

# Four Decades of Upper-Ocean Water Mass Changes in the South Atlantic in a Warming Climate

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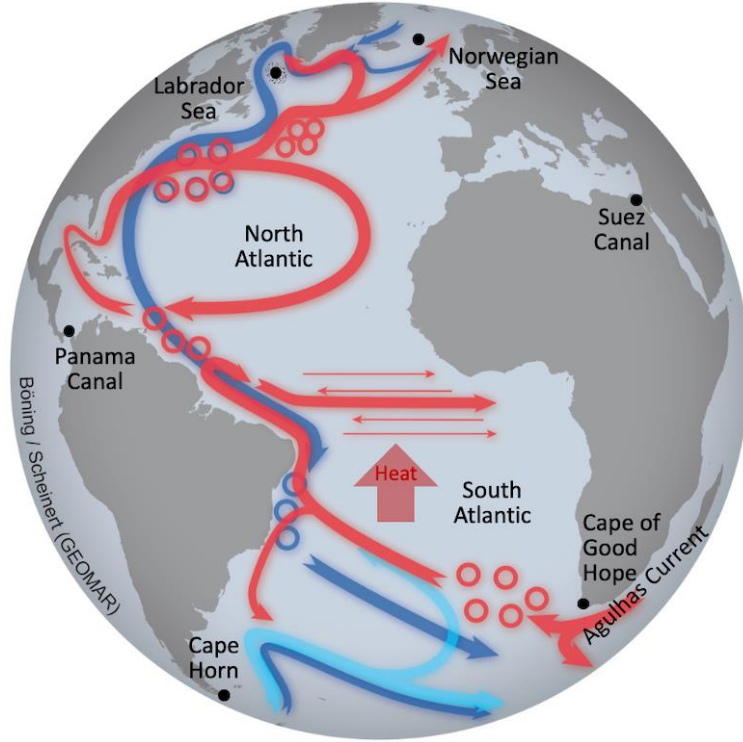
*Ocean Science Meeting, Glasgow, UK*

*Session: Atlantic Ocean Connectivity Across Latitudes: Large-Scale Processes, Observations, Modeling, and Impacts*

# The role of South Atlantic (SA) in the climate

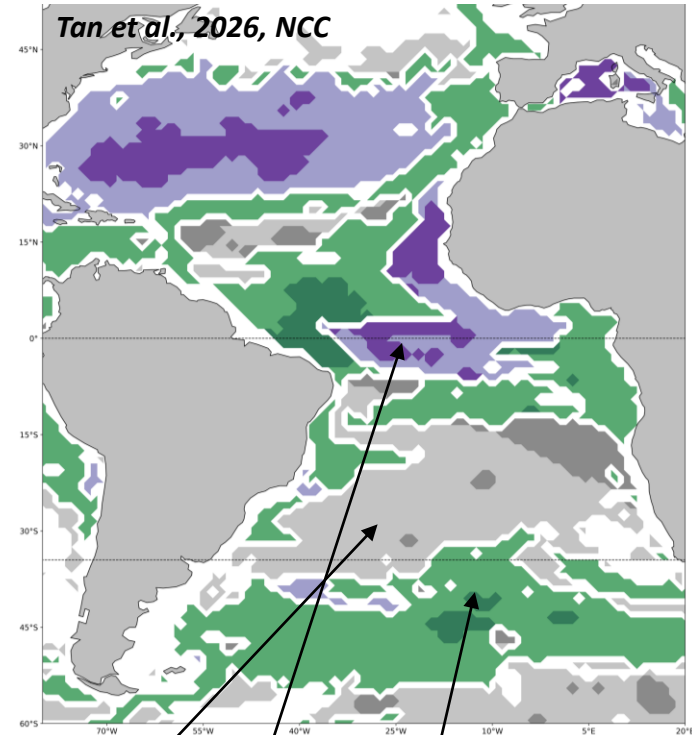
'Heave': adiabatic distribution (vertical displacement)  
 'Spice': diabatic change (true properties change)

## Source regions of AMOC



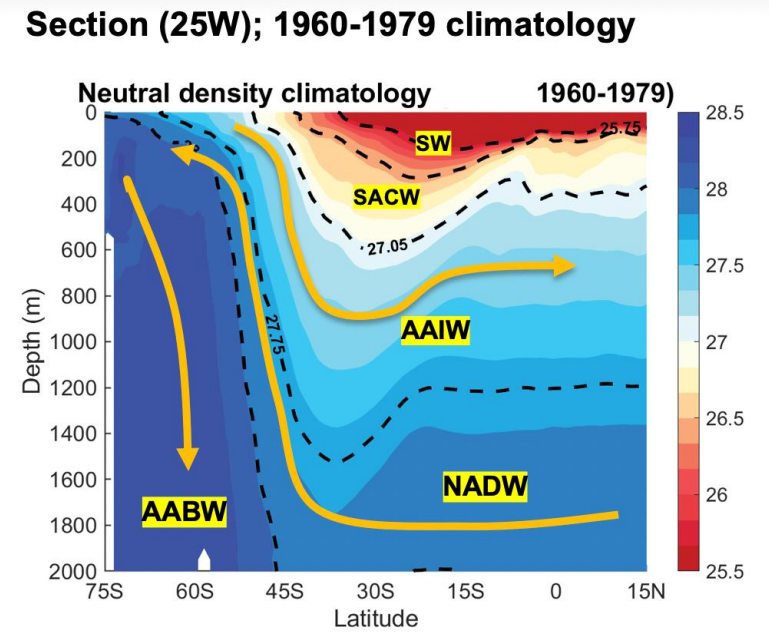
Global heat and freshwater redistribution, and linked to the state and evolution of AMOC

## Compound long-term changes in the upper-ocean (200-1000m; 1960-onward)



Only warming    warming & deoxygenation  
 warming & salinization & deoxygenation  
 But 'why' remains unclear!

## SA: Water mass for the upper limb of AMOC



SACW: South Atlantic Central Water  
 AAIW: Antarctic intermediate Water  
 Key subsurface indicators of climate change, but the response to compound change remains uncertain

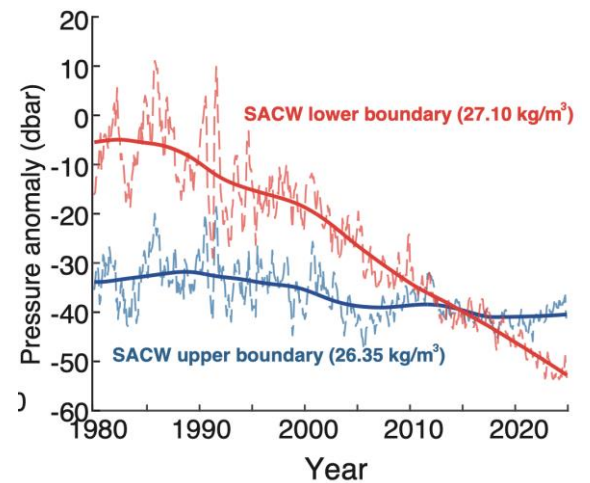
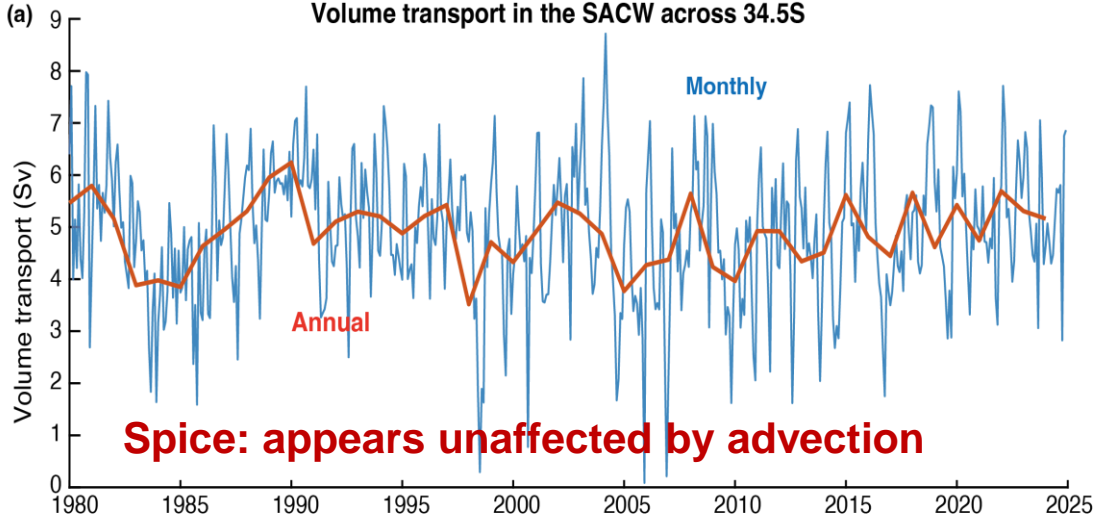
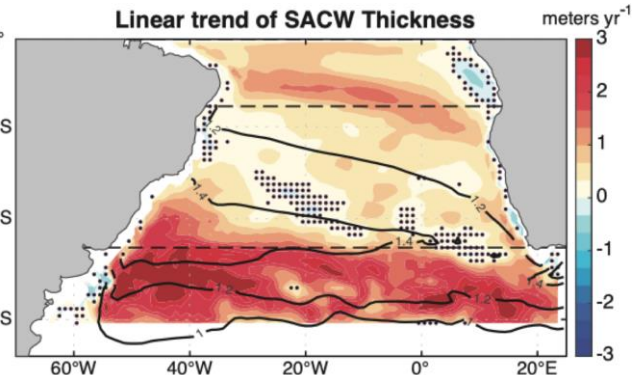
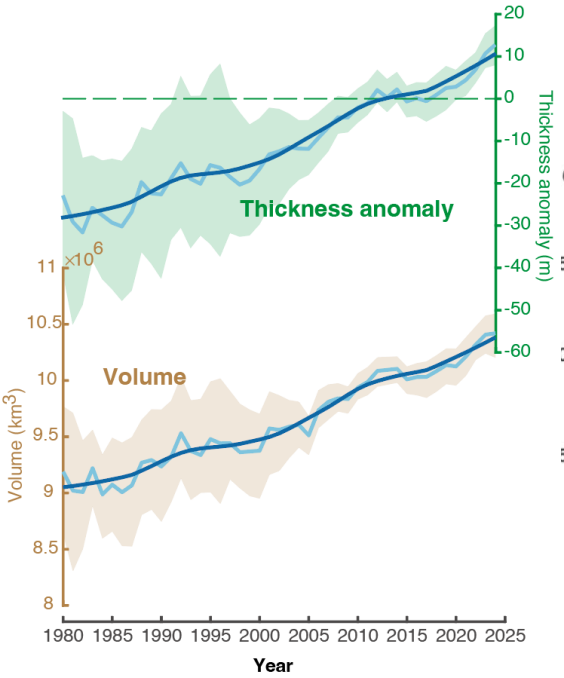
How have SA upper-ocean water-mass properties changed over the past 45 years based on observations, and what processes drove those compound changes?

# 3.2 Properties changes of South Atlantic Central Water (SACW): 200-600m

SACW:  $26.35 < \gamma < 27.10 \text{ kg/m}^3$

➤ Why? -- 'Heave' and 'Spice' theory decomposition

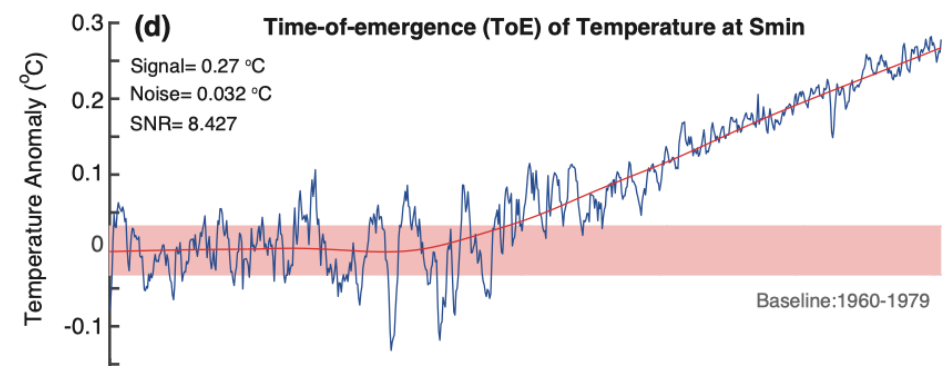
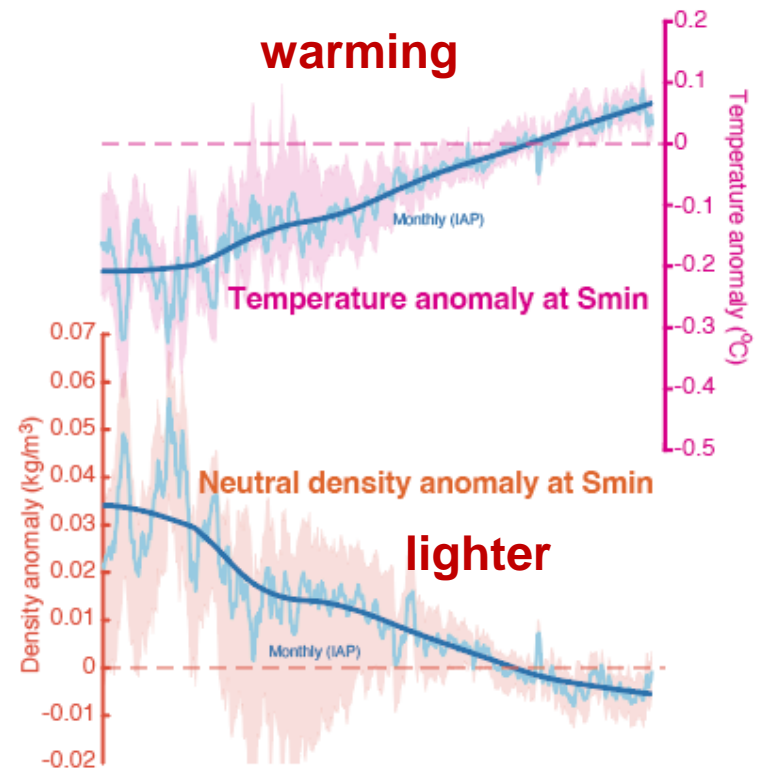
➤ SACW is getting fatter (thicker)



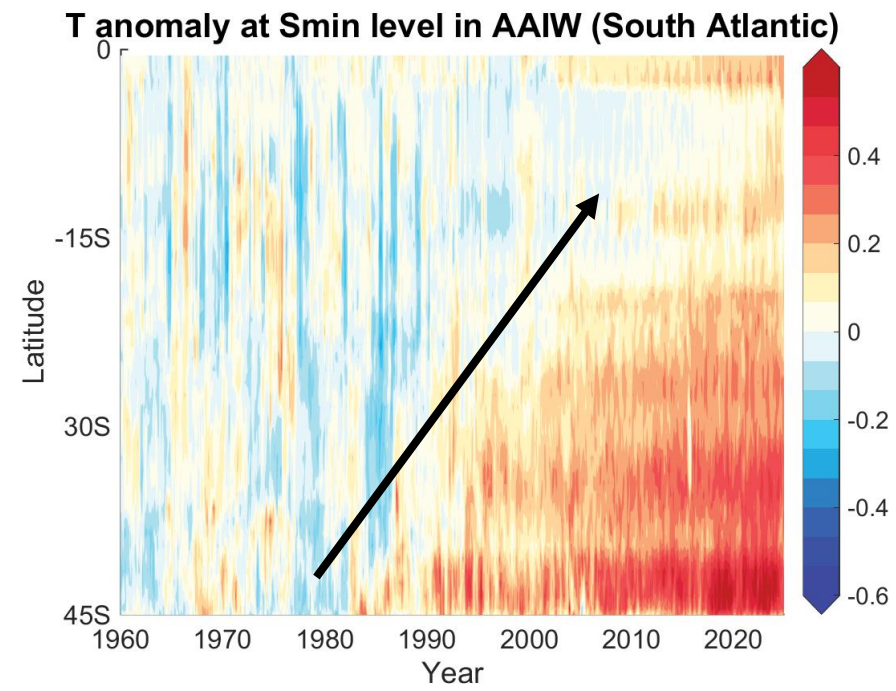
'Heave': depth of isopycnals is becoming deeper (vertical displacement)

# 3.3 Properties changes of core Antarctic Intermediate Water (AAIW): 600~1200m

AAIW:  $27.10 < \gamma < 27.60 \text{ kg/m}^3$ ; core AAIW: Smin



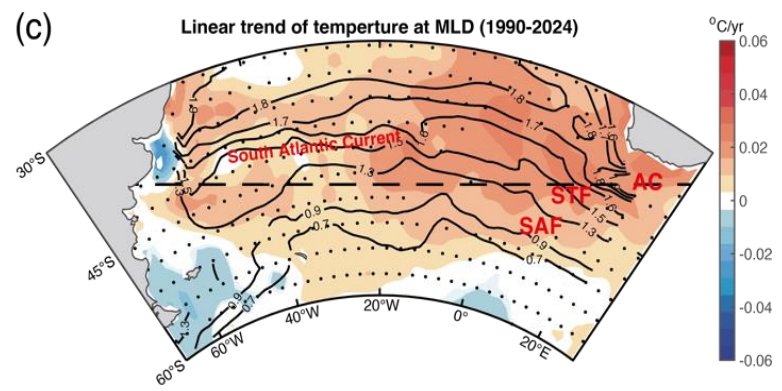
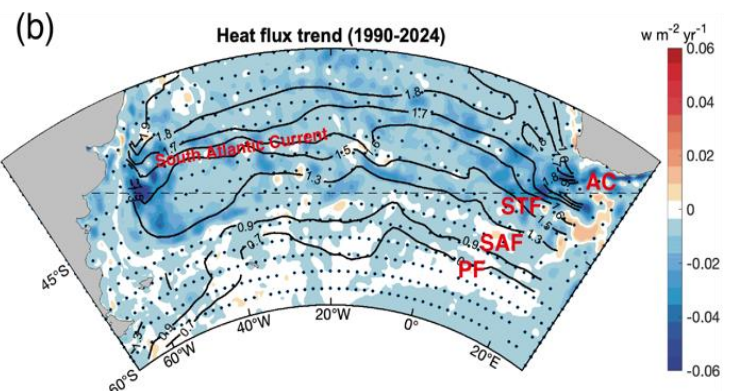
**A key fingerprint of anthropogenic change in intermediate waters**



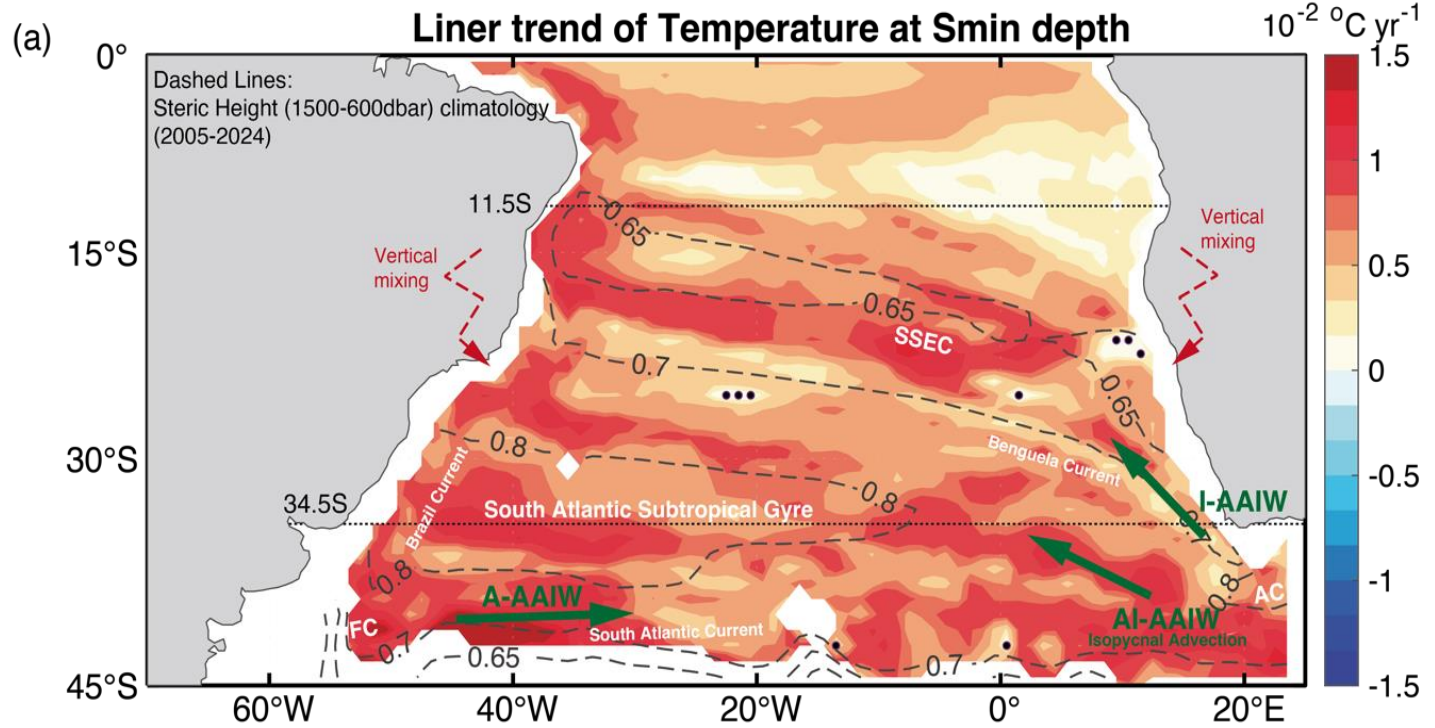
**Warming signal is propagating from south to north**

# 3.3 Properties changes of core Antarctic Intermediate Water (AAIW): 600-1200m

## Origin and Northward Propagation of Human-Induced Warming (Last 30 Years)



Contour Lines: Steric Height (1500-0dbar) climatology (2005-2024)



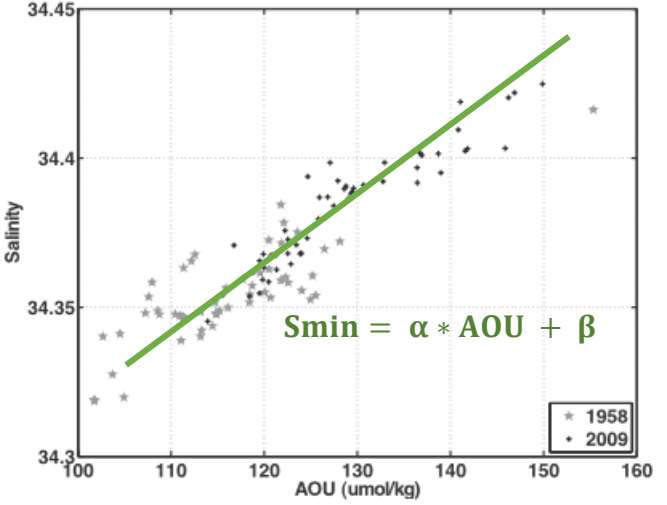
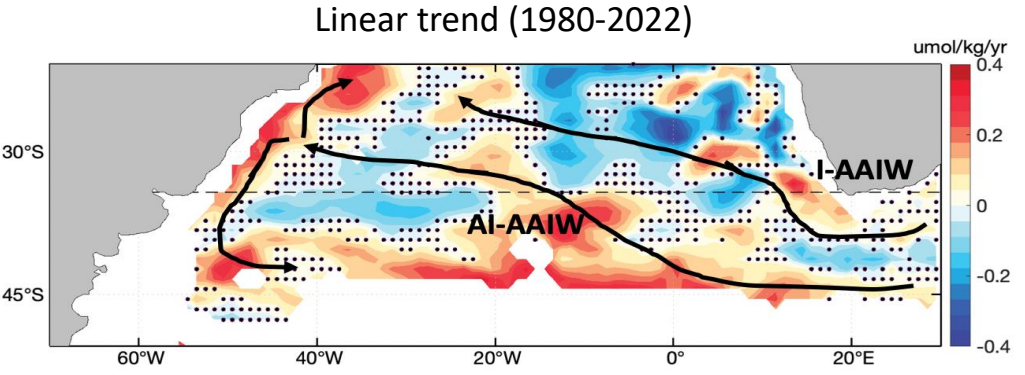
- **Two source/interface regions** (I-AAIW; A-AAIW; Rusciano et al., 2012): **surface/MLD warming signal**
- **Isopycnal transport** is dominant: traced by **positive steric height anomalies** with subduction and advection along currents

# 3.3 Properties changes of core Antarctic Intermediate Water (AAIW): 600-1200m

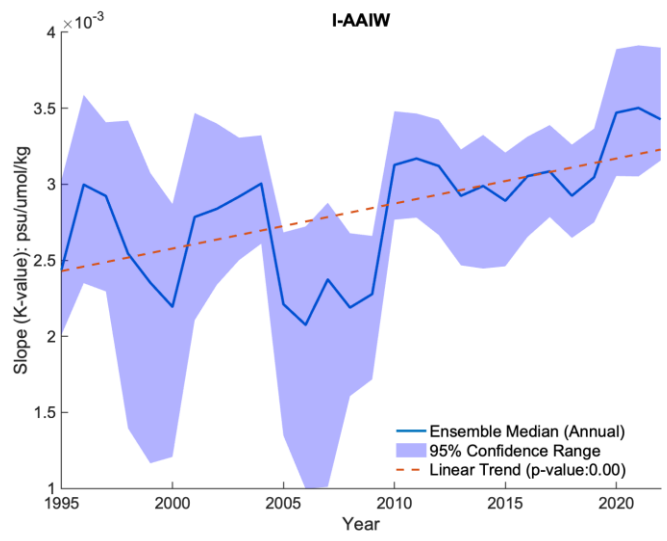
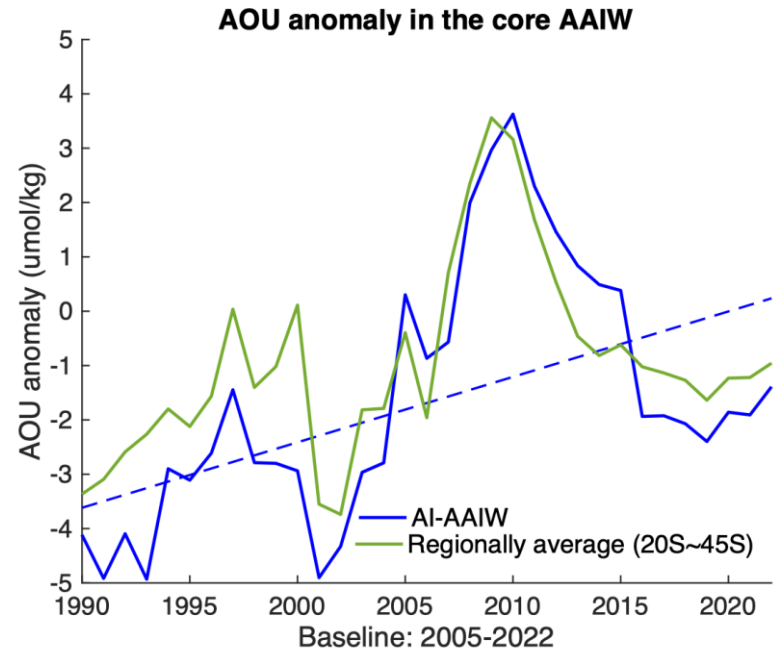
An increasing influence from the Indian Ocean water is another reason

➤ Increasing AOU (older water) since the 1985s

➤ Observed an 'Indianification' over the past 30 years



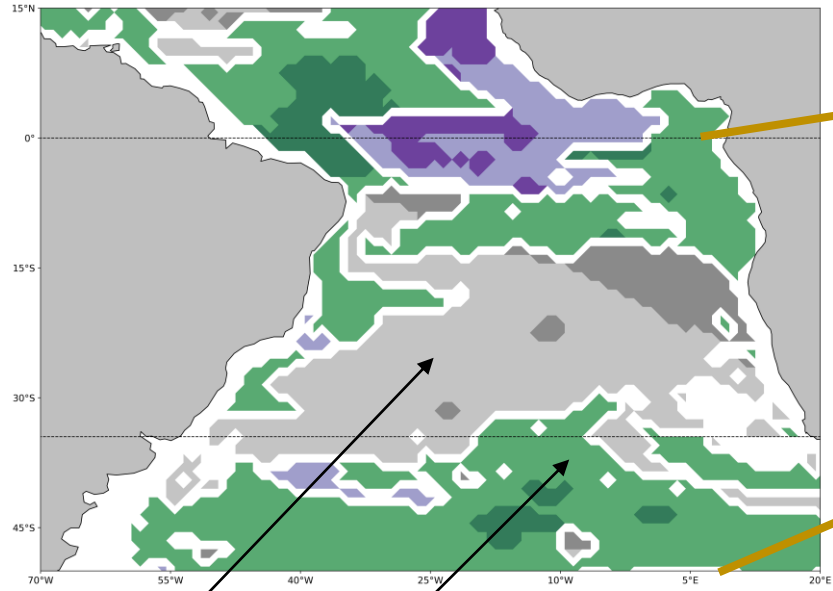
McCarthy et al., 2011  
Salinity-AOU index



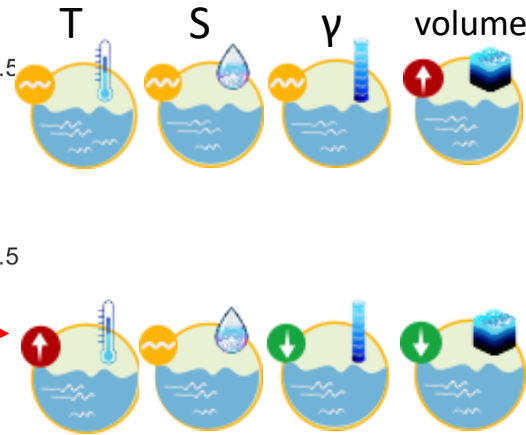
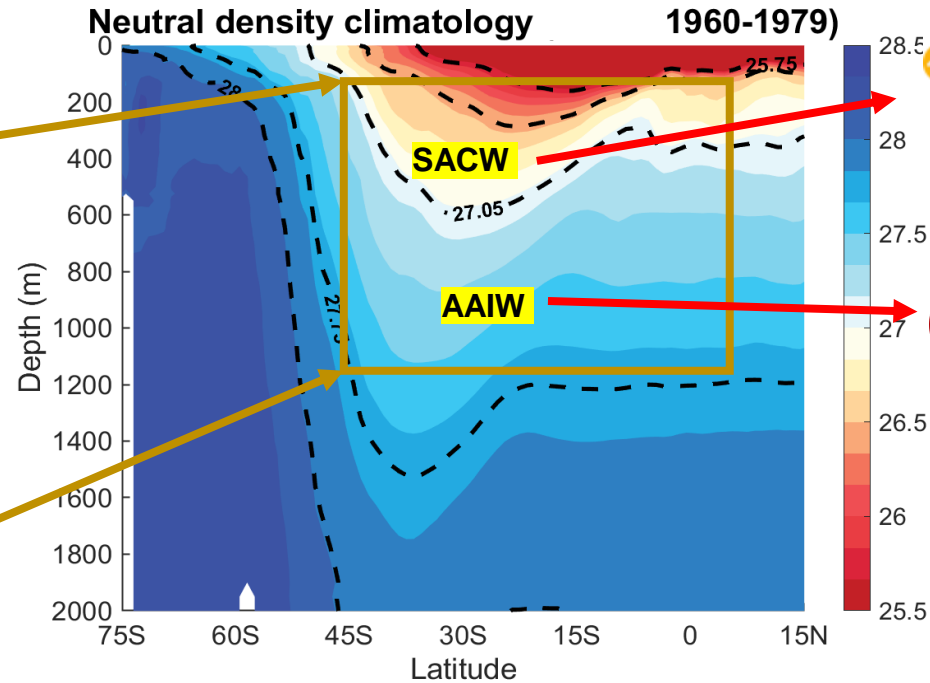
Salinity-AOU index  
in I-AAIW

With the above results using the water mass framework, we now go back to the starting point:

200-1000m (mesopelagic zone)



Only warming  
warming & deoxygenation



Elucidate the **physical processes** driving these changes in response to ongoing global warming from the water mass perspective:

- **SACW** is **heave-driven** (volume increasing)
- **Core AAIW** is **spice-driven** (subduct from the polar fronts + 'Indianification')

# Take-home messages

- The compound long-term change in the South Atlantic is responded in different water masses in different way: some are dominated by 'heave' (vertical displacement), others by 'spice' (isopycnal changes).
- The South Atlantic Subtropical Gyre and the eastern Tropical Gyre emerge as critical regions in the restructuring of upper-ocean water properties.
- We identify early [indications of anthropogenic warming](#) in intermediate waters and observed an 'Indianification' in the multi-decadal variability (>30 yr) in intermediate waters.
- The integration of transect/cruise data with observation-based gridded products now enables systematic, [continuous, high-resolution tracking](#) of water mass evolution [back to 1980s](#)

**Call attention to the ongoing transformations in the Global South (e.g., South Atlantic)**



# Comments welcome!

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- [1] **Zhetao Tan**, S. Speich, E. McDonagh, A. Rata, G. Manta: Four Decades of Upper-Ocean Water Mass Changes in the South Atlantic Under a Warming Climate. 2026. *Science Advances* (**under review**)
- [2] **Zhetao Tan**, E. McDonagh, S. Speich, C.F Lopez, X.D. Rodriguez, E. Jeansson et al. Observed an 'Indianification' in the South Atlantic intermediate layer over the past 30 years, 2026 (**in prep**)