**Path Dependence of AMOC Weakening: A Geostrophic Shear Approach**

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**Introduction**

AMOC (Atlantic Meridional Overturning Circulation) is a crucial component of the climate system. The mean AMOC strength is projected to weaken in the next century. Understanding its response (e.g., mechanisms, variability, trend, etc.) to forcing is crucial.

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**Research question:**

How, and to what degree, does AMOC weaken in different forcing pathways (SSP scenarios)?

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**Methodology**

**Strategy:** AMOC is forced by complex factors. Instead, we can analyze it by calculating an approximate streamfunction (volume transport) from density and wind. This allows us to manipulate and diagnose AMOC trends and variability through the lens of forcing mechanisms (e.g., changing T and S fields).

- Decomposition of AMOC:
  \[ \Psi_{AMOC} = \Psi_g + \Psi_{EK} + \Psi_{ext} \]
- Geostrophic shear component, driven by zonal boundary densities
- Ekman component, driven by wind
- External mode component, driven by bottom velocities

The geostrophic shear component is the main component and can be calculated by integrating the geostrophic shear (thermal wind) relation.

\[ f \frac{\partial v}{\partial z} = \frac{g}{\rho} \frac{\partial \rho}{\partial z} \]

\( f \) : Coriolis parameter
\( \rho \) : density
\( g \) : gravitational acceleration
\( \beta \) : northward velocity

Two methods were attempted. Method B is altered after the formulation in Waldman et al., 2023.

**Method A:** rough approximation. Assume AMOC trend is driven by \( \Psi_g \), which is dependent on boundary densities.

\[ \Psi_{AMOC} \approx \Psi_g(-\lambda) = 0 \]

**Method B:** better approximation. Calculate \( \Psi_g \) and \( \Psi_{EK} \) compensated with barotropic flow by no-net flow.

\[ \Psi_{AMOC} \approx \Psi_g + \Psi_{EK} \]

Method B has better trend and variability reproduction on almost all latitudes.

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**Results**

- AMOC decline and AMOC variability in the CESM2 SSP simulations is thermally driven; salinity changes act to oppose this, but weakening dominates (Fig 1, 3)
- Density-driven AMOC decline is most pronounced near the depth of maximum overturning (Fig 2)
- TW profiles show weakening is likely driven by both upper limb (e.g., Gulf Stream) and lower limb (e.g., DWBC) dynamics
- The divergence of AMOC trends greatly lags divergence in forcing (Fig 6); this lag is meridionally constant (Fig 5)

**Limitations & future opportunities**

This was a single-model study

In-depth analysis of scenario extension runs

- Expand framework to the complete CMIP6 model ensemble
- Better understanding of mechanisms behind lag in AMOC trend divergence
- Reduces effect of internal model variability, better assessment of AMOC trends among state-of-the-art models
- Better predictability of future AMOC, to direct policy/aid towards mitigating negative impacts of AMOC decline