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

Team

Can the Salt-Advection Feedback Be Detected in Internal Variability of the Atlantic Meridional Overturning Circulation?

WEI CHENG,[a,b] WILBERT WEIJER,[c] WHO M. KIM,[d] GOKHAN DANABASOGLU,[d] STEVE G. YEAGER,[d]
PETER R. GENT,[d] DONGXIAO ZHANG,[a,b] JOHN C. H. CHIANG,[e] AND JIAXU ZHANG[c]

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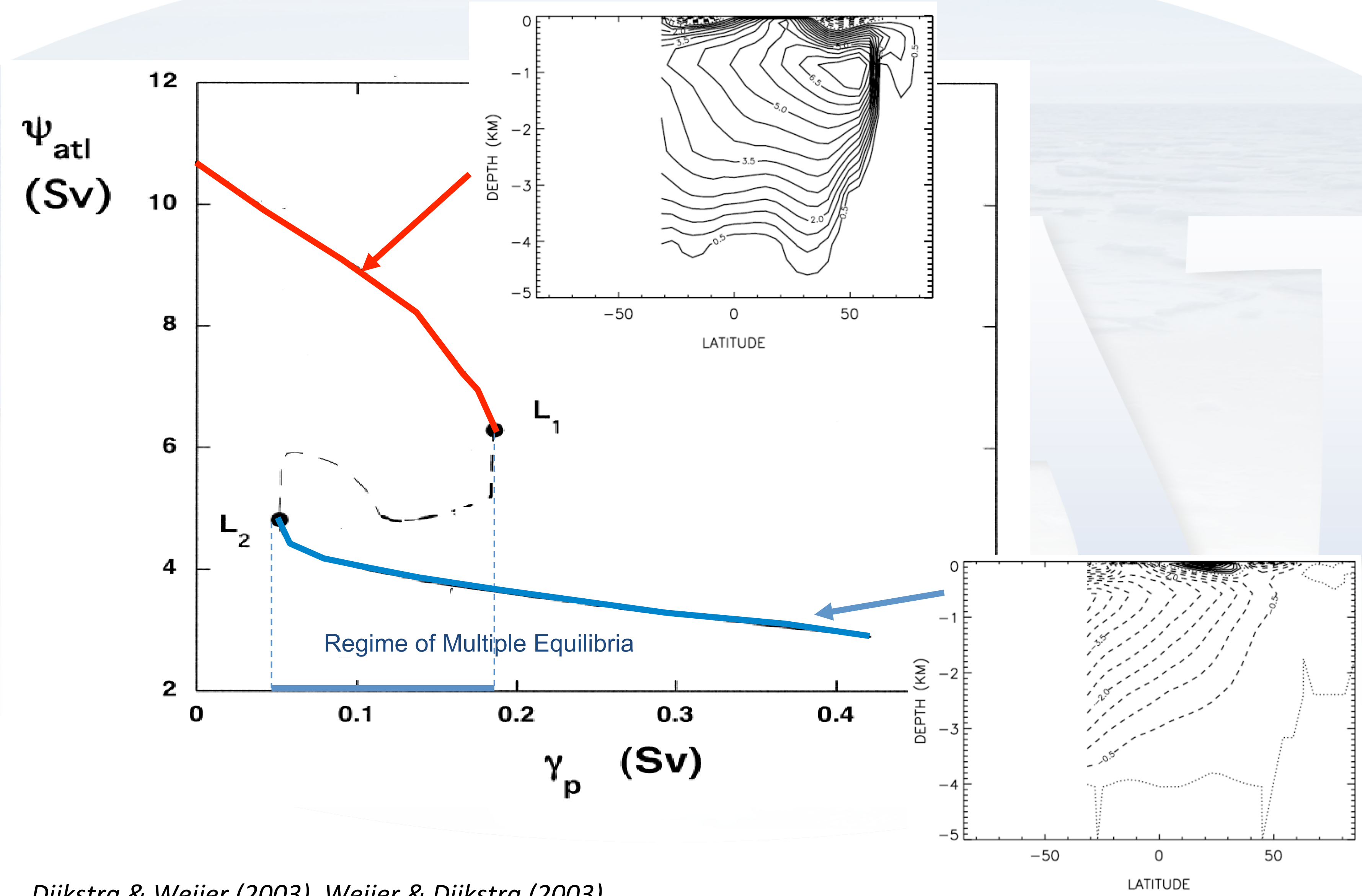
Problem: AMOC May Be Bi-stable

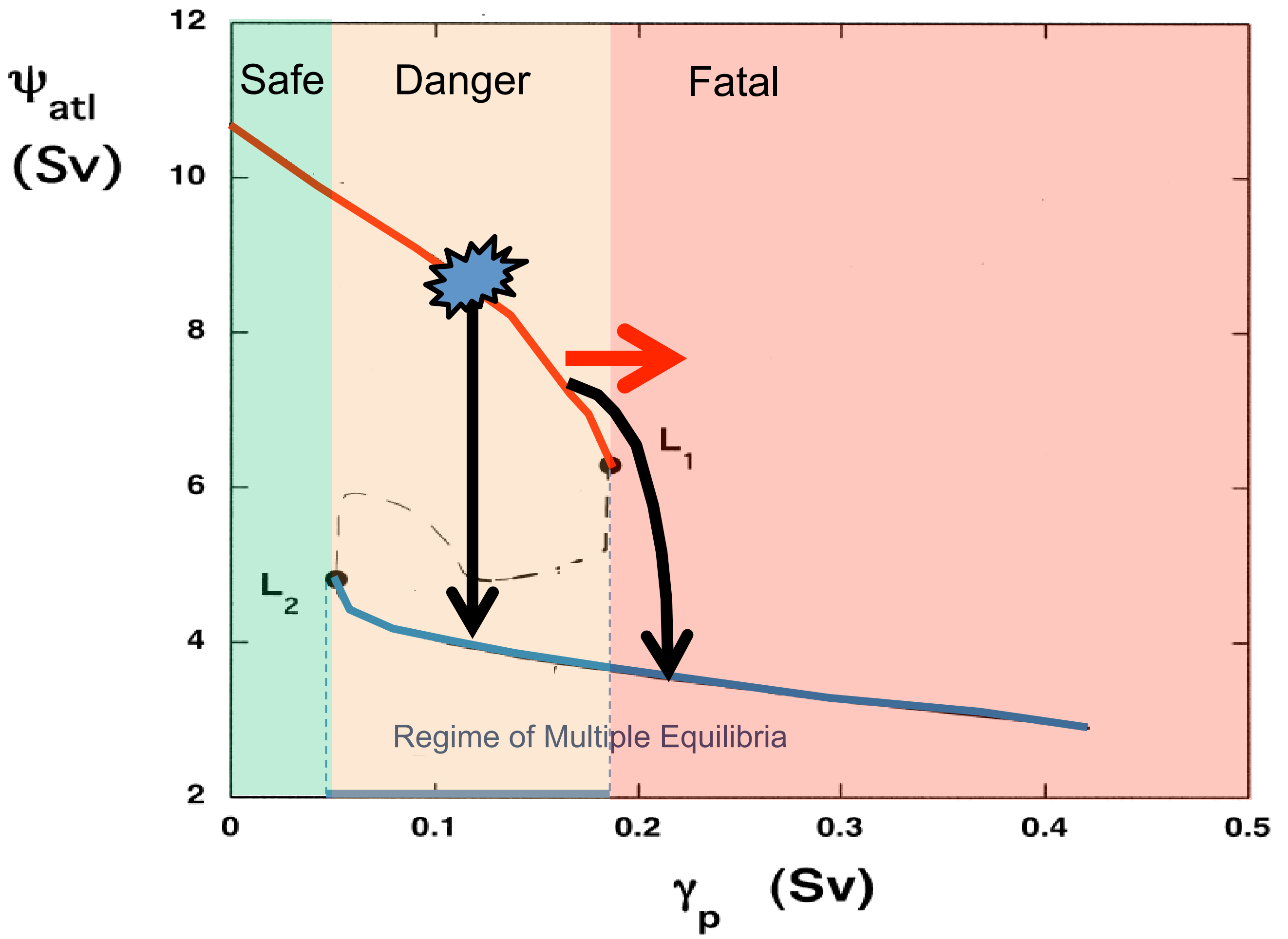
- Models suggest AMOC may be bi-stable
  - Two stable equilibria may exist
    - One with strong AMOC
    - One with collapsed AMOC
  - So AMOC may be prone to collapse if perturbed

Problem: AMOC May Be Bi-stable



Dijkstra & Weijer (2003), Weijer & Dijkstra (2003)

Problem: AMOC May Be Bi-stable



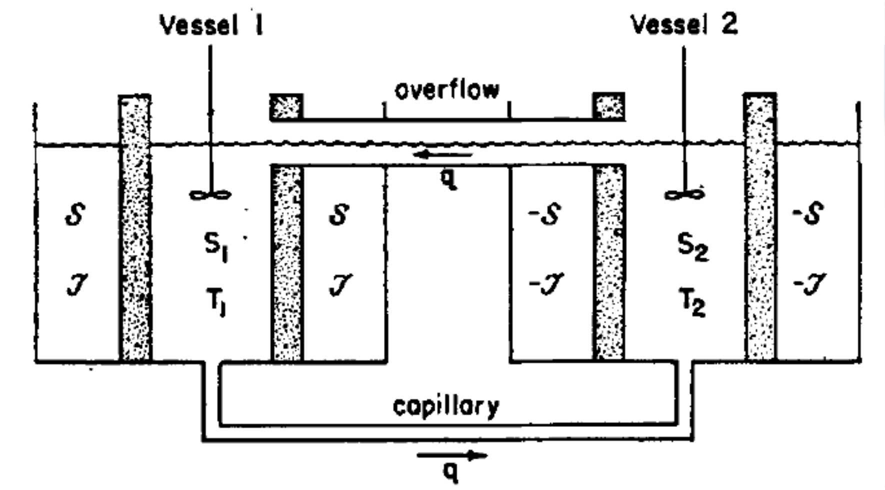
Dijkstra & Weijer (2003), Weijer & Dijkstra (2003)

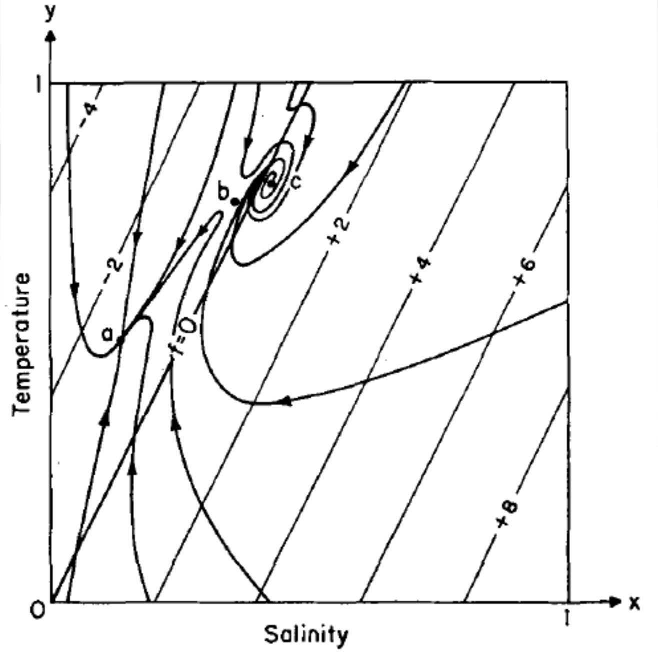
Pressing Question

- Where is the current climate state with respect to L_1 and L_2?

Mechanism: Salt Advection Feedback

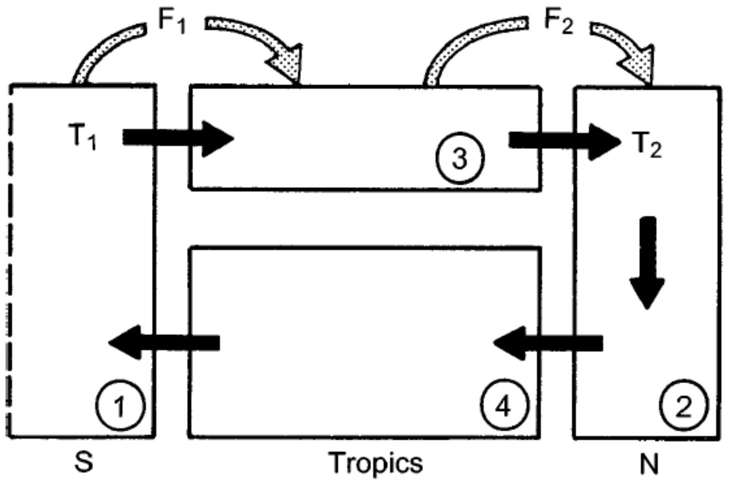
- North Atlantic (e.g., Stommel 1961)
  - AMOC transports salty subtropical waters northward
  - Preconditions subpolar North Atlantic for deep convection
  - Positive feedback on AMOC strength

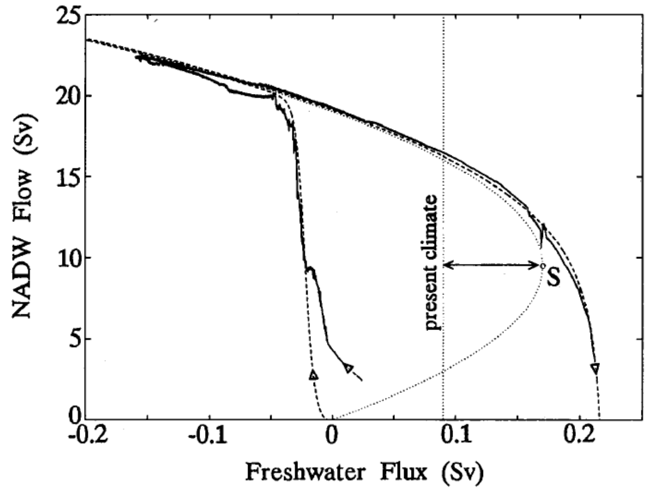




Mechanism: Salt Advection Feedback

- 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



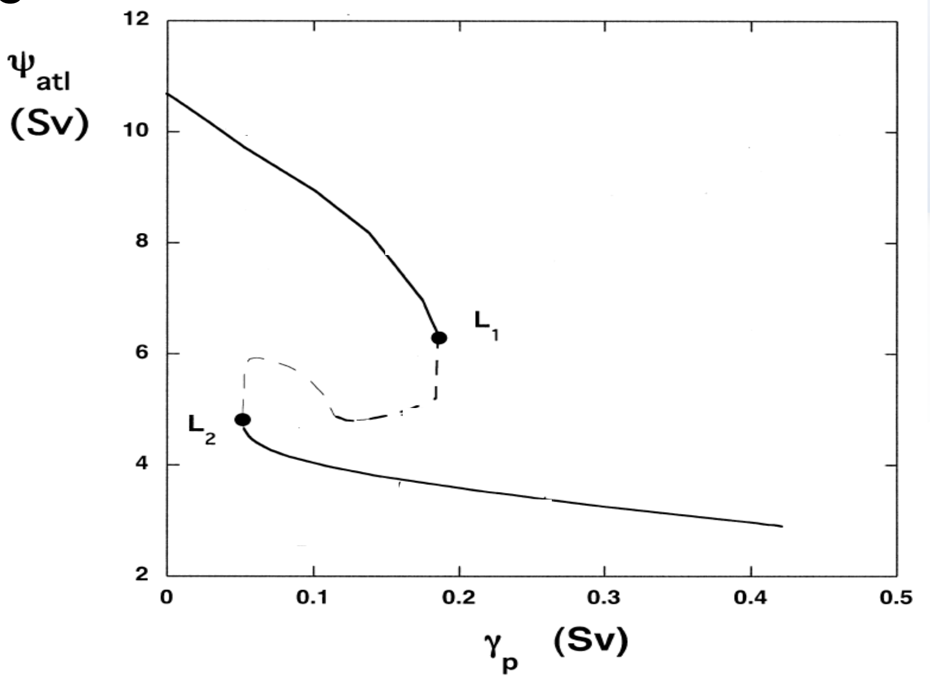


Stability Indicator: F_{ov}

- Studies suggest: L_1 is given by F_{ov} (34°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°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

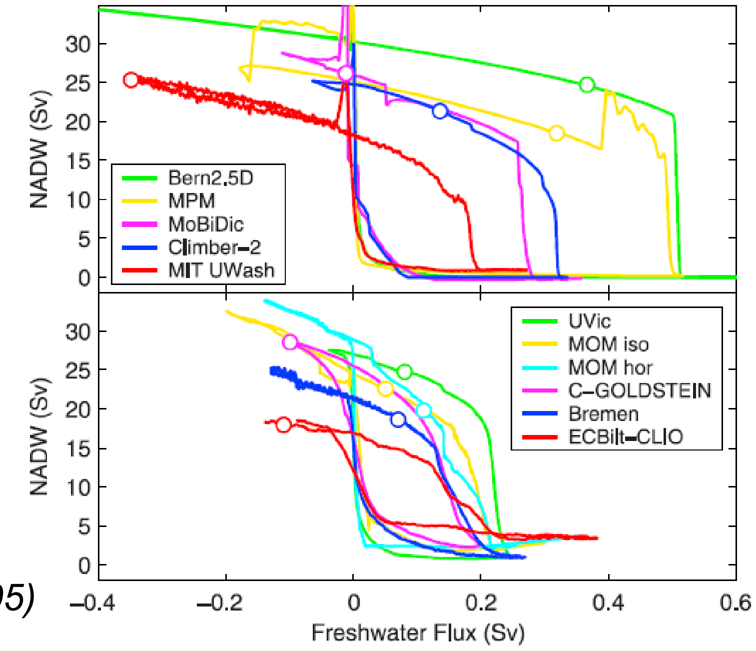
- Equilibrium diagrams
  - Calculate equilibria directly with iterative methods
- Downside
  - Technically and computationally challenging
  - Very few models capable



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



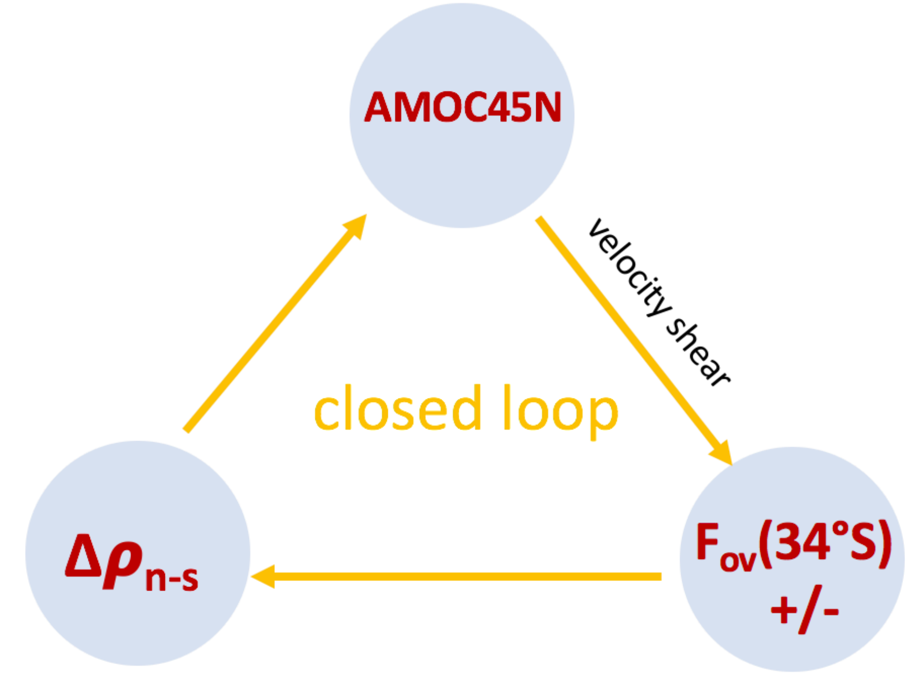
'EMICs'

'GCMs'

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

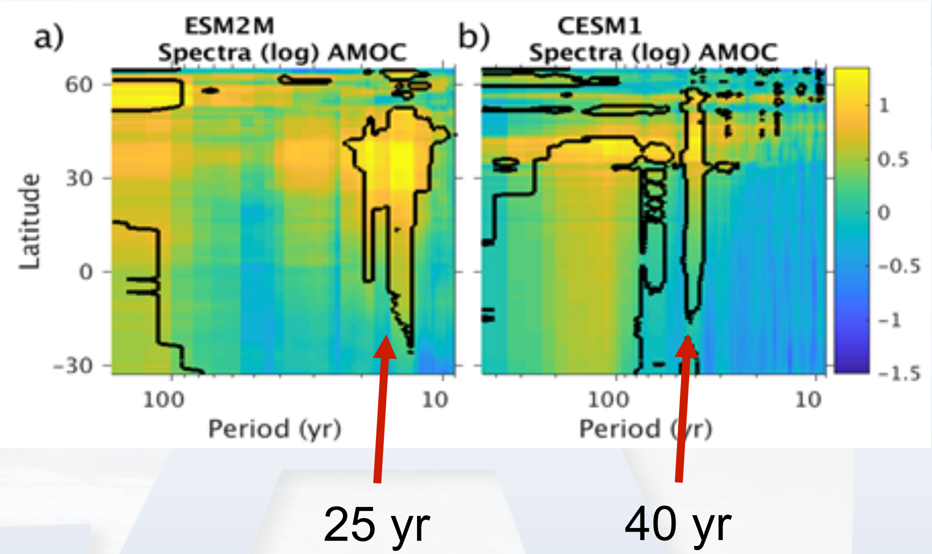
- Approach: Analyze PI control integrations of two ESMs
  - ESM2M (GFDL): 500 yr
  - CESM1 (NSF/DOE): 1400 yr
- Perform spectral analysis on key quantities

$$F_{ov} = -\frac{1}{S_0}\int_{-H}^{0} v\, S\, dz \qquad v(z) = \int_{X_w}^{X_e} v\, dx \qquad S(z) = \frac{1}{(X_w - X_e)}\int_{X_w}^{X_e} S\, dx$$

AMOC-induced freshwater transport — Zonally integrated meridional transport — Zonally averaged salinity

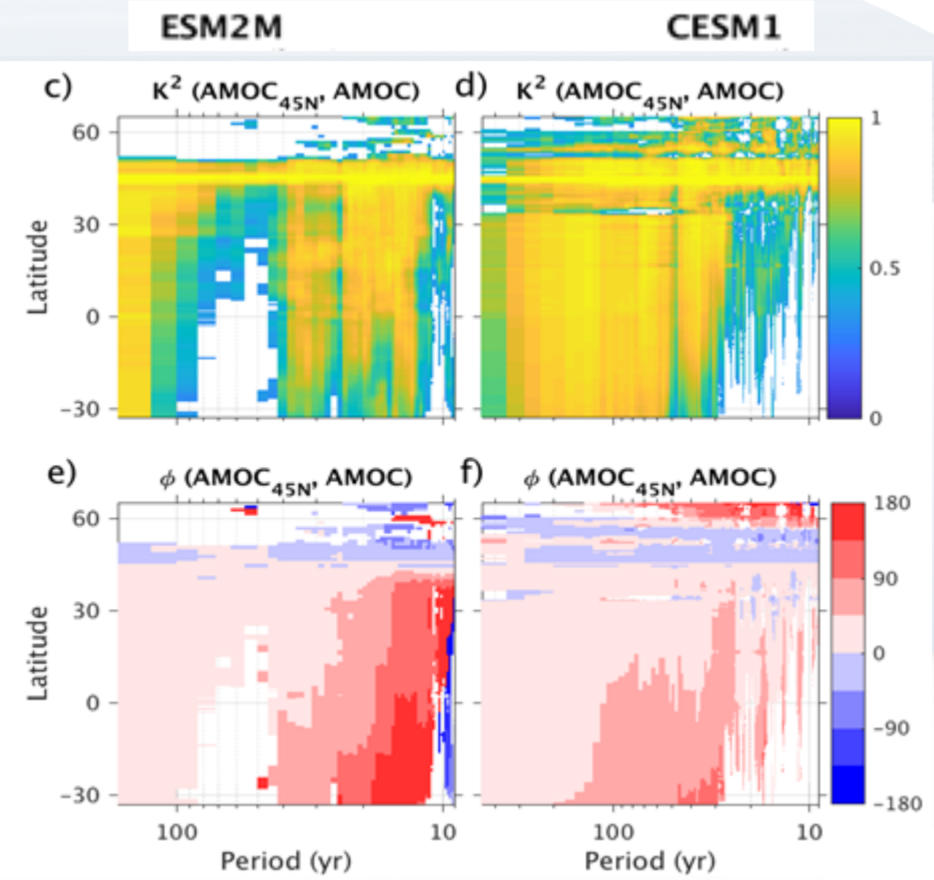
Meridional Coherence of AMOC

- What do the spectra of AMOC look like?



Meridional Coherence of AMOC

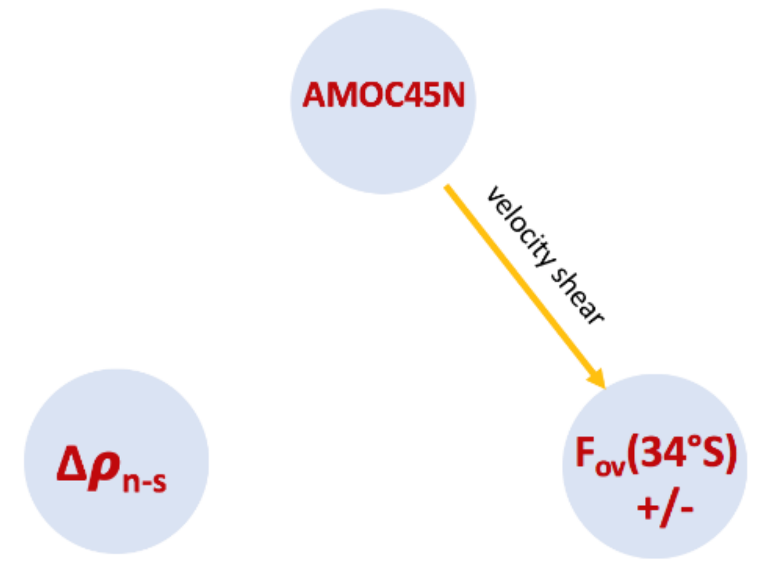
- How coherent is AMOC variability?

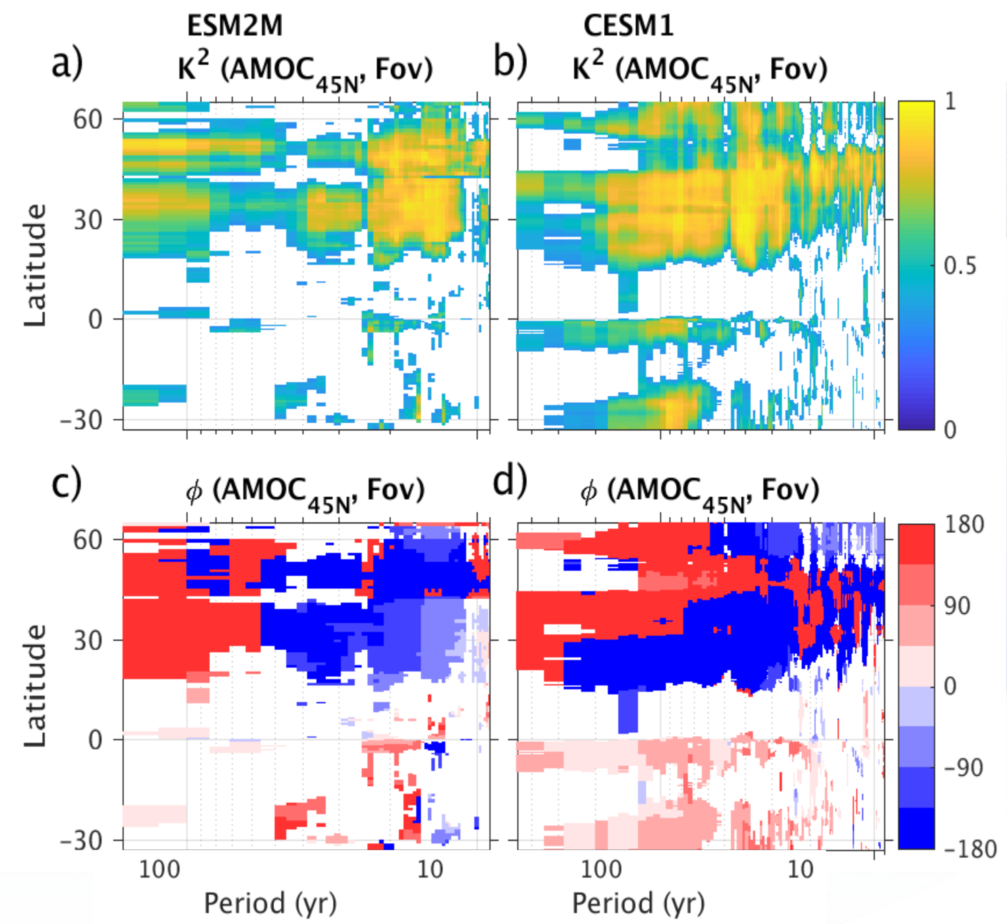


+ve phase: Index leads field

AMOC and F_{ov}

- Does AMOC variability impact F_{ov}?

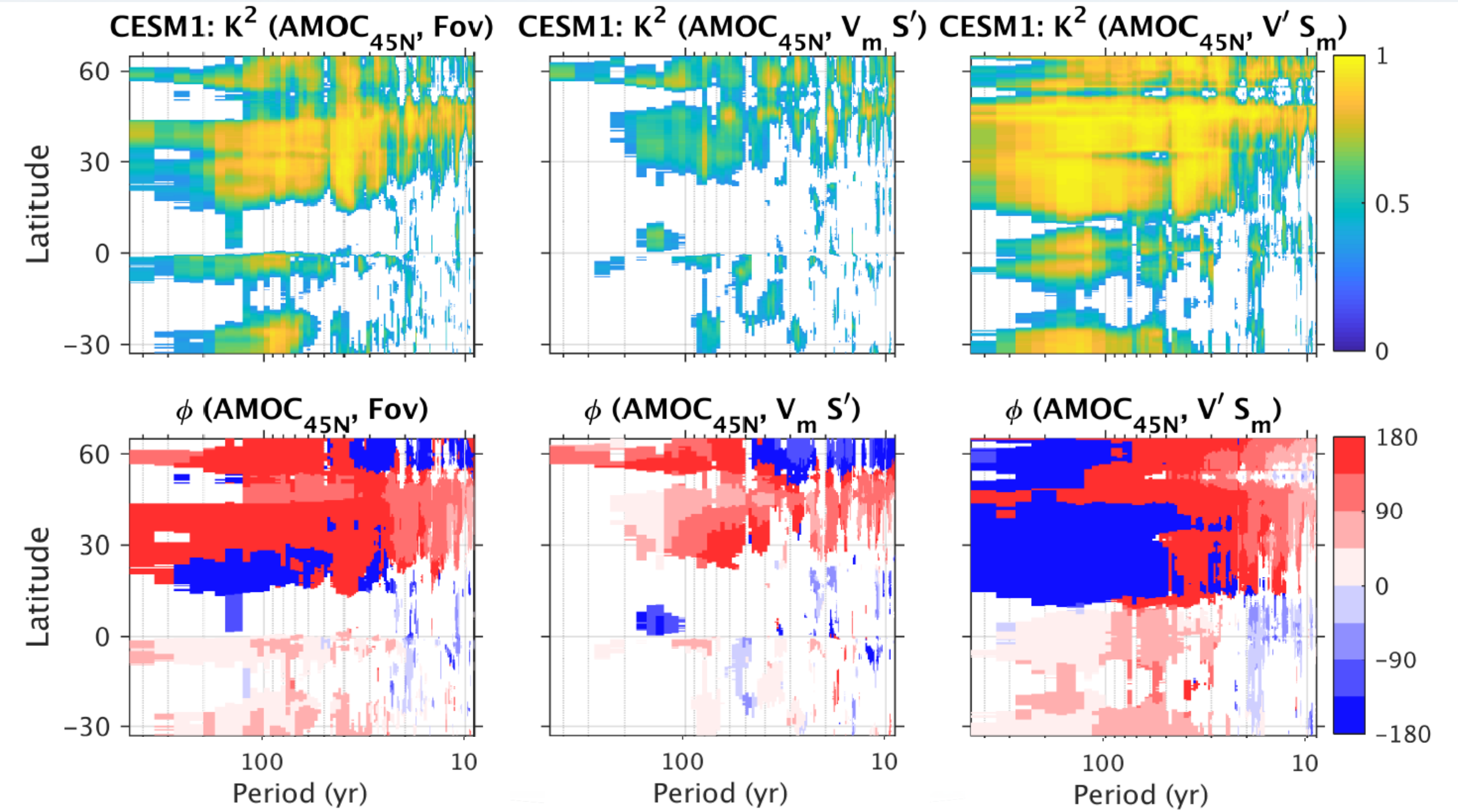




+ve phase: Index leads field

AMOC and F_{ov}: CESM

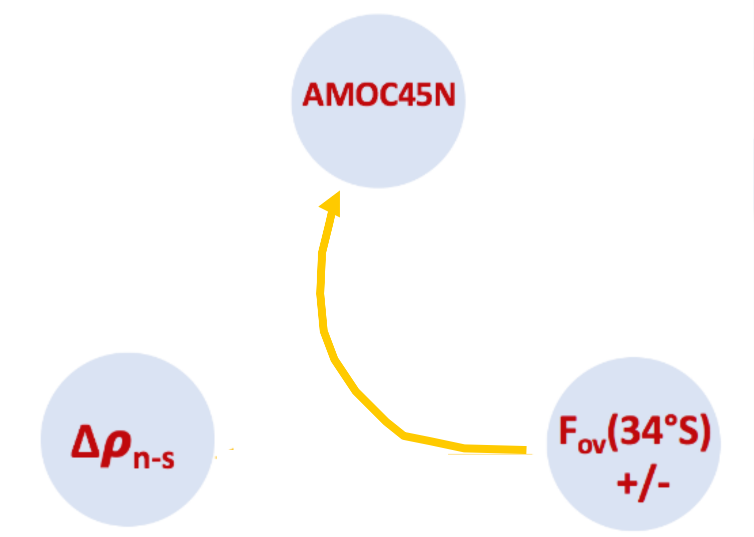
$$F_{ov} = -\frac{1}{S_0}\int_{-H}^{0} dz = -\frac{1}{S_0}\int_{-H}^{0} <v> S' dz - \frac{1}{S_0}\int_{-H}^{0} v' <S> dz$$

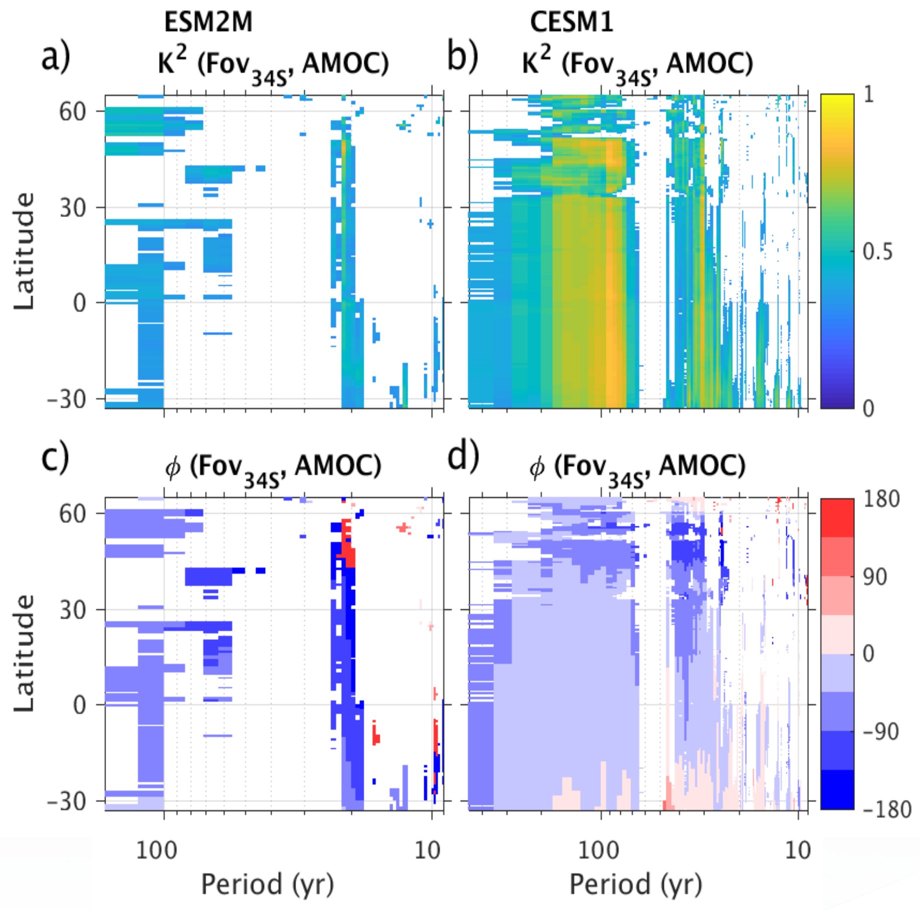


+ve phase: Index leads field

F_{ov} and AMOC

- Does F_{ov} (34°S) impact AMOC?

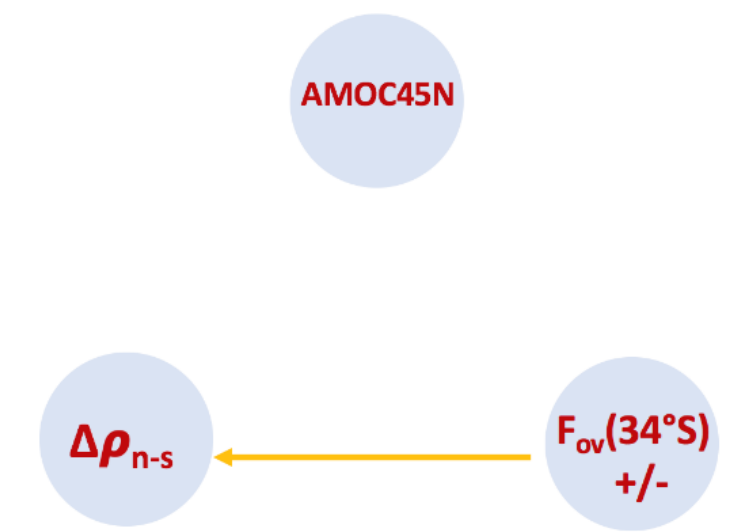


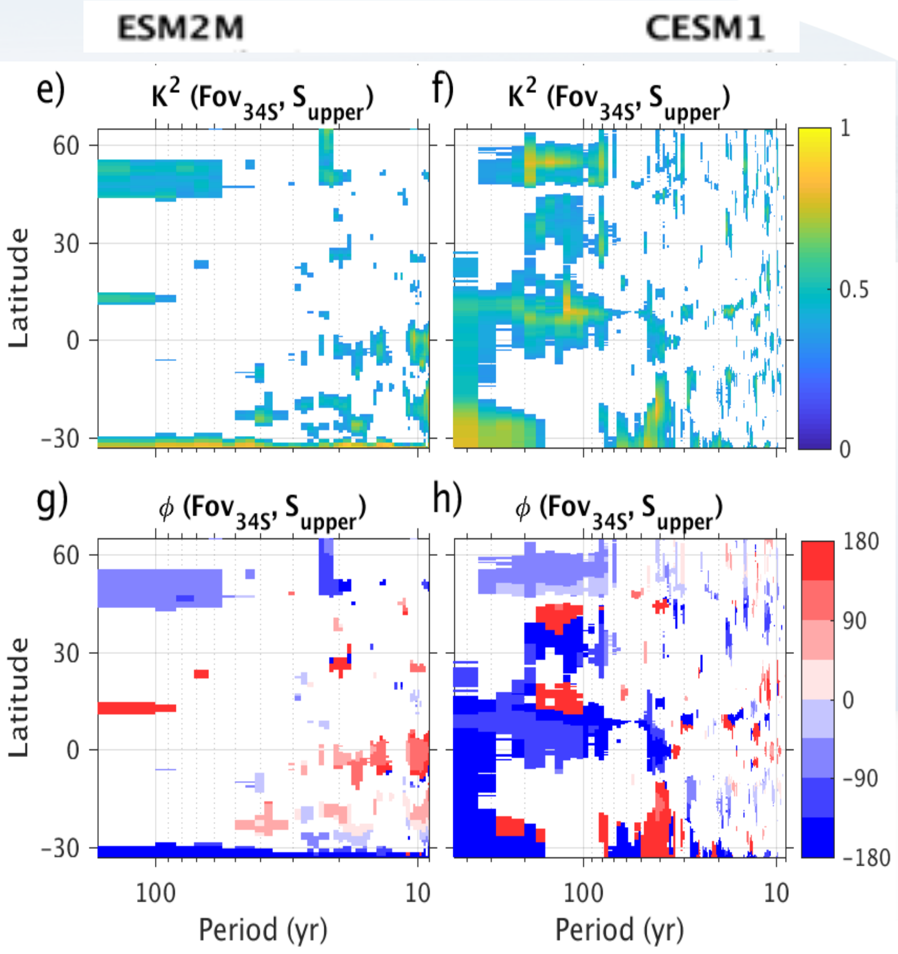


+ve phase: Index leads field

F_{ov} and Stratification

- Does F_{ov} (34°S) impact stratification?

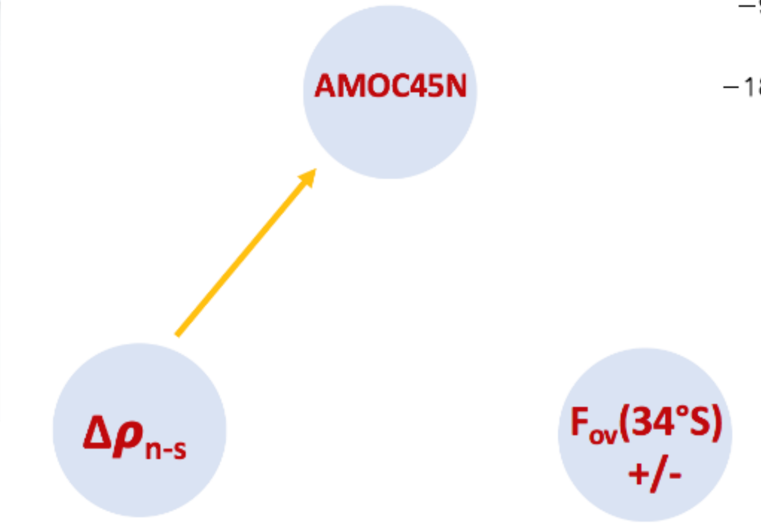




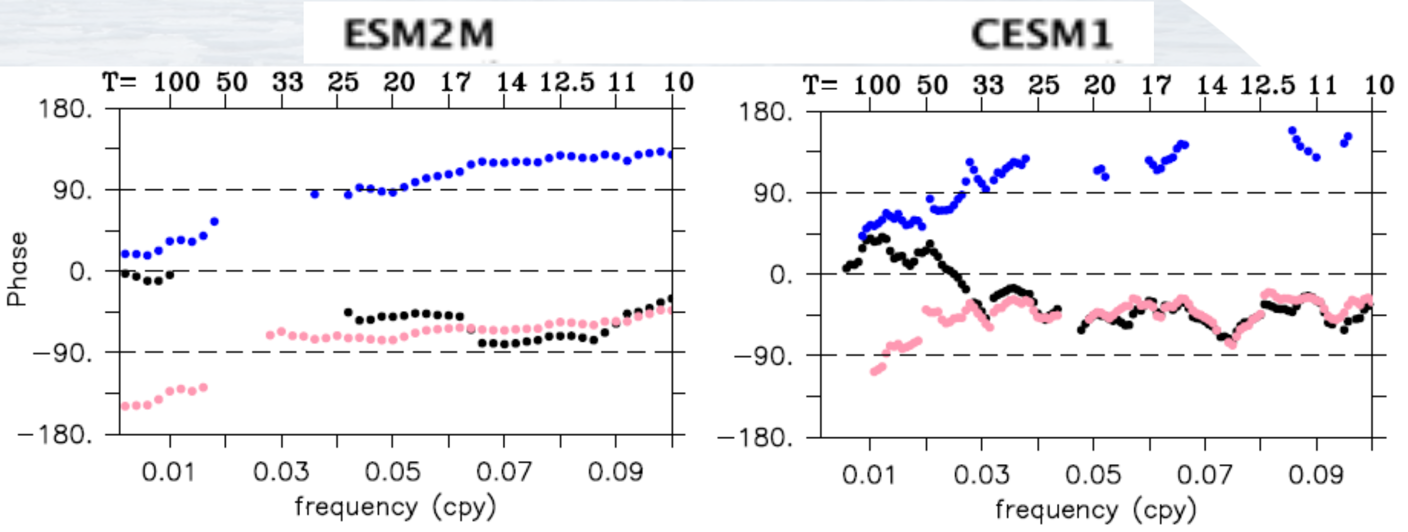
+ve phase: Index leads field

Density Difference and AMOC

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



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



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

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

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