Can the salt-advection feedback be detected in decadal AMOC variability?

1 Wilbert Weijer, 2,3 Wei Cheng, 4 Who Kim, 4 Gokhan Danabasoglu, 4 Steve Yeager, 4 Peter Gent, 2,3 Dongxiao Zhang, 5 John Chiang, 1 Jiaxu Zhang

1 Los Alamos National Laboratory
2 Univ. of Washington/JISAO
3 NOAA/Pacific Marine Environmental Laboratory
4 National Center for Atmospheric Research
5 University of California Berkeley
Can the Salt-Advection Feedback Be Detected in Internal Variability of the Atlantic Meridional Overturning Circulation?

Wei Cheng, Wilbert Weijer, Who M. Kim, Gokhan Danabasoglu, Steve G. Yeager, Peter R. Gent, Dongxiao Zhang, John C. H. Chiang, and Jiaxu Zhang
Problem: AMOC May Be Bi-stable

- Models suggest AMOC may be bi-stable
  - Two stable equilibria may exist
    - One with strong AMOC
    - One with collapsed AMOC
  - So AMOC may be prone to collapse if perturbed
Problem: AMOC May Be Bi-stable

\[ \psi_{\text{atl}} \quad (\text{Sv}) \]

\[ \gamma_p \quad (\text{Sv}) \]

Regime of Multiple Equilibria

Problem: AMOC May Be Bi-stable

$\psi_{\text{atl}} (\text{Sv})$

Safe  |  Danger  |  Fatal

$\gamma_p (\text{Sv})$

Regime of Multiple Equilibria

Pressing Question

- Where is the current climate state with respect to \( L_1 \) and \( L_2 \)?
Mechanism: Salt Advection Feedback

- North Atlantic (e.g., Stommel 1961)
  - AMOC transports salty subtropical waters northward
  - Preconditions subpolar North Atlantic for deep convection
  - Positive feedback on AMOC strength
Mechanism: Salt Advection Feedback

- **Full Atlantic (e.g., Rahmstorf 1996)**
  - AMOC exports NADW from the Atlantic, imports:
    - Salty thermocline water (warm water route)
    - Fresh intermediate water (cold water route)
  - AMOC stability depends on net freshwater exchange between South Atlantic and Southern Ocean: $F_{ov}$
    - If $F_{ov} > 0$, then negative feedback
    - If $F_{ov} < 0$, then positive feedback
Stability Indicator: $F_{ov}$

- Studies suggest: $L_1$ is given by $F_{ov} (34^\circ S) = 0$
  - If $F_{ov} > 0$ (negative feedback): AMOC mono-stable
  - If $F_{ov} < 0$ (then positive feedback): AMOC bi-stable
- Most climate models show $F_{ov} > 0$
  - Observations suggest $F_{ov} < 0$
  - Do models overestimate AMOC stability?
- Caveat
  - $F_{ov} (34^\circ S)$ is not external forcing but part of the solution
  - Part of balance between E-P-R and gyre-driven freshwater transport across 34°S
Probing AMOC Stability

- **Equilibrium diagrams**
  - Calculate equilibria directly with iterative methods

- **Downside**
  - Technically and computationally challenging
  - Very few models capable

---

*Dijkstra & Weijer (2003), Weijer & Dijkstra (2003)*
Probing AMOC Stability

- **Hysteresis diagrams** from hosing experiments
  - Apply freshwater flux perturbation to North Atlantic
  - Gradually increase, then decrease its amplitude

- **Downside**
  - No guarantee for true equilibria if perturbation change is not slow enough
  - Very expensive

---

Rahmstorf et al. (2005)
This Study

- **Goal:** Can we detect salt advection feedback from internal variability?
- **Objective:** examine the key physical links underlying salt-advection feedback in internal variability
This Study

- **Approach:** Analyze PI control integrations of two ESMs
  - ESM2M (GFDL): 500 yr
  - CESM1 (NSF/DOE): 1400 yr
- **Perform spectral analysis on key quantities**

\[
F_{\text{ov}} = -\frac{1}{S_0} \int_{-H_0}^{0} v S_{\text{w}}(z) dx = \int X_w X_e v dx \\
S(z) = \frac{1}{(X_w - X_e)} \int X_w X_e S dx
\]

AMOC-induced freshwater transport  Zonally integrated meridional transport  Zonally averaged salinity
Meridional Coherence of AMOC

- What do the spectra of AMOC look like?

![Diagram showing AMOC spectra with periods of 25 yr and 40 yr]
Meridional Coherence of AMOC

- How coherent is AMOC variability?

+ve phase: Index leads field
AMOC and $F_{ov}$

- Does AMOC variability impact $F_{ov}$?

$\Delta \rho_{n-s}$

$F_{ov}(34^\circ S)$ +/-

+ve phase: Index leads field
AMOC and $F_{ov}$: CESM

\[
F_{ov} = -\frac{1}{S_0} \int -H_{10} \phi \text{ d}t \int -H_{10} <v> \text{ d}t \int -H_{10} \phi \text{ d}t \int -H_{10} <v> <S> \text{ d}z \]

+ve phase: Index leads field
F_{ov} and AMOC

- Does $F_{ov}$ (34°S) impact AMOC?

+ve phase: Index leads field
Does $F_{ov}$ ($34^\circ$S) impact stratification?
Density Difference and AMOC

- Does $\Delta \rho_{NS}$ impact AMOC?

Decadal time scales
- Temperature dominates density
- AMOC slightly lags density

Multidecadal time scales
- Salinity dominates density
- In phase with AMOC

Coherence phase between AMOC (45°N) and density (saline, thermal contributions) in the subpolar North Atlantic
Conclusions

- Salt advection feedback cannot be detected in natural variability of long PI control integrations
  - AMOC controlled by North Atlantic density
  - Weak impact of AMOC variability on Fov (34°S)
  - But no noticeable impact of Fov (34°S) on stratification, or AMOC

- Natural variations in Fov (34°S) not strong enough to generate significant salinity perturbations in Atlantic