How does the AMOC affect the amplitude of global warming?

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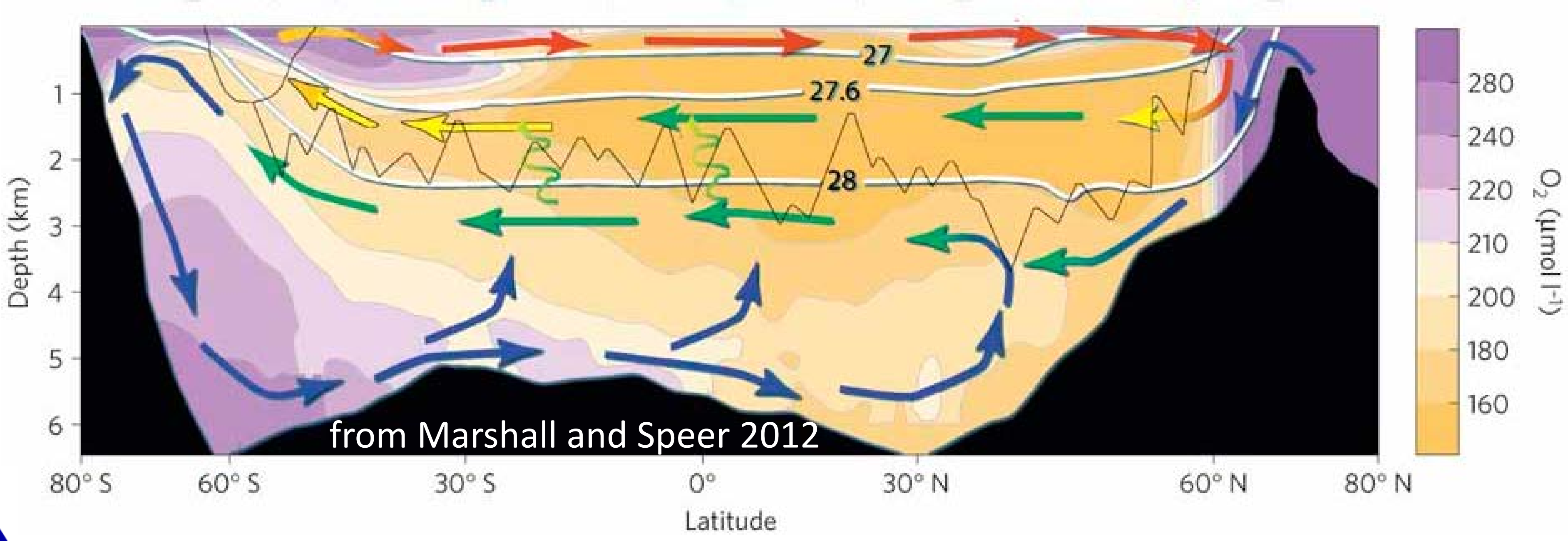
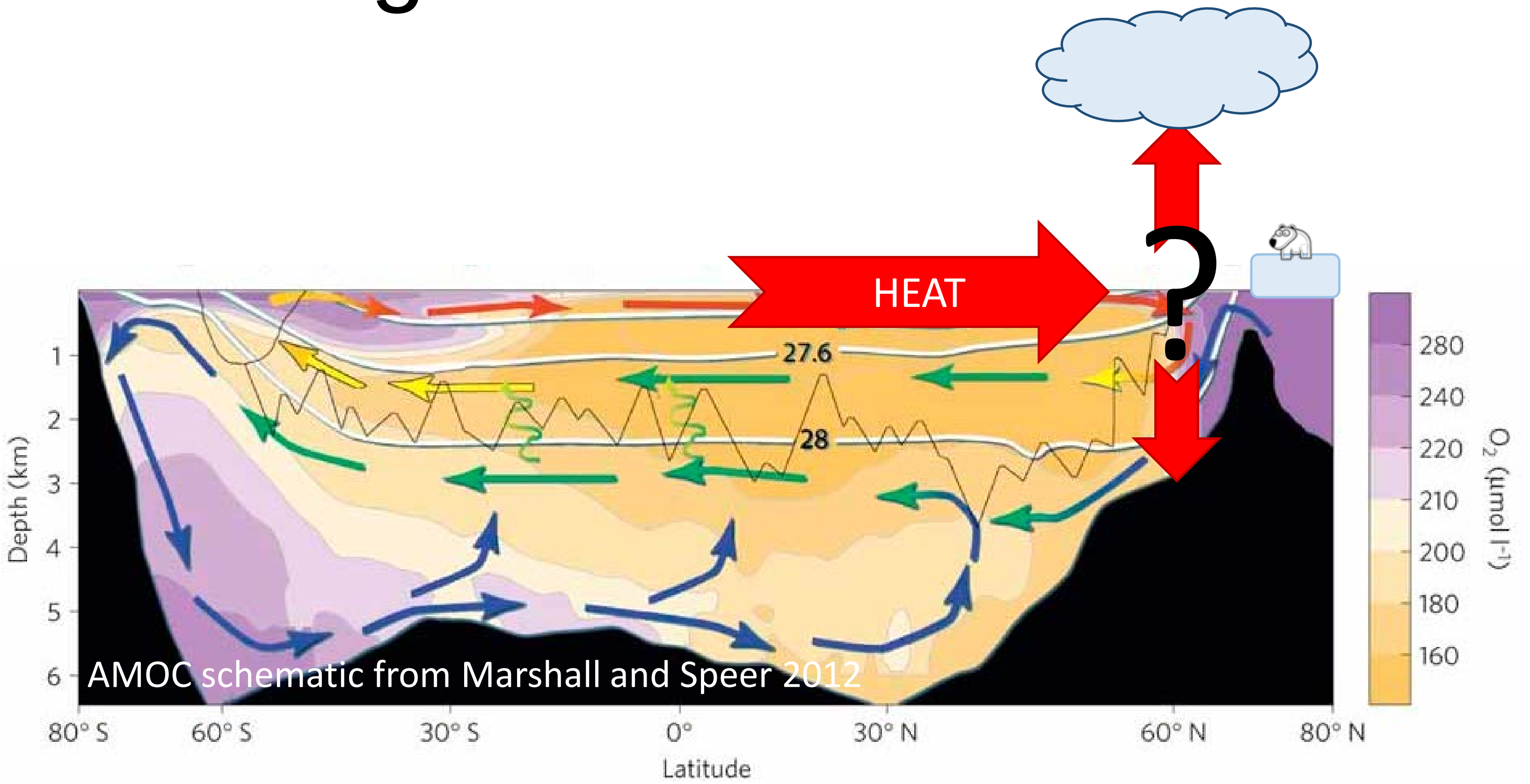


from Marshall and Speer 2012

Two ways the AMOC could influence global warming:



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

↓

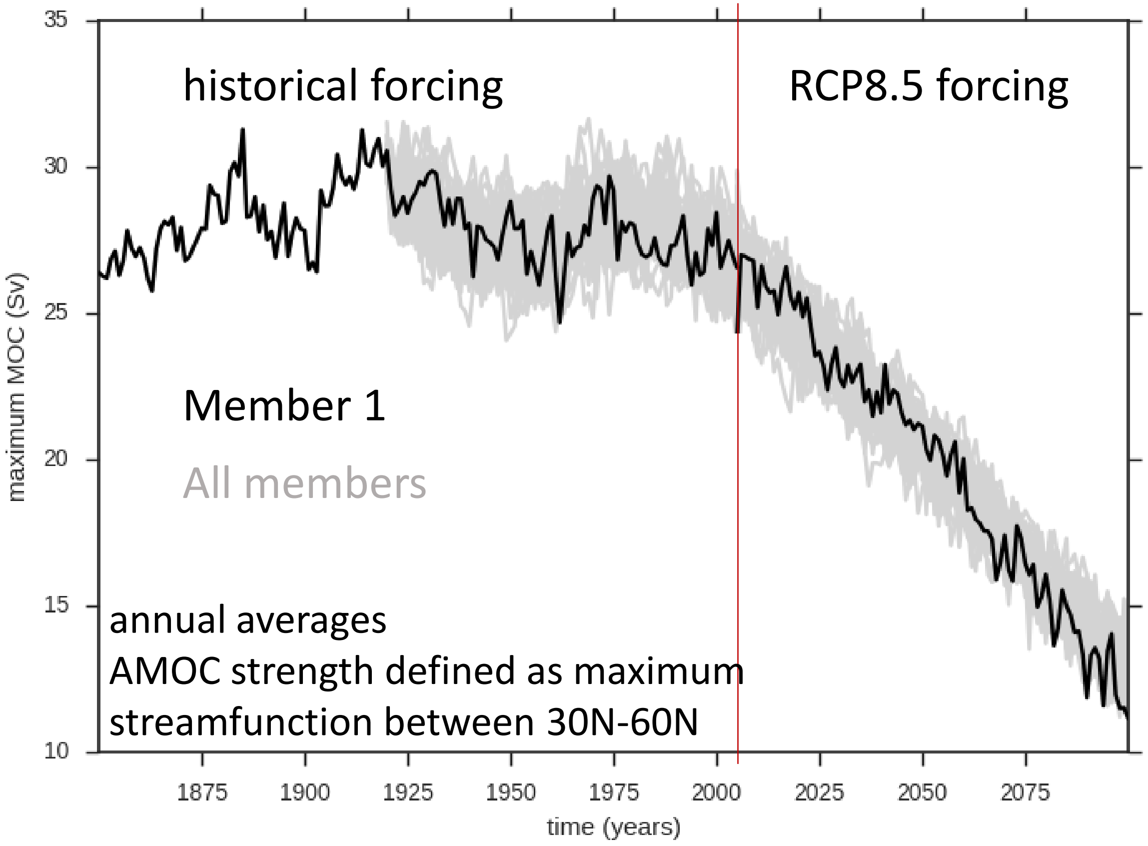
Increased global warming
(Winton et al. 2013, Rugenstein et al. 2013, Winton et al. 2014)

Models with stronger AMOCs sequester more heat in North Atlantic Ocean

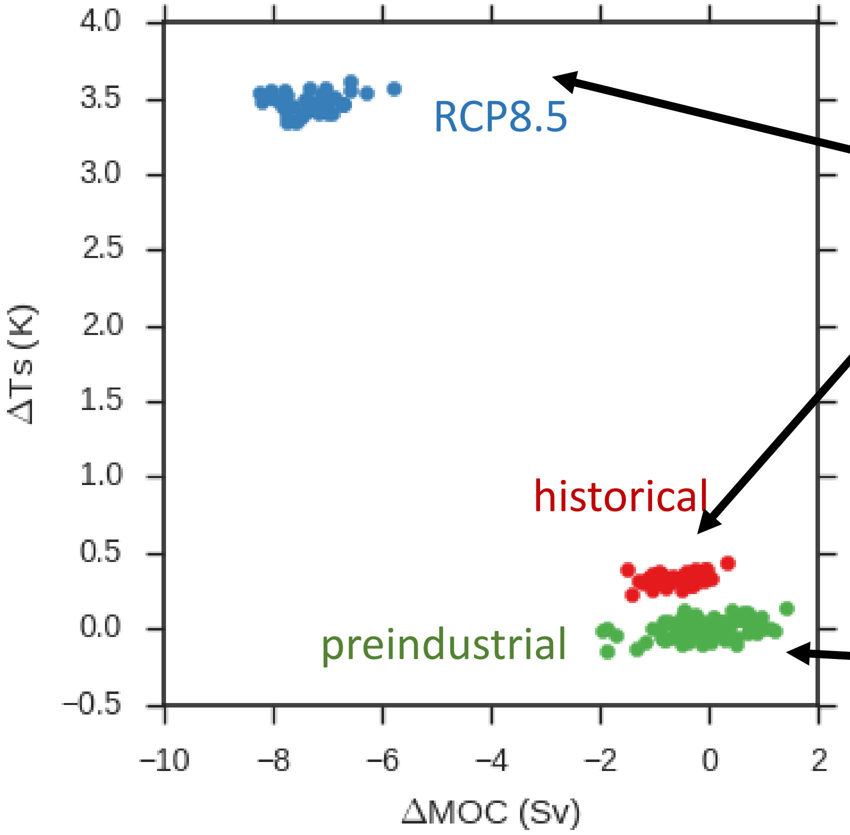
↓

Decreased global warming
(Kostov et al. 2014)

CESM Large Ensemble enables separation of forced response and internal variability



Forced response: AMOC weakening with global warming

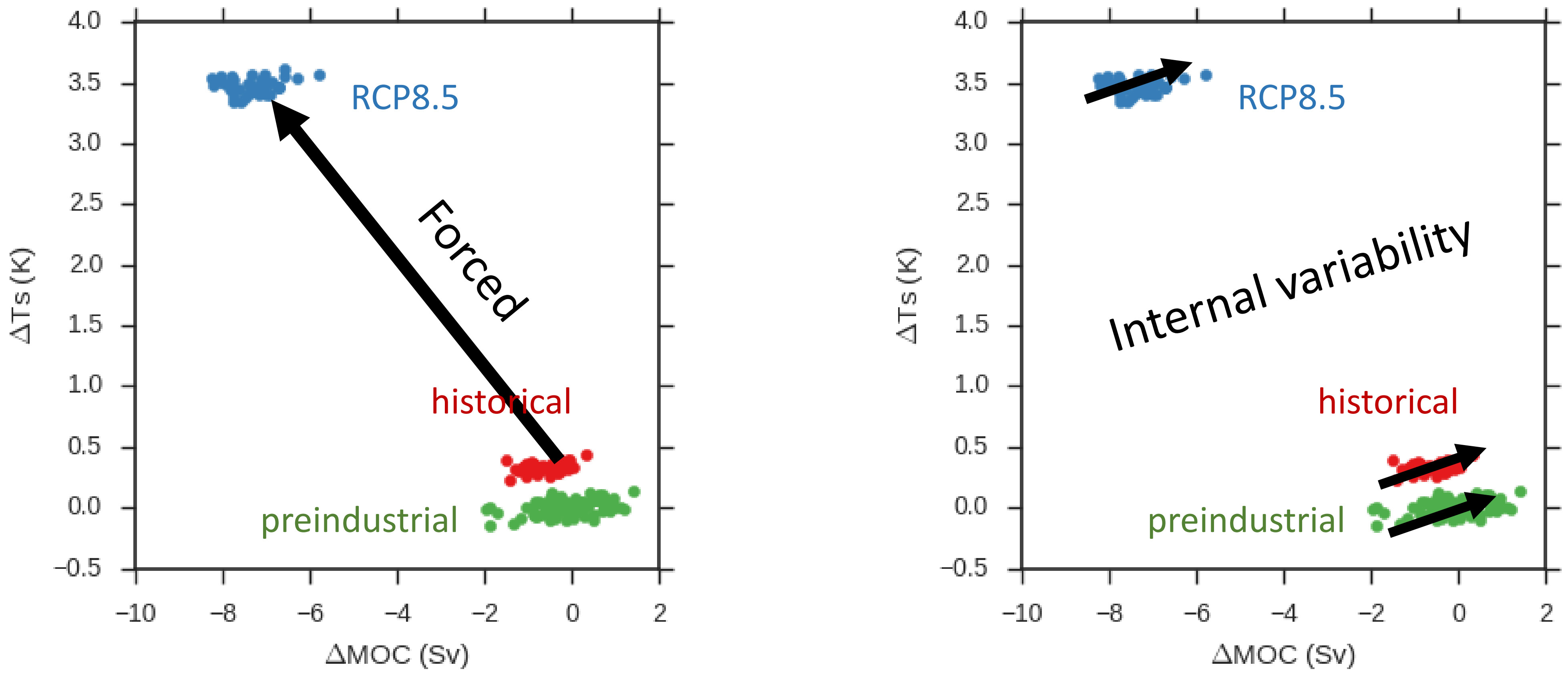


Each red or blue dot is an ensemble member

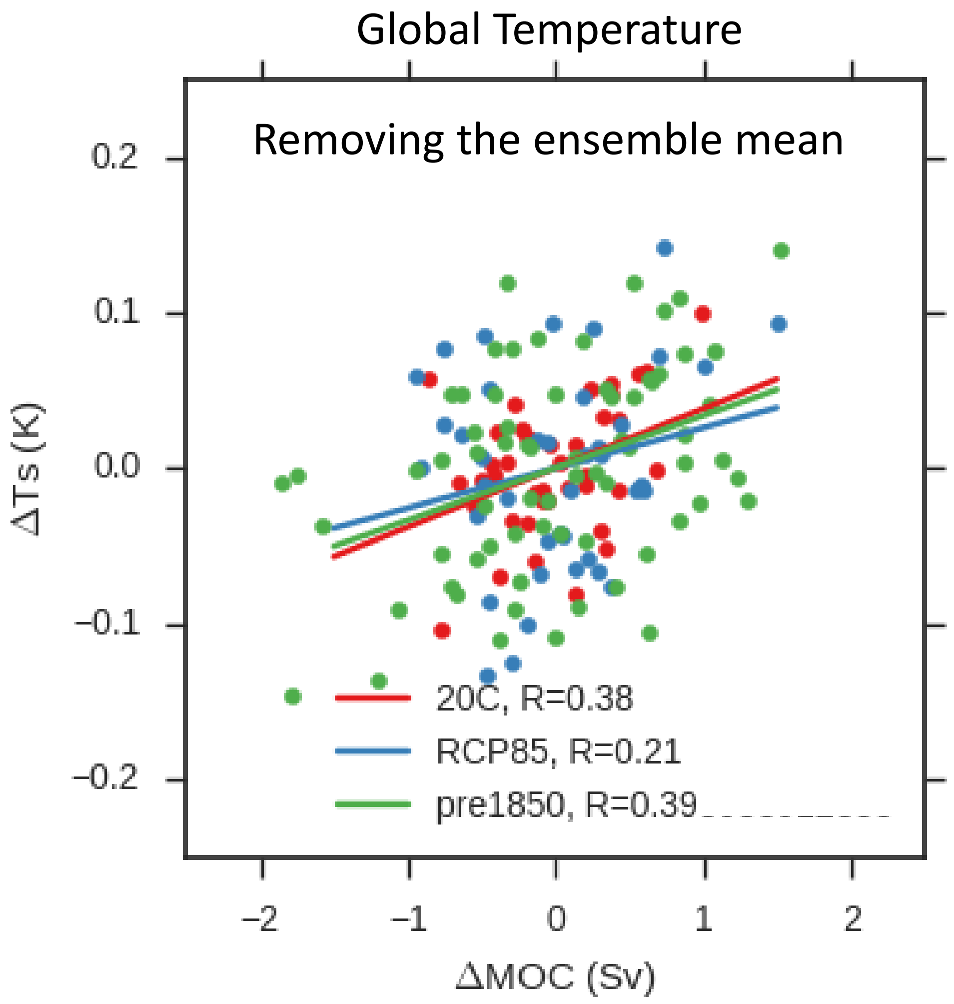
Each green dot is a 100-year trend taken from the long preindustrial simulation

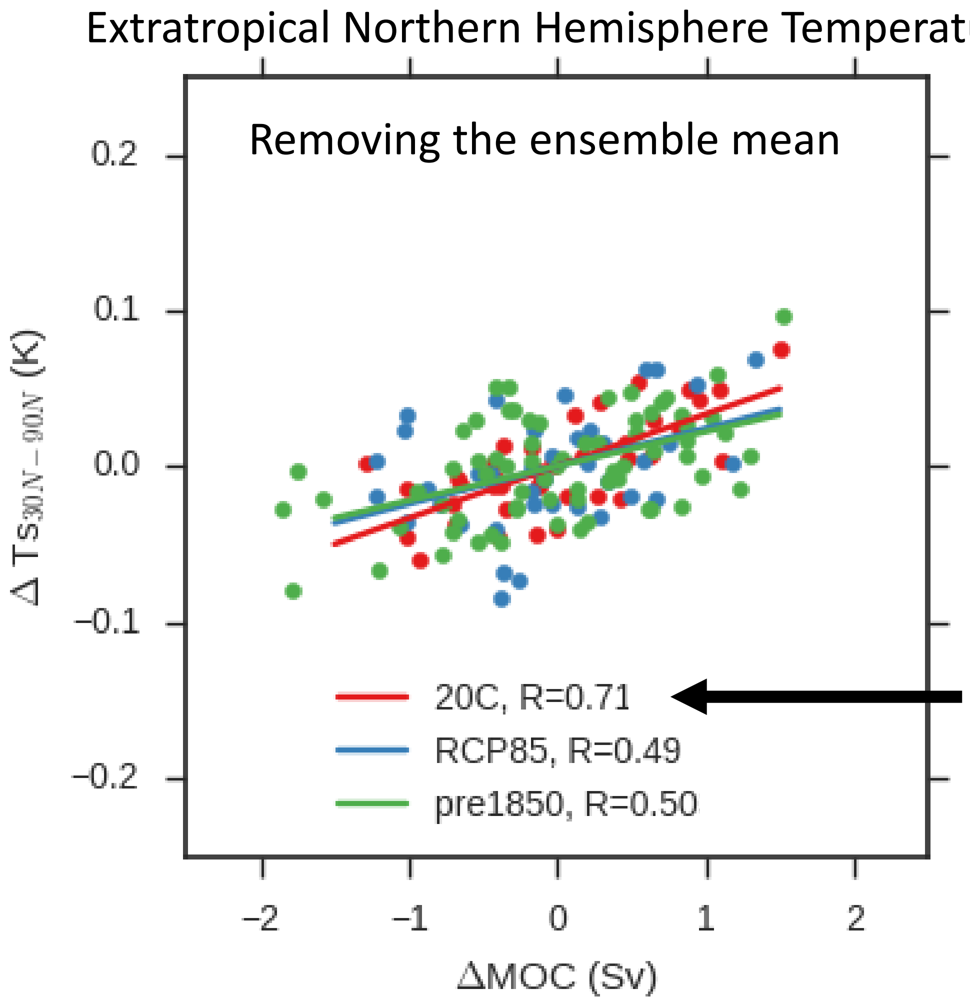
Trends are calculated as the difference between the last 20 years average and the first 20 year average

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.

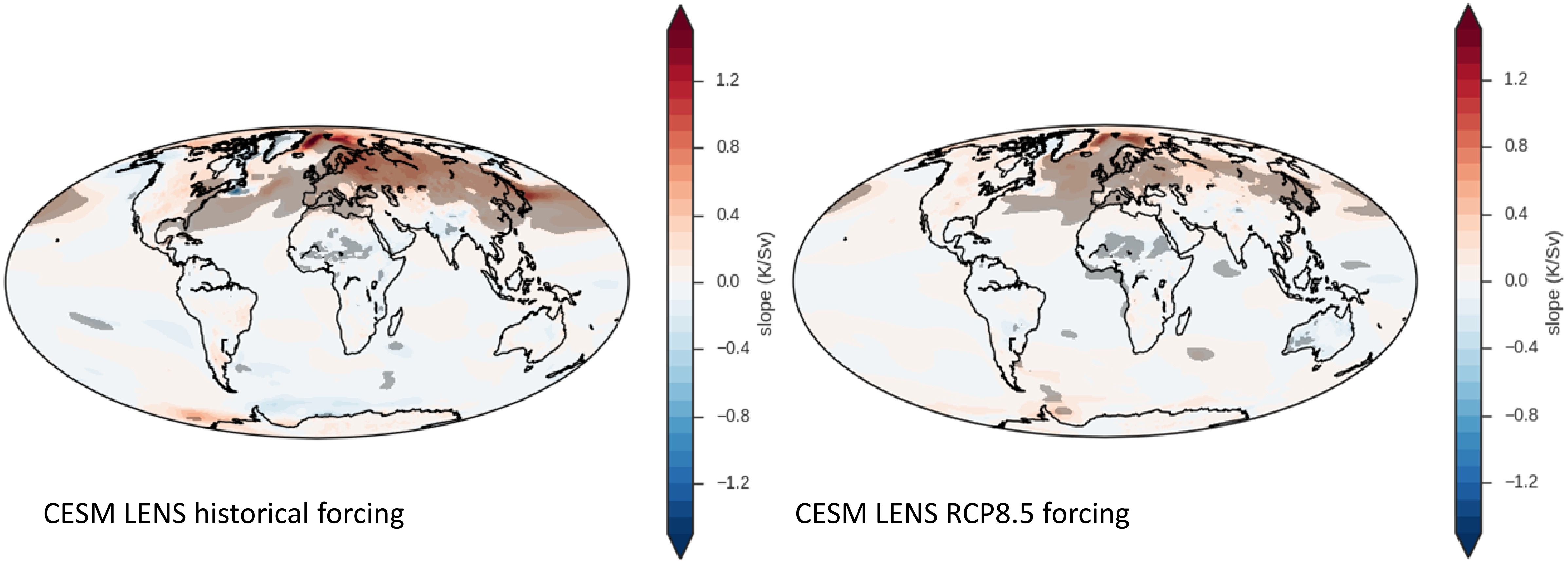




correlations always higher with historical forcing; currently examining ocean initial condition ensemble to determine importance of ocean state

Northern hemisphere warming when the AMOC strengthens relative to the forced response.

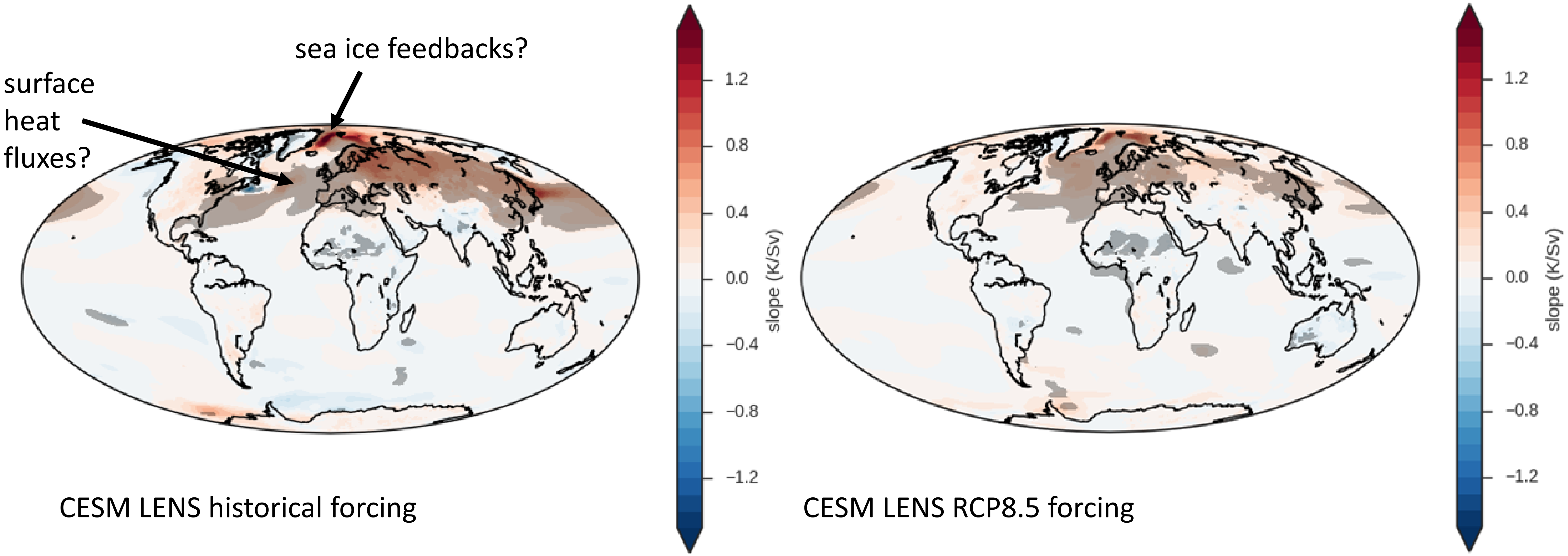
Regression of temperature trends in each member against AMOC trends in each member



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

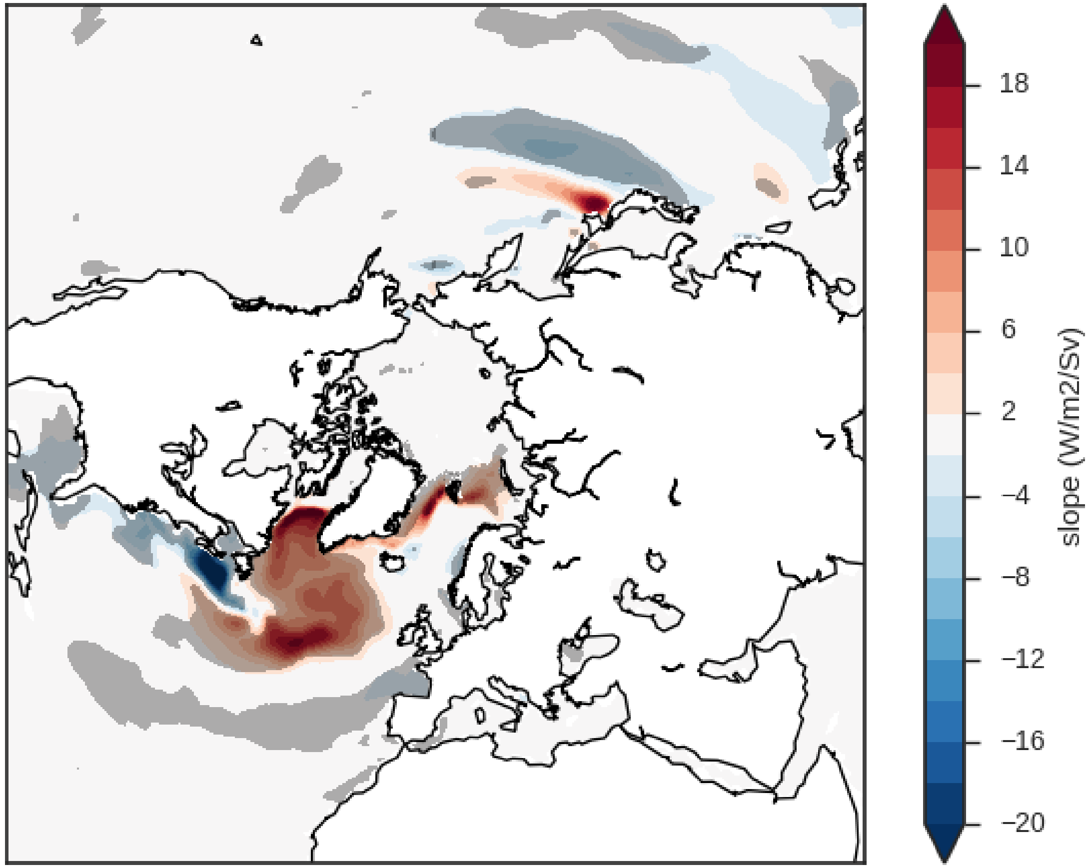


CESM LENS historical forcing

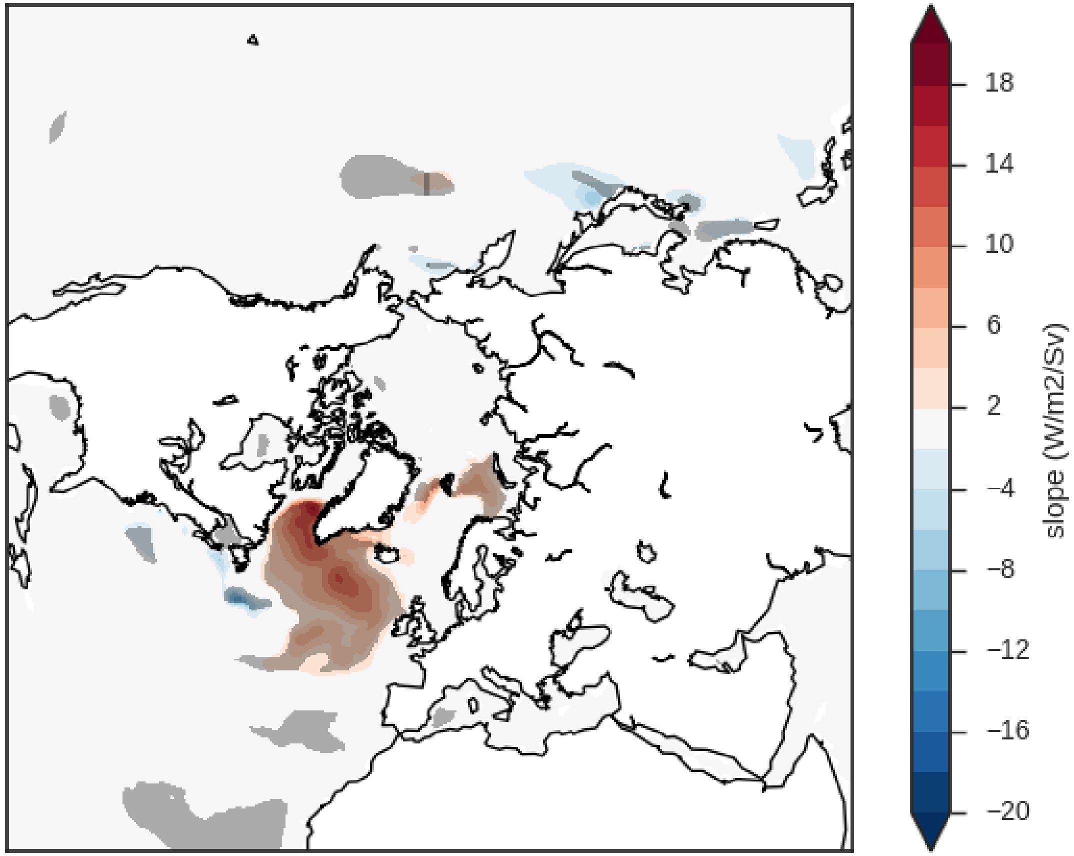
CESM LENS RCP8.5 forcing

shading indicates correlations significant at 99% confidence level

Increased surface heat flux over the North Atlantic Ocean associated with strengthening AMOC.



CESM LENS historical forcing

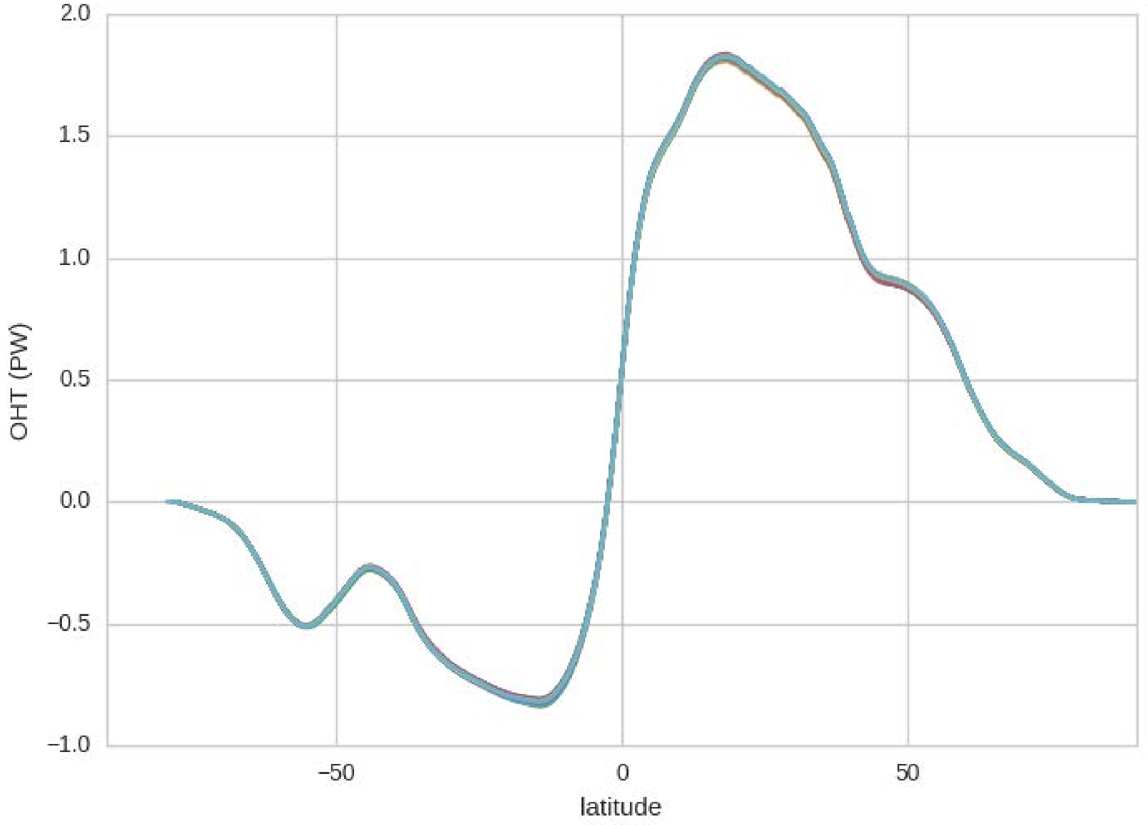


CESM LENS RCP8.5 forcing

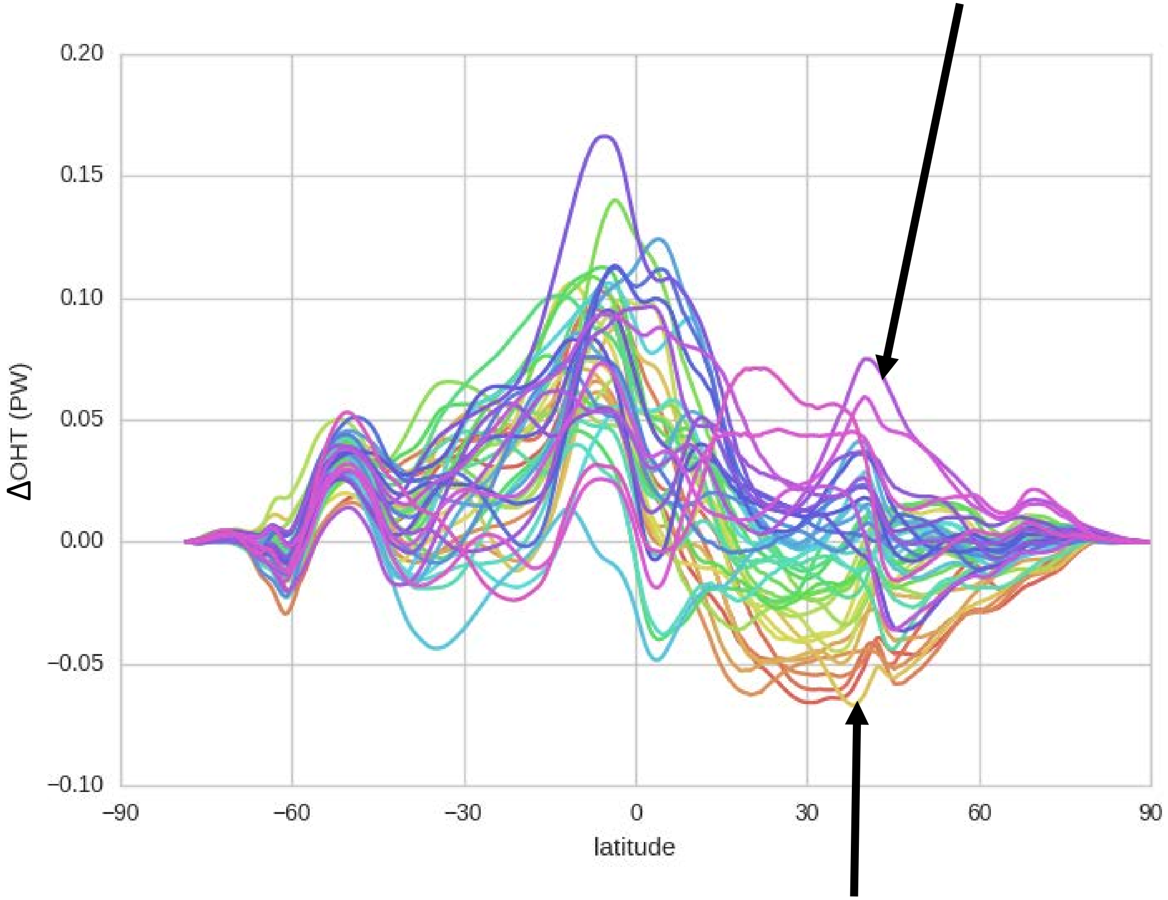
shading indicates correlations significant at 99% confidence level

Historical forcing: weakening AMOCs = decrease in poleward ocean heat transport in North Atlantic.

time mean meridional ocean heat transport

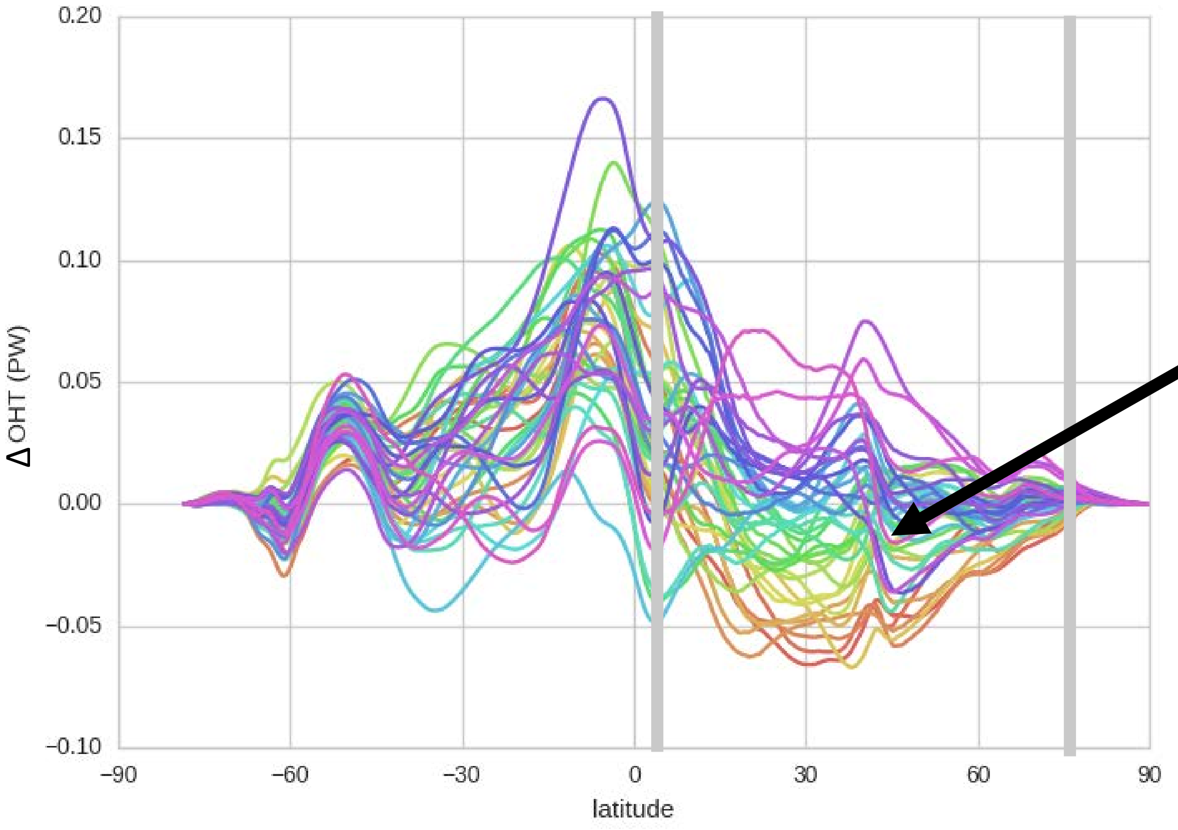


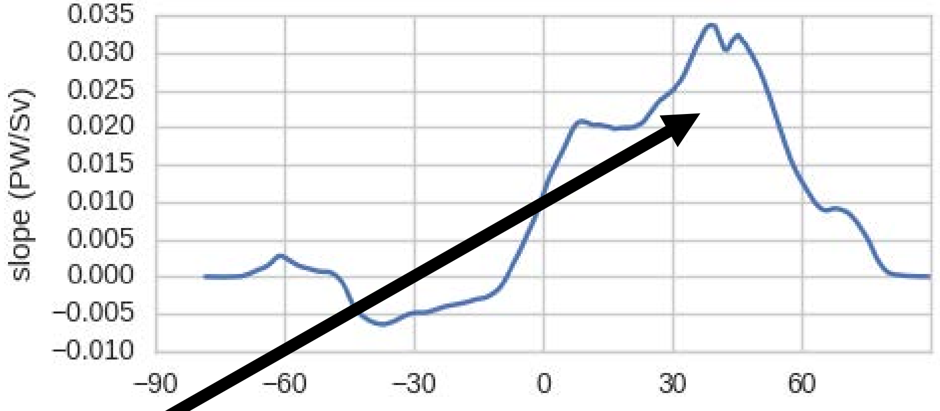
AMOCs that weaken the least

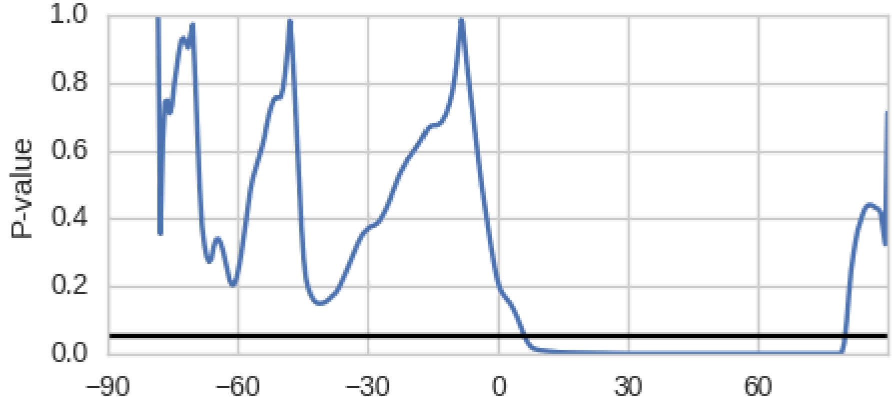


AMOCs that weaken the most

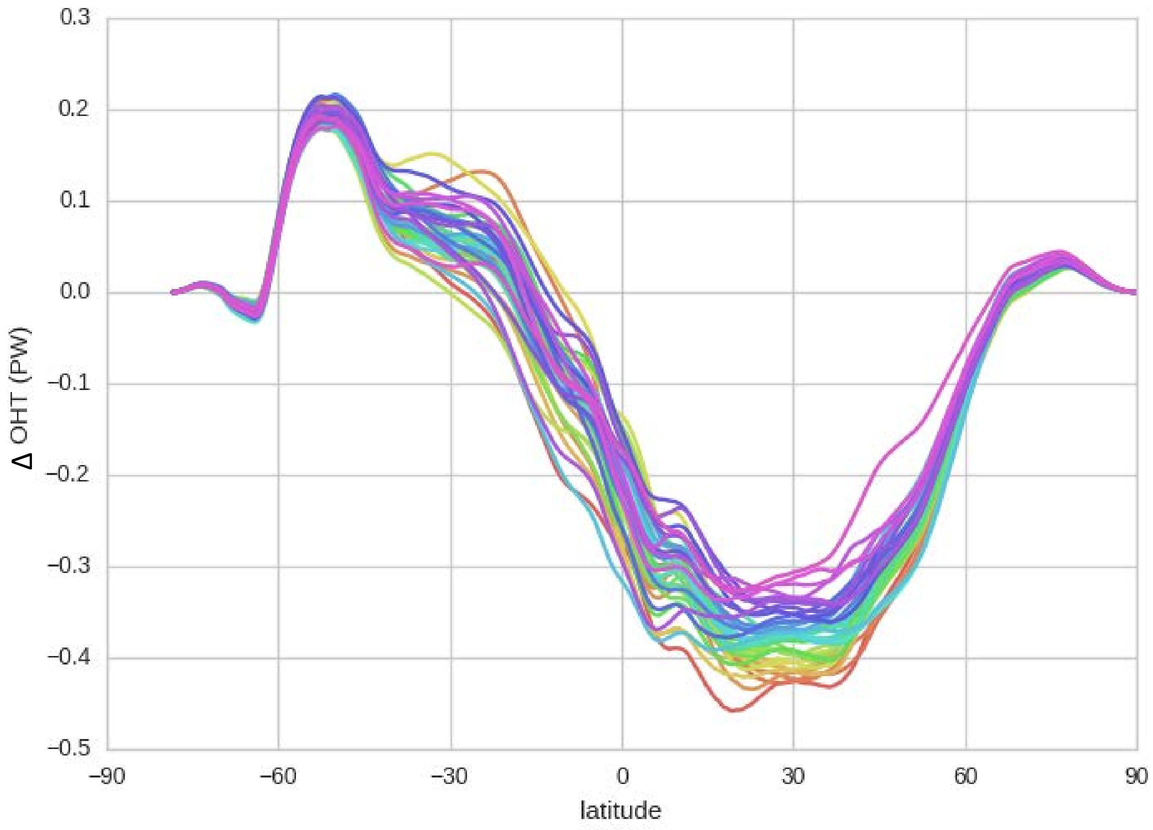
~60% of variability in global ocean heat transport trends in Northern Hemisphere extratropics is associated with AMOC

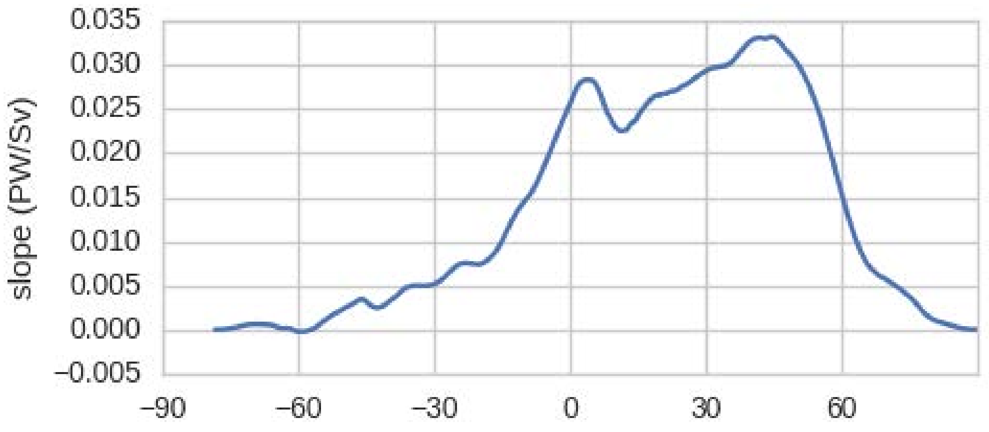


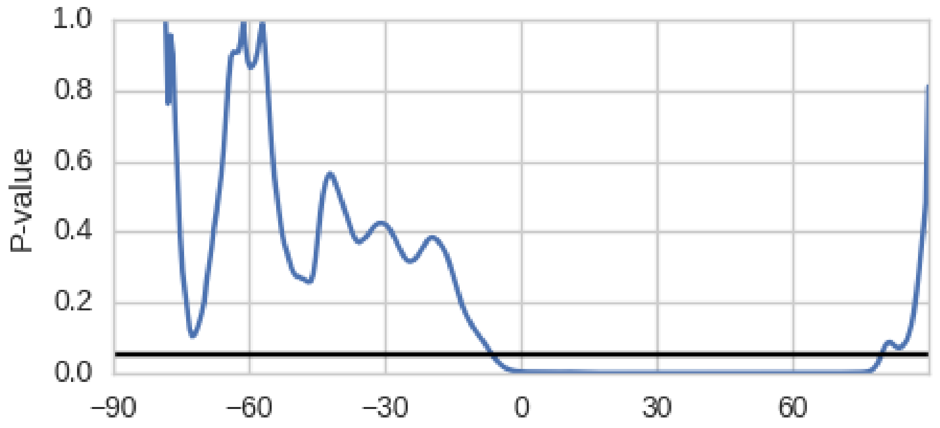




Similar association in RCP8.5 forcing between variability of OHT and AMOC.







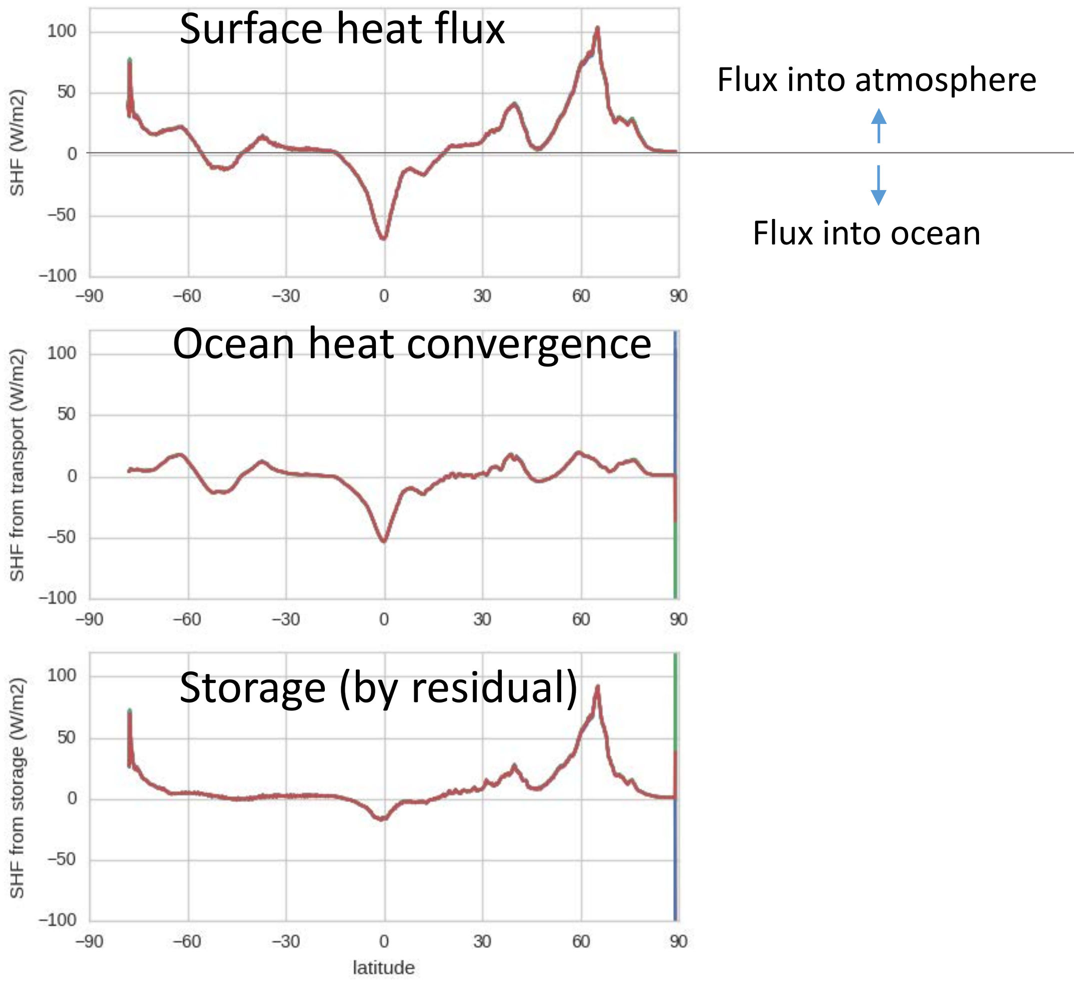
Decomposing surface heat flux into components from ocean heat transport and ocean heat storage

Zonal mean energy budget for the ocean:

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

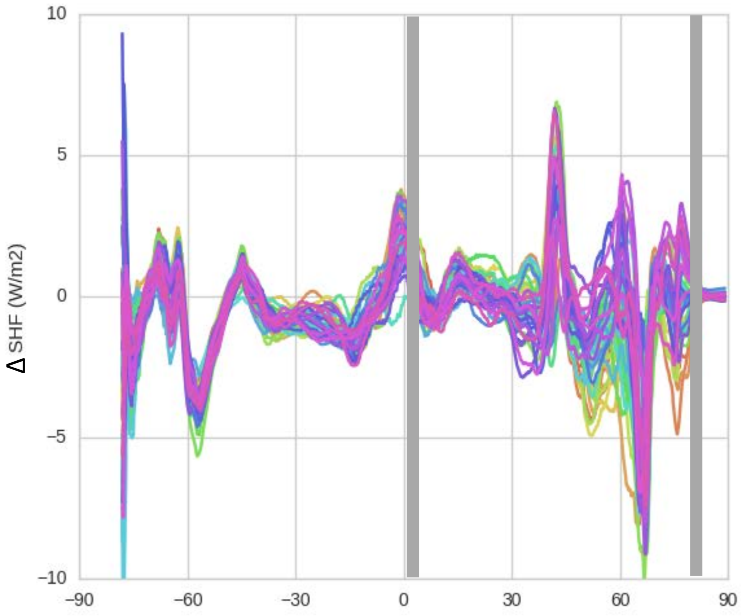
Storage | Convergence | Surface heat flux

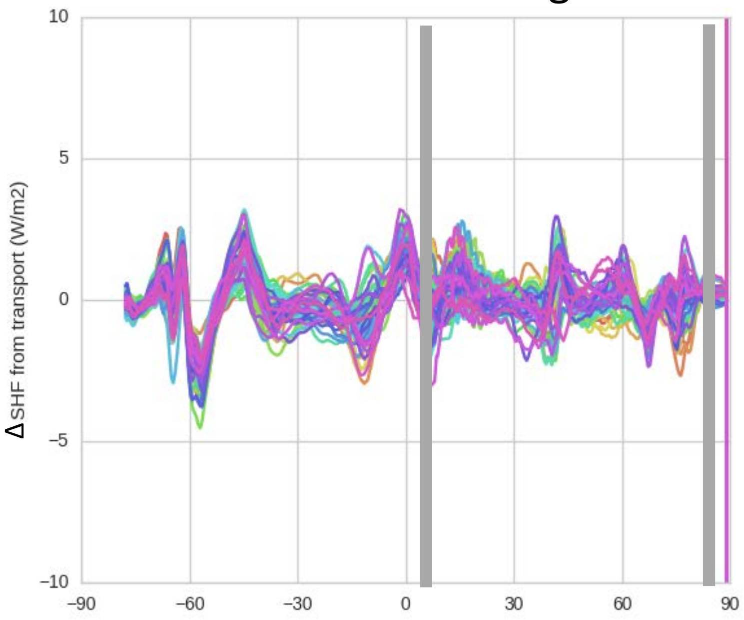
calculate storage by residual

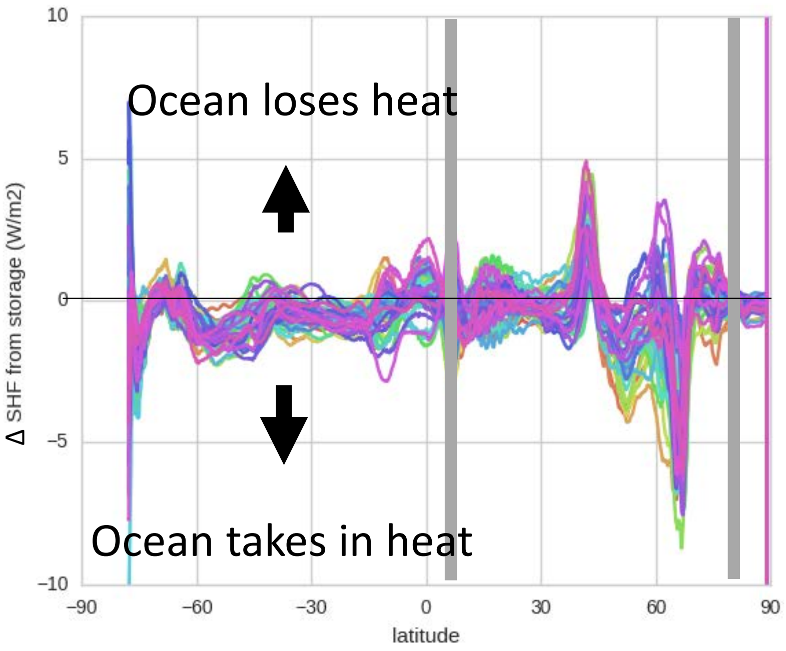


AMOCs that weaken most associated with more extratropical North Atlantic ocean heat storage.

CESM LENS historical forcing





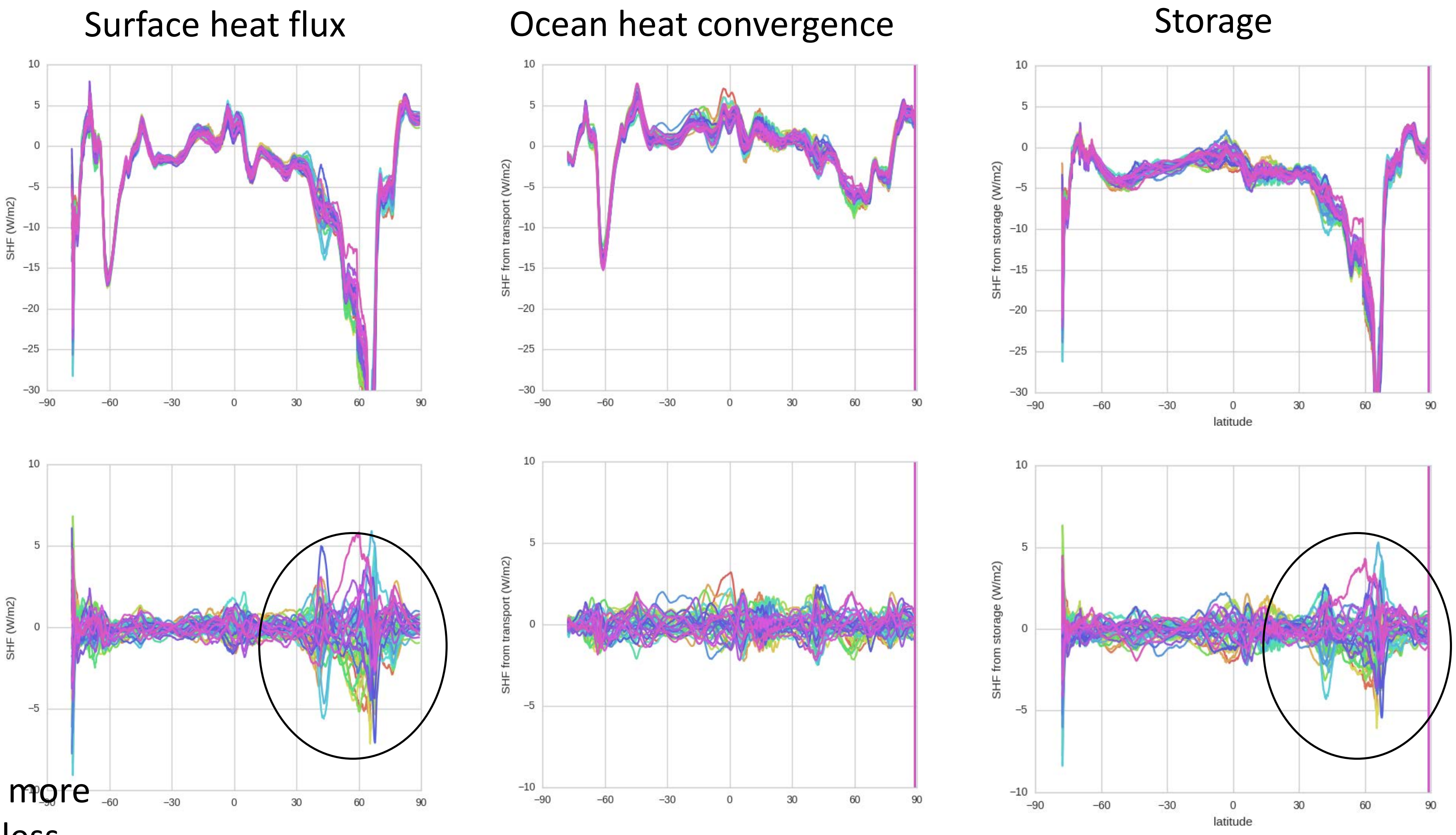


oranges: AMOCs that weaken more
purples: AMOCs that weaken less

consistent with Rugenstein et al. (2013)

Variability AMOC-associated ocean heat storage trends small compared to the forced trend.

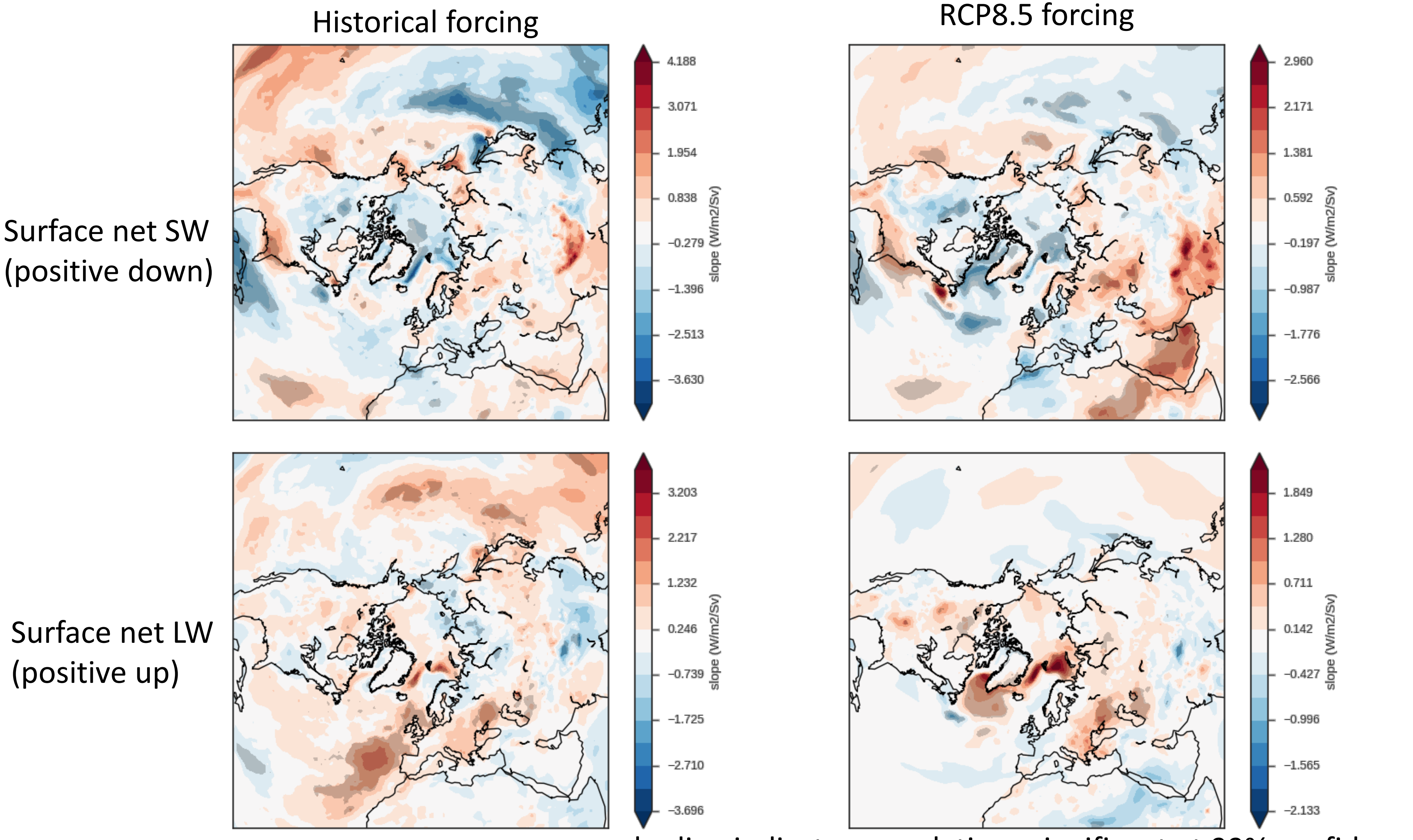
CESM LENS RCP8.5 forcing



ensemble mean removed

oranges: AMOCs that weaken more
purples: AMOCs that weaken less

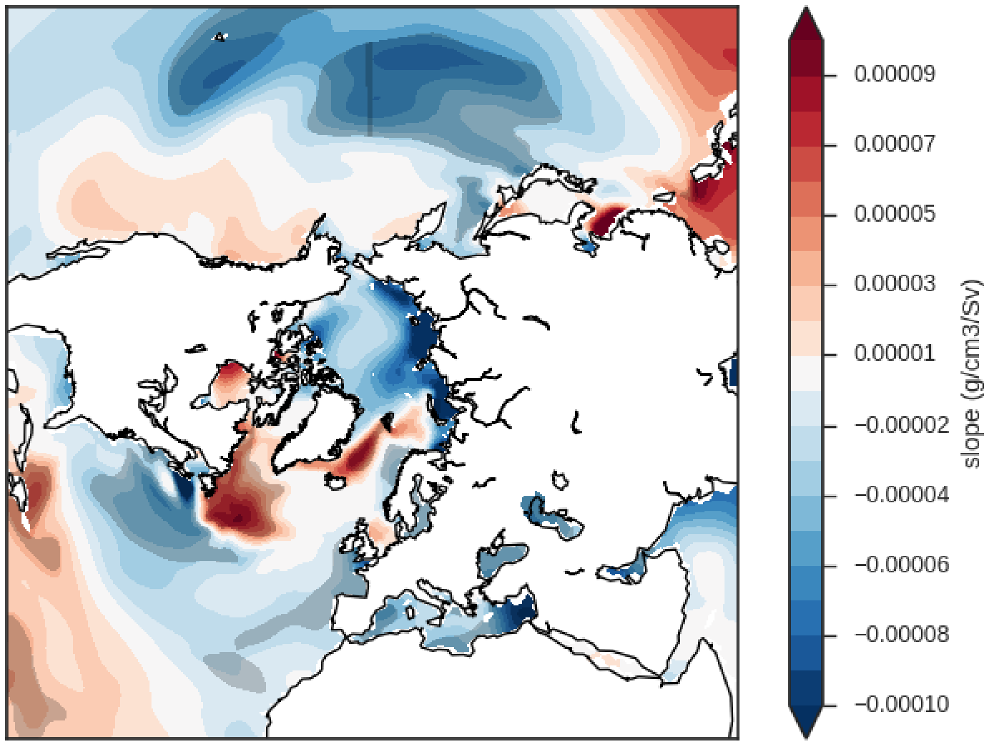
AMOC and SW/LW associations are inconsistent in the historical and RCP8.5 ensembles



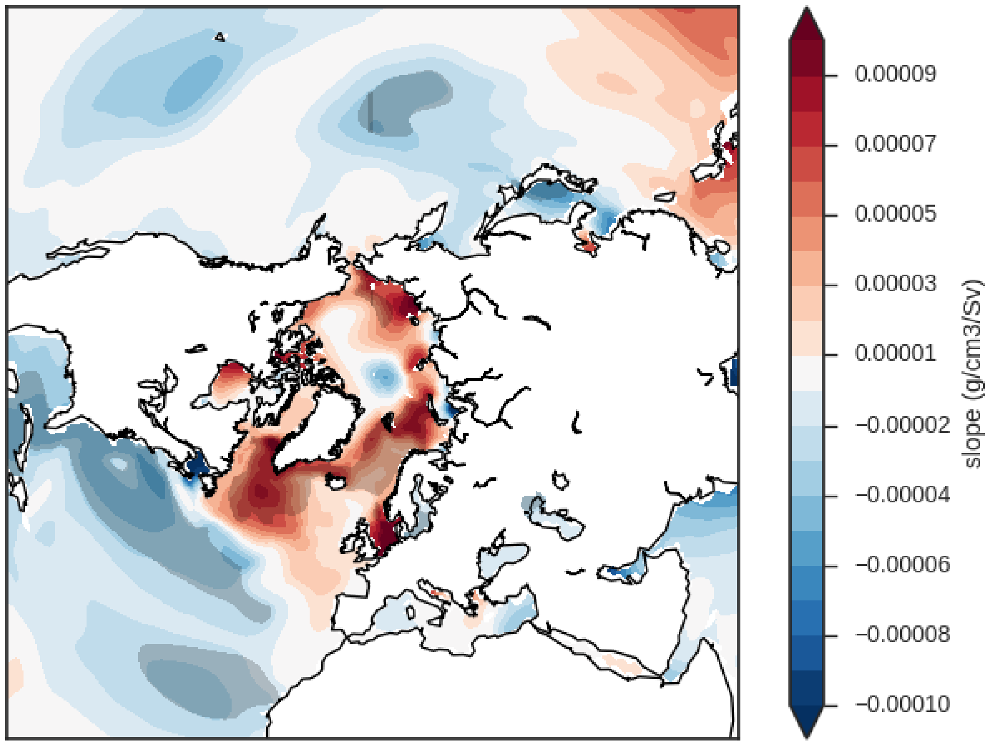
shading indicates correlations significant at 99% confidence level

Strengthening AMOCs associated with increasing density in the Labrador Sea.

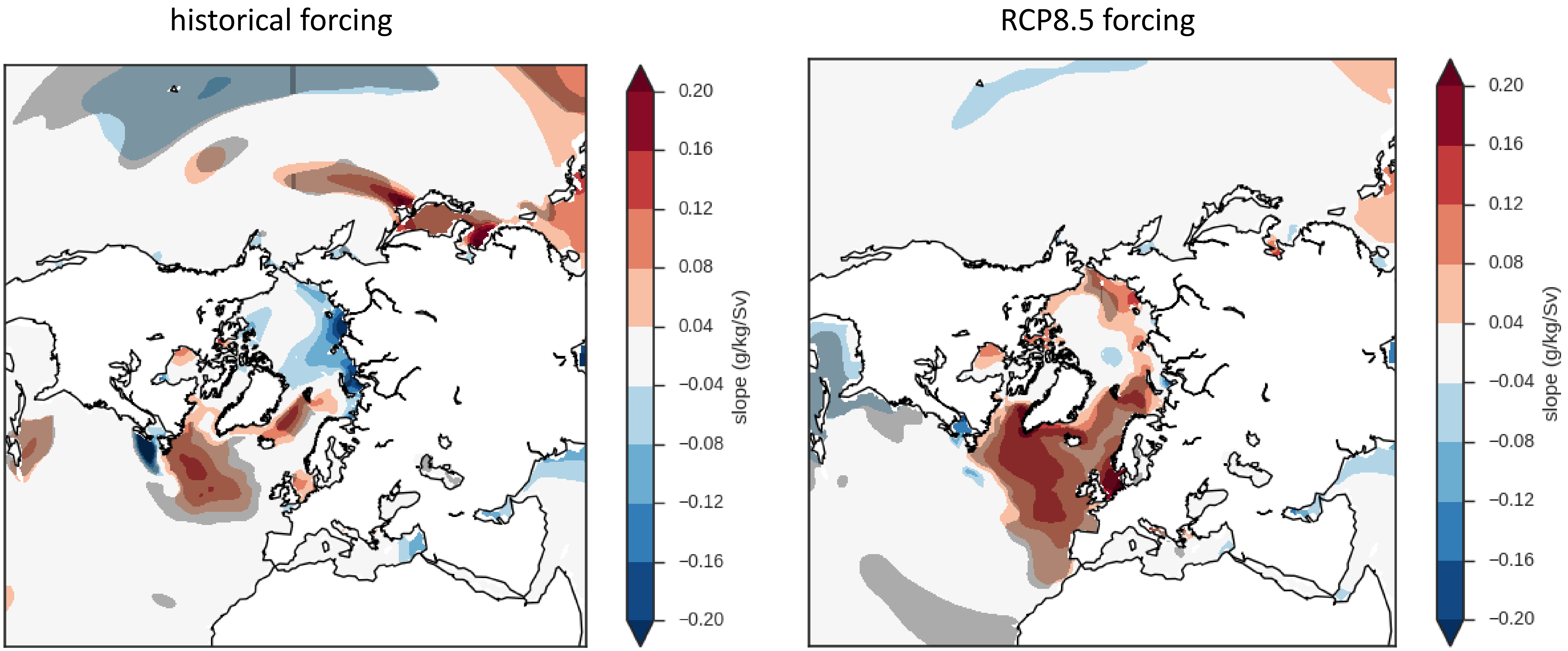
historical forcing



RCP8.5 forcing

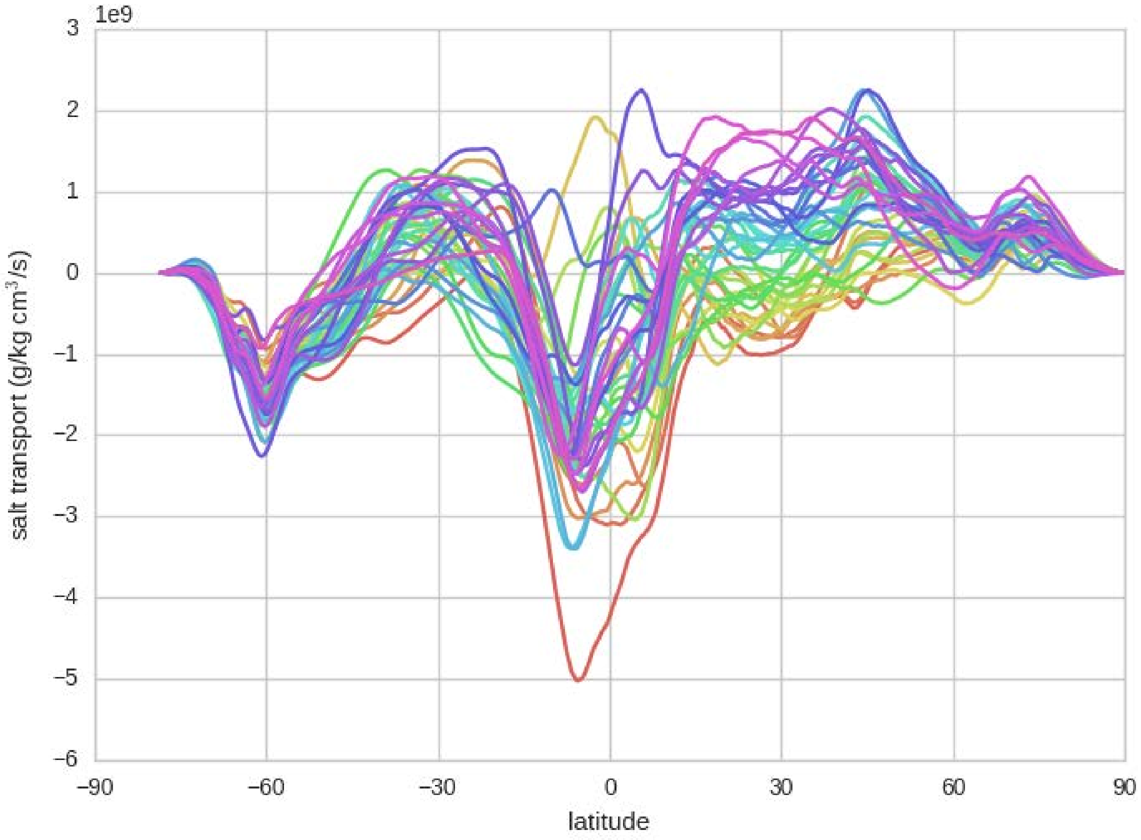


Increasing salinity in the North Atlantic when with strengthening AMOCs.

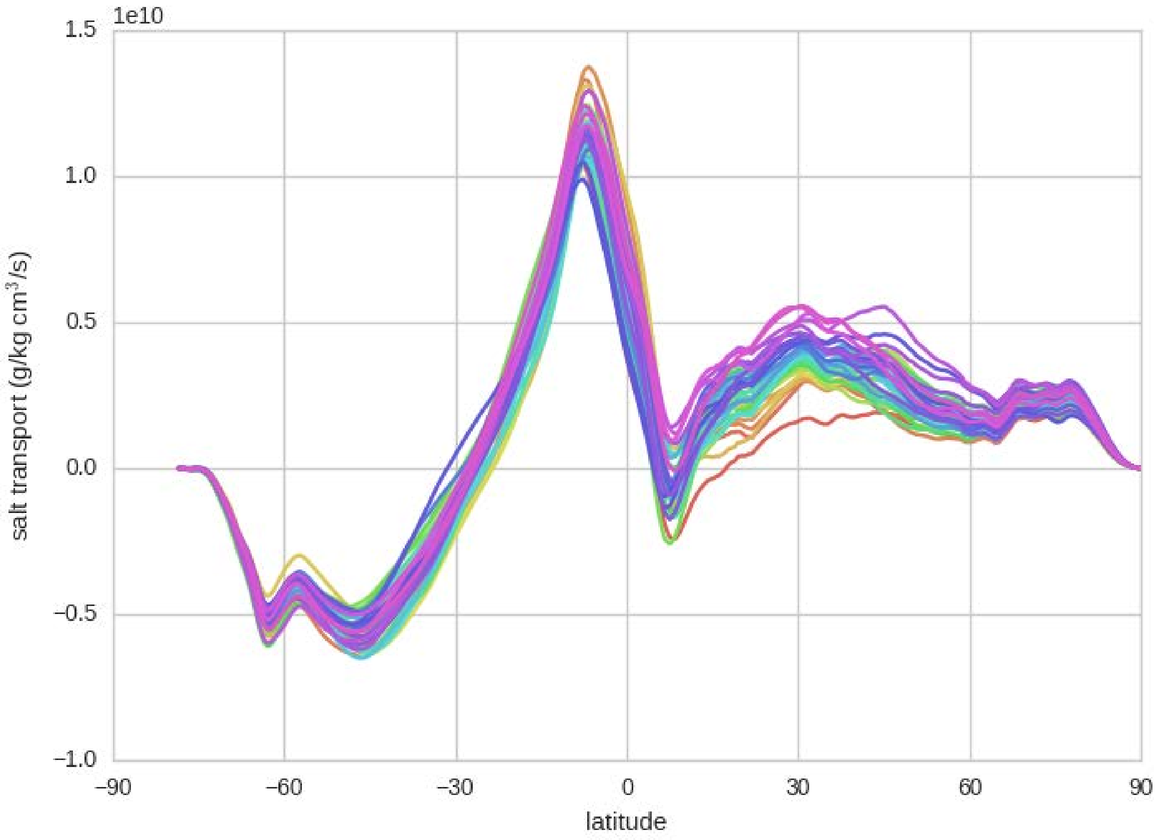


Member-to-member variability in salt transport changes is consistent with AMOC trends.

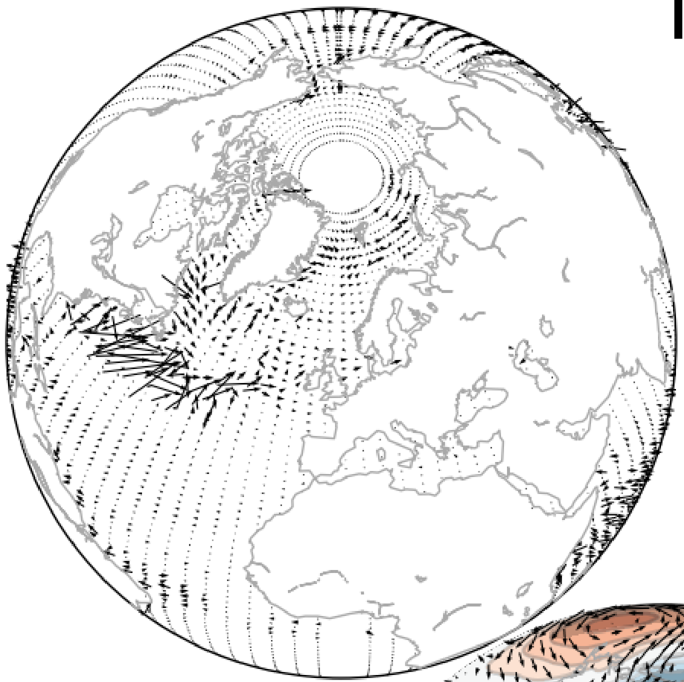
Historical ensemble



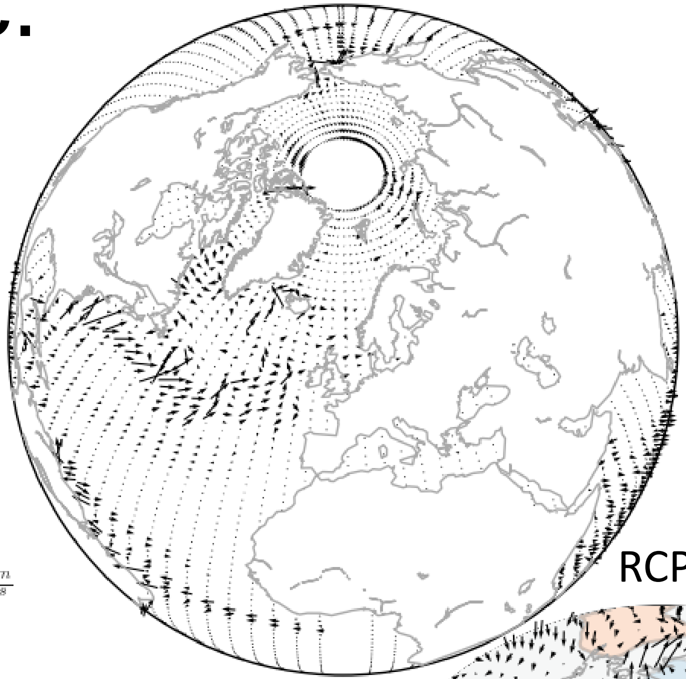
RCP8.5 ensemble



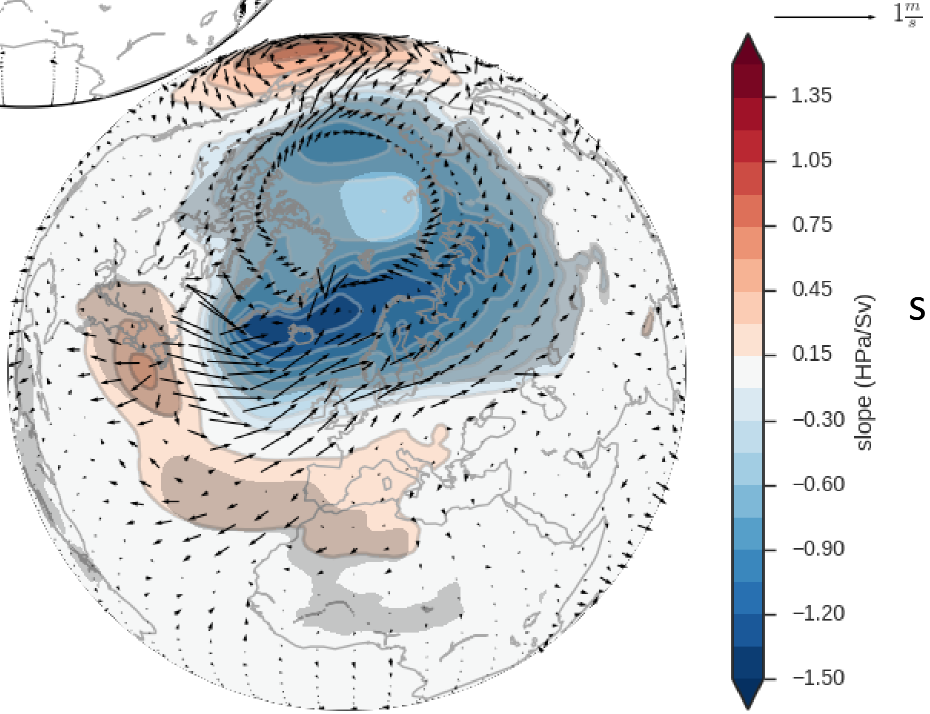
AMOCs that weaken less associated with westerlies in North Atlantic.



5m currents

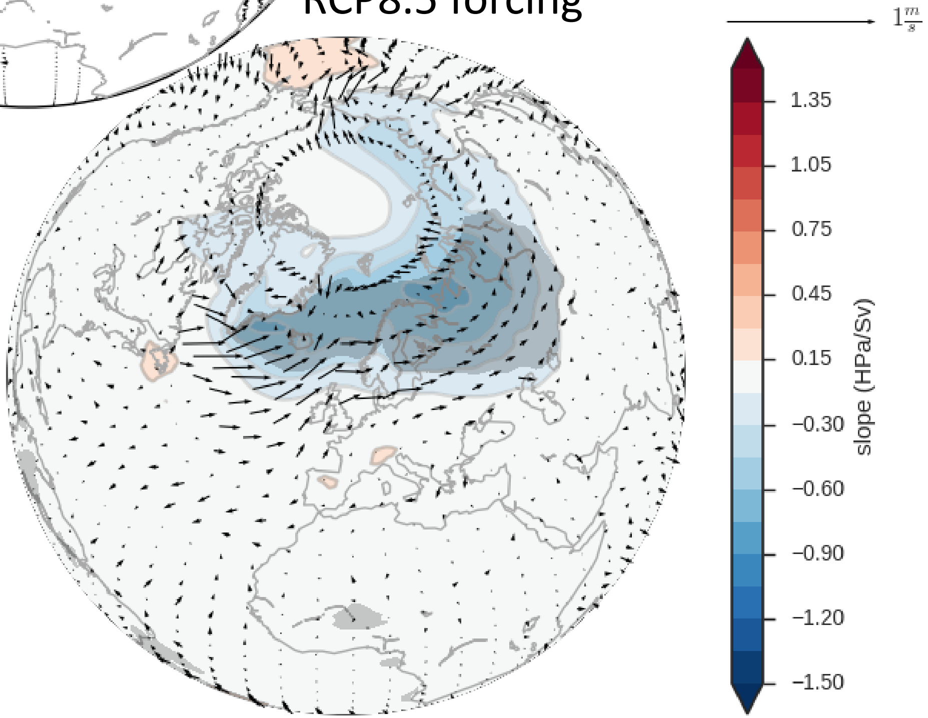


Historical forcing



surface winds and surface pressure

RCP8.5 forcing

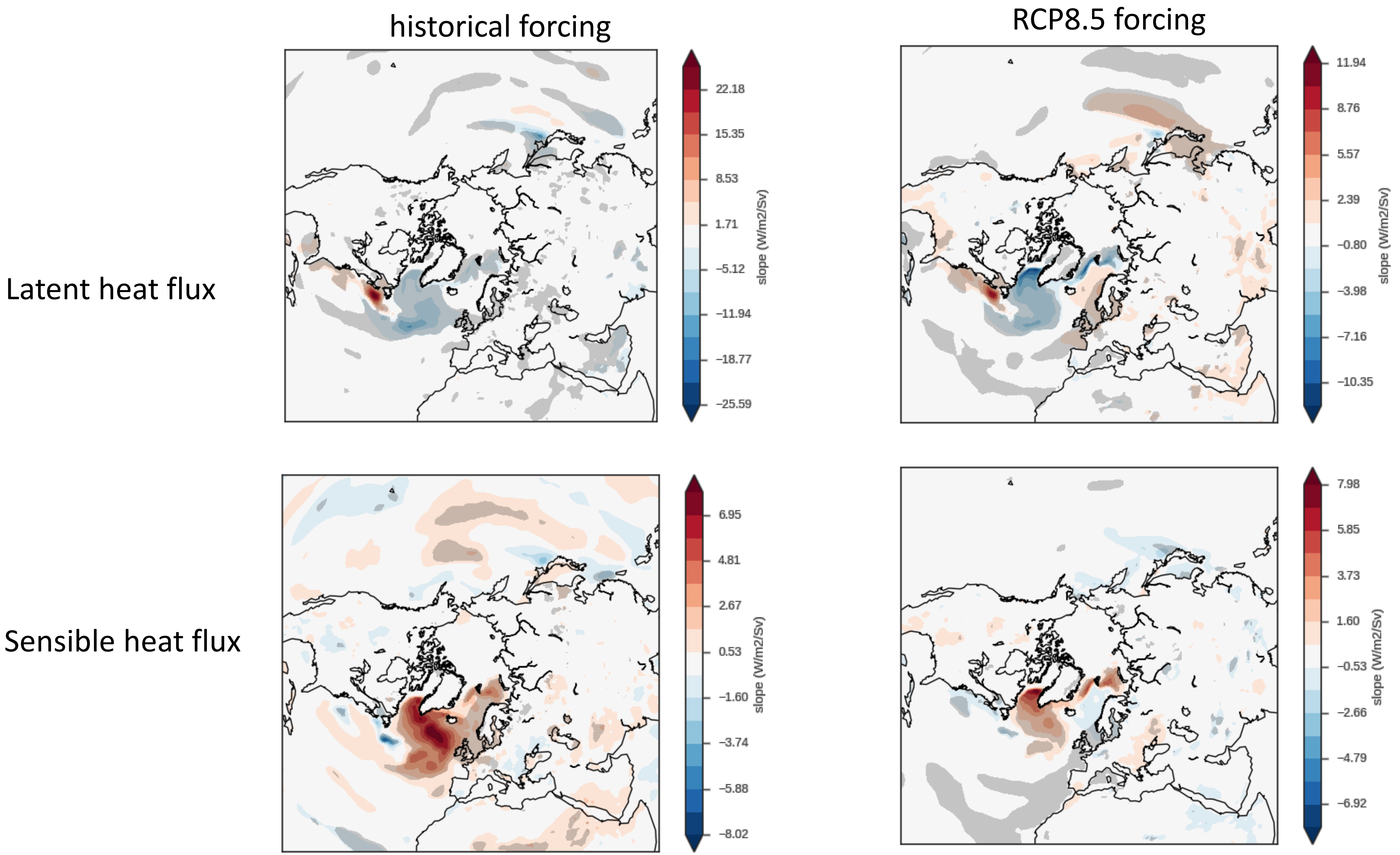


Conclusions, so far:

- 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
RCP8.5 forcing
Latent heat flux
Sensible heat flux
22.18
15.35
8.53
1.71
−5.12
−11.94
−18.77
−25.59
slope (W/m2/Sv)
11.94
8.76
5.57
2.39
−0.80
−3.98
−7.16
−10.35
slope (W/m2/Sv)
6.95
4.81
2.67
0.53
−1.60
−3.74
−5.88
−8.02
slope (W/m2/Sv)
7.98
5.85
3.73
1.60
−0.53
−2.66
−4.79
−6.92
slope (W/m2/Sv)

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