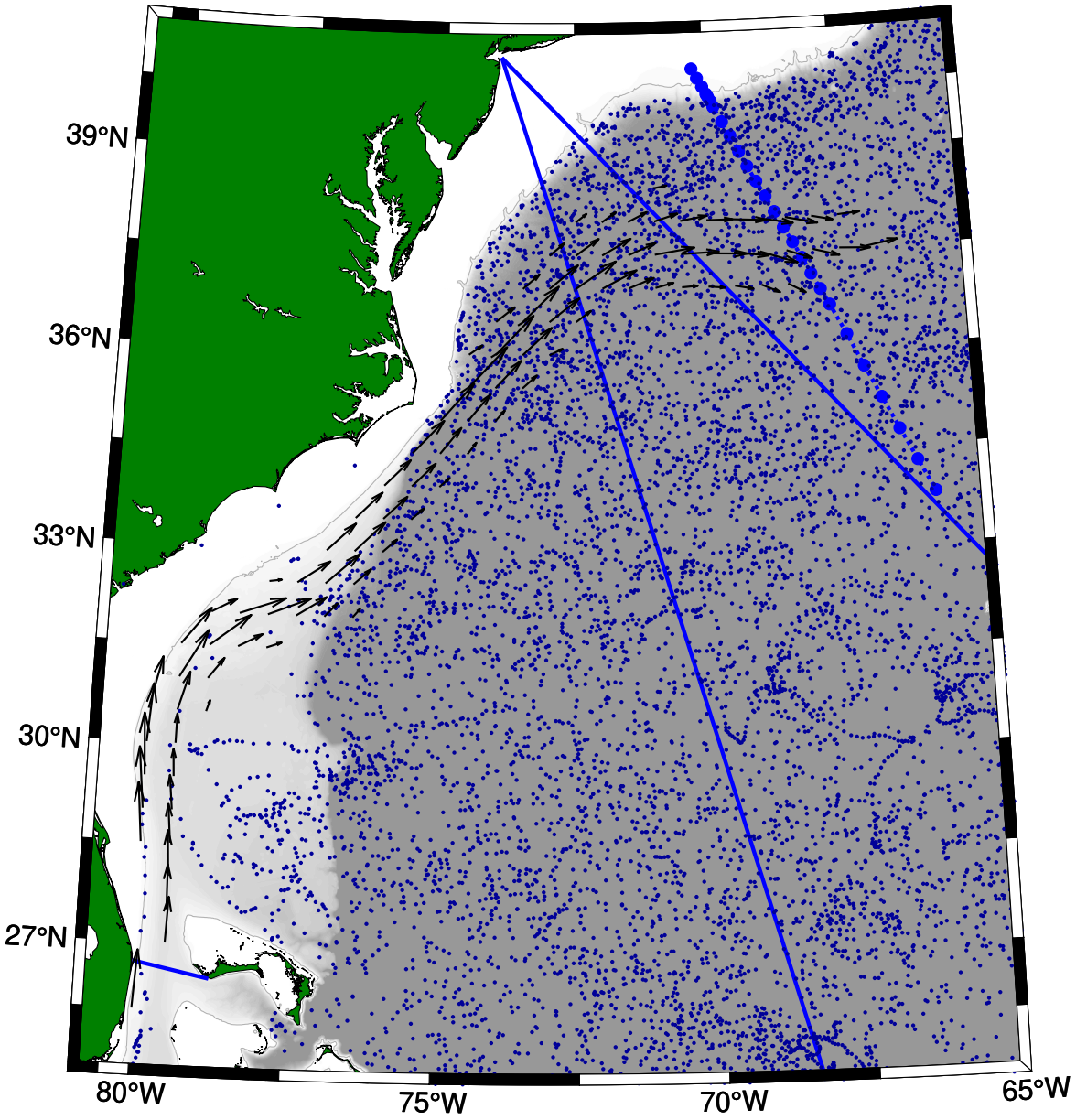

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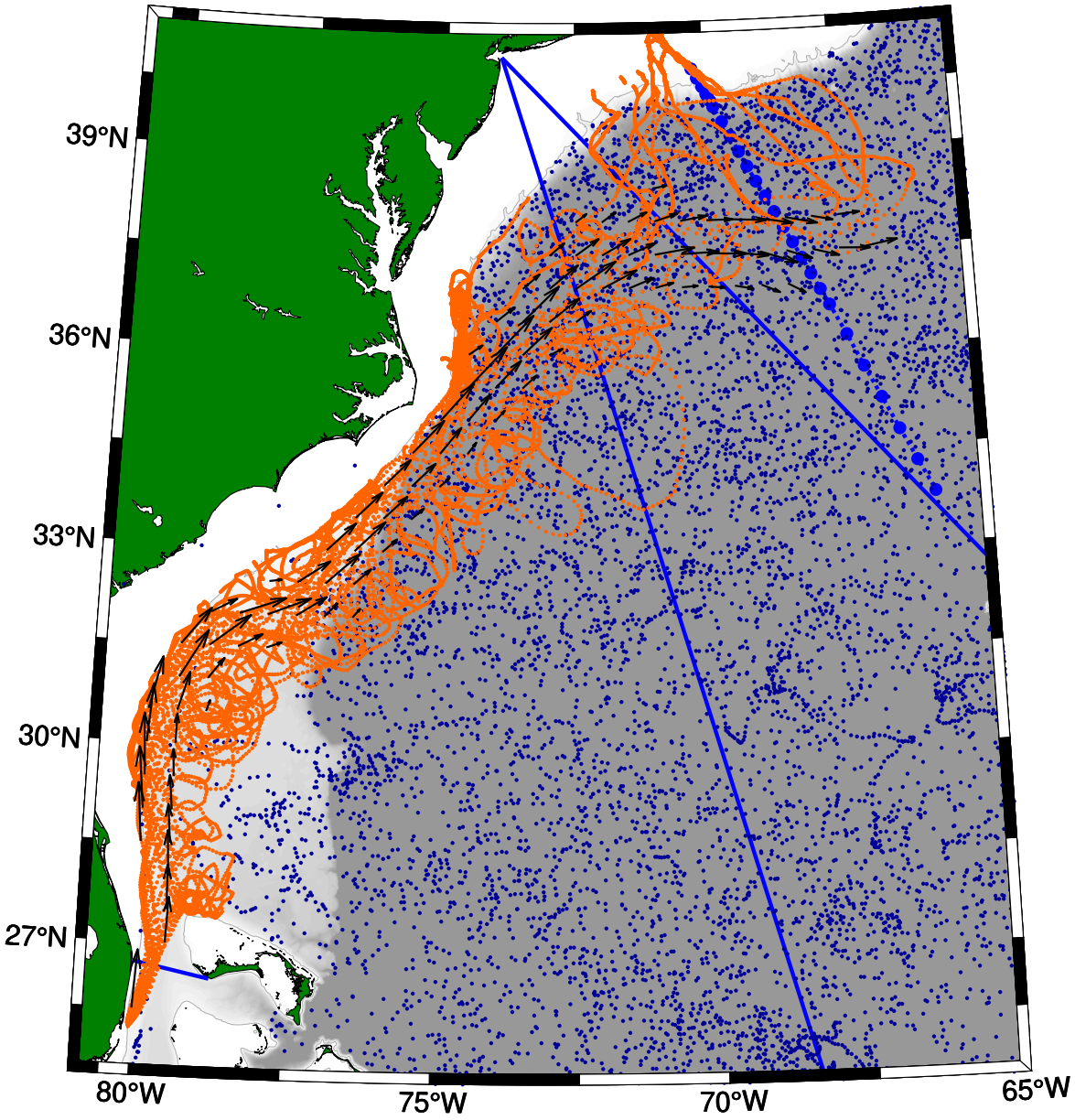

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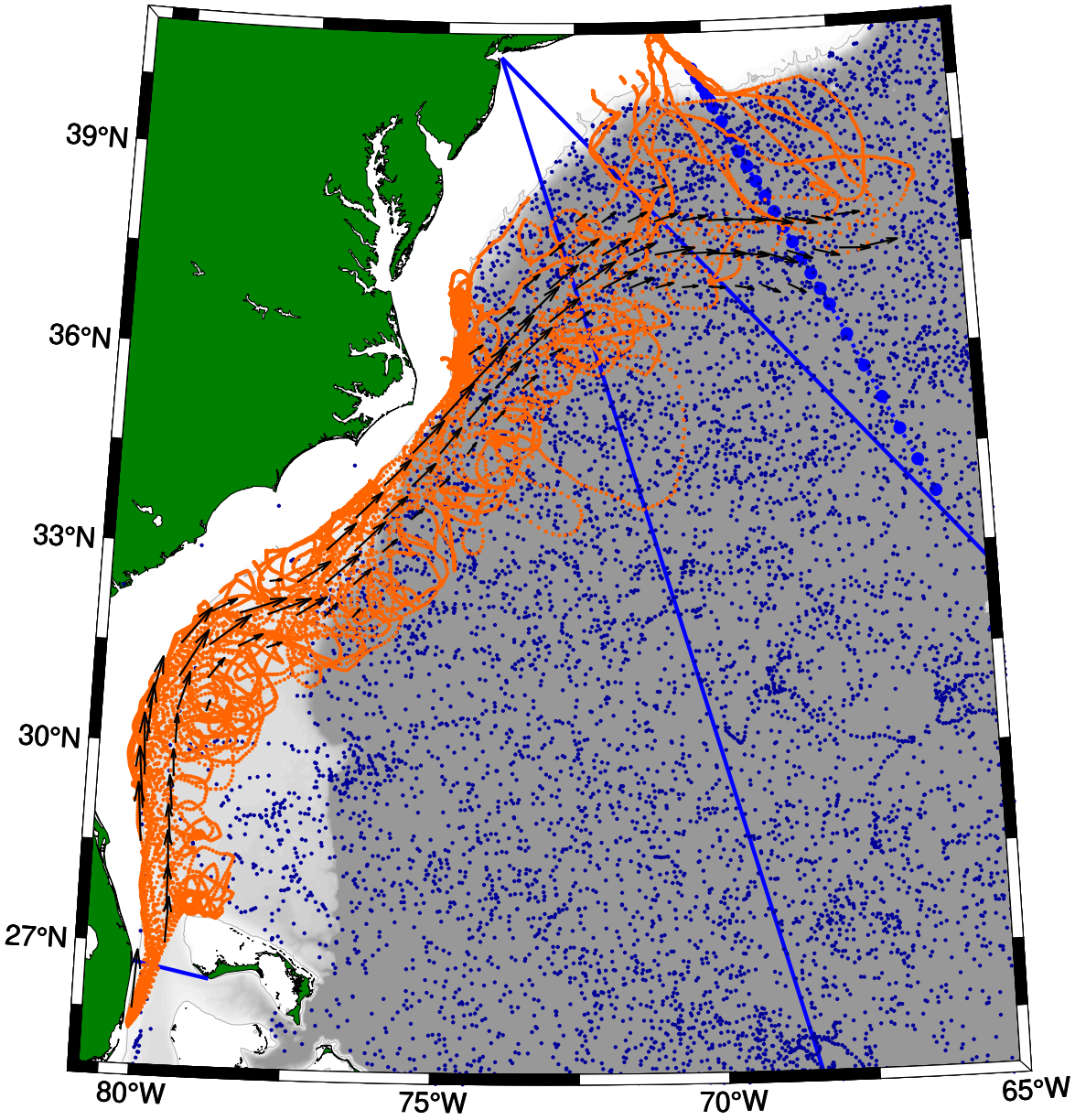

How is the Gulf Stream changing as the climate warms?

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Gulf Stream safe if wind blows and Earth turns

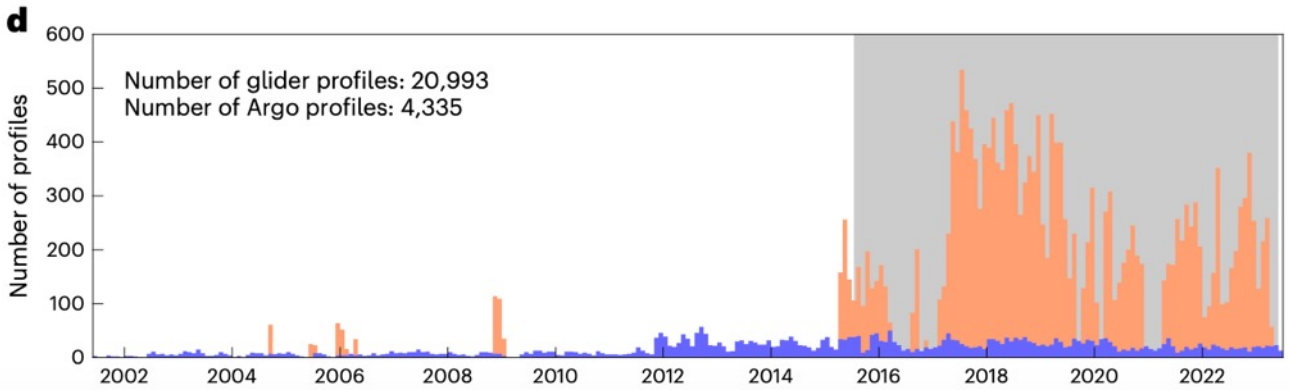
Carl Wunsch

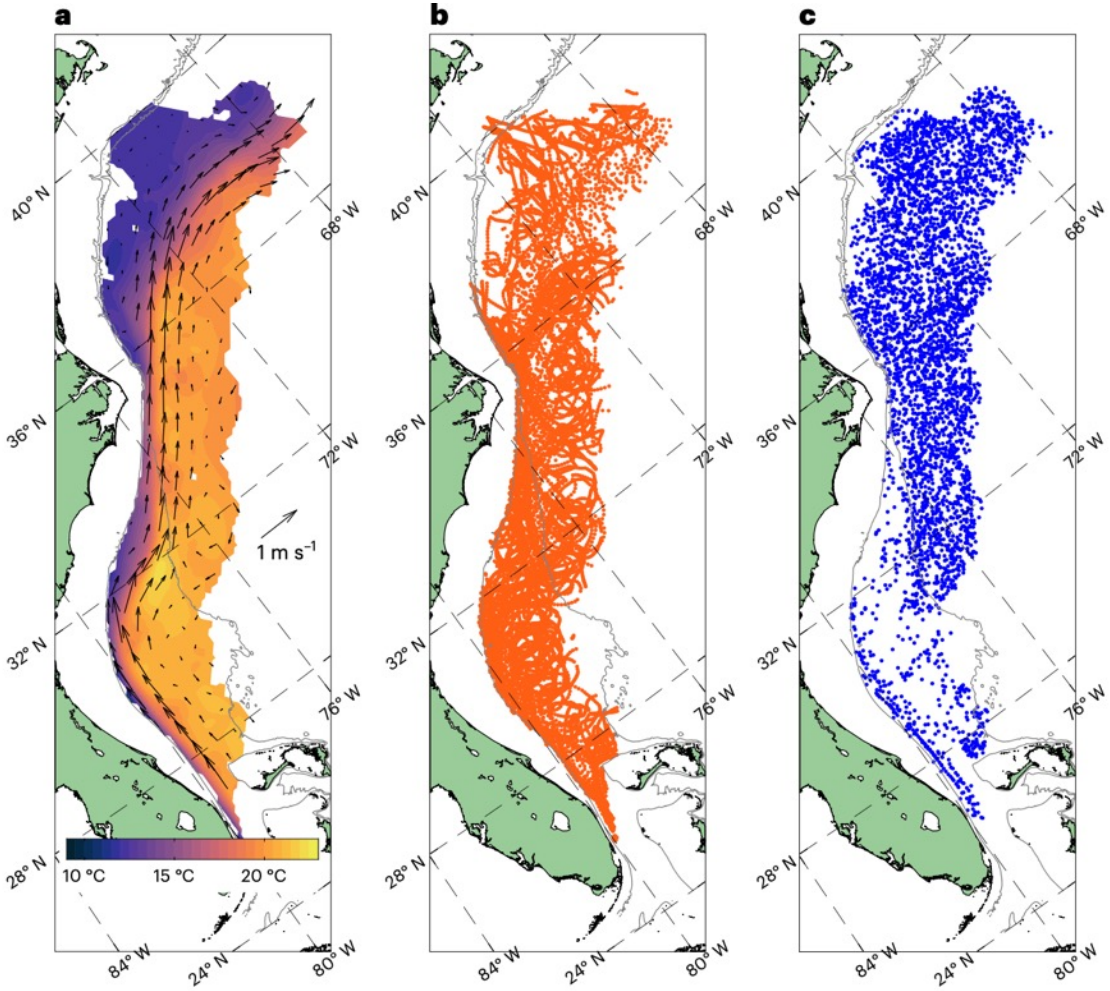
Nature **428**, 601 (2004) | Cite this article

How is the Gulf Stream changing as the climate warms?

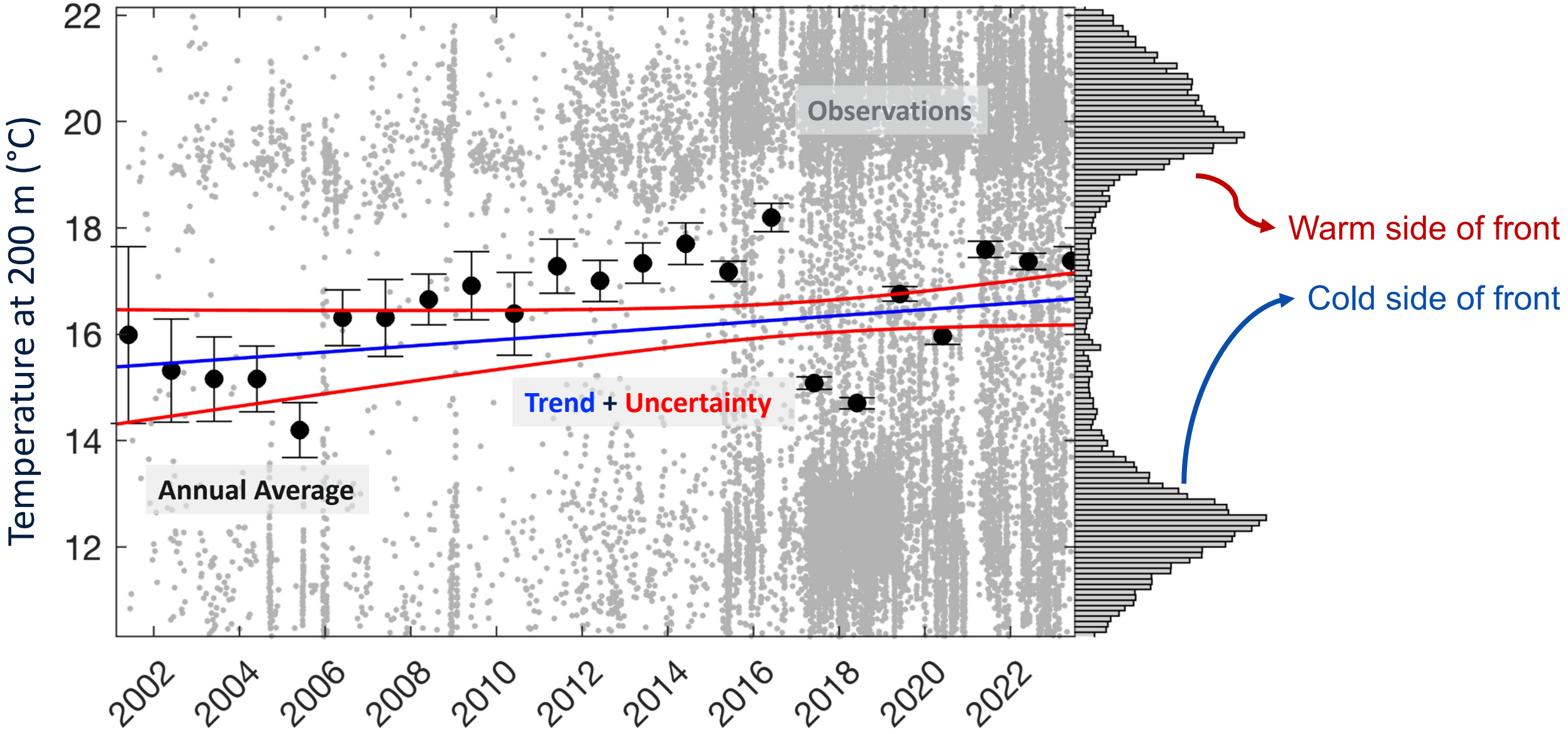
Goal:

Use 20+ years of profiles from gliders and Argo for <u>detection</u> and <u>attribution</u> of decadal-scale trends.





A small trend buried in large variability.



Gulf Stream Climatology from Glider Observations

- Weighted least-squares fit to data from 2015-2023
- Average 3D structure
- Seasonal variability

Measured Temperature

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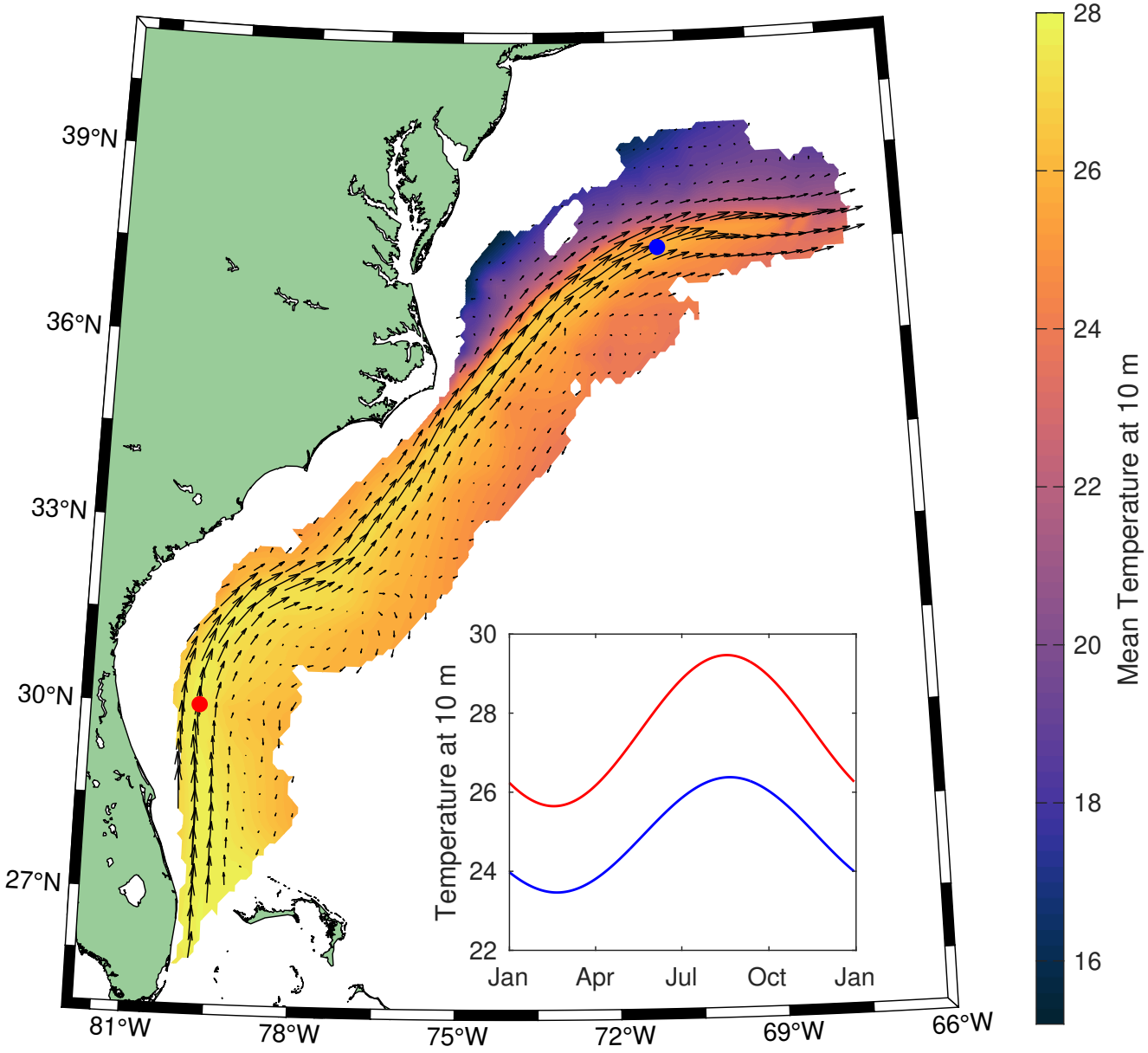
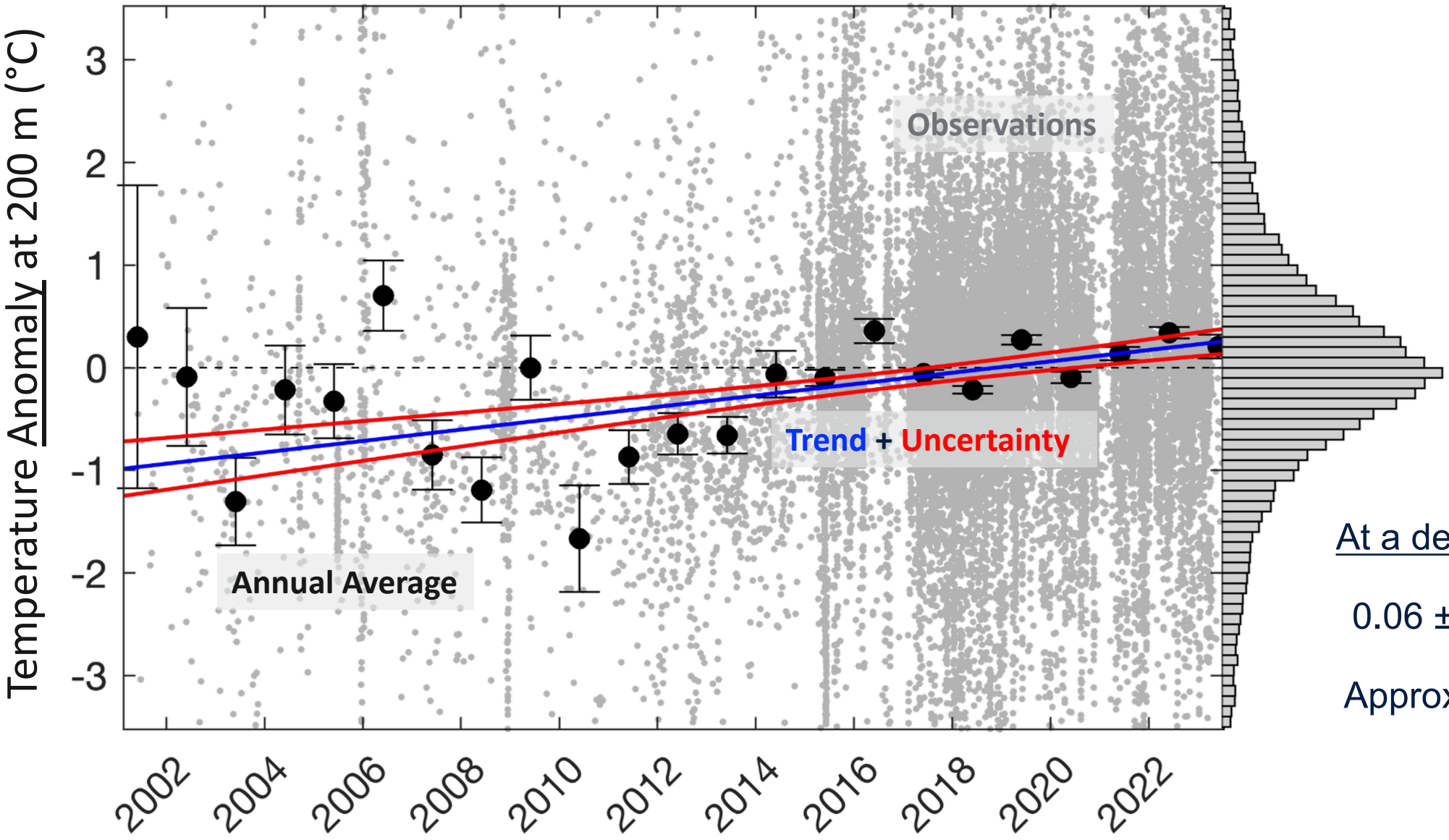
Climatological Temperature

+

Temperature Anomaly



A long-term temperature trend relative to climatology.

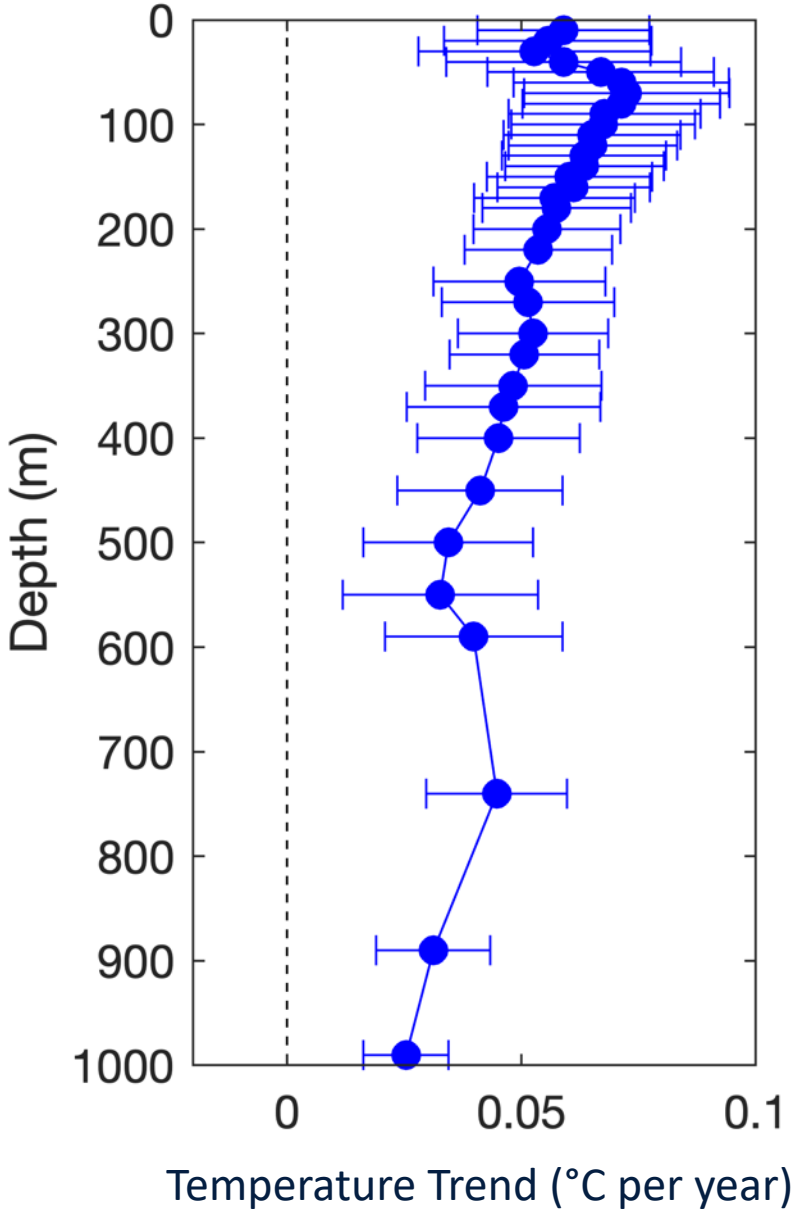


At a depth of 200 meters:

0.06 ± 0.02 °C per year
or
Approx. 1 °C since 2001

Waters have warmed throughout the upper 1000 m of the Gulf Stream.

Why?



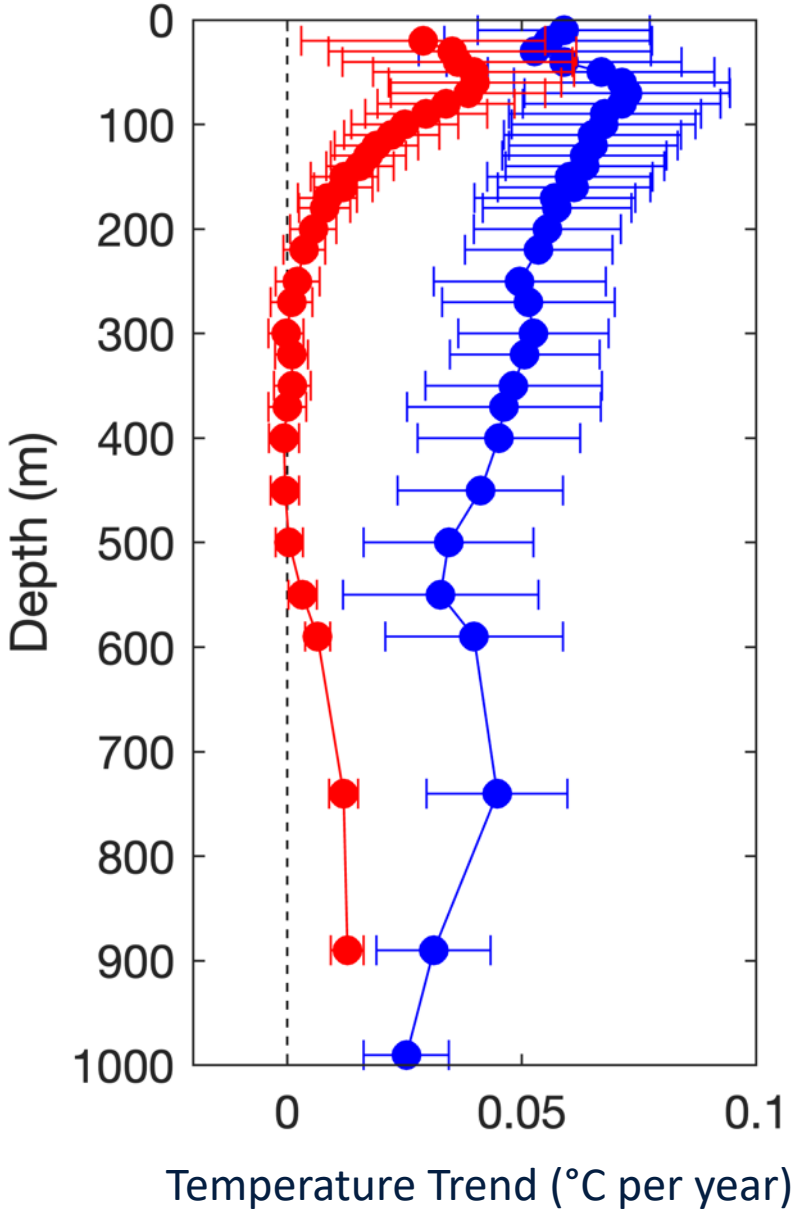
Waters have warmed throughout the upper 1000 m of the Gulf Stream.

Why?

Heat Uptake

- **Identified as warming along isopycnals**
- **Mostly above 200 m**
- **Not whole story**

What else??

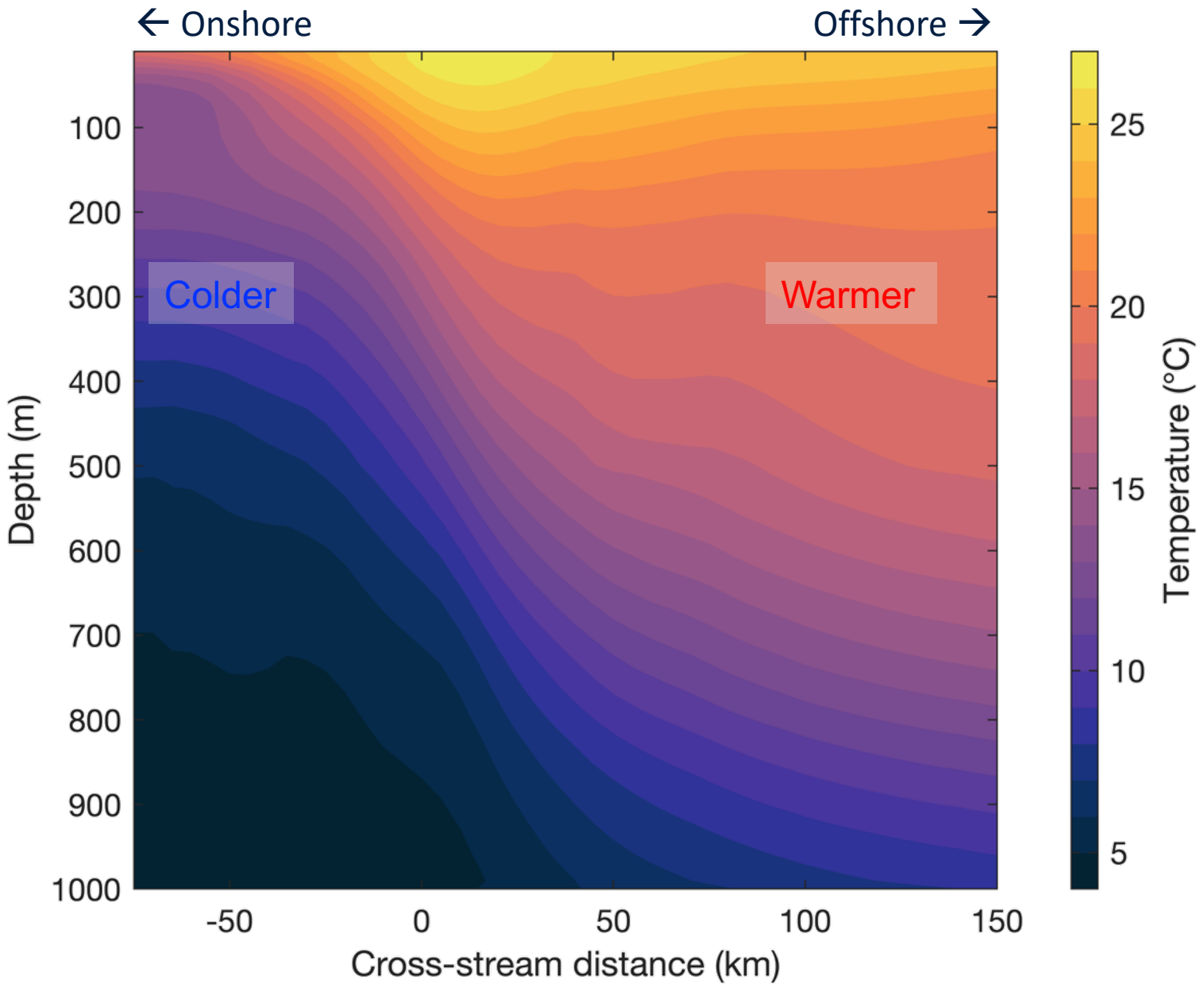


The Gulf Stream is a front.

$$\underbrace{\frac{dT}{dt}}_{\text{Total}} = \underbrace{\frac{\partial T}{\partial t}}_{\text{Warming}} + \underbrace{u\frac{\partial T}{\partial x}}_{\text{Shifting}}$$

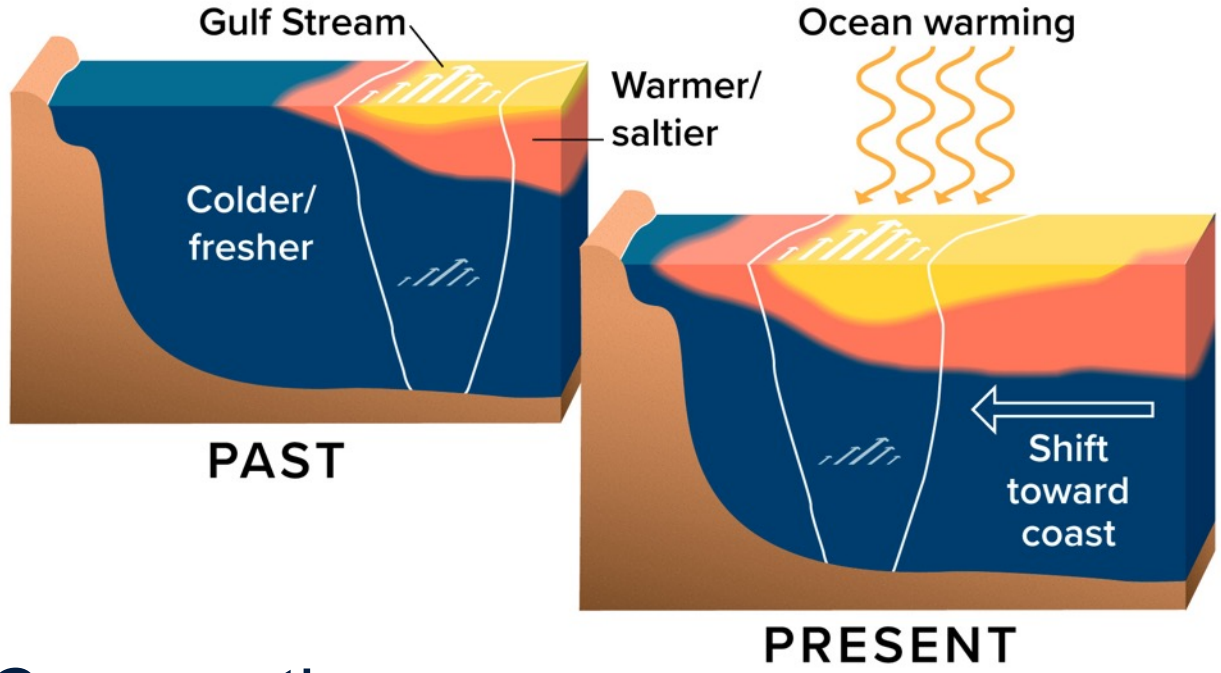
Least-squares fit gives 6±3 km per decade toward cold side of front.

The Gulf Stream has moved roughly 10 km toward the coast since 2001.



Summary and Outlook

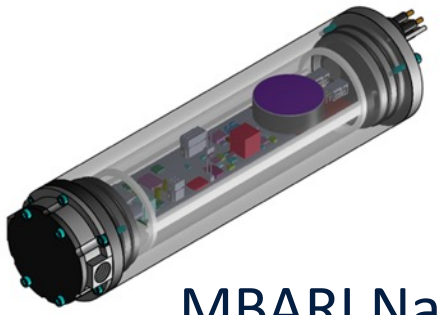
- Gliders and Argo capture 21st century warming in the Gulf Stream region.
- Warming is due to both heat uptake and a shift in Gulf Stream position.



- Moving toward sampling more BGC properties.

Spray2

+



MBARI NanoFET

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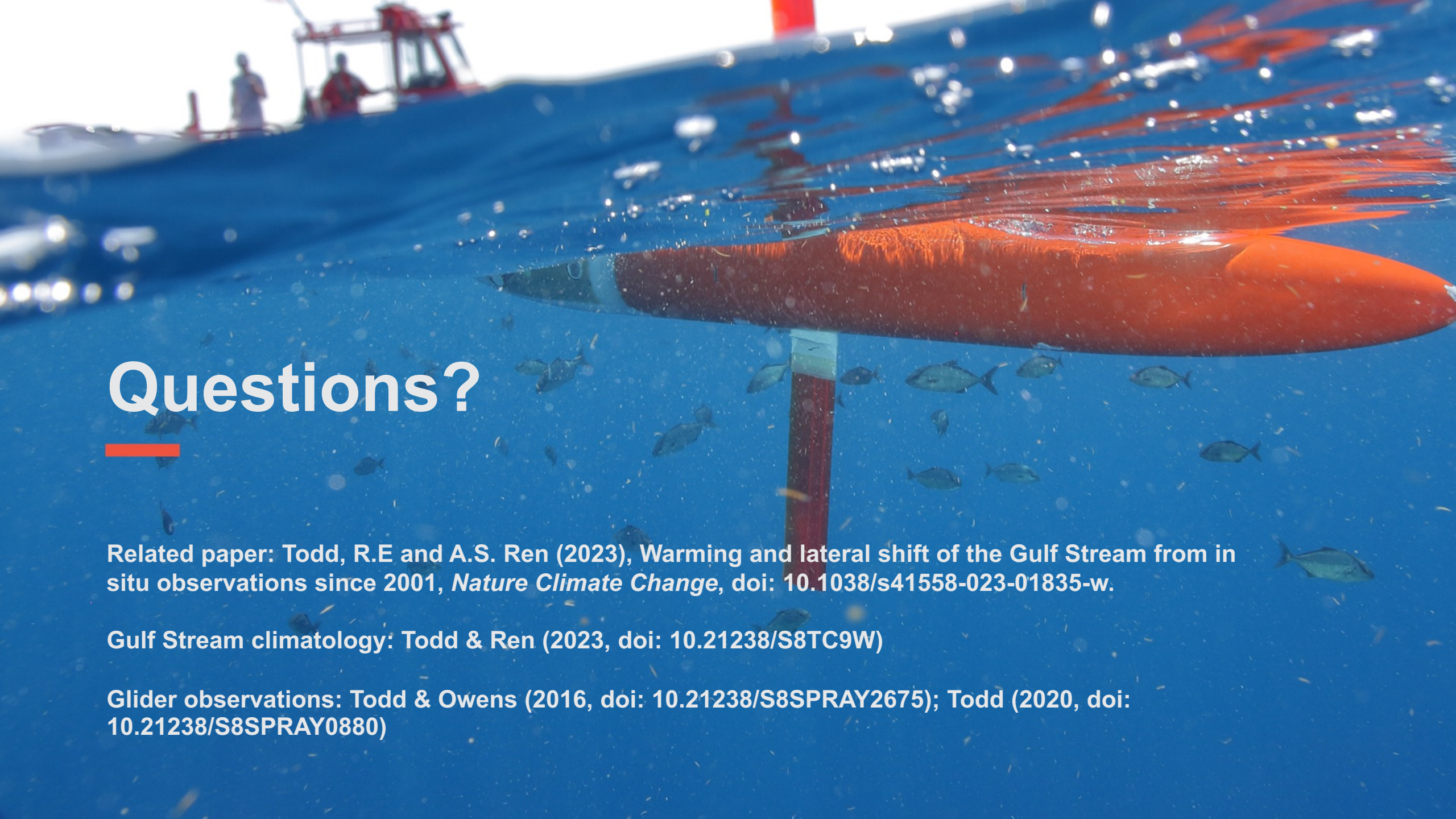
Gulf Stream pH and CO_2 uptake (starting late 2024)



Questions?

Related paper: Todd, R.E and A.S. Ren (2023), Warming and lateral shift of the Gulf Stream from in situ observations since 2001, *Nature Climate Change*, doi: 10.1038/s41558-023-01835-w.

Gulf Stream climatology: Todd & Ren (2023, doi: 10.21238/S8TC9W)

Glider observations: Todd & Owens (2016, doi: 10.21238/S8SPRAY2675); Todd (2020, doi: 10.21238/S8SPRAY0880)