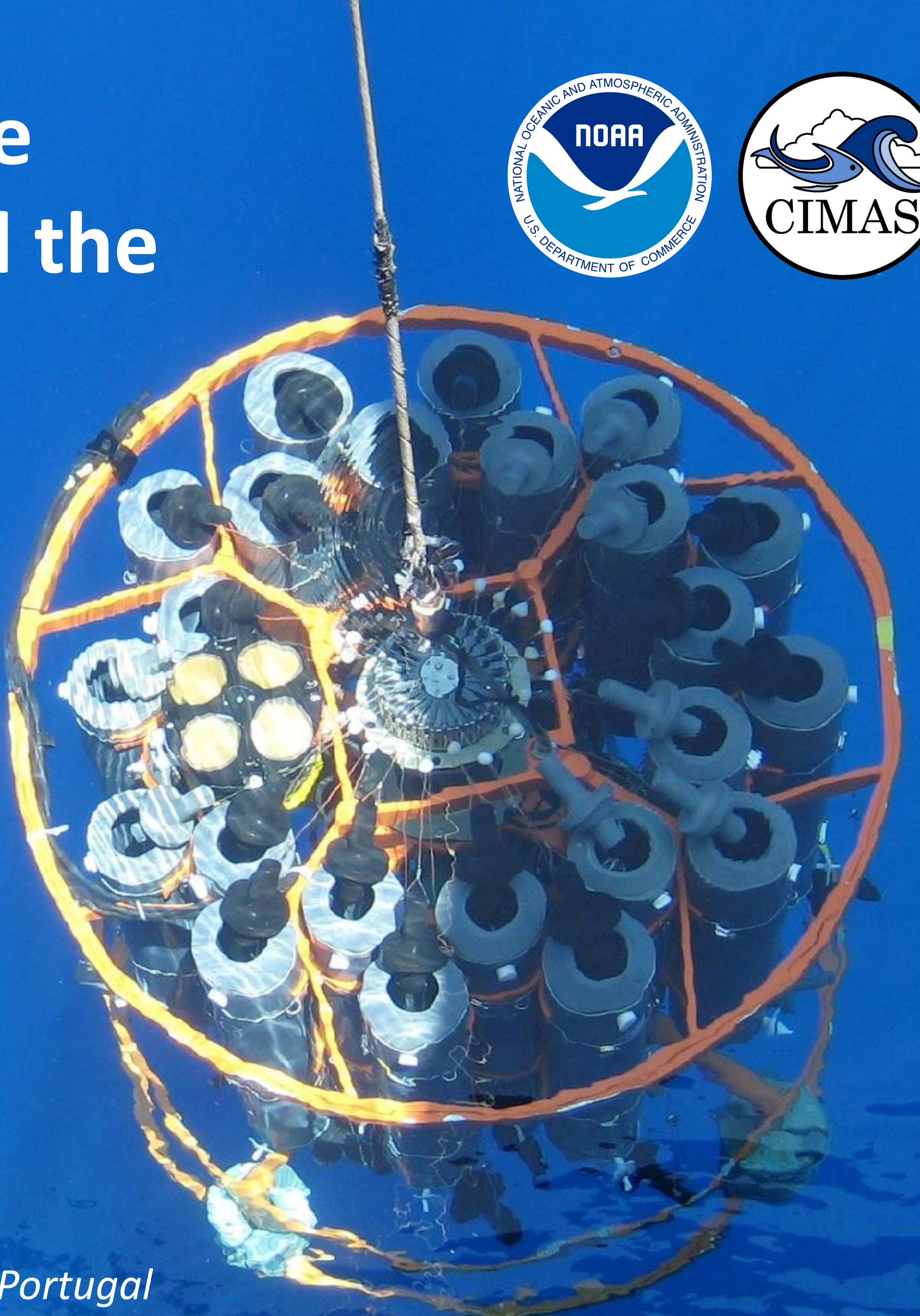
In Situ Observations Supporting the Western Boundary Time Series and the Southwest Atlantic MOC Projects



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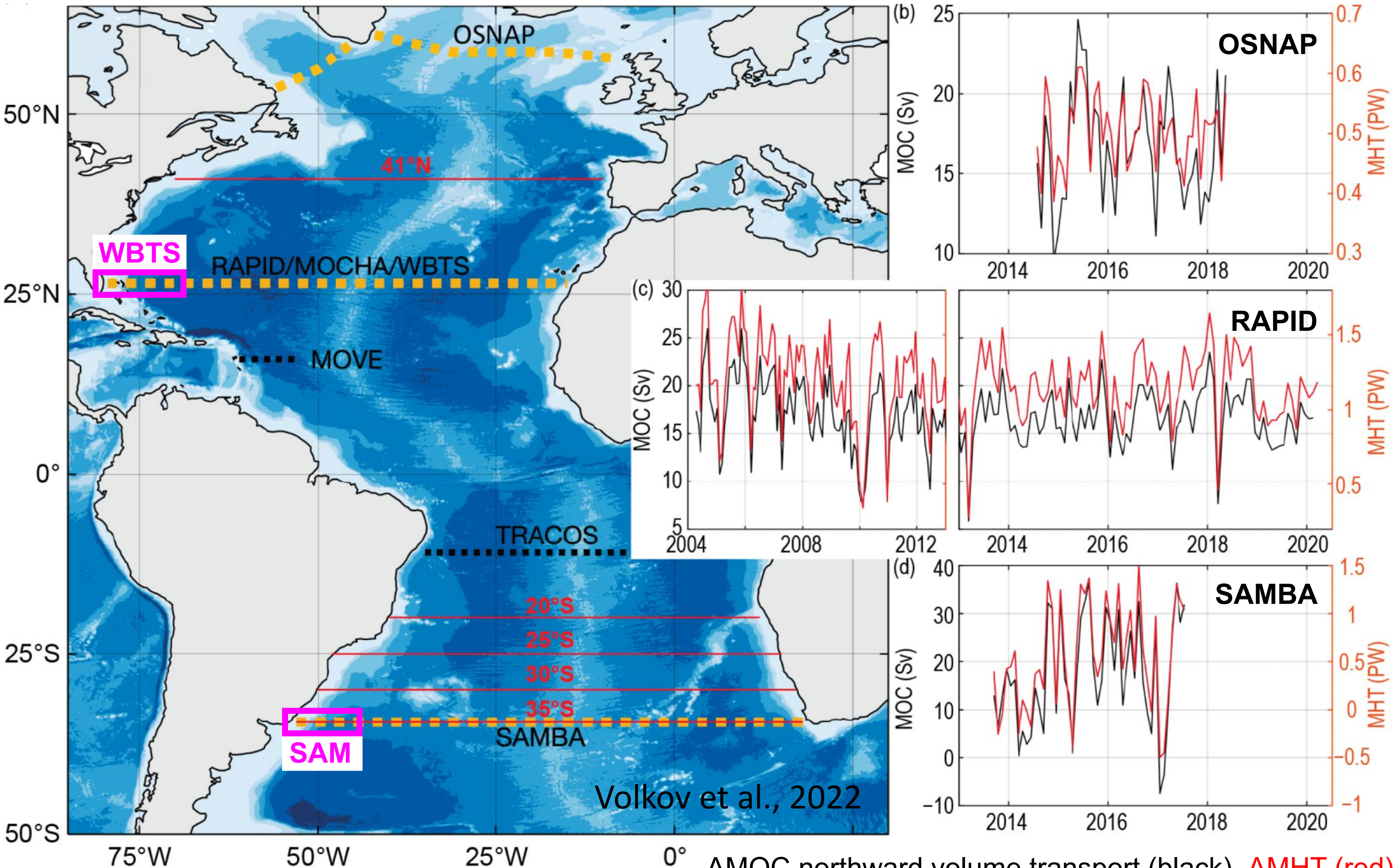
SMART Subsea Cable Workshop, 22-23 May 2023, University of Aveiro, Portugal

NOAA/AOML Field Programs

Western Boundary Time Series (WBTS) *and* ***Southwest Atlantic MOC (SAM)***

Focus on monitoring the western boundary current system in the Atlantic Ocean.

They are a critical component of international, trans-basin array partnerships aimed at monitoring the Meridional Overturning Circulation in the Atlantic Ocean.



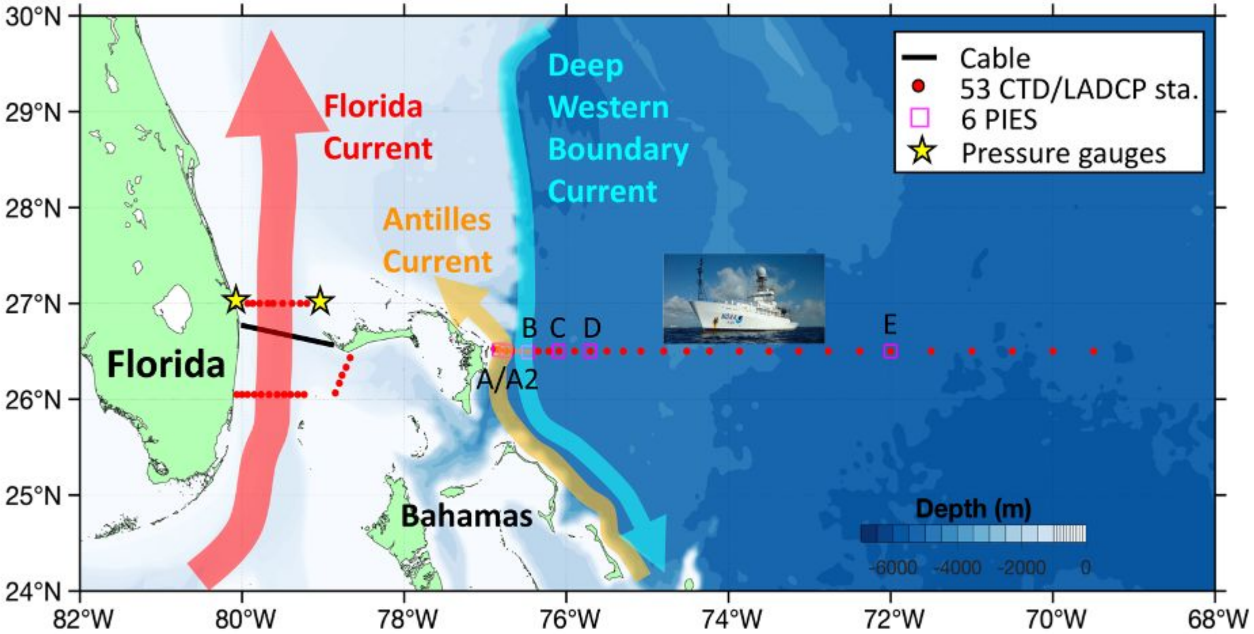
AMOC northward volume transport (black), AMHT (red)

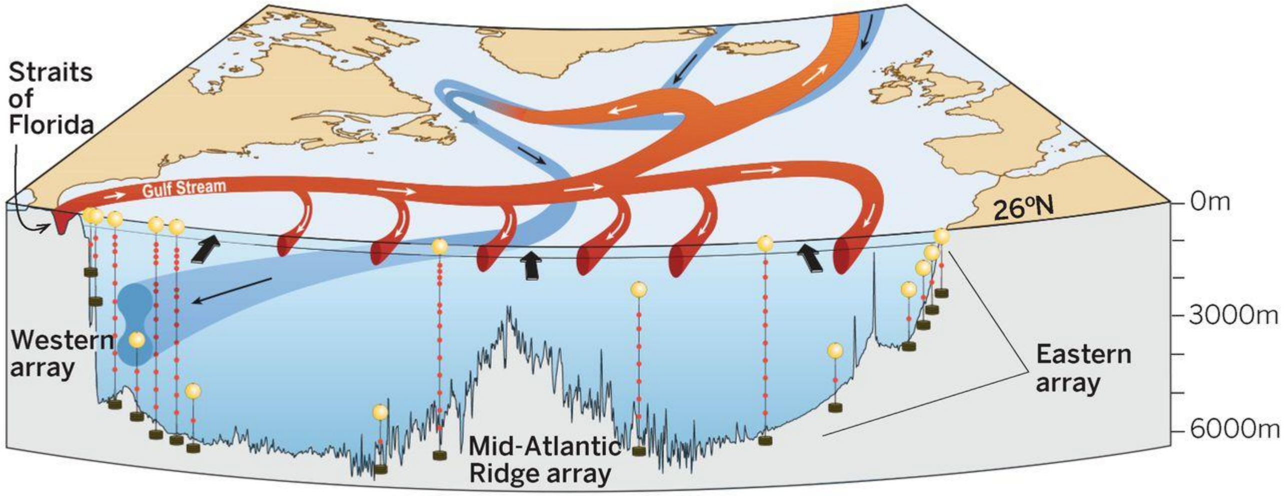
NOAA Western Boundary Time Series (WBTS)

Provide time series observations of the main components of the meridional overturning circulation in the western subtropical North Atlantic Ocean…

- **Florida Straits (27N): Florida Current**
- **North Atlantic (26.5N): Antilles Current, Deep Western Boundary Current, and portion of NA Subtropical Gyre interior**

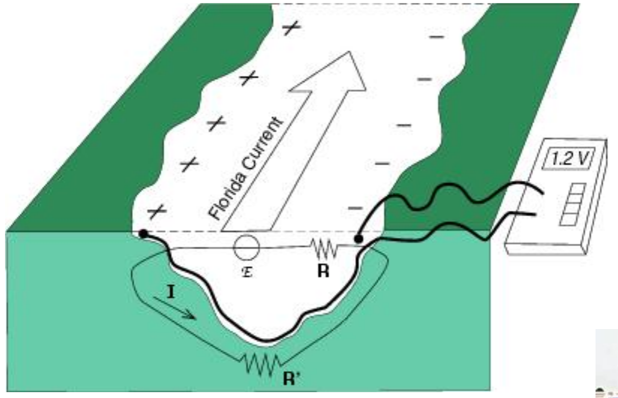
Serve as a western boundary endpoint of a subtropical MOC/heat transport monitoring system at about 26.5N established in 2004 in partnership with the University of Miami (MOCHA) and the UK National Oceanographic Centre (RAPID)…





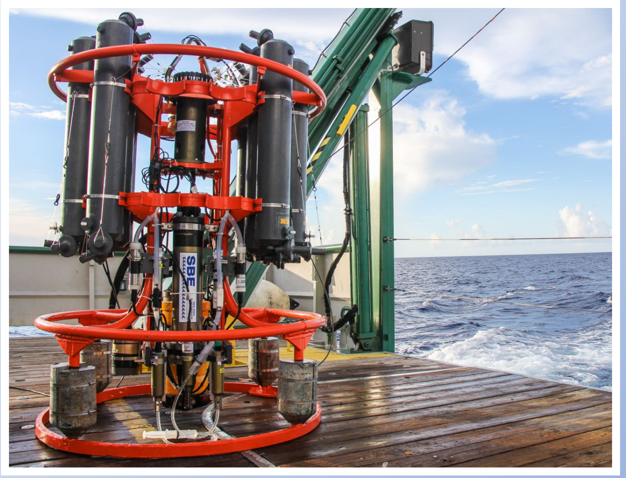
NOAA Western Boundary Time Series (WBTS)

Methodology: Straits of Florida at 27N / Florida Current

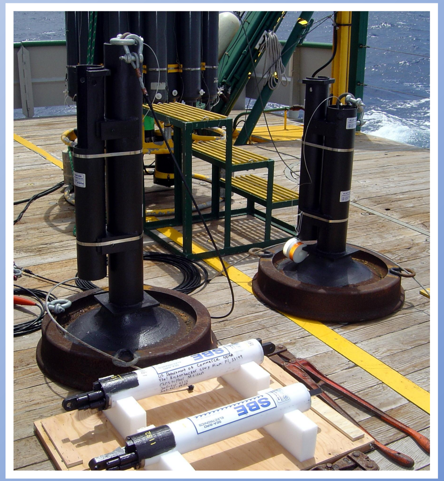


Continuous daily volume transports estimated from voltage recording system connected to submarine telephone cable, calibrated via dropsonde measurements
(beginning in 1982)

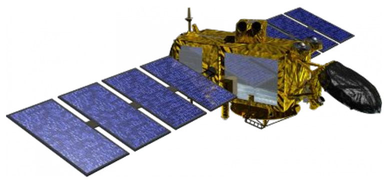
Dropsonde cruises, 8 to 10 per year
(beginning in 1982, '82-'88 Pegasus, later GPS dropsonde with XBT)



Quarterly (later, bimonthly) $CTDO_2$/LADCP hydrographic surveys
(beginning in 2001)



Shallow water pressure gauges on either sides of the Straits
(beginning in 2008)

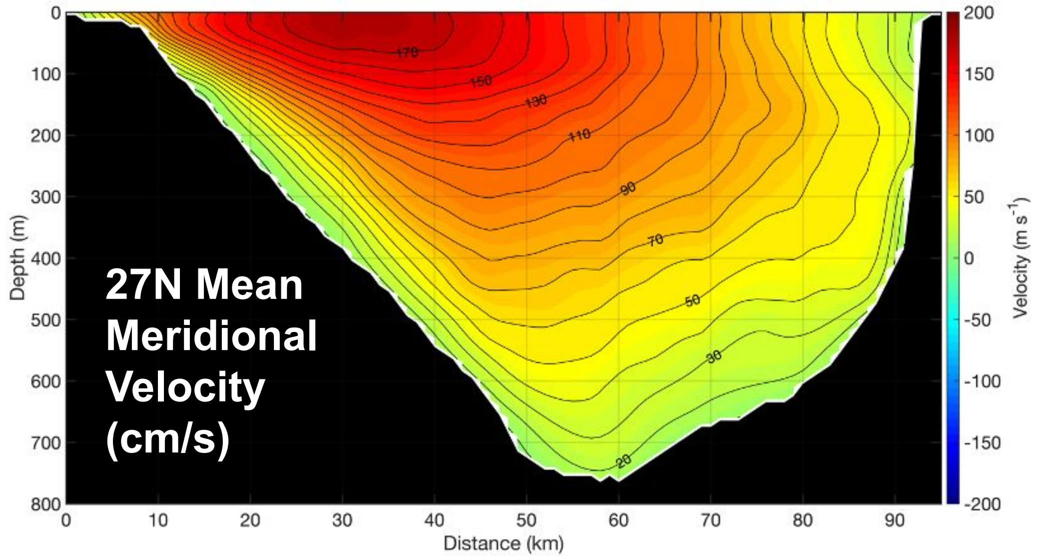


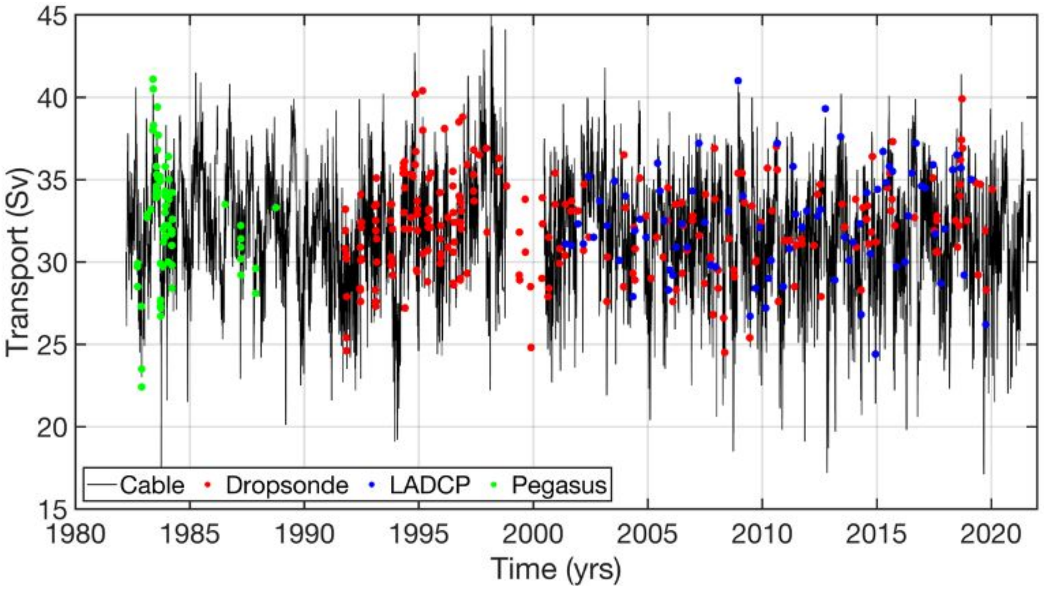
Satellite altimetry, overpasses every ~10 days *(beginning in 1993, altimetry data available in near real time since in 2020)*

NOAA Western Boundary Time Series (WBTS)

The Florida Current (part of the Gulf Stream System, and the upper limb of the AMOC) has been monitored at 27N in the Florida Straits since 1982.

- Nearly 400 shipboard velocity sections conducted since 1982 (pegasus, GPS dropsonde, LADCP/SADCP)
- The volume transport of the Florida Current, since 1982 has been relatively stable (0.3 Sv decrease per decade, 1 Sv = $1x10^6 m^3 s^{-1}$)
- The mean volume transport: 31.8 Sv ±3.4 Sv, Cable; 32.3 Sv ±3.1 Sv, Cruises
- Observed Florida Current transport variability is a result of local and remote signals
- The majority of this variability is sub-annual, daily monitoring of the current is needed to properly capture the varying time scales
- Sea level rise along the US east coast is associated with increased ocean warming, not by transport variability in the Florida Current



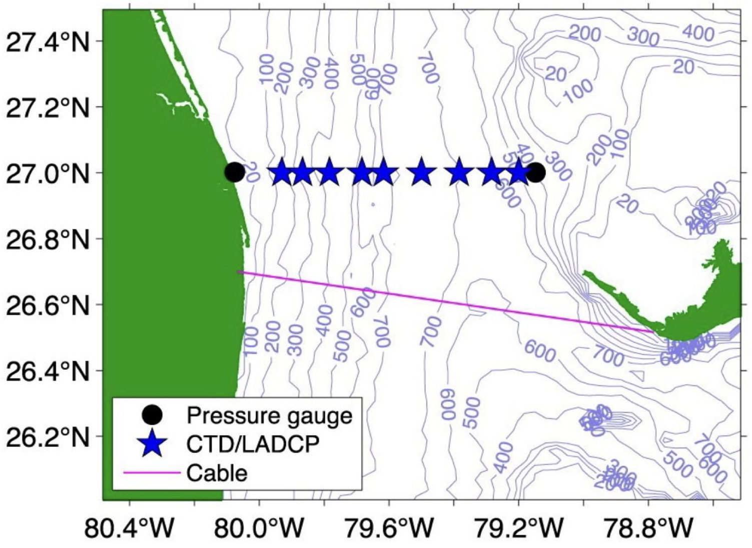


NOAA Western Boundary Time Series (WBTS)

What if the cable breaks?

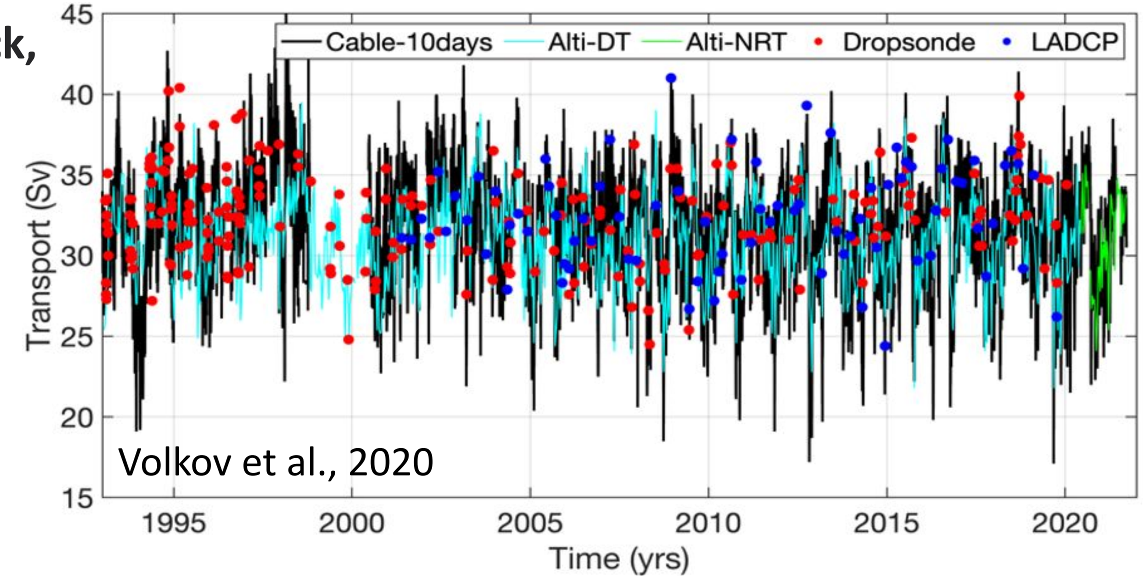
Shallow water pressure gauges are in use on either side of the 27N section in the Florida Straits (2008 to present)

- Correlation of 0.76 observed between the pressure difference and the transport time series, using the west gauge alone r=0.73
- Pressure gauge records capture only 55% of the variance observed by the cable (between 2008-2014)



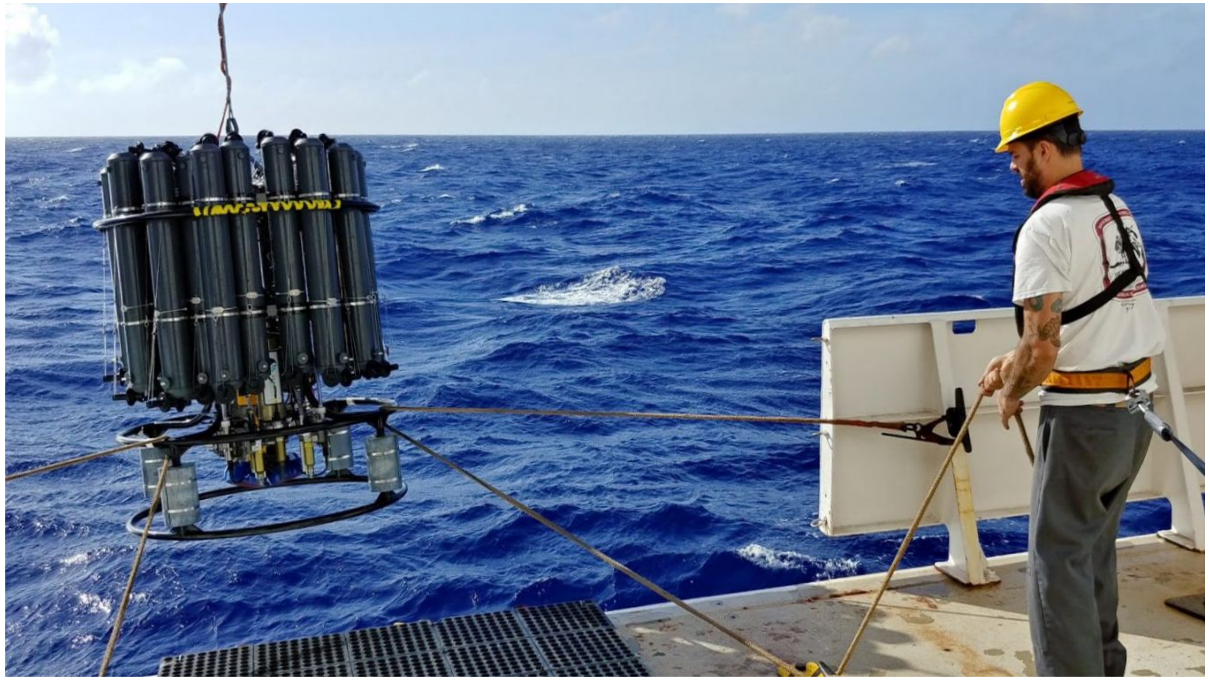
Satellite altimetry data (1993 to present) can provide along-track, east-west sea surface height (SSH) differences.

- Satellite overpass every ~10 days, with near real time data available since 2020 (a day after the overpass)
- A correlation of 0.79 is observed between the ΔSSH data and the transport time series (for 2008-2014)
- The inferred mean volume transport: 31.1 ±2.8 Sv



NOAA Western Boundary Time Series (WBTS)

Methodology: 26.5N
Antilles Current, Deep Western Boundary Current, North Atlantic Subtropical Gyre Interior

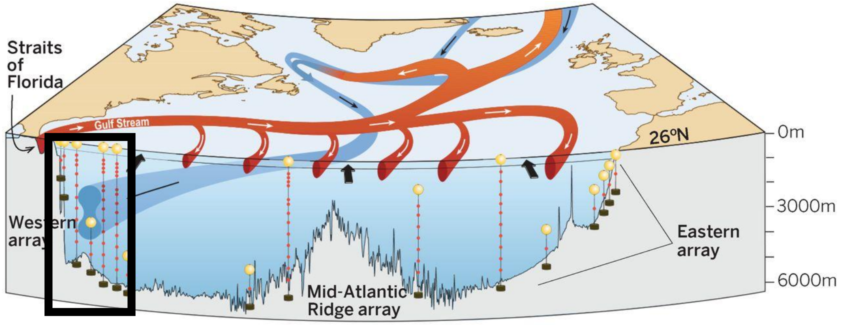


Regular $CTDO_2$/LADCP hydrographic surveys at 26.5N
(beginning in 1984, currently conducted at approximately 9 month intervals)

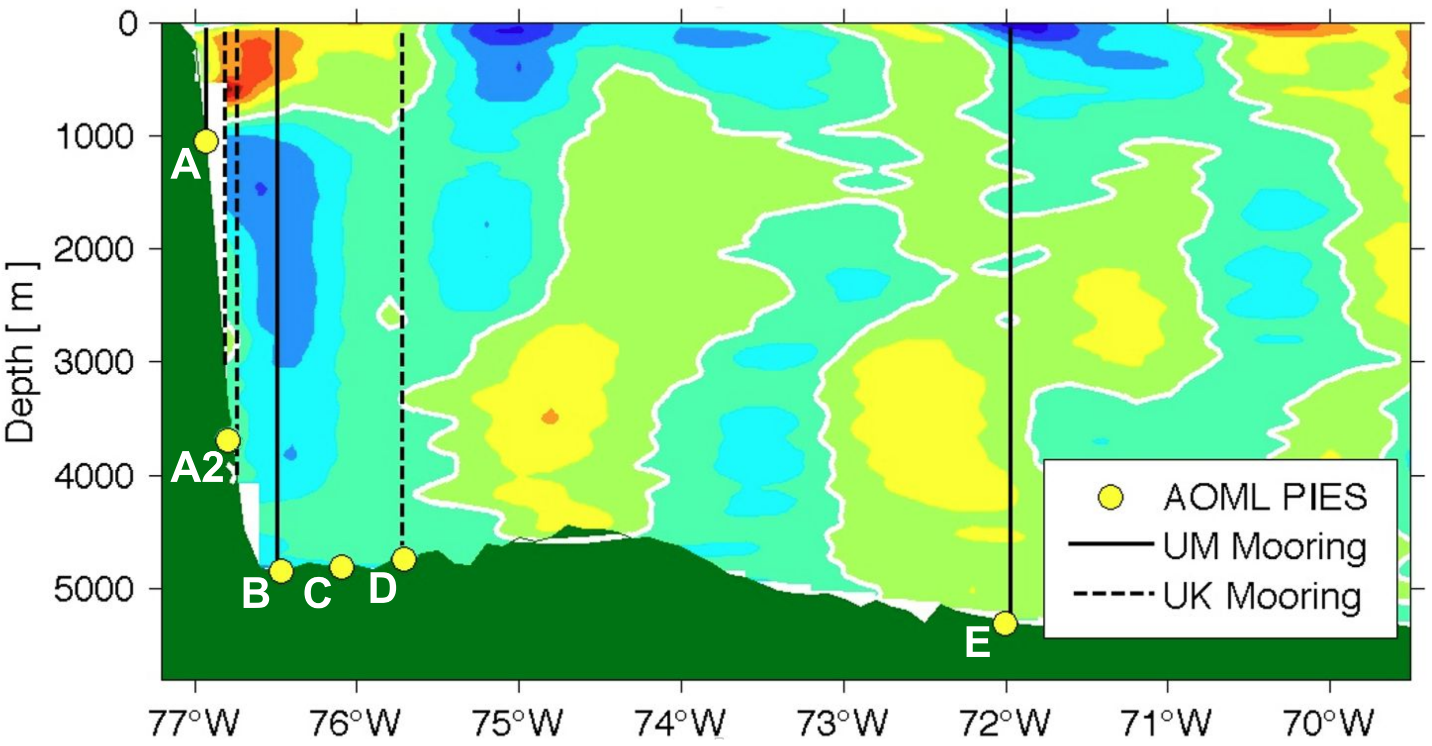
Moored Array of 6 Pressure Equipped Inverted Echo Sounders (PIES) along 26.5N
(beginning in 2004)

NOAA Western Boundary Time Series (WBTS)

Serve as a western boundary endpoint of the RAPID/MOCHA/WBTS array at 26.5N, established in 2004 in partnership with the University of Miami (MOCHA) and the UK National Oceanographic Centre (RAPID)…



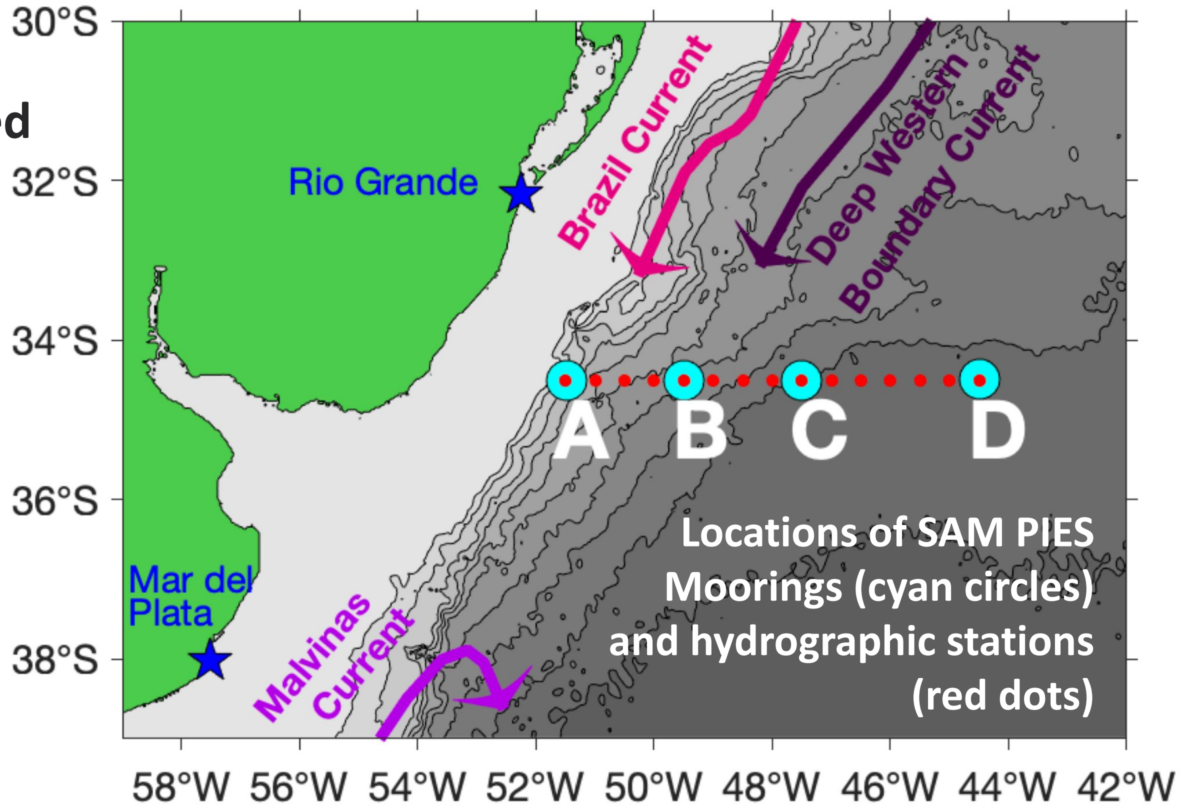
- The northward-flowing Antilles Current mean volume transport: ~5 Sv, with a highly variable flow centered near 400 m depth
- The southward-flowing Deep Western Boundary Current (DWBC) mean volume transport: ~40 Sv (with 25 Sv recirculating back to the north offshore), with peak velocities at 1800 - 3600 m depth
- AMOC strength at 26.5N = 16.9 Sv ±1.9Sv
- The RAPID/MOCHA/WBTS array uses multiple mooring types in combination with $CTDO_2$/LADCP hydrography



Southwest Atlantic MOC Project (SAM)

Monitoring changes in western boundary current transports and water mass properties in the subtropical South Atlantic Ocean along 34.5S. Western boundary endpoint of an international MOC monitoring system (South Atlantic MOC Basin-wide Array or "SAMBA"). Partners: Argentina, Brazil, France, Germany, South Africa, Spain

- **SAM involves an array of four PIES. Partners run hydrographic cruises twice a year, and have deployed additional moorings on the western boundary.**
- **SAM has collected 13 years of daily full-depth observations of temperature, salinity, velocity, as well as bottom temperature and pressure.**
- **Ten years of concurrent daily data from SAM and SAMBA have enabled study of seasonal-to-interannual MOC variability and facilitated comparisons with other observations, numerical models, and ocean reanalyses.**



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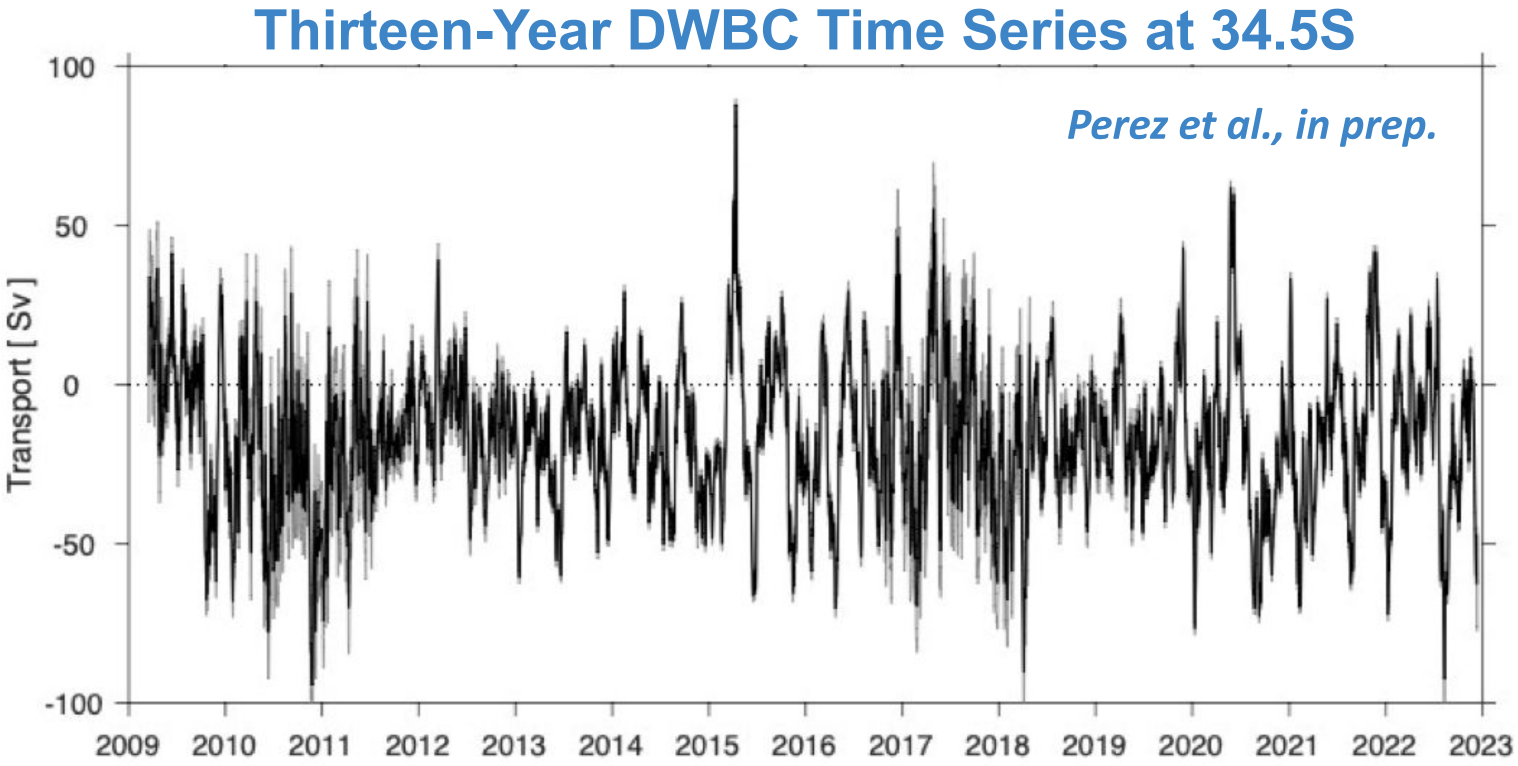
- **The DWBC is energetic on short time scales from 20 to 220 days**
- **The observed DWBC mean volume transport = -17.0 Sv (±22.4 Sv)**
- **Negative trend observed in the transport time series (-2.5 Sv/decade)**



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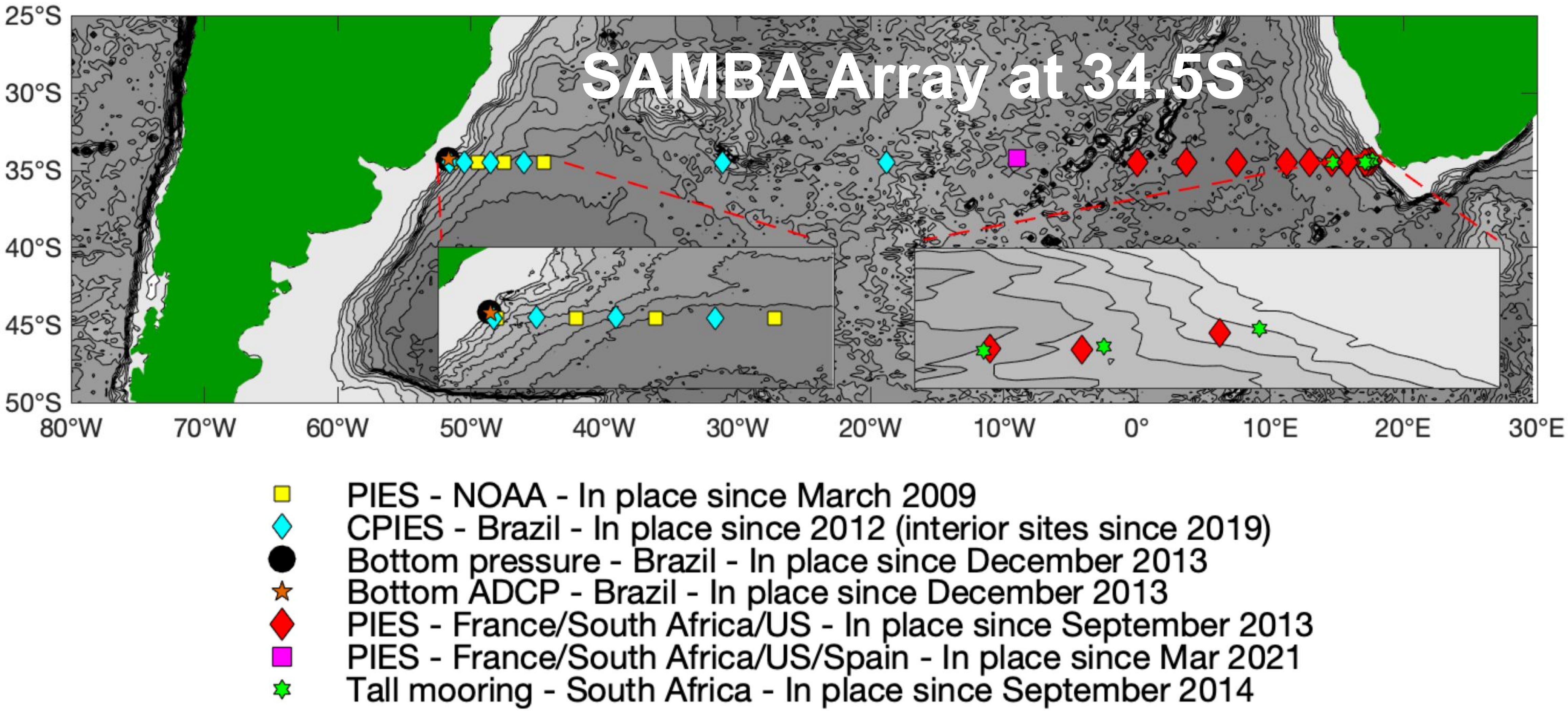
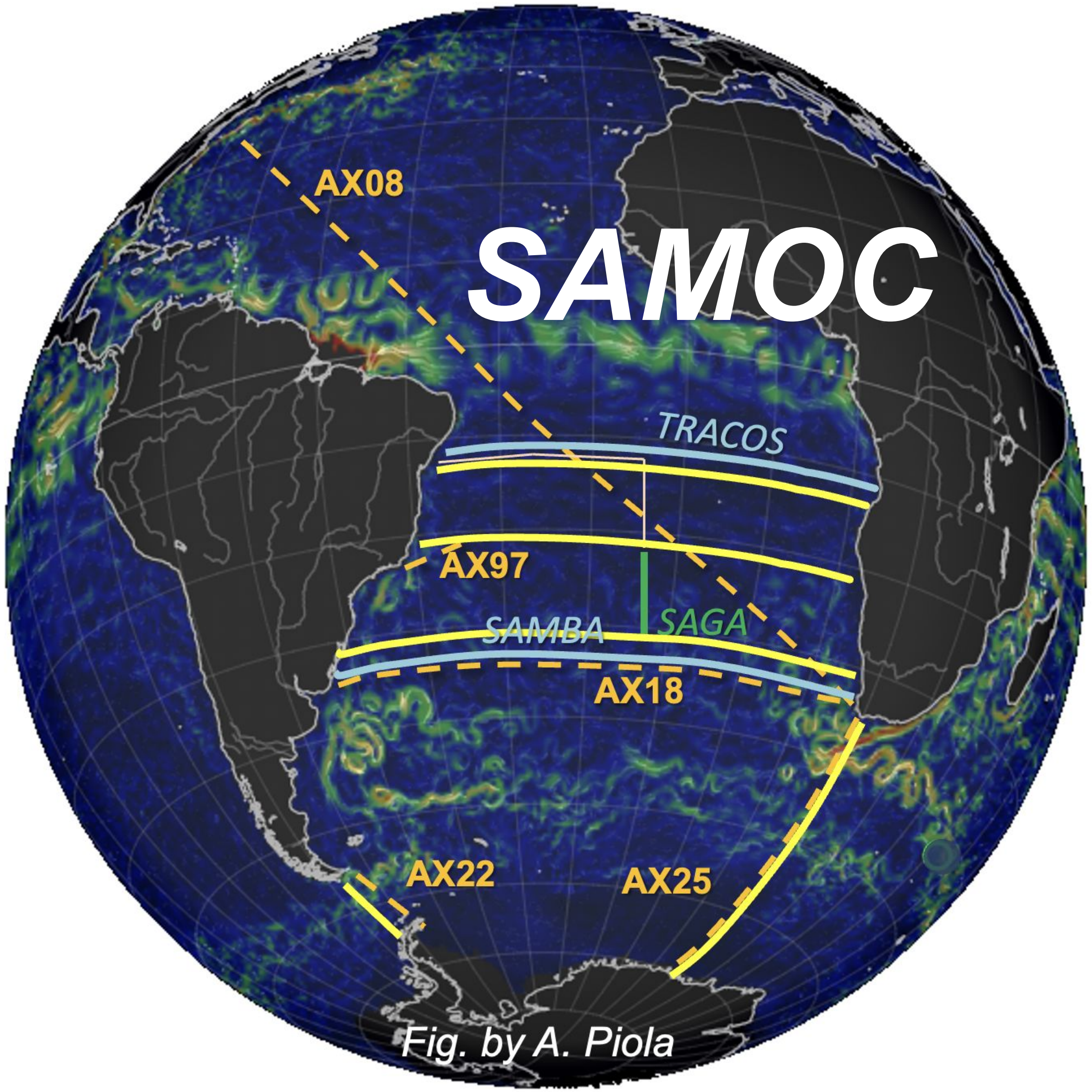


Southwest Atlantic MOC Project (SAM)

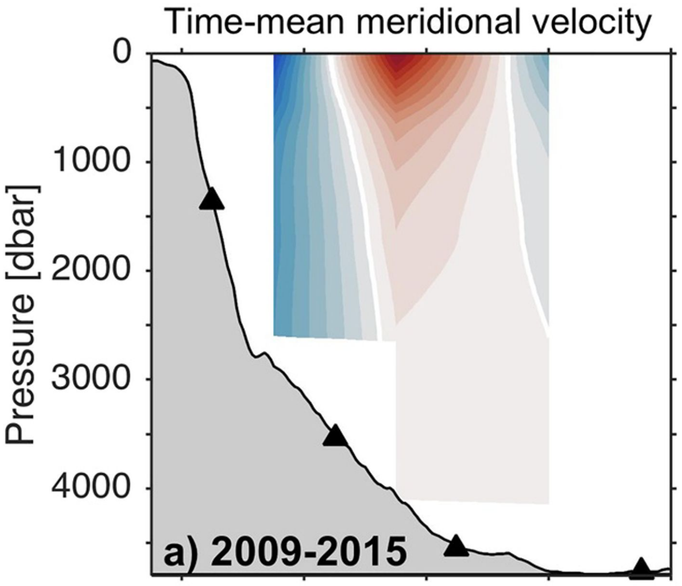


- The South Atlantic Meridional Overturning Circulation (SAMOC) initiative began in 2007 with the goal of measuring the strength and variability of the AMOC-related volume, heat and freshwater transports in the South Atlantic and interocean exchanges.
- Countries involved include: Argentina, Brazil, France, Germany, Mexico, Norway, Spain, South Africa, United Kingdom, United States, and Uruguay

SAMBA: South Atlantic MOC Basin-wide Array
TRACOS: TRopical Atlantic Circulation and Overturning at 11S
SAGA: South Atlantic Gateway Array
Trans-basin & interocean XBT transects
Trans-basin & interocean CTD transects
In situ & altimetry synthesis estimates

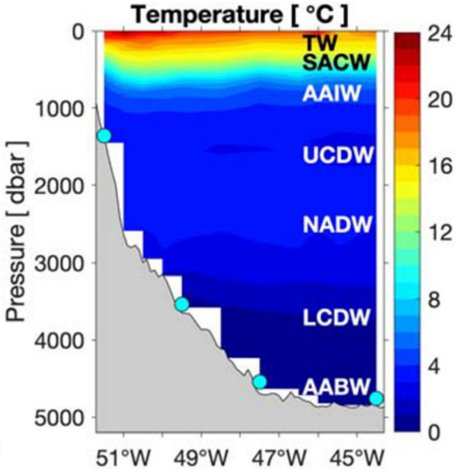
Pressure equipped Inverted Echo Sounder

- Originally developed by Tom Rossby and Randy Watts in the 1970s, the instruments are small and relatively inexpensive (when compared to traditional tall moorings).
- An Inverted Echo Sounder measures vertical acoustic travel time (τ) between the instrument and the sea surface, a function of the speed of sound in water, which is dependent on the temperature and salinity of the water column. Measurements recorded hourly.
- When combined with hydrographic data for the region, using empirical relationships between the travel time and temperature and salinity distribution over the water column, a time series of full-depth dynamic height can be inferred.
- Differencing dynamic height and pressure between adjacent PIES provides estimates of baroclinic (density-driven) and barotropic (pressure-driven) geostrophic velocity, respectively, across the segments connecting each pair of PIES.
- Integrating velocity zonally (east-west) and vertically gives estimate of volume transport by a current system.



Mean meridional velocity using the four SAM PIES moorings(Chidichimo et al., 2021)

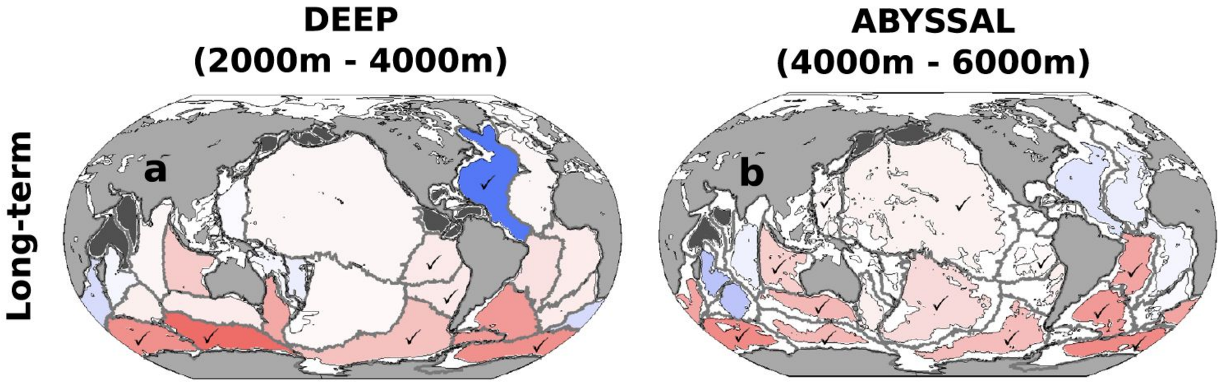
Deep/Abyssal Warming

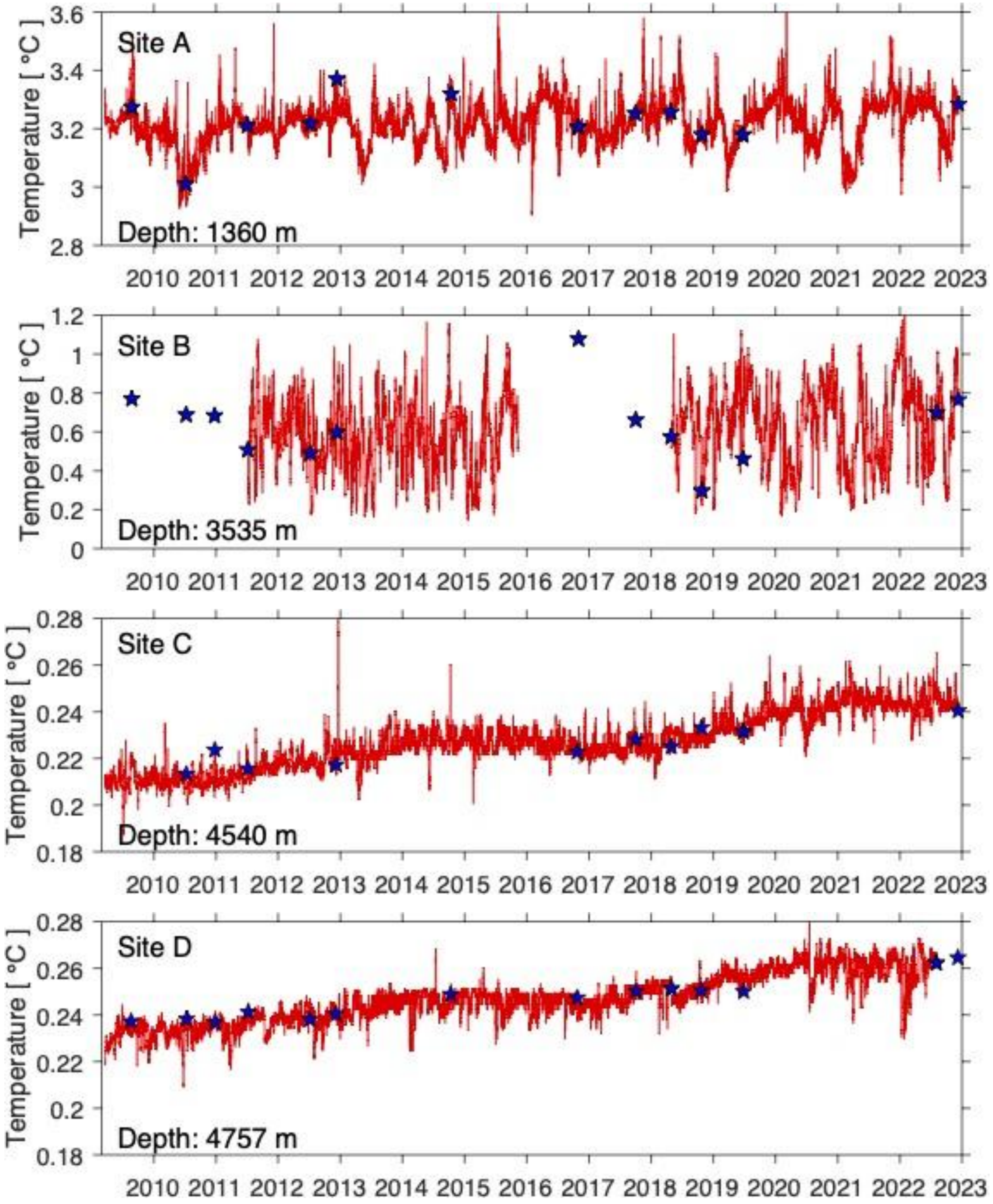


As part of a NOAA COM-CVP-GOMO funded study, we are using data from PIES moorings to construct time series of bottom temperature variations in the North and South Atlantic Ocean.

At right: 13-year time series of SAM PIES bottom temperature records, show warming trends of approximately 0.02–0.04°C per decade (updated from Meinen et al. 2020)

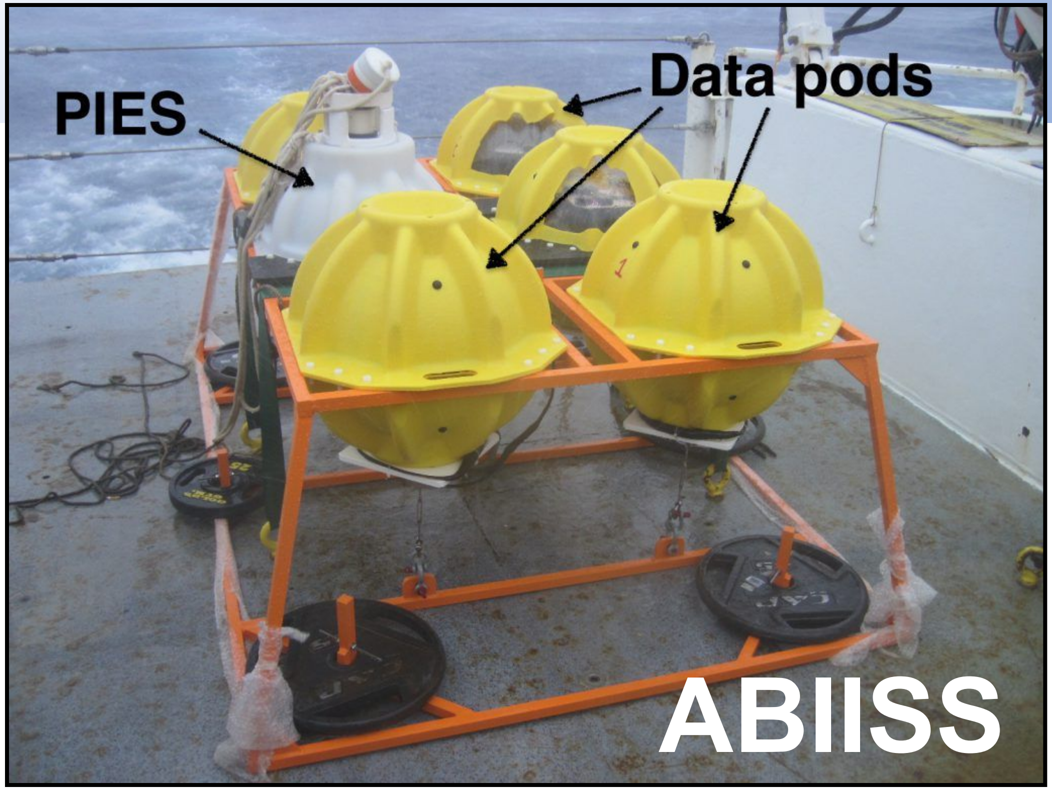
Below: Desbruyeres et al. (2016) show multi-decadal (35-year) warming trends below 2000 m in the global ocean





Adaptable Bottom Instrument Information Shuttle System (ABIISS)

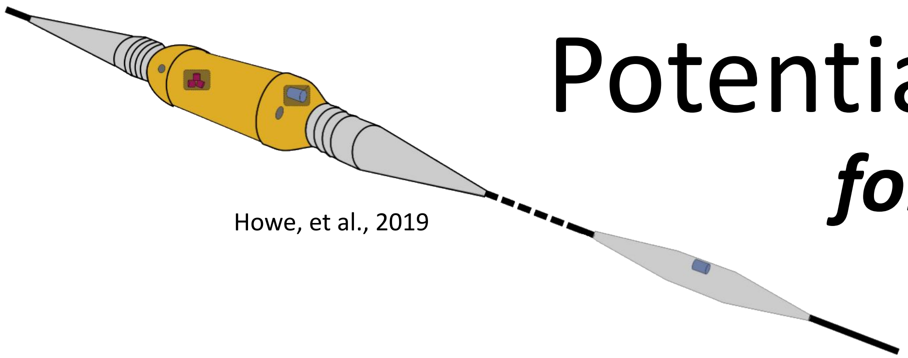
- Developed at NOAA/AOML, ABIISS *data pods* are released at predetermined intervals from the mooring lander, reporting collected instrument data back to scientists via Iridium Satellite
- Designed to help mitigate the high costs of data recovery (using traditional methods, e.g. research vessels)
- Can help minimize data loss in long term time series, by transmitting data subsets and by alerting scientists to a potential problem with the mooring



What is the feasibility of dedicated scientific SMART cable lines, connected via Branching Units (BU), being configured with the additional IES travel time (τ) measurement? This would require the development of a smaller IES unit conforming to a suitable power budget and communications protocol for the cable. The size of the travel time dataset itself would be on the same order of magnitude as the other SMART cable measurements [P,T,Acc.].

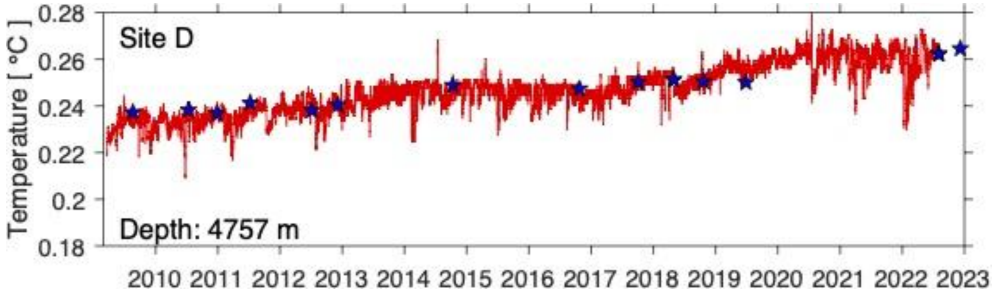
Potential SMART Sensor Benefits…

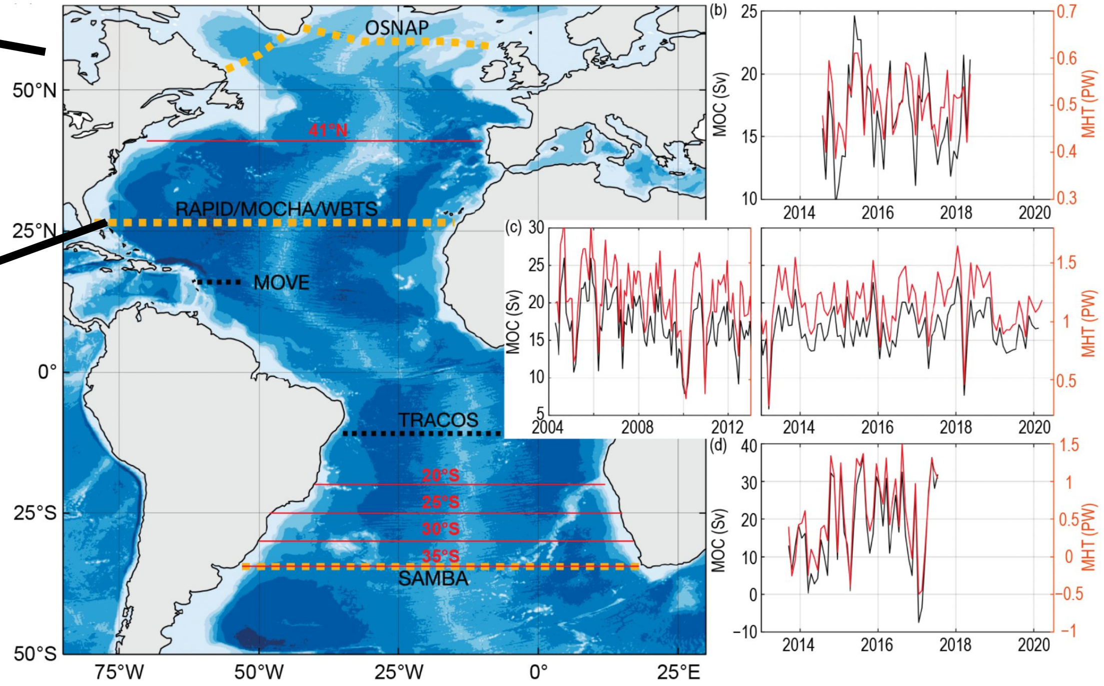
for WBTS, SAM, Deep/Abyssal Temperature Monitoring, and more…

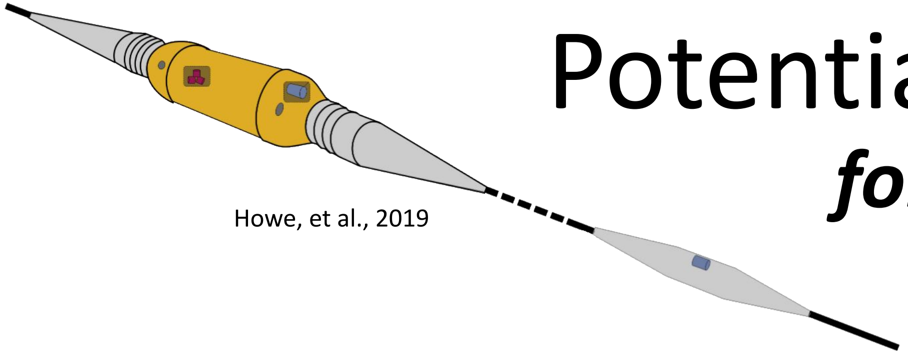


Howe, et al., 2019

- ***A global expansion of bottom temperature time series has the potential to improve the assessment of ocean warming and sea level rise calculations***
- ***Increasing the number of bottom pressure and temperature time series (within the vicinity of existing Trans-Basin Arrays) has the potential to enhance long term time series data products (e.g. meridional volume / heat transport calculations)***
- ***Branch Unit (BU) opportunities for targeted study areas using science cables capable of additional measurements such as travel time (e.g. PIES) should be explored***
- ***Required international data sharing agreements will support time series continuity***







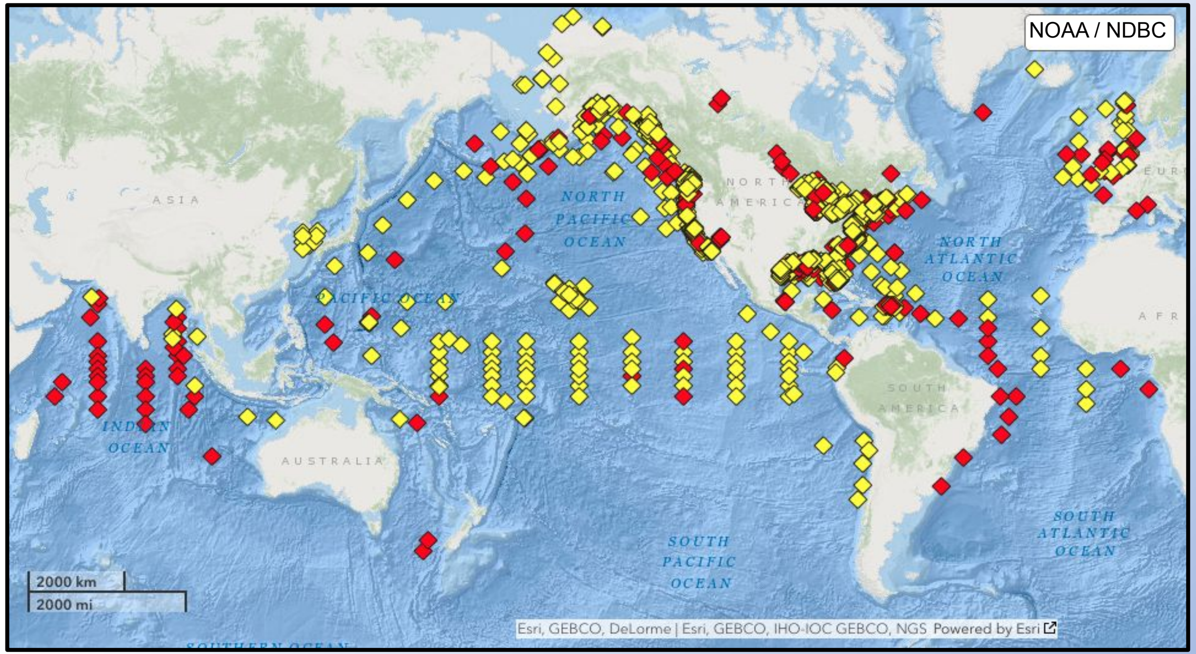
Howe, et al., 2019

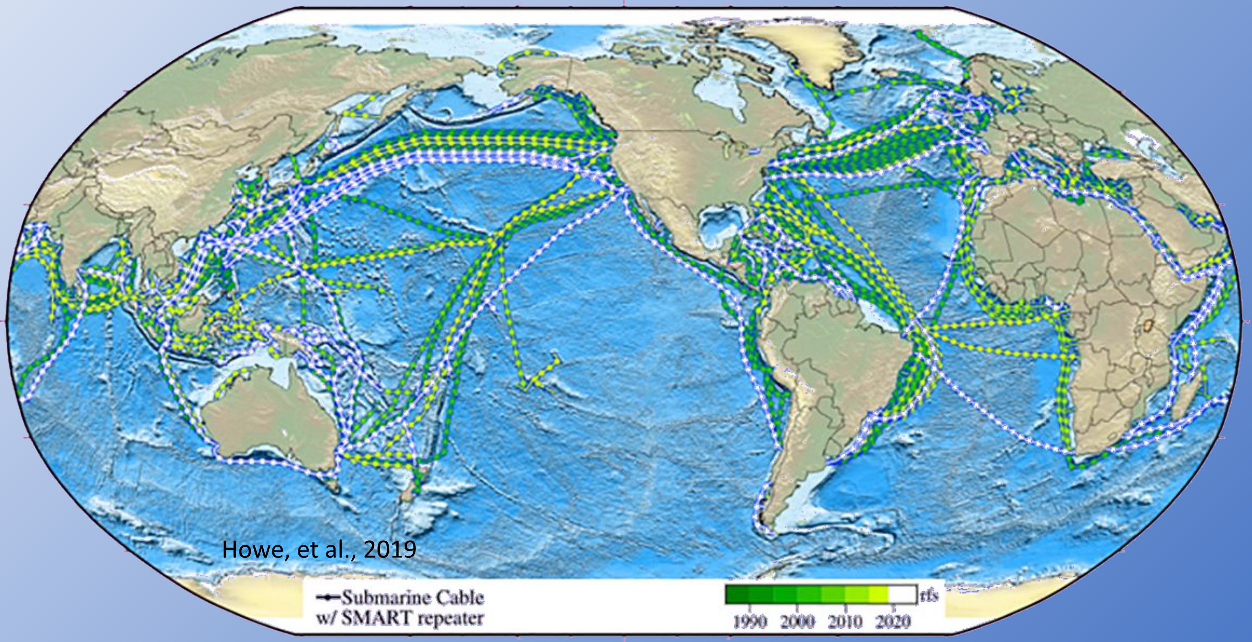
Potential SMART Sensor Benefits…

for WBTS, SAM, Deep/Abyssal Temperature Monitoring, and more…

- ***Augment other existing real-time monitoring arrays with hardline support via SMART Cable infrastructure (with the standard SMART repeater [P,T,Acc.] or with dedicated science cables via branching units)***

Many possibilities exist…





Howe, et al., 2019