How does the AMOC affect the amplitude of global warming?

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from Marshall and Speer 2012
Two ways the AMOC could influence global warming:

AMOC transports heat poleward where climate feedbacks are more positive than in the tropics

- Increased global warming (Winton et al. 2013, Rugenstein et al. 2013, Winton et al. 2014)

- Models with stronger AMOCs sequester more heat in North Atlantic Ocean

- Decreased global warming (Kostov et al. 2014)
CESM Large Ensemble enables separation of forced response and internal variability.

- Historical forcing
- RCP8.5 forcing
- Annual averages
- AMOC strength defined as maximum streamfunction between 30N-60N

Member 1

All members
Forced response: AMOC weakening with global warming

Each red or blue dot is an ensemble member. Each green dot is a 100-year trend taken from the long preindustrial simulation.

Trends are calculated as the difference between the last 20 years average and the first 20 year average.
Forced response (left, AMOC weakening with global warming) vs. Internal Variability (right, weaker AMOC with increased global warming)
Largest warming correlations with AMOC in Northern Hemisphere – unsurprising.

Removing the ensemble mean

Global Temperature

Extratropical Northern Hemisphere Temperature

Removing the ensemble mean

correlations always higher with historical forcing; currently examining ocean initial condition ensemble to determine importance of ocean state
Northern hemisphere warming when the AMOC strengthens relative to the forced response.

Regression of temperature trends in each member against AMOC trends in each member

Climatic model output:
- CESM LENS historical forcing
- CESM LENS RCP8.5 forcing

Shading indicates correlations significant at 99% confidence level.
Why is a strengthening AMOC associated with warming over Eurasia?

Regression of temperature trends in each member against AMOC trends in each member

shading indicates correlations significant at 99% confidence level

surface heat fluxes?

sea ice feedbacks?

CESM LENS historical forcing

CESM LENS RCP8.5 forcing
Increased surface heat flux over the North Atlantic Ocean associated with strengthening AMOC.

shading indicates correlations significant at 99% confidence level
Historical forcing: weakening AMOCs = decrease in poleward ocean heat transport in North Atlantic.
~60% of variability in global ocean heat transport trends in Northern Hemisphere extratropics is associated with AMOC.
Similar association in RCP8.5 forcing between variability of OHT and AMOC.
Decomposing surface heat flux into components from ocean heat transport and ocean heat storage

Zonal mean energy budget for the ocean:

\[ \frac{dE_{ocean}}{dt} = -\frac{\partial (vE_{ocean})}{\partial y} + R_{sfc} \]

Storage  Convergence  Surface heat flux

calculate storage by residual

Flux into atmosphere

Flux into ocean
AMOCs that weaken most associated with more extratropical North Atlantic ocean heat storage.

CESM LENS historical forcing

Surface heat flux

Ocean heat convergence

Storage

oranges: AMOCs that weaken more

purples: AMOCs that weaken less

consistent with Rugenstein et al. (2013)
Variability AMOC-associated ocean heat storage trends small compared to the forced trend.

CESM LENS RCP8.5 forcing

Surface heat flux  
Ocean heat convergence  
Storage

ensemble mean removed

oranges: AMOCs that weaken more  
purples: AMOCs that weaken less
AMOC and SW/LW associations are inconsistent in the historical and RCP8.5 ensembles.

Surface net SW (positive down)

Surface net LW (positive up)

Shading indicates correlations significant at 99% confidence level.
Strengthening AMOCs associated with increasing density in the Labrador Sea.
Increasing salinity in the North Atlantic when with strengthening AMOCs.
Member-to-member variability in salt transport changes is consistent with AMOC trends.
AMOCs that weaken less associated with westerlies in North Atlantic.
Conclusions, so far:

• Ensemble members with AMOCs that are stronger than the ensemble mean associated with warming in northern North Atlantic, across Eurasia, and into the western Pacific

• AMOC trend – climate correlations are stronger with historical forcing than RCP8.5 forcing

• Ensemble members with AMOCs that strengthen relative to ensemble mean also have decreased heat storage, which should increase amount of global warming

• High latitude climate feedbacks are also potentially important for a mechanism where a strengthening AMOC can increase the amount of global warming

• Next steps:
  • AMIP experiments to test sensitivity of Eurasian surface temperature on Arctic sea ice albedo variability and/or surface flux heating in North Atlantic
  • Feedback “locking” experiments in fully coupled CESM to examine sensitivity of global temperature and AMOC strength to climate feedbacks.
Extra slides
Historical forcing vs. RCP8.5 forcing:

- Latent heat flux
- Sensible heat flux
Previous studies have also indicated that “locking” cloud feedbacks alters the strength of the Atlantic Meridional Overturning Circulation, as does sea ice.