Using observations and models to better understand the meridional overturning circulation (MOC)

What is the state the MOC and do models get this right?

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AOML Program Review

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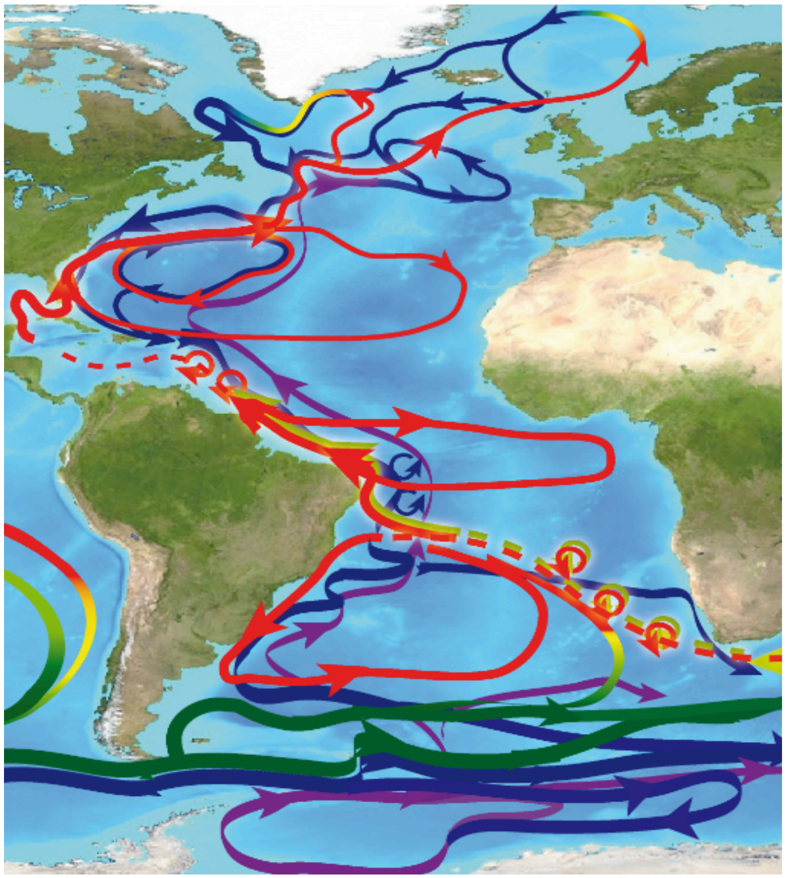
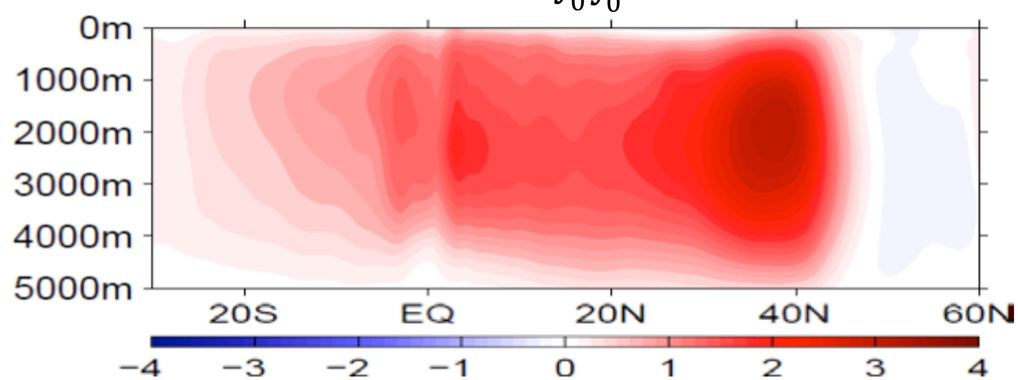
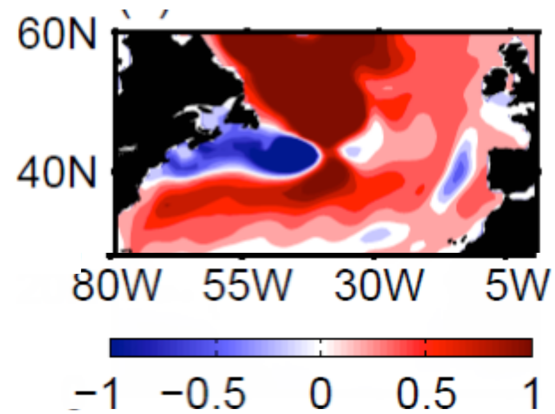
Overview

<u>The MOC impacts temperature, salinity, sea-level and ecosystems</u>



$$\text{MOC} = max \int_0^z \int_0^L \vec{v}(x,z)\ dx\ dz$$

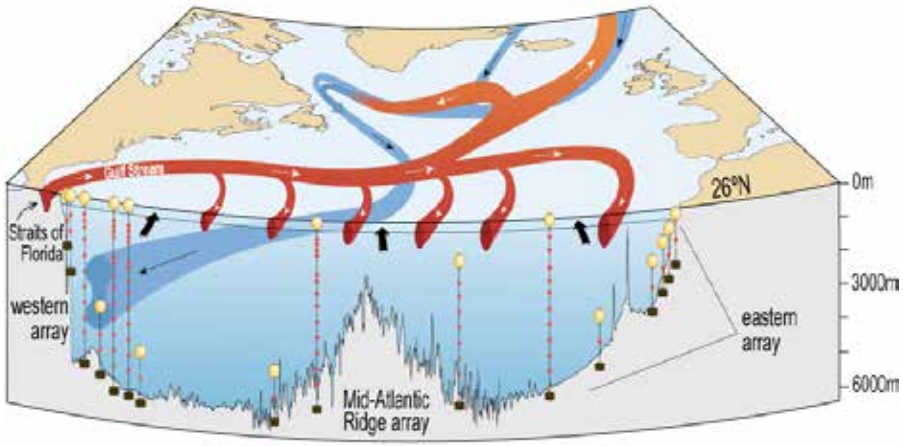


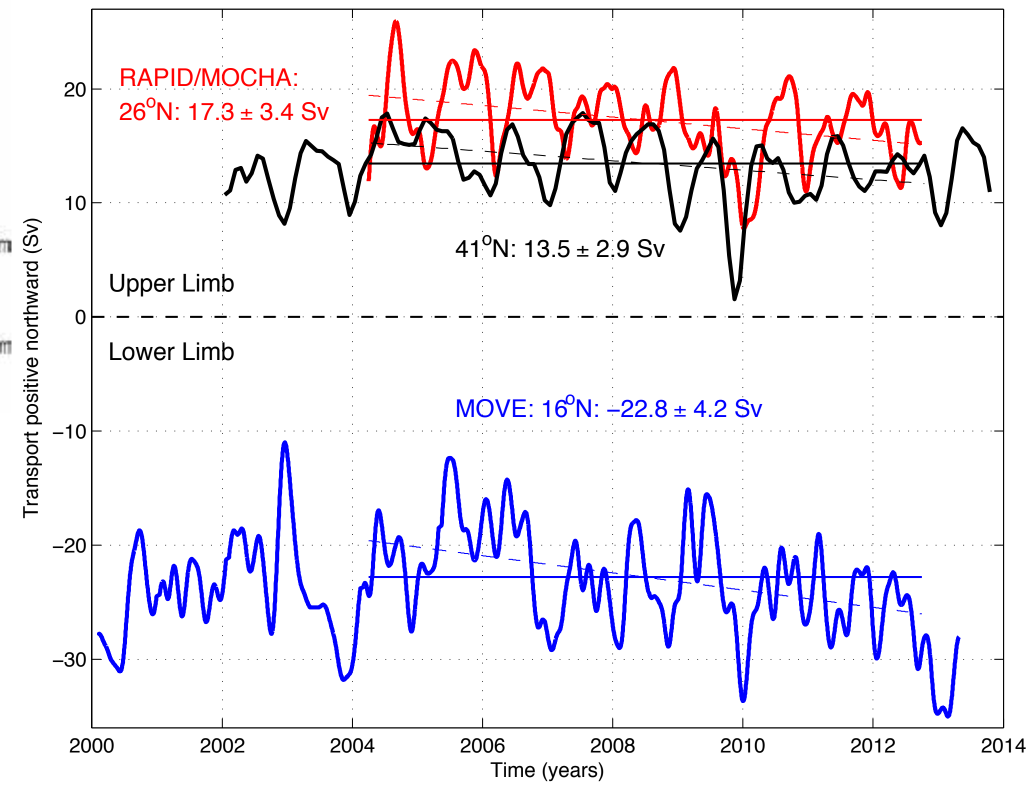


- A strong MOC is associated with warm SST in the North Atlantic.

PHOD is uniquely positioned to contribute to this effort through a combination of data collection and analysis and numerical model experiments

Observations of the MOC in the North Atlantic





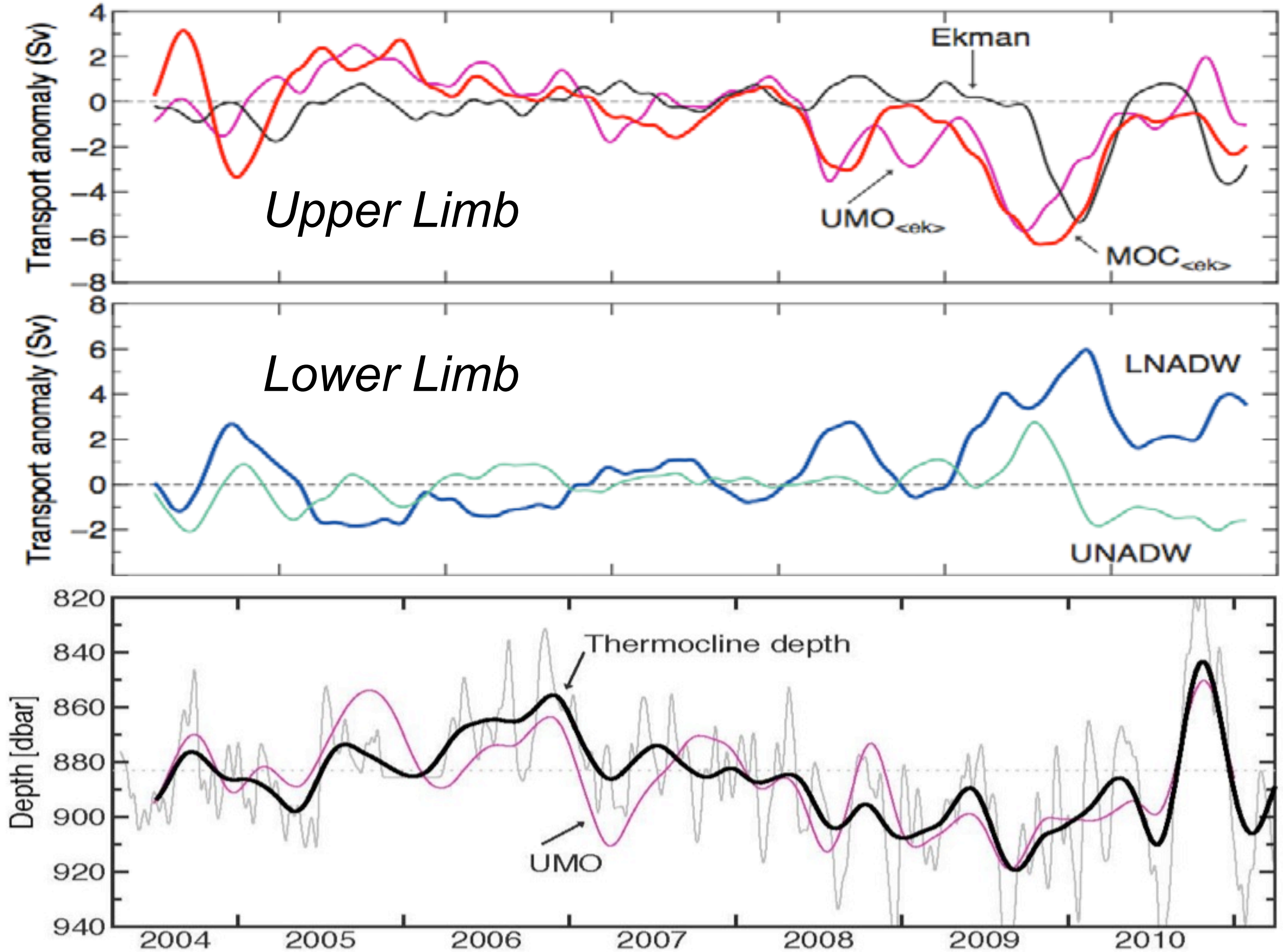
Goals: NOAA partners with the National Science Foundation and the National Environmental Research Council to measure the MOC at 26°N.

Our goals support NOAA's mission to assess the state of the climate system and improve scientific understanding of a changing climate and its impacts. This leverages a long term NOAA program and a key strength in PHOD.

Understanding the state of the MOC at the 26°N array and its forcing

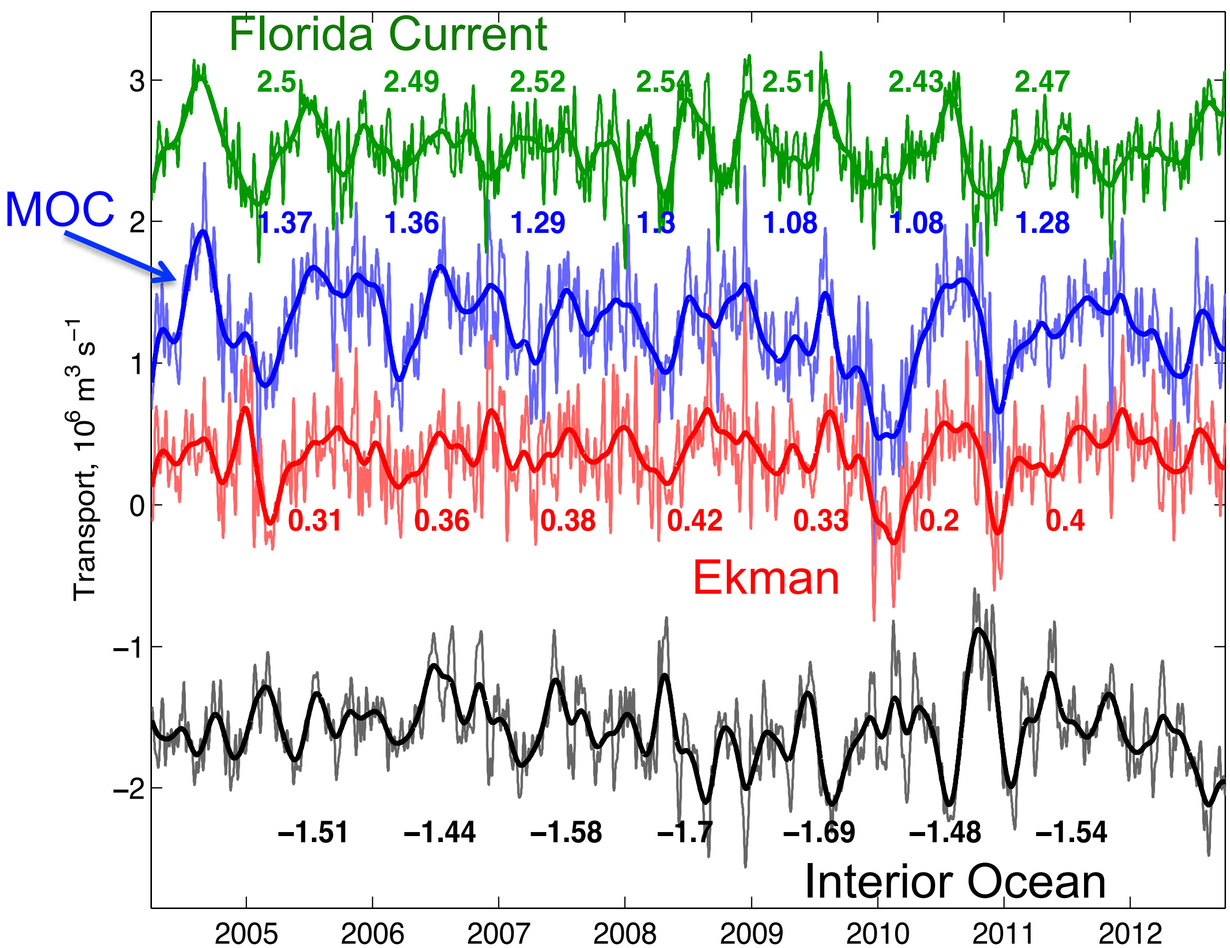
MOC variability forced by internal density changes in the ocean

- The annual cycle was removed from all the MOC components of the 26°N array.
- The MOC showed a pronounced decrease in the winter on 2009 (6 Sv below average).
- The MOC decrease was largely due to mid-ocean transport changes.
- Interannual variability in the deepest part of the ocean is not always in phase.
- Thermocline depth in west drives interannual variability



Interannual variability of meridional heat transport in the North Atlantic

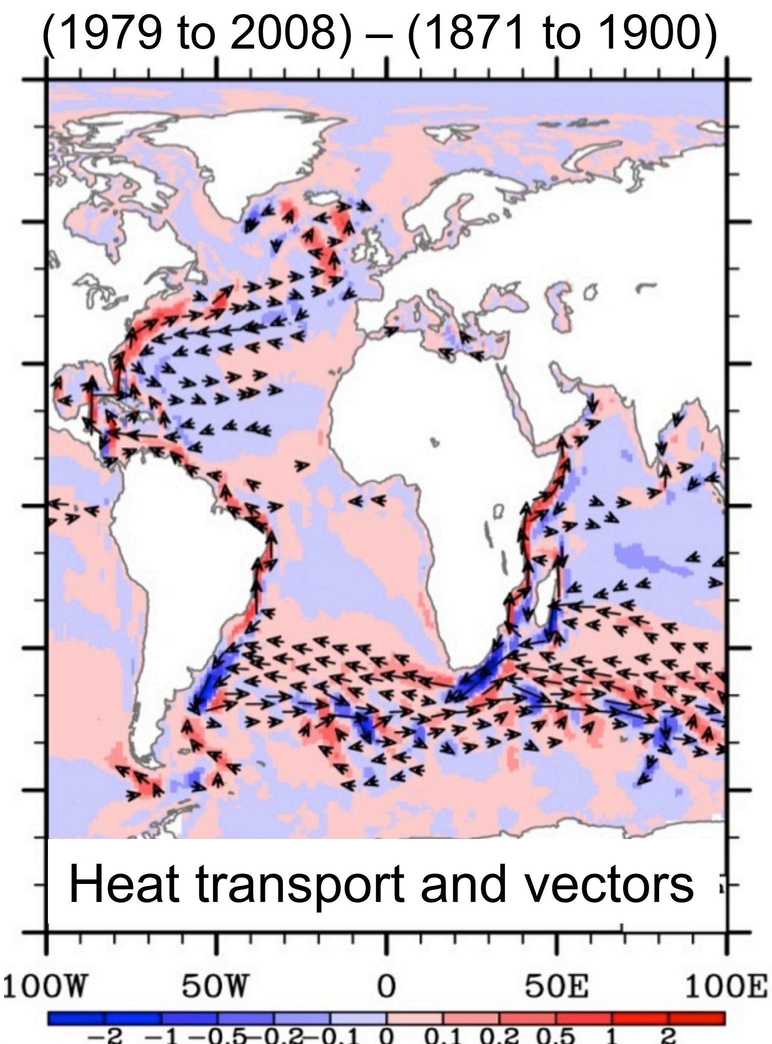
<u>90% of the heat transport is associated with the overturning circulation</u>

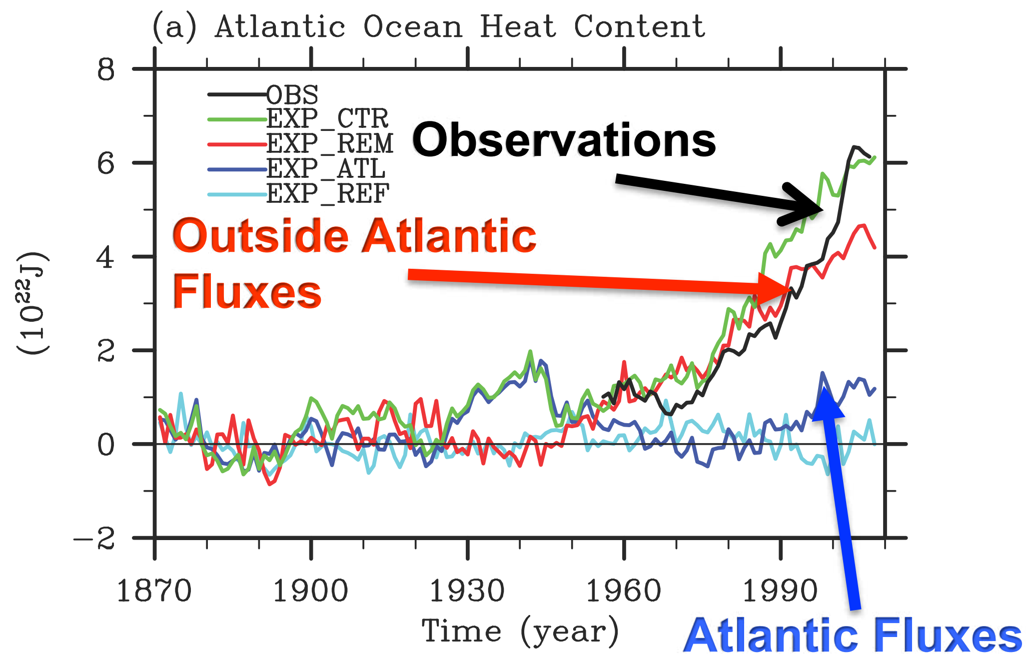


- Meridional heat transport is derived from the 26°N array using moorings, cable, XBTs, Argo and wind stress data.
- The mean meridional heat transport is 1.25 ± 0.11 PW (about 25% of the total ocean and atmospheric heat transport at this latitude).
- Ekman, Florida Current and Mid-Ocean all contribute similar variance to the total.

MOC pathway into South Atlantic effects North Atlantic SST

South Atlantic MOC and heat transport explains warming in the North Atlantic

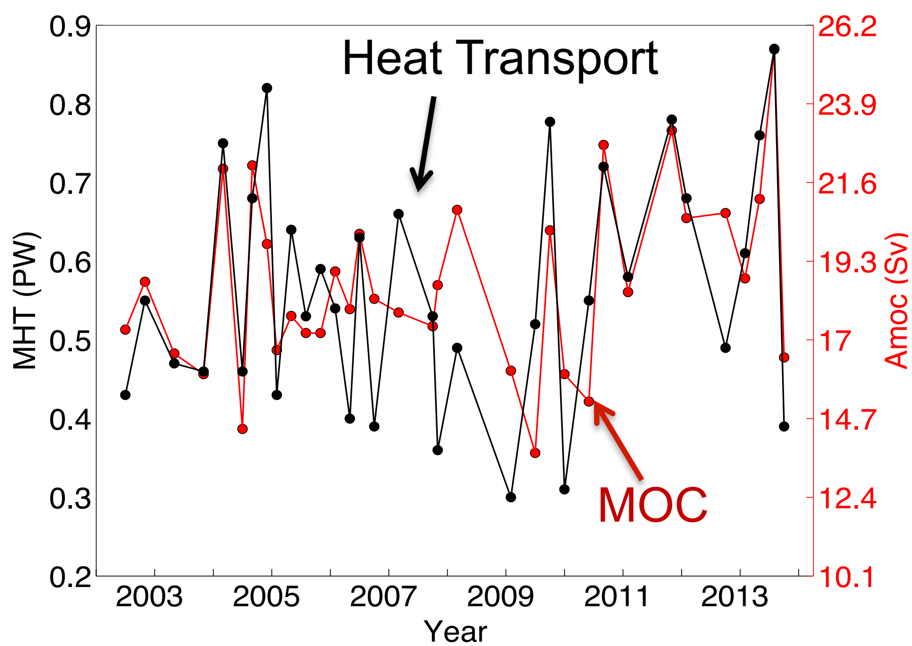


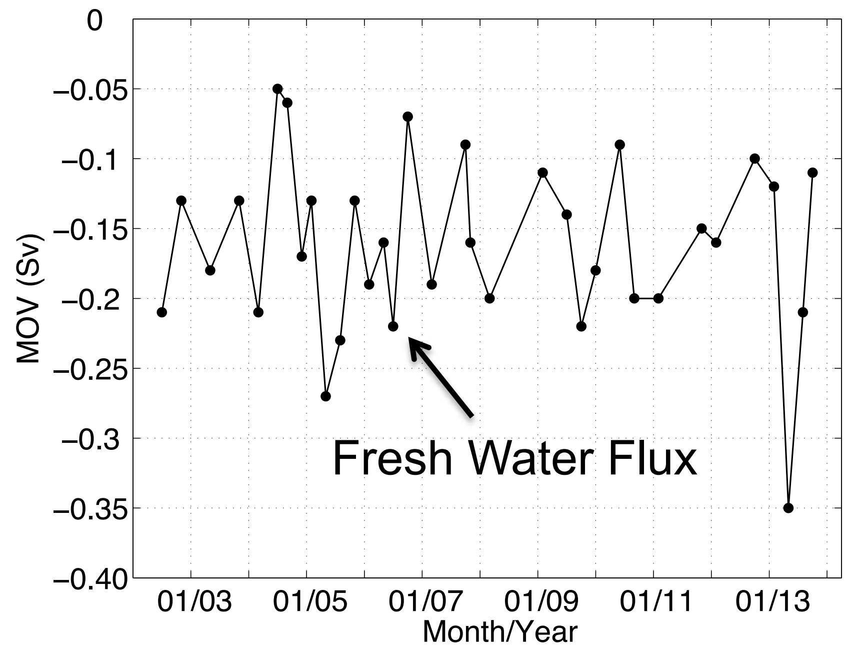


- The NCAR CCSM3 model is forced with fluxes isolated from the Atlantic only vs. from the rest of the ocean.
- Flux forcing outside the Atlantic induces large heat advection south of Africa following the MOC pathway.
- The South Atlantic MOC can modulate secular and multidecadal warming in the Atlantic Ocean.

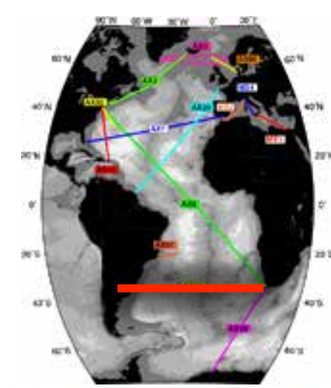
MOC associated fluxes and transports in the South Atlantic at 35°S

South Atlantic XBT observations can estimate MOC, heat and fresh water fluxes





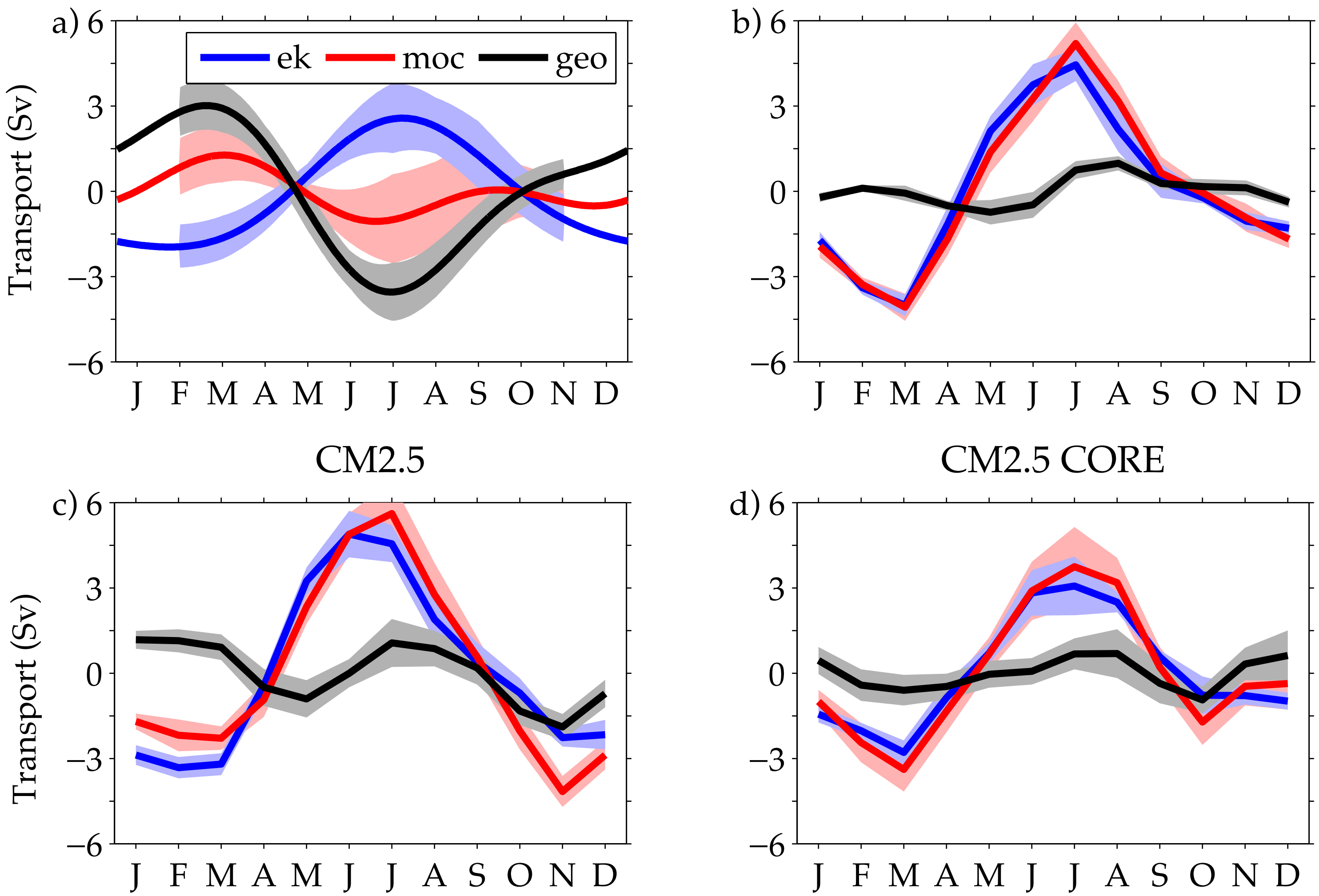
- Meridional heat transport at 35°S in the South Atlantic is 0.55 ± 0.14 PW, with larger variability than at 26°N.
- MOC is 18.17 ± 2.3 Sv, similar in magnitude as 26°N, but with slightly lower variability.
- Fresh Water fluxes are less than zero, implying that the MOC is bi-stable. Note that numerical models have a stable MOC with a positive salinity flux in the South Atlantic.



Garzoli et al. (2013); Dong et al. (2009)

MOC seasonal cycle in observations not reproduced in models

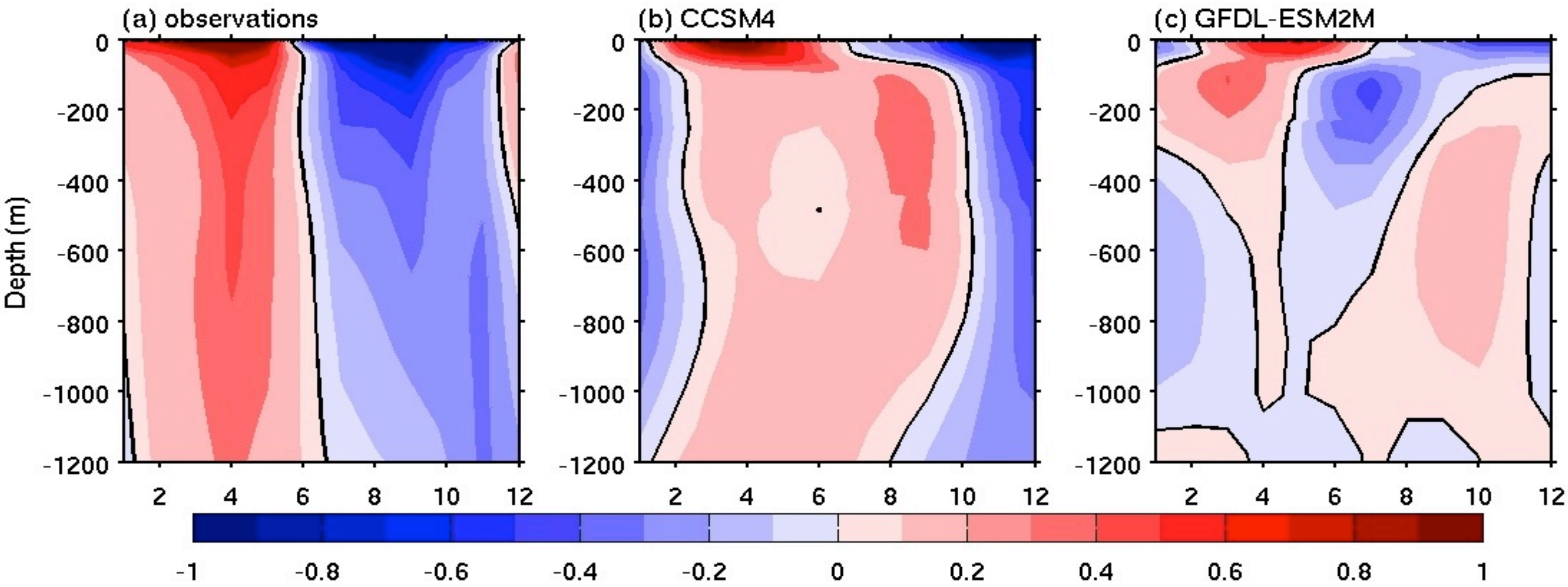
Models do not reproduce seasonal cycle at 35°S, regardless of resolution



- Amplitude of geostrophic heat transport is too weak in models
- Observations show opposing Ekman and geostrophic components
- Model heat transport is dominated by Ekman heat transport

Models contain too much baroclinicity, reducing vertically coherent motions

South Atlantic XBT observations compared to models identifies deficiencies

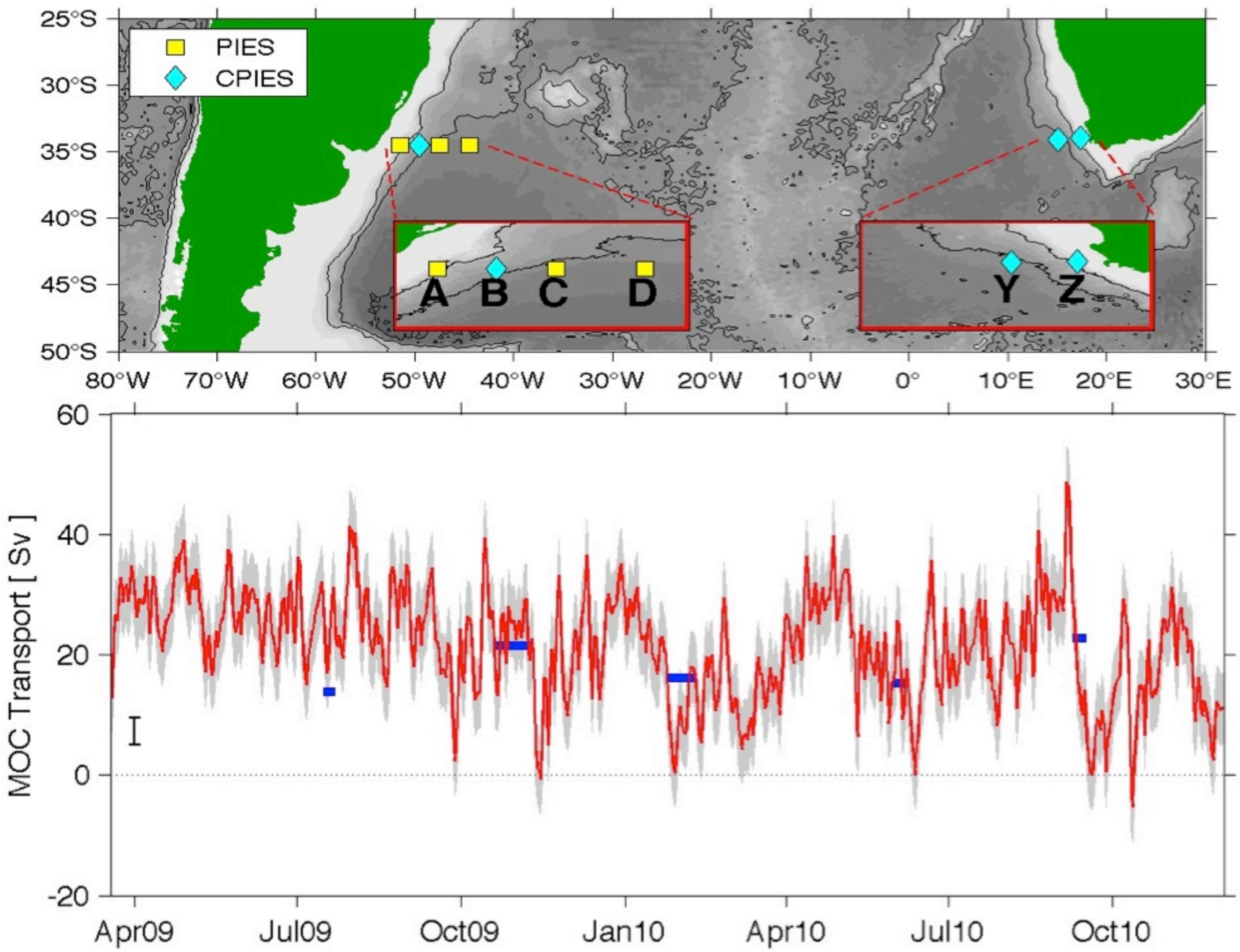


- Zonally-averaged Meridional Velocity Estimated from Observed and Modeled T/S Fields averaged by month (x axis) along 35°S
- Observations (Argo) show vertically coherent seasonal changes in the meridional velocity, but not in the models. Both models show strong baroclinicity.

Dong et al. (2014)

Pilot array to continuously measure the South Atlantic MOC (SAMOC)

South Atlantic MOC estimated from a daily time series of dynamic height from inverted echosounders

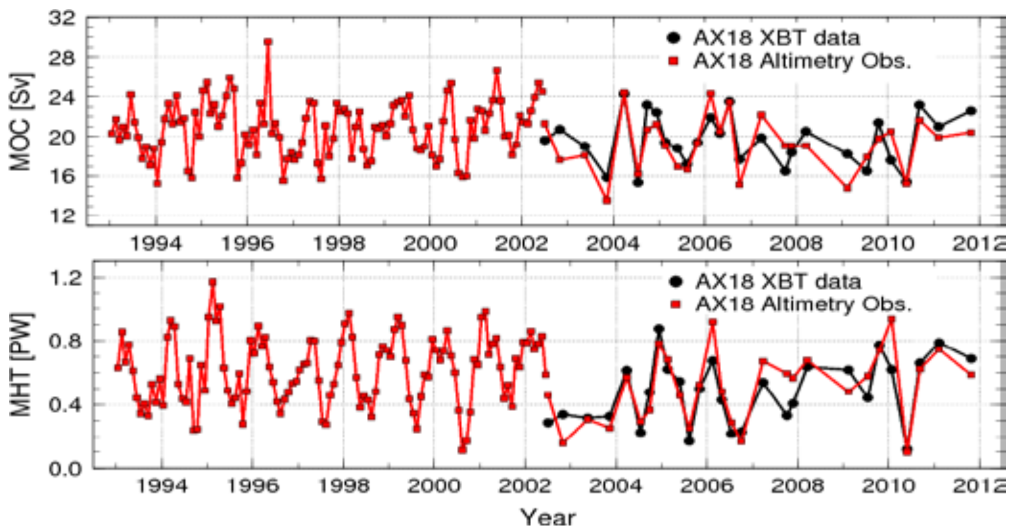


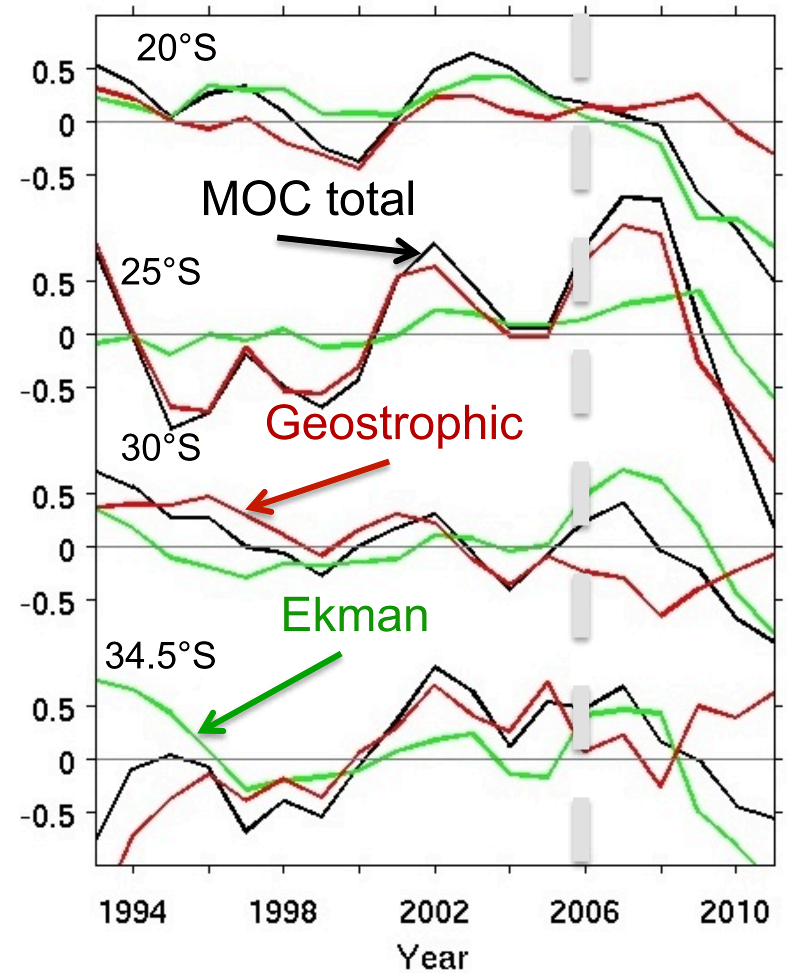
- A 20-month overlap of the two pilot arrays and a novel technique using model output and Argo data helps estimate the daily MOC strength at 35°S.
- Eighteen-month long MOC time series compares favorably with XBT derived time series.
- MOC variability is as large at that at 26°N, with both eastern and western boundary flows contributing equally to the variance.
- Eastern array was reestablished in the fall of 2013 in collaboration with France, Brazil, Argentina and South Africa.

Meinen et al. (2013)

South Atlantic altimetry-derived MOC temporal and spatial variability

South Atlantic MOC and heat transport (MHT) estimates based on altimetry shows different leading contributors at different times





- Largely dominated by geostrophic component before 2006.
- Largely dominated by Ekman component after 2006 (except 25°S).
- At 34.5°S, long period variability with high in mid 2000's and low in mid 1990s.

Dong et al. (2014)

Summary

<u>PHOD is striving to characterize the three dimensional state of the MOC and improve our understanding of this important ocean-climate process.</u>

PHOD houses a great number of critical observational platforms that are being used to evaluate models and determine physical processes of climate variability.

- **26°N MOC array**
- **Expanding 35S MOC array**
- **XBT, CTD/O2, Argo**

1. Analysis done using observations and models shows the importance of the MOC on SST.
2. The large variability of the MOC/MHT including mesoscale, seasonal and longer variability.
3. The MOC on seasonal and longer time scales and models don't reproduce the observations particularly well (e.g. seasonal cycle in heat transport, fresh water transport in the SA, changes in deep water properties, and phasing of AMO).

The Future

<u>PHOD will continue to show critical value of the observing system</u>

Observations:

- Improving observations including Deep Argo, climate quality XBTs, data retrieval systems from moorings, South Atlantic MOC
- Evaluating observing systems to make more cost effective (OSE, OSSE, etc)

Models:

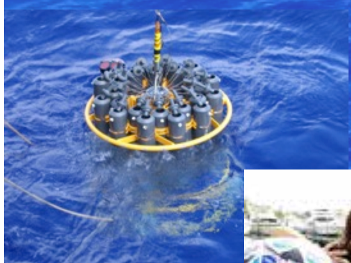
- Confronting models with observations on different time scales (seasonal to decadal and longer)
- Testing a hierarchy of models to develop hypotheses of physical processes

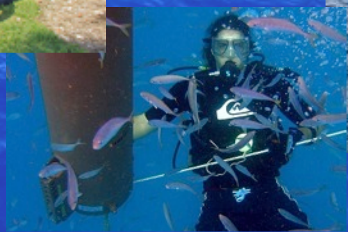
Partnerships:

- Expanding partnerships:
    - e.g. South Atlantic Meridional Overturning Circulation (SAMOC) community and the expansion of the 35°S array
    - UK Rapid community and the expansion of the 26°N array to include oxygen, nutrients and eventually carbon.

Thank you very much

Questions?



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