Salinity change and the AMOC: Understanding remote influences

Sam Levang, Ray Schmitt
MIT/WHOI
AMOC instability and freshwater

1. Freshwater input to the North Atlantic can cap deep convection sites
   **Under warming scenario:**
   - Subpolar precip and ice melt likely to increase
   - Subtropical Atlantic gets saltier

2. Ocean dynamics control the response
   - What is the rate of exchange between subtropical and subpolar waters?
   - Do current climate models get this right?
Motivation: CMIP5 salinity response

Amplification of E-P pattern

RCP8.5 100 year trends (2000-2100), multi-model means

(Levang and Schmitt 2015)
Motivation: CMIP5 salinity response

Amplification of E-P pattern

Ocean integrates basin-wide forcing

RCP8.5 100 year trends (2000-2100)

(Levang and Schmitt 2015)
Moisture budget
Atmospheric response very robust
Different salinity responses in the Subpolar Atlantic
Different salinity responses in the Subpolar Atlantic

Which is realistic?

GFDL-CM3

Observations (1950-2000)

(Durack et al. 2012)
AMOC and density: cause or effect?

• More freshening
  • Buoyancy increase
  • Weaker AMOC

• Weaker AMOC
  • Decreased northwards heat flux
  • Less warming

Also: $\beta \approx 8 \cdot \alpha$ for NADW (2°C, 35psu)
Need big $\Delta T$ to affect density
AMOC and density: cause or effect?  It’s salinity!

- **More freshening**
  - Buoyancy increase
  - Weaker AMOC

- **Weaker AMOC**
  - Decreased northwards heat flux
  - Reduced $dT/dy$

Also: $\beta \sim 8 \cdot \alpha$ for NADW (2°C, 35psu)
Need big $\Delta T$ to affect density
Outline

1. Freshwater input to the North Atlantic can cap deep convection sites
   Under warming scenario:
   • Subpolar precip and ice melt likely to increase
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2. Ocean dynamics control the response
   • What is the rate of exchange between subtropical and subpolar waters?
   • Do current climate models get this right?
1) What are the relevant circulations and exchange timescales between these regions?

2) How do these timescales control the salinity (density) response in the NADW convection sites?
Working hypothesis:
Treat freshwater anomaly as a passive tracer

- Assume that anomalies persist indefinitely along circulation pathways
- Ignore density-advection feedbacks

- Advect salinity anomalies along “present-day” circulation
- Make use of data assimilated reanalyses
  - SODA3: <1/4° GFDL CM2.5, 1980-2016
    - Use 5-day outputs, and climatology (eddies removed)
  - ECCOv4.3: 1° MITgcm, 1992-2015
    - Proxy for CMIP5-type models
Others that have used this technique:

**Anthropogenic temperature signal**
(Marshall et al. 2015)

**Little ice age and deep Pacific cooling**
(Gebbie and Huybers 2018)

**Persistent observed salt anomalies**
(Dickson et al. 1988)
Why use the Lagrangian frame?

- Focus on what the circulation is doing in terms of connectivity
  - Not possible in Eulerian perspective

- Pathways are 3D and chaotic
  - Need many datapoints to understand the circulation statistically
Insufficient Observations

(Brambilla and Talley 2006)
Remote influences:

- What is the pathway history of water masses in the subpolar?

- Where do they contact the mixed layer? Anomalous surface fluxes absorbed here

$$\int \frac{1}{MLD} dt$$

Eddies

No Eddies

SODA (1/4°)

SODA climatology
Accumulate forcing to predict SSS changes

Use monthly trends in E-P-R from CMIP5
Proof of concept:
Accumulate anomalous freshwater forcing along reverse trajectories

Individual model mixing schemes, circulation feedbacks

Simple passive tracer along 'present day' trajectories

$$\Delta S = \int \frac{S \cdot \Delta (E - P)}{MLD} \, dt$$
Forward spreading experiment
Summary:
• Increasing CO2 forces regular pattern of freshwater flux anomalies
• Fast exchange between tropics/subtropics
• Slower exchange between subtropics/subpolar – eddy driven
• Subtropical waters spreading to subpolar stabilizes the AMOC – poorly represented in coarse models