Exploratory Glider Deployments Reveal Changes in the Upper Oceanic Water Masses of the Caribbean Through-Flow

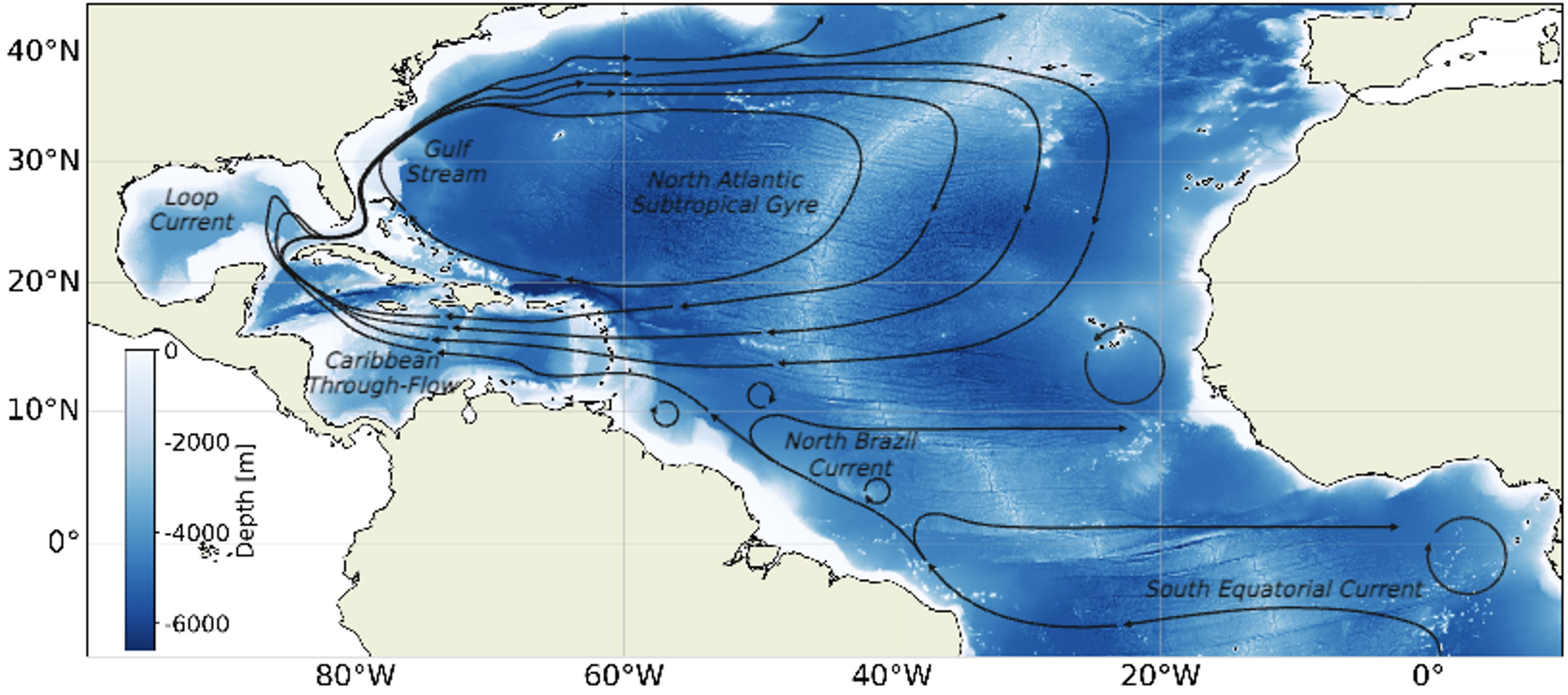
Joe Gradone

Doug Wilson, Jaime Palter, Scott Glenn, and Travis Miles

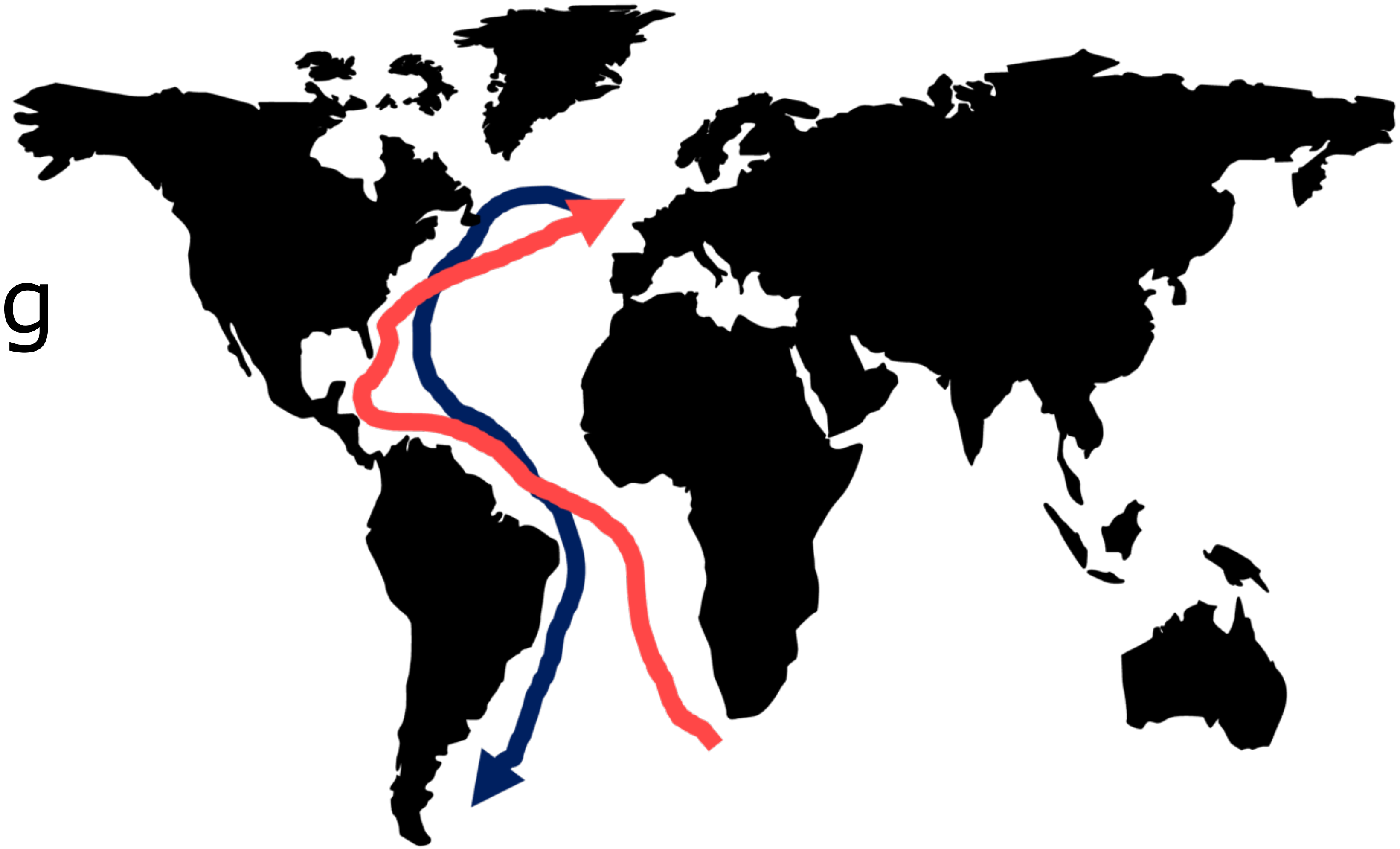
International Underwater Glider Conference 2024

Photo Credit: Dan Mele

Caribbean Through-Flow is a **chokepoint** for **both** AMOC return flow and subtropical gyre recirculation

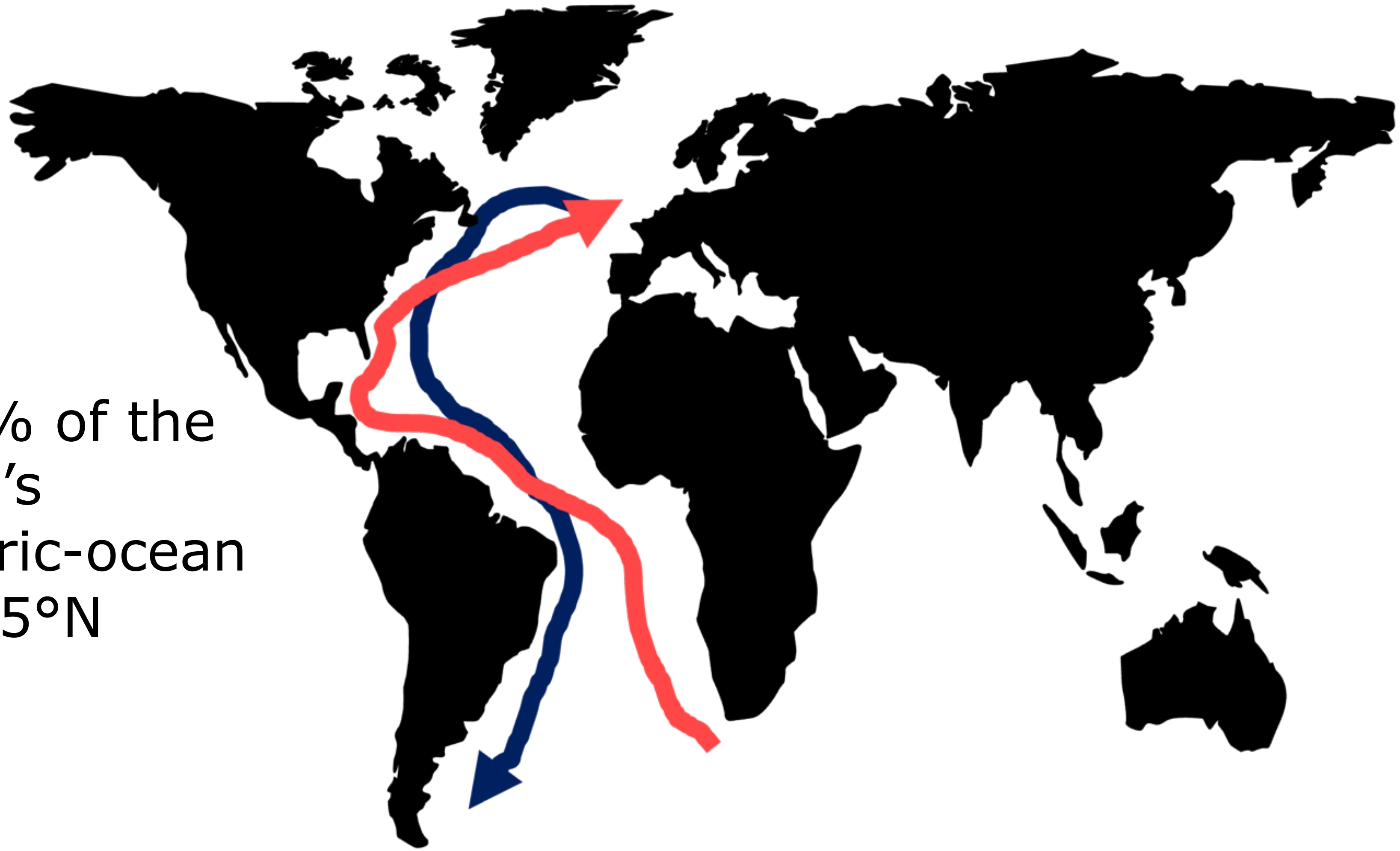


Atlantic
Meridional
Overturning
Circulation



Why is the AMOC important?

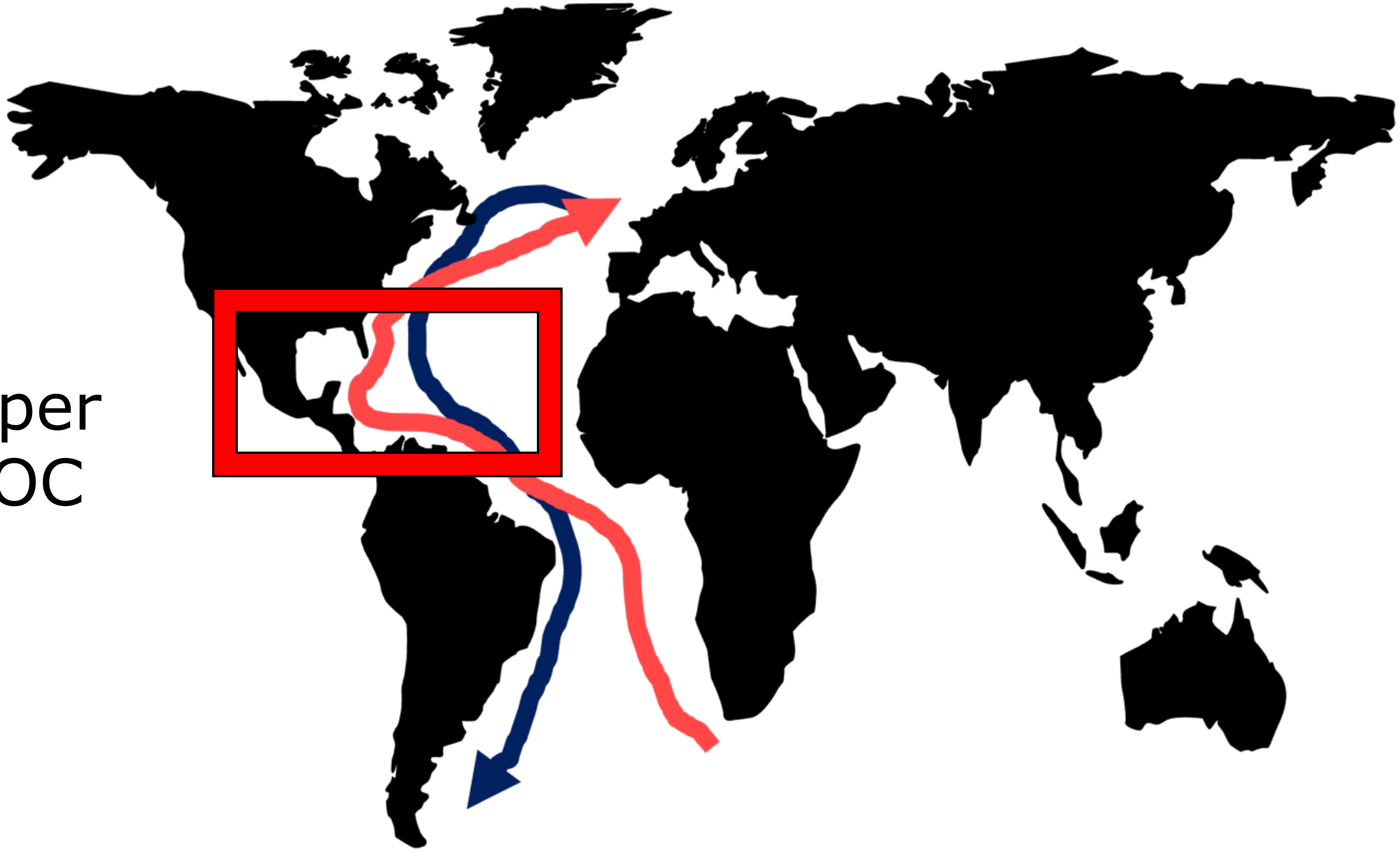
Heat Transport:
Responsible for ~25% of the northern hemisphere’s northward atmospheric-ocean heat transport at 26.5°N

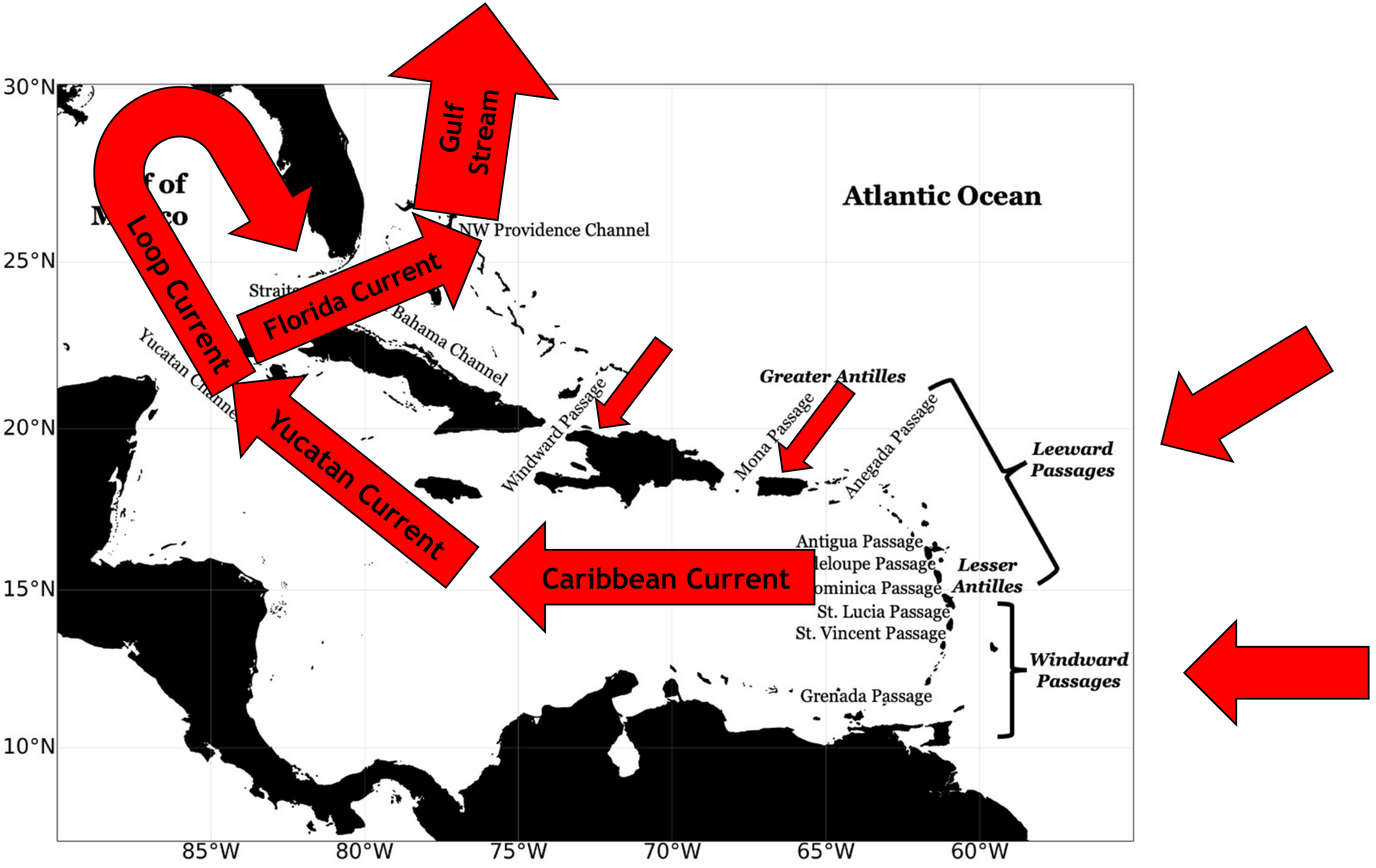


(Johns et al. 2002)

Why the Caribbean?

Start of the upper limb of the AMOC





(Johns et al. 2003; Rhein et al. 2005)

Why the Caribbean?

- Question around/evidence for AMOC slowdown

nature
International journal of science

Letter | Published: 11 April 2018

Anomalously weak Labrador Sea convection and Atlantic overturning during the past 150 years

David J. R. Thornalley, Delia W. Oppo, Pablo Ortega, Jon I. Robson, Chris M. Brierley, Renee Davis, Ian R. Hall, Paola Moffa-Sanchez, Neil L. Rose, Peter T. Spooner, Igor Yashayaev & Lloyd D. Keigwin

Nature **556**, 227–230 (2018) | Download Citation

nature
International journal of science

NEWS AND VIEWS · 11 APRIL 2018

North Atlantic circulation slows down

Evidence suggests that the circulation system of the North Atlantic Ocean is in a weakened state that is unprecedented in the past 1,600 years, but questions remain as to when exactly the decline commenced.

Summer K. Praetorius

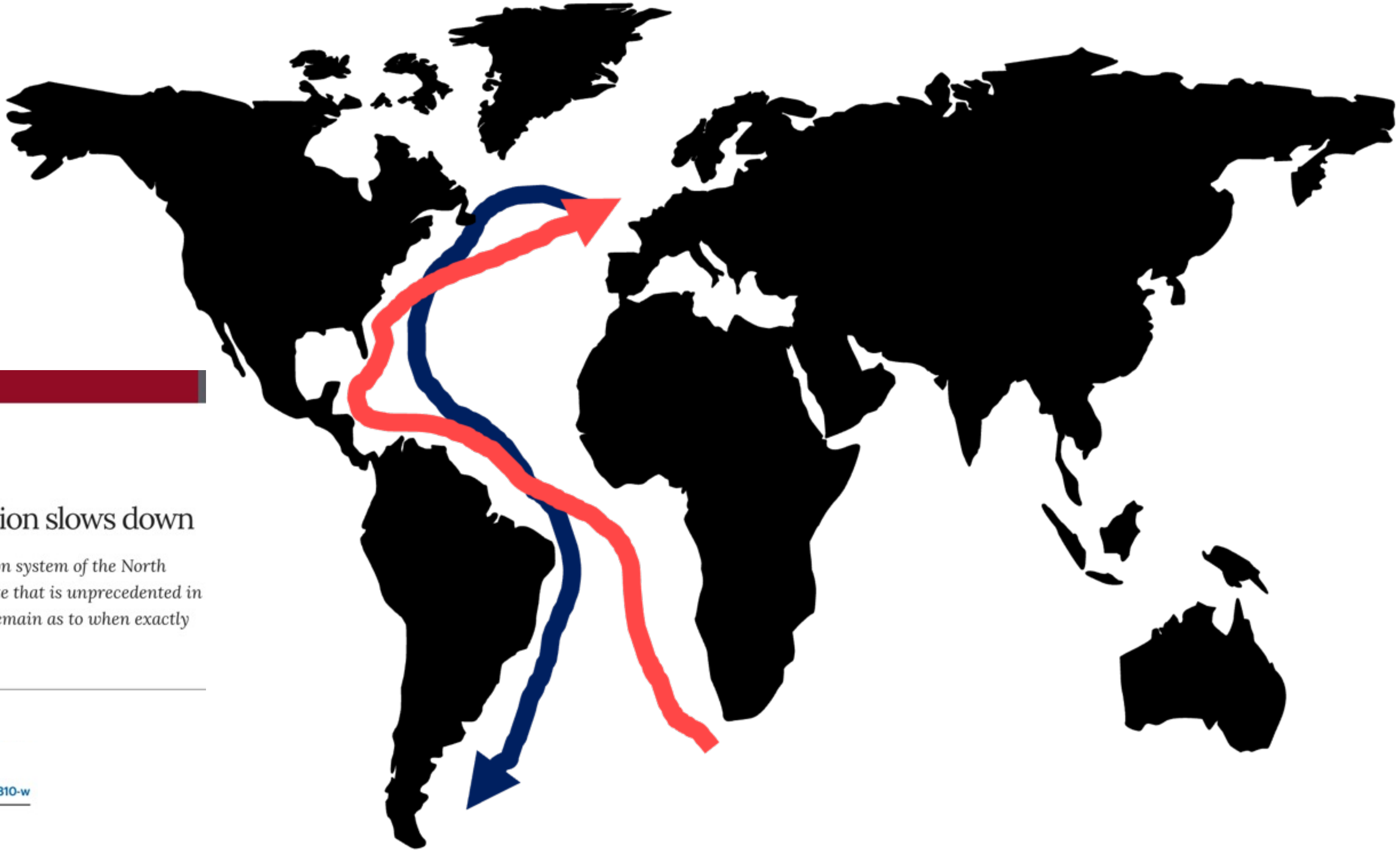
nature communications

Article https://doi.org/10.1038/s41467-023-39810-w

Warning of a forthcoming collapse of the Atlantic meridional overturning circulation

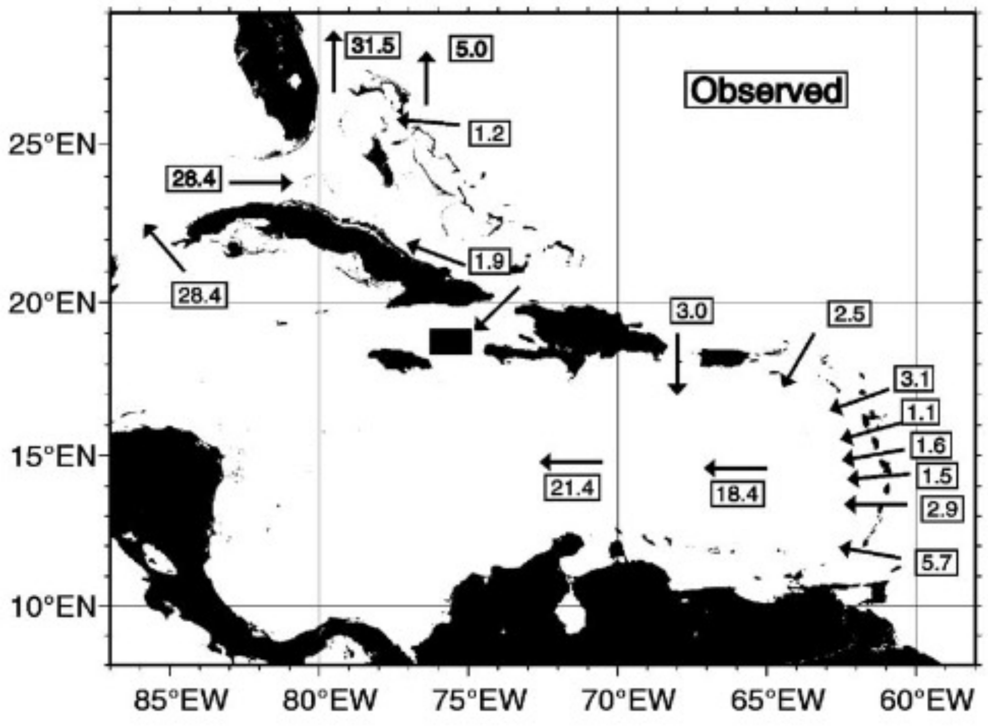
Received: 3 March 2023
Accepted: 29 June 2023

Peter Ditlevsen [1,3] & Susanne Ditlevsen [2,3]

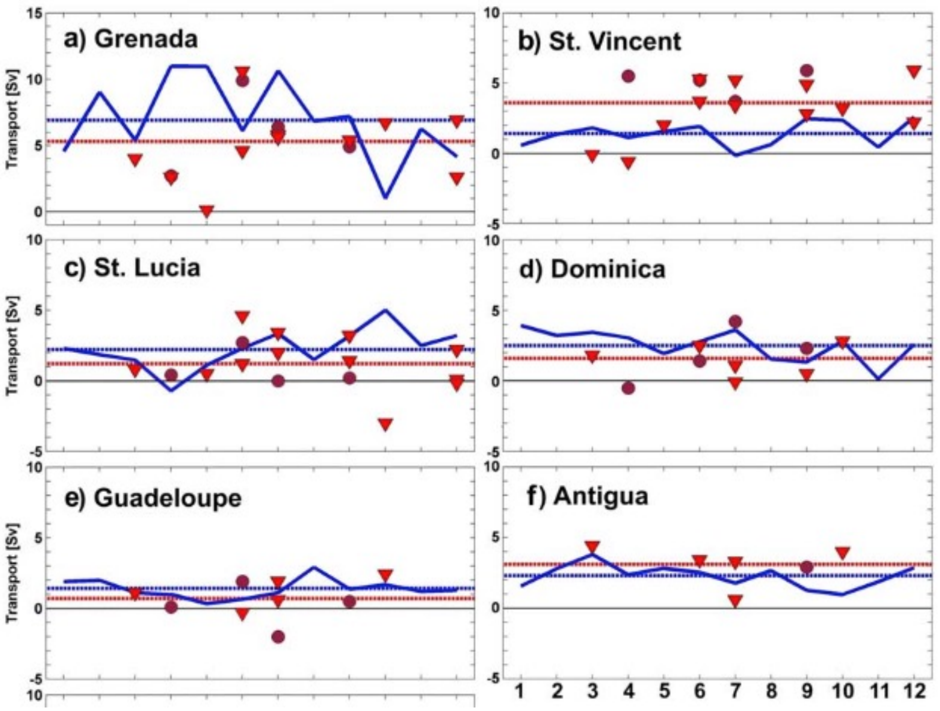


Caribbean Through-Flow is significantly under-sampled!

Wilson and Johns, 1997; Johns et al. 2002
Observations: 1991-2001



Kirchner et al. 2008
Observations: 2002 & 2005



~20 years

No transport observations in the Caribbean Through-Flow in 20 years

AGU ADVANCING EARTH AND SPACE SCIENCES

JGR Oceans

RESEARCH ARTICLE

10.1029/2022JC019608

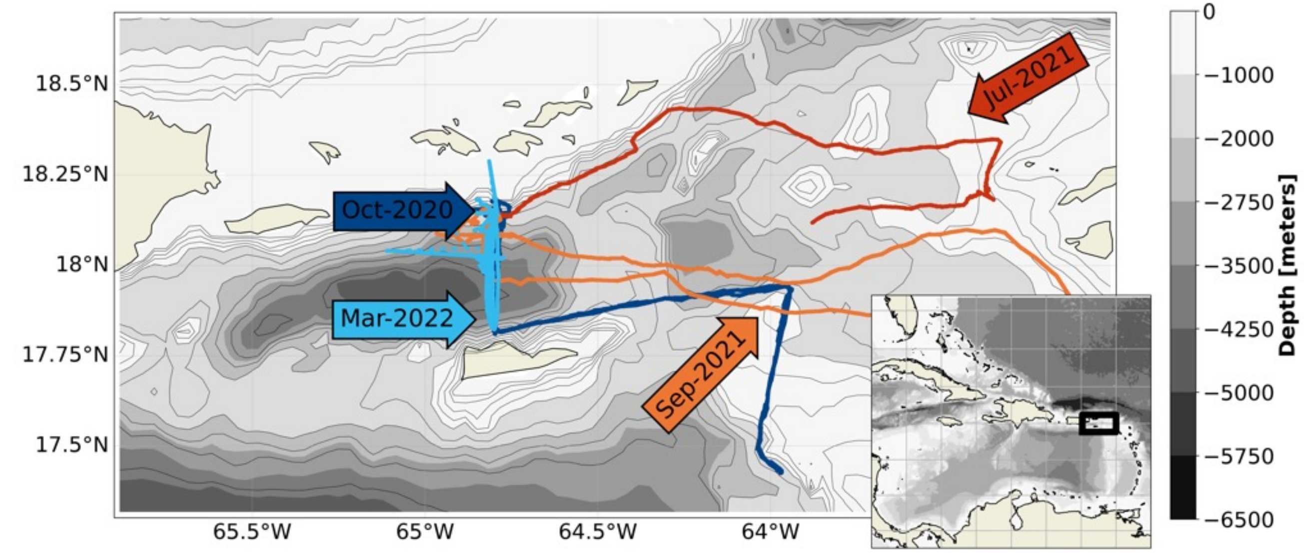
Key Points:

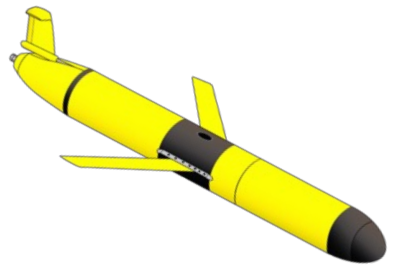
- Total transport and transport of South Atlantic Water through the Anegada Passage (AP) may be larger than previously estimated
- The AP is a pathway for both Atlantic Meridional Overturning Circulation return flow and subtropical gyre recirculation

Upper Ocean Transport in the Anegada Passage From Multi-Year Glider Surveys

J. C. Gradone[1], W. D. Wilson[2,3], S. M. Glenn[1], and T. N. Miles[1]

[1]Center for Ocean Observing Leadership, Department of Marine and Coastal Sciences, School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ, USA, [2]Center for Marine and Environmental Studies, University of the Virgin Islands, St. Thomas, VI, USA, [3]Ocean and Coastal Observing—Virgin Islands, Inc, St. Thomas, VI, USA





Since September 2020

4 glider deployments

>2700 kilometers sampled

>130 days at sea

TELEDYNE WEBB RESEARCH

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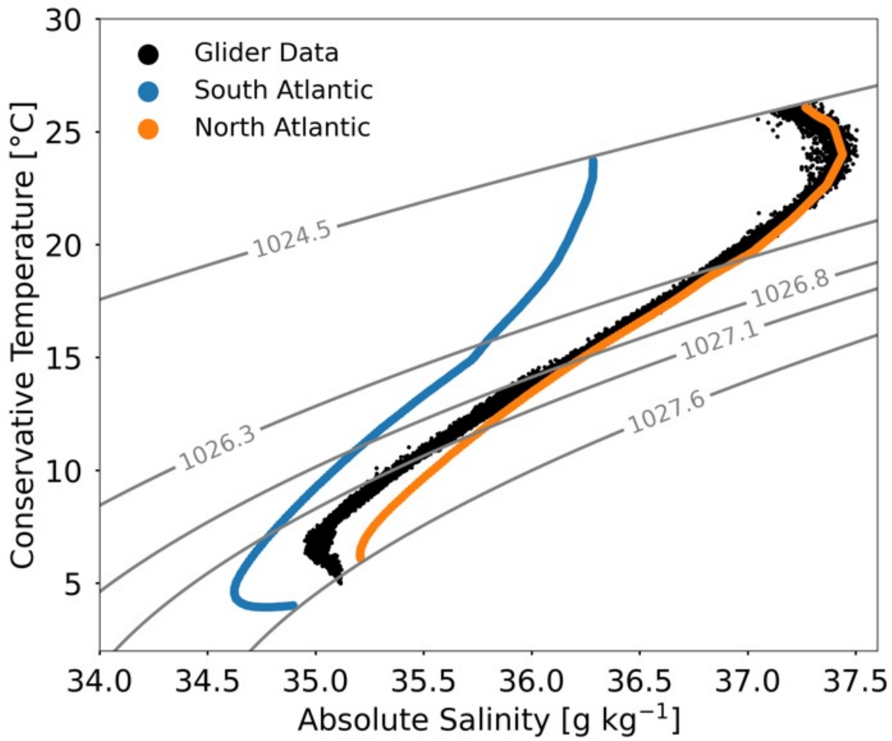
Office of Naval Research Science & Technology

Heat/salt flux of the Caribbean through-flow largely determined by its role as location where water masses from the North & South Atlantic mix

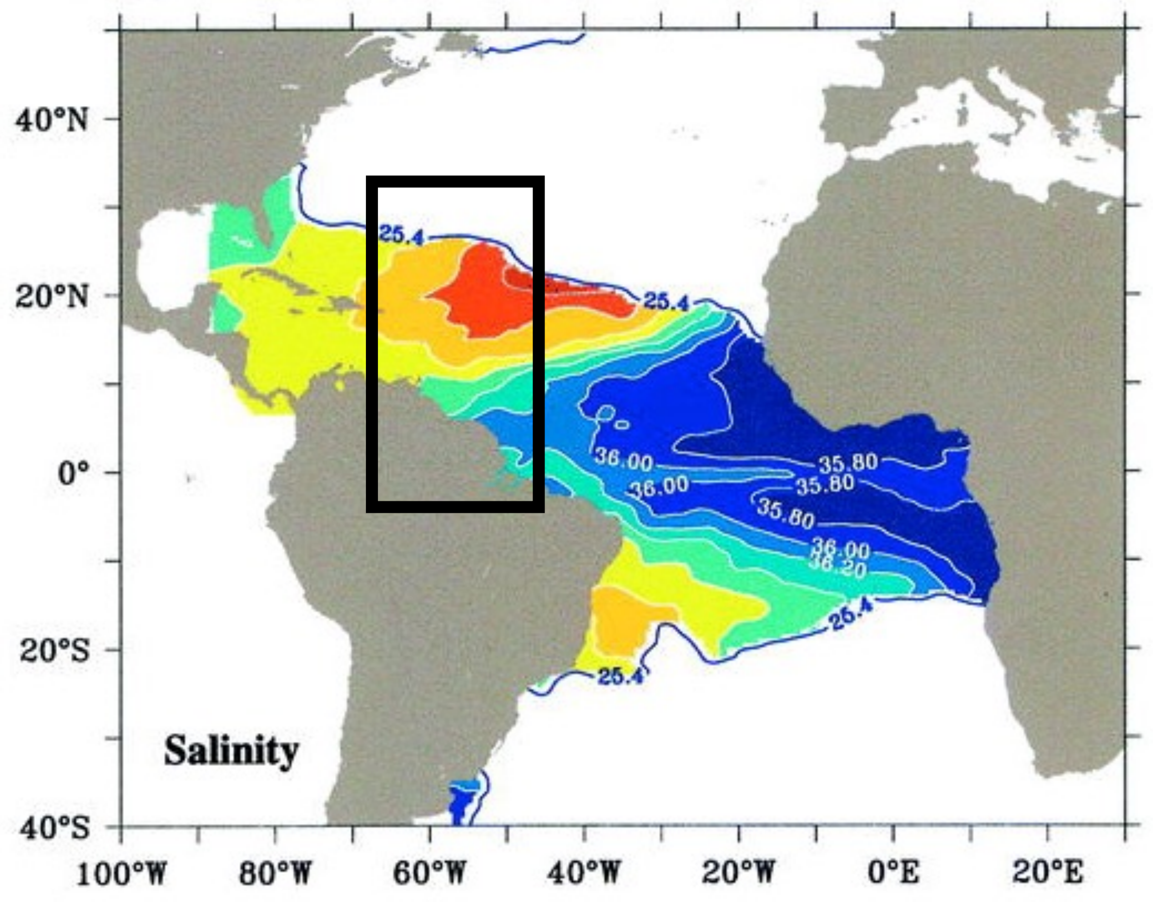
Generally

North Atlantic:
Warmer and Saltier

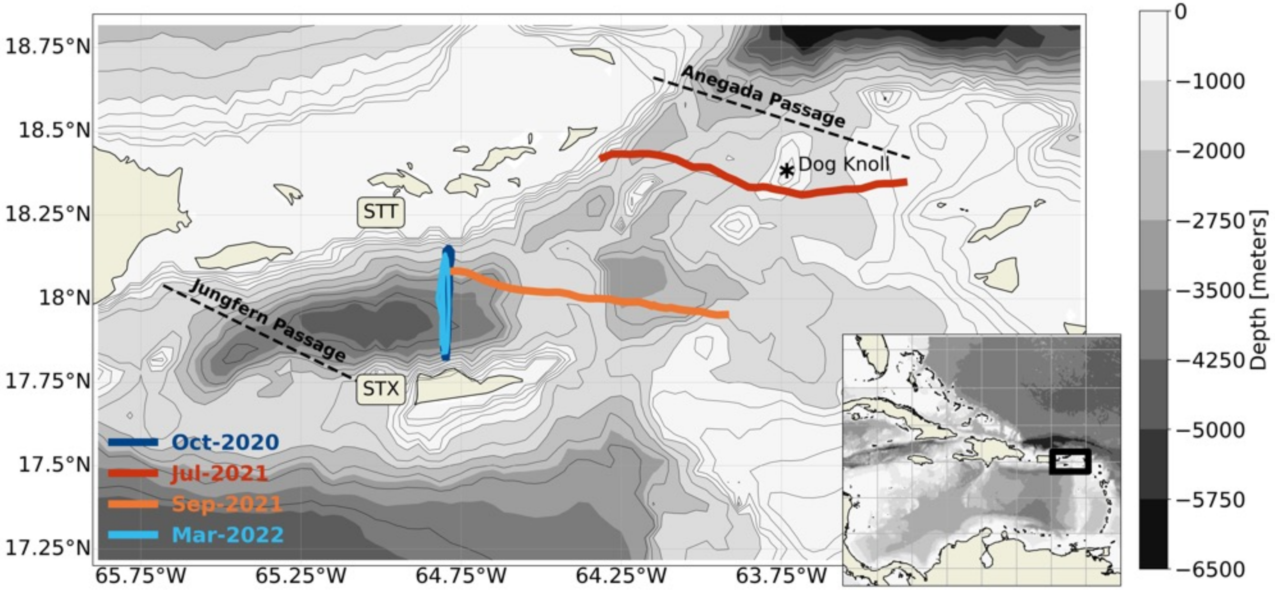
South Atlantic:
Colder and Fresher



Glider observations in passages spanning north to south, a large gradient in water mass properties



(Zhang et al. 2003)



Anegada Passage

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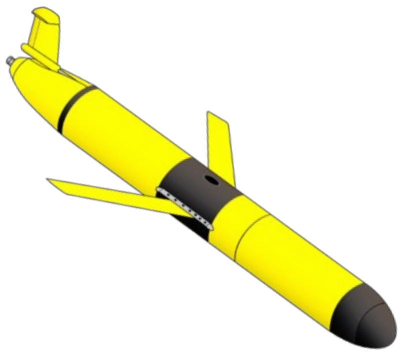

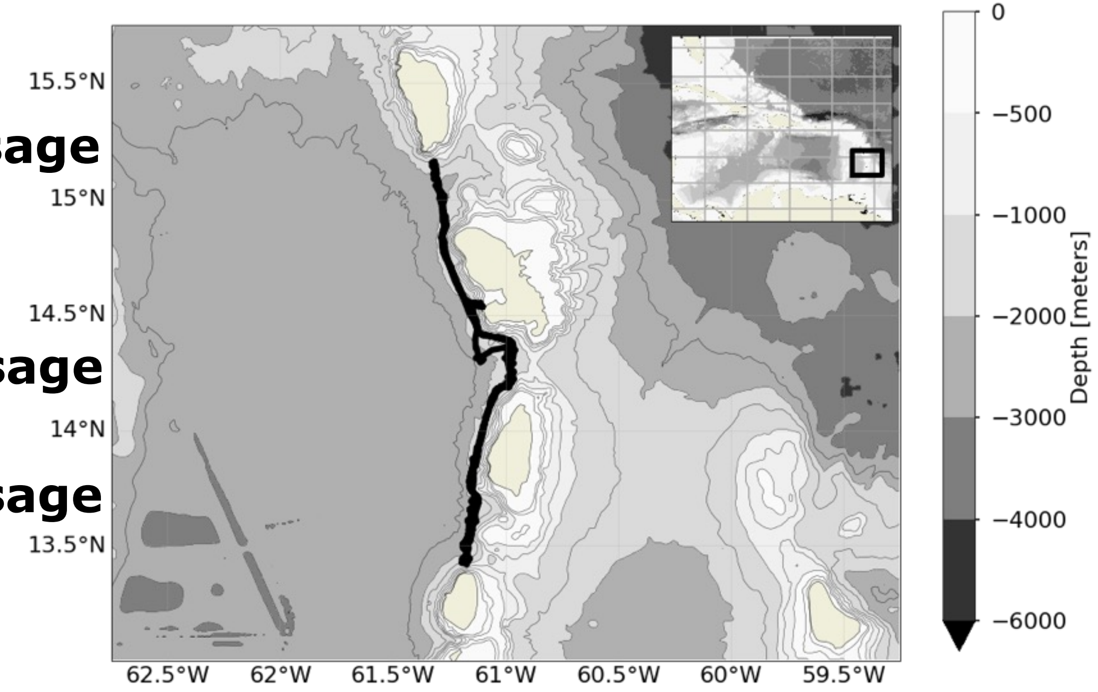

Dominica Passage

St. Lucia Passage

St. Vincent Passage

Glider observations in passages spanning **north to south**, a **large gradient in water mass properties**

Windward **I**sland **P**assage Monitoring **P**rogram (**WIPP**) 1991-2001

PERGAMON

Deep-Sea Research I 49 (2002) 211–243

DEEP-SEA RESEARCH PART I

www.elsevier.com/locate/dsr

On the Atlantic inflow to the Caribbean Sea

William E. Johns[a,*], Tamara L. Townsend[b], David M. Fratantoni[c], W. Douglas Wilson[d]

[a] Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA
[b] Naval Research Laboratory, Stennis Space Center, MS 39529, USA
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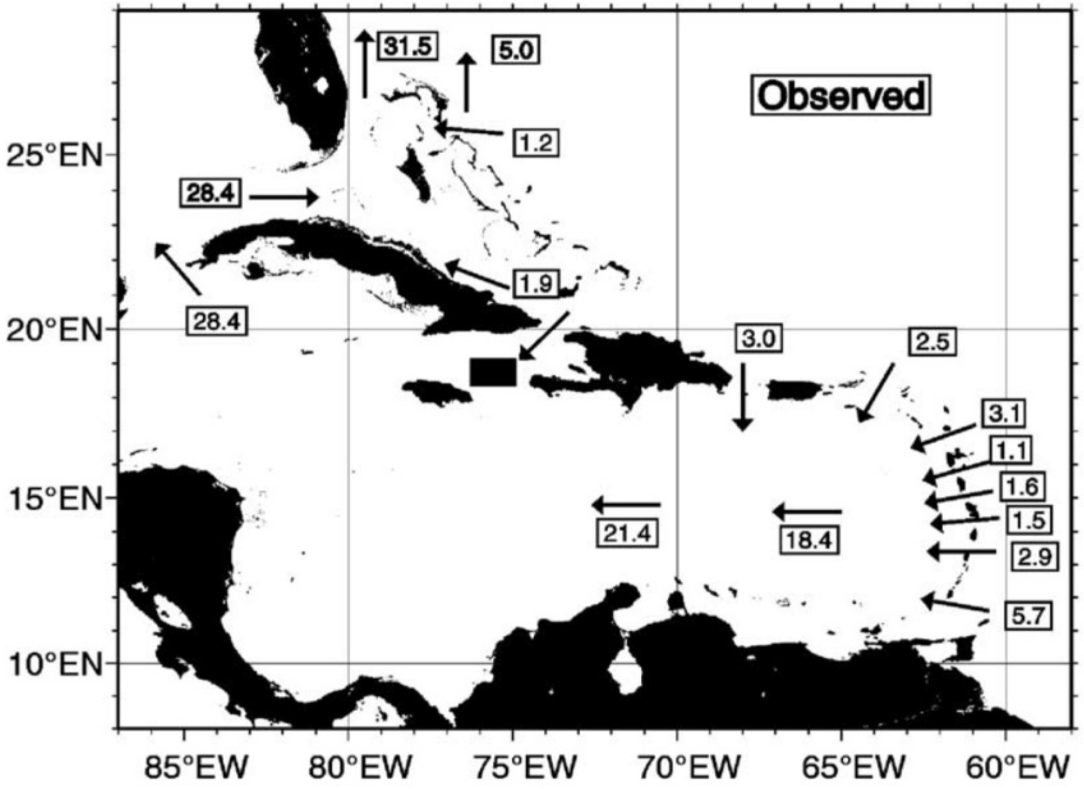
Received 26 September 2000; received in revised form 4 June 2001; accepted 4 June 2001

Table 1
Transport estimates derived from shipboard occupations of the Caribbean Passages, after Wilson and Johns (1997), updated with results from 5 additional cruises. Not all passages were sampled on each cruise. Average transports and related statistics from all available estimates for each passage are shown at the bottom. The quantity labeled "Mean" is the average transport from only those cruises with full water column directly velocity measurements (cruises 5 and later) the quantity labeled "Mean (all)" is the average of all cruises including early ones where part of the deep flow in the passages was determined geostrophically. The former is used for the final transport values in the paper, and the standard errors listed for each passage are also based on this data

Cruise		Passage							
		Grenada	St. Vincent	St. Lucia	Dominica	Guadeloupe	Antigua	Anegada	Mona
1	Dec 91	6.9	5.9	0.1					
2	May 92	0.1	2.0	0.5					
3	Sep 92		4.9	1.4	0.5				
4	Dec 92	2.6	2.2	2.2					
5	Jun 93	10.6	5.3	1.2					
6	Apr 94	2.6	−0.6						
7	Jul 94	5.8	5.2	2.0	−0.1	1.9	0.6	3.3	
8	Dec 94			−0.2					
9	Sep 95	5.4	2.8	3.2					
10	Mar 96	4.0	−0.1	0.8	1.8	1.1	4.4	3.5	3.4
11	Jul 96	5.6	3.4	3.4	1.1	0.6	3.3	2.2	1.7
12	Jun 97	4.6	3.7	4.6	2.5	−0.3	3.4	2.0	
13	Oct 98	6.7	3.2	−3.0	2.8	2.4	4.0	0.1	
Mean		5.7±2.4	2.9±2.2	1.5±2.4	1.6±1.2	1.1±1.1	3.1±1.5	2.5±1.4	2.6±1.2
Mean (all)		5.0±2.8	3.2±2.1	1.4±2.0	1.4±1.1	1.1±1.1	3.1±1.5	2.5±1.4	2.6±1.2
Std. error		0.8	0.8	0.8	0.5	0.5	0.7	0.6	1.2
		Windward Islands 10.1±2.4			Leeward Islands 8.3±2.3				
		Lesser Antilles 18.4±4.7							

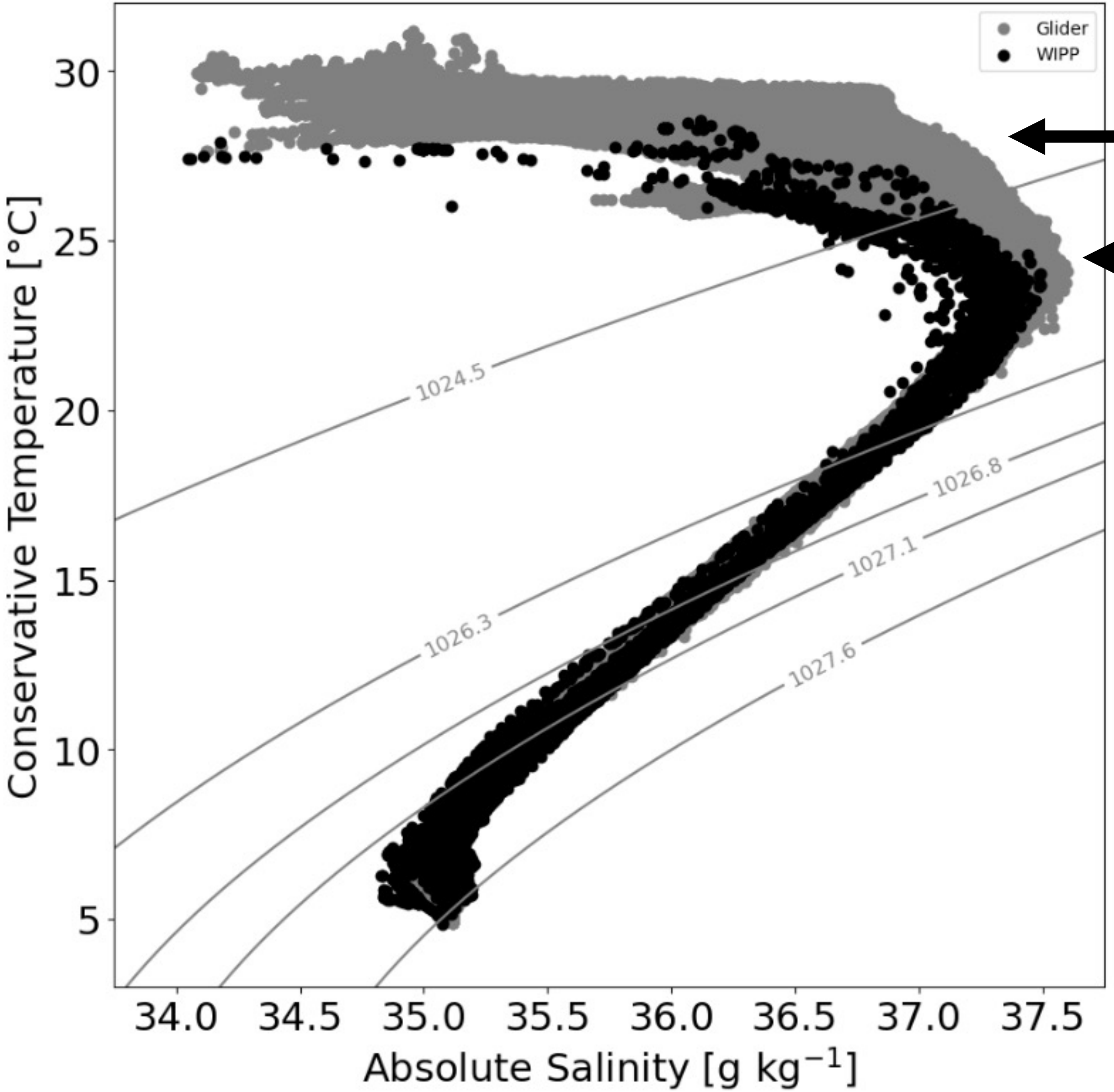


Observations of Change

Glider (2020-2023)

versus

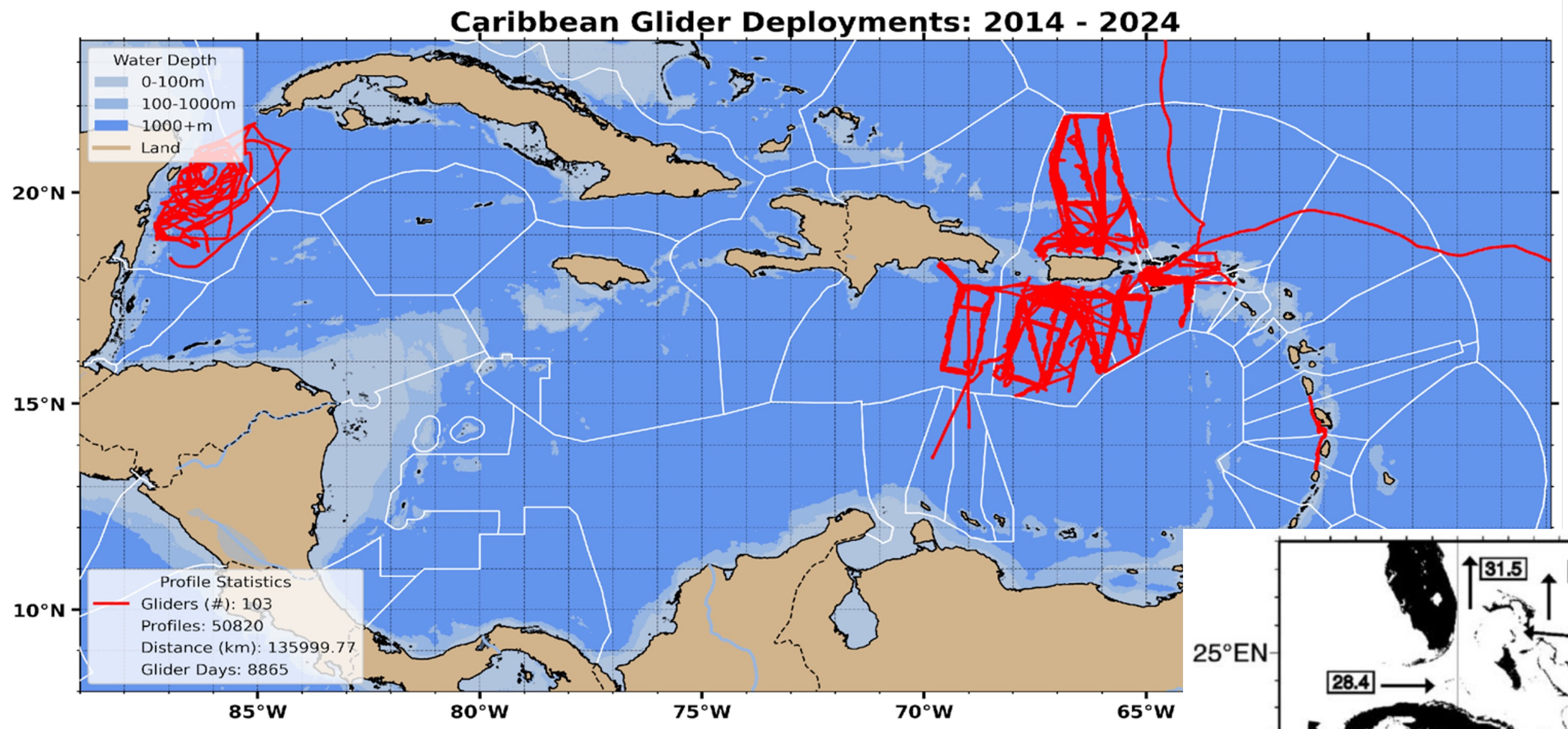
Windward **I**sland **P**assage Monitoring **P**rogram
(**WIPP**)
(1991-2001)

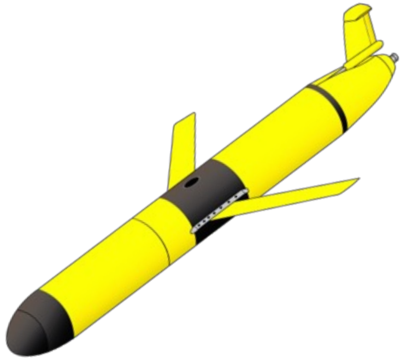


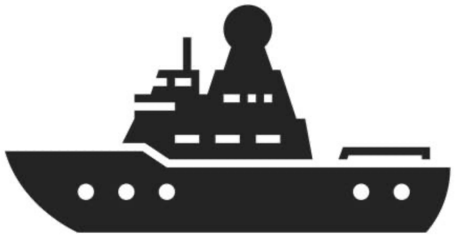
Upper ocean warming

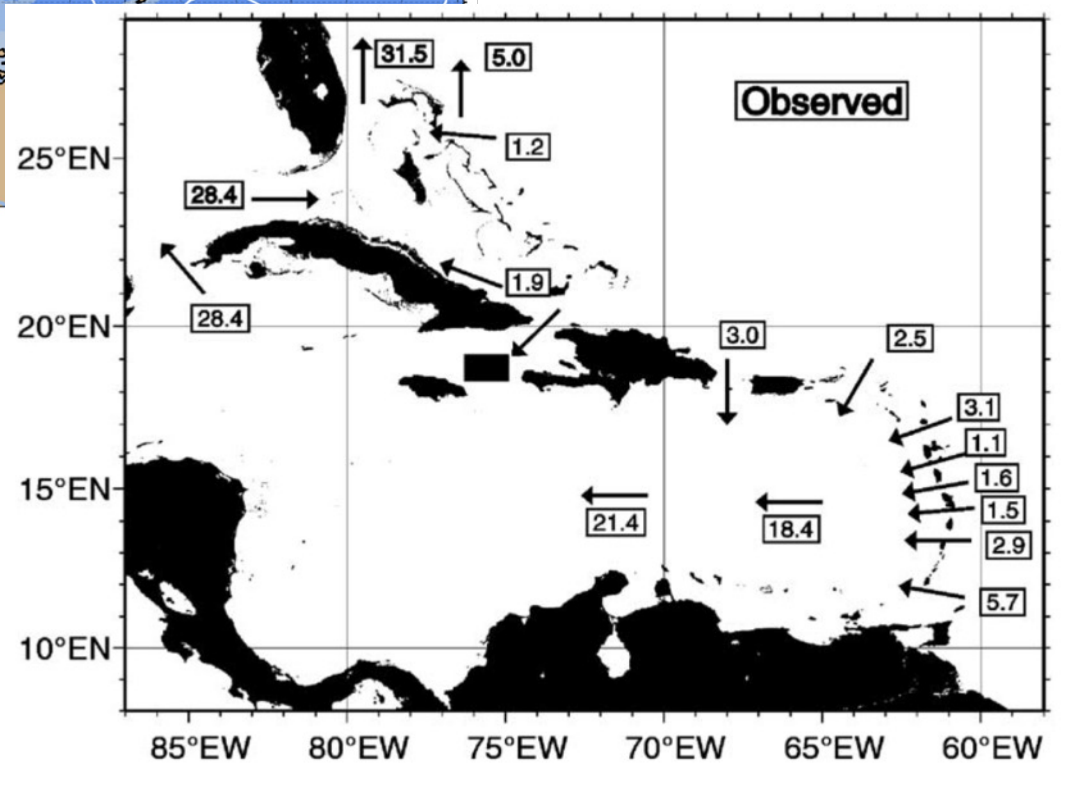
Salinification of Salinity Max Waters

- Limited deployments
- End-members/no ability to determine trends
- Does not capture bulk of Caribbean Through-Flow

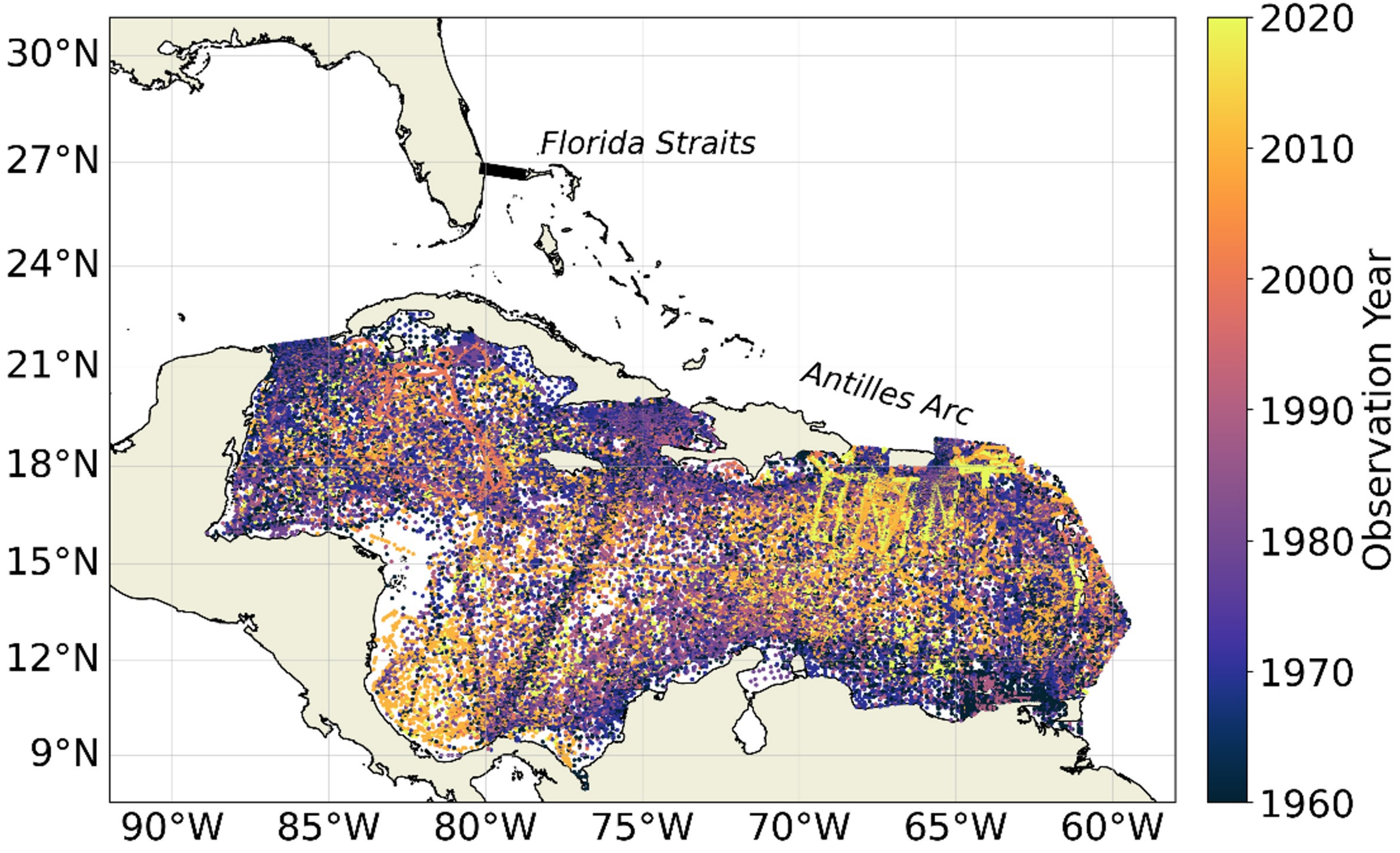

Caribbean Glider Deployments: 2014 - 2024
Water Depth
0-100m
100-1000m
1000+m
Land
Profile Statistics
Gliders (#): 103
Profiles: 50820
Distance (km): 135999.77
Glider Days: 8865
20°N
15°N
10°N
85°W
80°W
75°W
70°W
65°W






Observed
31.5
5.0
1.2
28.4
28.4
1.9
3.0
2.5
3.1
1.1
1.6
1.5
2.9
5.7
21.4
18.4
25°EN
20°EN
15°EN
10°EN
85°EW
80°EW
75°EW
70°EW
65°EW
60°EW

Leveraging glider data + all other T/S profiles in the Caribbean Through-Flow



Comprehensive Water Mass Analysis

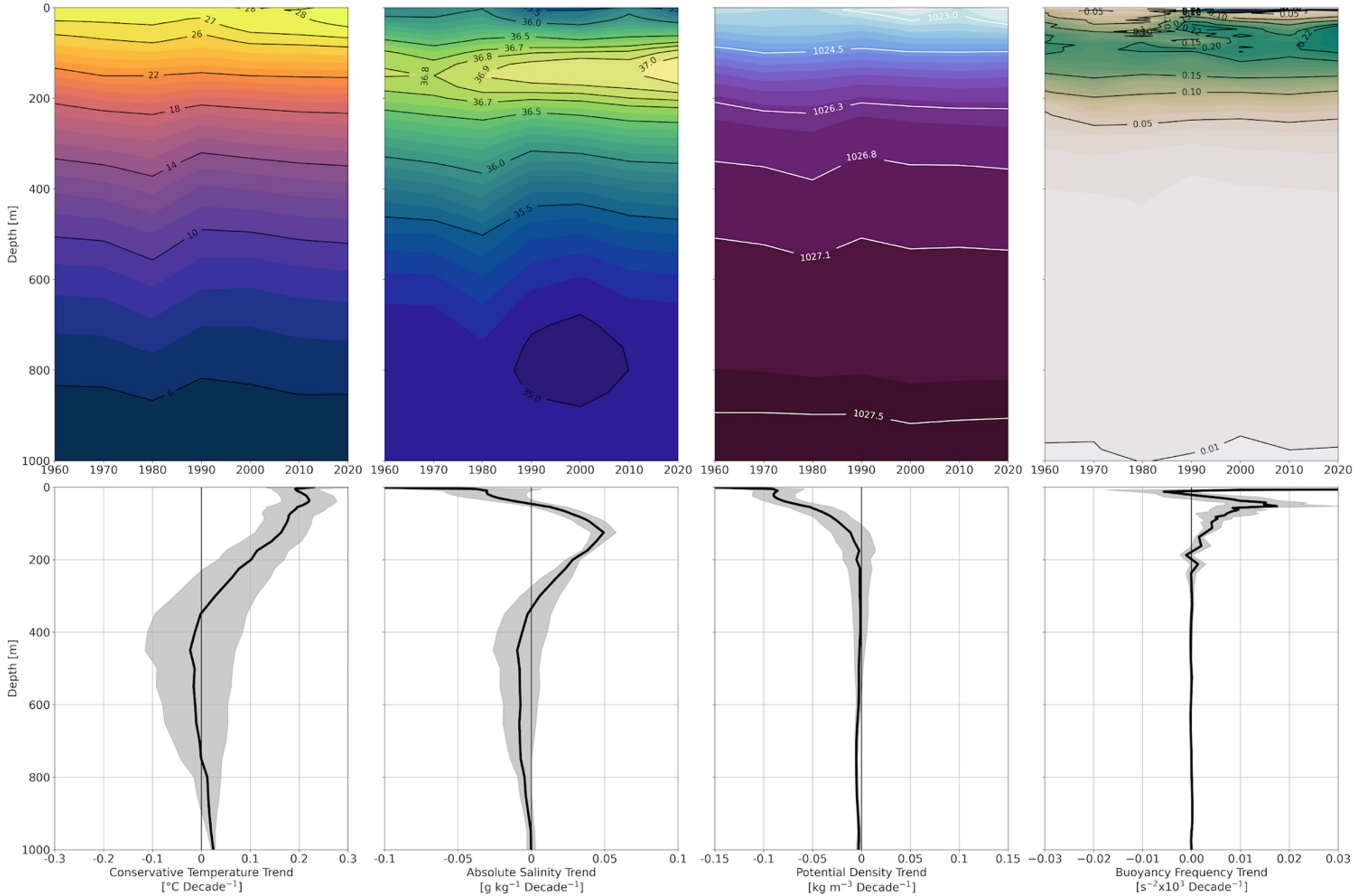
<u>EN4 Database</u>

>28,000 profiles

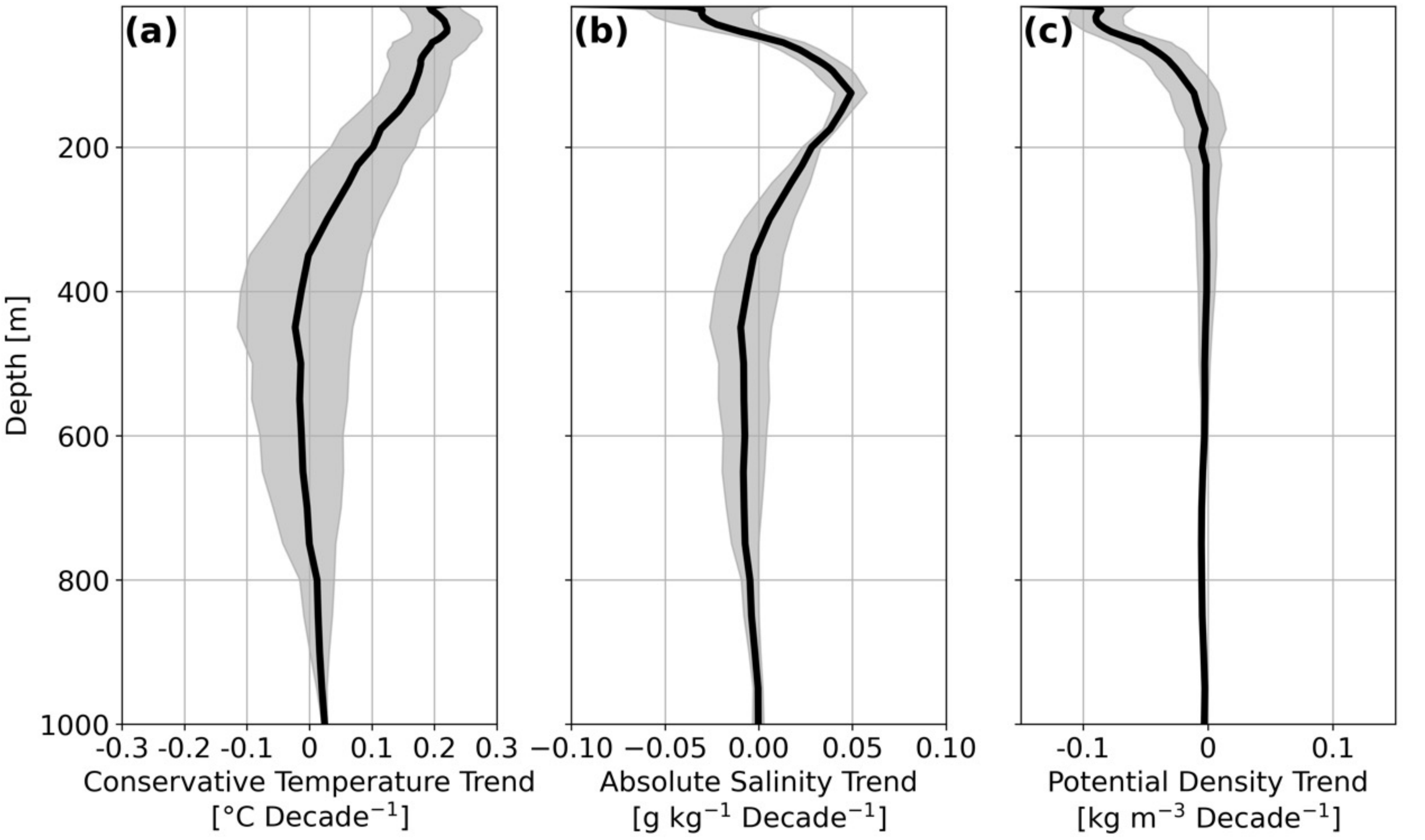
Gradone et al. In Review: *Nature Comms. Earth & Environ.*

Observations of water mass changes

1. **Warming ~0.2°C decade^{-1}**
2. **Surface freshening ~0.13 g kg^{-1} decade^{-1}**
3. **Subsurface salinification ~0.05 g kg^{-1} decade^{-1}**
4. **Surface density reduction ~0.17 kg m^{-3} decade^{-1}**
5. **Increased stratification 20x global trends**



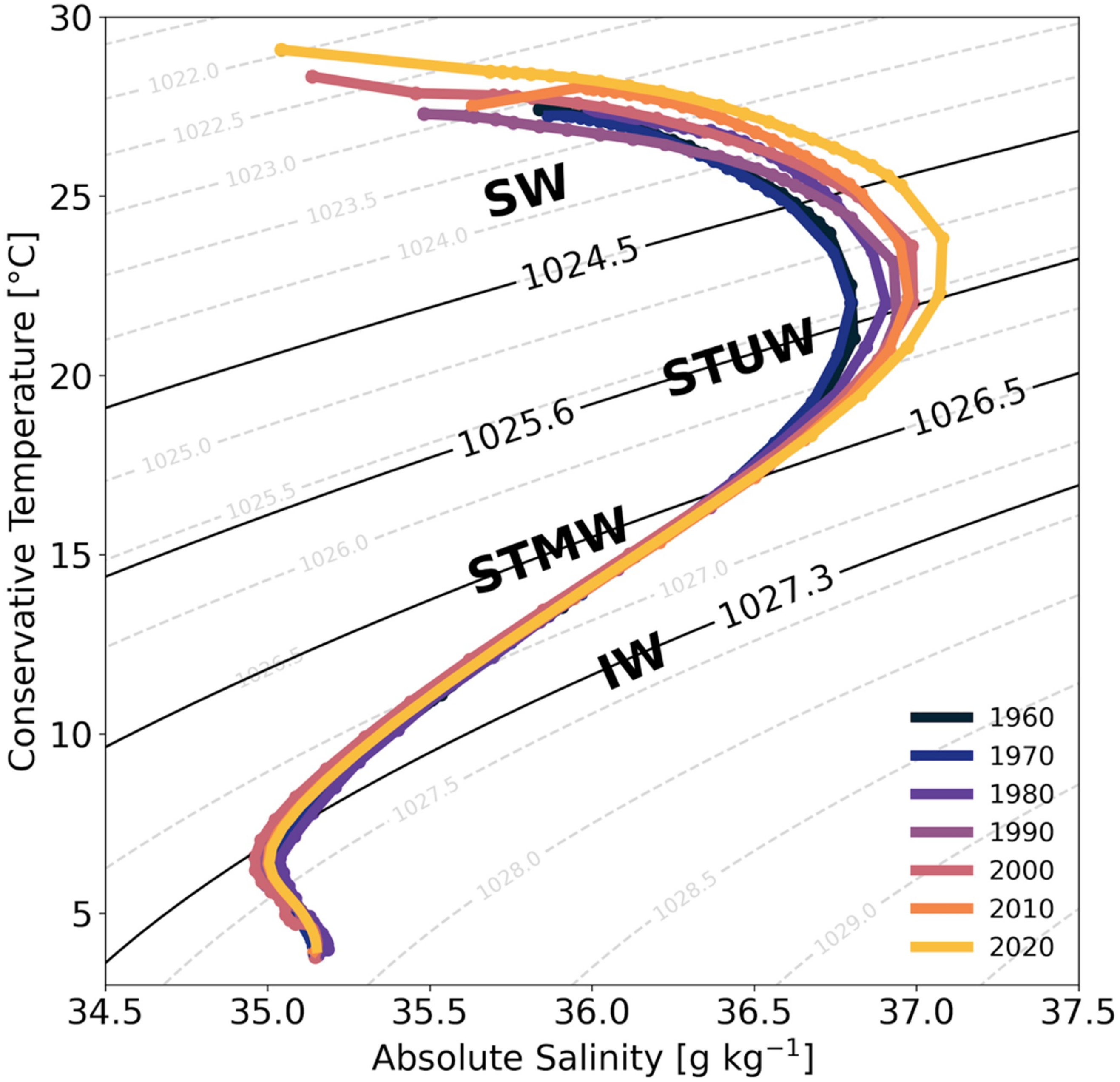
Gradone et al.
In Review: *Nature Comms. Earth & Environ.*



<u>Gulf Stream Trends in upper 250 m:</u>
(Todd and Ren 2023)

0.5-0.7°C decade^{-1} 0.1 g kg^{-1} decade^{-1} 0.1 kg m^{-3} decade^{-1}

Gradone et al. In Review: *Nature Comms. Earth & Environ.*

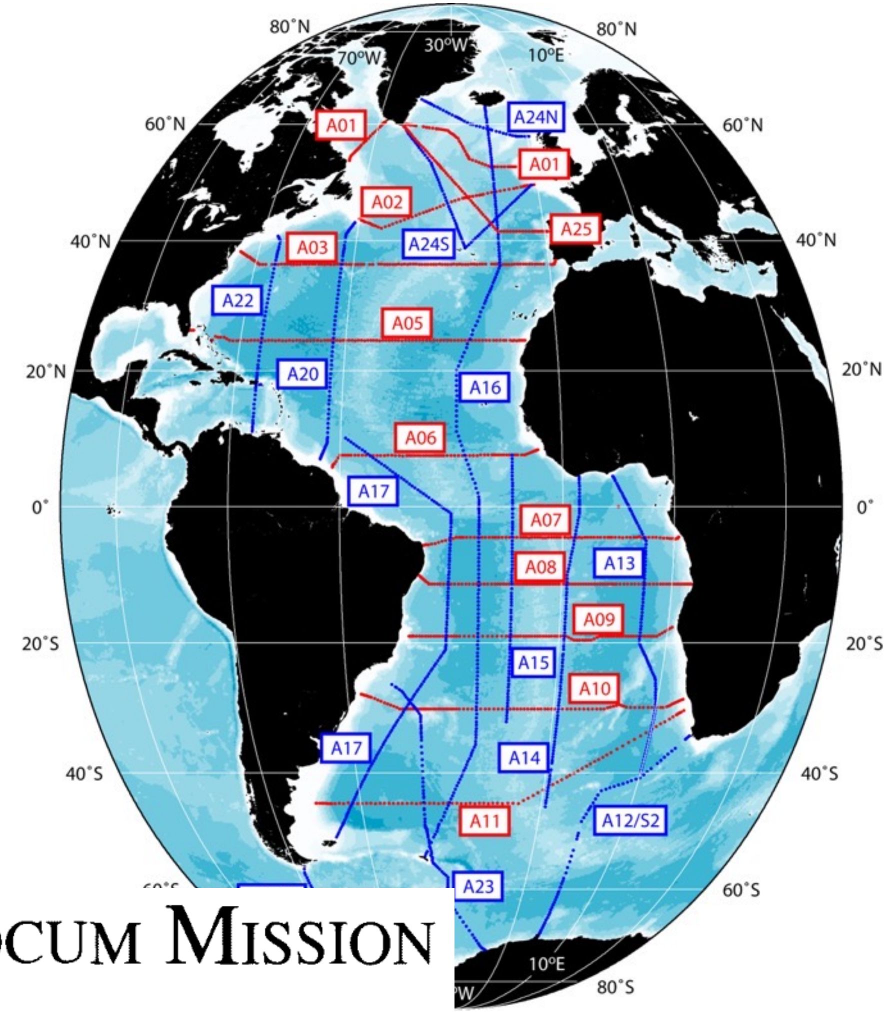


<u>Implications for:</u>

1. Sea-level rise
2. Tropical cyclone activity
3. Biodiversity
4. Downstream water mass formation

Gradone et al. In Review: *Nature Comms. Earth & Environ.*

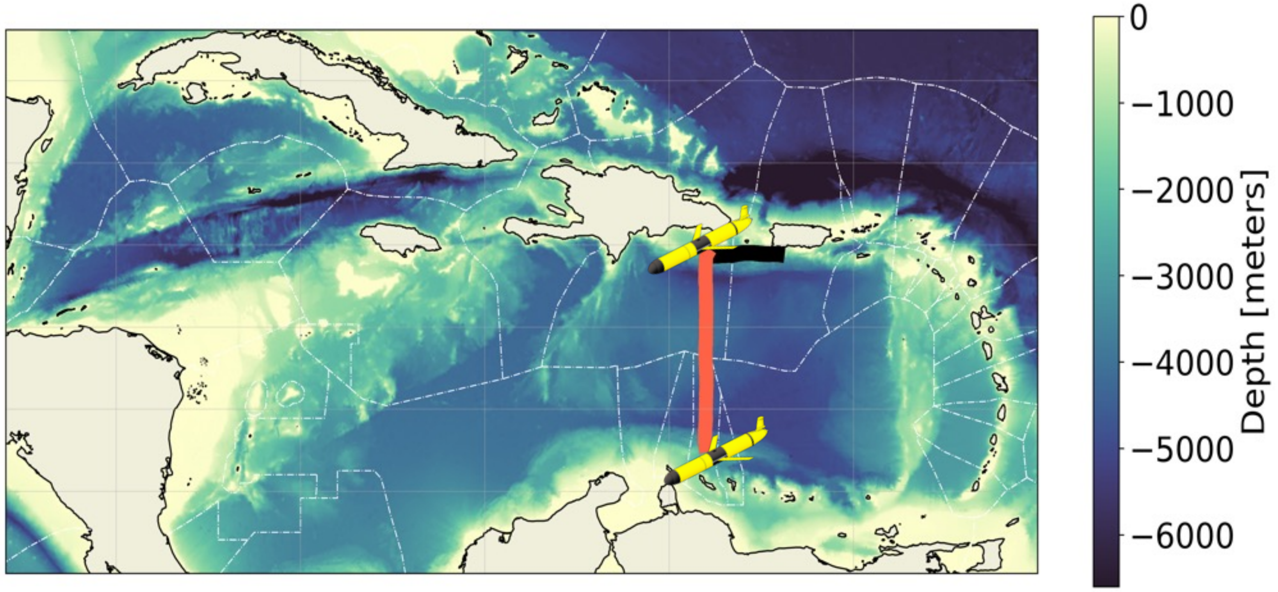
Climate Line Monitoring with Next Generation Gliders

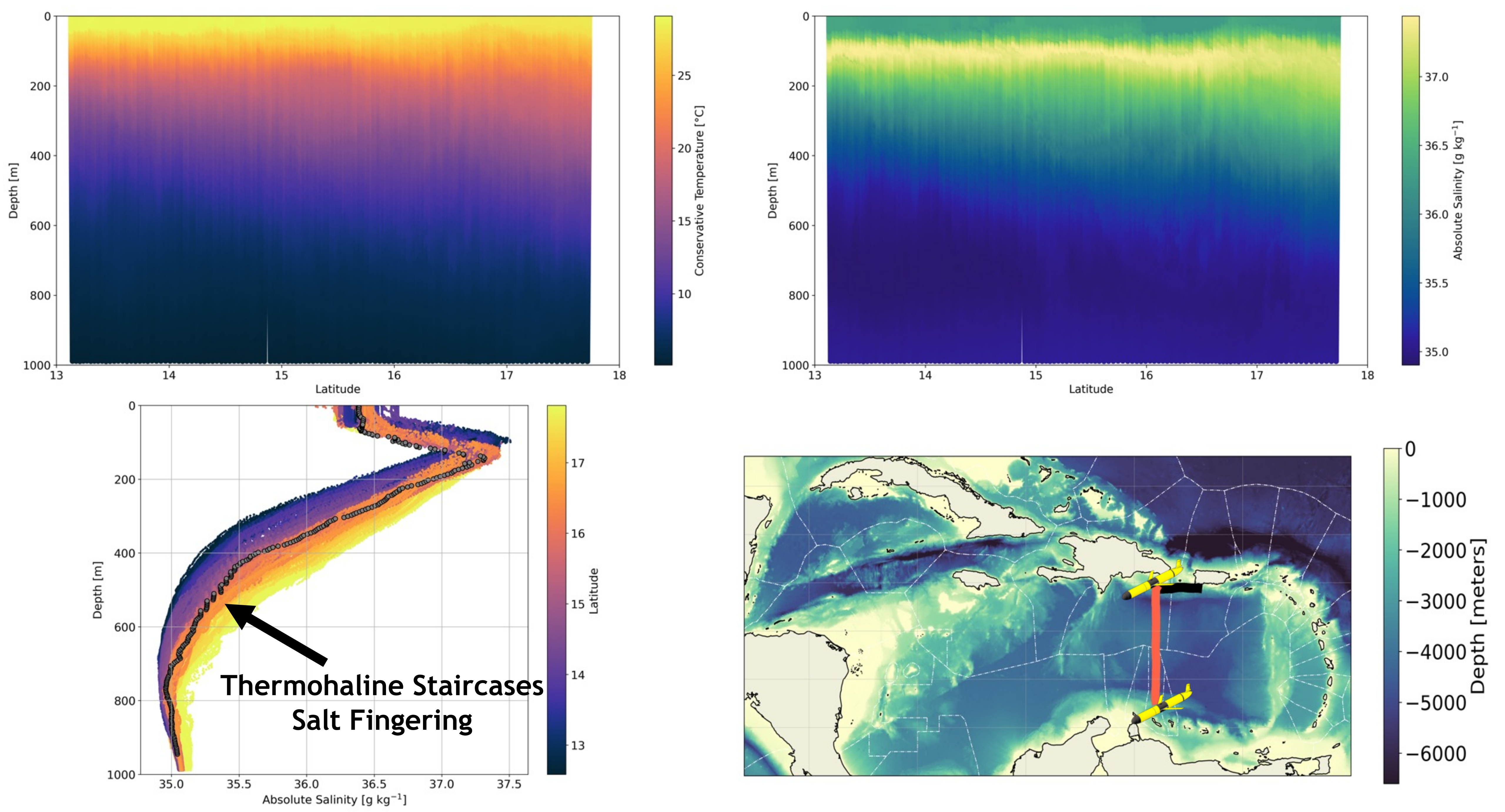


THE SLOCUM MISSION

Narrative and Illustration
By Henry Stommel

ABC2DR Pilot Climate Line




Depth [m]
Latitude
Conservative Temperature [°C]
Absolute Salinity [g kg^{-1}]
Thermohaline Staircases
Salt Fingering
Depth [meters]
0
200
400
600
800
1000
13
14
15
16
17
18
25
20
15
10
37.0
36.5
36.0
35.5
35.0
35.0
35.5
36.0
36.5
37.0
37.5
0
−1000
−2000
−3000
−4000
−5000
−6000

Acknowledgements

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Laurine Polinice (Agoa)

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Yair Rosenthal
Patty Gillen
Donna Napoli
Lucy Lettini

Dave Aragon
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Brian Buckingham
Jess Leonard
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Julia Engdahl
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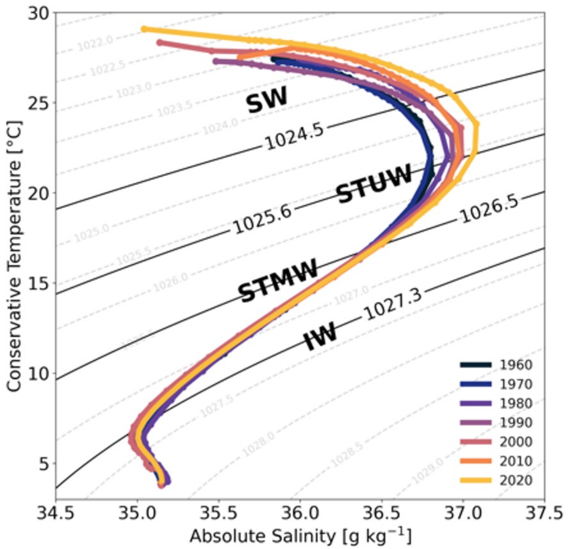
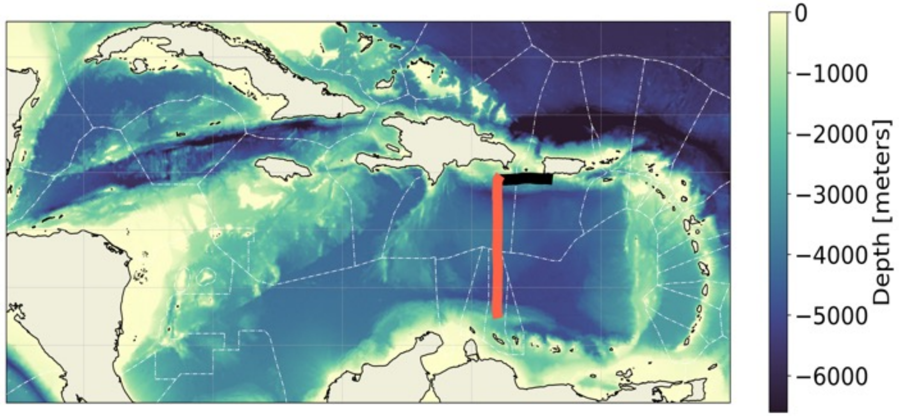
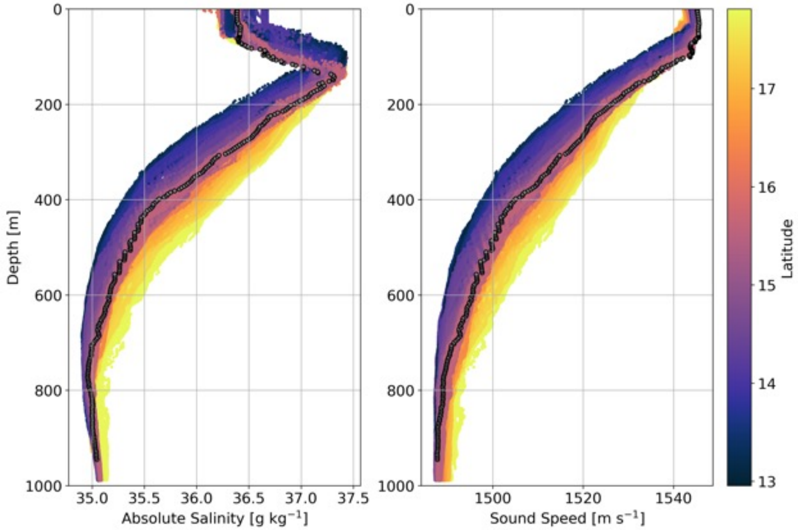
Summary

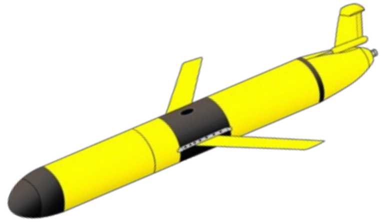






1. **Improving methods for measuring island passage transport**

2. **Caribbean Through-Flow**
   1. **Changes in water mass properties**
   2. **Water mass modification processes**



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