



# Warming and lateral shift of the Gulf Stream

from in situ observations since 2001

Miami



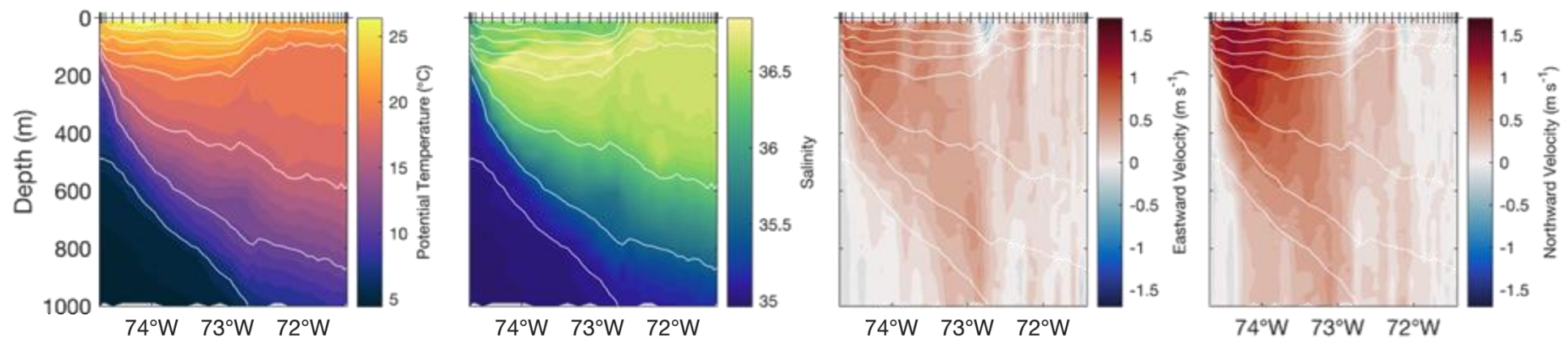
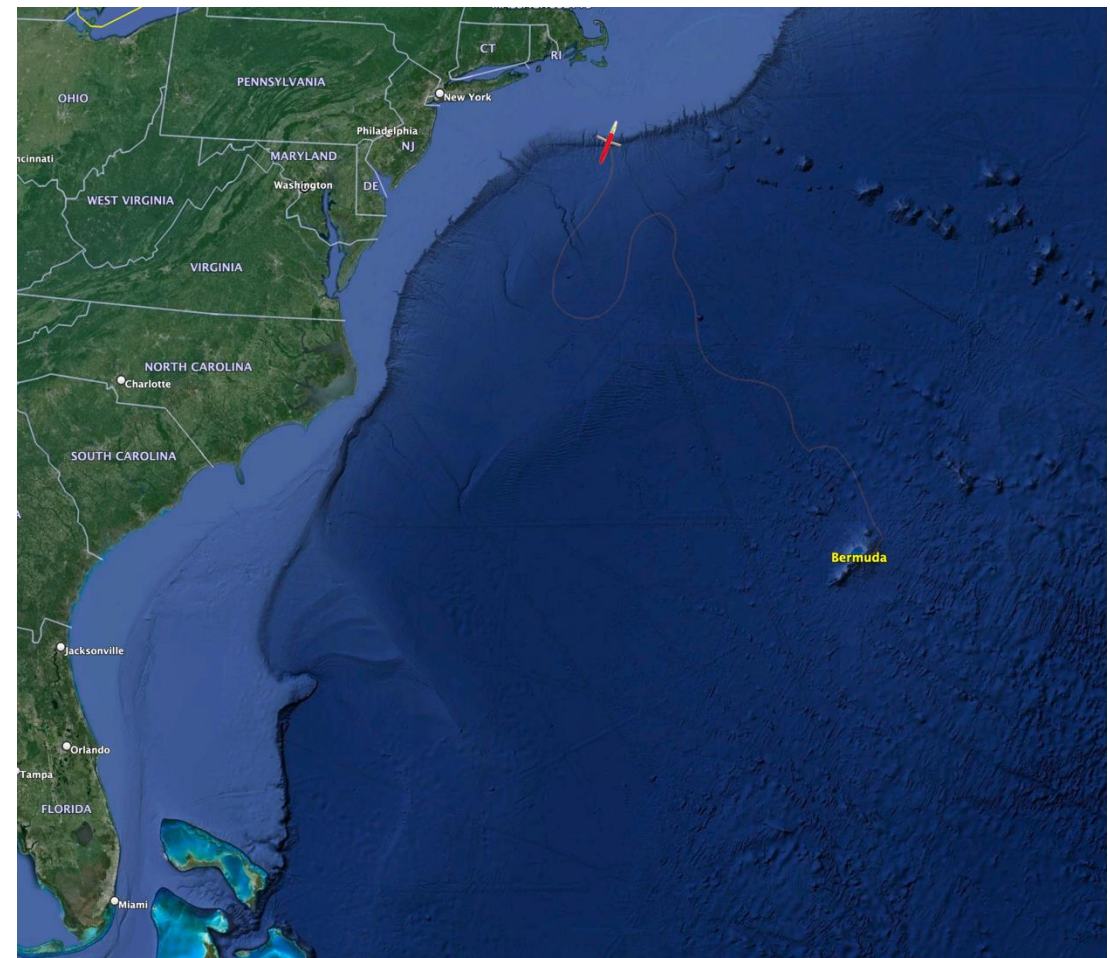
WOODS HOLE  
**OCEANOGRAPHIC**  
INSTITUTION

Robert E. Todd  
Alice S. Ren



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

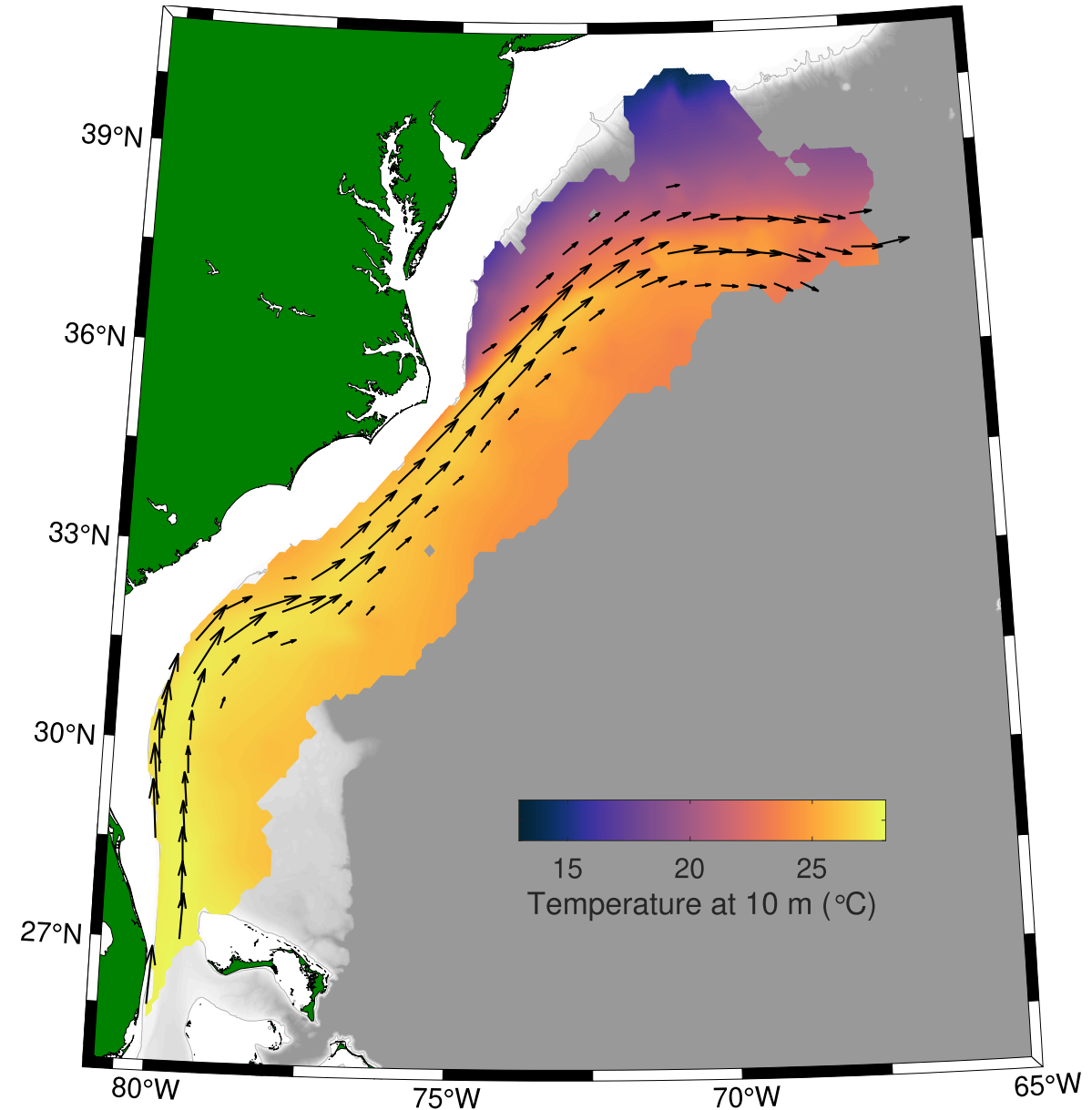
- 64 glider missions
- >5,000 glider-days (>13 years at sea)
- >38,000 profiles
- ~450 Gulf Stream crossings



# The Observing System for the Gulf Stream

## Challenges:

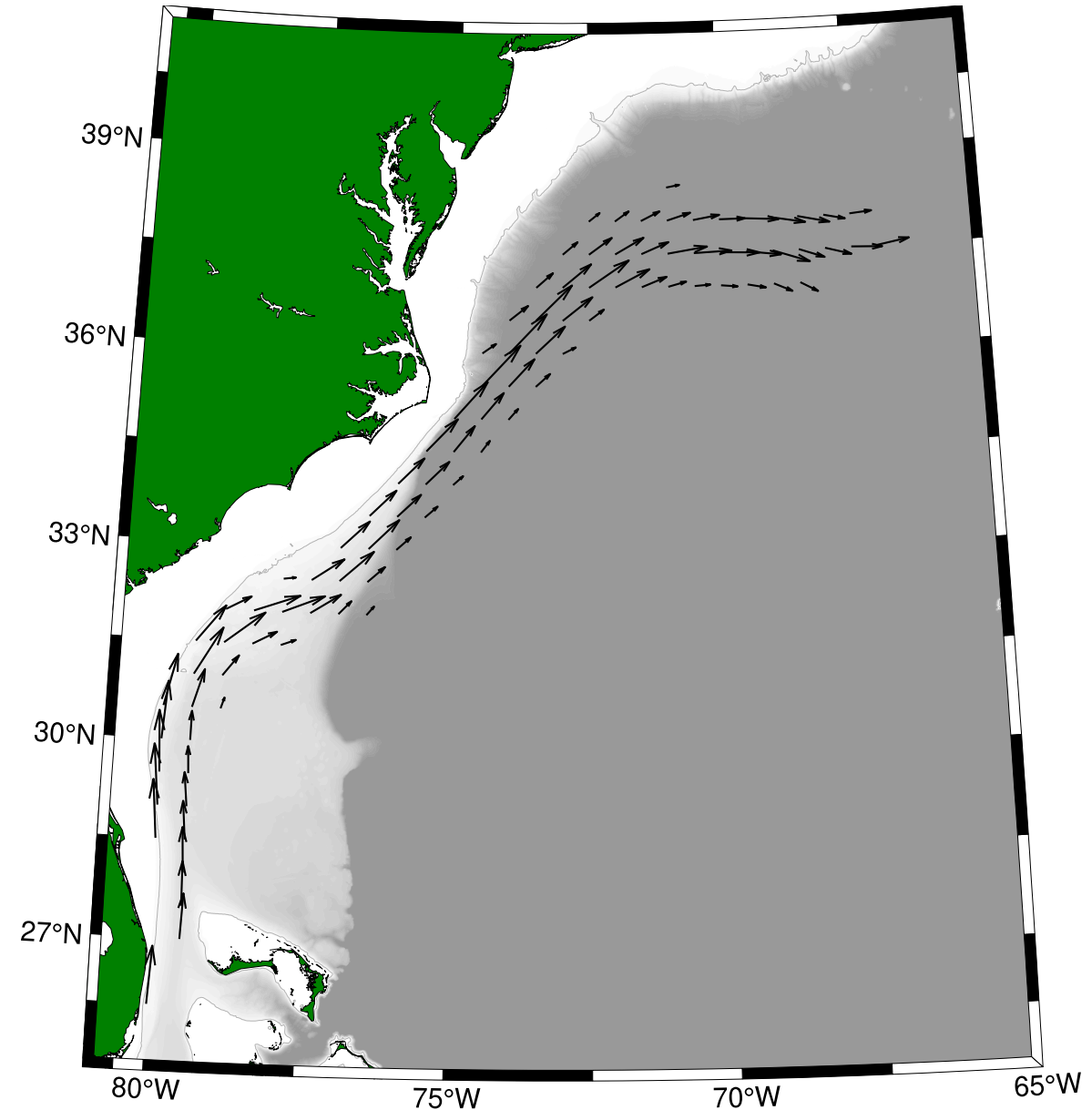
- Strong currents
- Sharp gradients
- Large scale



# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale



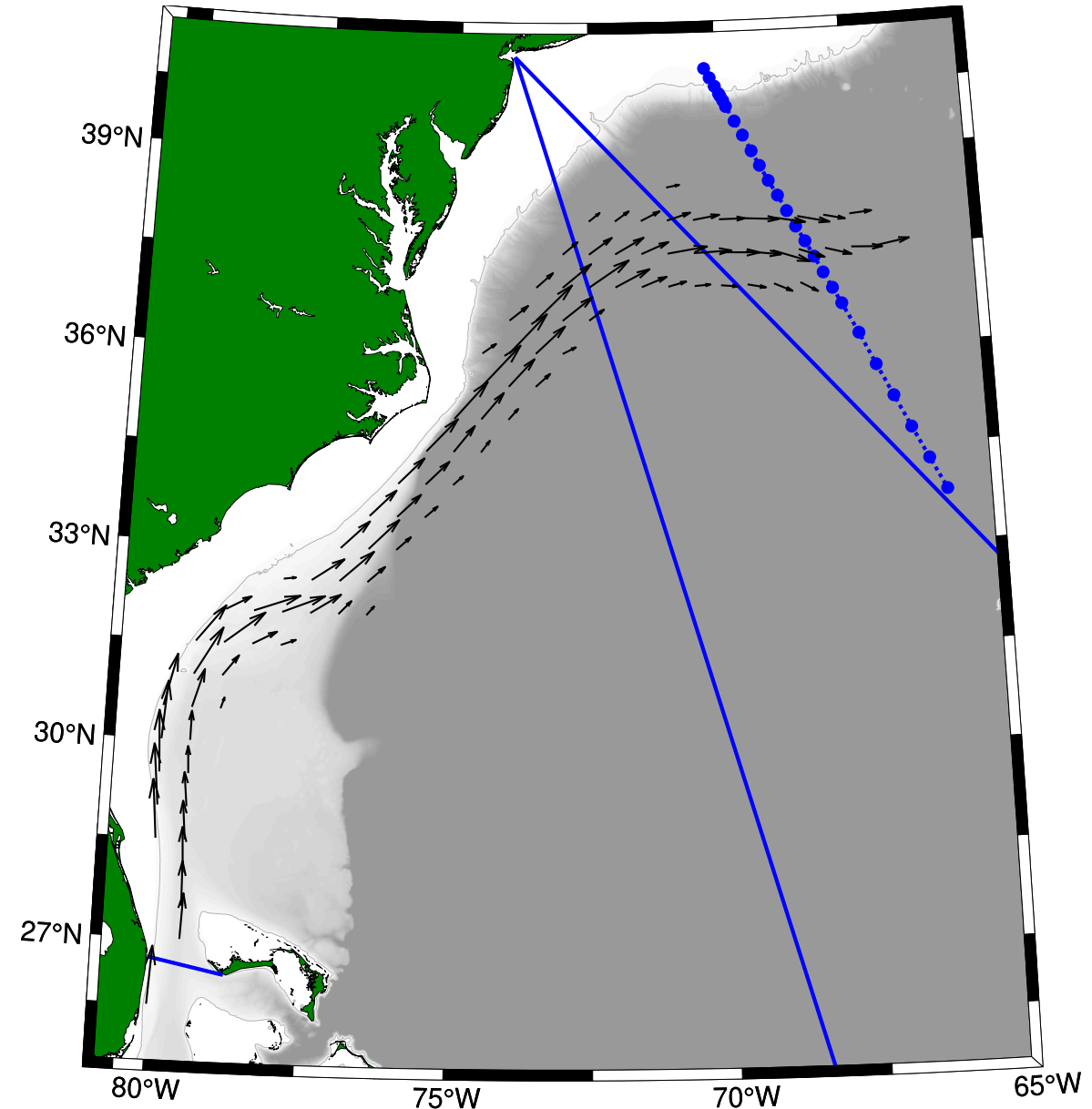
# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale

## Components:

- Ships, moorings, cables



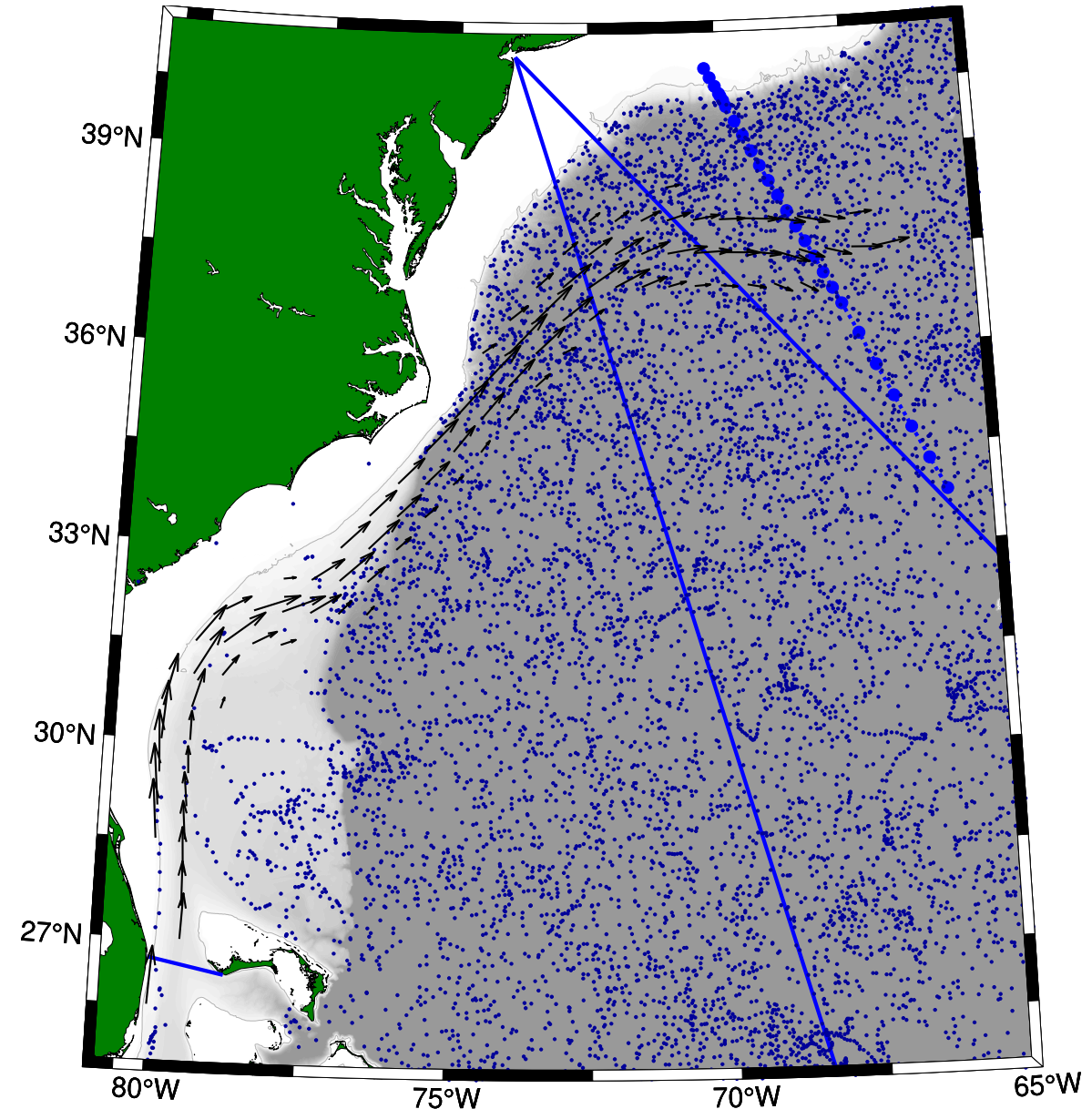
# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale

## Components:

- Ships, moorings, cables
- Argo (2001-present)



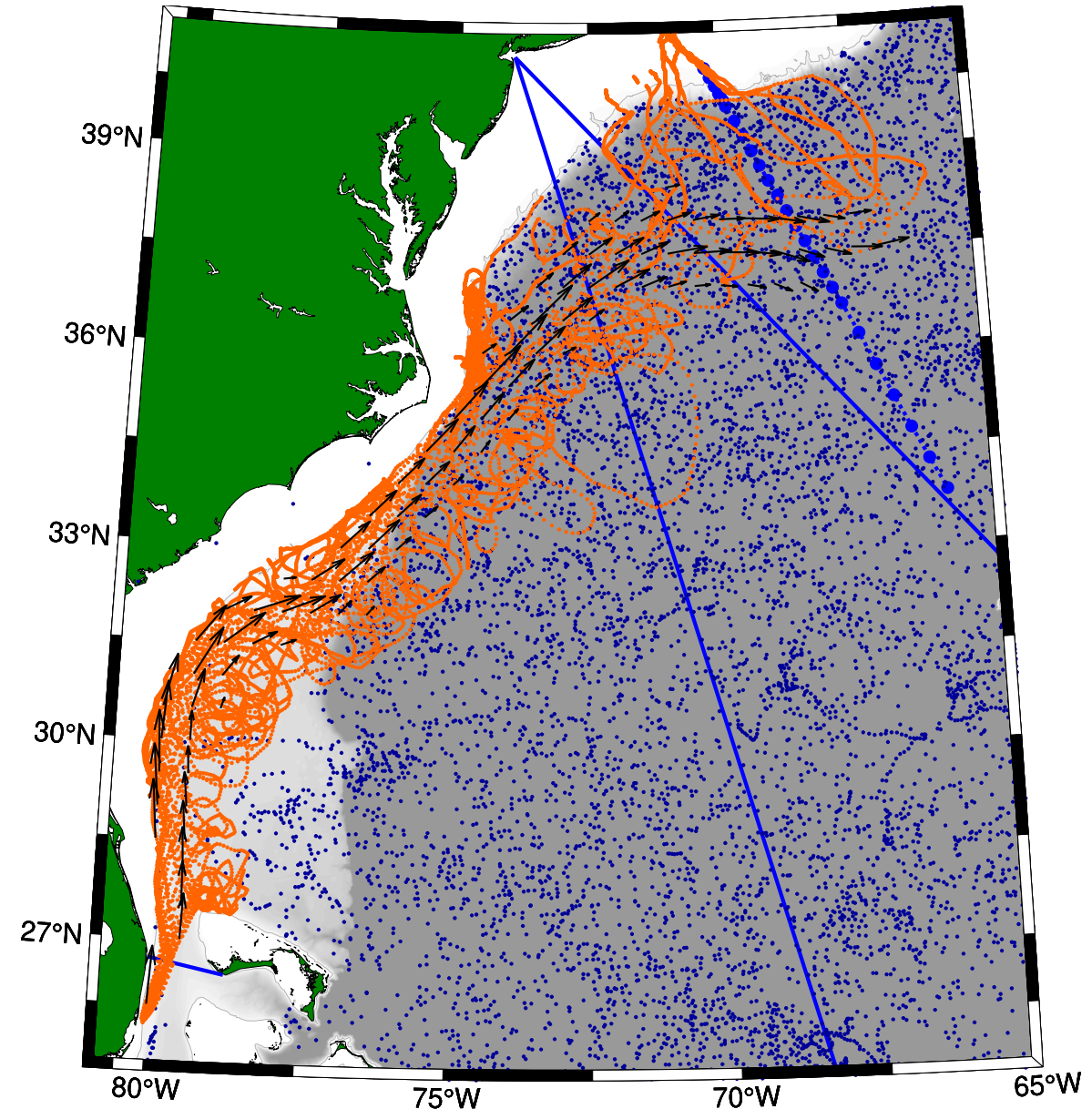
# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale

## Components:

- Ships, moorings, cables
- Argo (2001-present)
- Gliders (2015-present)



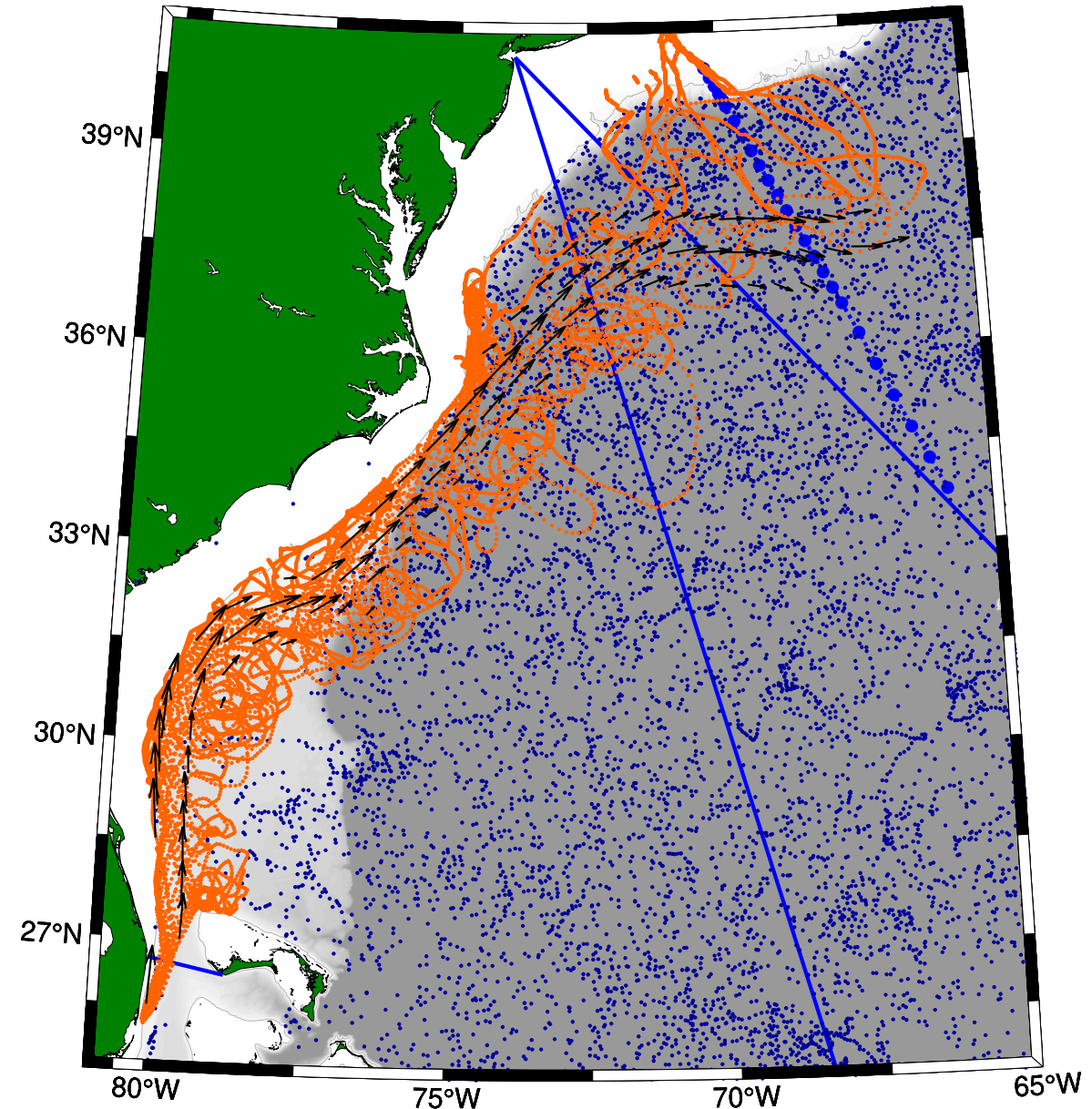
# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale

## Components:

- Ships, moorings, cables
- Argo (2001-present)
- Gliders (2015-present)
- Remote sensing (not shown)





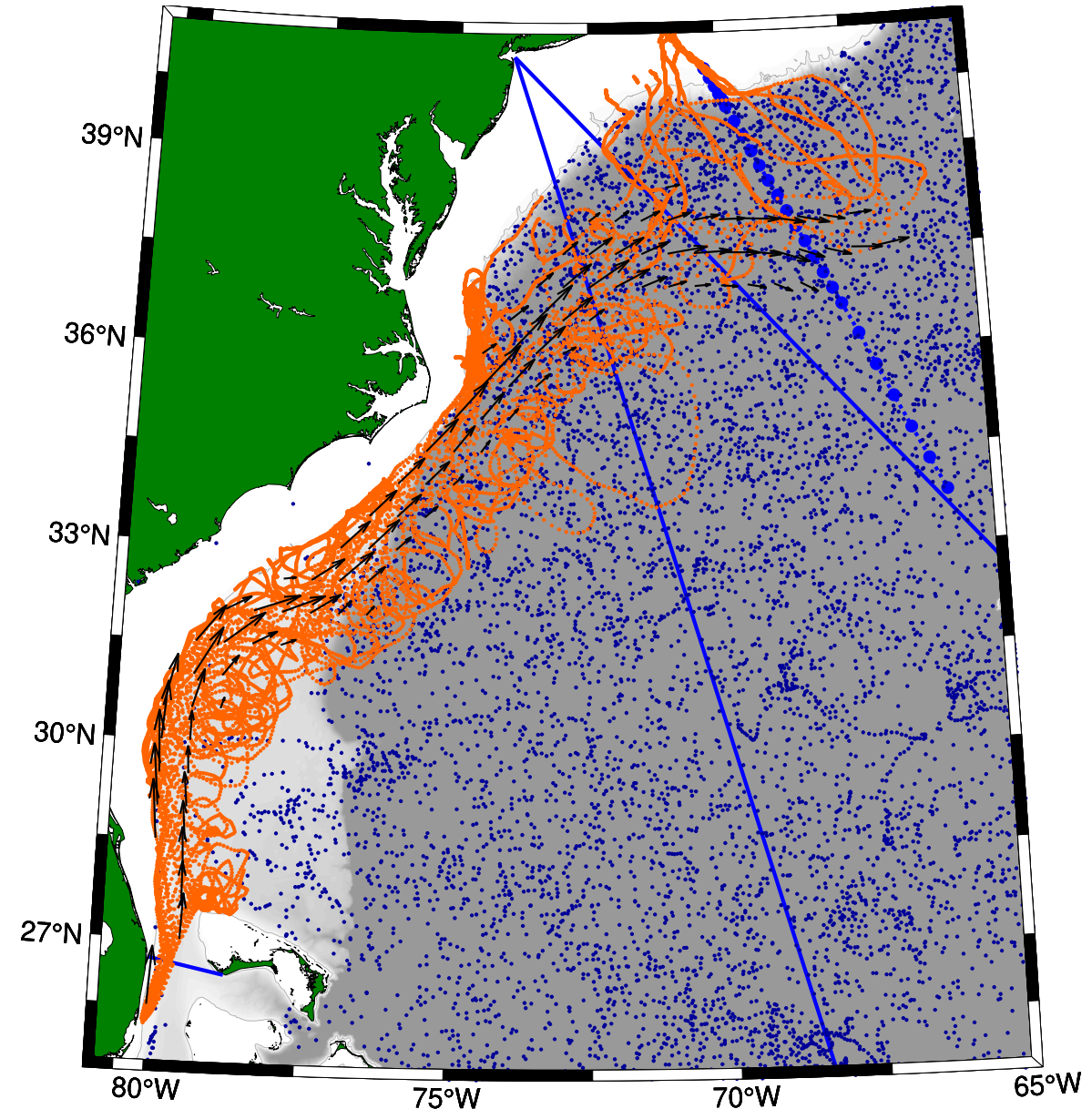
# The Observing System for the Gulf Stream

## Challenges:

- Strong currents
- Sharp gradients
- Large scale

## Components:

- Ships, moorings, cables
- Argo (2001-present)
- Gliders (2015-present)
- Remote sensing (not shown)



**How is the Gulf Stream changing  
as the climate warms?**

# How is the Gulf Stream changing as the climate warms?

**THE ECONOMIC TIMES** News  
English Edition | 10 June, 2024, 12:58 PM IST | Today's ePaper

Melting glaciers threaten Gulf Stream collapse by 2025, new study warns

ET Online - Last Updated: Feb 15, 2024, 03:40:00 PM IST

Gulf Stream could collapse as early as 2025, study suggests

Atlantic Ocean is headed for a tipping point – once melting glaciers shut down the Gulf Stream, we would see extreme climate change within decades, study shows

Published: February 9, 2024 2:01pm EST Updated: February 11, 2024 12:11pm EST

## Gulf Stream safe if wind blows and Earth turns

[Carl Wunsch](#)

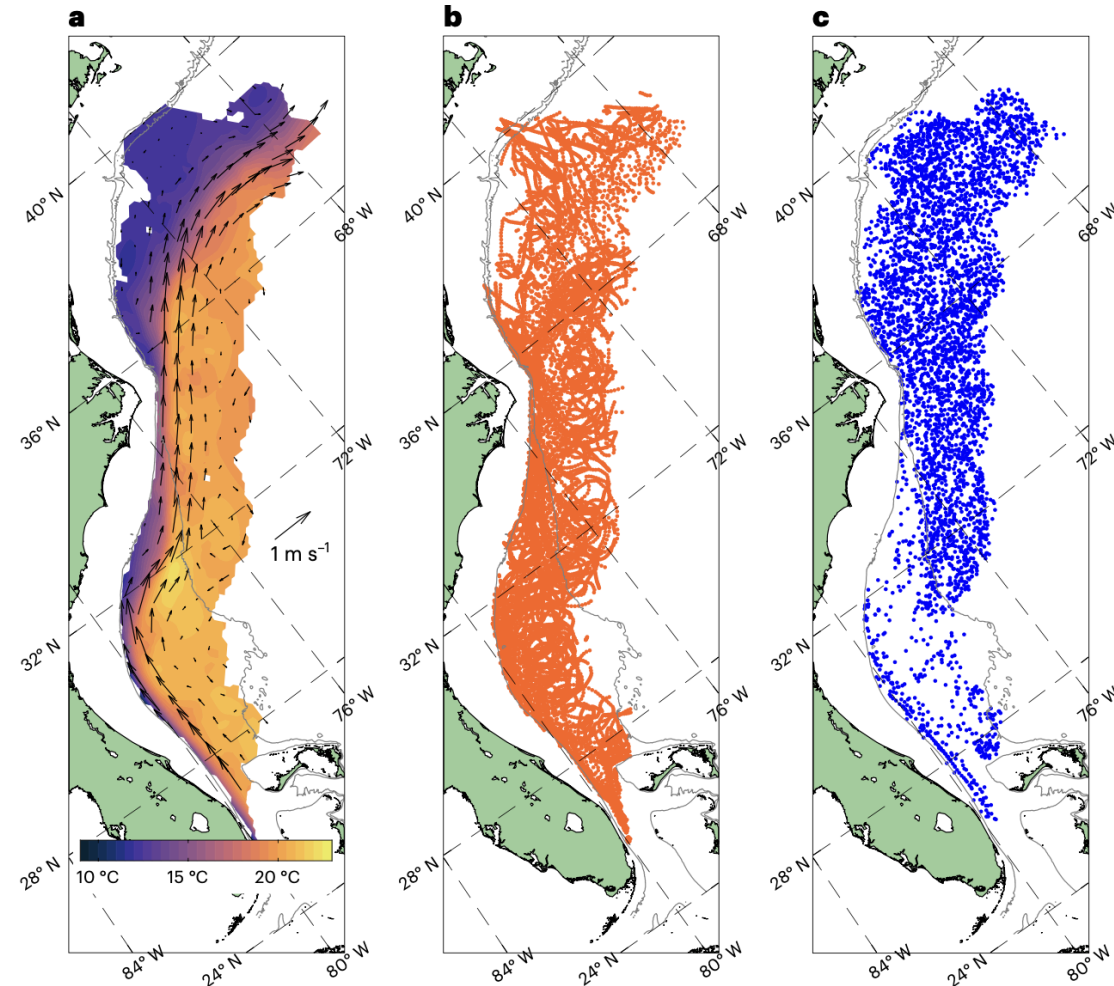
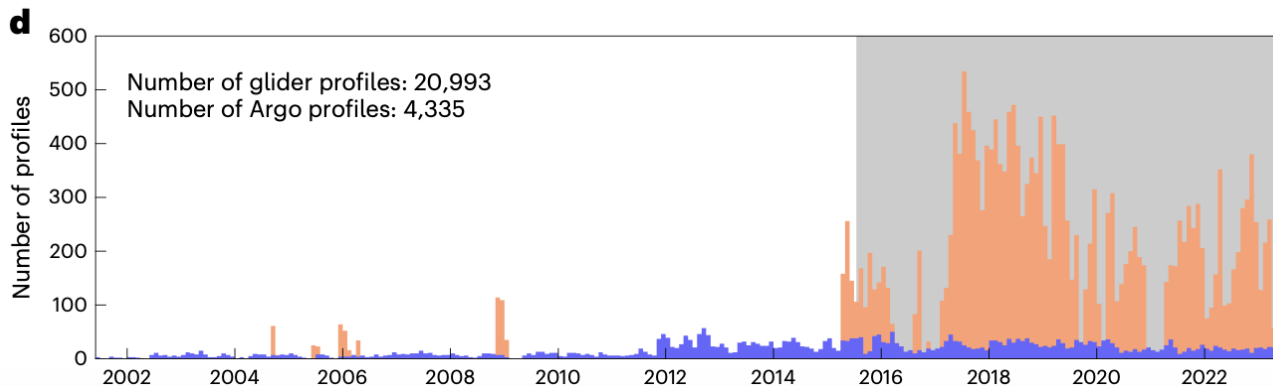
[Nature](#) 428, 601 (2004) | [Cite this article](#)



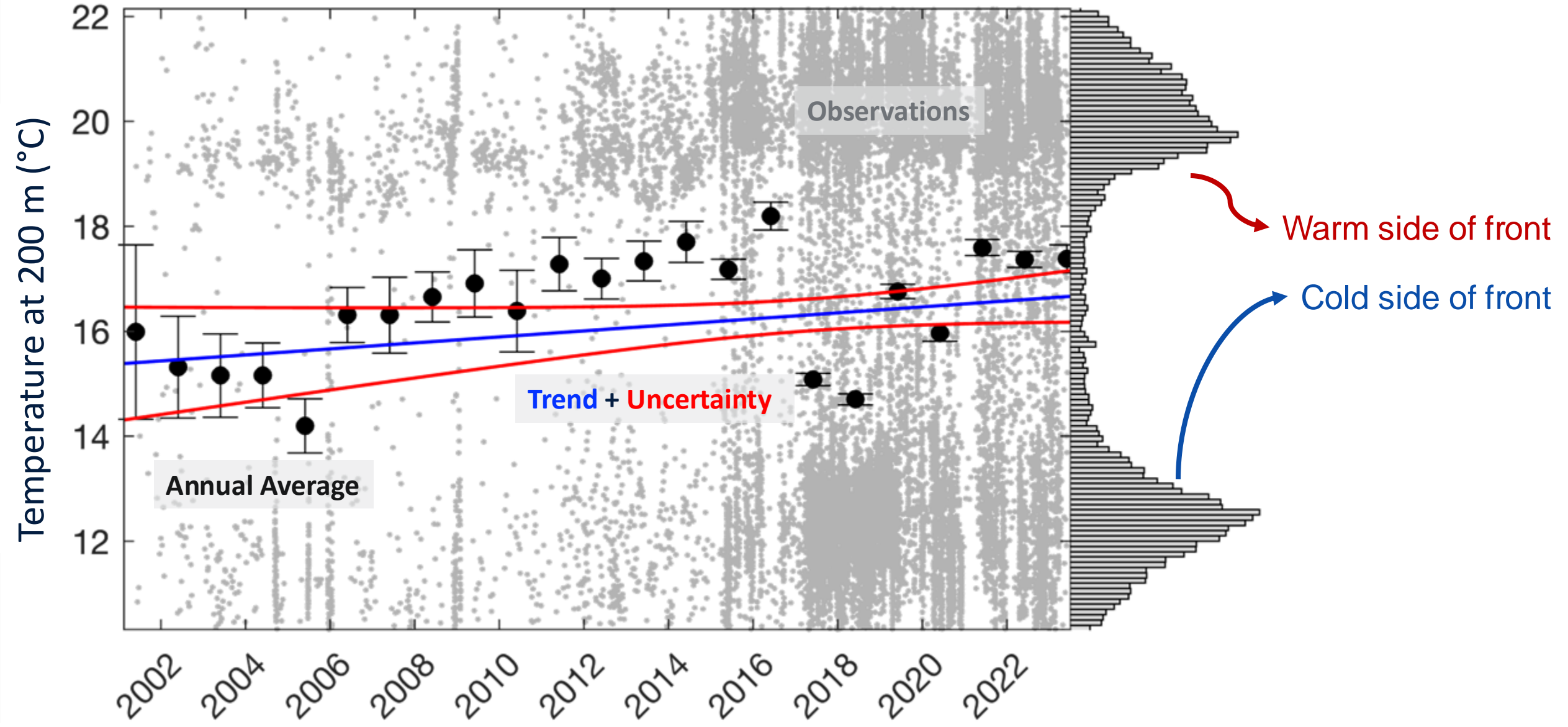
# How is the Gulf Stream changing as the climate warms?

**Goal:**

**Use 20+ years of profiles from gliders and Argo for detection and attribution 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

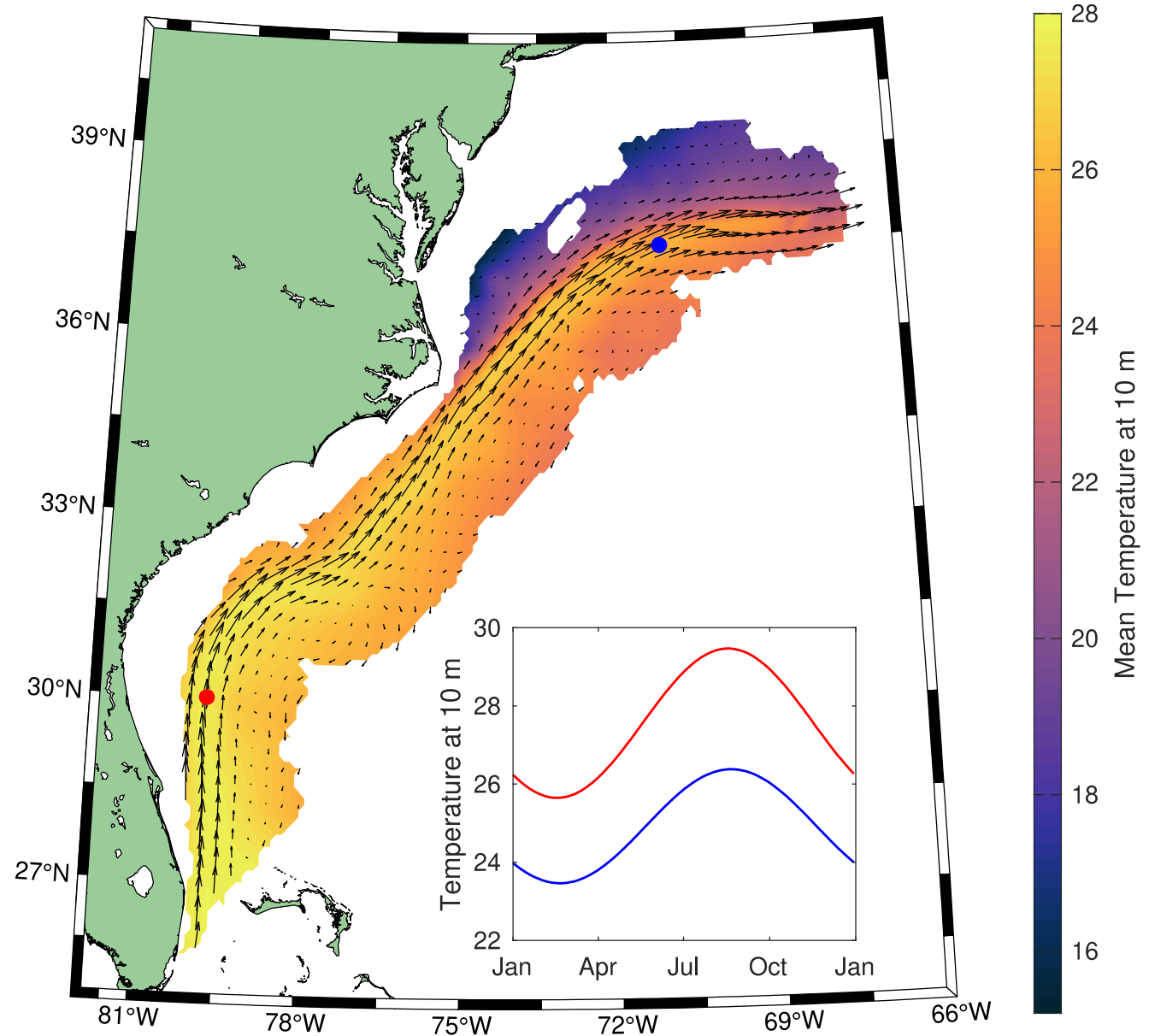
**Measured Temperature**

=

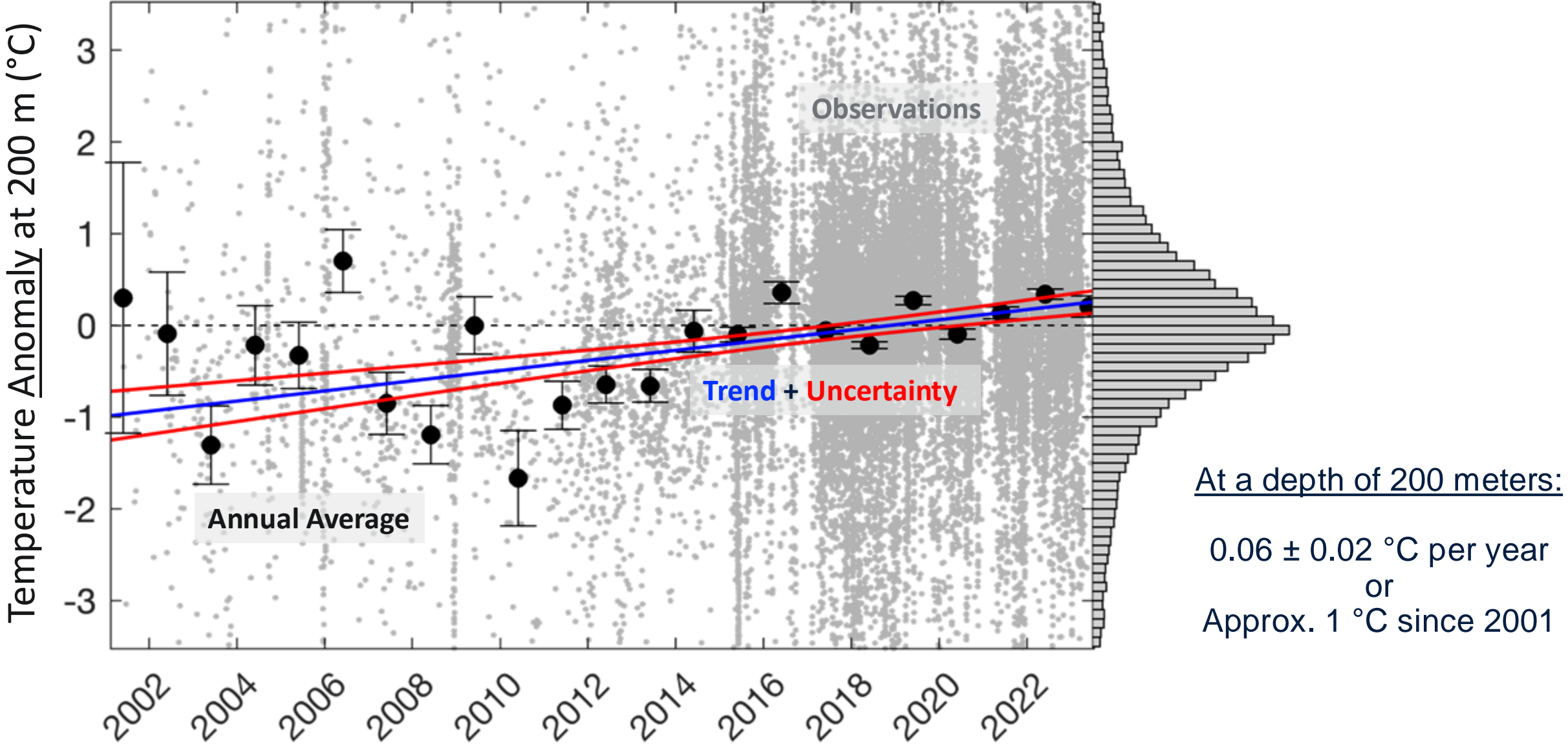
**Climatological Temperature**

+

**Temperature Anomaly**

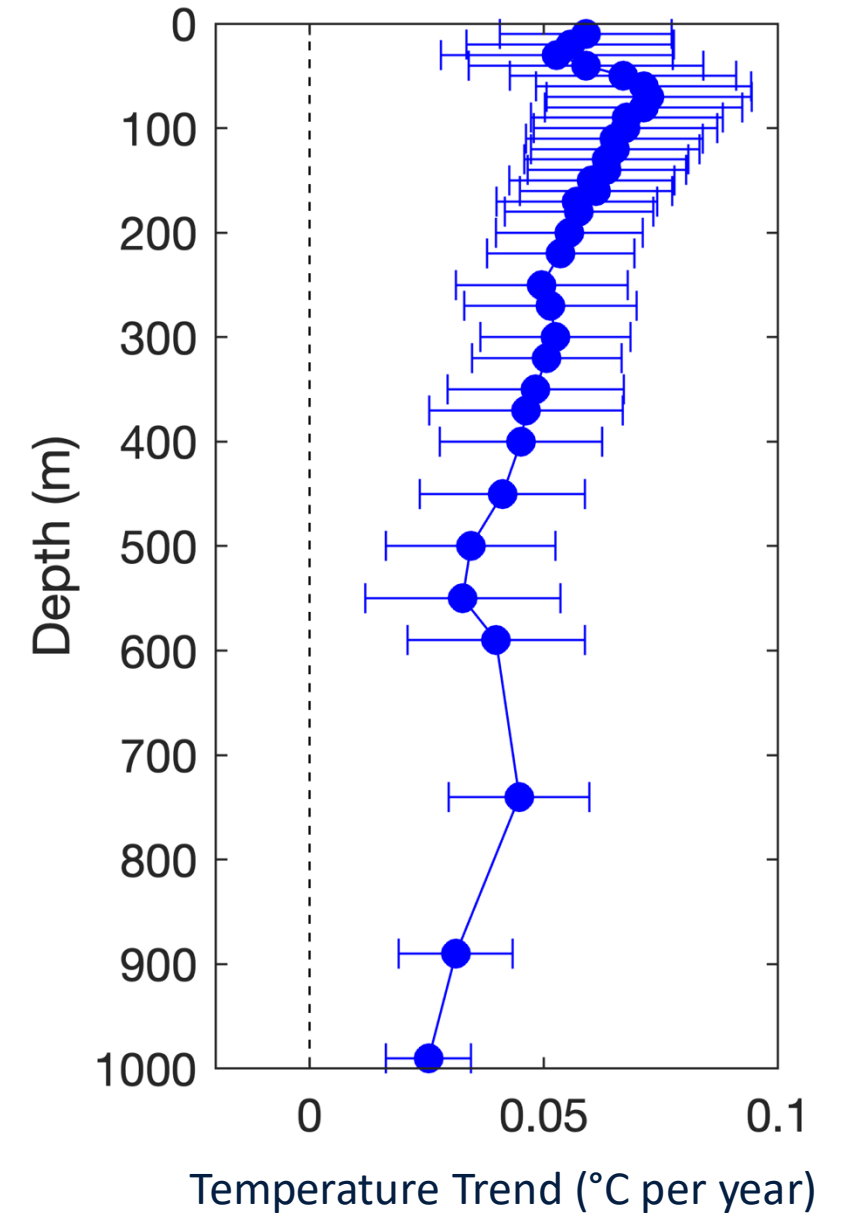


# A long-term temperature trend relative to climatology.



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

**Why?**





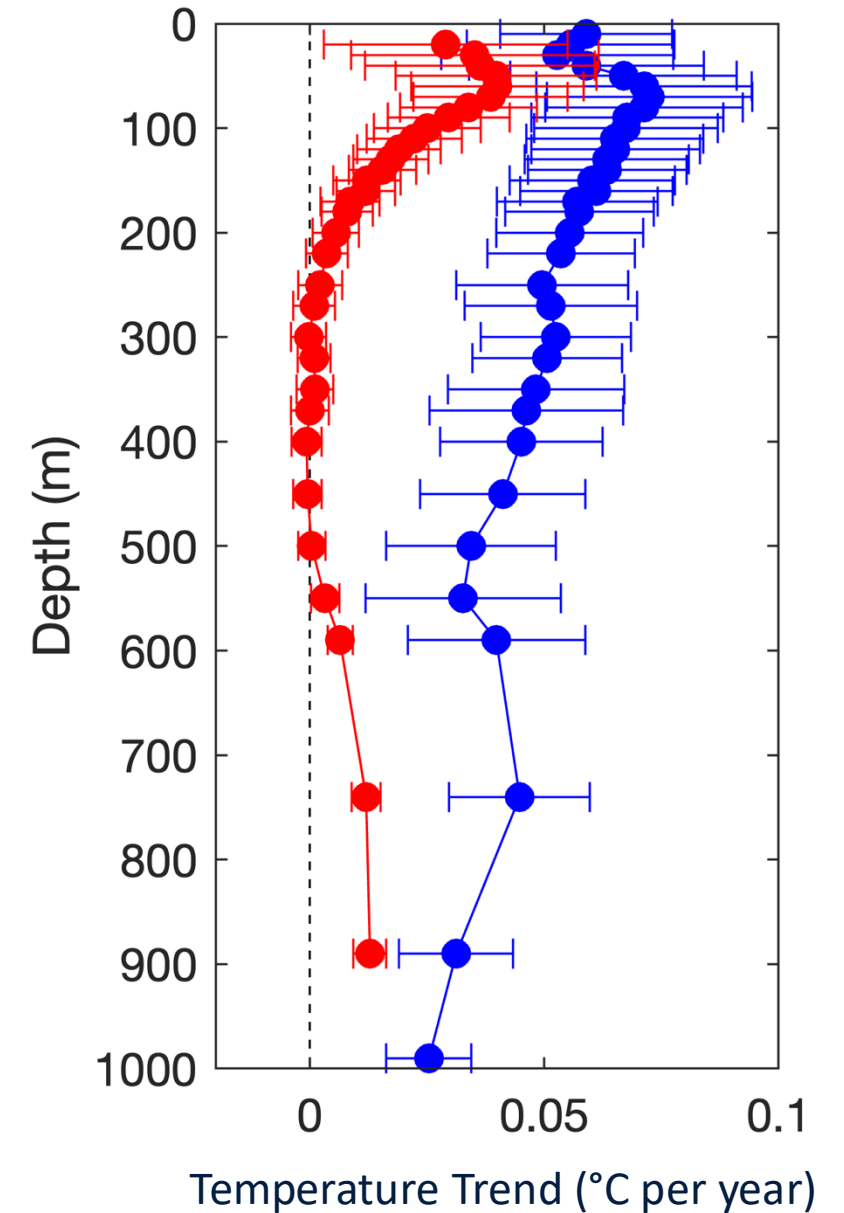
# Waters have warmed throughout the upper 1000 m of the Gulf Stream.

## Why?

### Heat Uptake

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

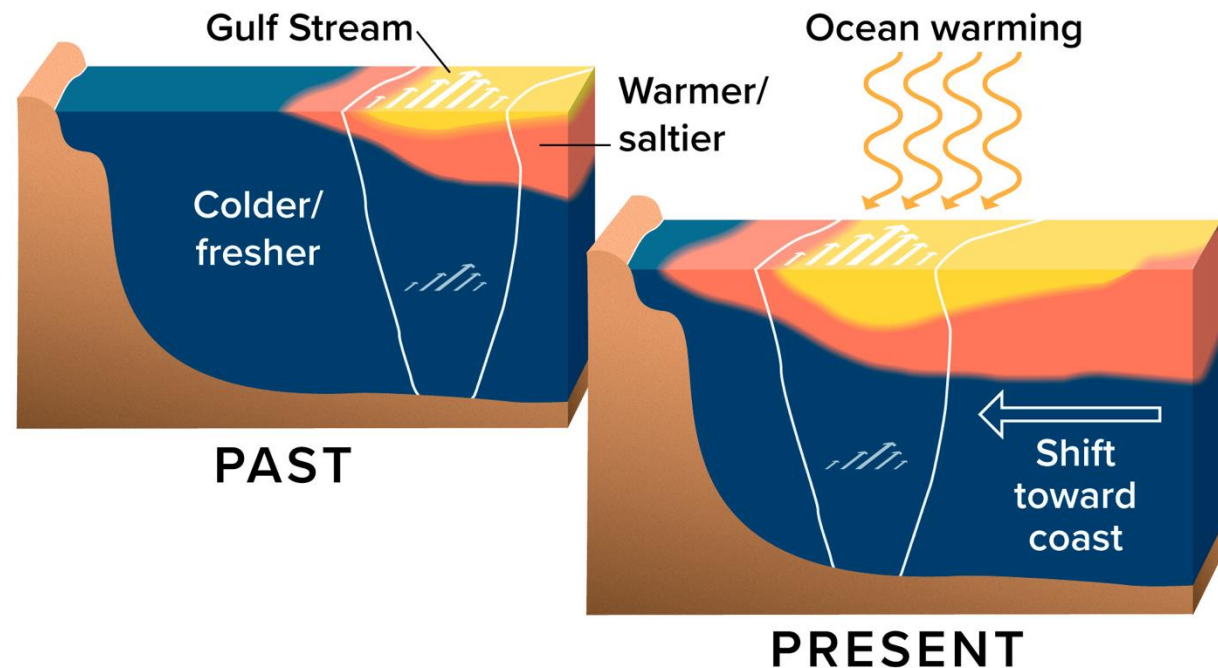
## What else??



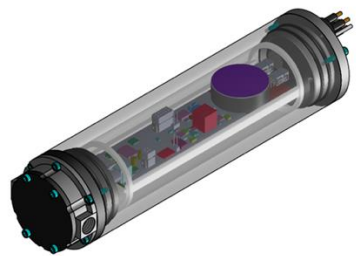


# Summary and Outlook

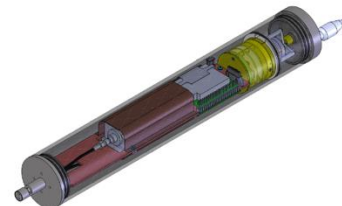
- Gliders and Argo capture 21<sup>st</sup> century warming in the Gulf Stream region.
- Warming is due to both heat uptake and a shift in Gulf Stream position.
- Moving toward sampling more BGC properties.



Spray2



MBARI NanoFET



MBARI Mini-ISUS



Gulf Stream pH, CO<sub>2</sub> uptake, and nitrate (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](https://doi.org/10.1038/s41558-023-01835-w).

Gulf Stream climatology: Todd & Ren (2023, doi: [10.21238/S8TC9W](https://doi.org/10.21238/S8TC9W))

Glider observations: Todd & Owens (2016, doi: [10.21238/S8SPRAY2675](https://doi.org/10.21238/S8SPRAY2675)); Todd (2020, doi: [10.21238/S8SPRAY0880](https://doi.org/10.21238/S8SPRAY0880))