Rethinking the AMOC stability in climate models

Wei Liu, Zhengyu Liu, Shang-Ping Xie,
Esther Brady, Aixue Hu and Jiang Zhu

October 20, 2016

US CLIVAR Webinar

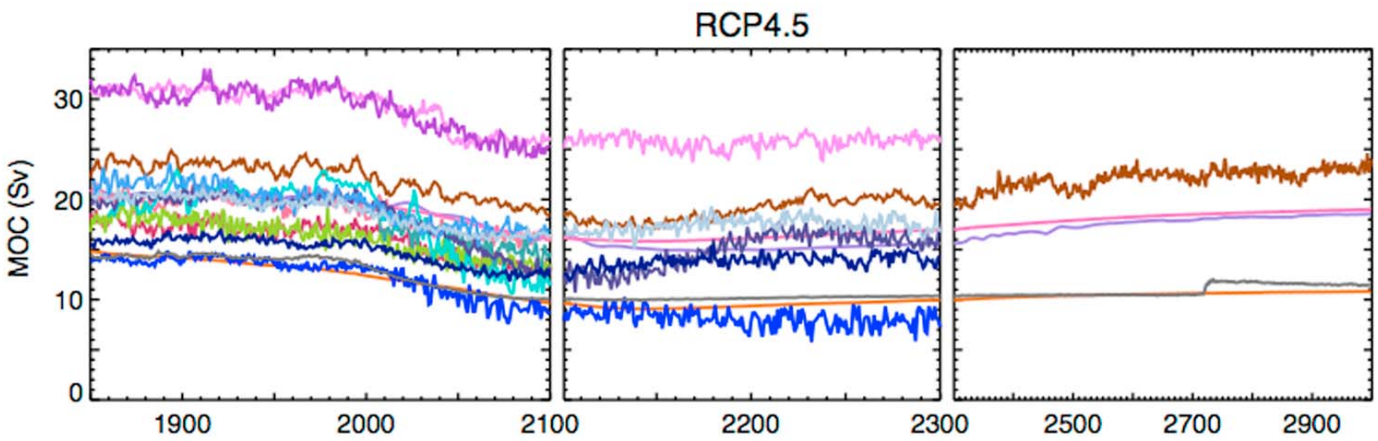
SCRIPPS INSTITUTION OF OCEANOGRAPHY UCSD

THE UNIVERSITY of WISCONSIN MADISON

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Background and motivation

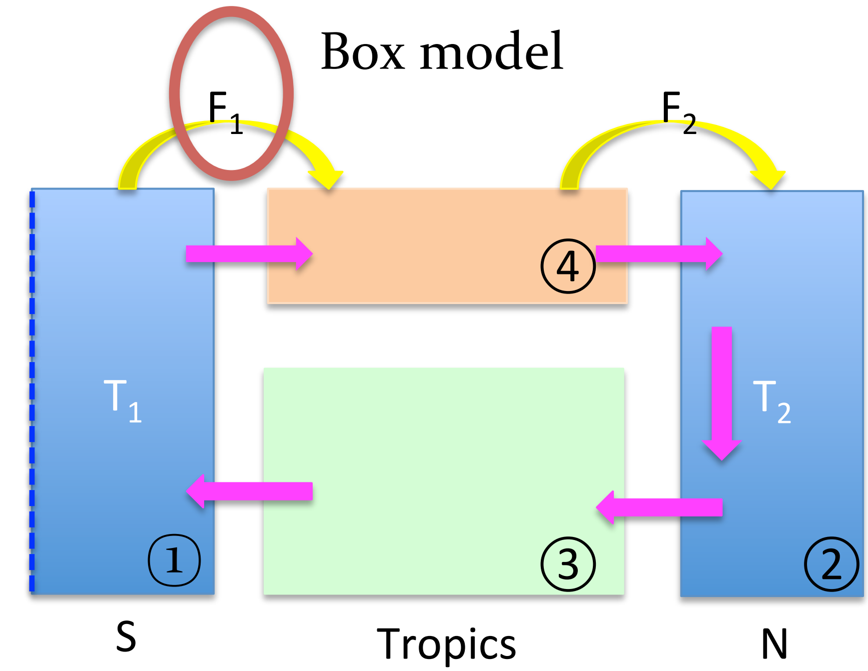
- An abruptly collapsed AMOC can cause abrupt climate change. This AMOC change is considered to be associated with multiple equilibria (ME) of the AMOC.
- Nevertheless climate models mostly simulate AMOCs with Single equilibrium (SE).
- Example 1: A strong and long lasting freshwater forcing is needed to keep an collapsed AMOC during Heinrich Event 1 (Liu et al. 2009).
- Example 2: The AMOC recovers in pulse-like hosing experiments (e.g., Stouffer et al. 2006).
- Also, the CMIP5 model projection shows a moderately weakened but not collapsed AMOC till 2300 (e.g., Weaver et al. 2012).



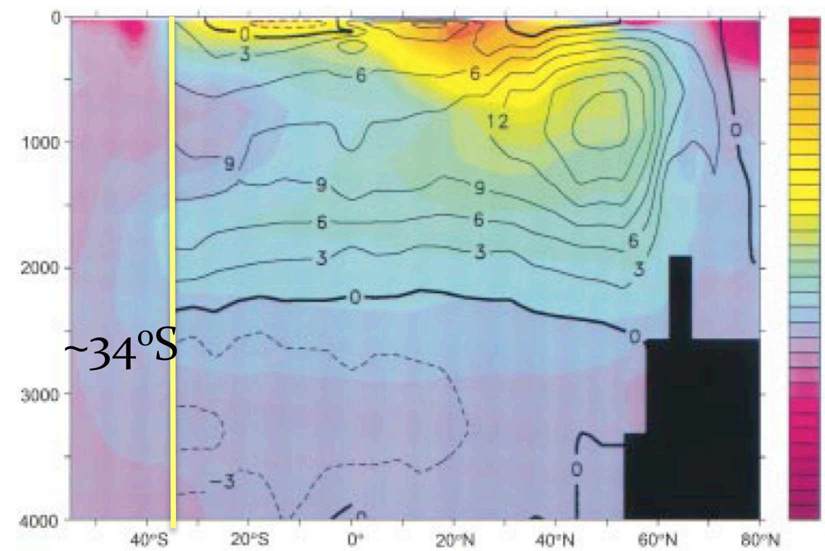
Scientific questions

a. What is the indicator of the AMOC stability in fully coupled climate models?
b. Why do most state-of-art climate models fail to obtain AMOCs with ME?
c. How does this AMOC stability bias affect model projection?

a. The AMOC stability indicator



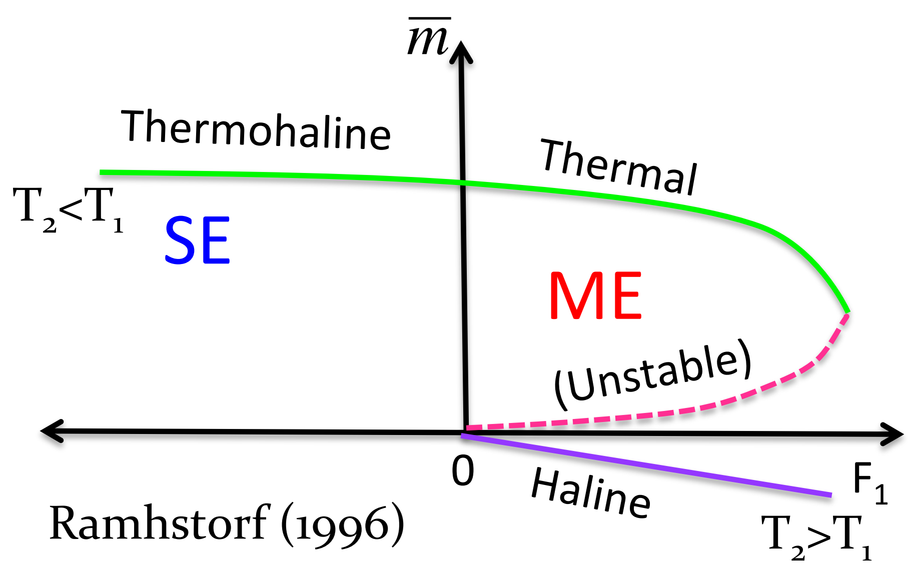
Climate model



$$[E-P-R] = M_{ov} + M_{az} + M_{dif} + M_{BS}$$

FWT by MOC

FWT by gyre



Ramhstorf (1996)

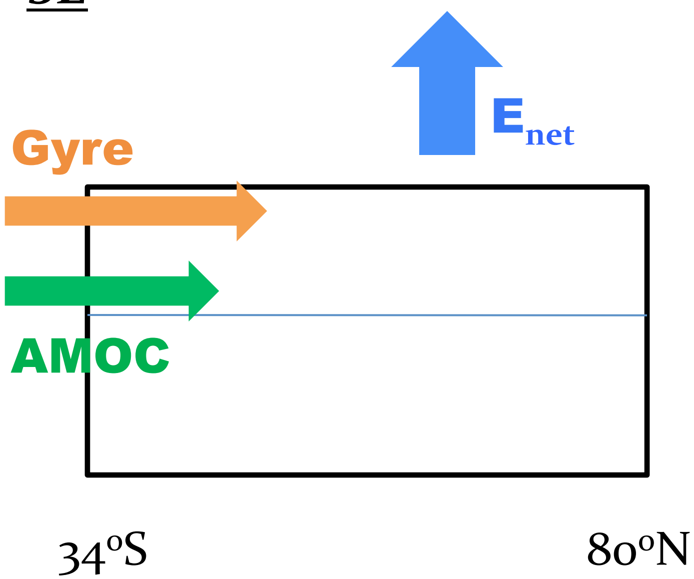
$$M_{ov} = -\frac{1}{S_0}\int dz\,\bar{v}(z)\left[\langle S(z)\rangle - S_0\right]$$

Indicator

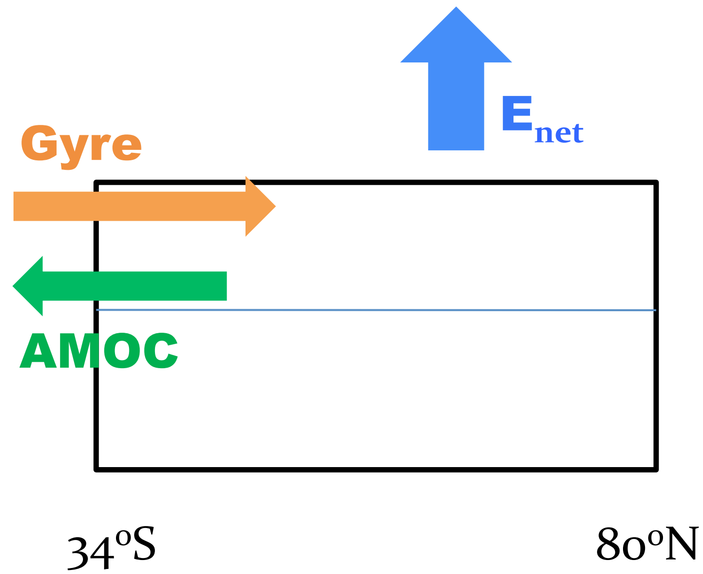
a. The AMOC stability indicator

Why does M_{ov} act as an AMOC stability indicator?

SE



ME



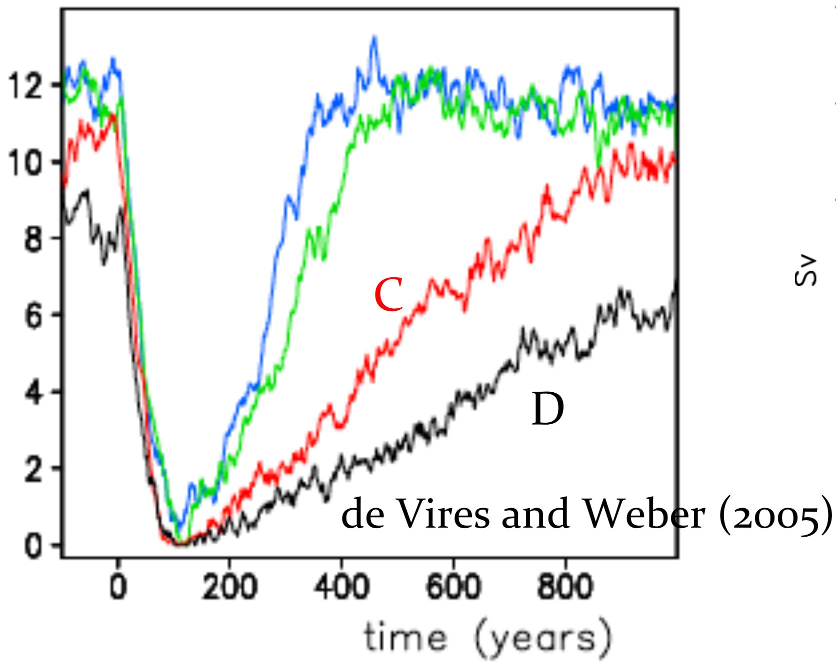
M_{ov}>0, freshwater import,
AMOC recovery,
SE(monostable)

M_{ov}<0, freshwater export,
No AMOC recovery
ME(bistable)

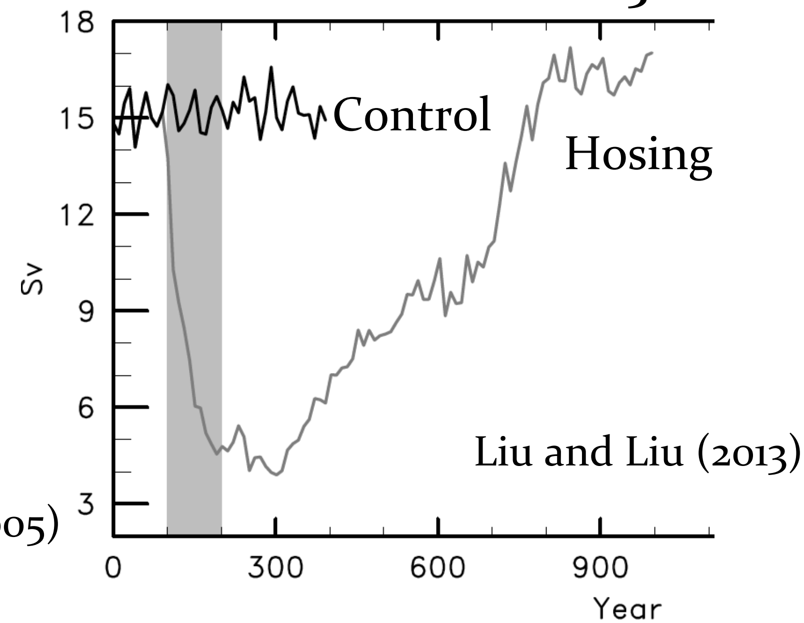
a. The AMOC stability indicator

M_{ov} may not work

ECBilt/CLIO



NCAR CCSM3



The ECBilt/CLIO Runs C & D and CCSM3 PD control run show negative M_{ov} (FW exports at ~34°S) but AMOCs in a SE regime.

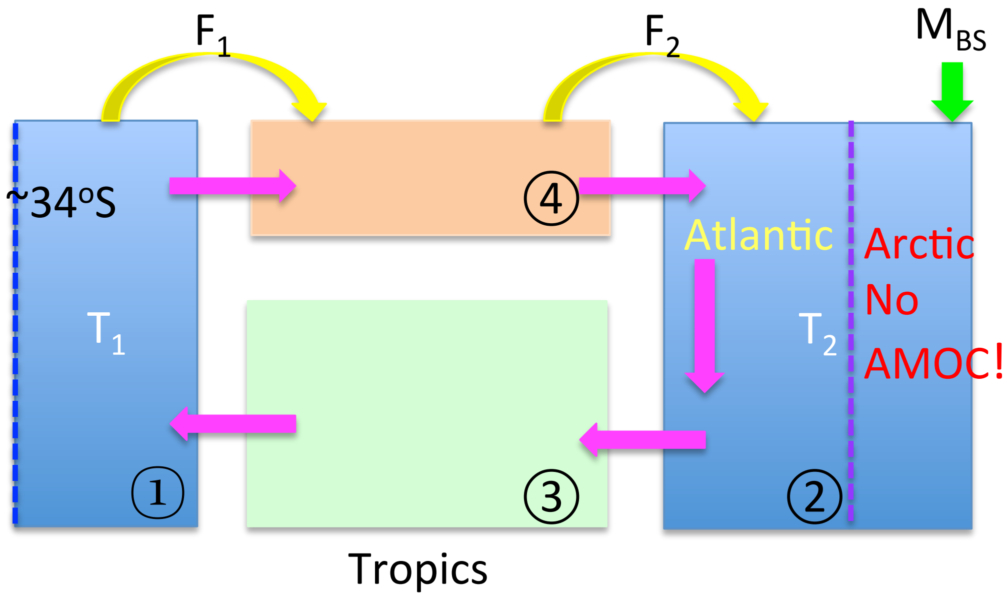
An alternative indictor? (Dijkstra 2007)

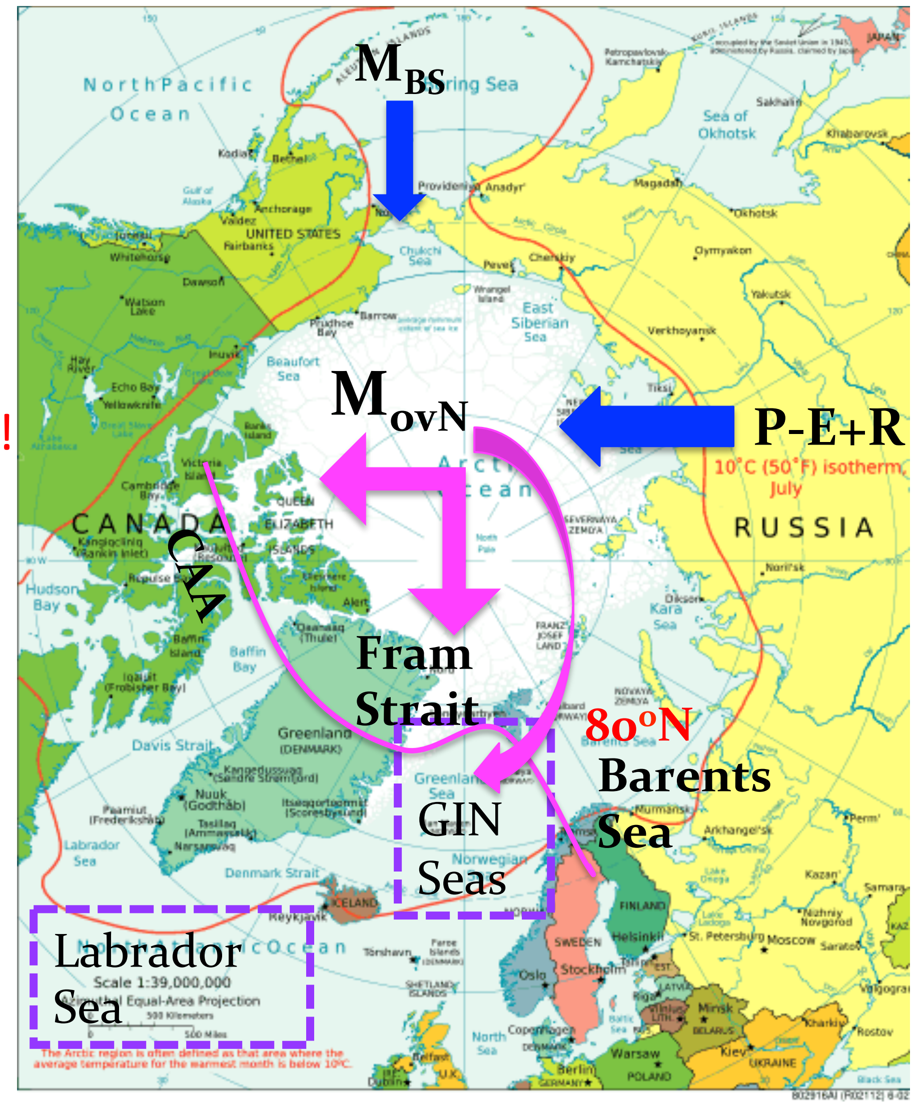
$$\Sigma(\theta_s, \theta_n) = M_{\mathrm{ov}}(\theta_s) - M_{\mathrm{ov}}(\theta_n).$$

Θ_s =35°S; Θ_s =60°N

a. The AMOC stability indicator

Reason





A refined indicator

(Liu and Liu 2013,2014)

$$\Delta M_{ov} = M_{ovS} - M_{ovN}$$

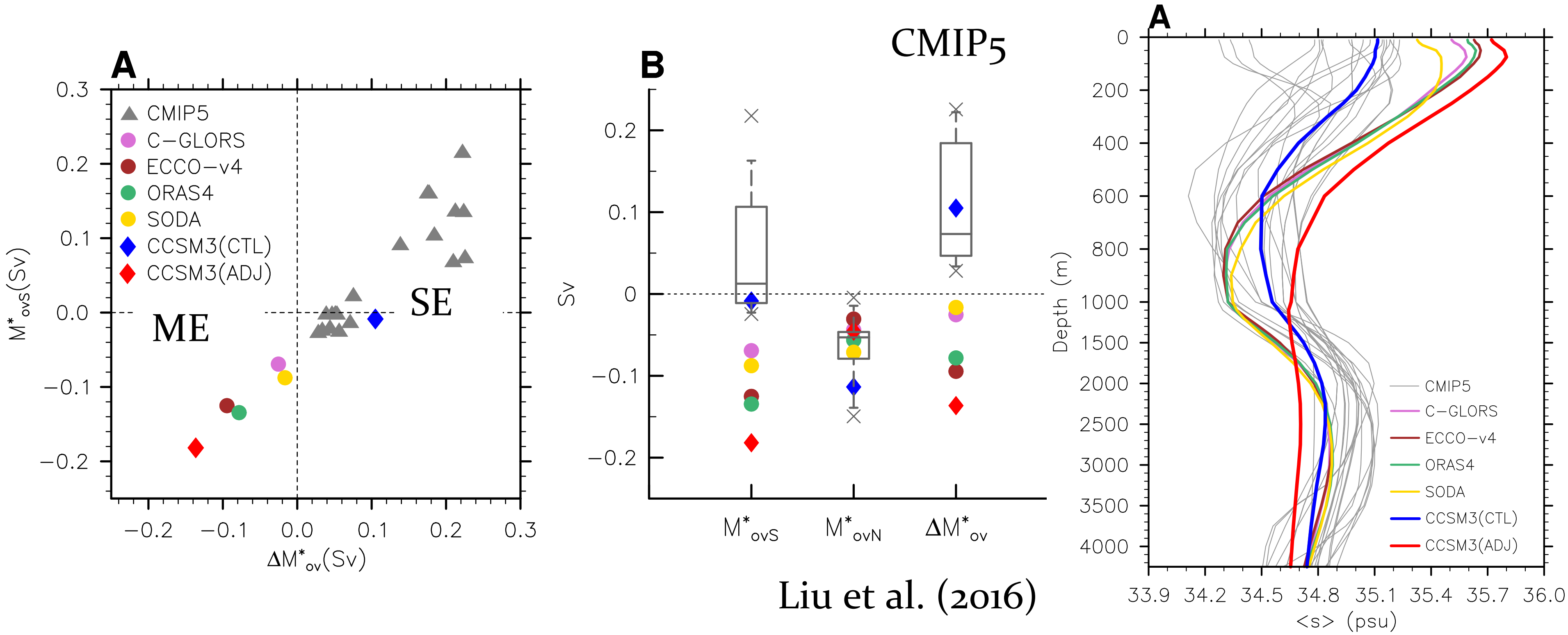
Θ_s ~34°S: the boarder b/ the Atlantic & SO

Θ_n ~80°N: the boarder b/ the Atlantic & Arctic

ΔM_{ov} <0, FW divergence, AMOC ME

ΔM_{ov}>0, FW convergence, AMOC SE

b. The AMOC stability bias in climate models



Liu et al. (2016)

Similar results can also be found in the CMIP3 simulations (Liu et al. 2014)

- Observations suggest a FW divergence (ΔM_{ov}<0) and an AMOC with ME.
- Climate models show a FW convergence (ΔM_{ov}>0) and an AMOC with SE.
- This AMOC stability bias mainly comes from the southern boundary and is related to a fresh bias in the upper ocean of the South Atlantic.

b. The AMOC stability bias in climate models

How to correct this bias? Flux adjustment (CCSM3)

Restore sfc heat flux $H_{res} = (\mathrm{SST} - SST_{obs})/\tau_T$

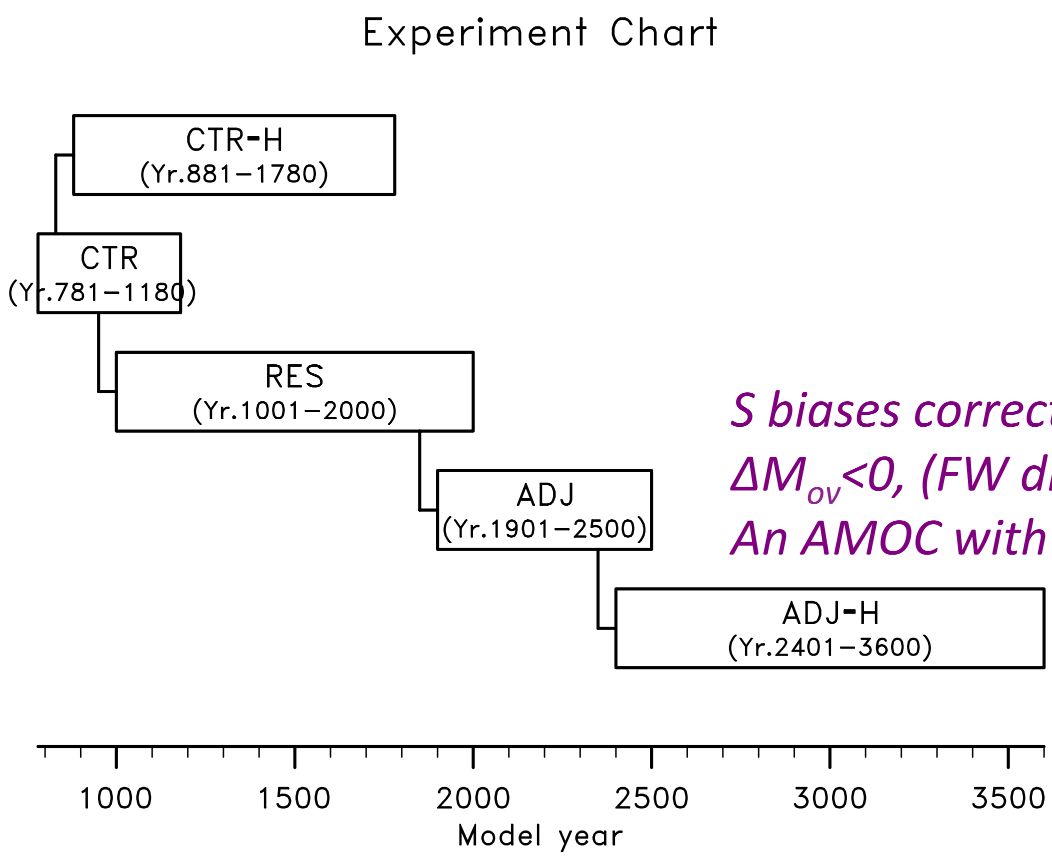
Restore sfc freshwater flux $F_{res} = (\mathrm{SSS} - SSS_{obs})/\tau_S$

equilibrium →

$H_{adj} = H_{res}$

$F_{adj} = F_{res}$

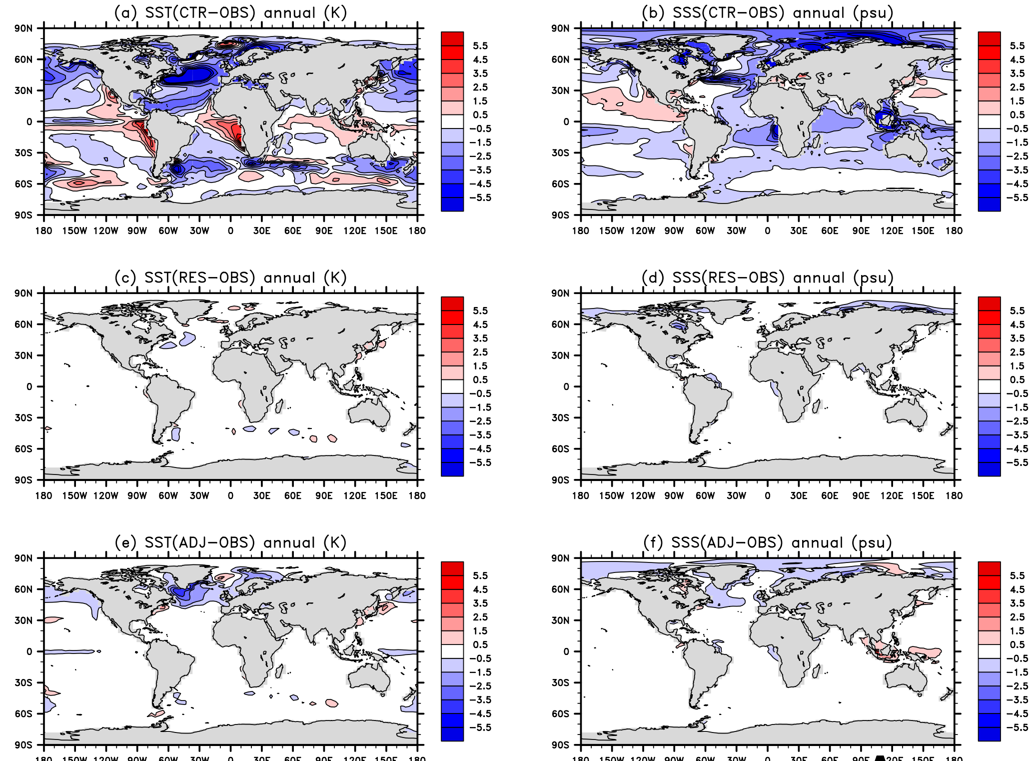
S biases uncorrected
ΔM_{ov}>0, (FW conv.)
An AMOC with SE

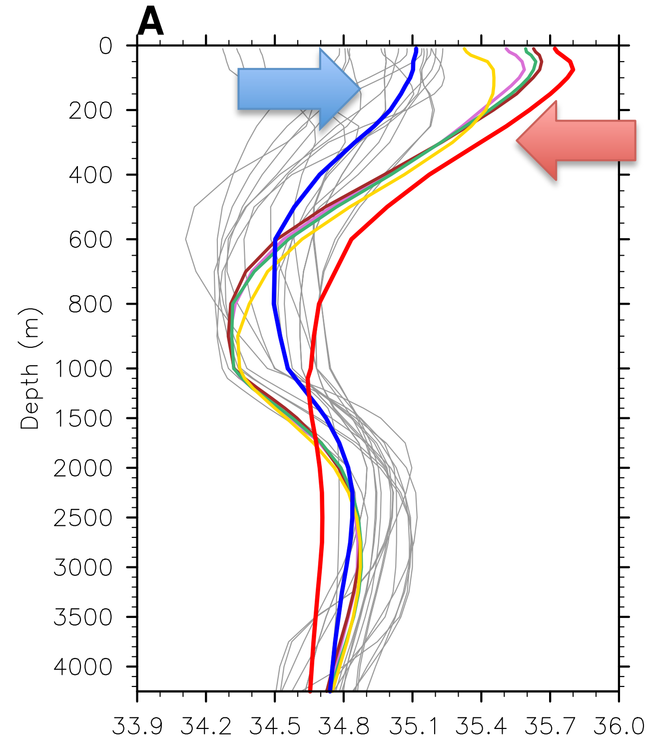


S biases corrected
ΔM_{ov}<0, (FW div.)?
An AMOC with ME?

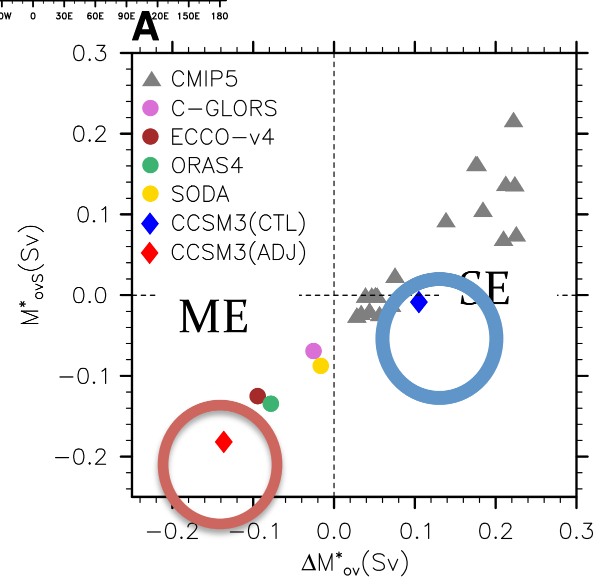
Liu et al. (2014)

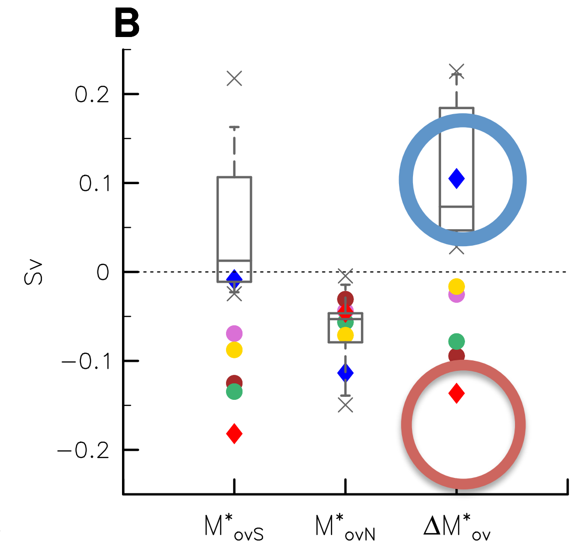
b. The AMOC stability bias in climate models





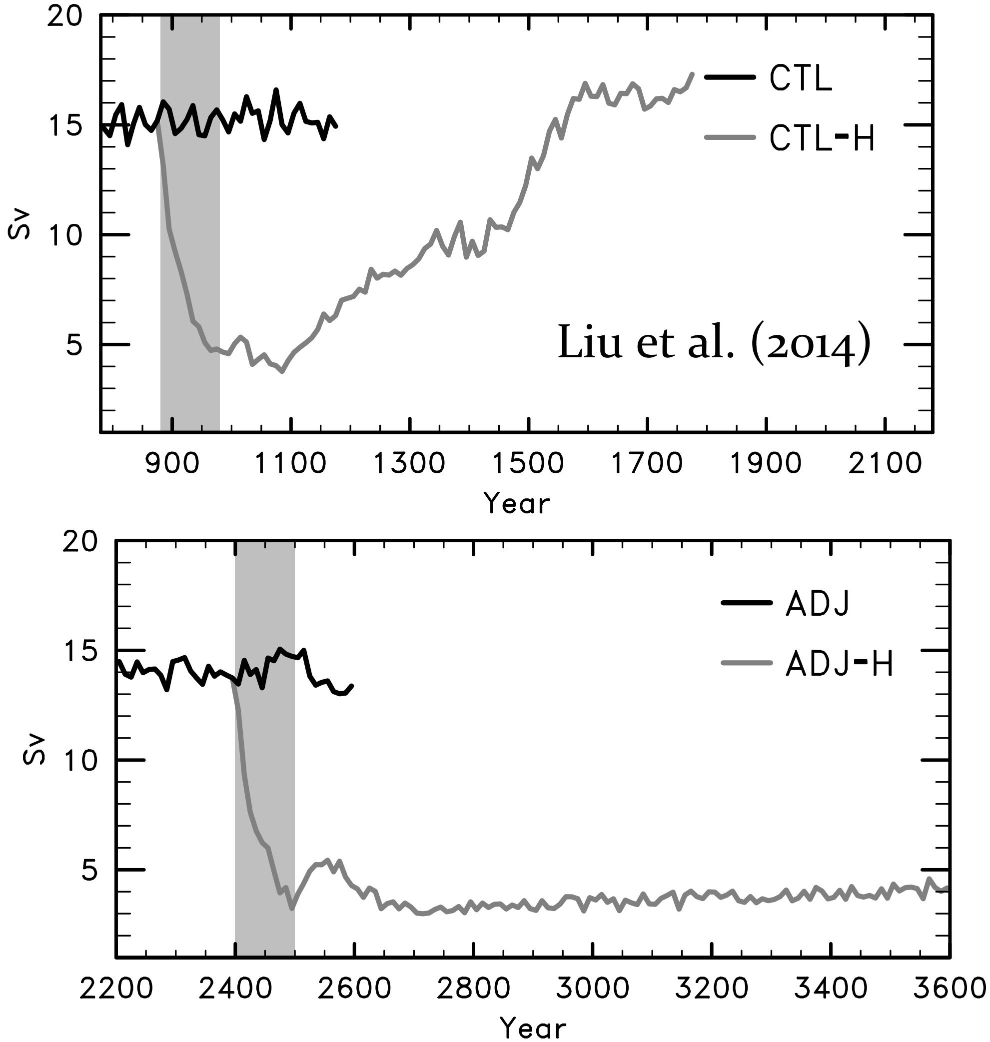
The flux adjustment corrects the salinity bias and tunes the model AMOC into a ME regime to be consistent with observations.

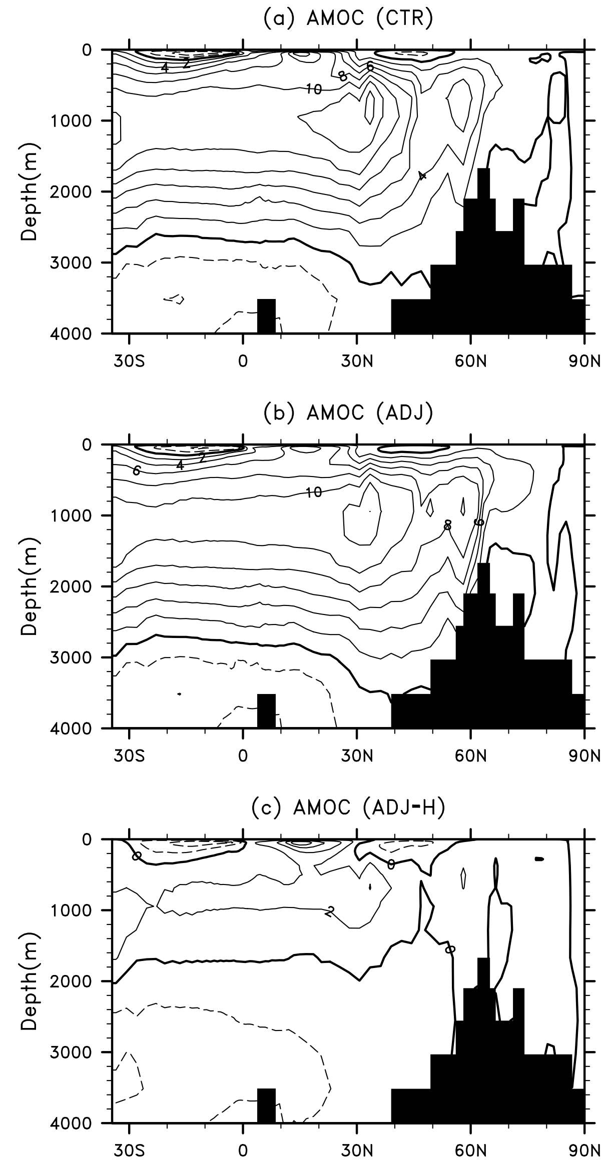




b. The AMOC stability bias in climate models

Test: 1Sv, 100-yr pulse-like hosing experiment

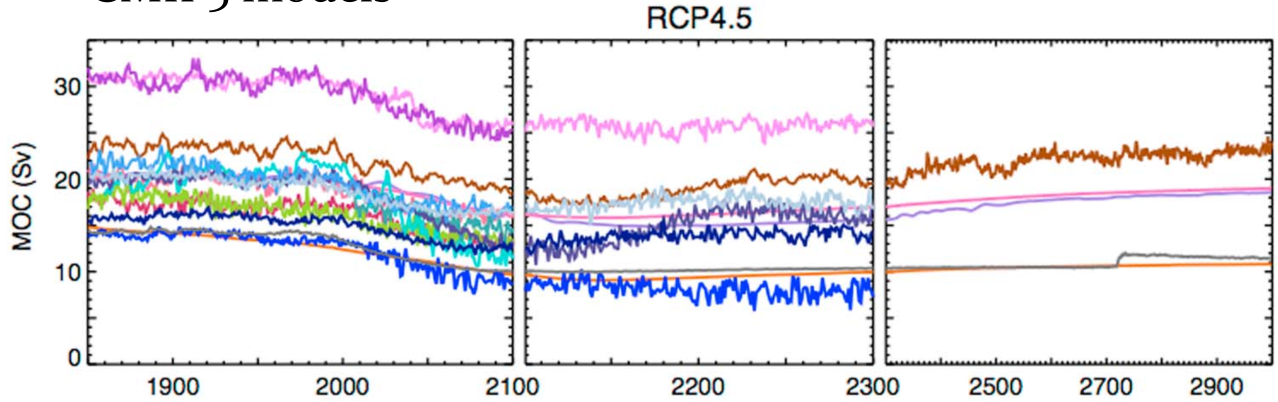




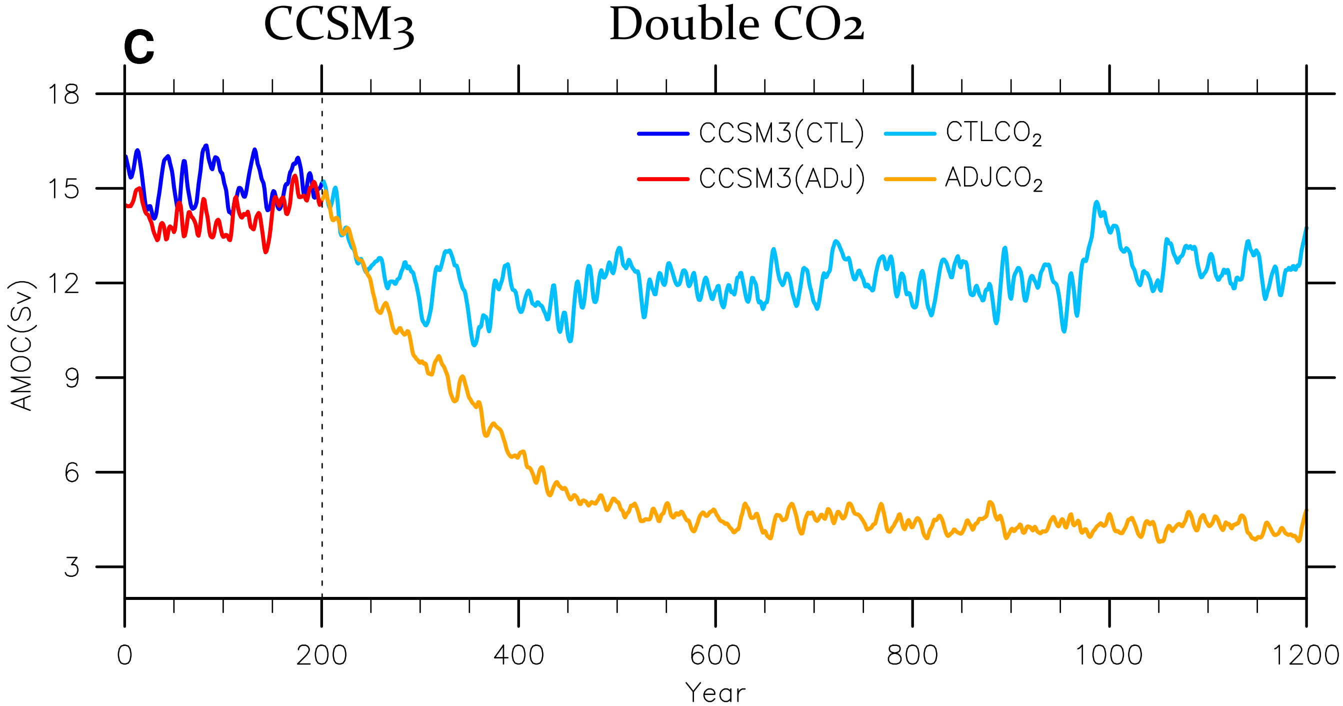
How will this bias change future projection by climate models?

c. Effects of the AMOC stability bias on future projection

CMIP5 models



CCSM3 Double CO2

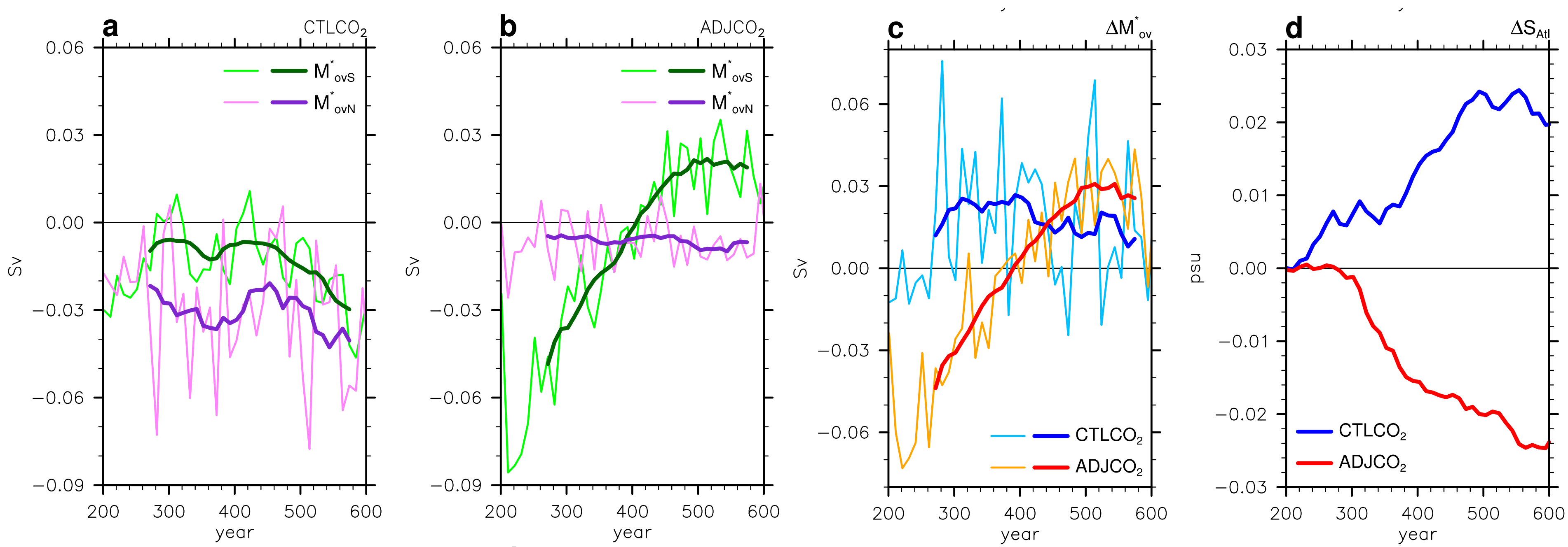


Liu et al. (2016)

c. Effects of the AMOC stability bias on future projection

Different processes during years 250-500
（50-250 years after CO2 doubling)

Liu et al. (2016)

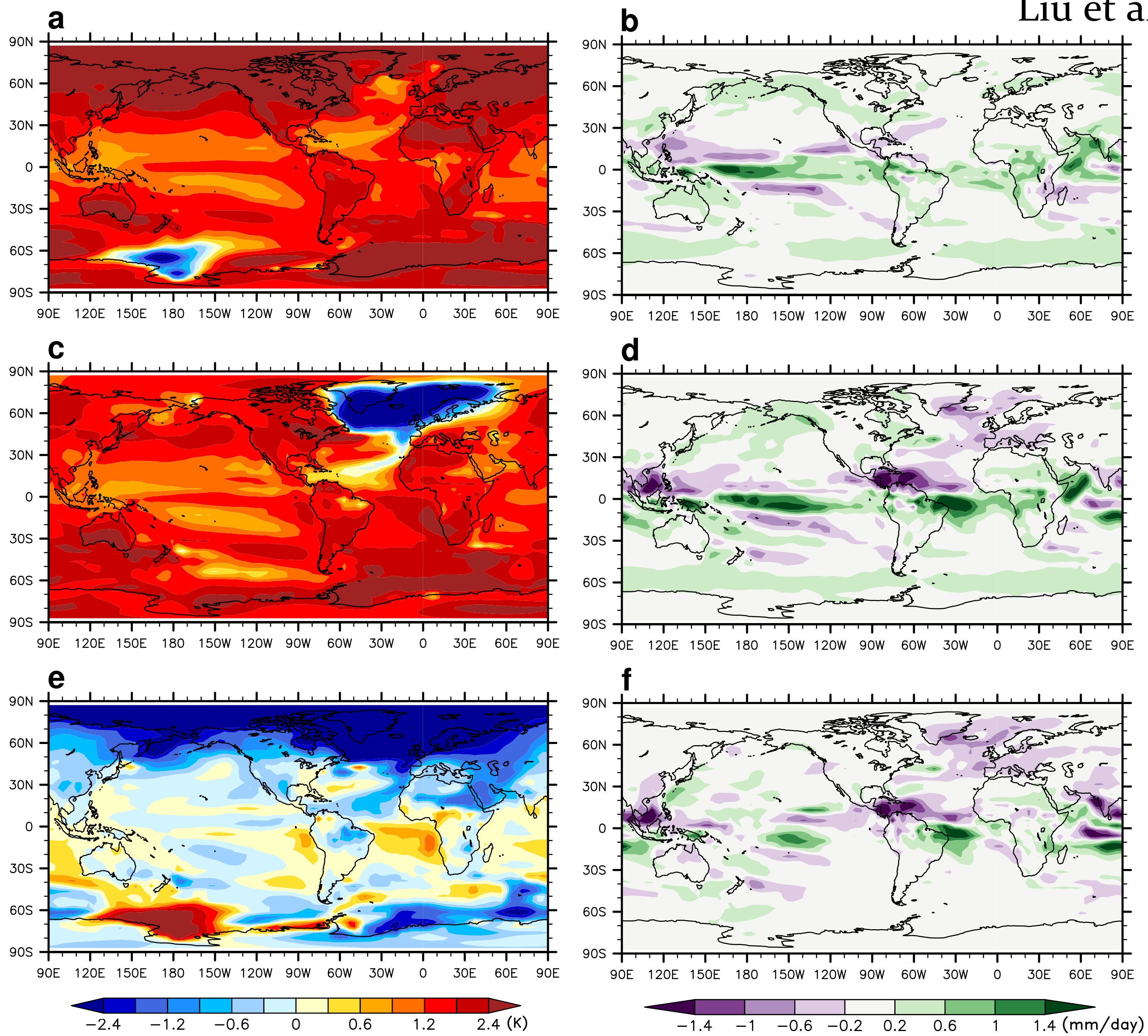


- The initial weakening of the AMOC in the $ADJCO_2$ ($CTLCO_2$) causes a decline of freshwater divergence (convergence) in the Atlantic.
- This change freshens (salinifies) the Atlantic, inhibits (promotes) deep convection and deep-water formation, and finally leads to a collapse (partial recovery) of the AMOC.

c. Effects of the AMOC stability bias on future projection

300 years after CO2 doubling

Liu et al. (2016)



c. Effects of the AMOC stability bias on future projection

Density flux | Thermal | Haline

Double CO_2

1Sv Hosing

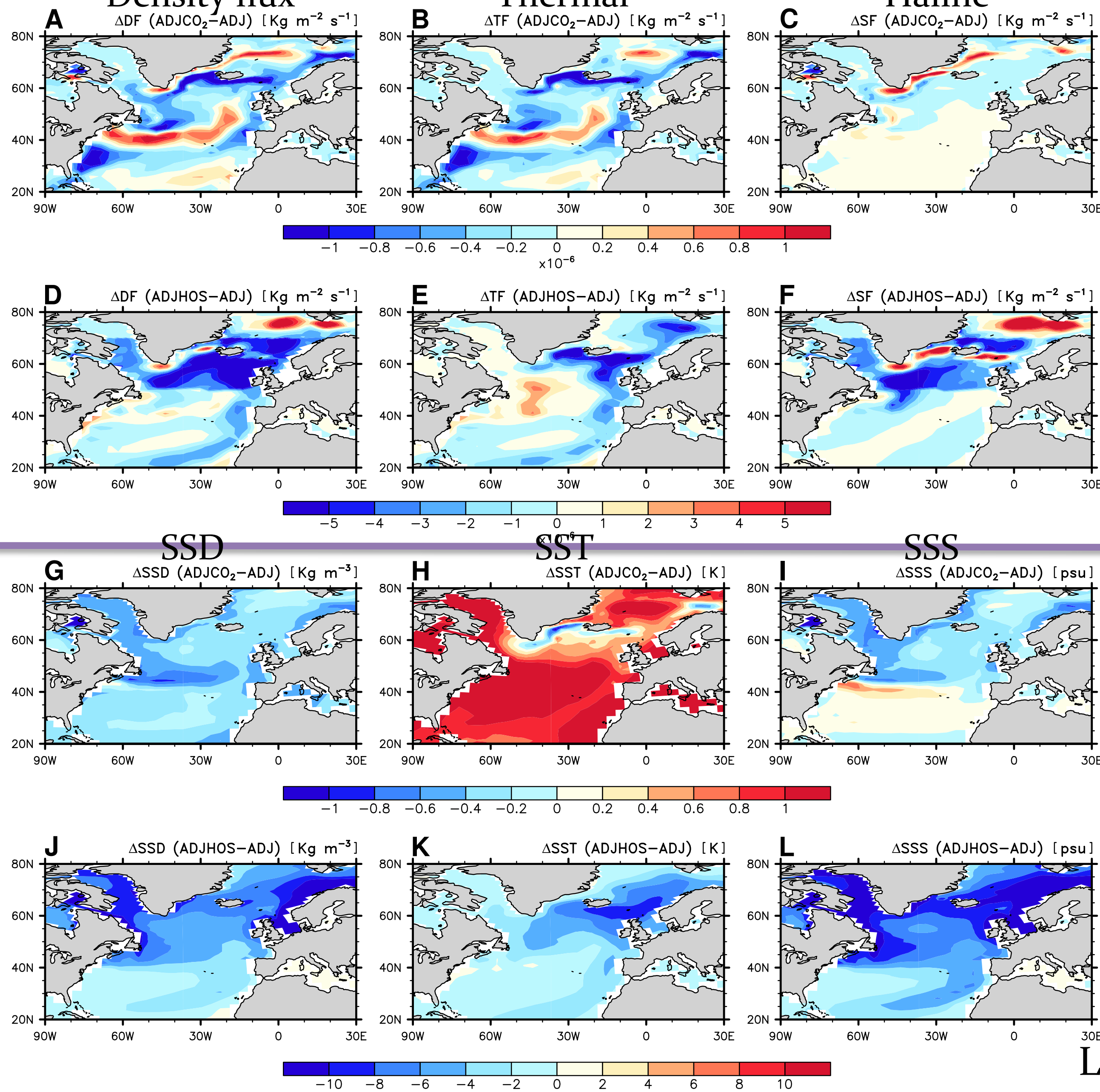
Surface fluxes

SSD | SST | SSS

Double CO_2

1Sv Hosing

Surface water properties



Liu et al. (2016)

Conclusion and discussions

- A diagnostic indicator ΔM_{ov} is proposed to monitor the AMOC stability. A negative (positive) ΔM_{ov} indicates that the AMOC is in a ME (SE) regime.
- Observations suggest that modern AMOC in a ME regime, whereas climate models simulate AMOCs in a SE regime.
- This AMOC stability bias is primarily related to a salinity bias in the upper ocean of the South Atlantic and can remarkably change future projection by climate models.

- How to solve this problem using physically improved model?
- Address the double ITCZ issue?
- High resolution model to resolve Agulhas leakage and improve the stratification at ~34°S?