On the Dynamics of Caribbean Through-Flow Water Mass Transport

Joe Gradone

PhD Dissertation Defense

Committee: Travis Miles (advisor), Scott Glenn, Rebecca Jackson, Jaime Palter (URI)

Photo Credit: Dan Mele

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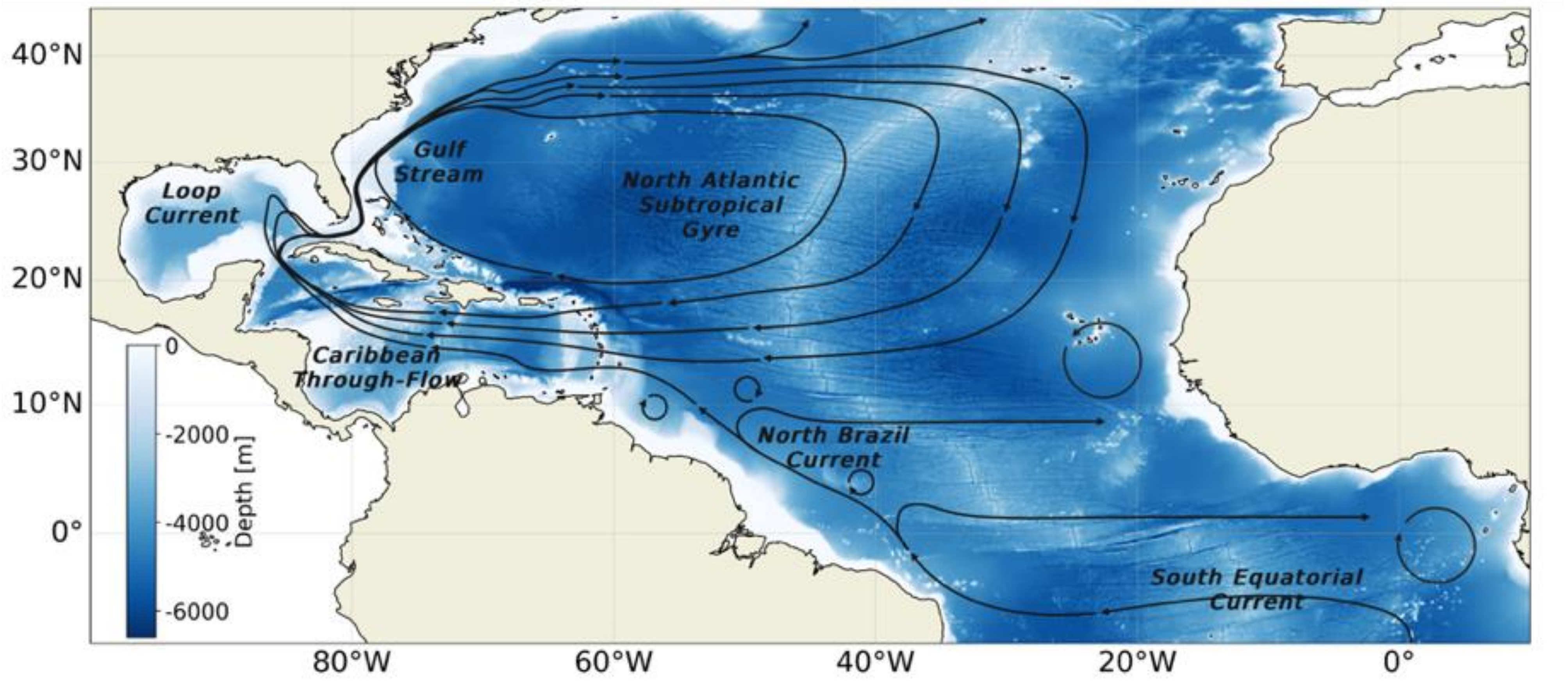
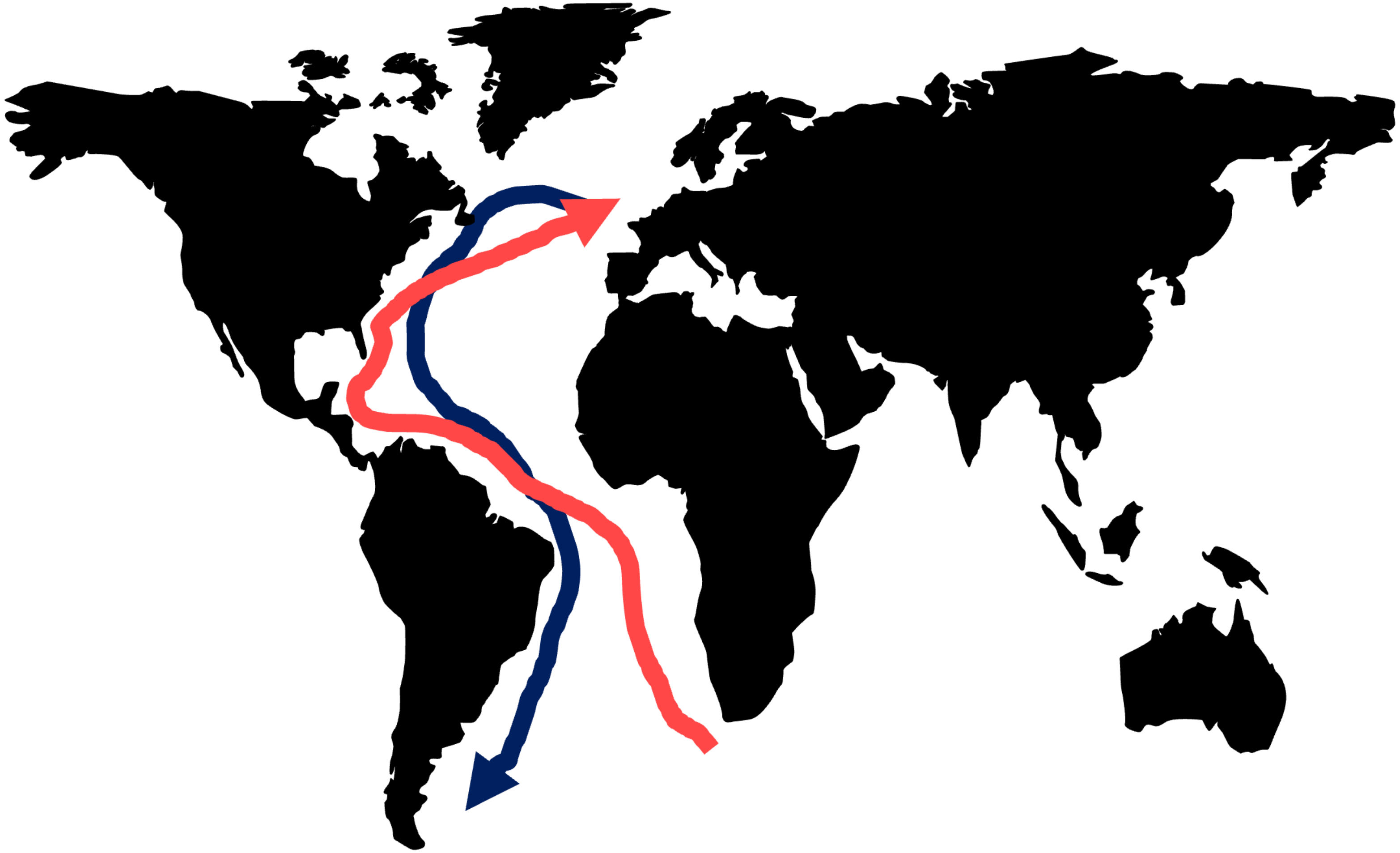
Caribbean Through-Flow is a **chokepoint** for **both** AMOC return flow and subtropical gyre recirculation

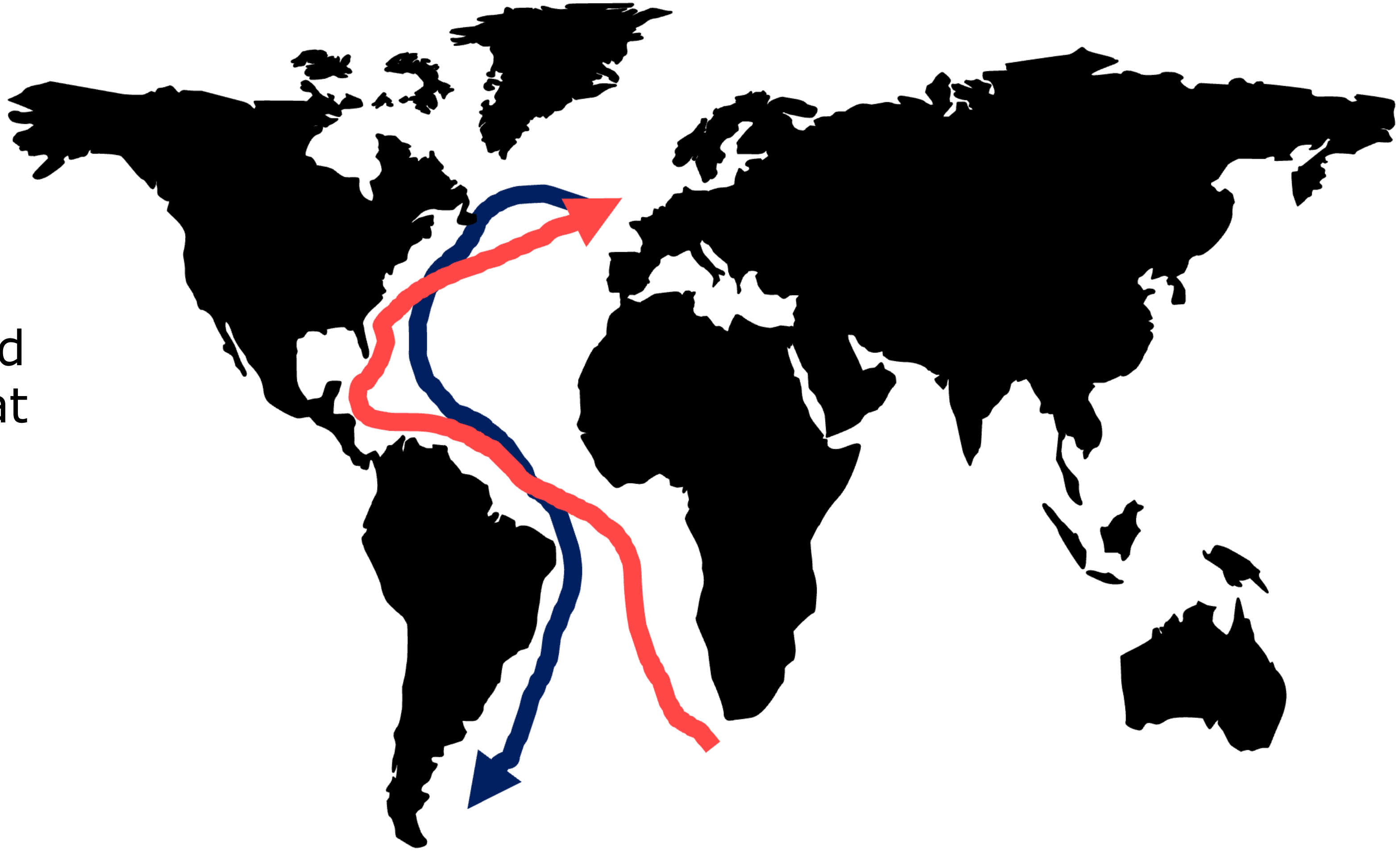


Atlantic **M**eridional **O**verturning **C**irculation



Why is the AMOC important?

Heat Transport:
~25% of the northern hemisphere’s northward atmospheric-ocean heat transport



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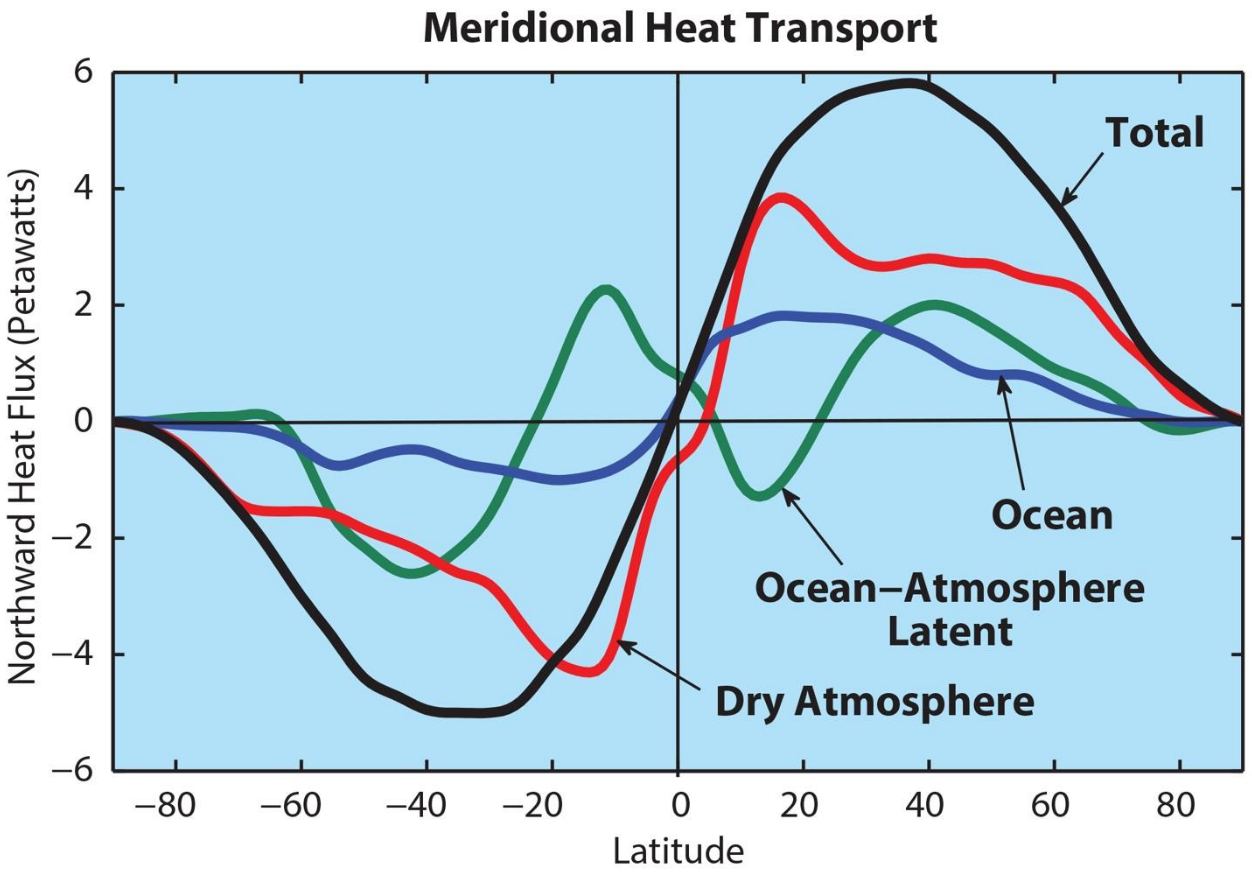
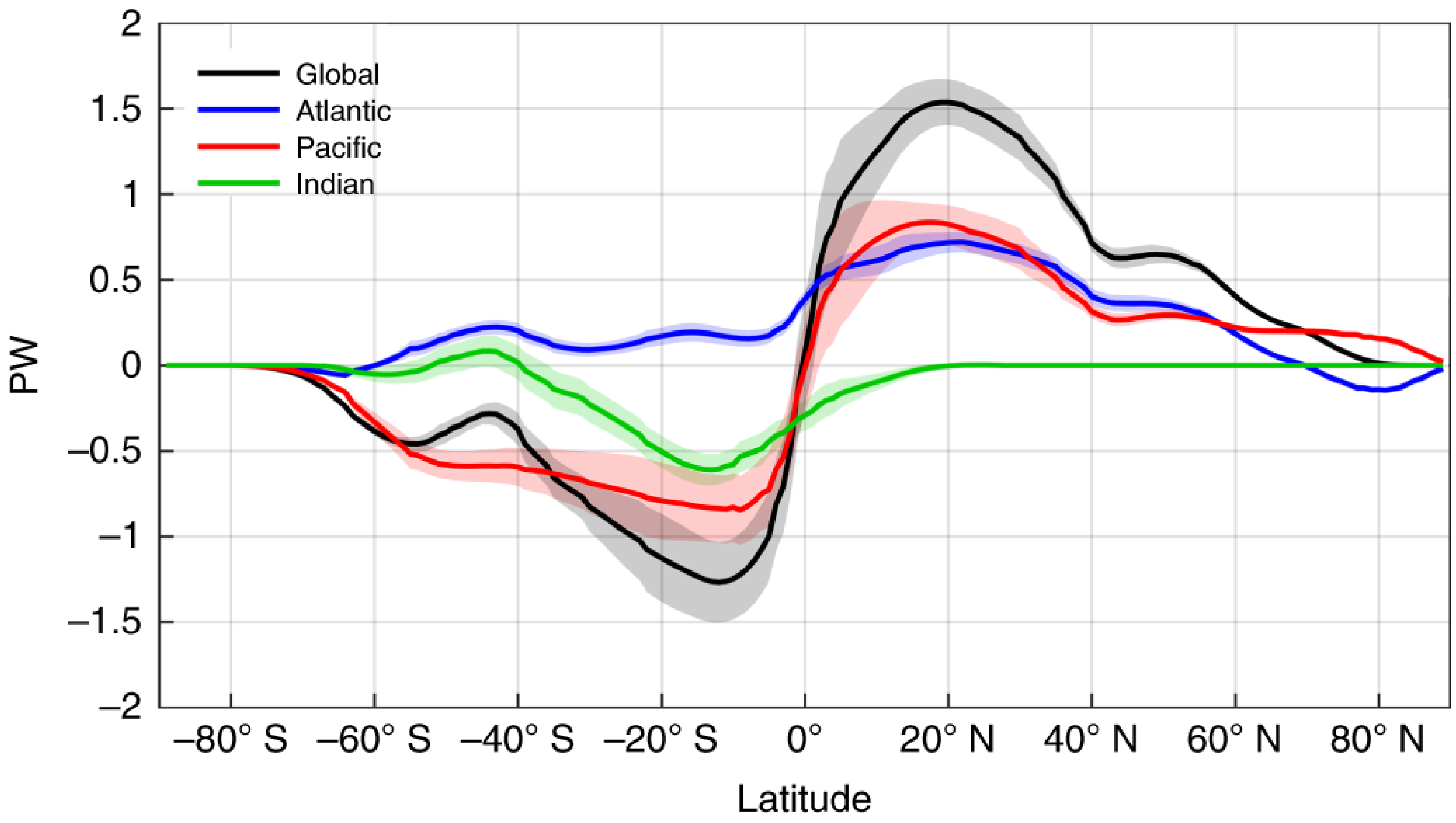


Schmitt (2018)

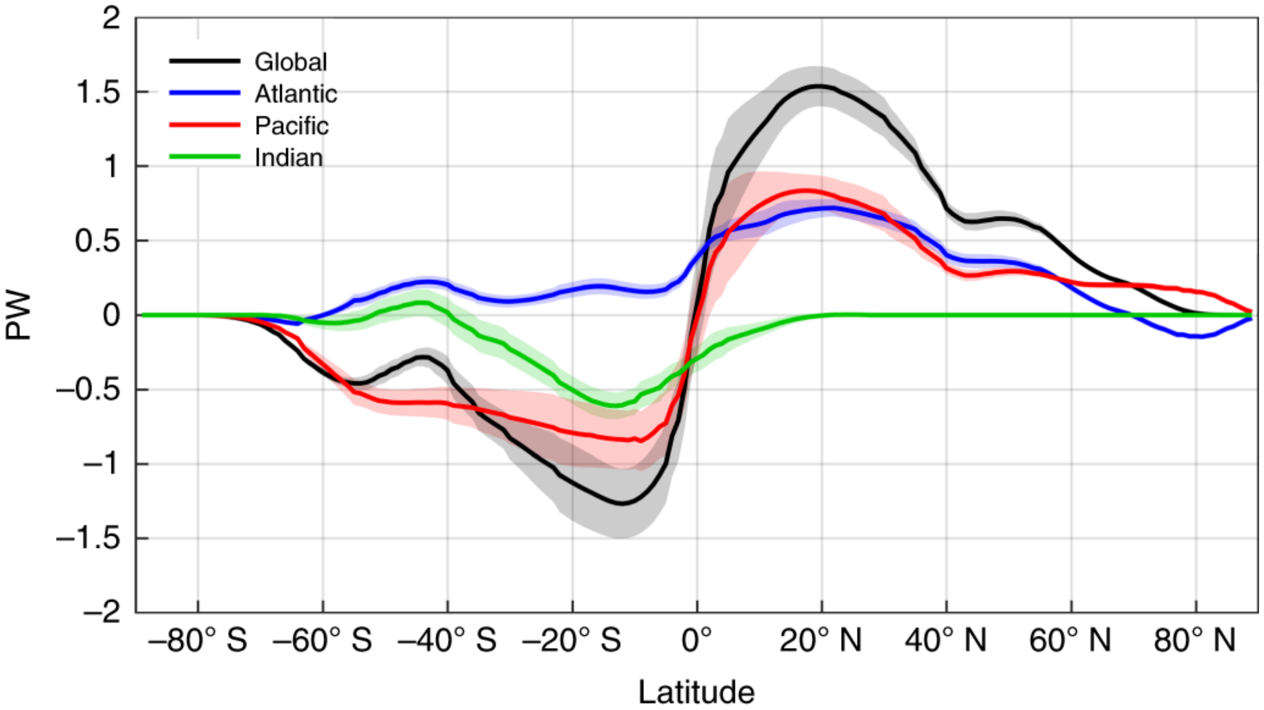
Why is the AMOC important?

Heat Transport:
Ocean heat transport is always positive in the Atlantic!



Forget and Ferreira (2019)

Why is the AMOC important?



14 MW

$$1\,Watt = 1\,\frac{Joule}{second}$$

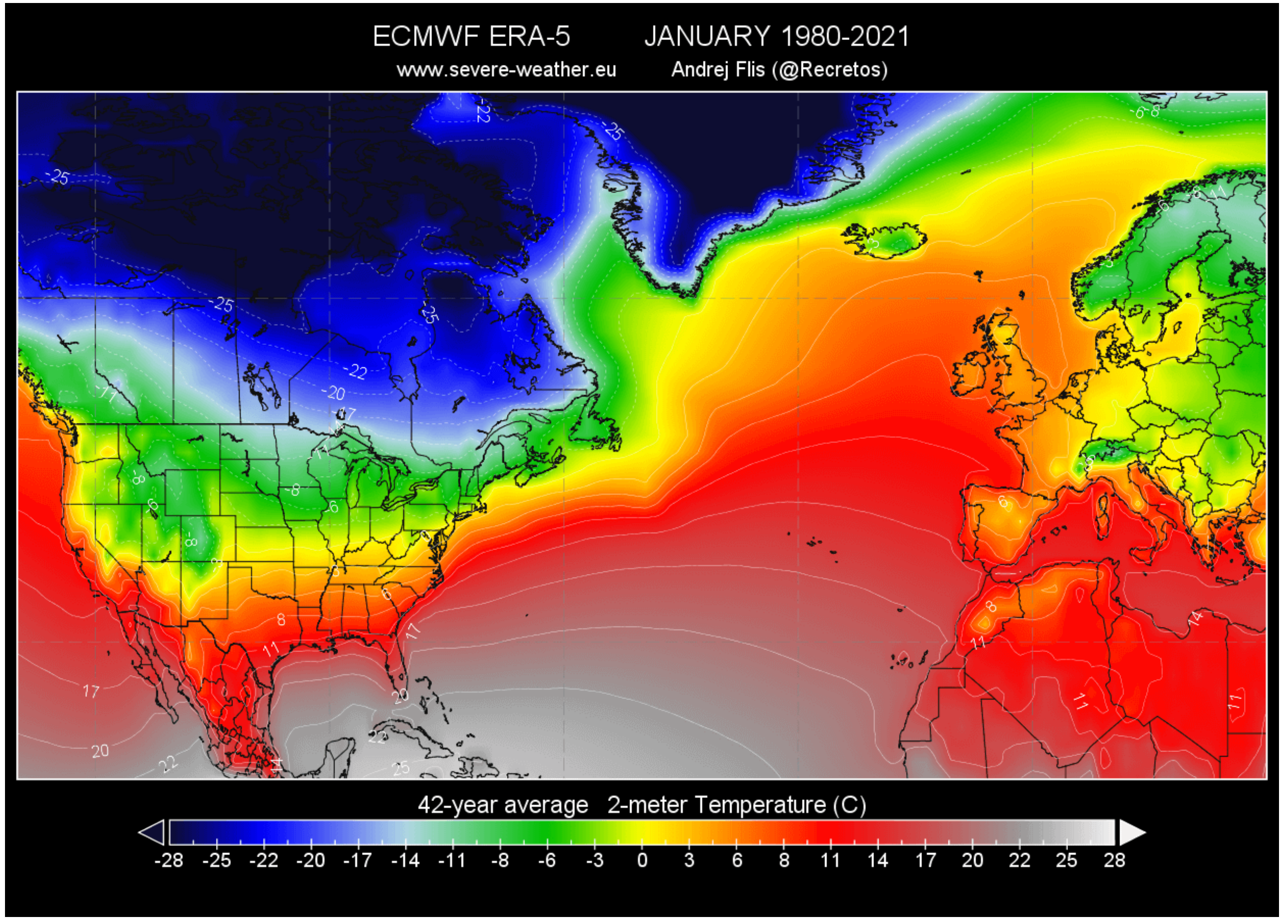
Equivalent to **~90 million** of world's largest wind turbines

Claudine Hellmuth/POLITICO (graphic); iStock (images)

Forget and Ferreira (2019)

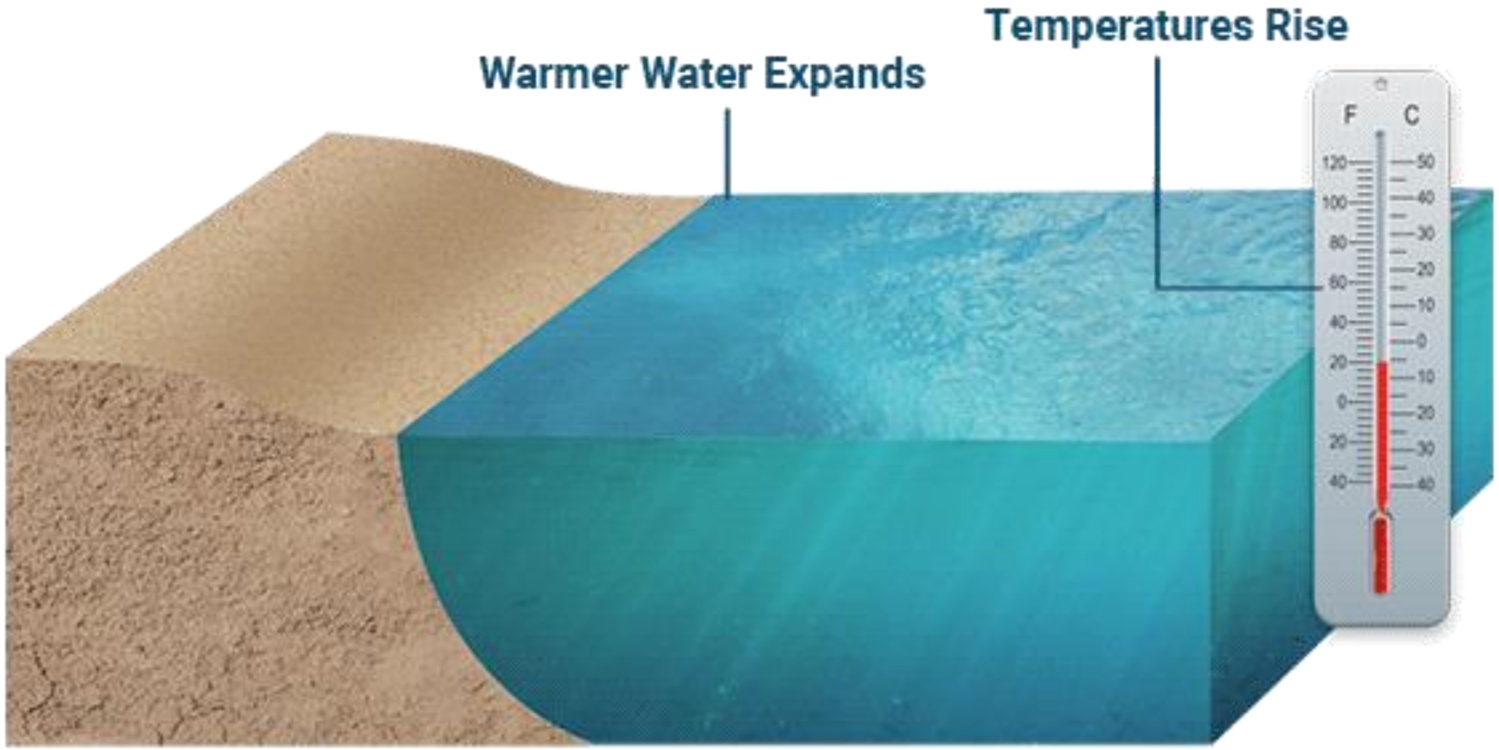
Why is **heat transport** important?

Climate



Why is **heat transport** important?

Sea Level
Rise

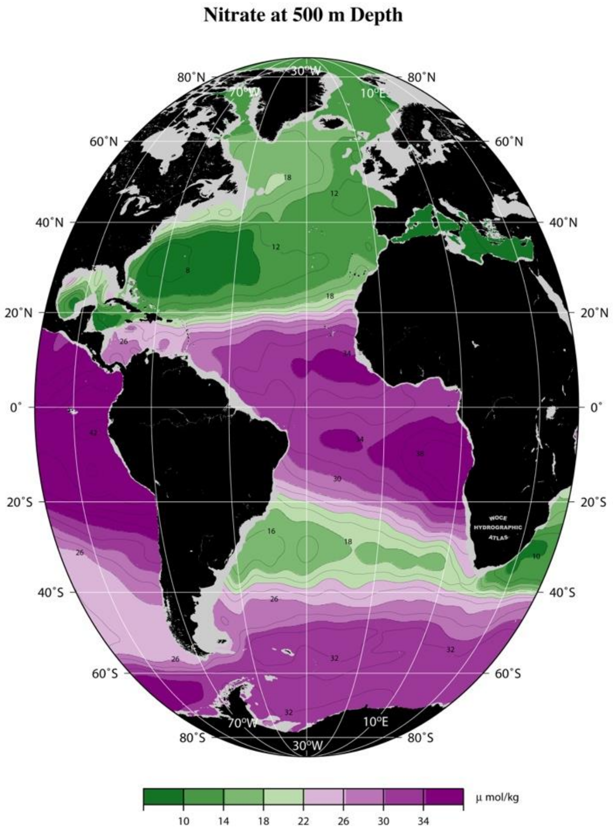


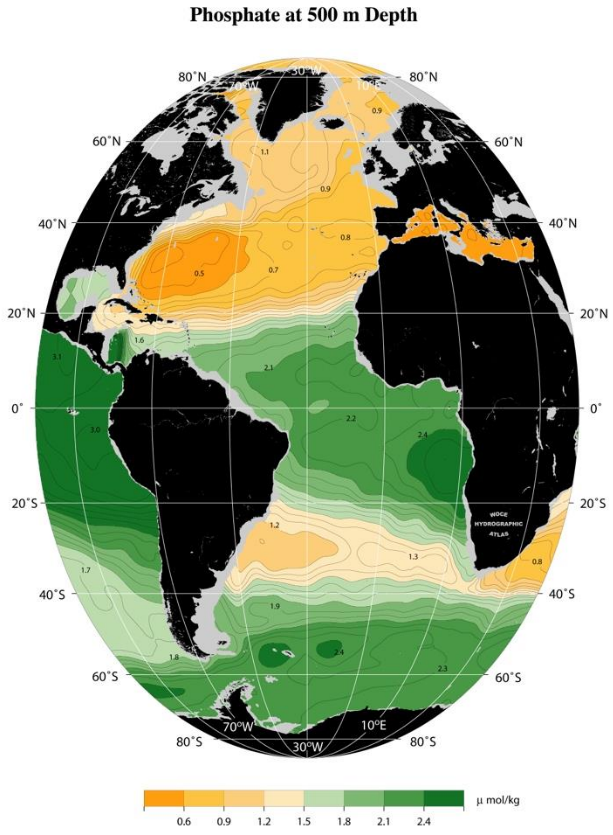
https://climateyou.org/

Why is **heat transport** important?

Marine Ecosystems

Changes in water mass pathways impact regional and global **nutrient delivery**

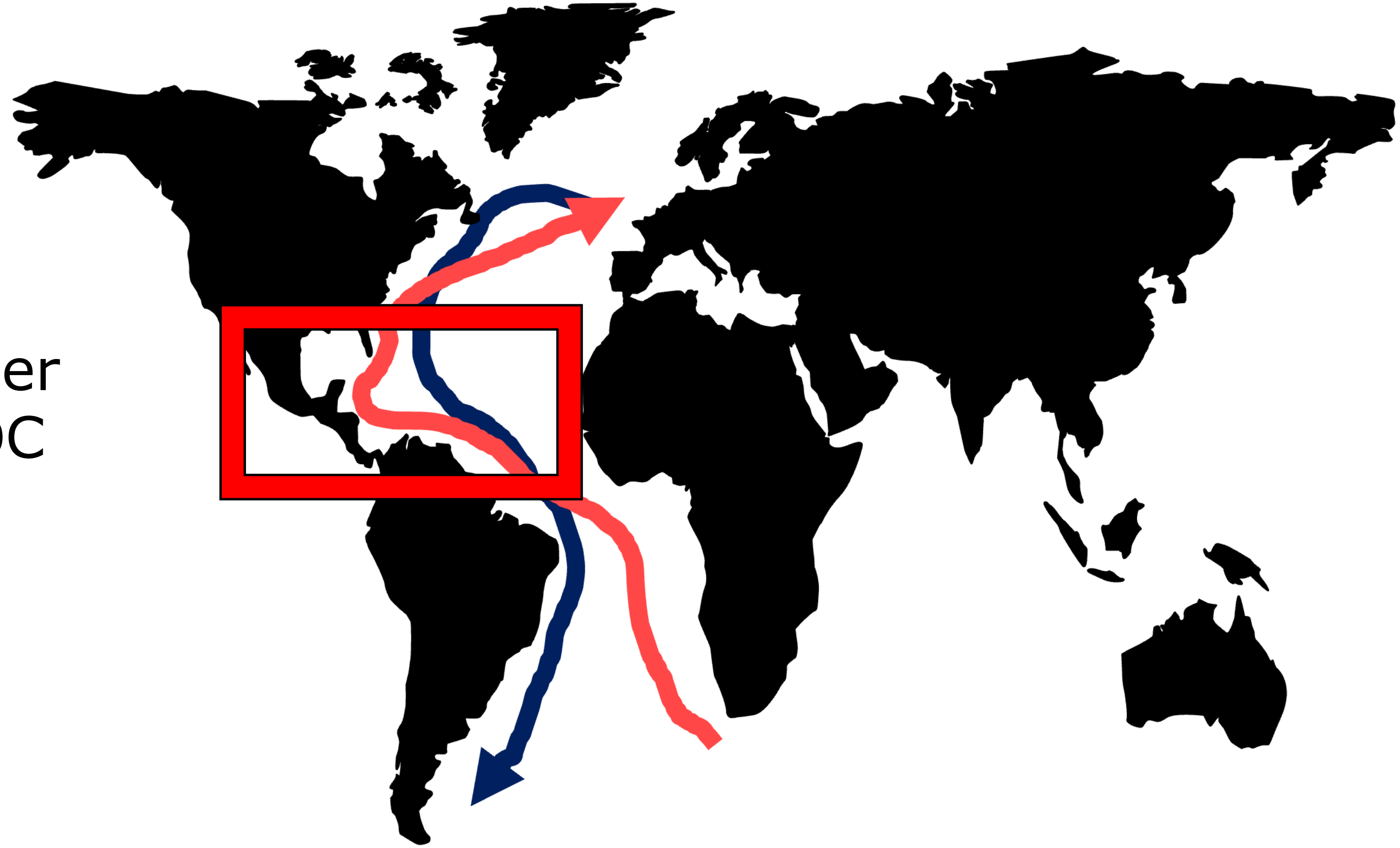


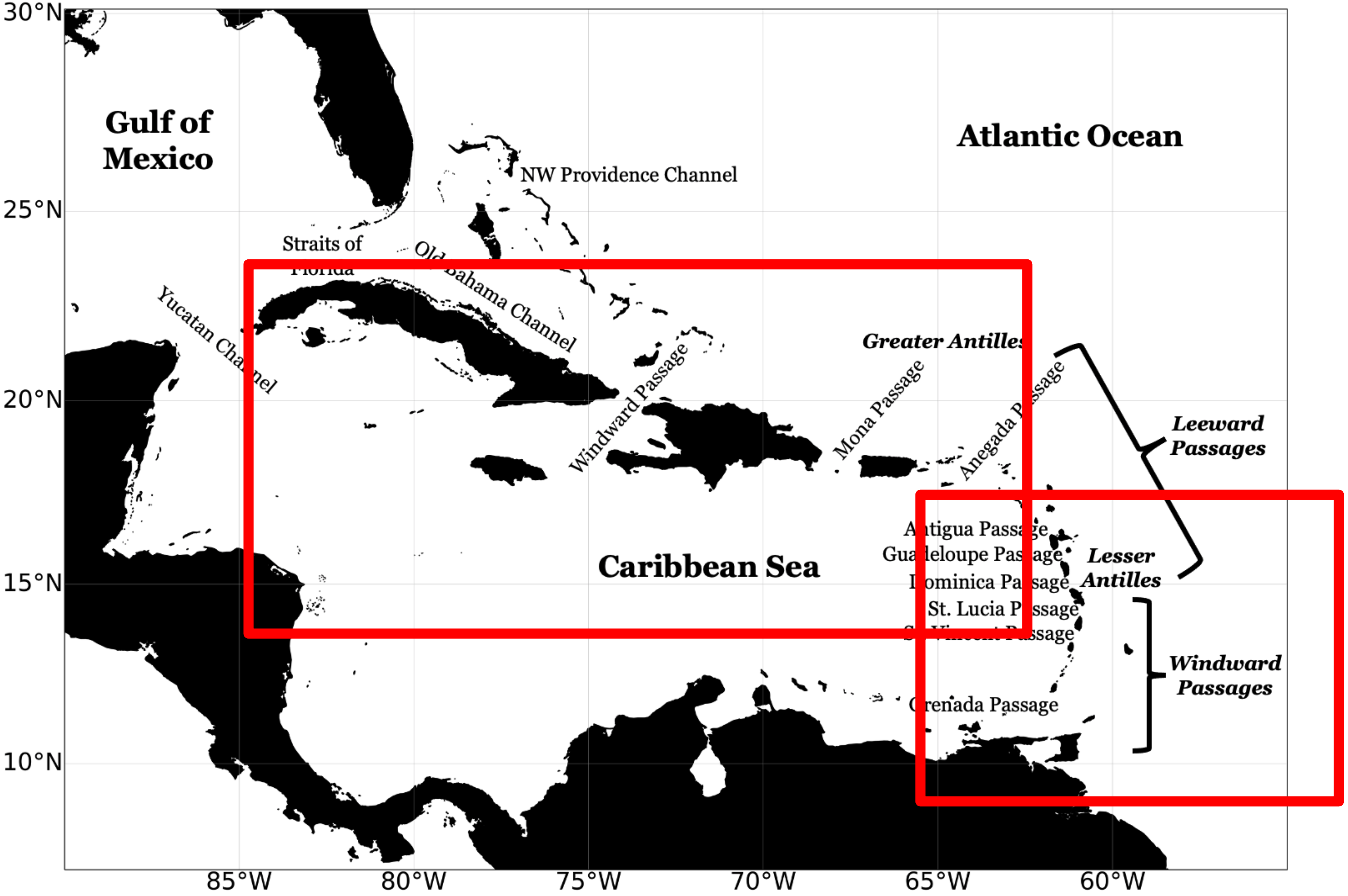


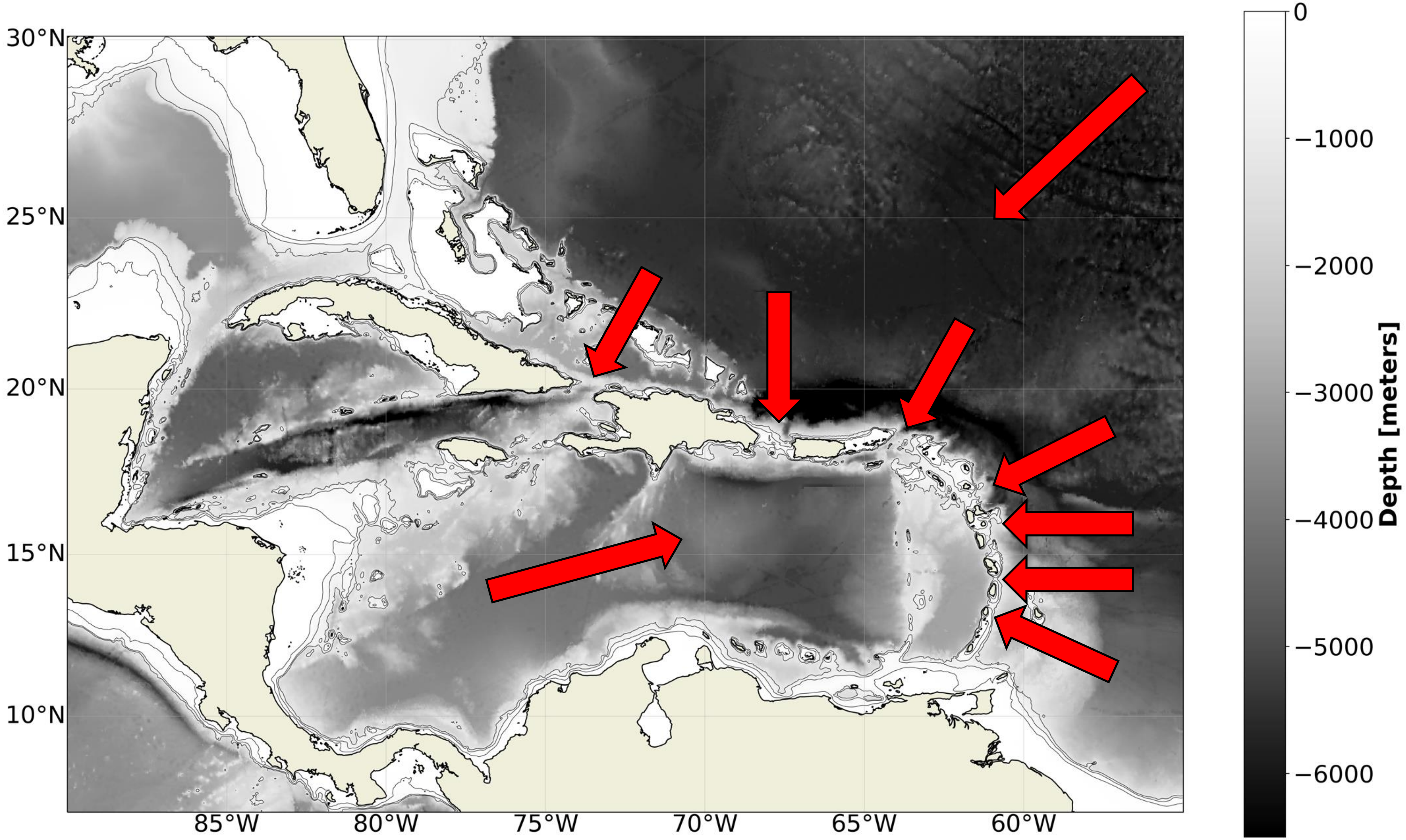
WOCE Atlas V.3

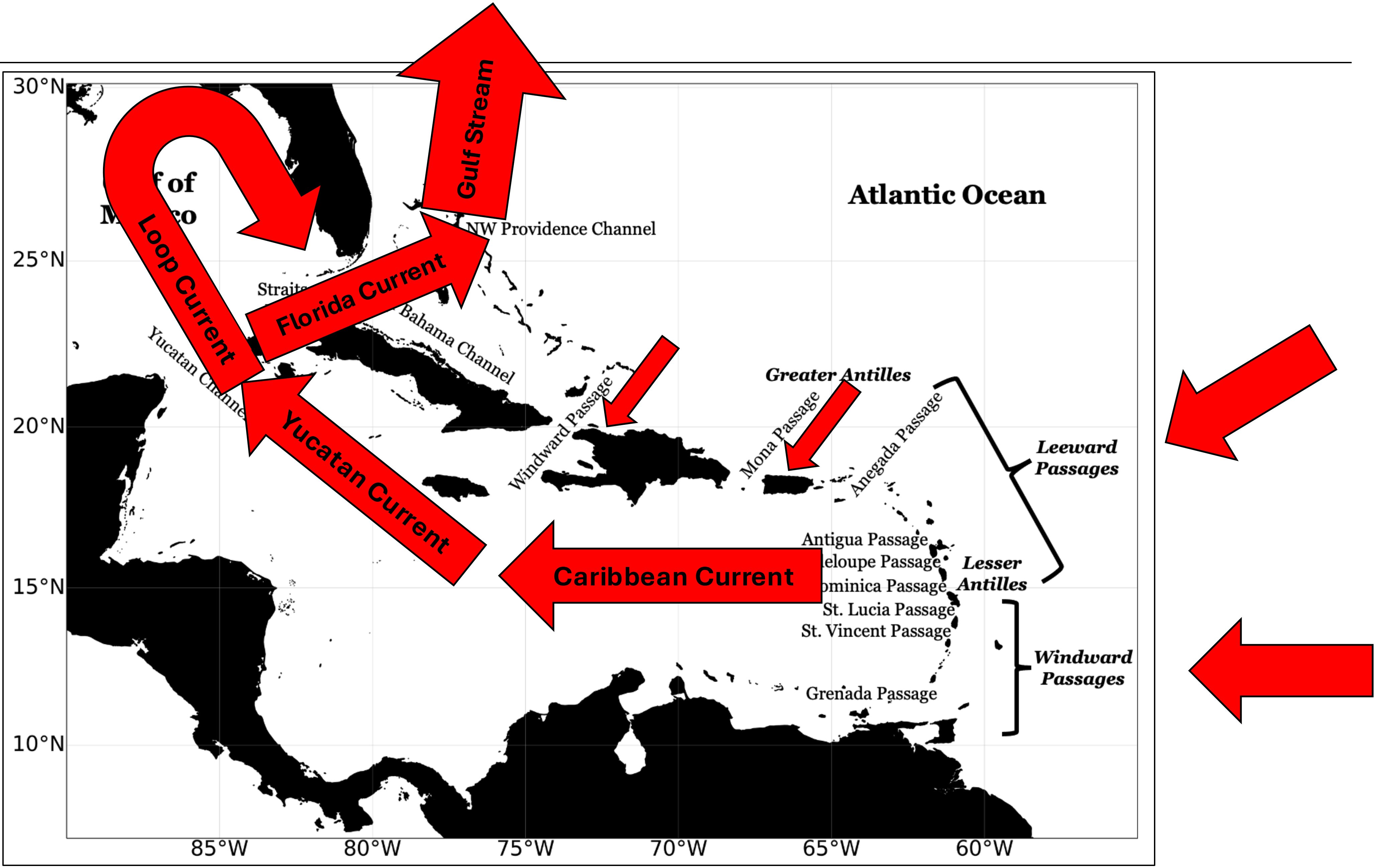
Why the Caribbean?

Start of the upper limb of the AMOC




Gulf of Mexico
Atlantic Ocean
NW Providence Channel
Straits of Florida
Old Bahama Channel
Yucatan Channel
Greater Antilles
Windward Passage
Mona Passage
Anegada Passage
Leeward Passages
Antigua Passage
Guadeloupe Passage
Dominica Passage
St. Lucia Passage
St. Vincent Passage
Lesser Antilles
Windward Passages
Caribbean Sea
Grenada Passage
30°N
25°N
20°N
15°N
10°N
85°W
80°W
75°W
70°W
65°W
60°W


30°N
25°N
20°N
15°N
10°N
85°W
80°W
75°W
70°W
65°W
60°W
0
−1000
−2000
−3000
−4000
−5000
−6000
Depth [meters]



Atlantic Ocean
Gulf Stream
Loop Current
Florida Current
Yucatan Current
Caribbean Current
NW Providence Channel
Bahama Channel
Yucatan Channel
Windward Passage
Mona Passage
Anegada Passage
Greater Antilles
Leeward Passages
Antigua Passage
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St. Lucia Passage
St. Vincent Passage
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Grenada Passage
30°N
25°N
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85°W
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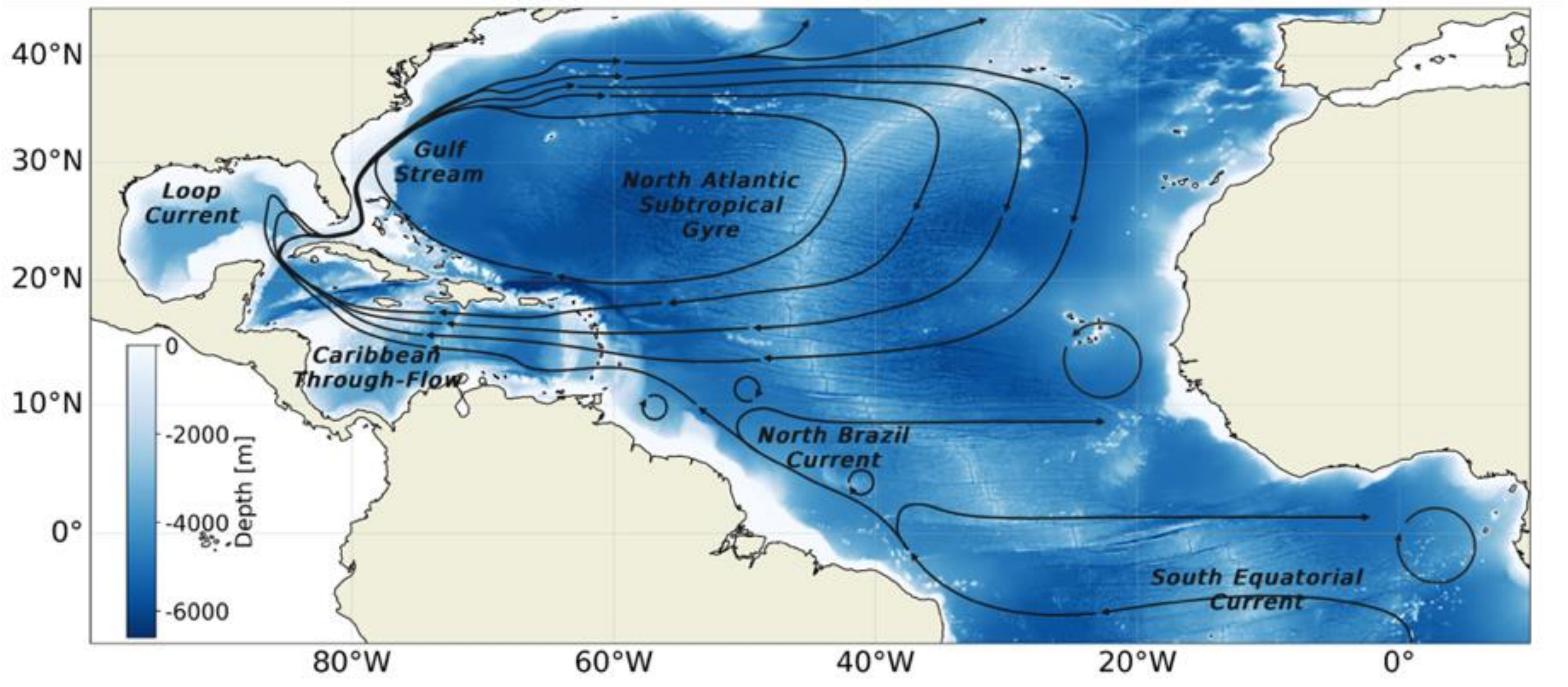
75°W
70°W
65°W
60°W

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



Significant changes are occurring in the North Atlantic Subtropical Gyre

nature climate change

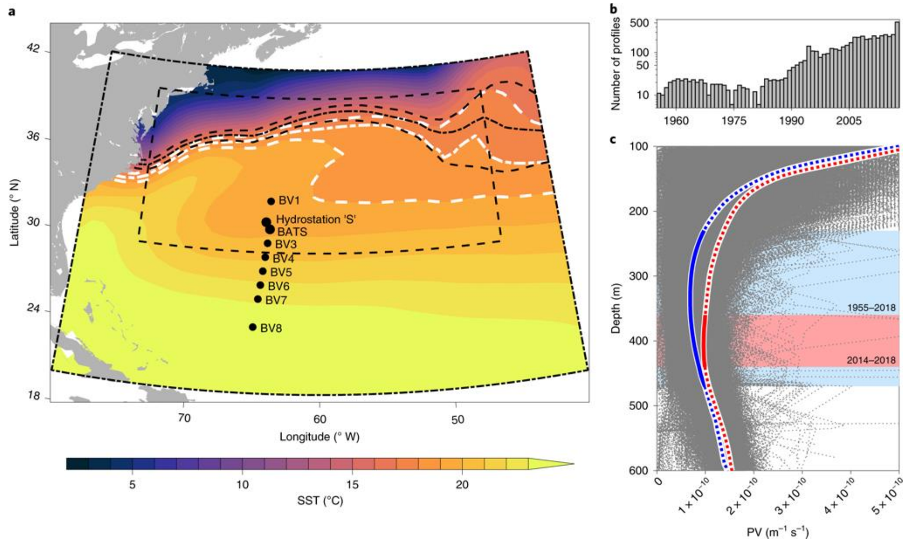
ARTICLES

https://doi.org/10.1038/s41558-020-0722-3

Check for updates

A recent decline in North Atlantic subtropical mode water formation

Samuel W. Stevens[1,2], Rodney J. Johnson[2], Guillaume Maze[3] and Nicholas R. Bates[2,4]



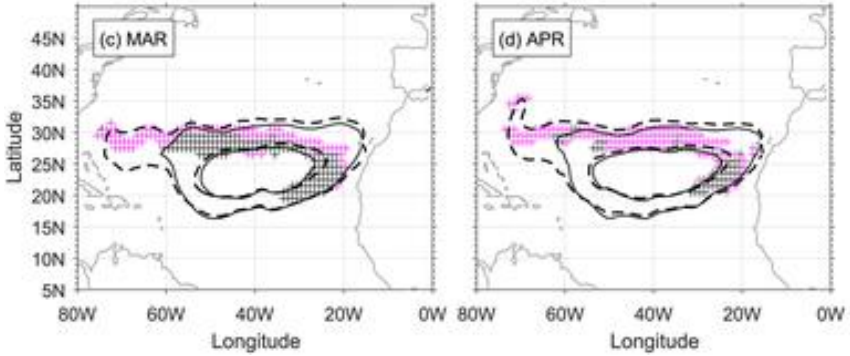
JGR Oceans

Research Article | Free Access

Recent Decadal Change in the North Atlantic Subtropical Underwater Associated With the Poleward Expansion of the Surface Salinity Maximum

Hao Liu, Lisan Yu, Xiaopei Lin

First published: 11 June 2019 | https://doi.org/10.1029/2018JC014508 | Citations: 2



Questions around and recent showing a slowdown/collapse in the AMOC

nature

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]

WIRED SUBSCRIBE

The New York Times

In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

The warming atmosphere is causing an arm of the powerful Gulf Stream to weaken, some scientists fear.

By MOISES VELASQUEZ-MANOFF and JEREMY WHITE

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RESEARCH ARTICLE | OCEANOGRAPHY

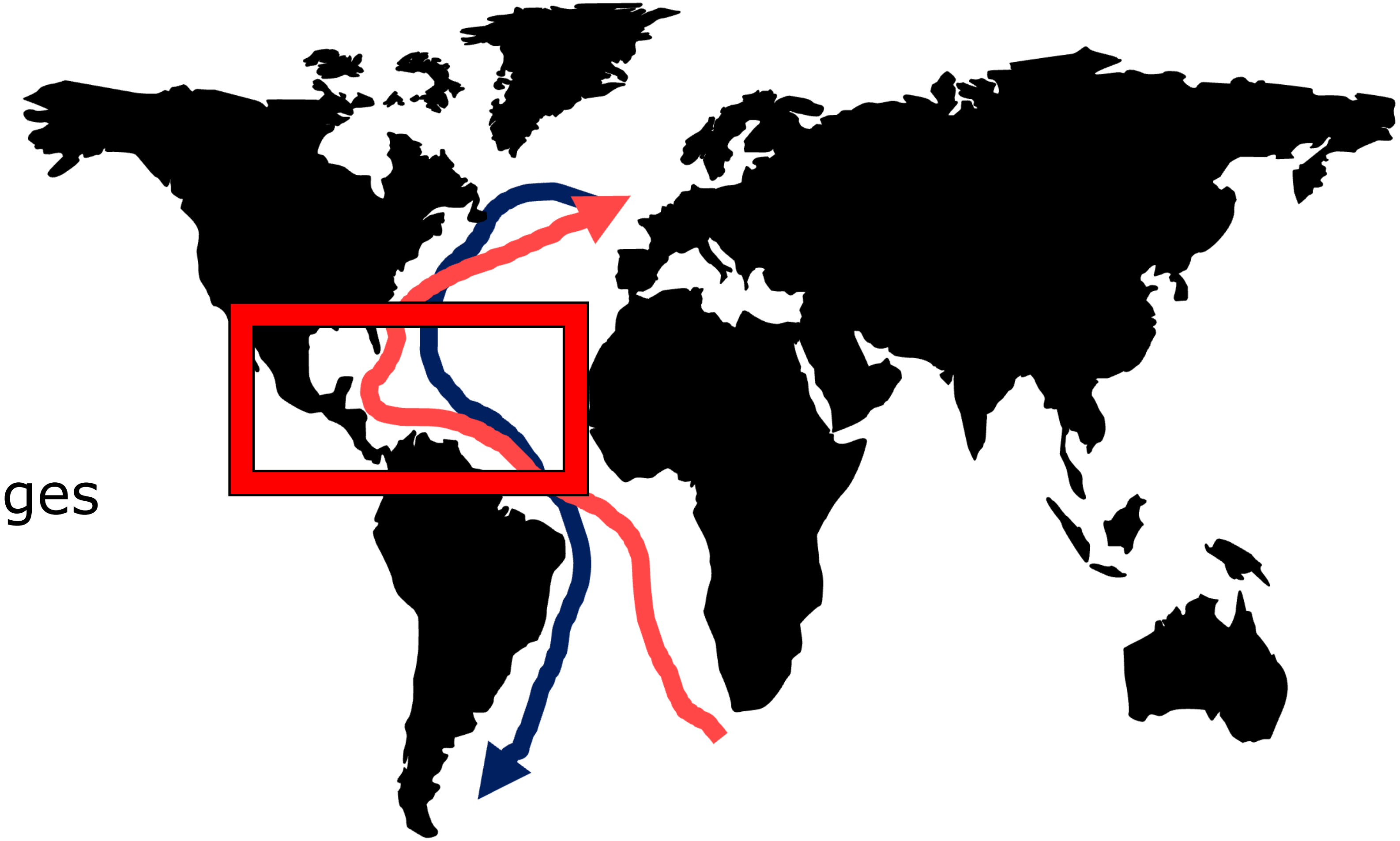
Physics-based early warning signal shows that AMOC is on tipping course

RENÉ M. VAN WESTEN, MICHAEL KLIPHUIS, AND HENK A. DIJKSTRA Authors Info & Affiliations

Why the Caribbean?

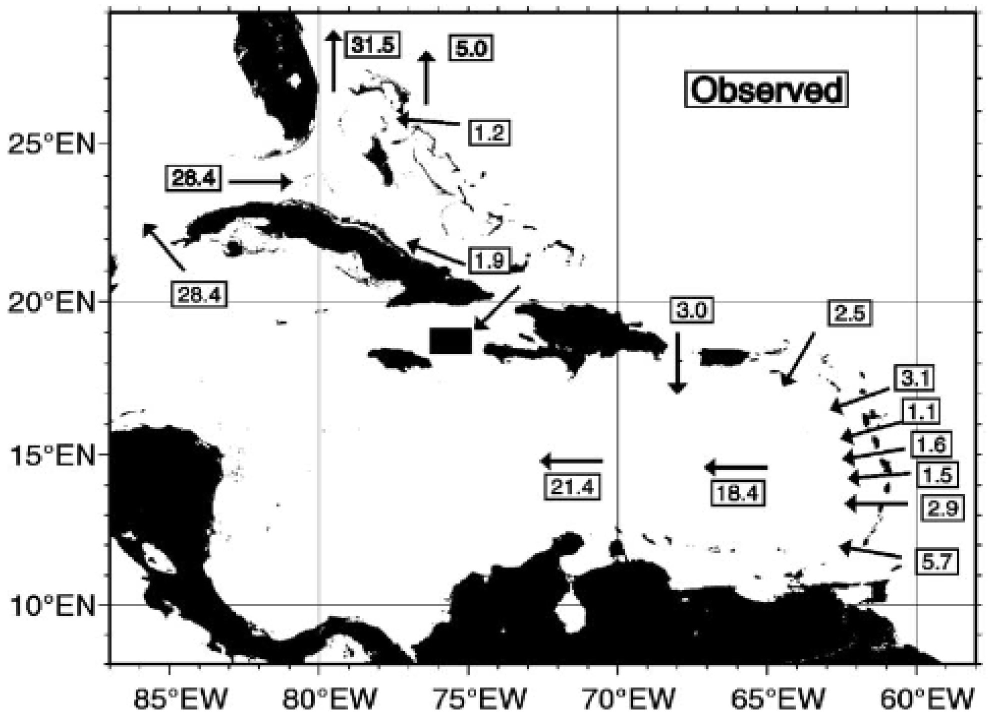
- Chokepoint for major Atlantic circulations

- Significant changes and uncertainty surrounding Atlantic-wide circulation

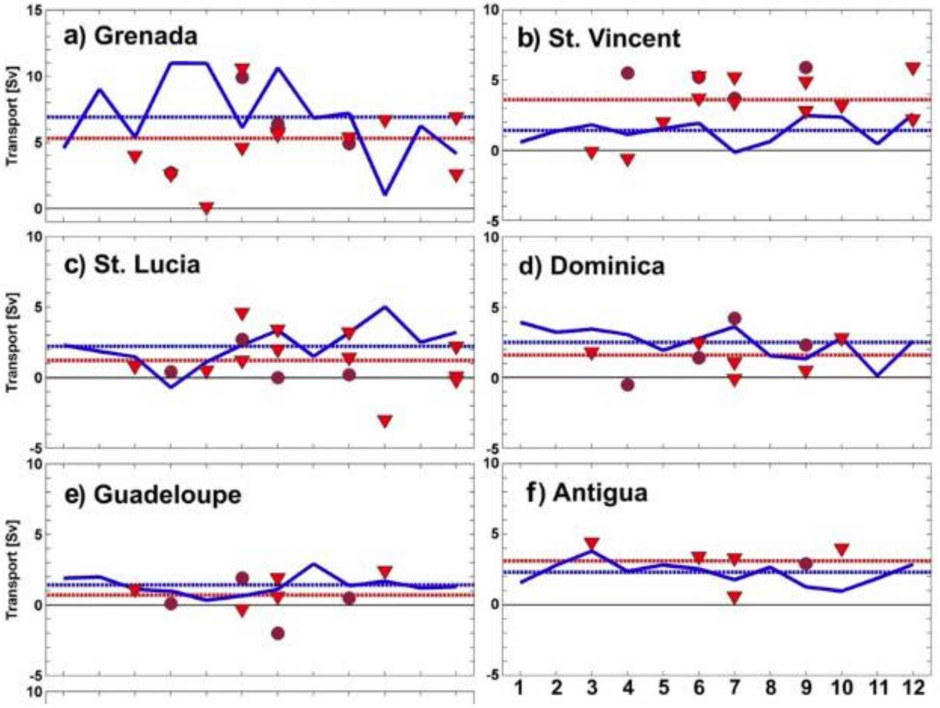


Caribbean Through-Flow is significantly under-sampled!

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

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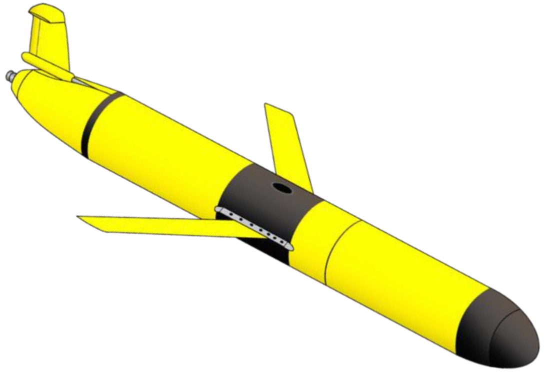
Chapter 1



JGR Oceans

RESEARCH ARTICLE

10.1029/2022JC019608

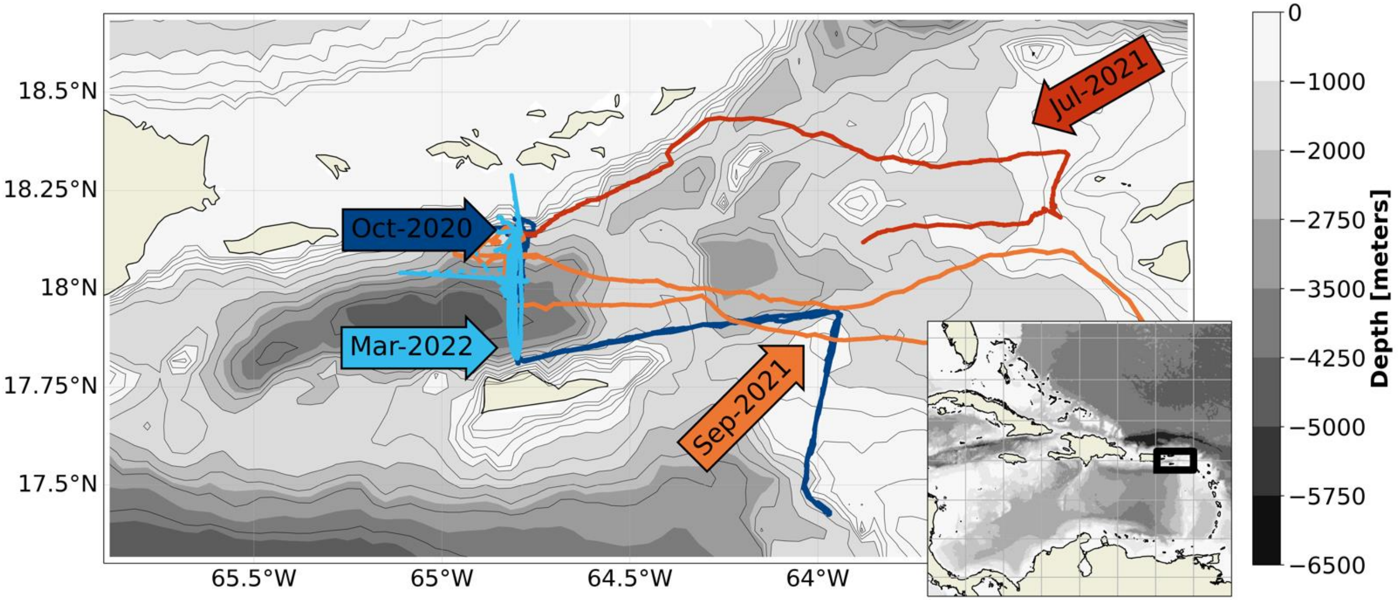
Key Points:

- 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



4

glider deployments

>2700

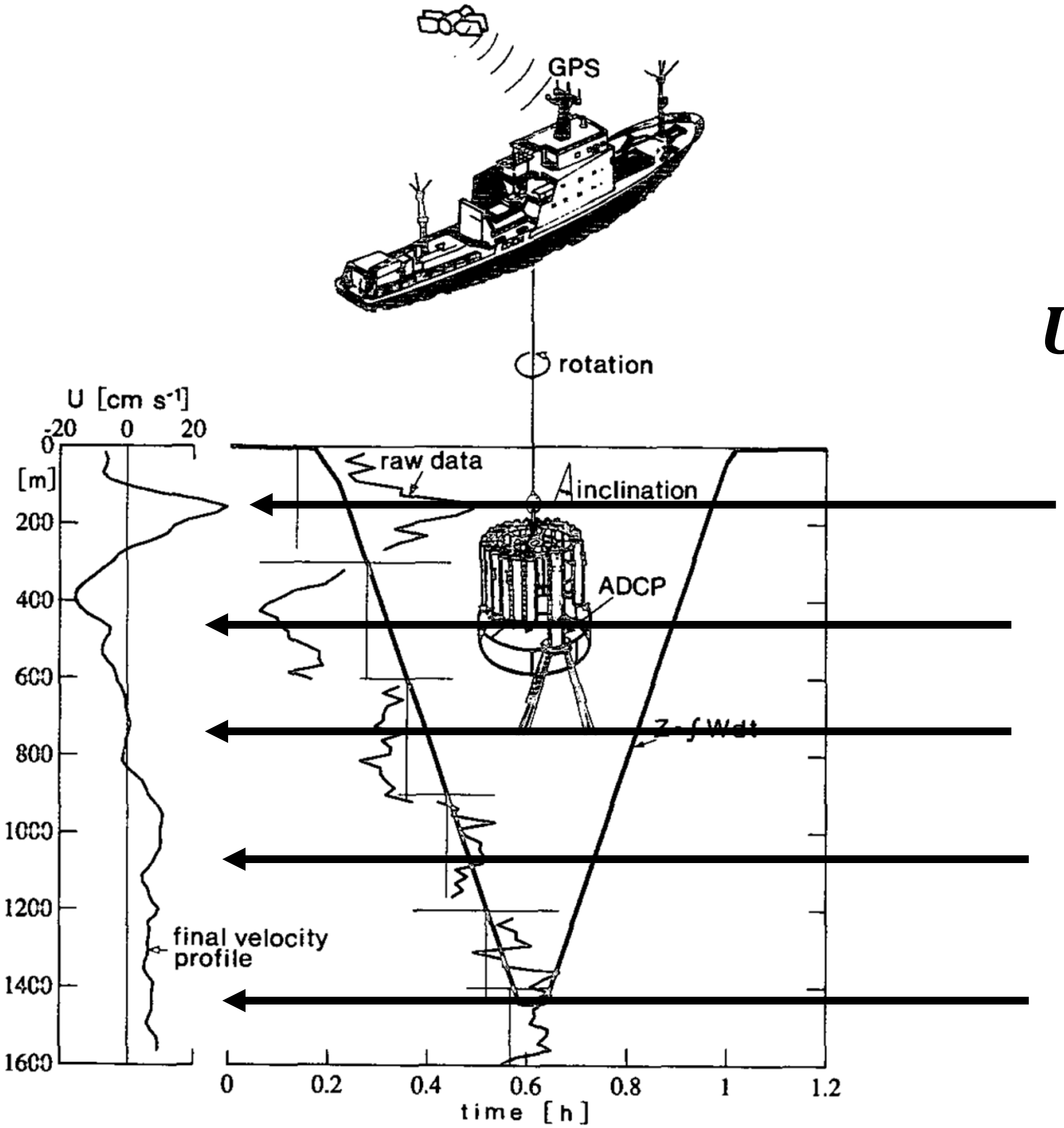
kilometers sampled

>130

days at sea

Chapter 1

Gradone et al. (2023)



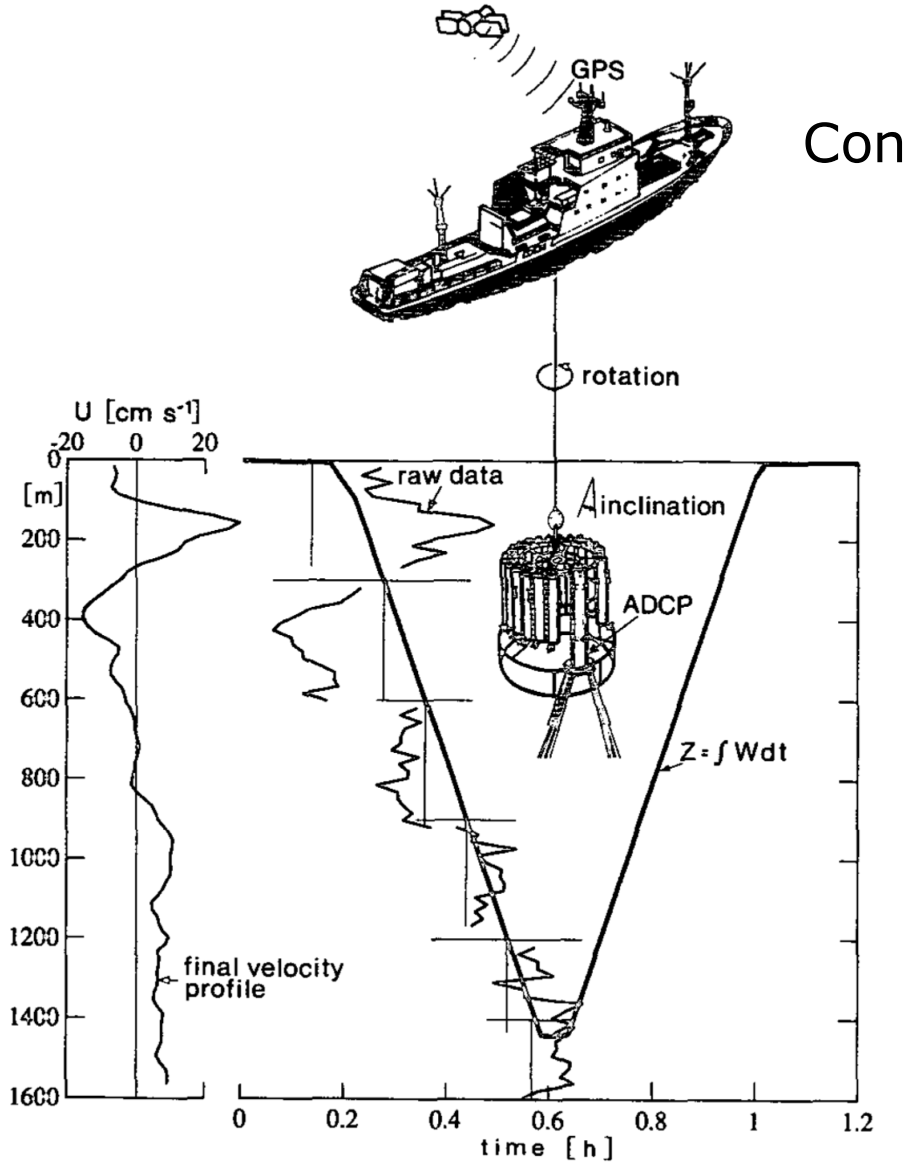
$$U_{adcp} = U_{ocean} + U_{ctd} + U_{noise}$$

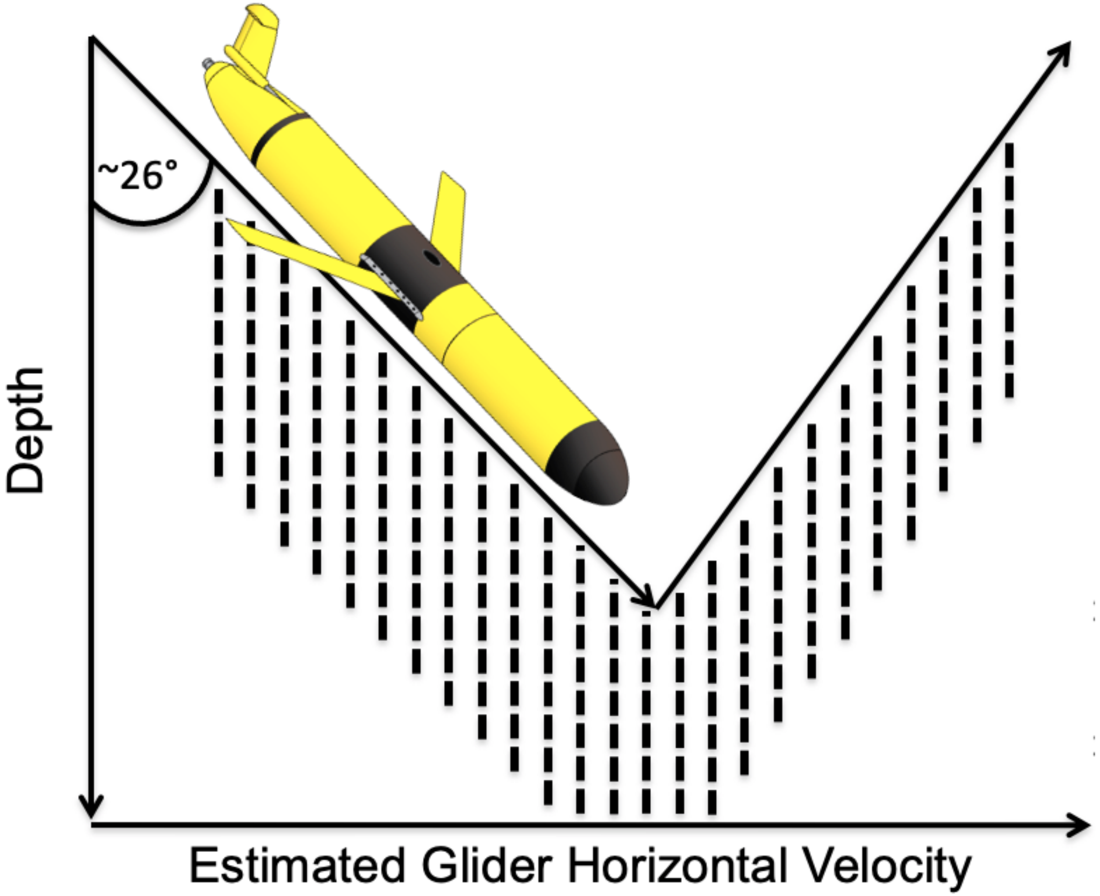
Visbeck (2002)
Least Squares Linear Inversion

Gradone et al. (2023)

Adapting for use on gliders:

Constrain solution using glider depth averaged velocity





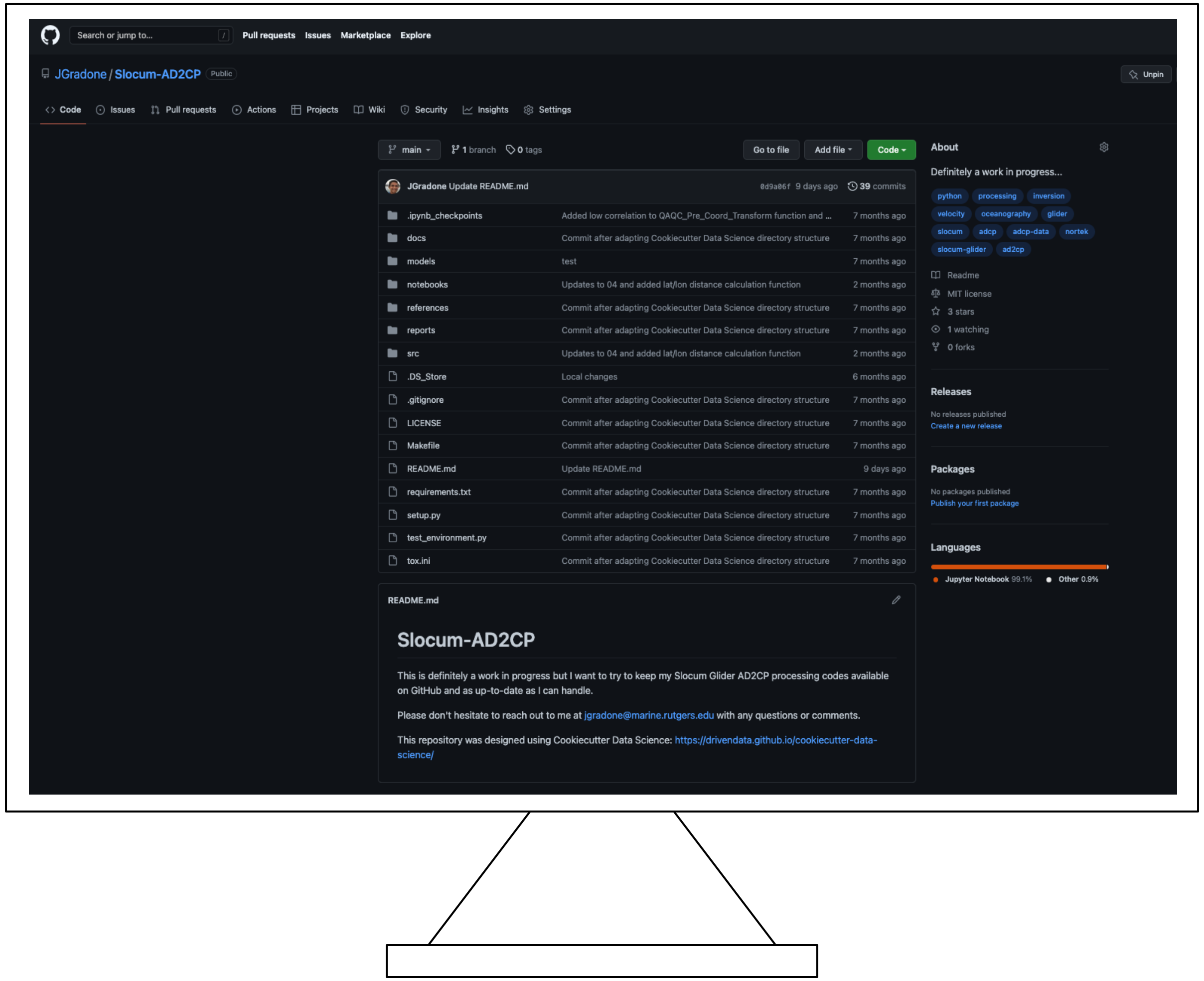
Todd et al. 2011, 2017; Miles et al. 2015, 2017; Gradone et al. 2021, 2023; and many others

GitHub

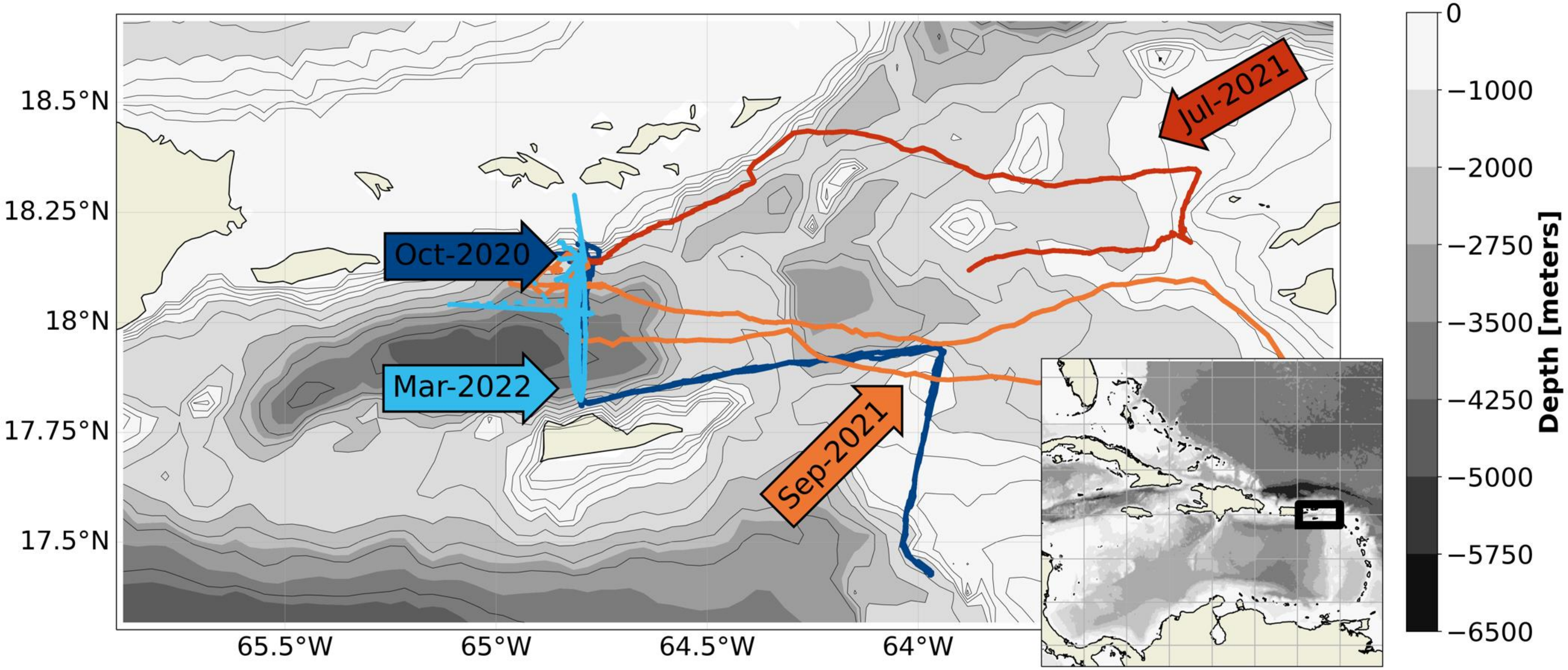
Open-Source Code.

https://github.com/JGradone/Slocum-AD2CP

Glider and sensor agnostic processing package

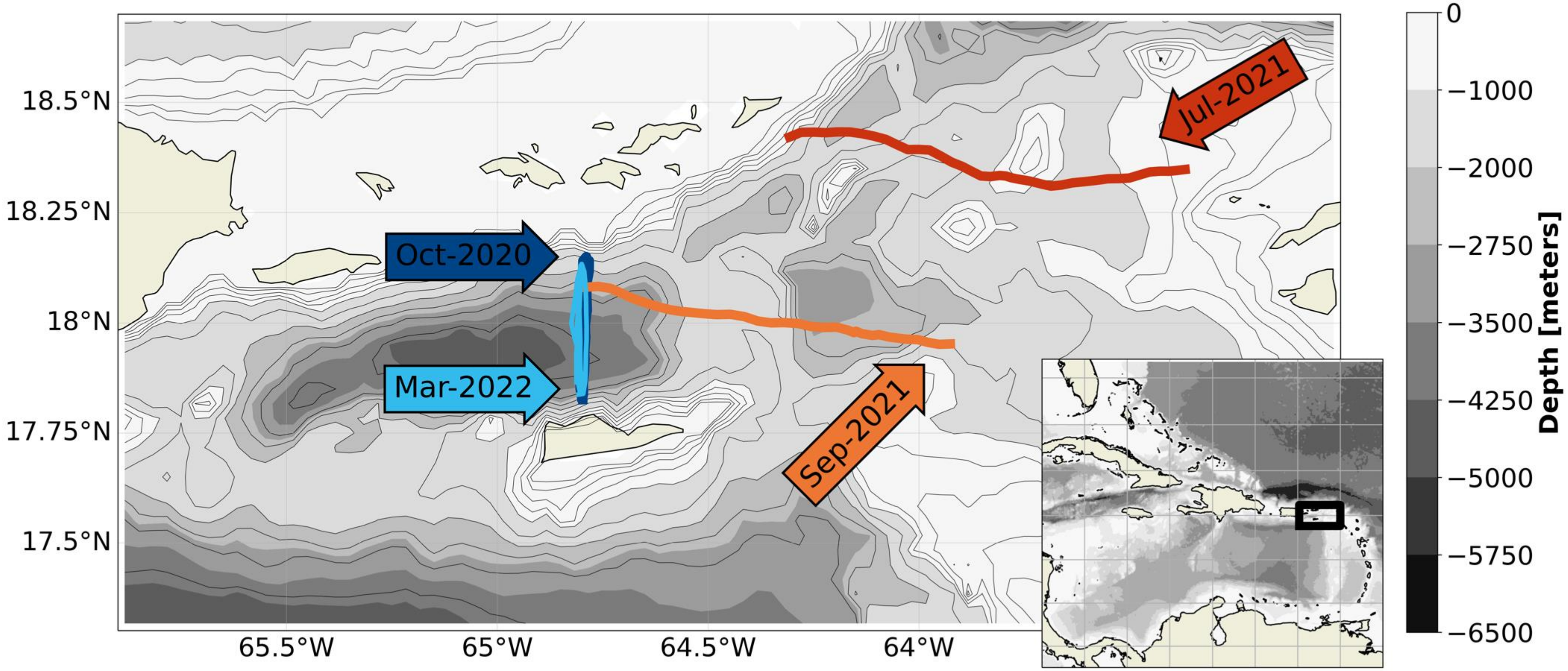


Gradone et al. (2023)



Subset these tracks to just passage “**crossings**”

Gradone et al. (2023)

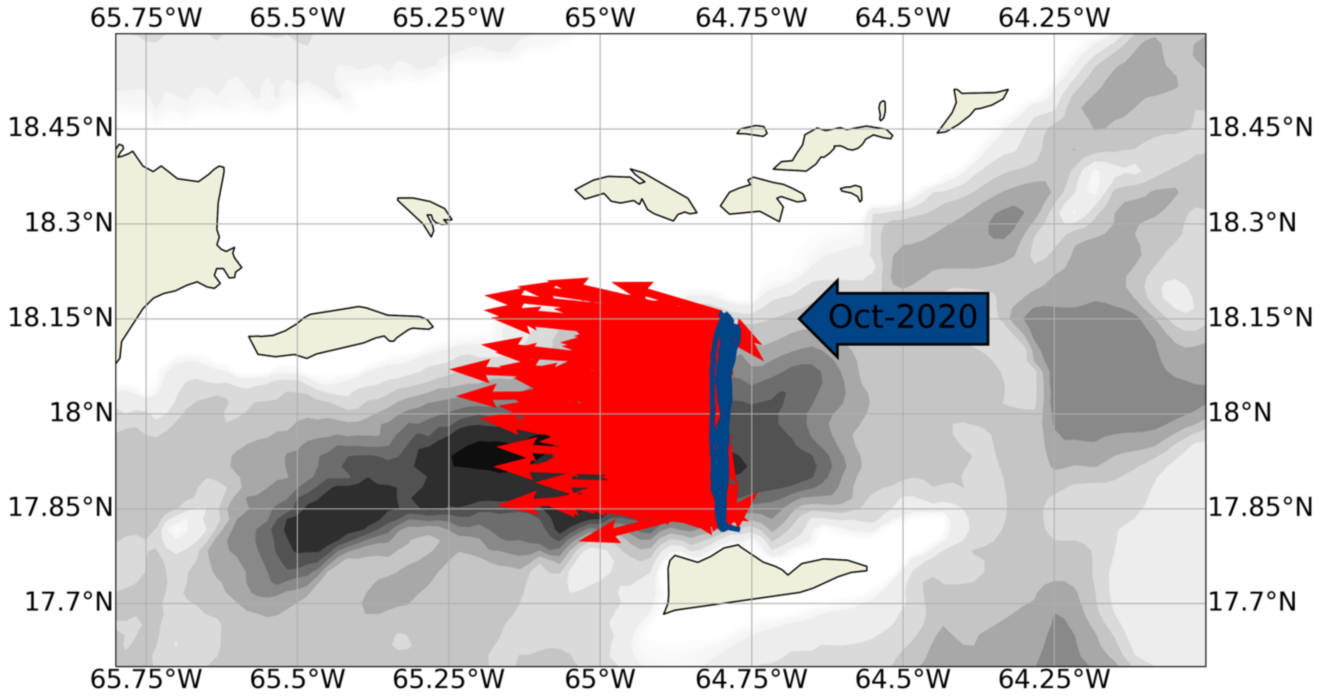


	Oct-2020	**Mar-2022**
Number of Transects	15	6
Current Profiler	Nortek AD2CP	TRDI Pathfinder

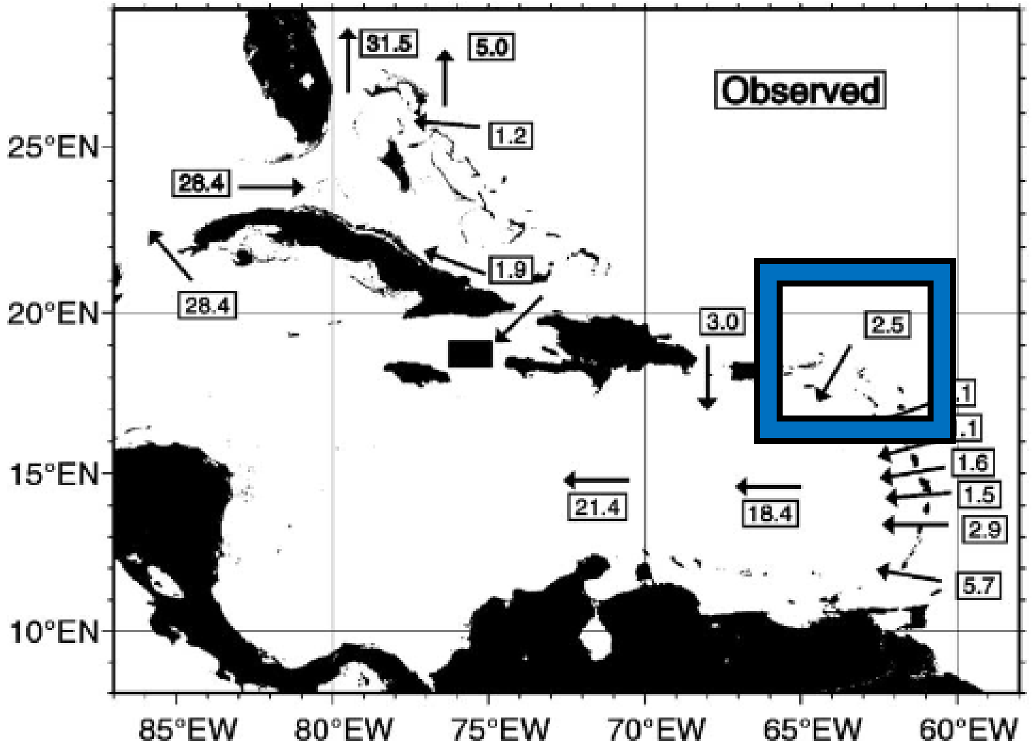
Gradone et al. (2023)

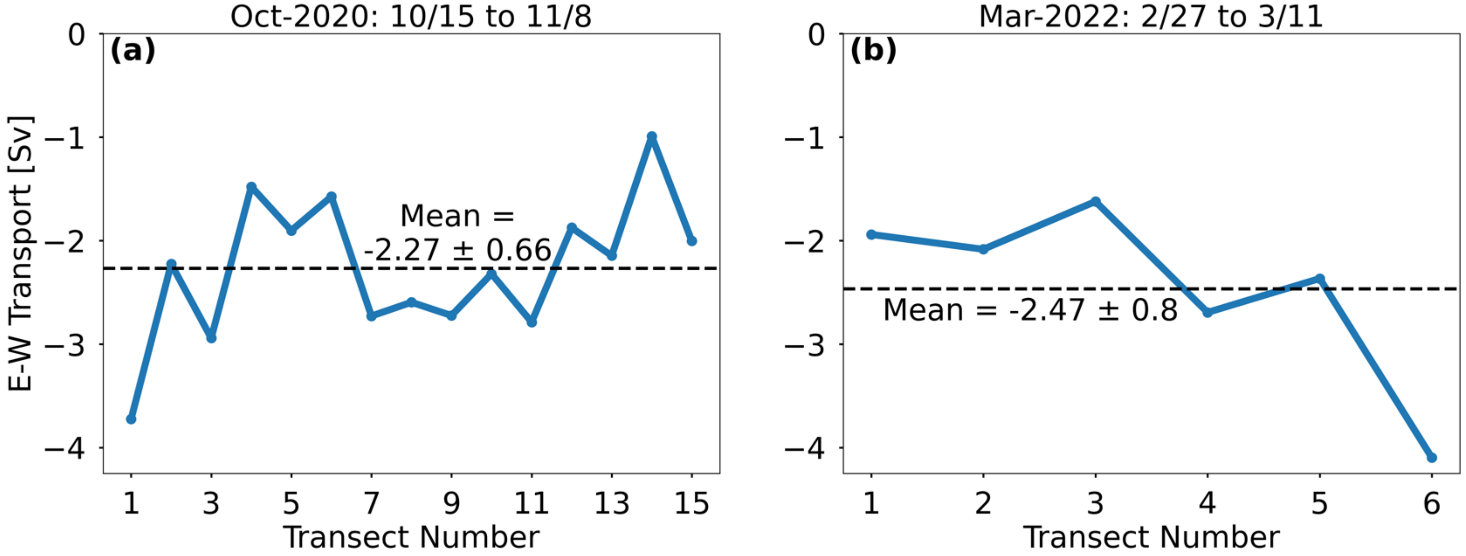
Calculating Transport

Integrate velocity horizontally and vertically across passage per transect



Gradone et al. (2023)



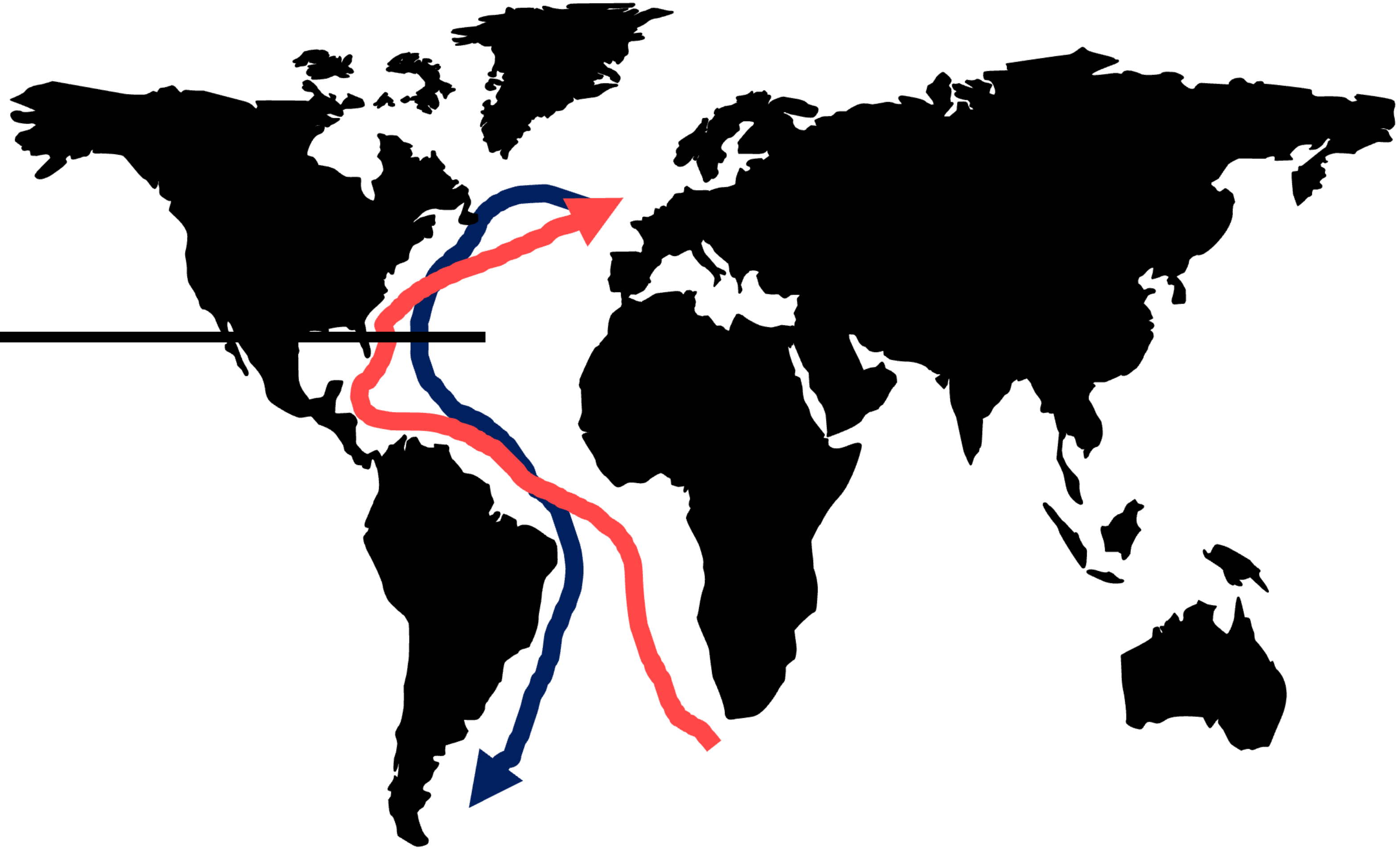


1 Sverdrup (Sv) = 1,000,000 $m^3 s^{-1}$

(Johns et al. 2002; Gradone et al. 2023)

AMOC balance conundrum:

Florida Current: ____________
~31 Sv



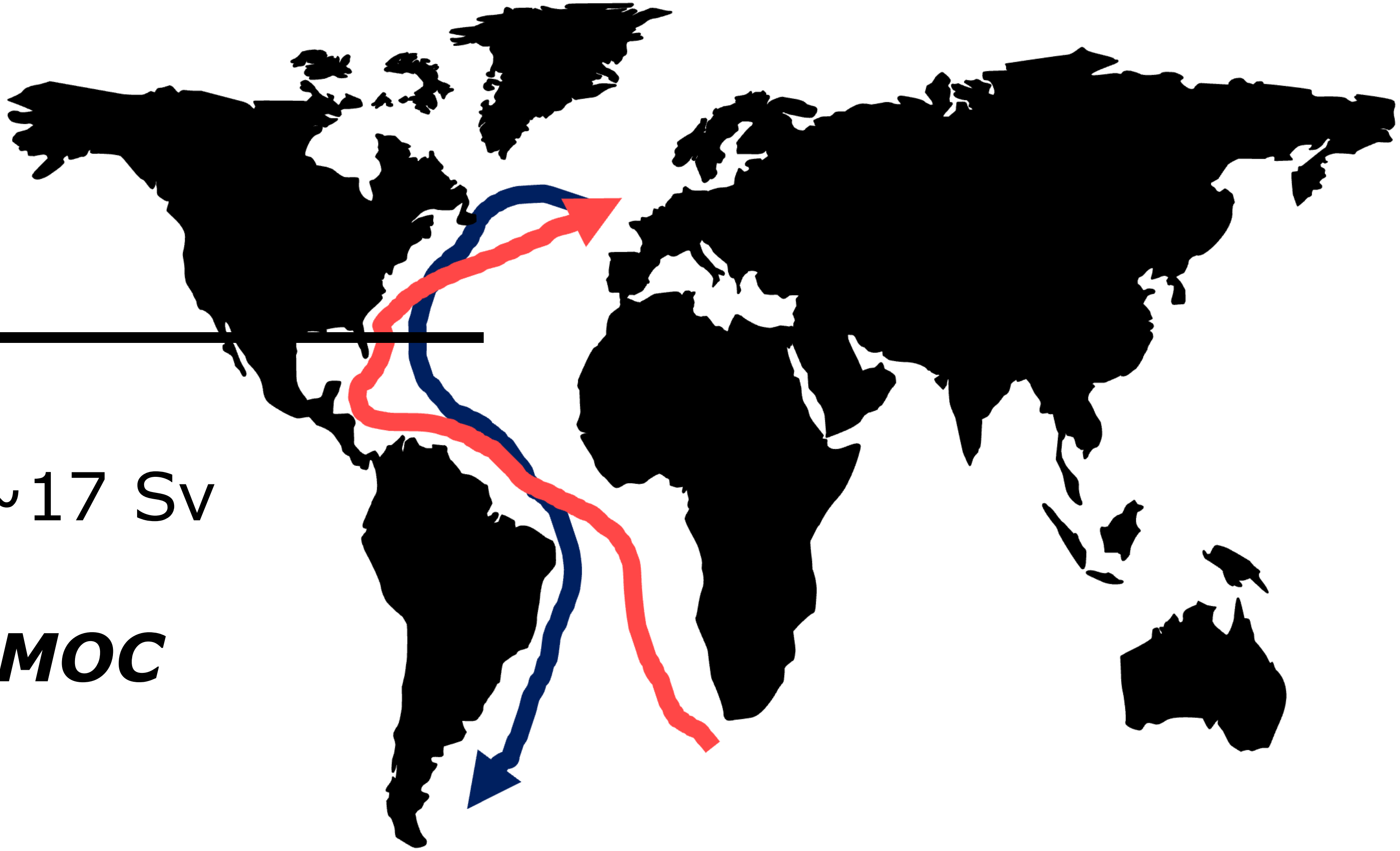
Schmitz and Richardson, 1991

AMOC balance conundrum:

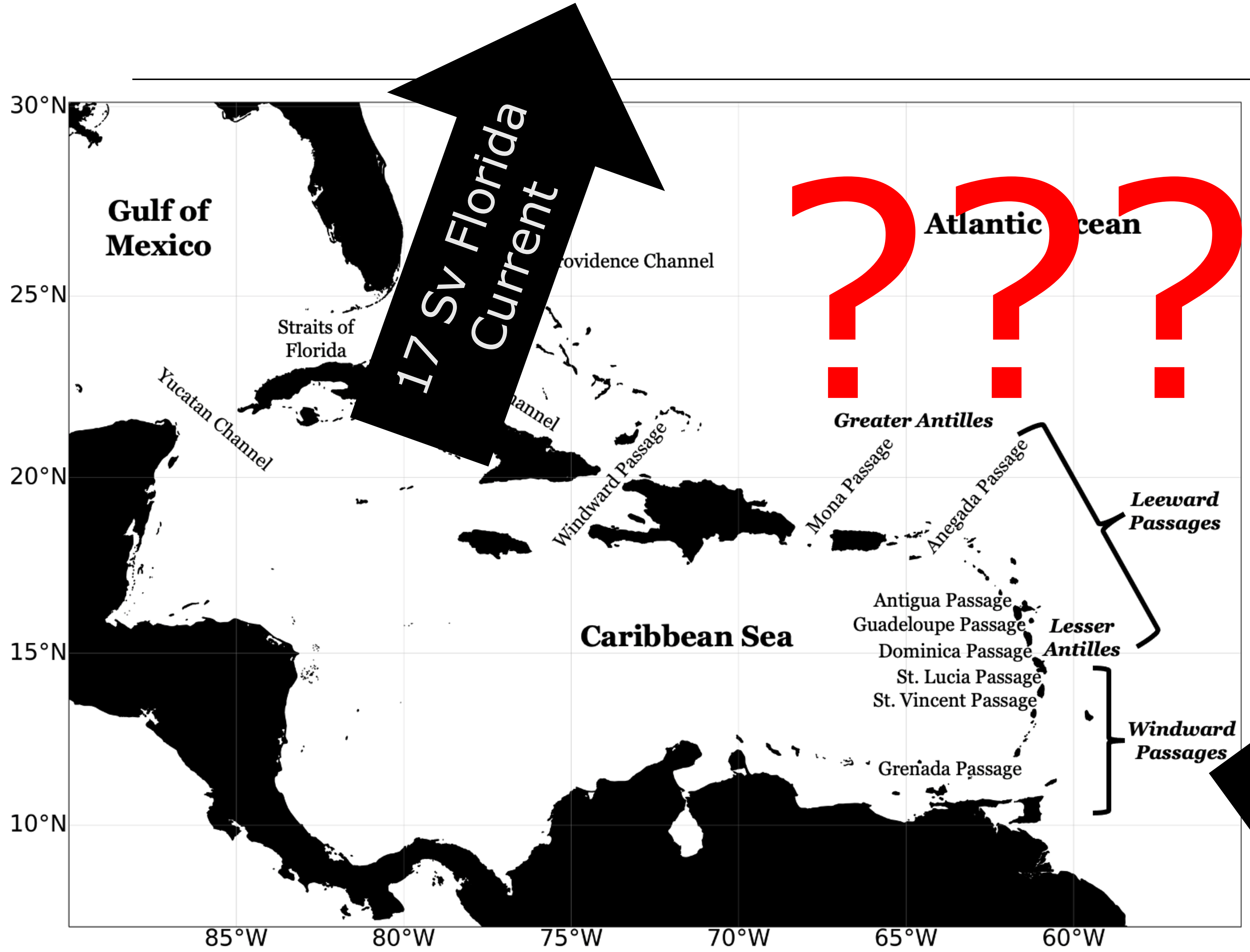
Florida Current: ~31 Sv

AMOC Strength: ~17 Sv

Cross-Equatorial MOC return flow



Schmitz and Richardson, 1991



Caribbean Cross-Equatorial Box Model

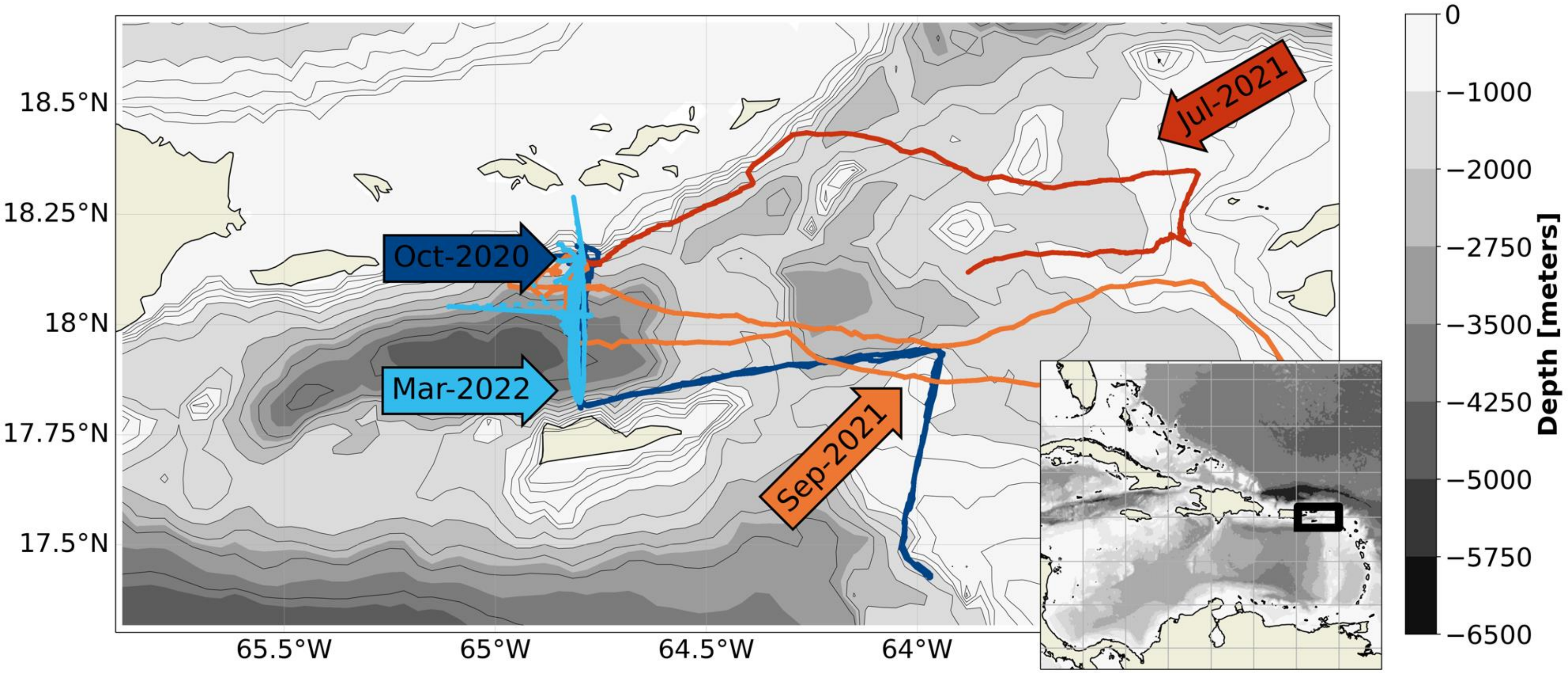
(17 Sv out)
- (11 Sv in)

6 Sv remaining

(Schmitz and Richardson, 1991; Wilson and Johns, 1997; Rhein et al. 2005)

AMOC balance conundrum:

Anegada Passage has been suggested as a potential alternate pathway



(Schmitz and Richardson, 1991; Wilson and Johns, 1997; Rhein et al. 2005)

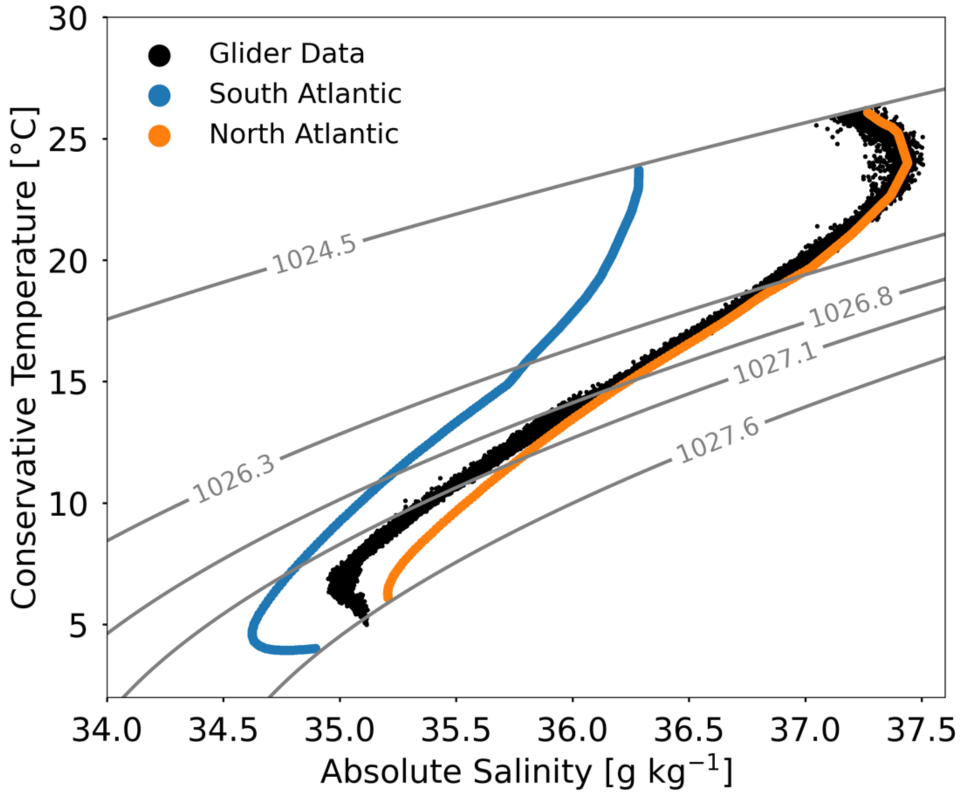
Determining Water Masses Origin

Isopycnal Water Mass Analysis

$$x_{SA}T_{SA} + x_{NA}T_{NA} - T_{obs} = R_T$$

$$x_{SA}S_{SA} + x_{NA}S_{NA} - S_{obs} = R_S$$

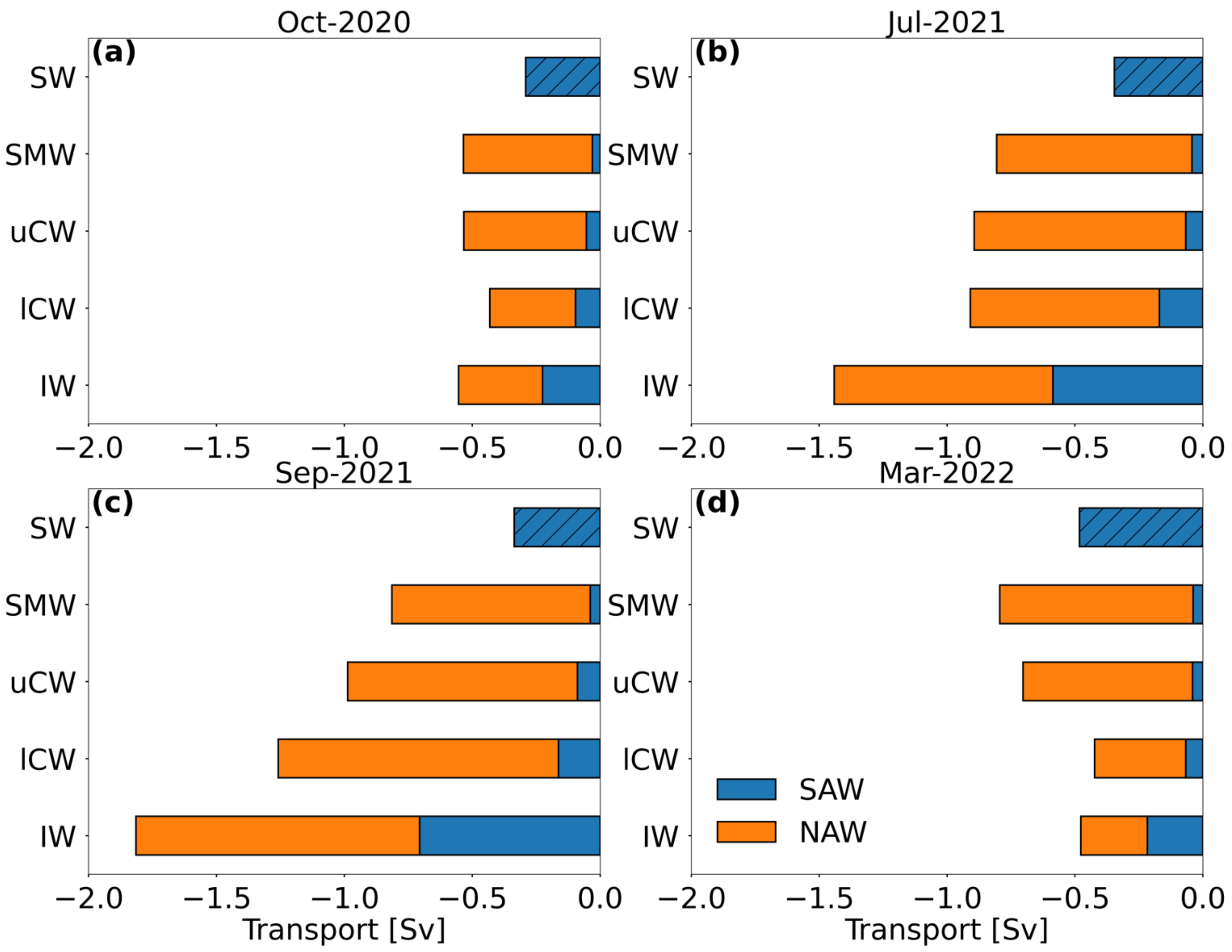
$$x_{SA} + x_{NA} - 1 = R_{MC}$$



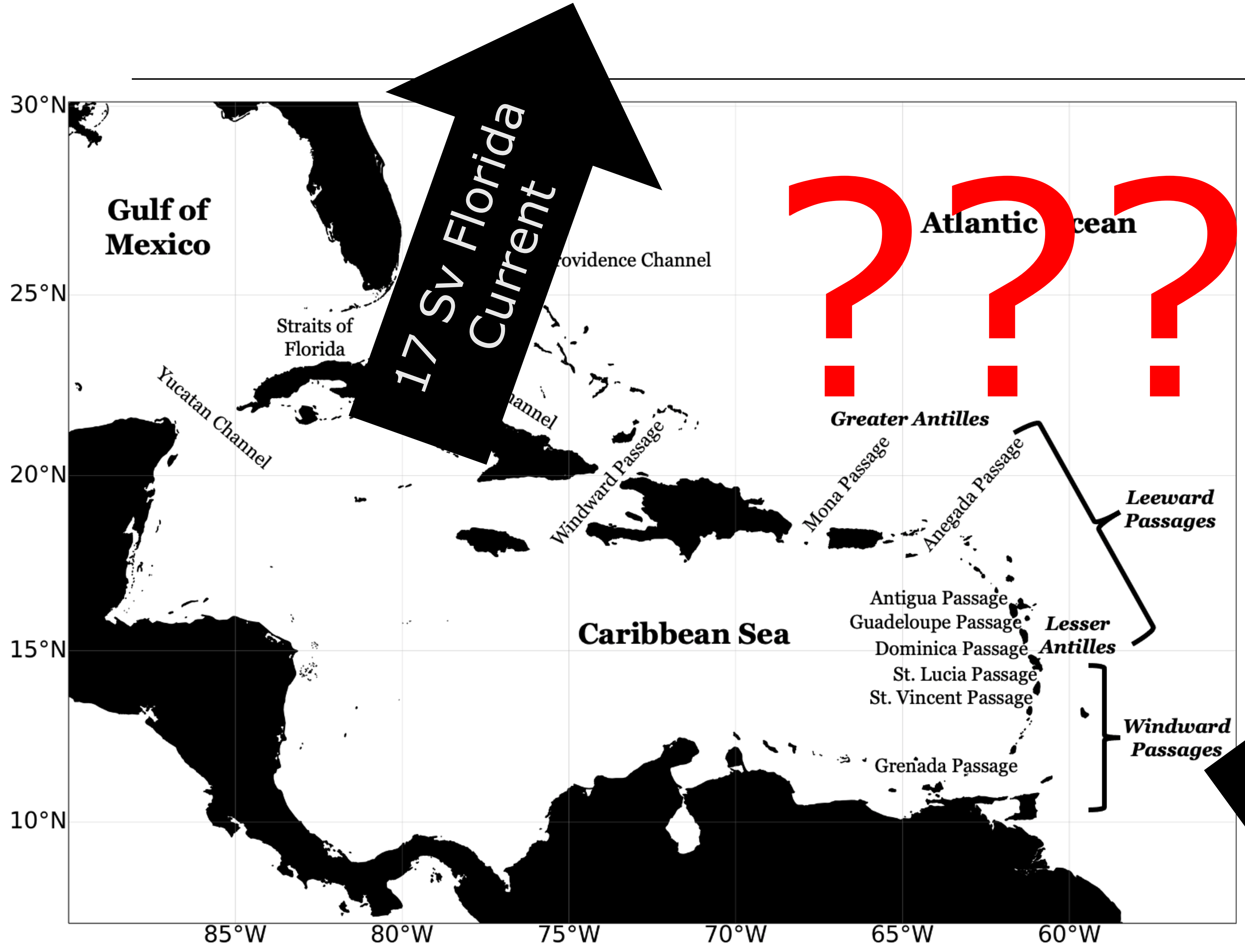
(Schmitz and Richardson, 1991;
Wilson and Johns, 1997; Rhein et al. 2005)

South Atlantic Water Transport

- Transport of SAW through AP (1.66 Sv) is larger than previously estimated (0 to minimal Sv)
- 35% of the total AP transport
- 28% of the SAW transport entering Caribbean north of the Windward Island Passages



Gradone et al. (2023)



Caribbean Cross-Equatorial Box Model

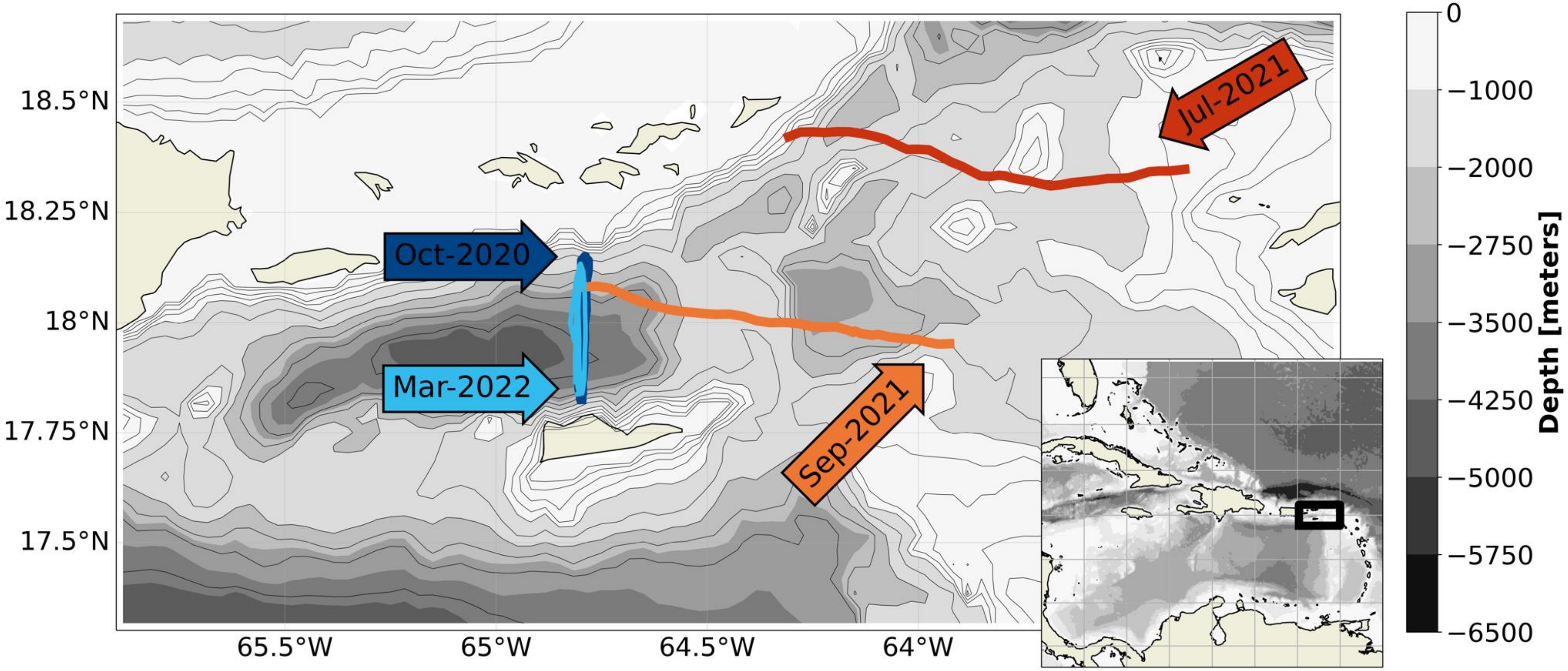
(17 Sv out)
- (11 Sv in)

---

6 Sv remaining

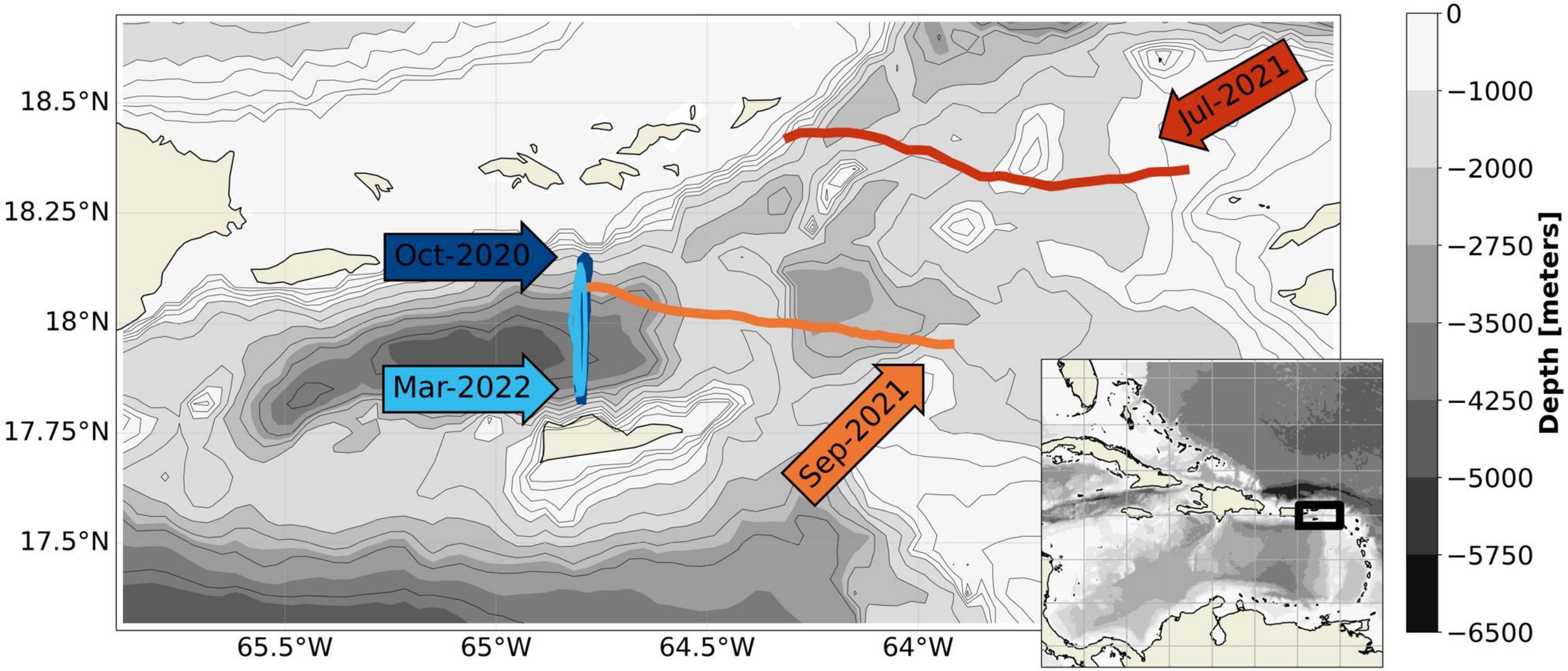
Anegada Passage = ~1.66 Sv

(Schmitz and Richardson, 1991; Wilson and Johns, 1997; Rhein et al. 2005; Gradone et al. 2023)



	Oct-2020	Mar-2022
Number of Transects	15	6
ADCP Derived Transport	-2.27 ± 0.66 Sv	-2.47 ± 0.8 Sv

Gradone et al. (2023)



	Oct-2020	Jul-2021	Sep-2021	Mar-2022
Number of Transects	15	**1**	**1**	6
ADCP Derived Transport	-2.27 ± 0.66 Sv	**-4.36 Sv**	**-5.02 Sv**	-2.47 ± 0.8 Sv

Gradone et al. (2023)

Table of Contents.

Motivation

- Importance of the circulation in the Tropical Atlantic
- Advancing the use of gliders as components of the global ocean observing system

Chapter 1

1. AP transport may be larger than previously estimated
2. AP may be a larger inflow route of SAW than previously estimated

Chapter 2

- Decadal trends in water mass properties
- What are the implications of changes in the CTF?

Chapter 3

- Westward modification of CTF water mass structure
- How important are CTF water mass mixing processes?

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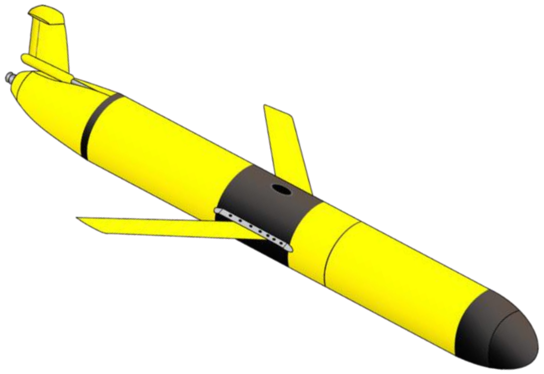
Chapter 2

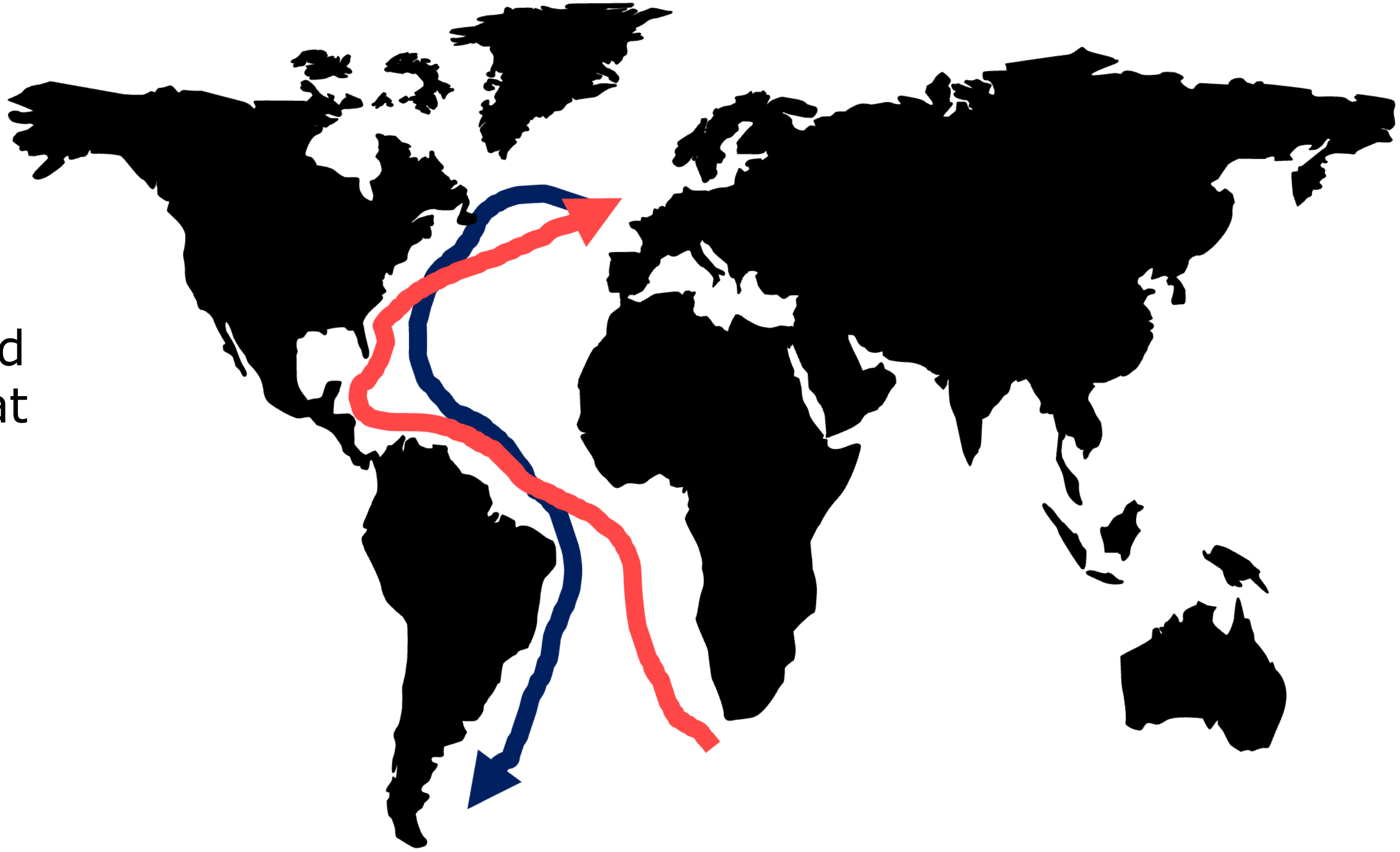
Warming and salinity changes of the upper ocean Caribbean Through-Flow since 1960



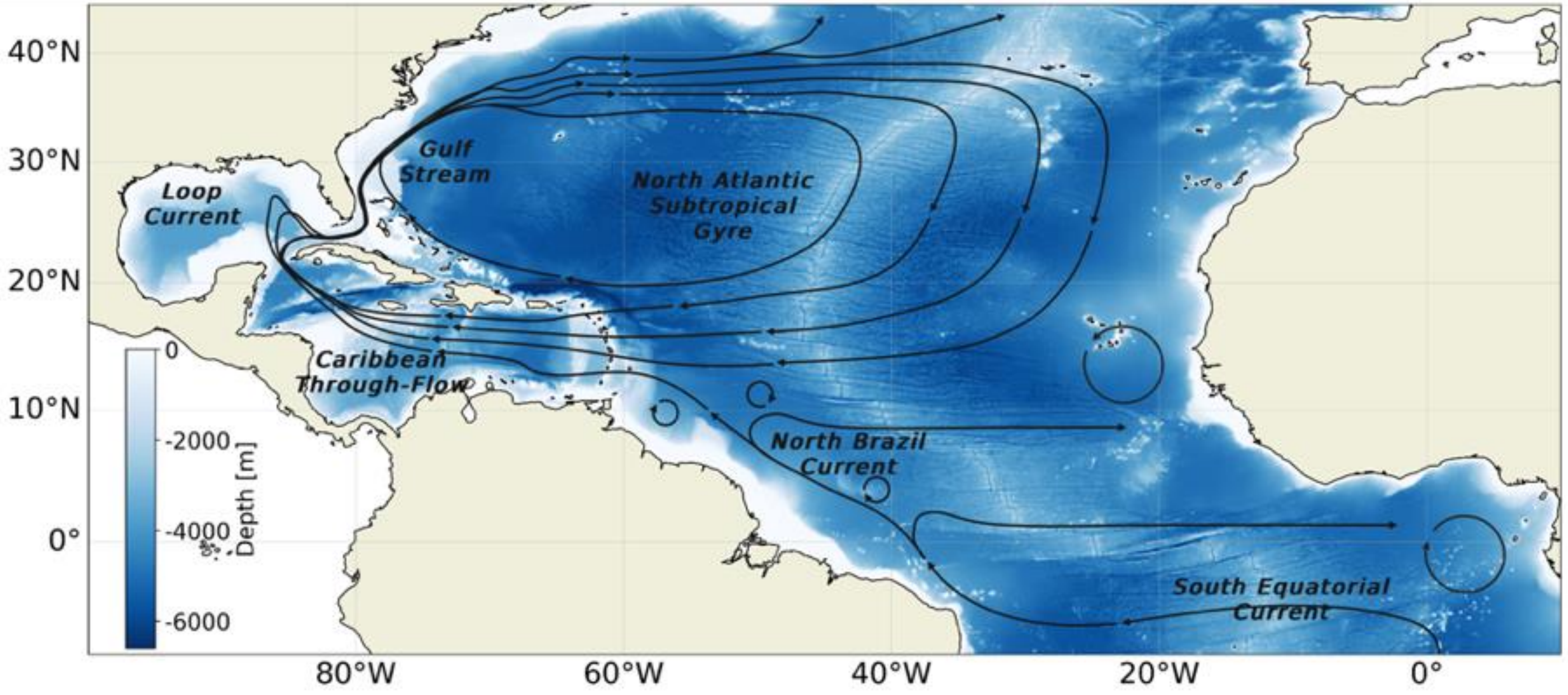
Gradone et al. In Review: *Nature Comms. Earth & Environ.*

Why is the AMOC important?

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



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

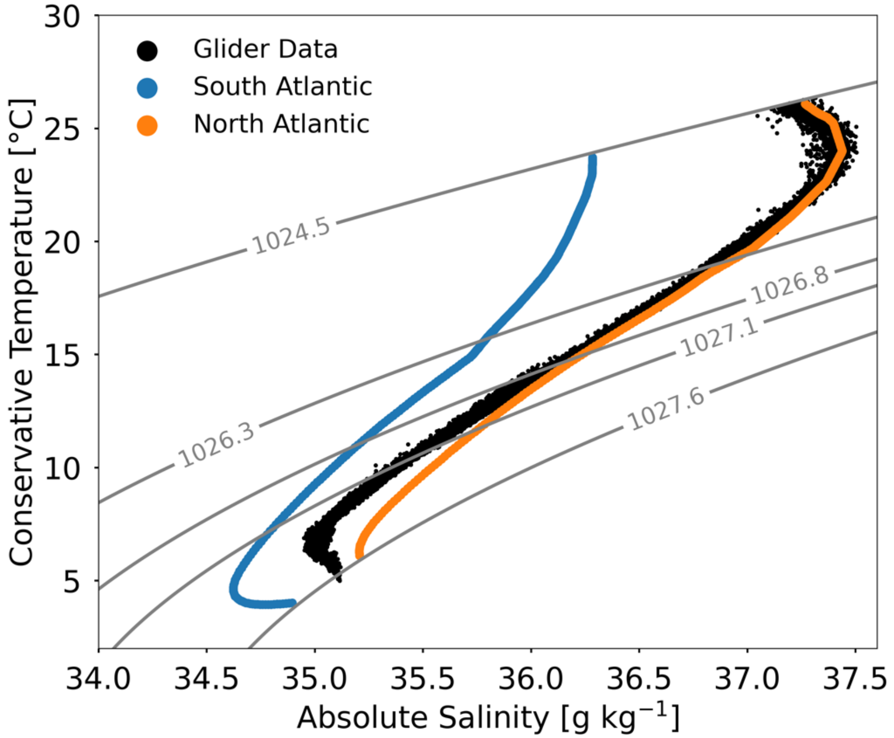


Heat/salt flux of the Caribbean through-flow largely determined by its role as location where water masses from the North & South Atlantic mix

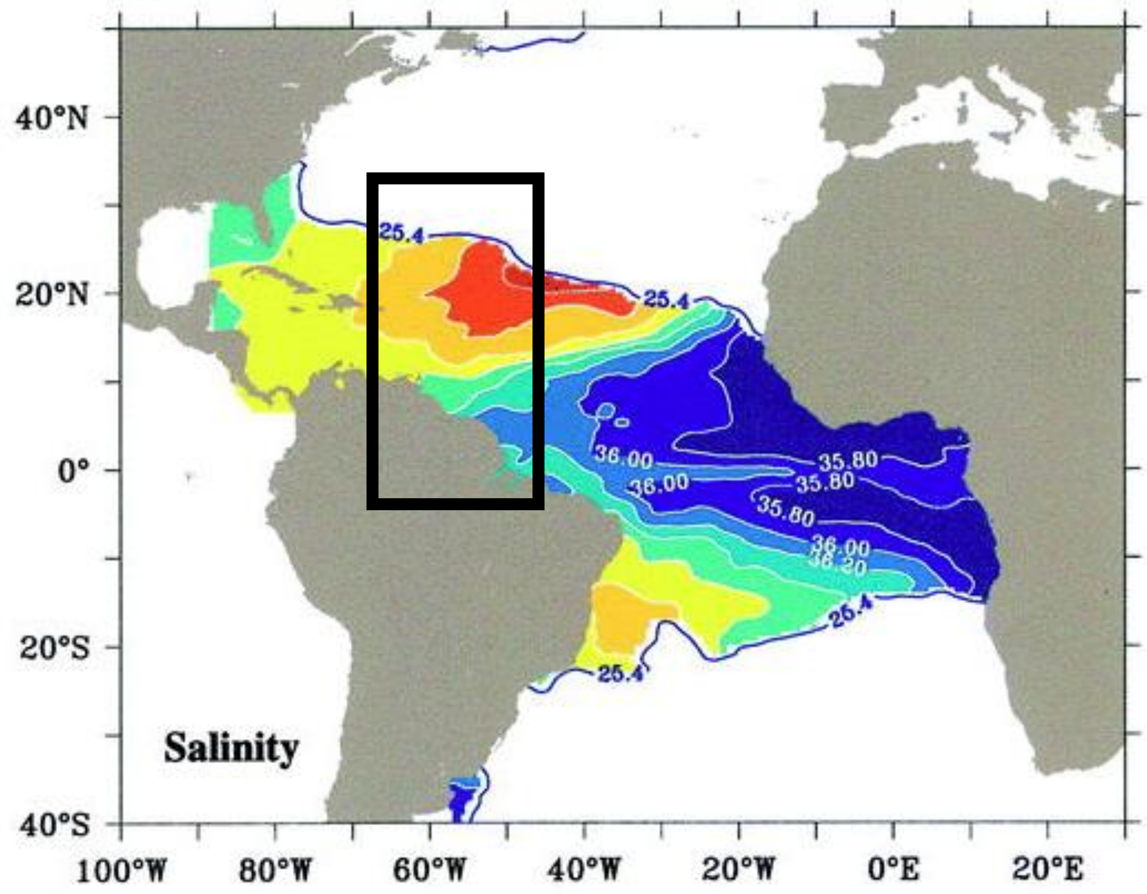
Generally

North Atlantic:
Warmer and Saltier

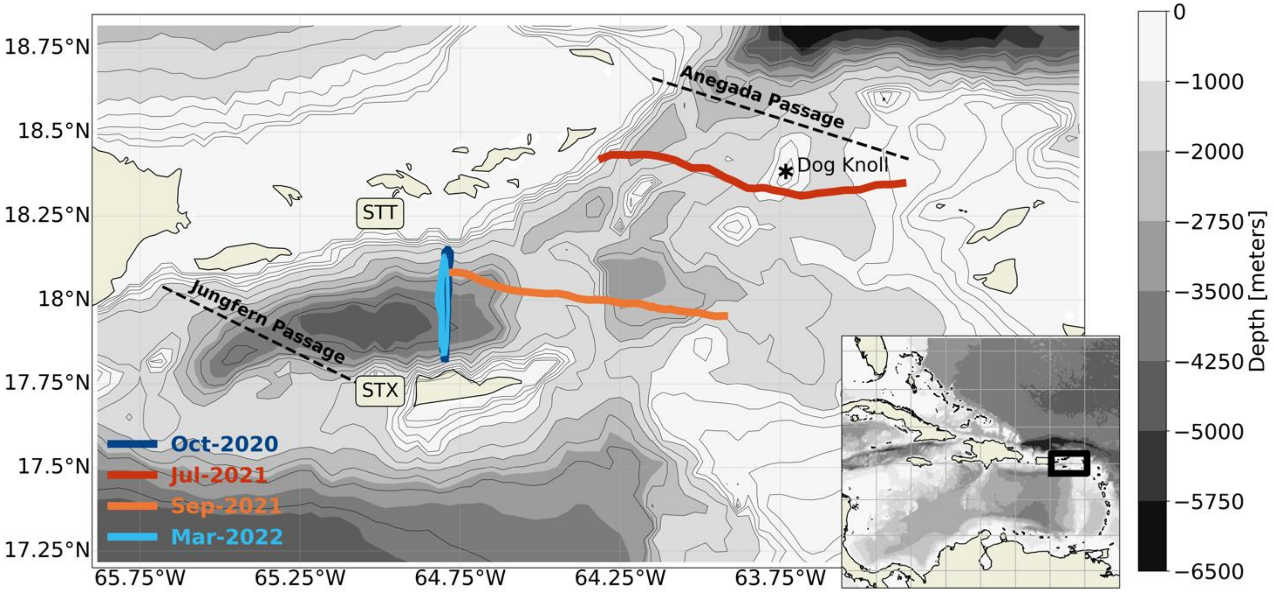
South Atlantic:
Colder and Fresher



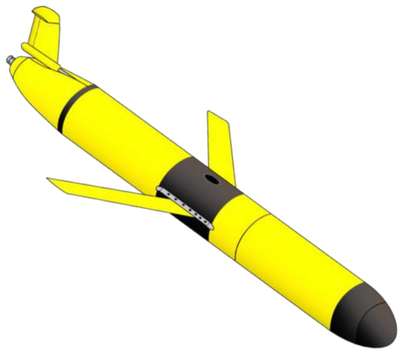
Glider observations in passages spanning north to south, a large gradient in water mass properties



(Zhang et al. 2003)



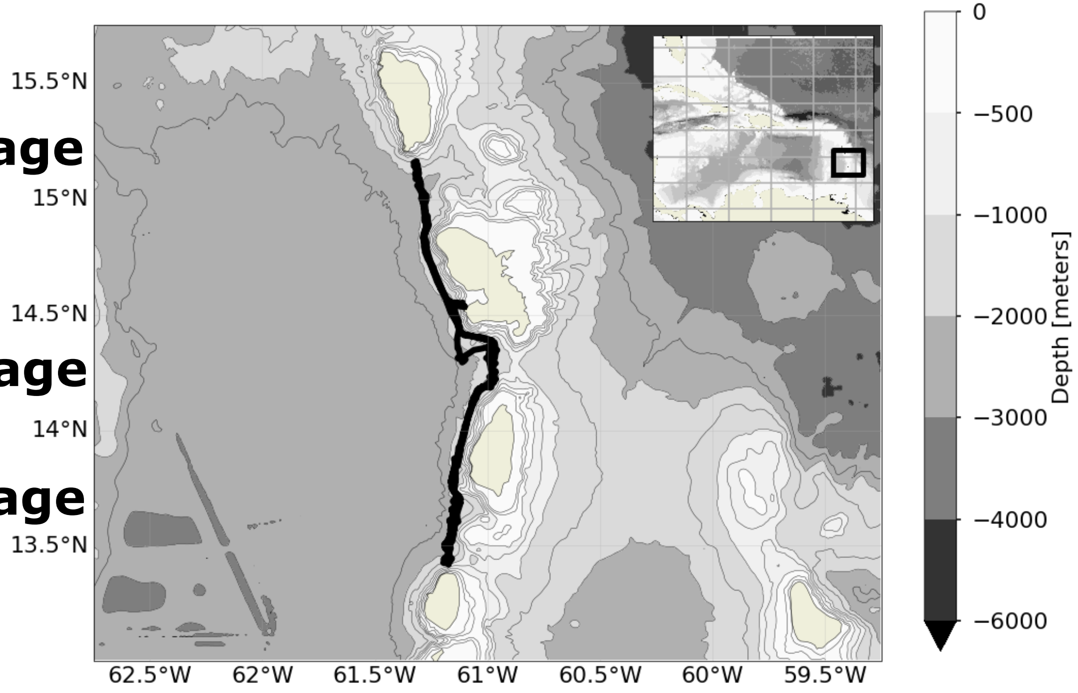
Anegada Passage



Dominica Passage

St. Lucia Passage

St. Vincent Passage



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

Windward Passages Deployments (2023)

A scientific machine surveys the Caribbean waters

a collaboration between American scientists and the Agoa Sanctuary

Field activities | Scientific monitoring | Martinique | Lesser Antilles

October 05, 2022

Since Monday October 3, three American scientists have been hosted in the premises of the Agoa Sanctuary as part of an opportunistic collaboration. Our scientists are taking advantage of the deployment of an American glider in the waters of the French West Indies to attach a hydrophone and test a data collection method.

Travis Miles, Joe Gradone, and Doug Wilson, American researchers from the University of the US Virgin Islands and Rutgers University in New Jersey, are working on ocean water parameters. They are carrying out a mission in the South of the Antilles arc with the aim of studying the heat transfers of currents coming from Brazil and entering the Caribbean. This mission also allows them to improve weather models for predicting cyclones, the latter requiring precise water temperature to gain strength. To carry out this mission they use an underwater glider, or glider in English.

The glider is an **autonomous satellite-controlled machine** that will take measurements in the water column along its path. It carries out programmed dives up to 1000 m deep during which its sensors (oxygen, temperature, salinity) will record the characteristics of the water masses depending on the depth. Each time it returns to the surface, the glider sends the results of its dive to land via satellites.

Around the world, gliders are also used to study the chemistry of the oceans and the animals that inhabit them. Equipping them with hydrophones allows you to hear the animals that are on the the mission route: whale songs, sperm whale clicks or dolphin whistles. The interest is then to obtain recordings of areas inaccessible by boats, offshore, in the depths, while avoiding the sea conditions of the hurricane season. Thus, this type of mission can help **improve knowledge on the distribution of cetaceans across the Caribbean** .

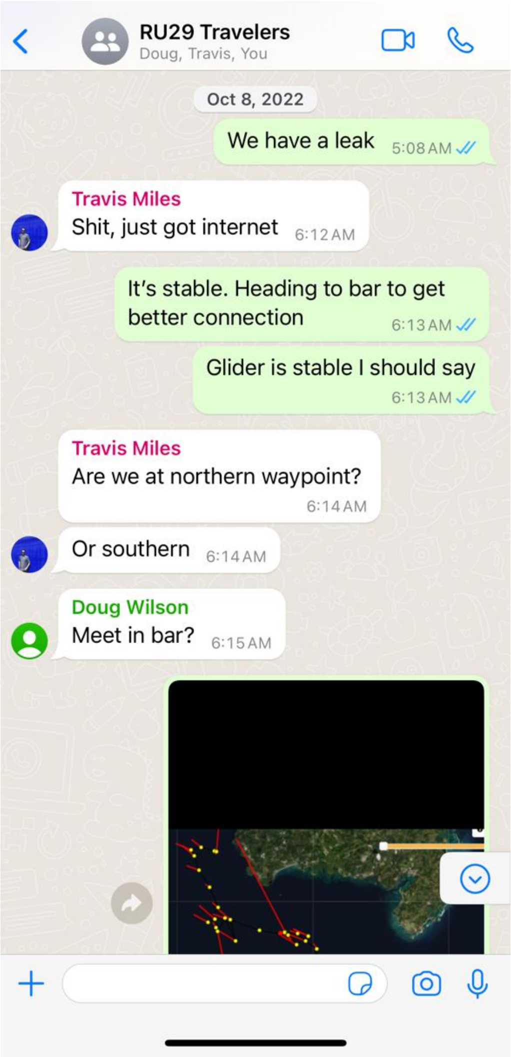
AGOA
sanctuaire mammifères marins
french west indies ANTILLES FRANÇAISES

TELEDYNE MARINE
Everywhereyoulook™

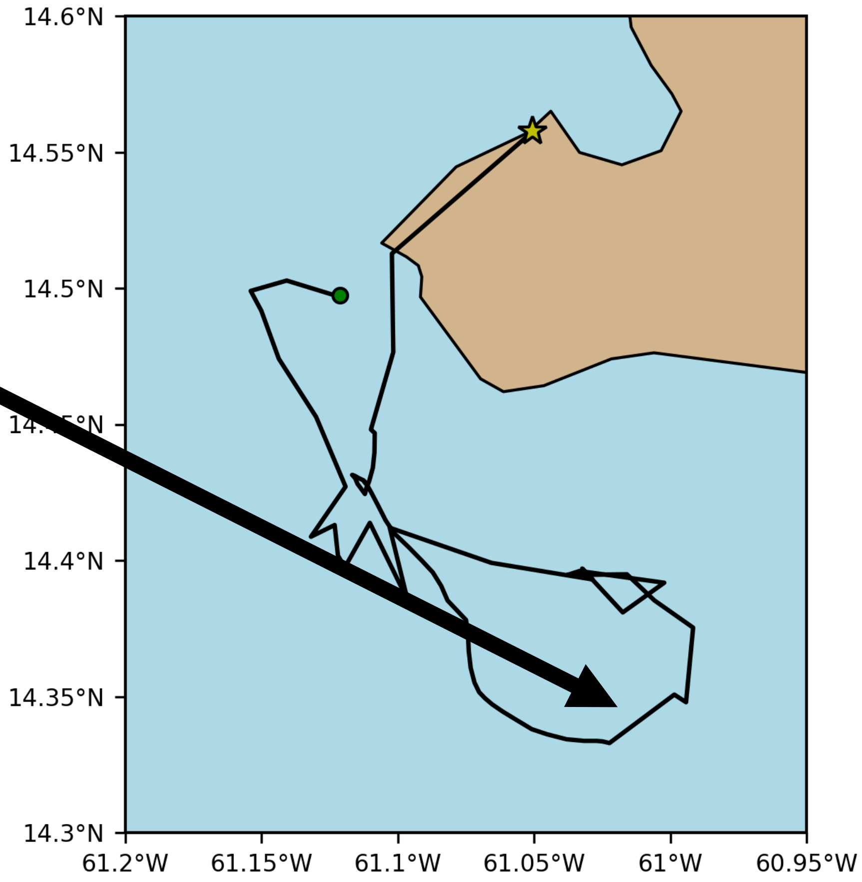
THE G. UNGER VETLESEN FOUNDATION

RUCOOL

Windward Passages Deployments (2023)

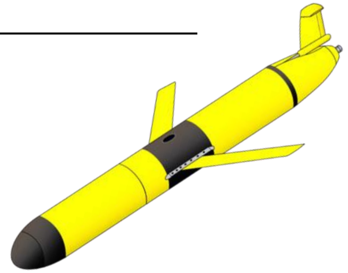


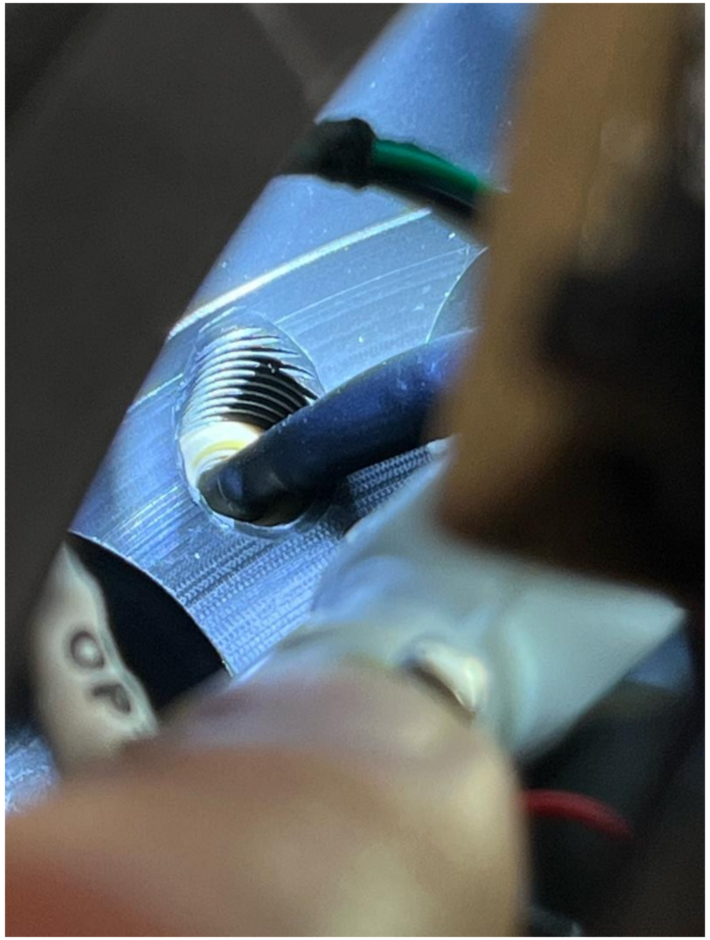
Leak!

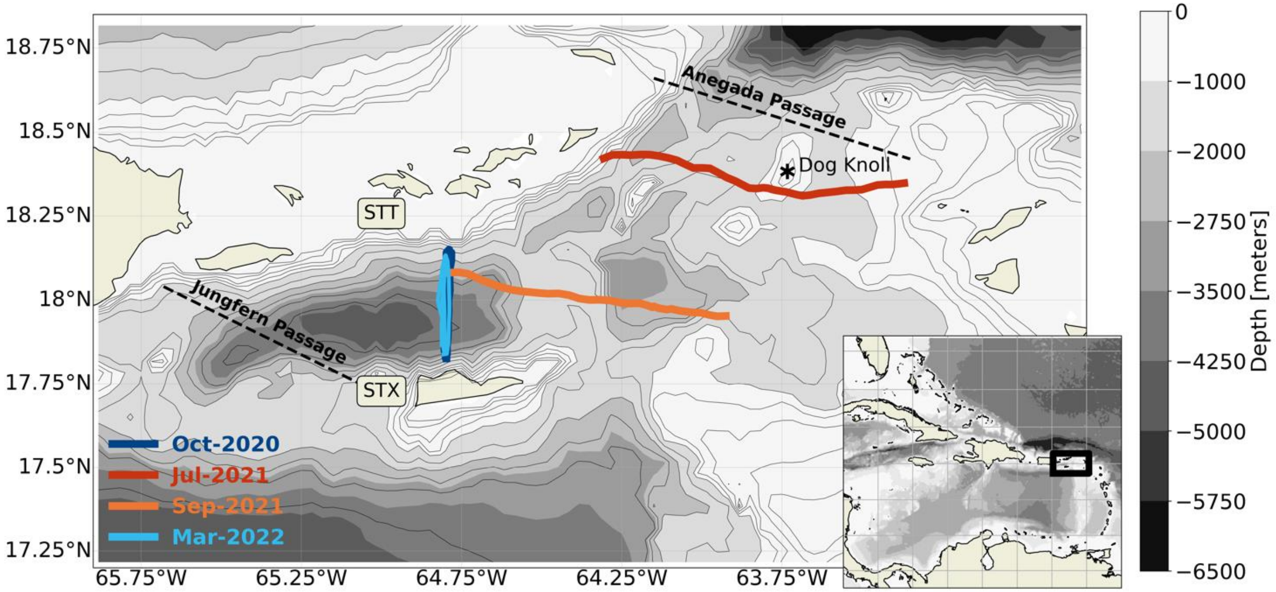


Windward Passages Deployments (2023)

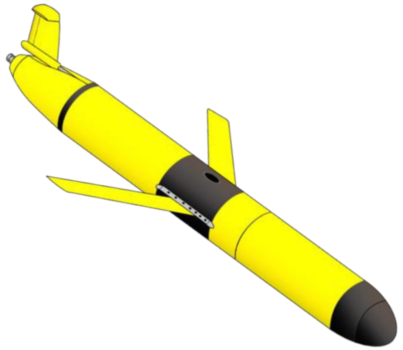
Windward Passages Deployments (2023)







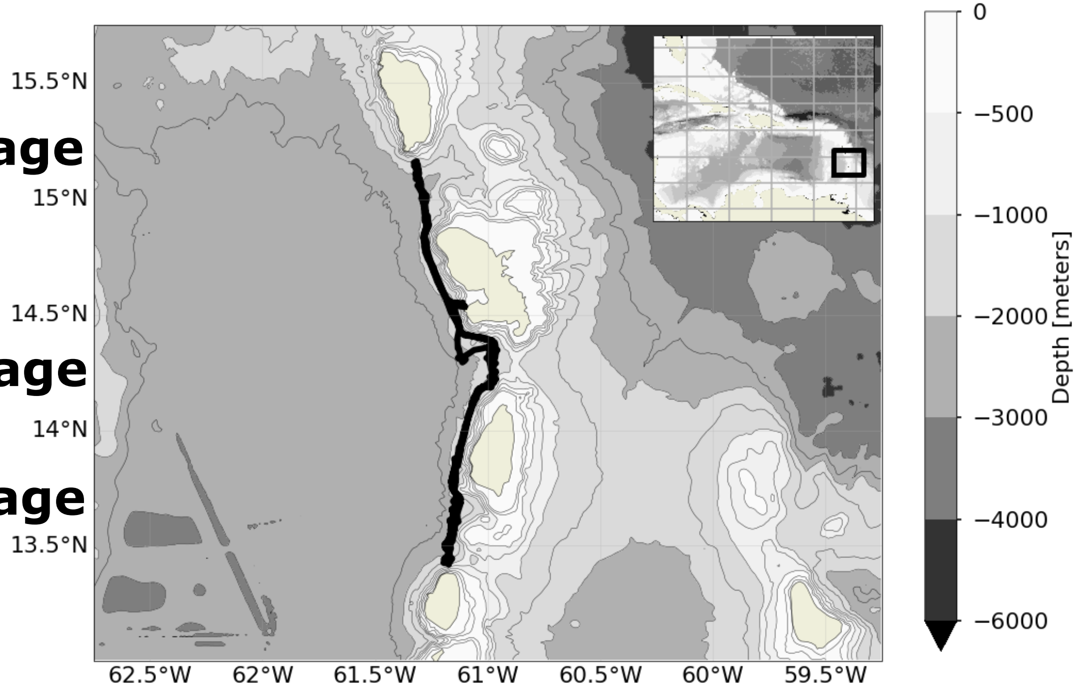
Anegada Passage



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

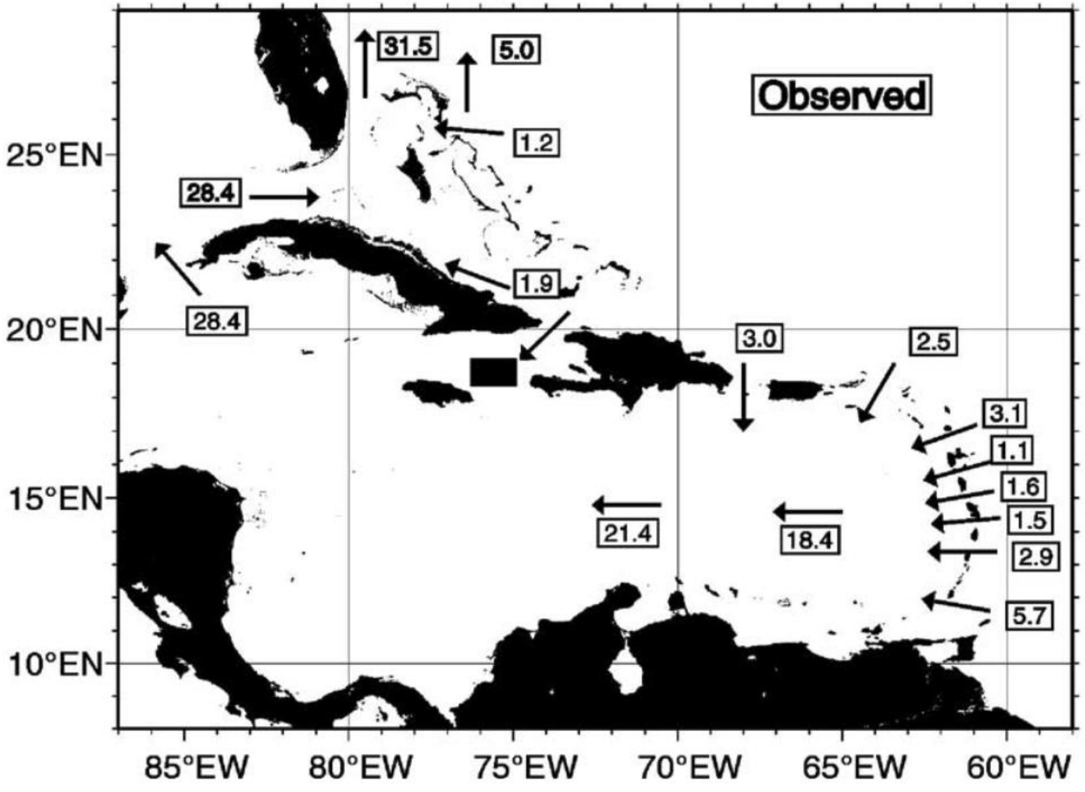
William E. Johns[a,*], Tamara L. Townsend[b], David M. Fratantoni[c], W. Douglas Wilson[d]

[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
[c] Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
[d] Physical Oceanography Division, NOAA/AOML, 4301 Rickenbacker Causeway, Miami, FL 33149, USA

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

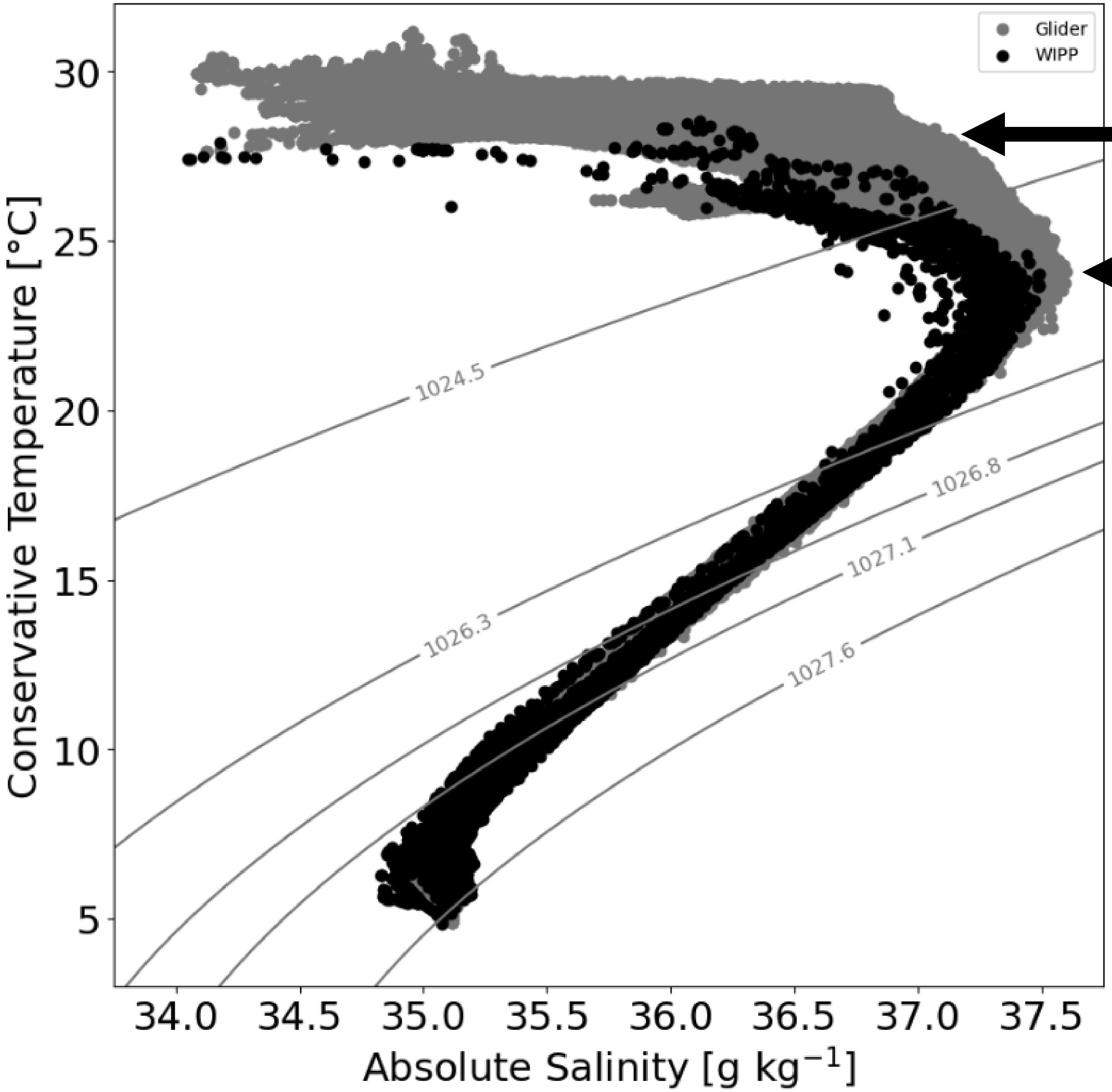
Glider (2020-2023)

versus

Windward **I**sland **P**assage Monitoring **P**rogram

(**WIPP**)

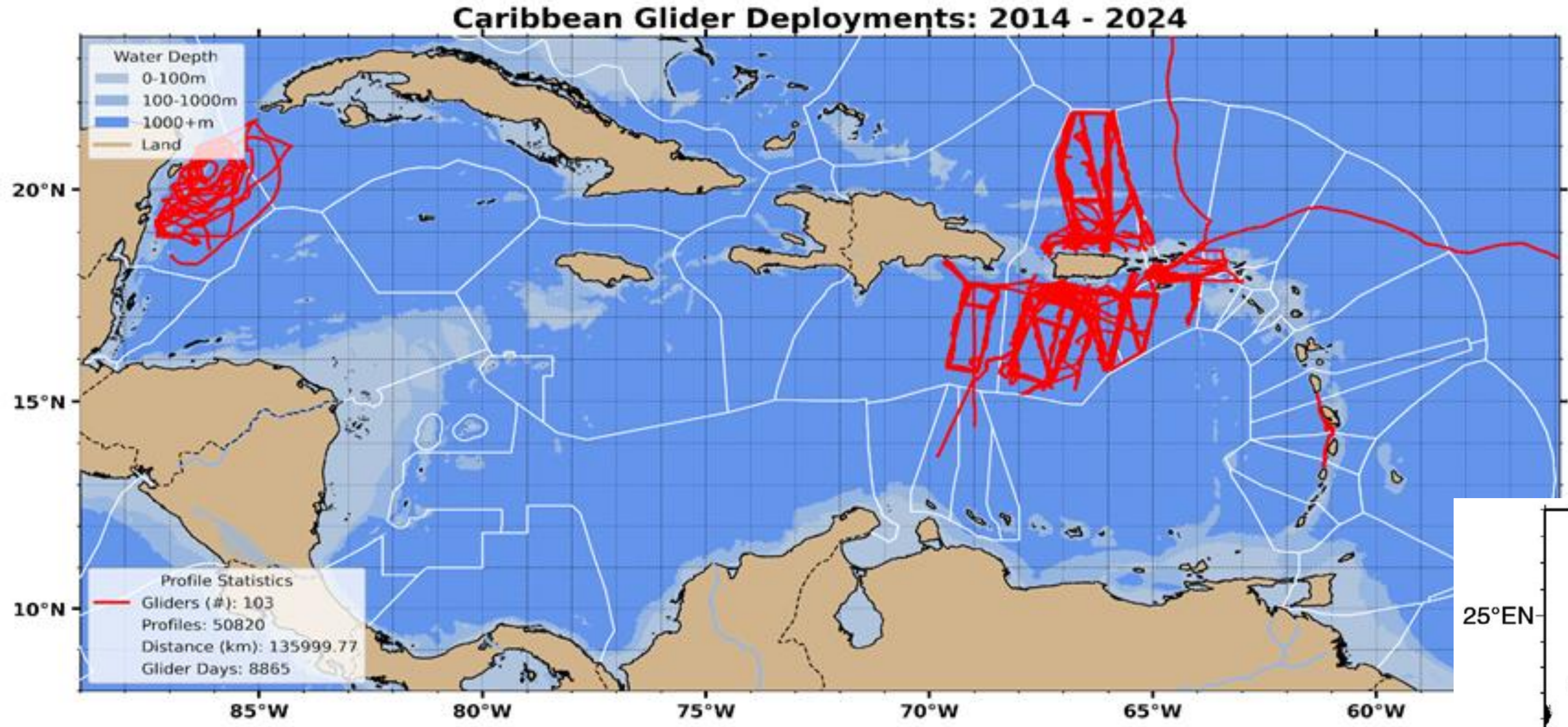
(1991-2001)

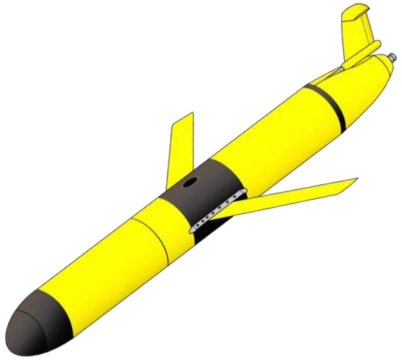


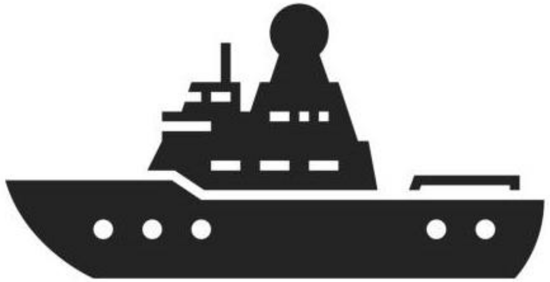
Upper ocean warming

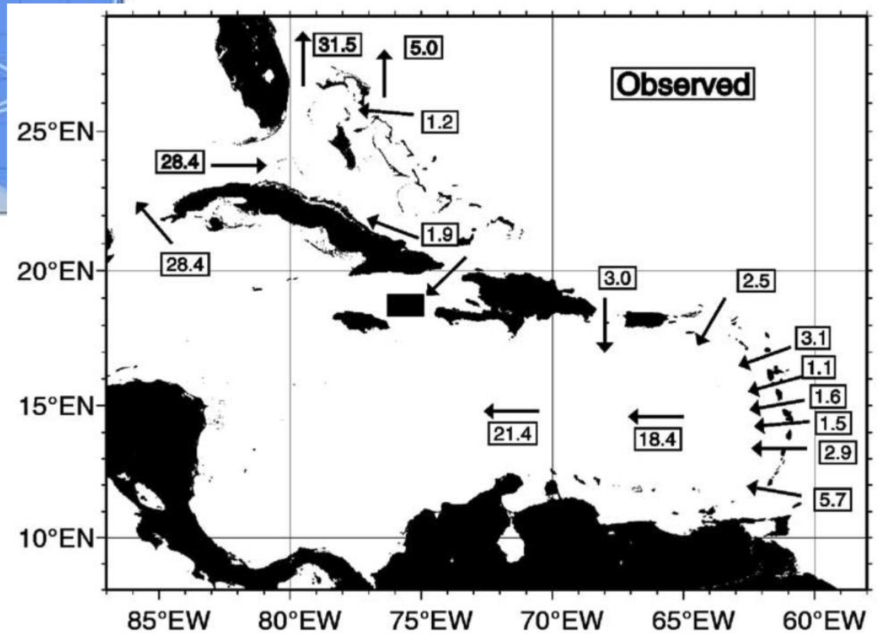
Salinification of Salinity Max Waters

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

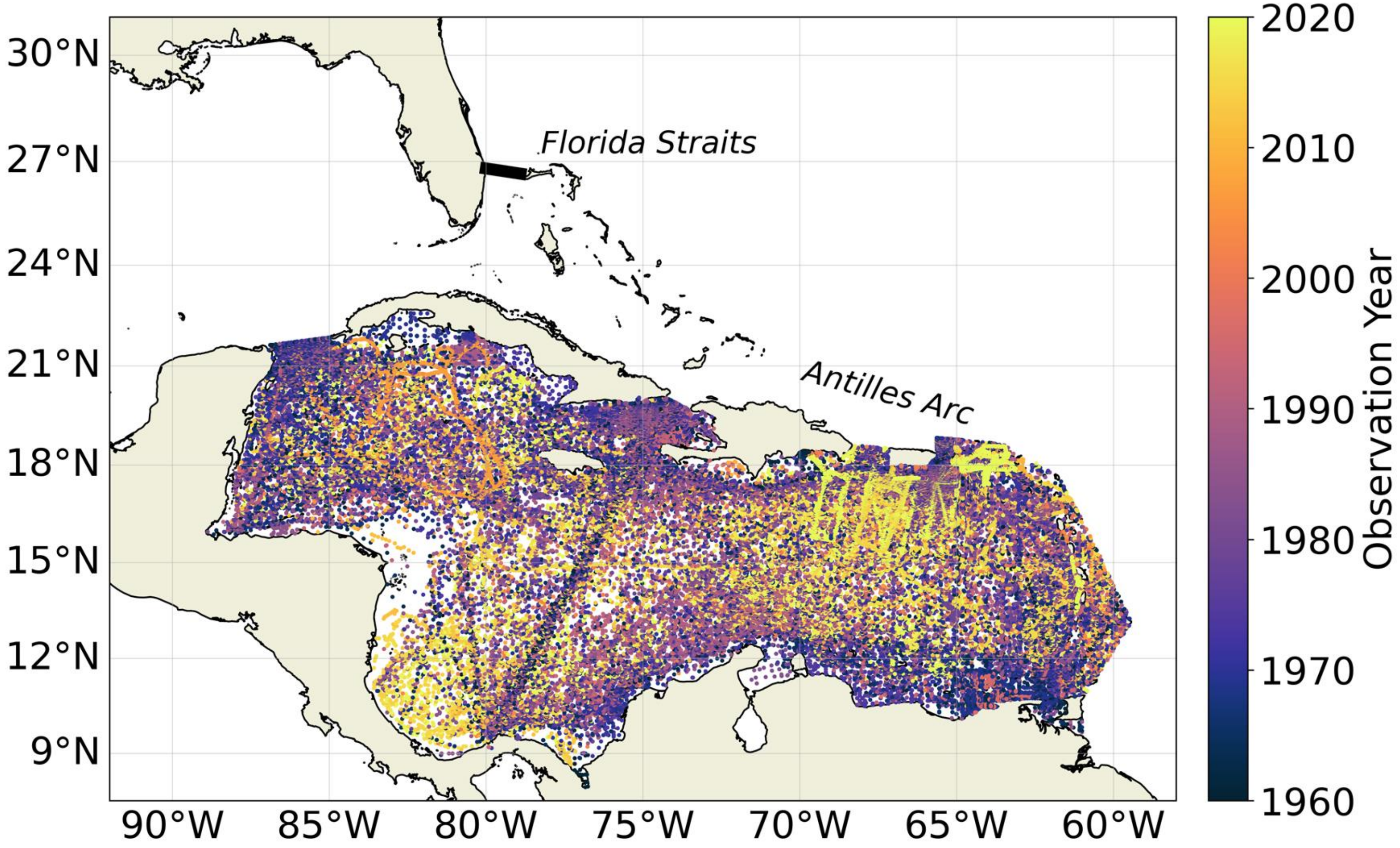

Caribbean Glider Deployments: 2014 - 2024
Water Depth
0-100m
100-1000m
1000+m
Land
Profile Statistics
Gliders (#): 103
Profiles: 50820
Distance (km): 135999.77
Glider Days: 8865
20°N
15°N
10°N
85°W
80°W
75°W
70°W
65°W
60°W






Observed
31.5
5.0
1.2
28.4
1.9
28.4
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



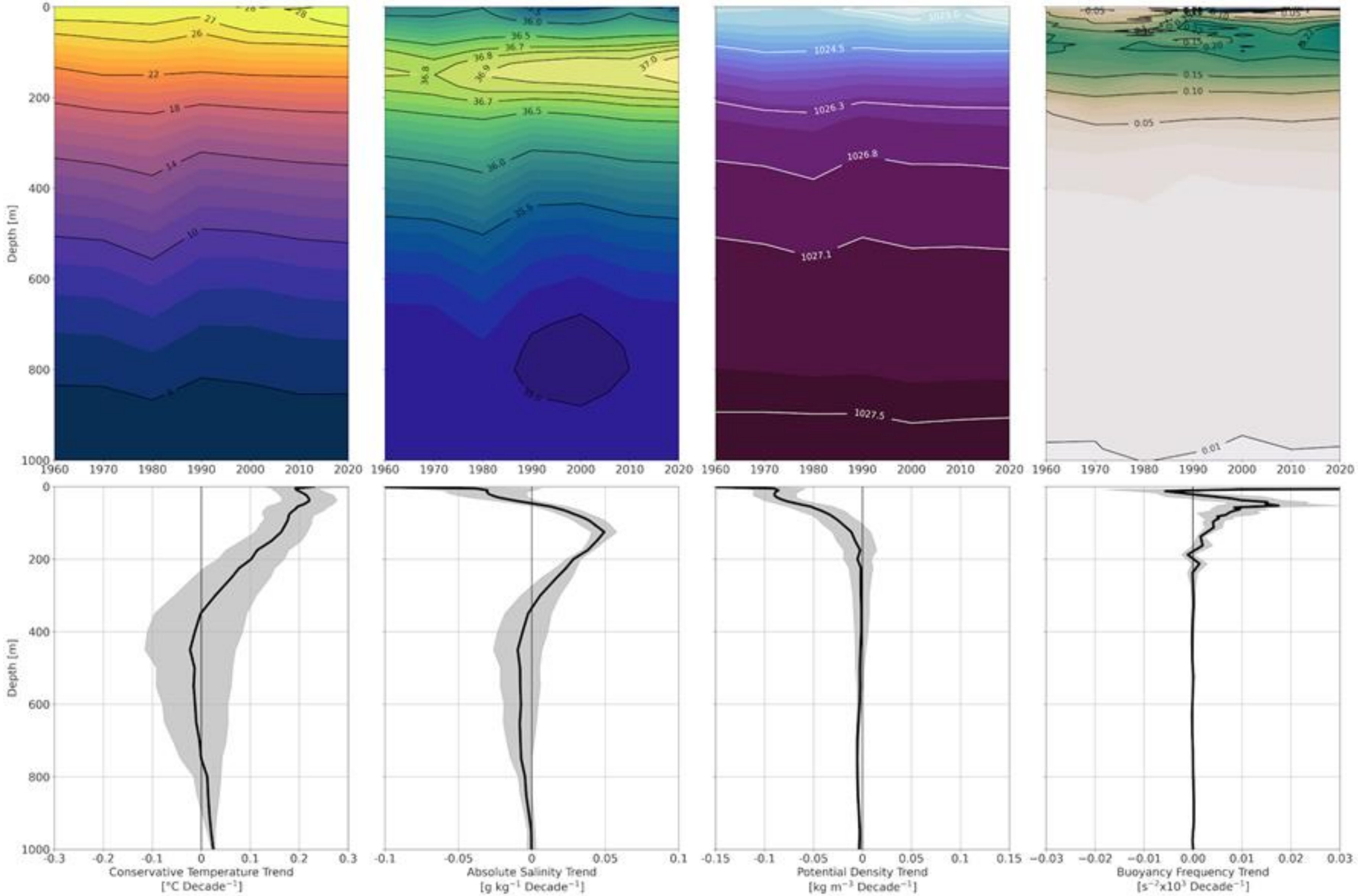
Comprehensive Water Mass Analysis

<u>EN4 Database</u>
>28,000 profiles

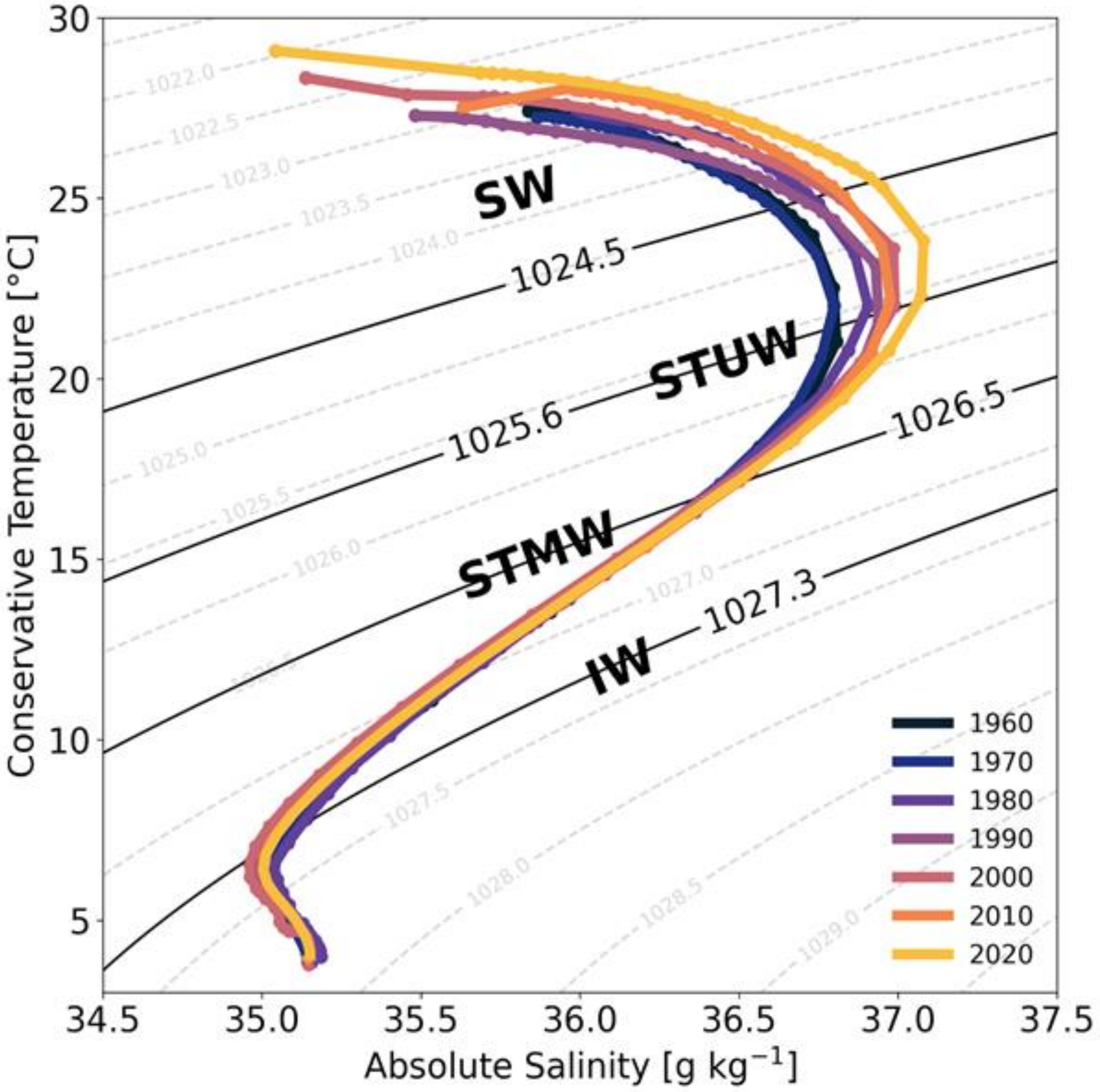
Gradone et al. In Review: *Nature Comms. Earth & Environ.*

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}**
5. **Increased stratification 20x global trends**



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



Implications for:

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

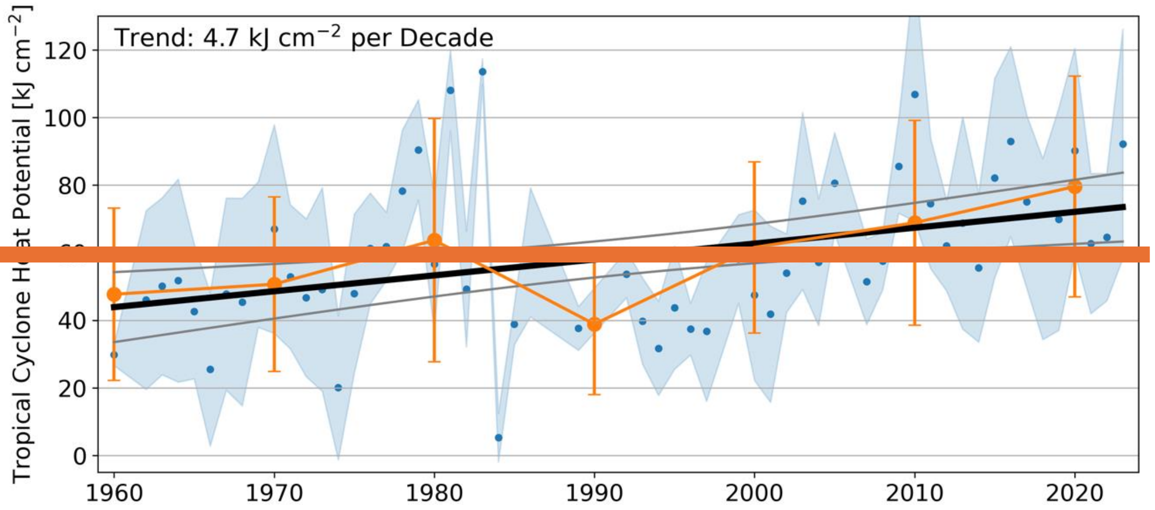
Gradone et al. In Review: *Nature Comms. Earth & Environ.*

Tropical Cyclone Heat Potential:

$$Q = \rho C_p \Delta T \Delta z$$

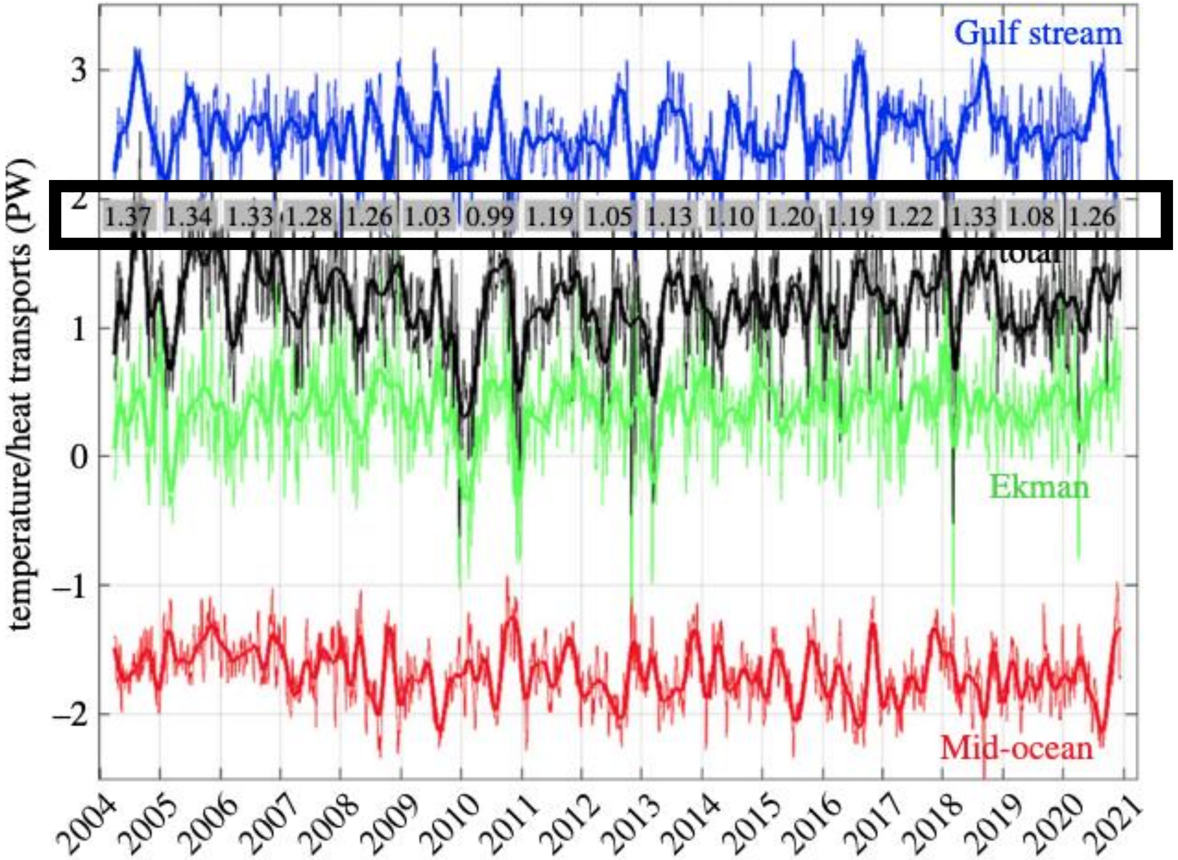
>60 kJ cm^{-2}

threshold for intensification

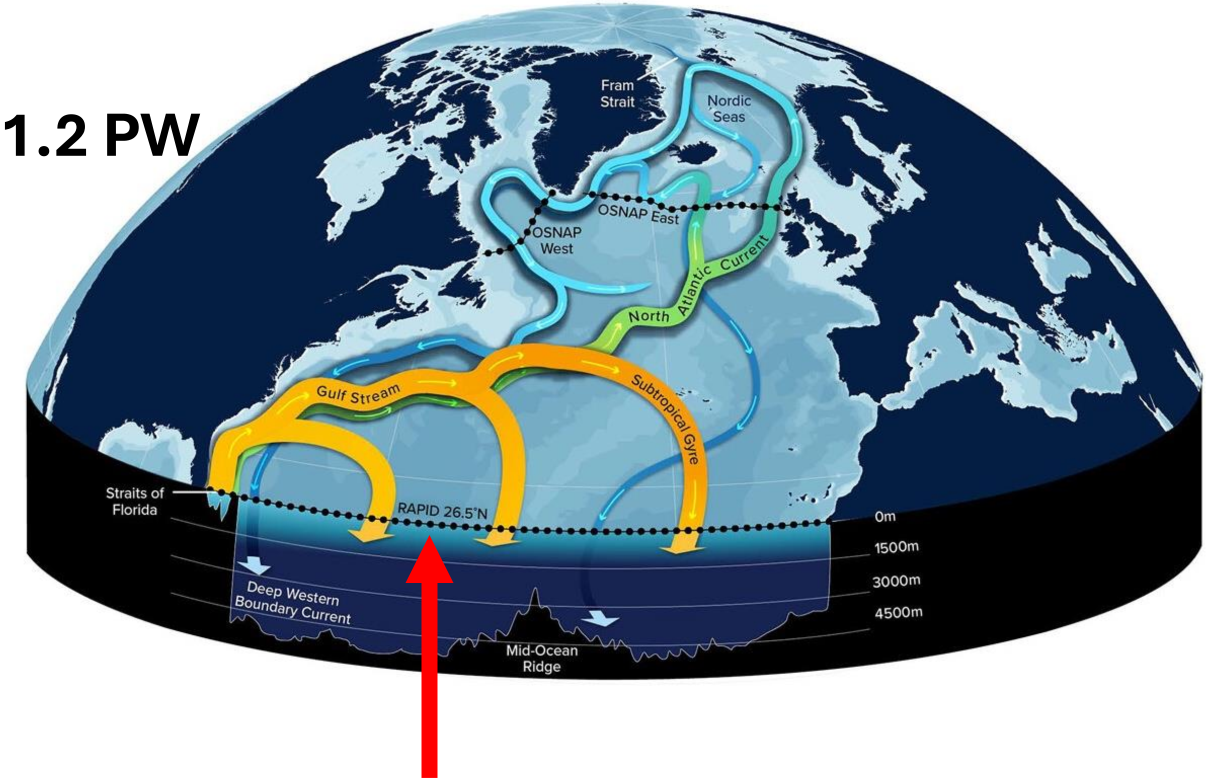


Gradone et al. In Review: *Nature Comms. Earth & Environ.*

With mass balanced: net heat transport



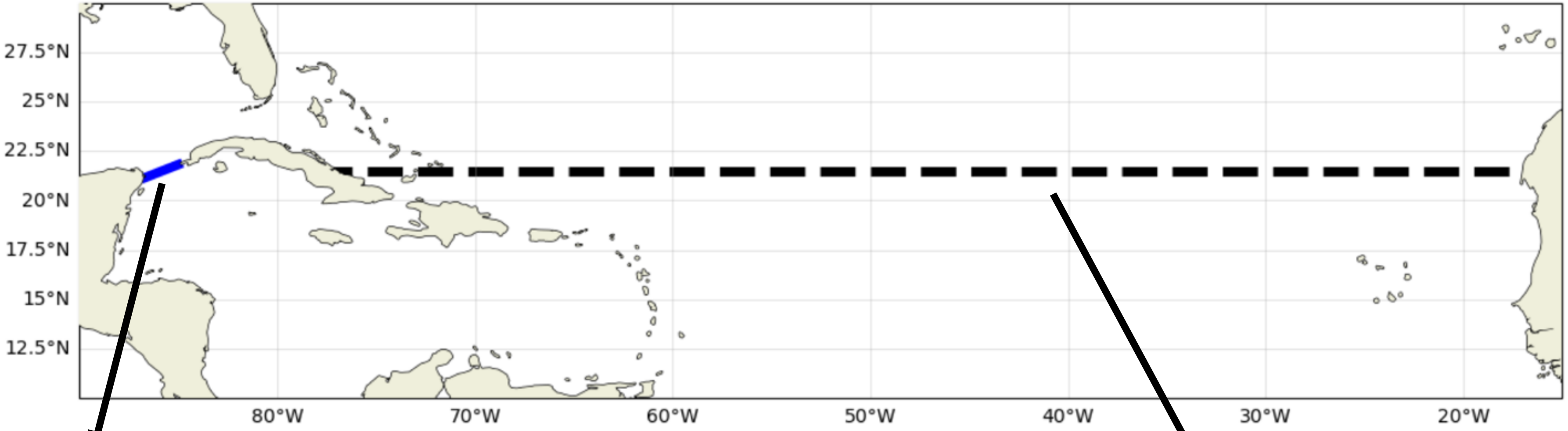
1.2 PW

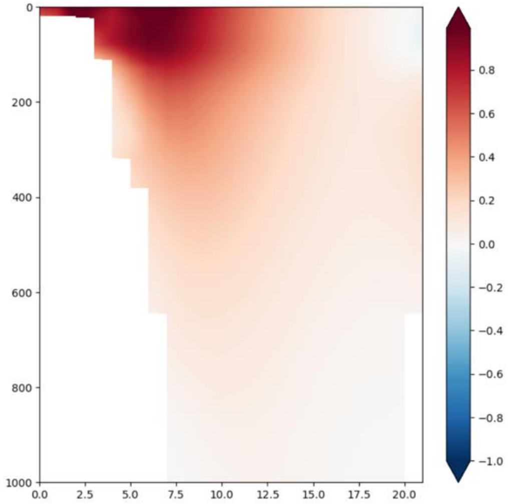


Total = (Gulf Stream + Ekman) - (Mid-ocean)

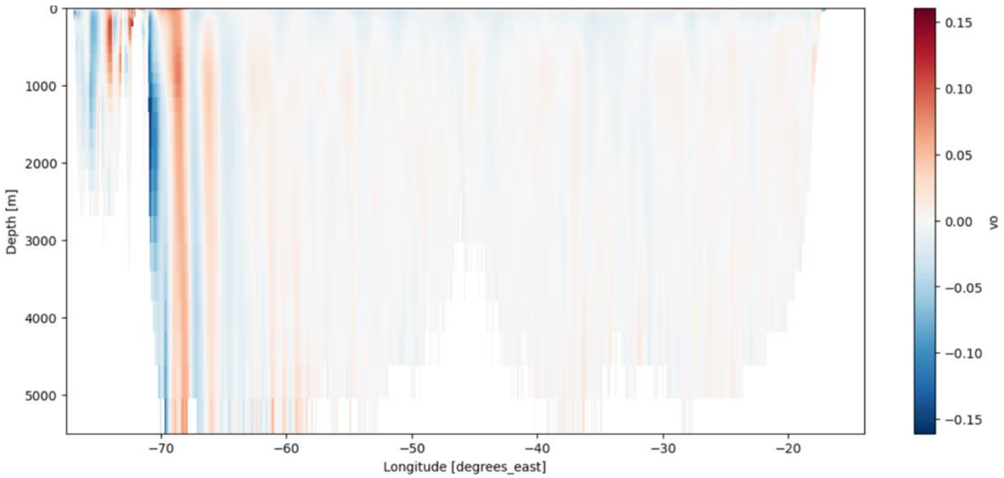
Johns et al. (2023)

Basin-wide mass balance at 21.5ºN





Copernicus Marine
GLORYS Reanalysis
1993-2023
10-day
1/12º



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

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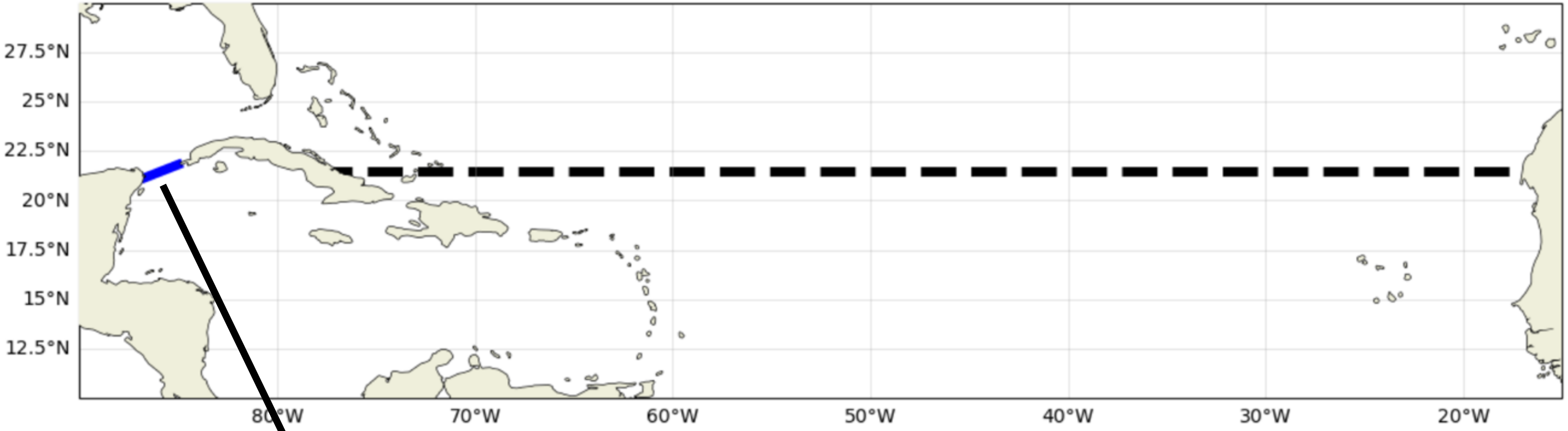
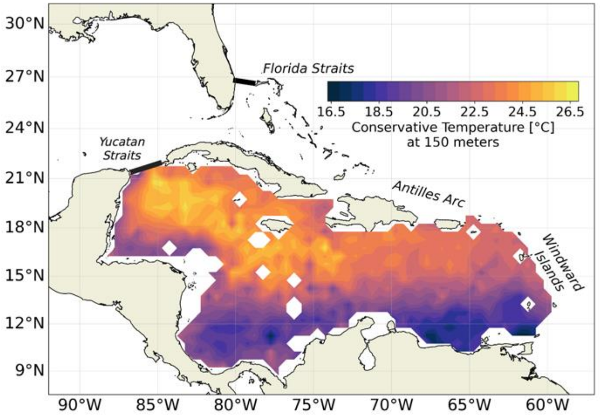
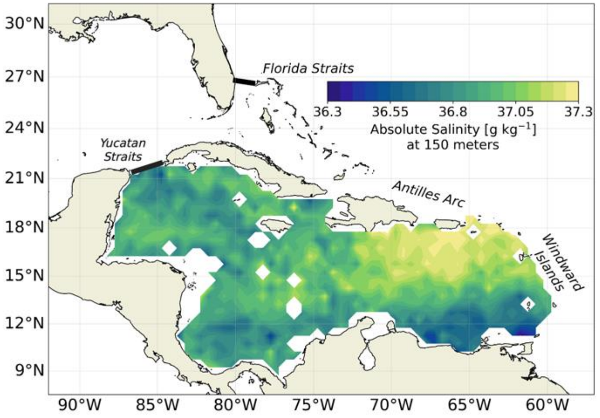


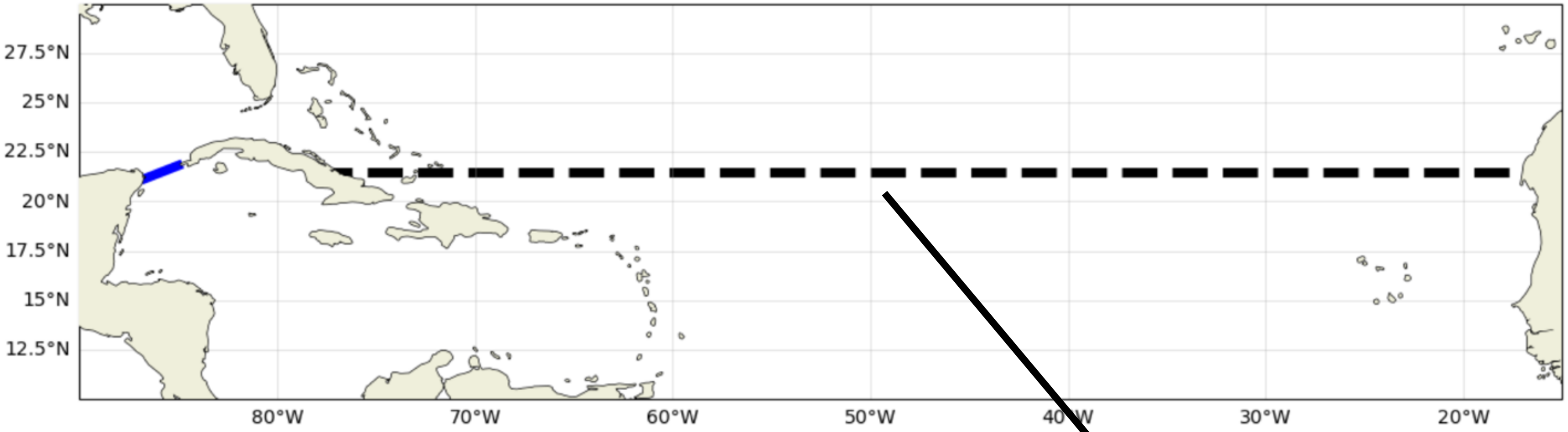
Yucatan Straits hydrographic data from water mass analysis dataset

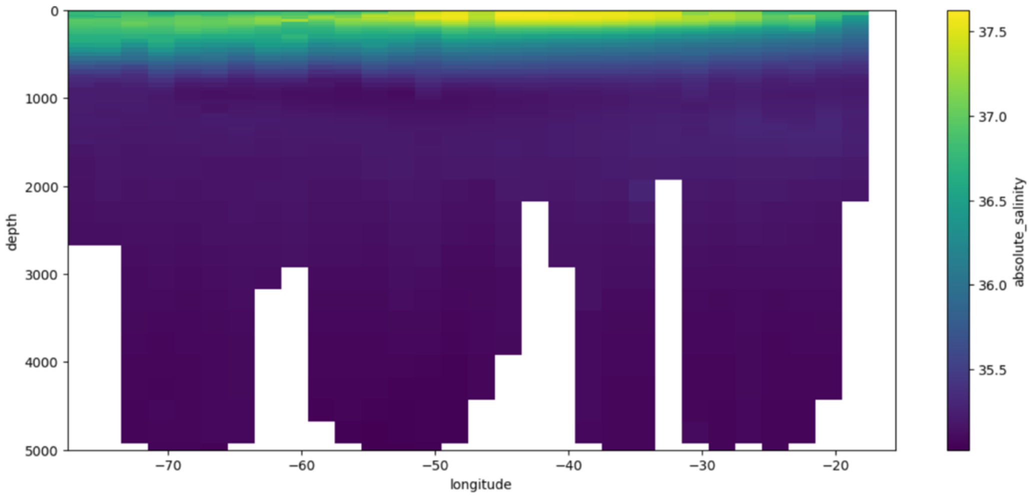




Gradone et al. In Review: *Nature Comms. Earth & Environ.*

Basin-wide mass balance at 21.5ºN





Atlantic interior hydrographic data from EN4 database

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

With mass balanced: Yucatan Straits transport 1960-2023

Heat Transport: $\iint \rho c_p v\theta \, dx \, dz$

Salt Transport: $\iint vS \, dx \, dz$

Freshwater Transport: $-\frac{1}{\bar{s}}(F_S - \bar{s}\, T)$

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

With mass balanced: Yucatan Straits transport 1960-2023

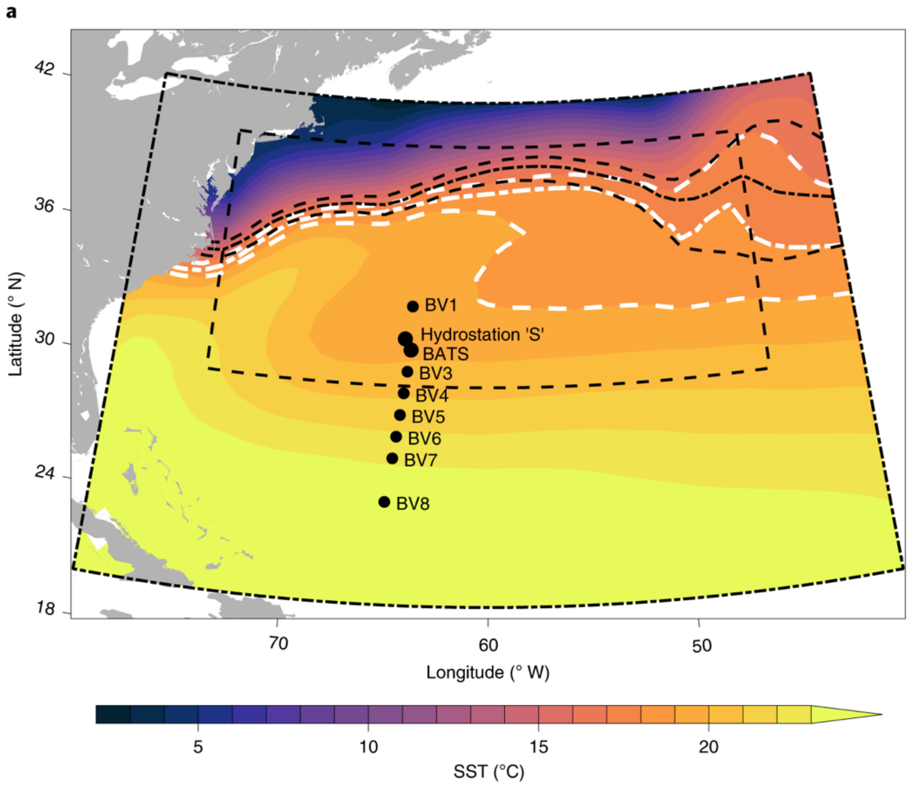
Heat Transport: increase of ~0.07 ± 0.05 PW

Salt Transport: increase of ~1.46 + 2.6 x 10^6 kg s^{-1}

Freshwater Transport: decrease of ~0.025 Sv

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

North Atlantic Subtropical Mode Waters



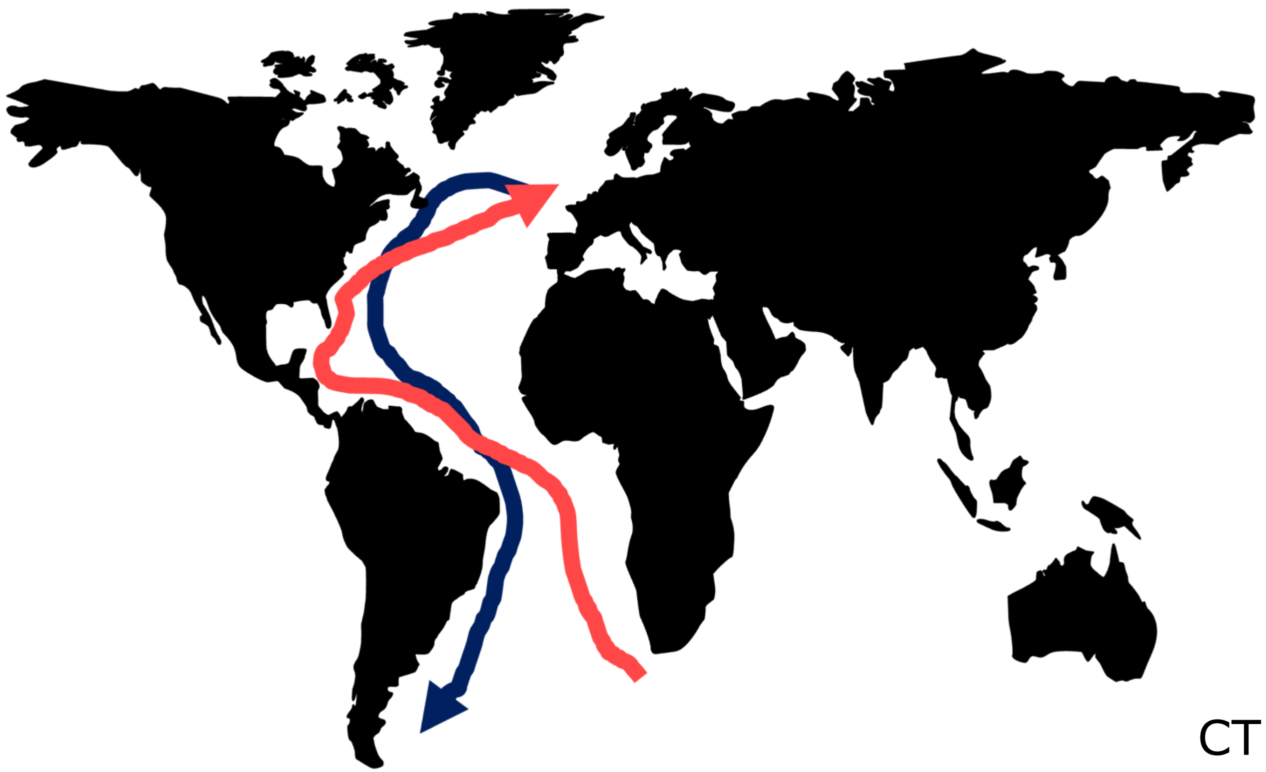
Stevens et al. (2020)

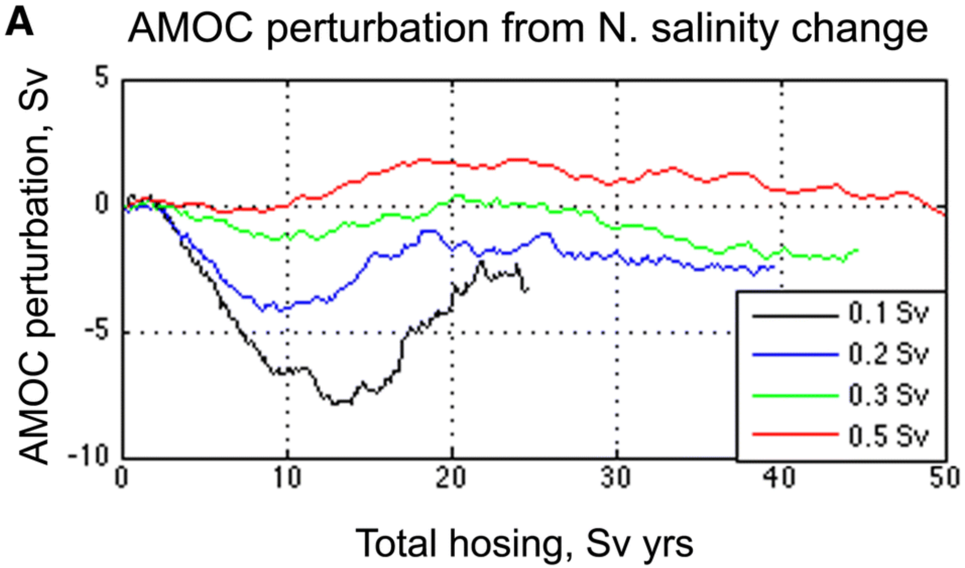
Formed by heat loss of ~0.096 PW
Kwon & Riser (2004)

CTF heat transport *increase* of ~0.07 ± 0.05 PW
~70%

Quantitative support of impact on downstream water mass formation

AMOC stability investigated with freshwater hosing experiments





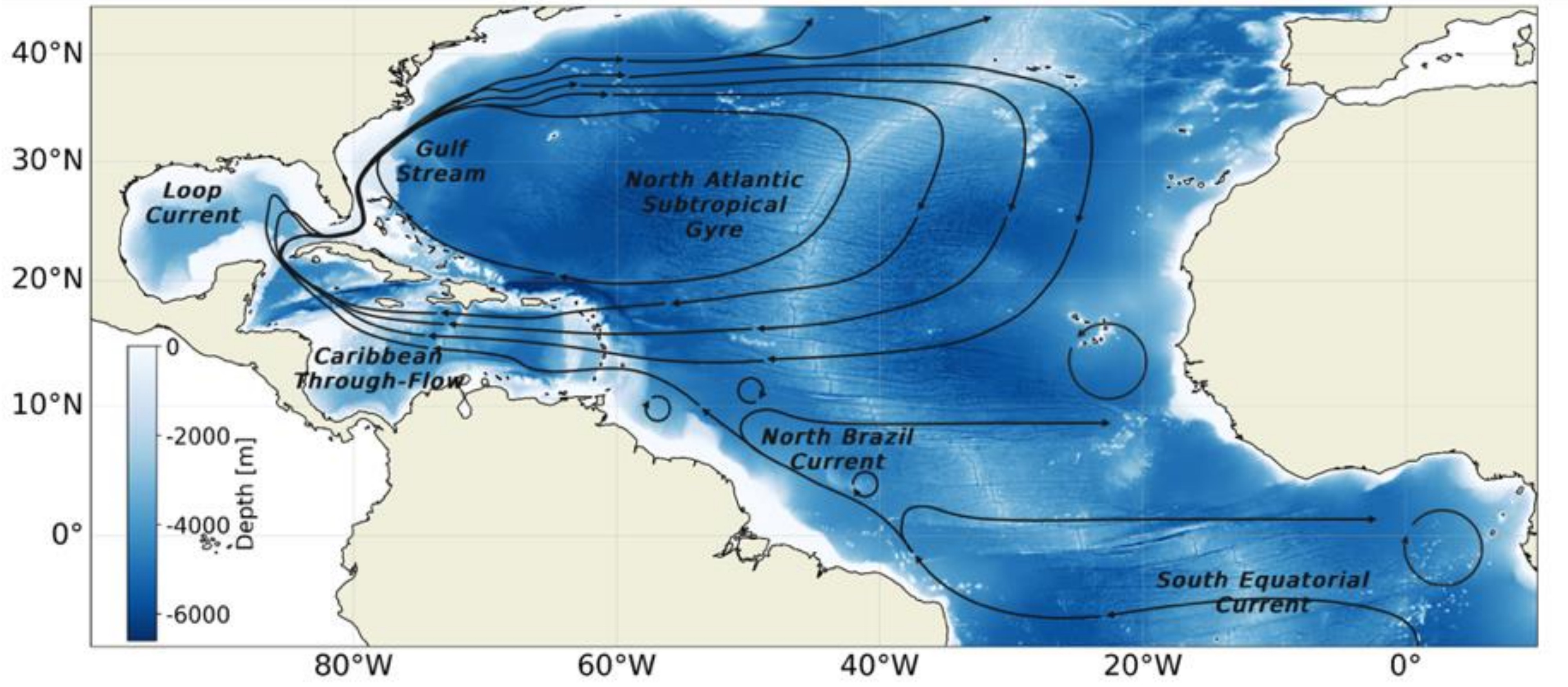
0.5 Sv slowdown in AMOC strength for every **0.01 Sv** of freshwater added at 0.001 Sv/year

CTF freshwater transport trend **-0.004 Sv/decade**

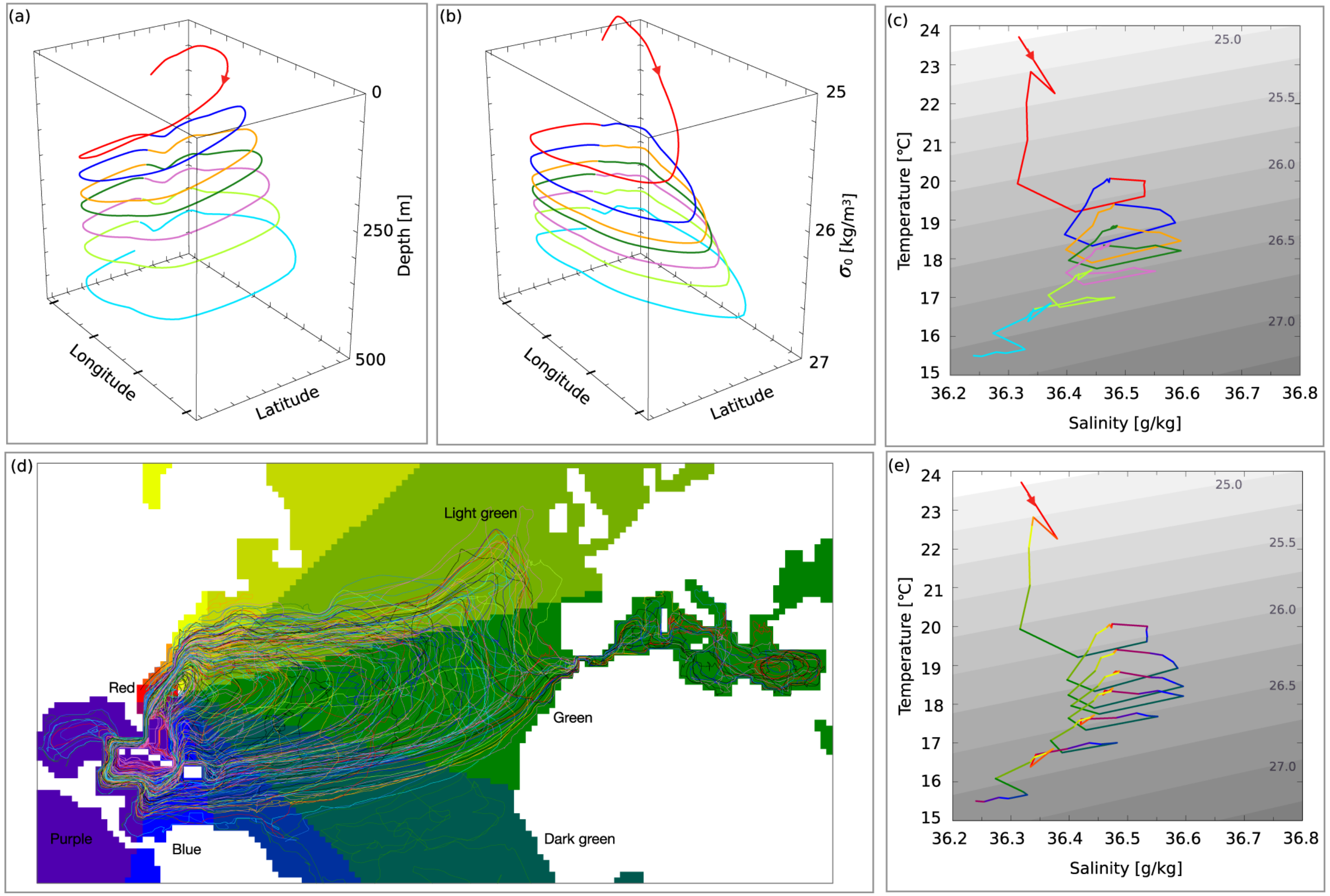
Big Question: Salinification as a stabilizing feedback?

(Haskins et al. 2019; Hu et al. 2023)

Changes in Caribbean Through-Flow water mass properties are impacting water masses formed in the North Atlantic Subtropical Gyre



Downward Spiraling Nature of the North Atlantic Subtropical Gyre



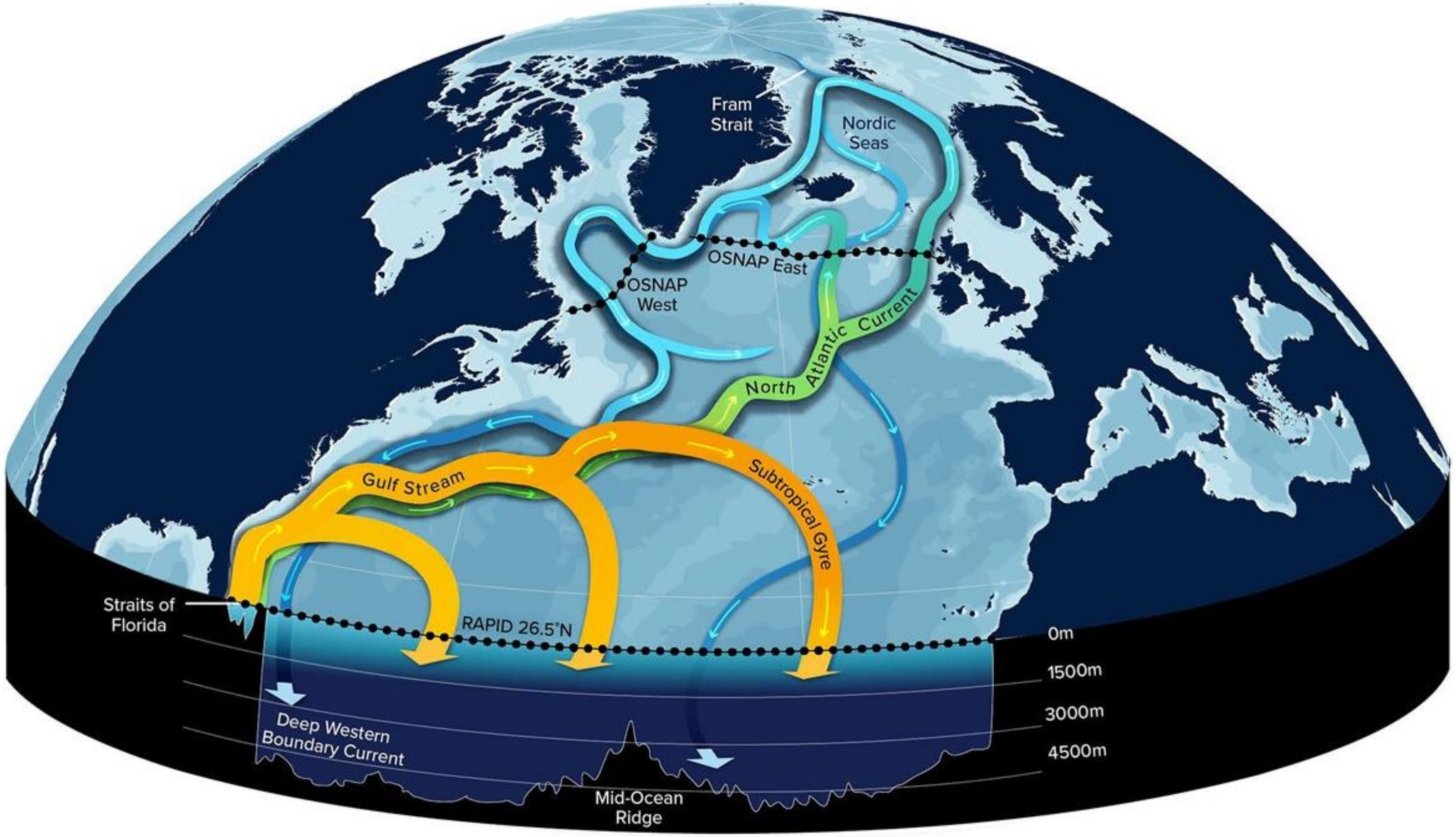
Largely cooling driven

Berglund et al. (2022)

Connecting the subtropical gyre and the AMOC

70% northward flowing **AMOC** upper-limb must recirculate in the **gyre** at least **once**

Subsurface connection between the **subtropical** and **subpolar** gyre



Tooth et al. (2024)

Table of Contents.

Table of Contents.

Motivation

- Importance of the circulation in the Tropical Atlantic
- Advancing the use of gliders as components of the global ocean observing system

Chapter 1

1. AP transport may be larger than previously estimated
2. AP may be a larger inflow route of SAW than previously estimated

Chapter 2

1. Decadal trends in the water mass properties of the CTF
2. Implications:
   - Sea level rise
   - TC activity
   - Biodiversity
   - Water mass formation

Chapter 3

- Westward modification of CTF water mass structure
- How important are CTF water mass mixing processes?

Chapter 3

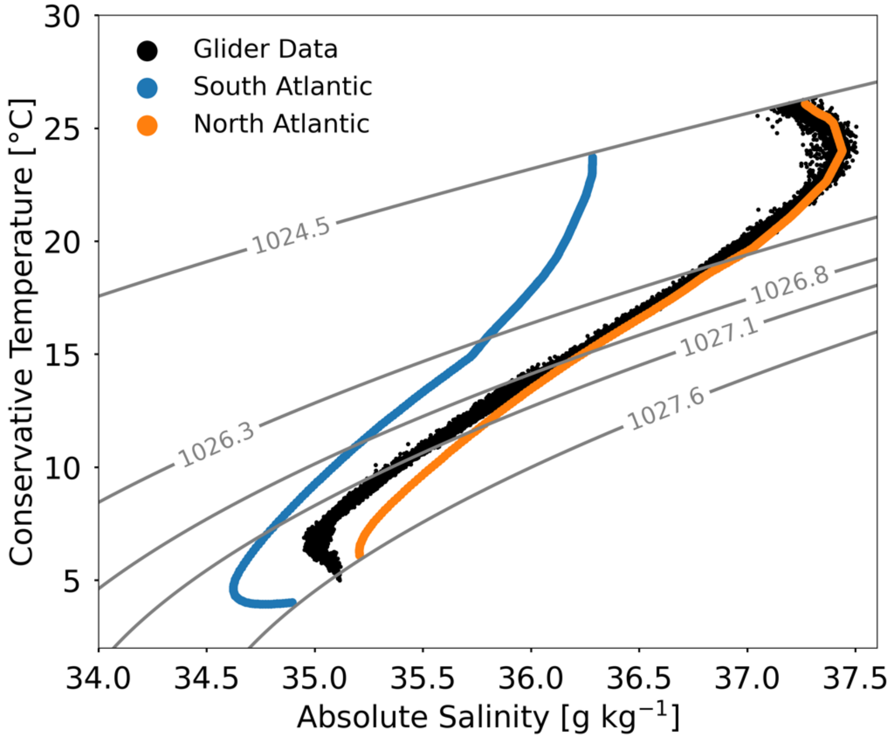
Spatial and Temporal Variability in Caribbean Through-Flow Water Mass Structure

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



The Caribbean's role as a bottleneck for North and South Atlantic water masses motivates <u>two research questions</u>:

1. How does water mass structure vary temporally and spatially in the CTF?

2. Does this variability impact the transport of heat, salt, and freshwater in the CTF?

Gradone et al. In Prep

The Caribbean's role as a bottleneck for North and South Atlantic water masses motivates <u>two research questions</u>:

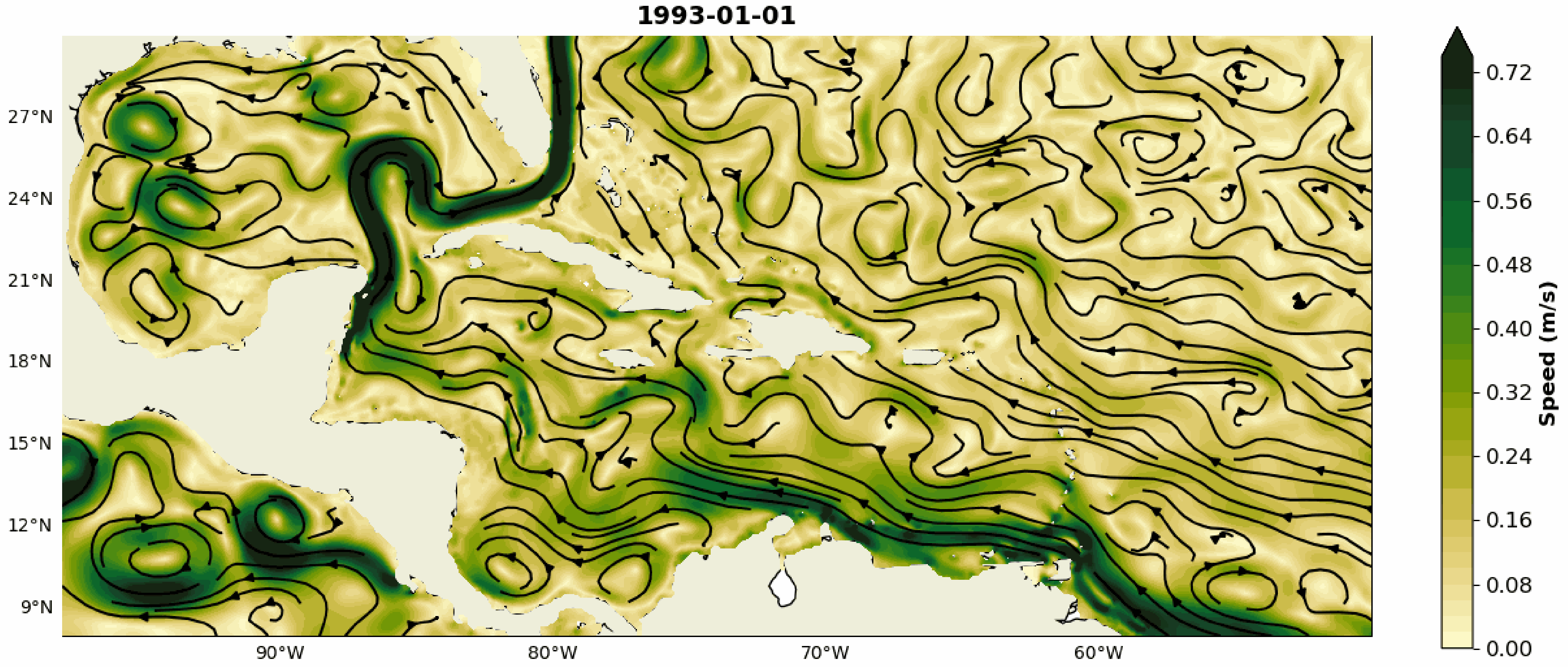
1. How does water mass structure vary ~~temporally~~ and <u>spatially</u> in the CTF?

2. Does this variability impact the transport of heat, salt, and freshwater in the CTF?

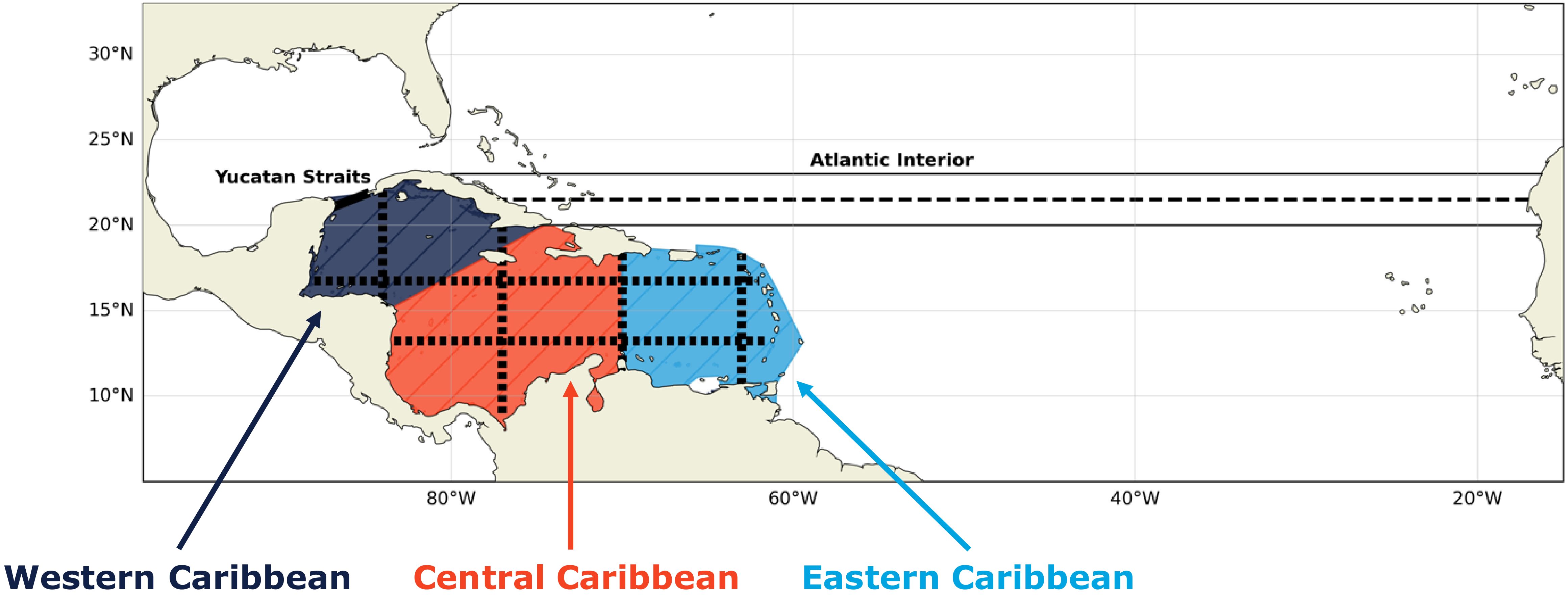
Gradone et al. In Prep

Copernicus Marine 1/12º GLORYS Reanalysis

Captures mesoscale variability in velocity fields ✓



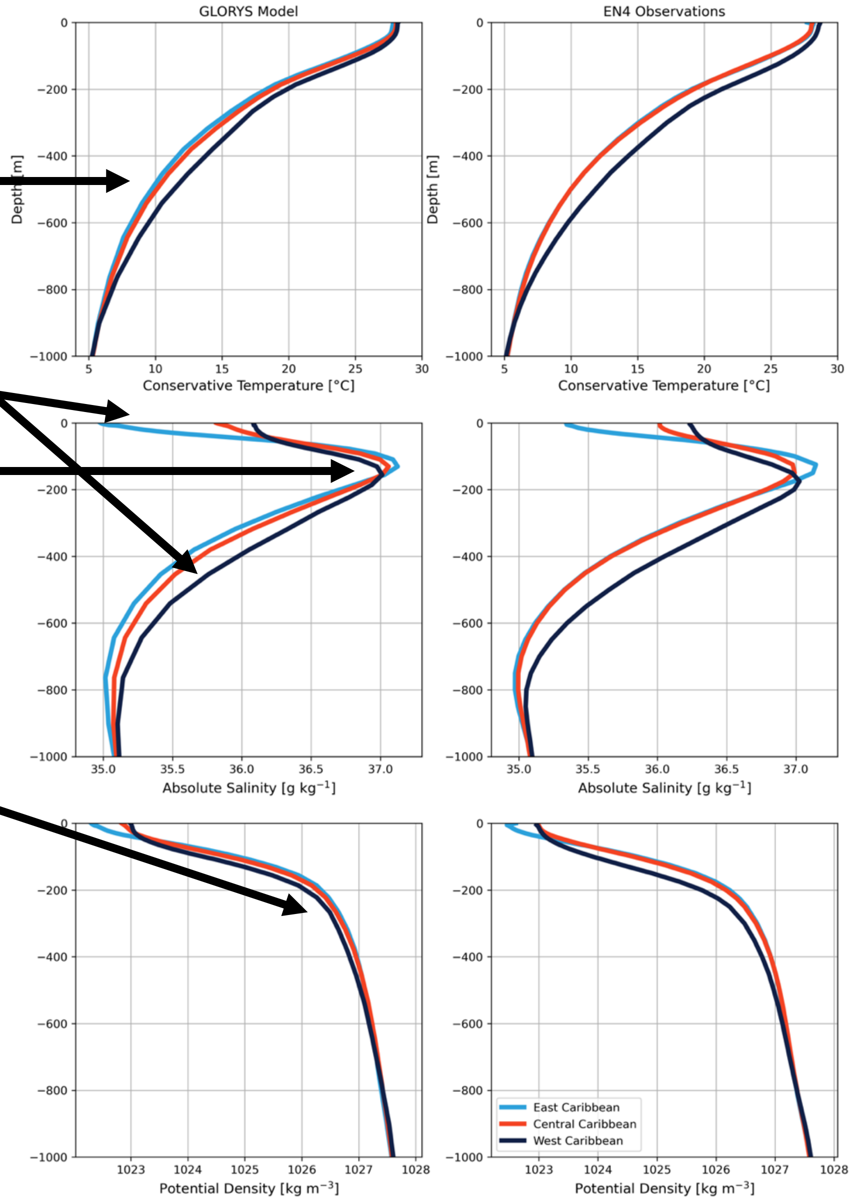
Gradone et al. In Prep



Gradone et al. In Prep

Spatial Variability:

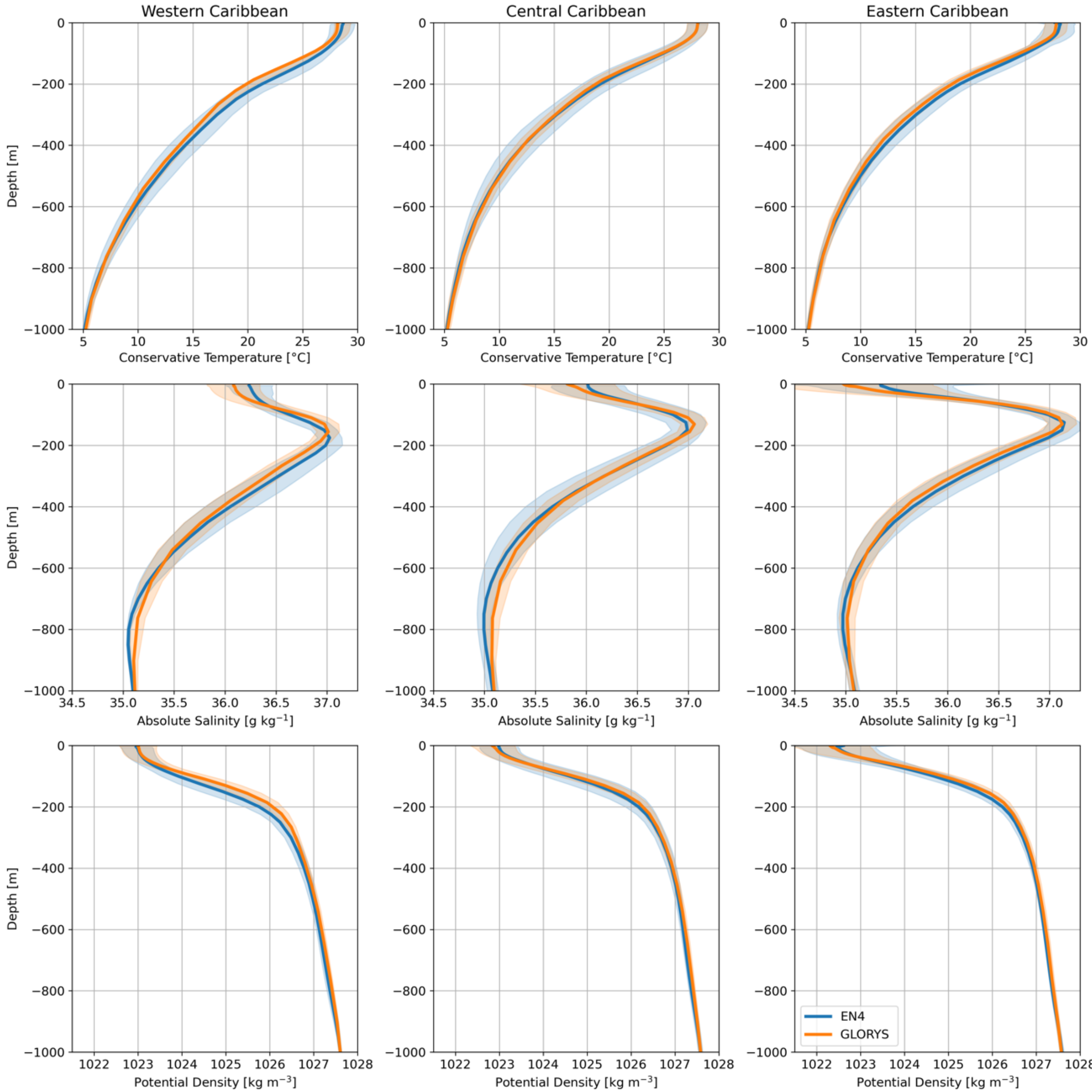
- Subsurface warming and salinification
- Surface salinification
- Deepening and "rounding" of subsurface salinity maximum
- Deepening of isopycnals



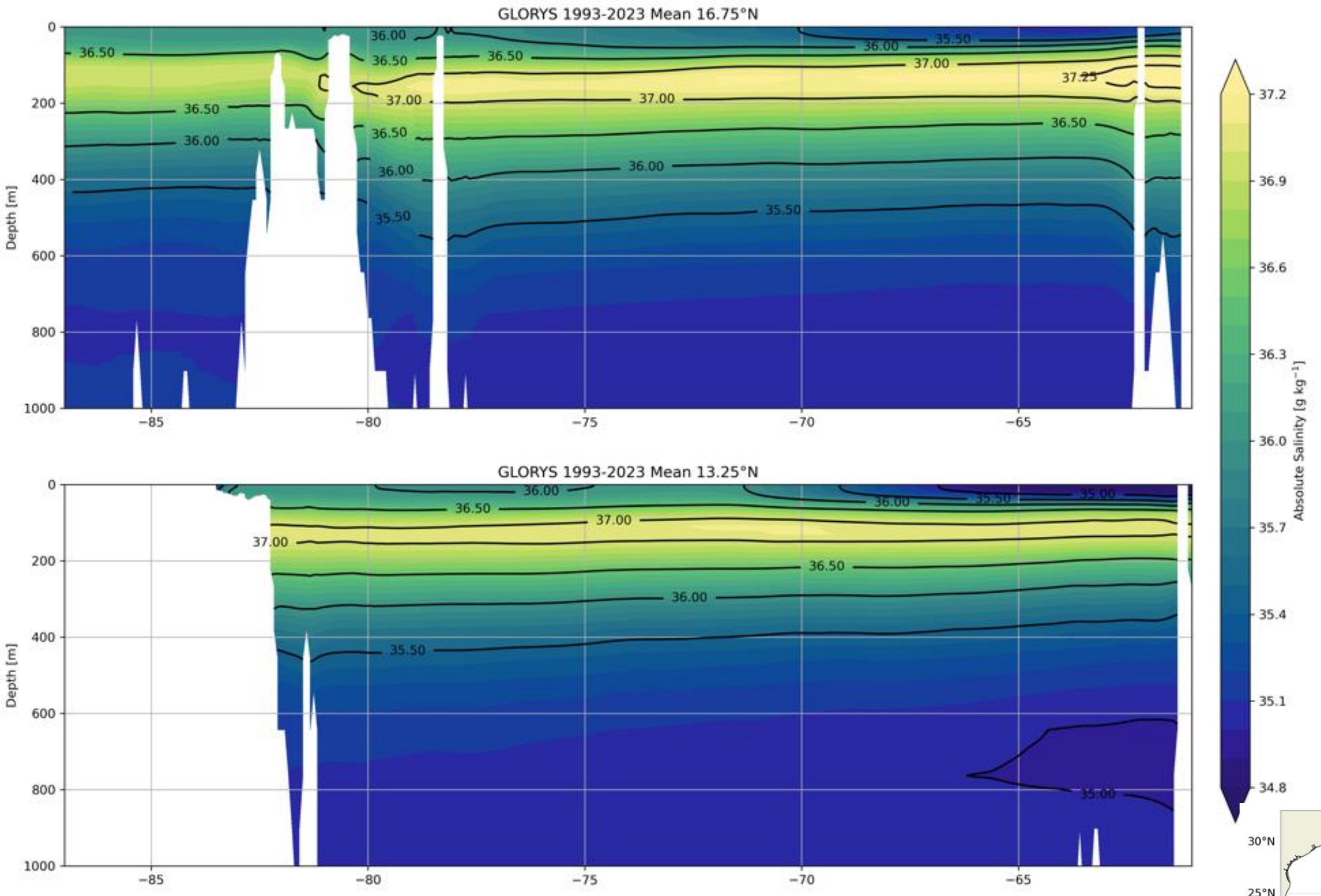
Gradone et al. In Prep

General agreement between GLORYS and observations

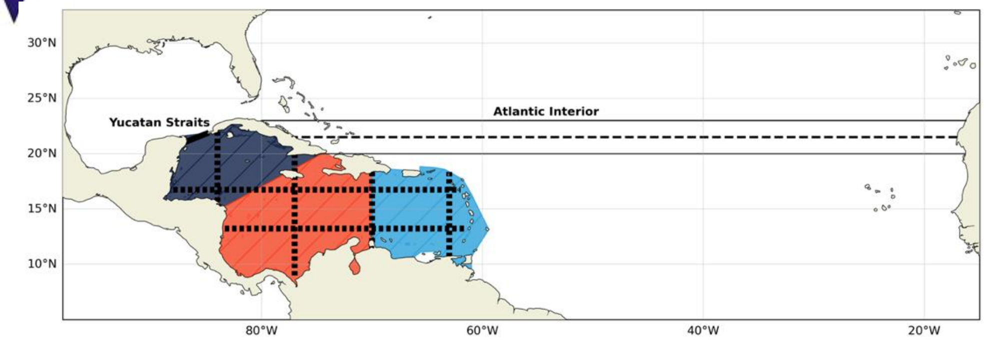
Slight differences in Western Caribbean



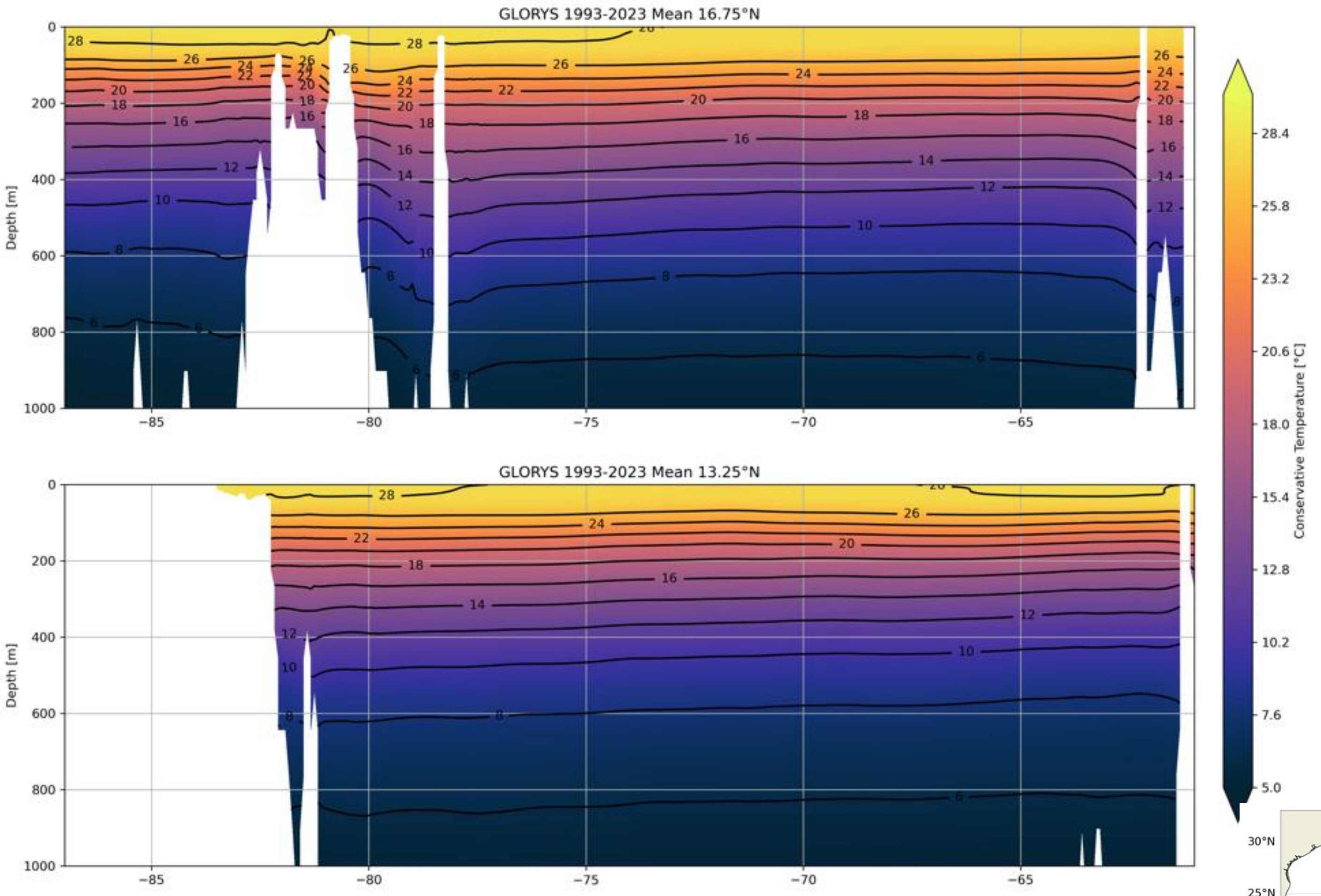
Gradone et al. In Prep



Westward **modification** of water mass structure



Gradone et al. In Prep



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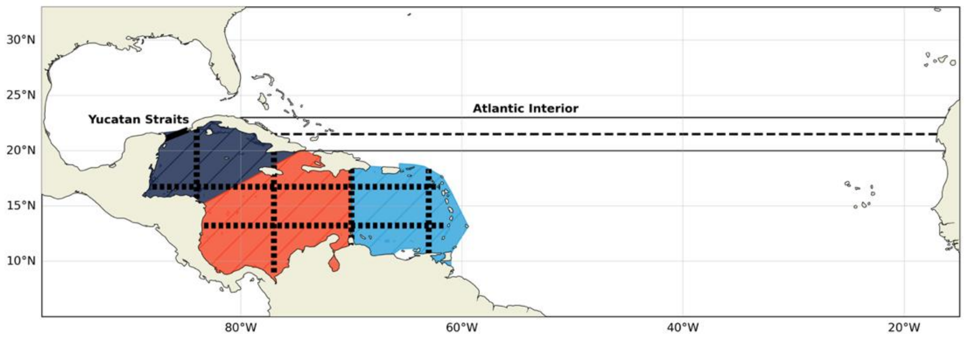
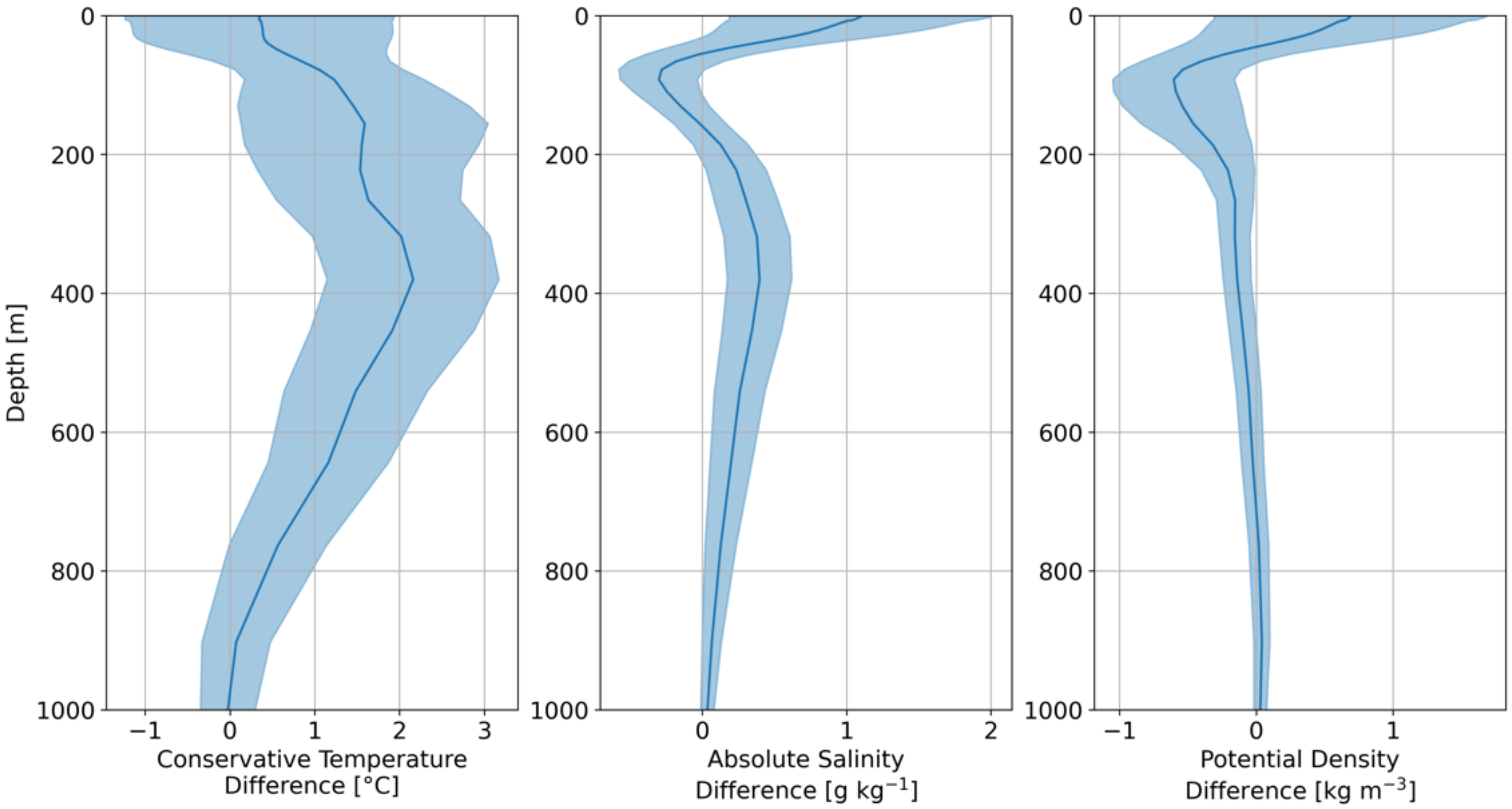
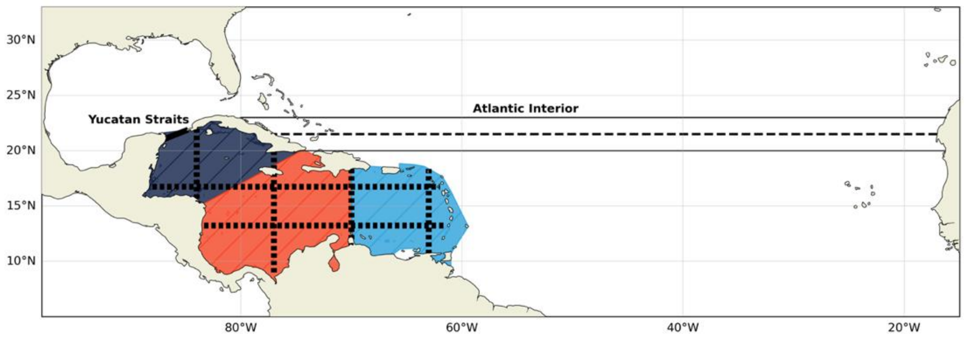


Gradone et al. In Prep



“West-East” on depth levels

Significant modification in water mass properties/structure

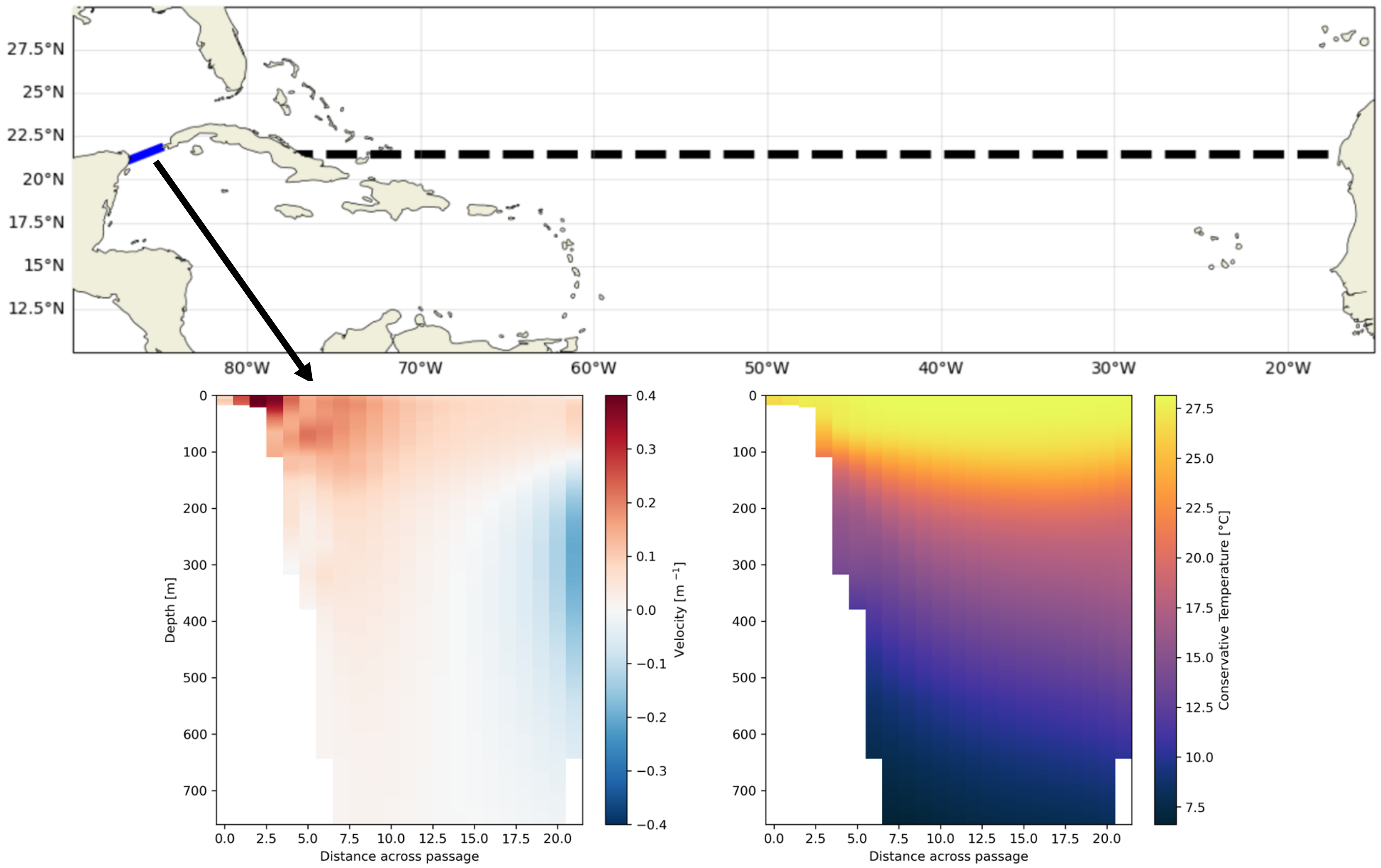


Gradone et al. In Prep

Why does this matter?

Gradone et al. In Prep

Basin-wide mass balance at 21.5ºN



Chapter 3

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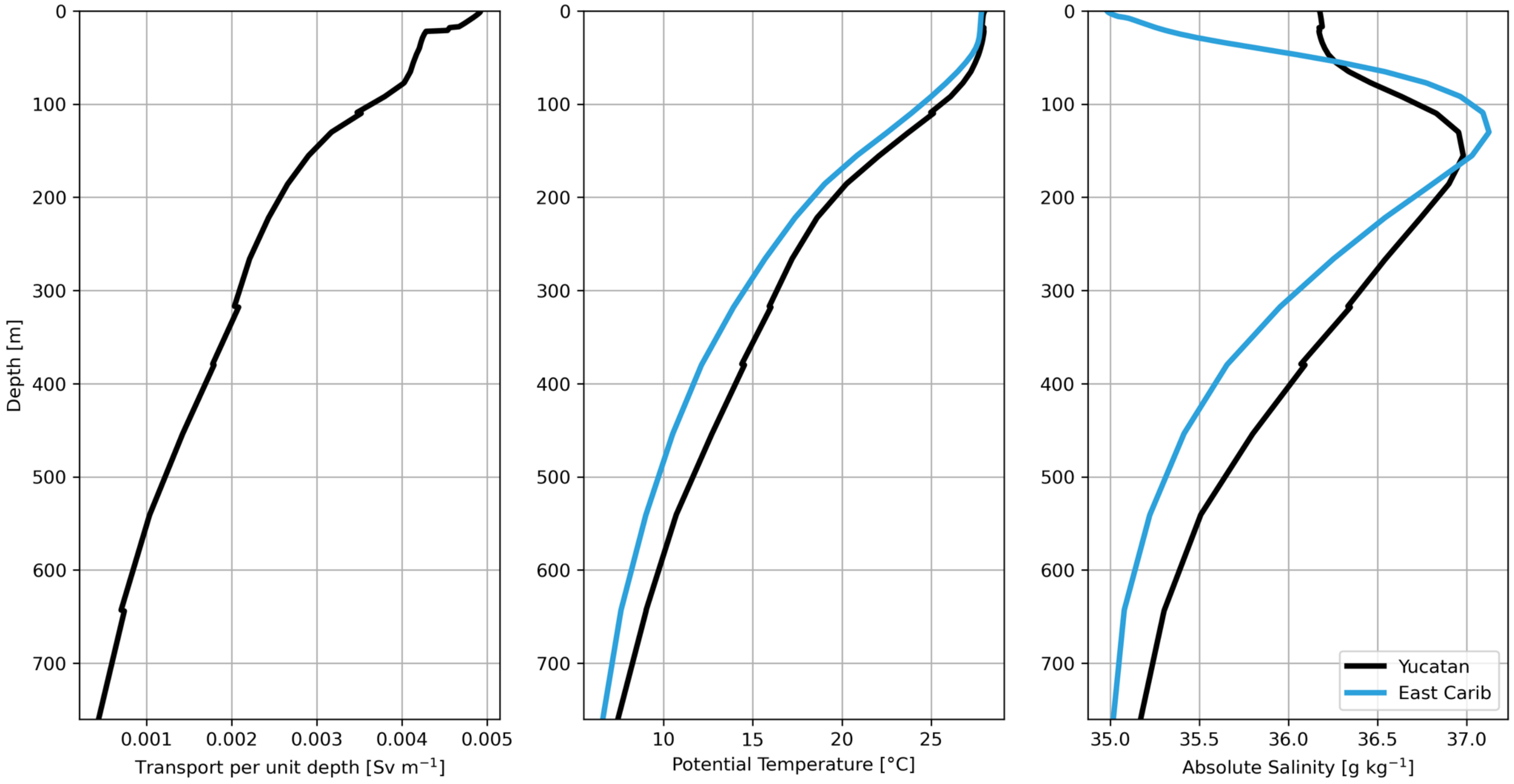
How does heat, salt, and freshwater transport change by using "unmodified" CTF water mass structure?



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	True net transport (YS+21.5°N) Net transport (RAPID)
Heat [PW]	**1.19 ± 0.13** 1.2 ± 0.12[a]
Salt [Sv]	**8.85 ± 52.0** 15.1 ± 1.0[c]
Freshwater [Sv]	**-0.24 ± 0.077** -1.17 ± 0.20[b]

[a]Johns et al. (2011), [b]McDonagh et al. (2015), [c]Li et al. (2021)

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	True net transport (YS+21.5°N) Net transport (RAPID)	**Eastern Caribbean (unmodified) net transport**
Heat [PW]	**1.19 ± 0.13** 1.2 ± 0.12[a]	**1.07 ± 0.13**
Salt [Sv]	**8.85 ± 52.0** 15.1 ± 1.0[c]	**3.20 ± 51.7**
Freshwater [Sv]	**-0.24 ± 0.077** -1.17 ± 0.20[b]	**-0.083 ± 0.054**

[a]Johns et al. (2011), [b]McDonagh et al. (2015), [c]Li et al. (2021)

	True net transport (YS+21.5°N) Net transport (RAPID)	**Eastern Caribbean (unmodified) net transport**	**% change in net transport (true vs eastern Caribbean)**
Heat [PW]	**1.19 ± 0.13** 1.2 ± 0.12[a]	**1.07 ± 0.13**	**-10%**
Salt [Sv]	**8.85 ± 52.0** 15.1 ± 1.0[c]	**3.20 ± 51.7**	**-64%**
Freshwater [Sv]	**-0.24 ± 0.077** -1.17 ± 0.20[b]	**-0.083 ± 0.054**	**65%**

Representation of water mass modification processes is important!

[a]Johns et al. (2011), [b]McDonagh et al. (2015), [c]Li et al. (2021)

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Representation of water mass modification processes is important!

Impacts:

1. **Downstream water mass formation**

   Heat lost by the ocean to the atmosphere during winter formation of North Atlantic Subtropical Mode Water is **~0.096 PW** (Kwon & Riser, 2004)

   CTF heat transport from true Yucatan Straits vs. unmodified, eastern Caribbean mean temperature profile is reduced by **~0.12 PW**

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Representation of water mass modification processes is important!

Impacts:

2. Basin-wide circulation stability

Freshwater hosing experiments show a **0.5 Sv slowdown** in AMOC strength for every **0.01 Sv** of freshwater added (Hu et al. 2023)

CTF freshwater transport from true Yucatan Straits vs. unmodified, eastern Caribbean mean salinity profile is increased **0.157 Sv**

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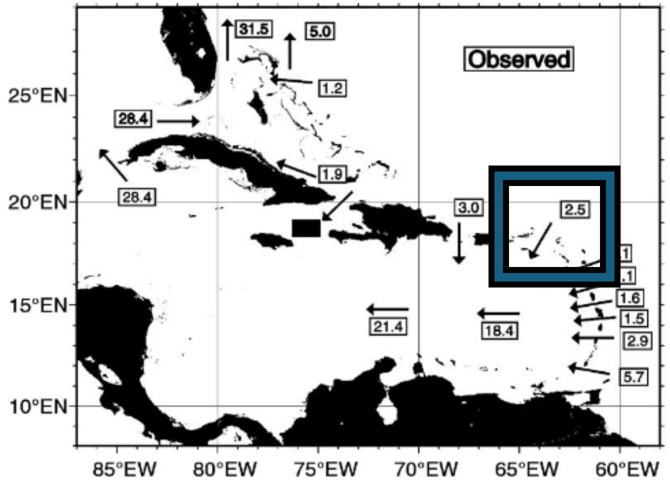
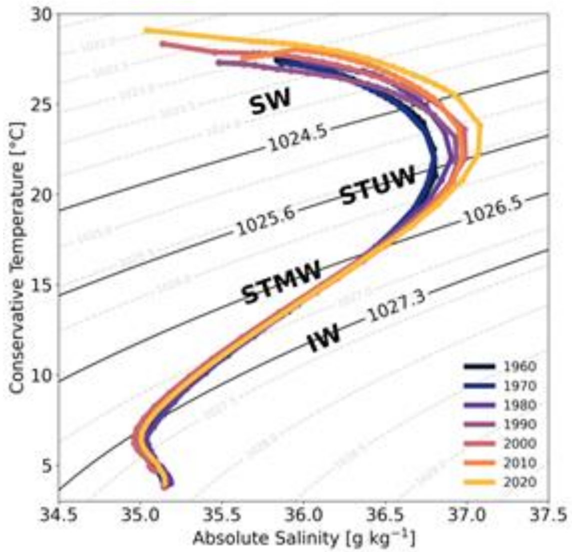
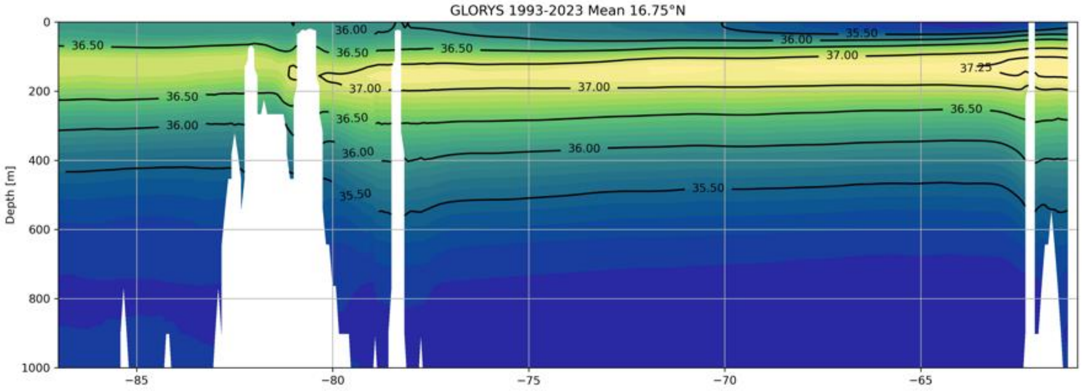
Summary

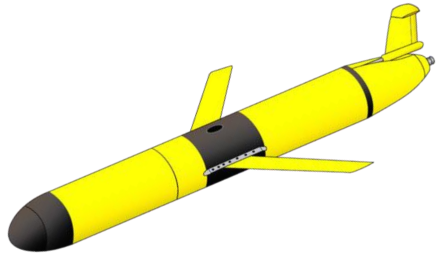






1. **Improving methods for measuring island passage transport**

2. **Caribbean Through-Flow**
   1. Water mass transport pathways
   2. Changes in water mass properties
   3. Water mass variability and modification

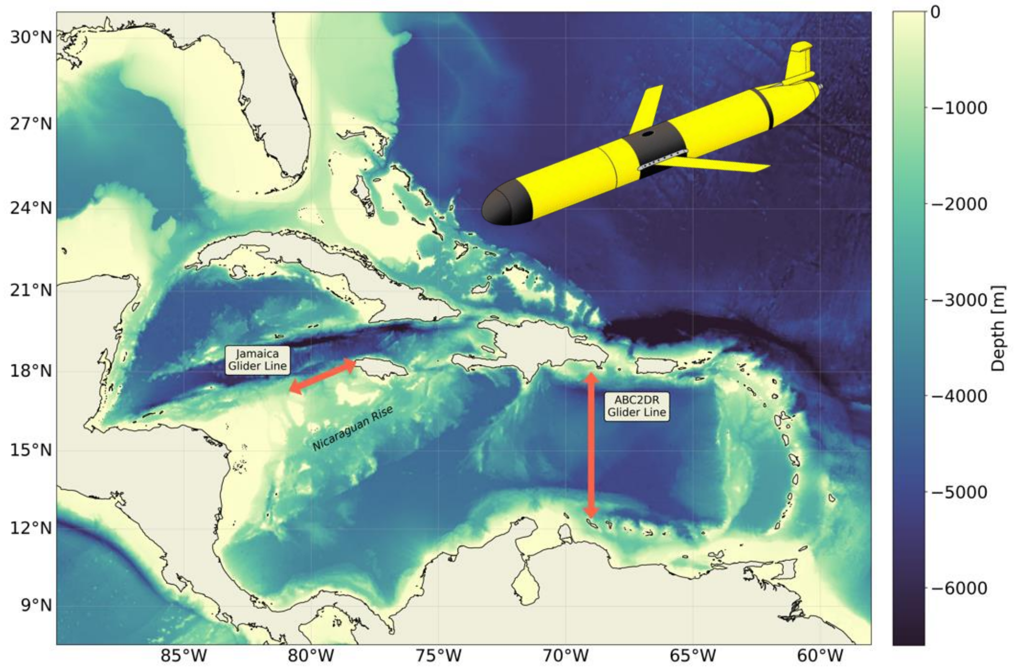


Next Step: Postdoc!

OCE-PO

"Caribbean through-flow water mass transformation processes"

Targeted glider deployments and modeling experiments



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Committee:

Travis Miles

Scott Glenn

Becca Jackson

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Nicole Waite
Chip Haldeman
Brian Buckingham
Jess Leonard
Eli Hunter
Mike Smith
Kaycee Coleman

OGSA
Fellow Grad Students
Sam Coakley
Leah Hopson
Becca Horwitz
Julia Engdahl

Jérôme Couvat (Agoa)
Magali Combes (Agoa)
Laurine Polinice (Agoa)
Antonio Farchette (UVI)

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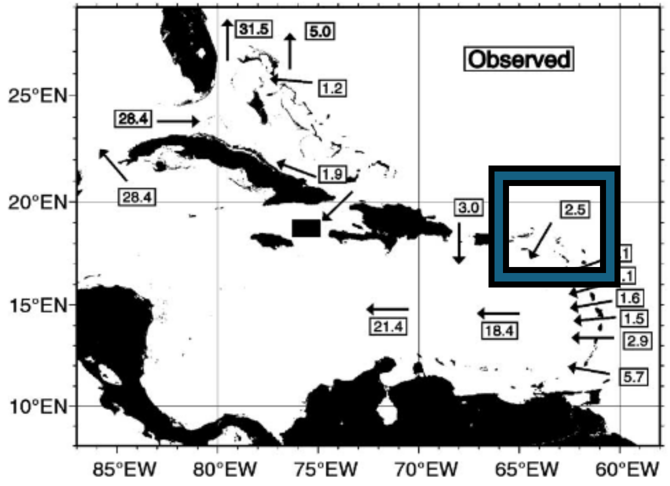
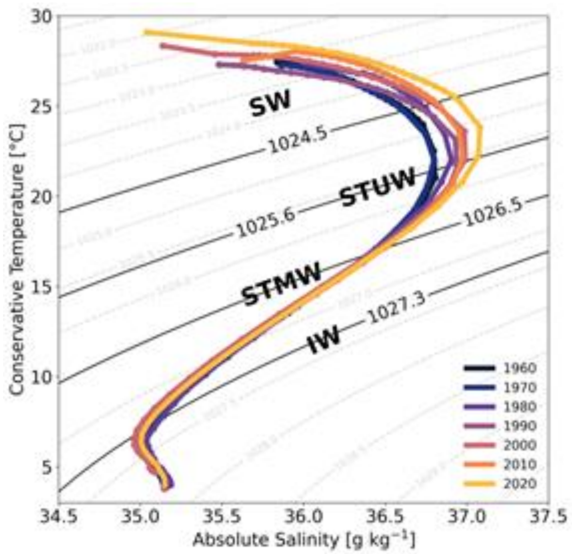
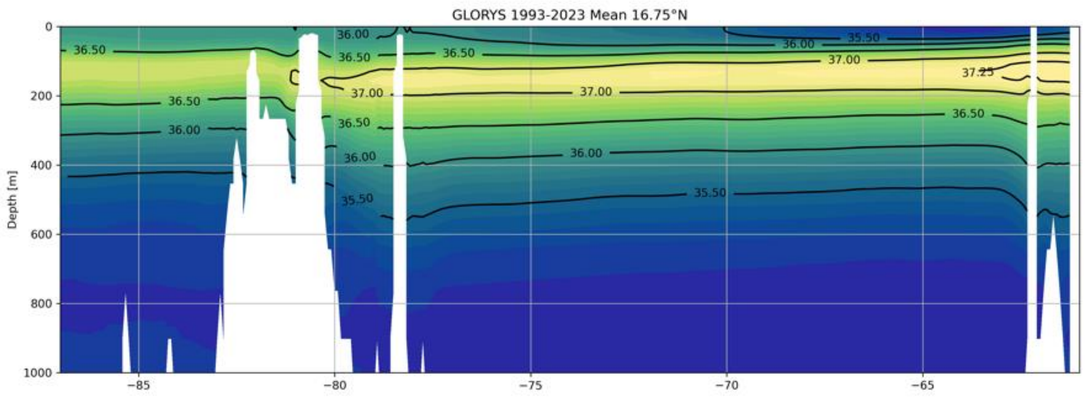
Summary







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