Why is AMOC mono-stable in CGCMs?

----- Is AMOC bi-stable in the real world?

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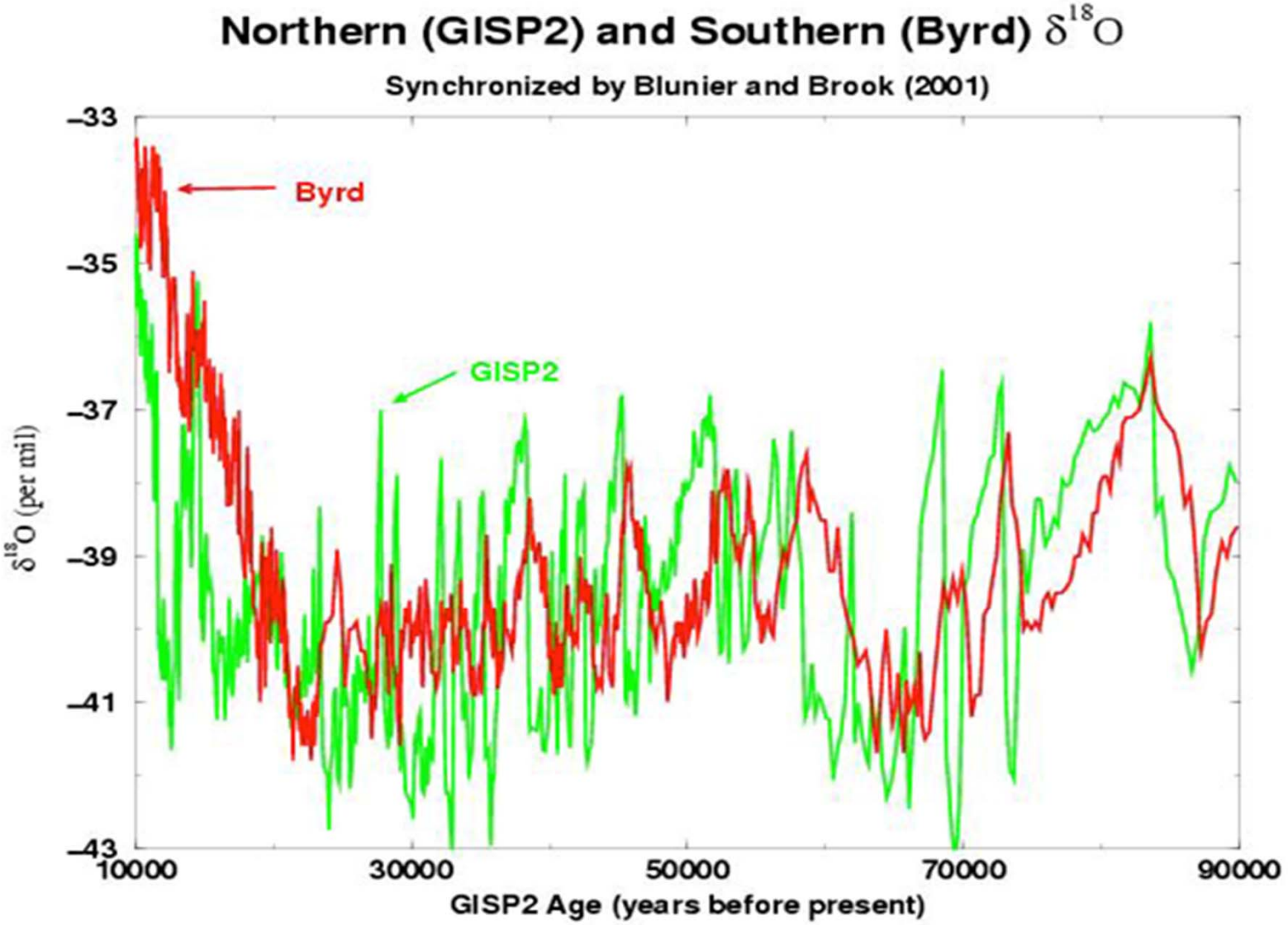
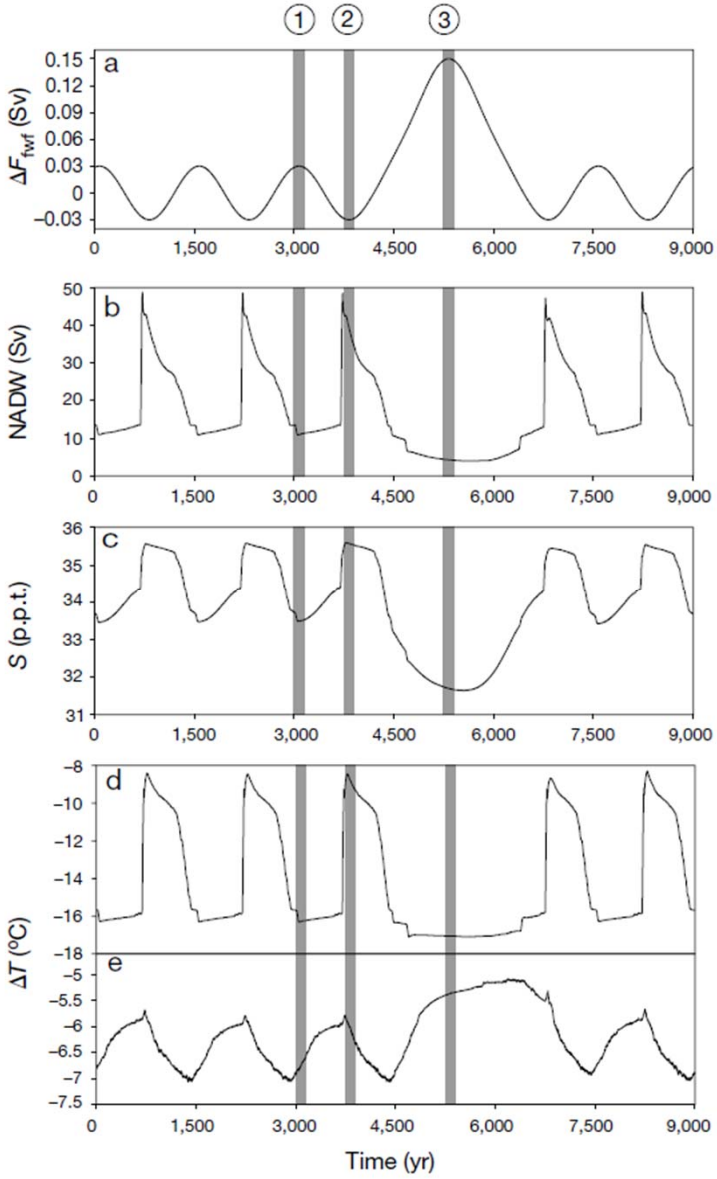
AMOC Instability or Ice Sheet Instability?

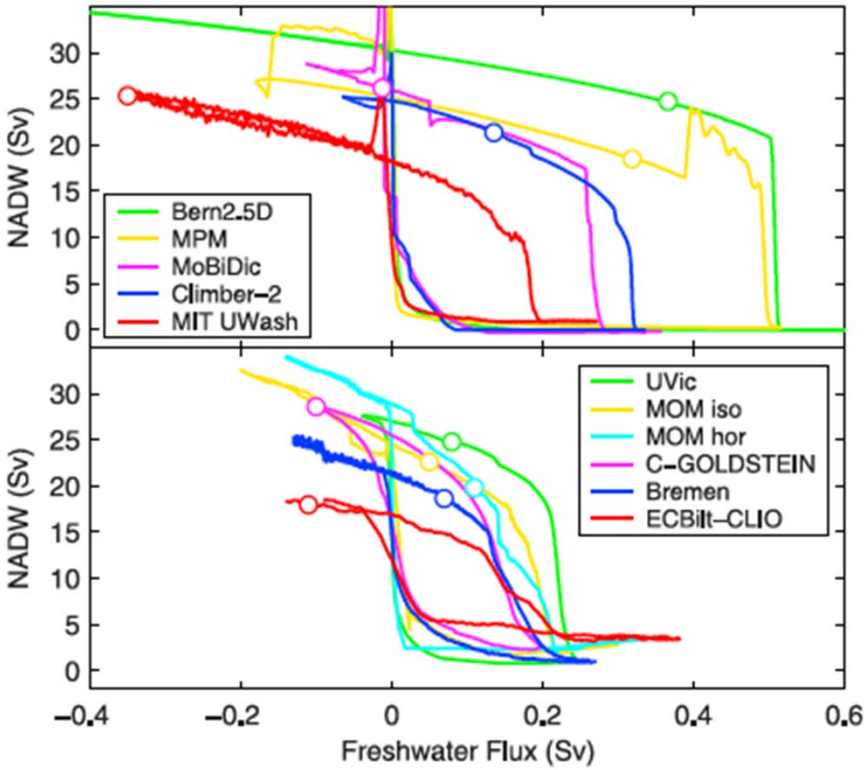


Models of Intermediate Complexity



Ganoposki and Rahmstorf, 2001

EMIC hysteresis

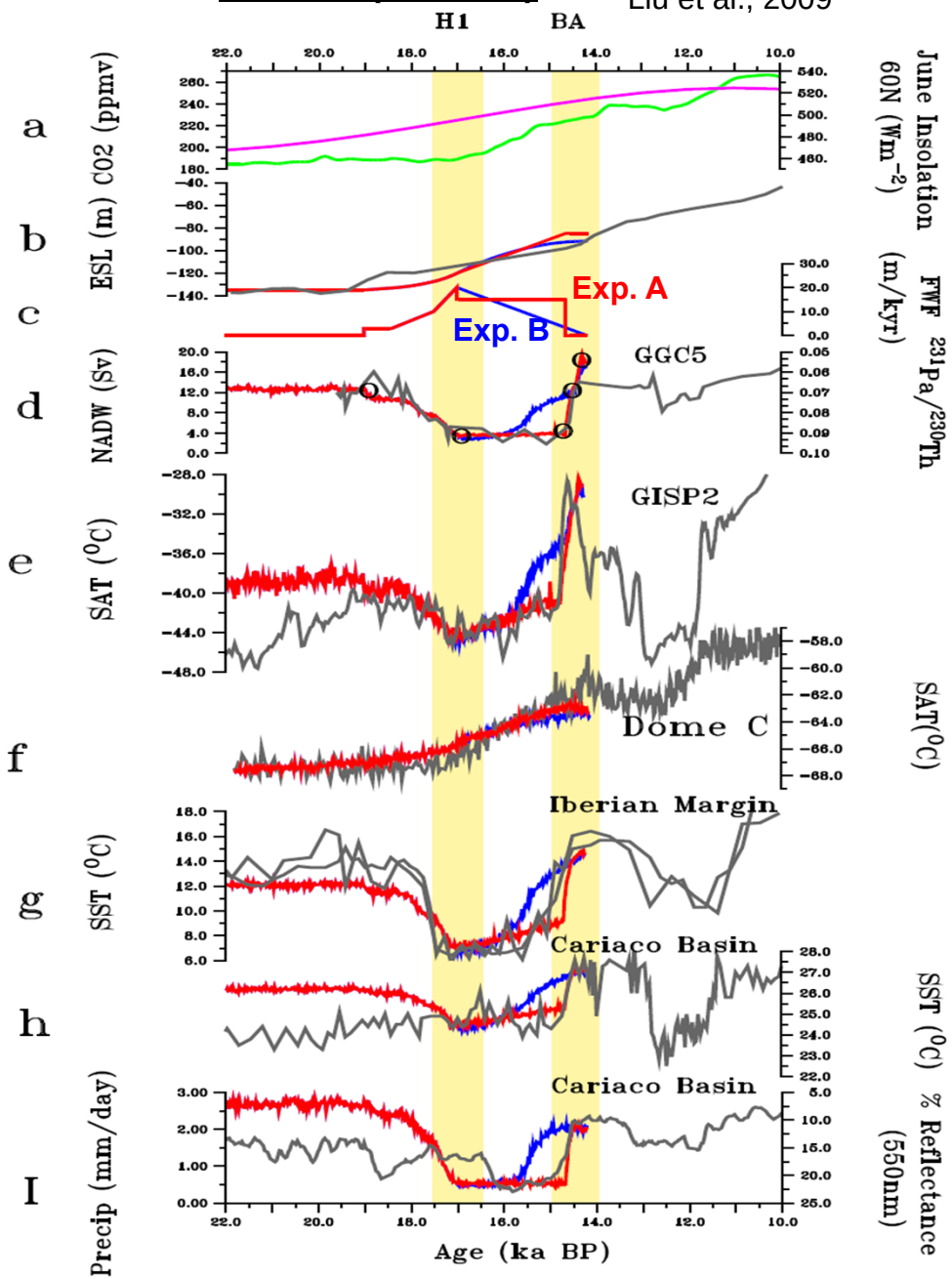


Rahmstorf et al. 2005

CGCM Simulations

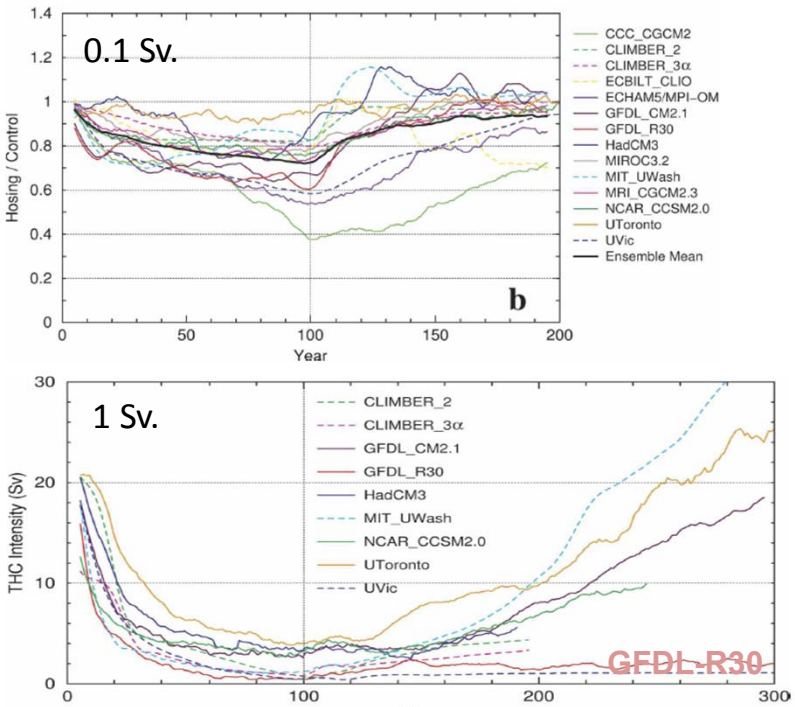
TRACE (CCSM3)

Liu et al., 2009



Hosing Exp.

Stouffer et al., 2006

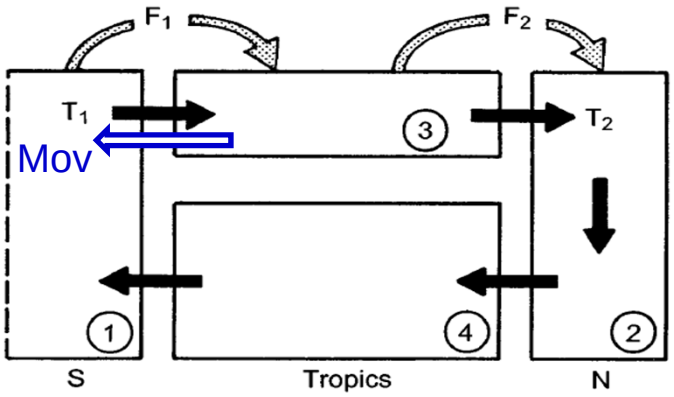


- **Why AMOC monostable in CGCMs?**
- **Is AMOC bistable in real world:**
  - **Paleo data?**
  - **Present obs?**

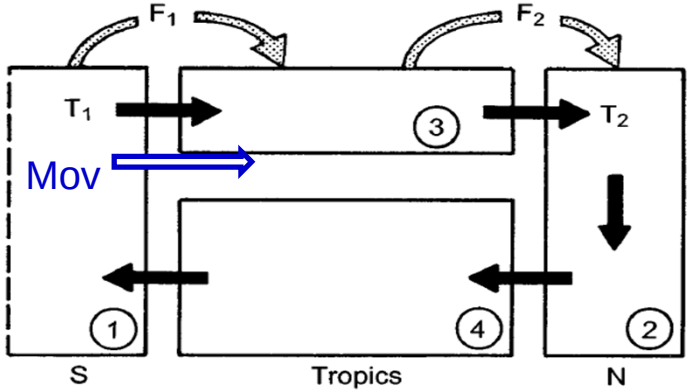
Freshwater Transport Stability Indicator Mov

Mov: Freshwater transport by AMOC (overturning)

Bi-stable



Mono-stable

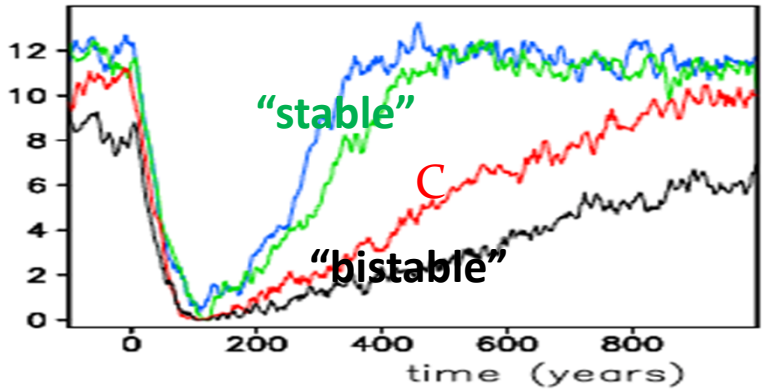


Salinity transport positive feedback

Rahmstorf, 1996

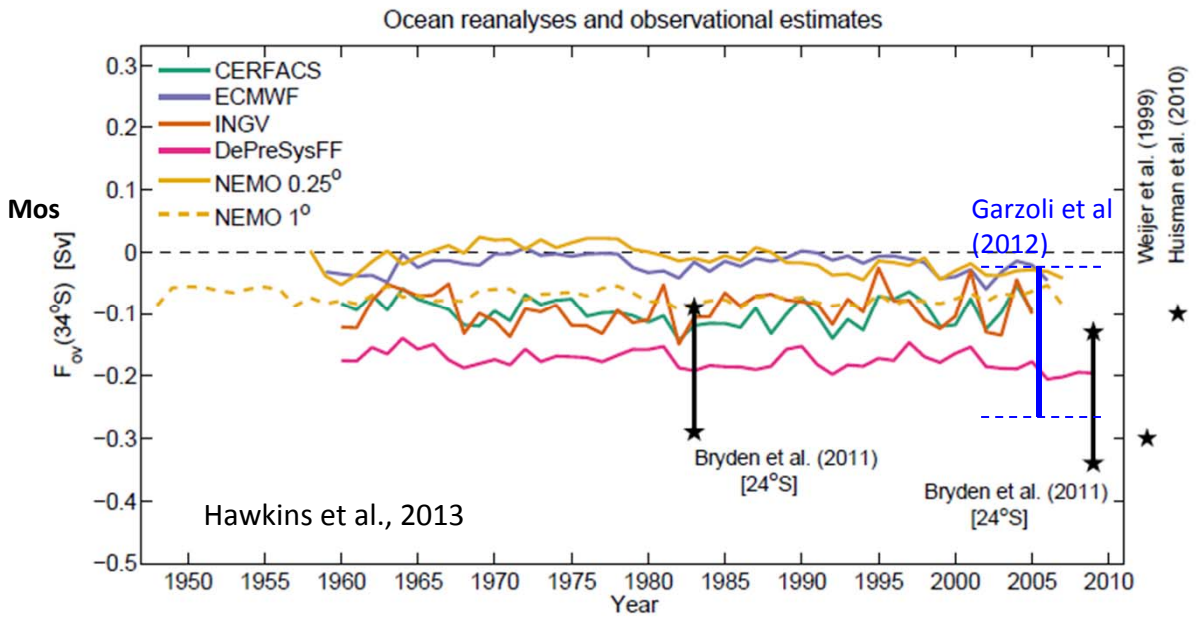
Meltwater in NA ↑ → S ↓ → AMOC ↓ → Freshwater export M_{ov} ↓

Does Mov works? (Sort of…. But……)



De Vires and Weber , 2005

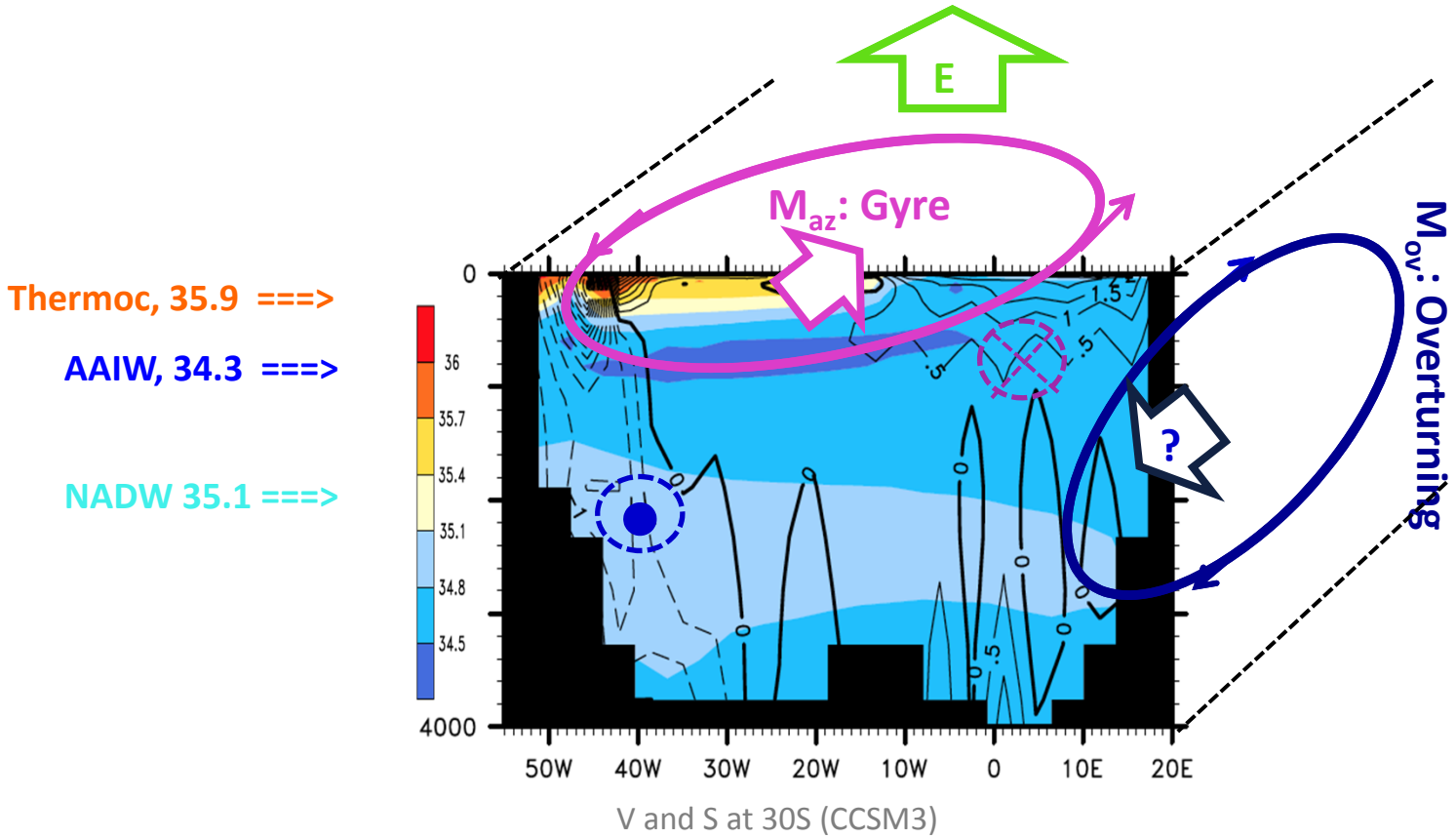
M_{ov} for Real World: "Bistable"



Publication	MovS (Sv)	Data
Bryden et al., 2010	-0.09- -0.34	24oS, 1983 (16 Sv), 2009 (21 Sv) two hydrographic sections
Garzoli et al., 2012	-0.05- -0.28	35S, XBT, CDT, ARGO, 2002-2011 (14-27Sv, 0.5 PW)
Hawkins et al., 2013	-0.0- -0.20	Ocean reanalysis

Atlantic Freshwater Budget

$$E\text{-}P \approx M_{az} + M_{ov}$$



V and S at 30S (CCSM3)

<u>Freshwater Transport</u>: (24°S transections, 1983, 2009)

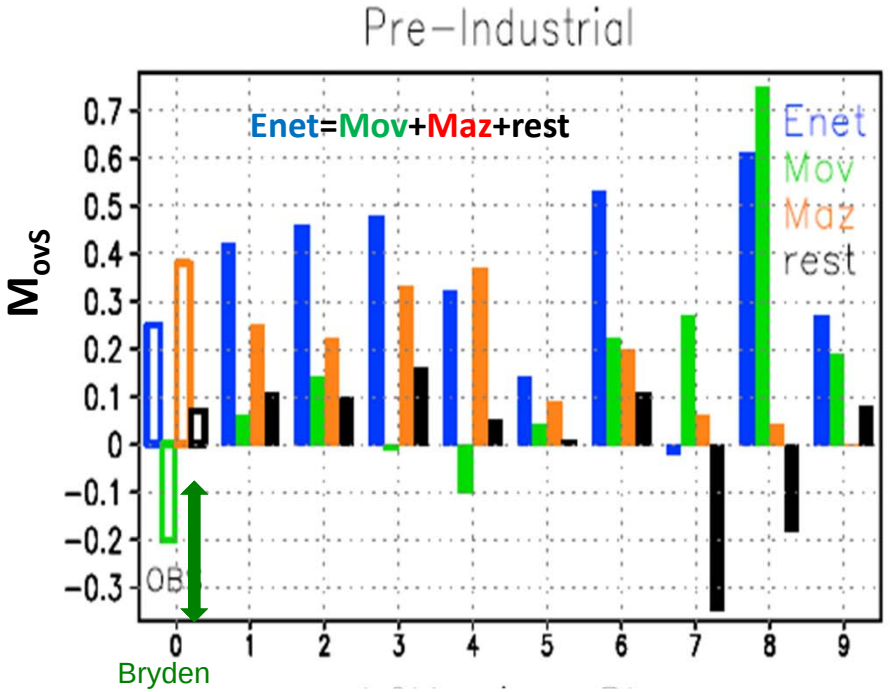
Total: 0.04 -- 0.17 Sv. > 0 (NA weakly evaporative)

M_{ov}: -0.09 -- -0.34 Sv. < 0 (AMOC bistable)

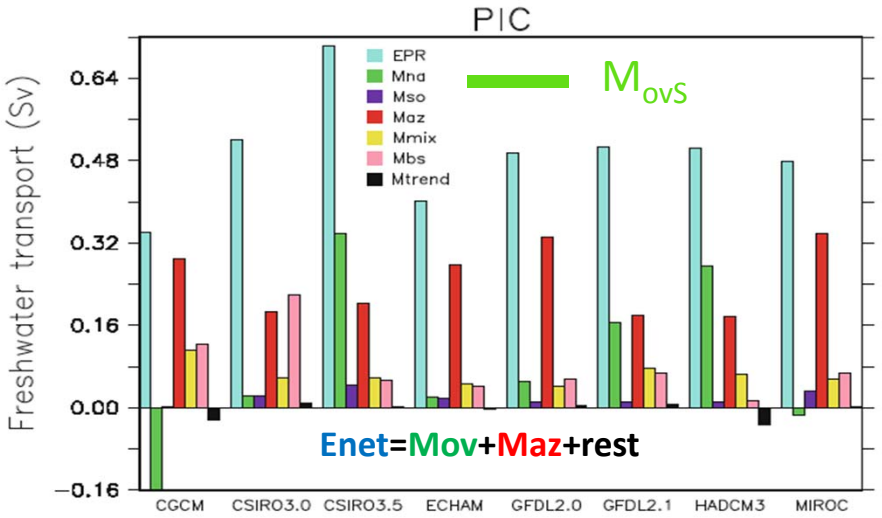
Bryden et al., 2011, JMR

M_{ov} in CGCMs: "Monstable"

PMIP/CMIP3 model freshwater budget



Weber et al., 2007



Drijfhout et al., 2011

Questions?

1. Does the indicator really work? in a complex CGCM? (real world....)?

Yes! ....after a modification

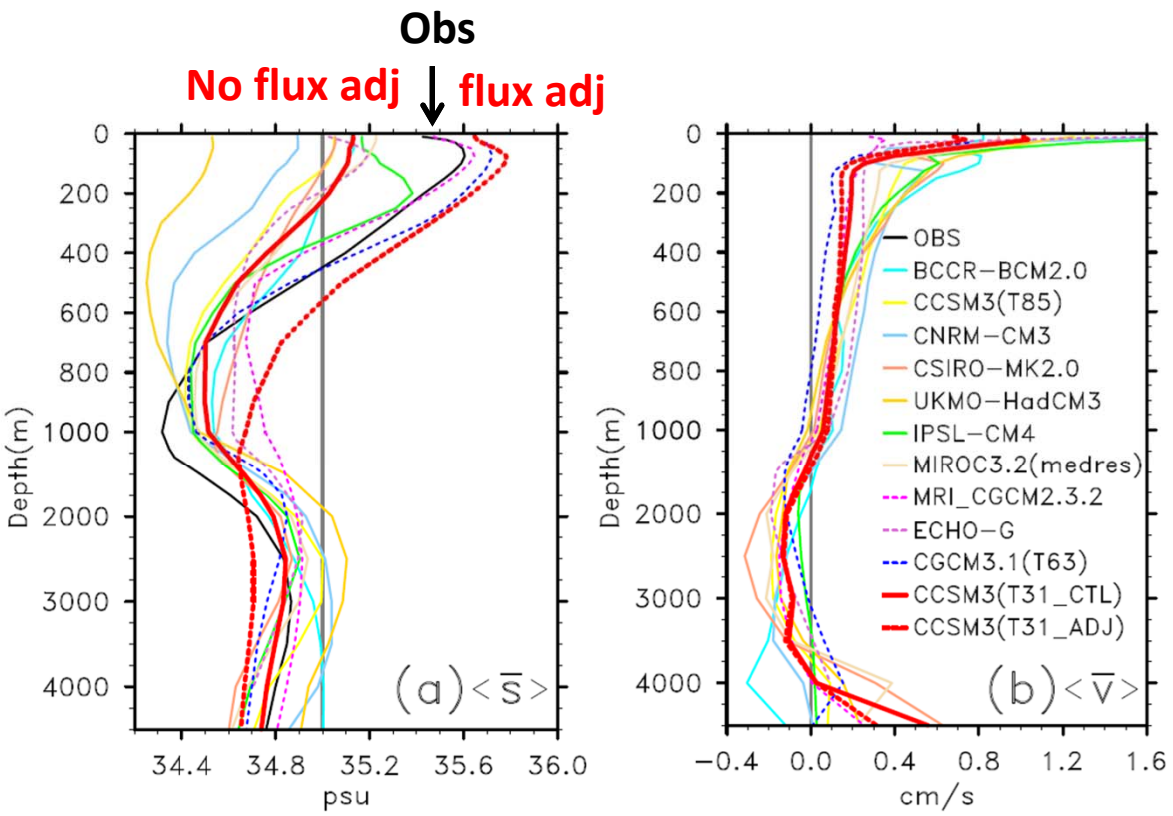
Liu W. and Liu Z., 2012, Liu W. et al. 2013.....JC

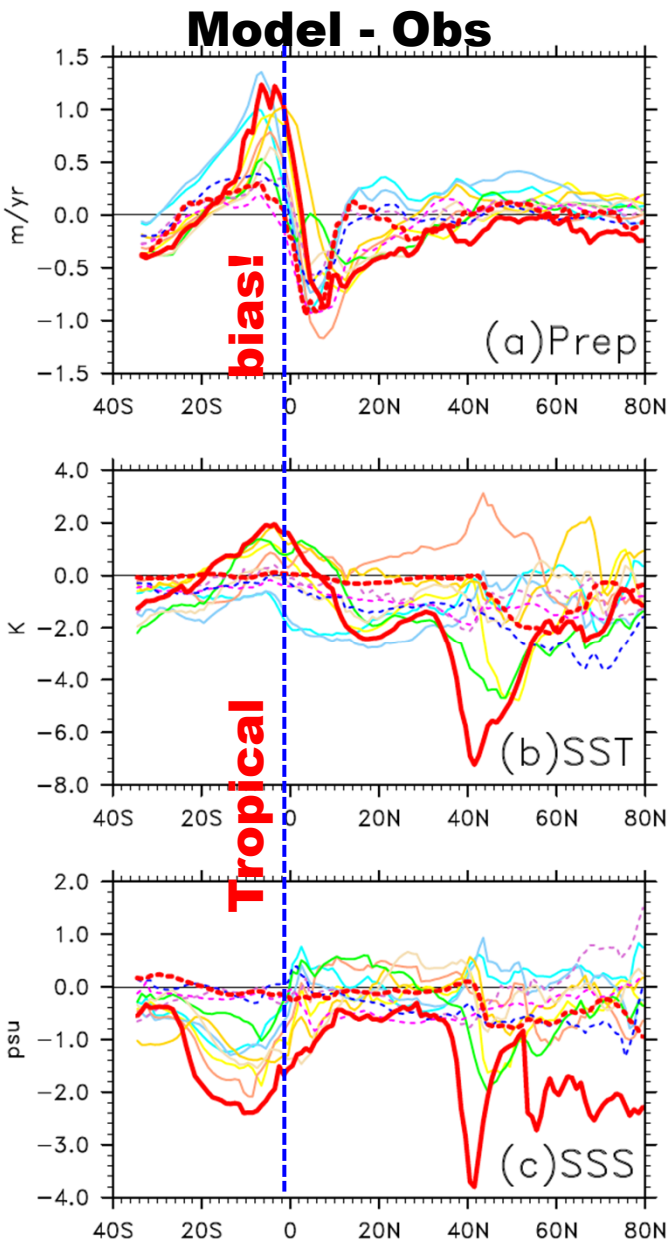
2. What caused the bias in freshwater transport, and, in turn, implied AMOC over-stabilization, in CGCMs?

Tropical bias! ....partly

Liu W., Z. Liu & E. Brady, 2014: Why is the AMOC Monostable in CGCMs. J. Climate, 27, 2427-2443

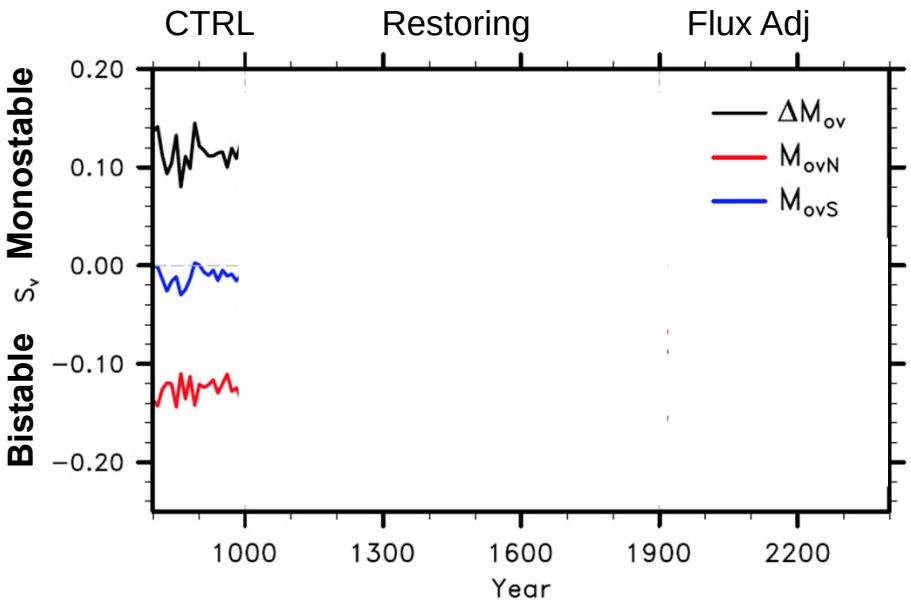
Bias: Freshwater Transport, and Tropical Climate (in AR4 CGCMs)



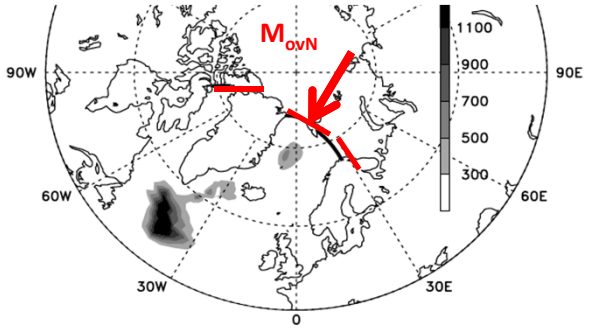


Liu et al., ,2014

Testing Climate Bias and Convergence Indicator ΔM_{ov} (in CCSM3)

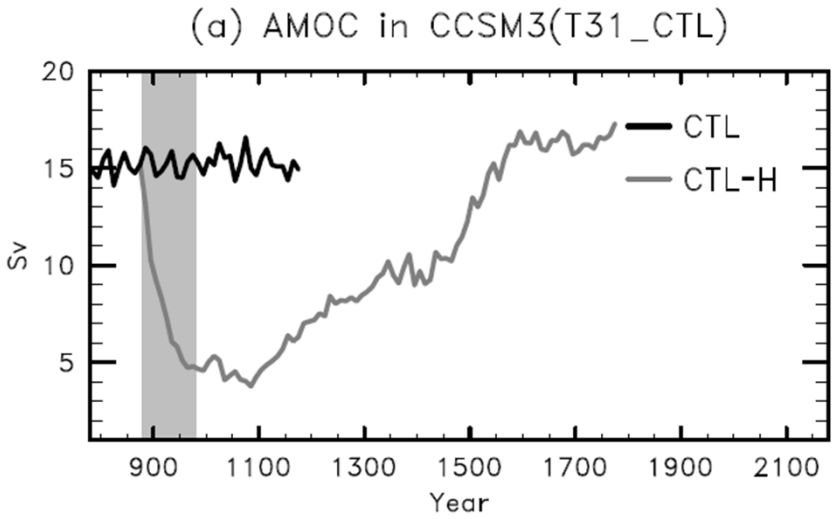


Conv. Indicator $\Delta M_{ov} = M_{ovS} - M_{ovN}$

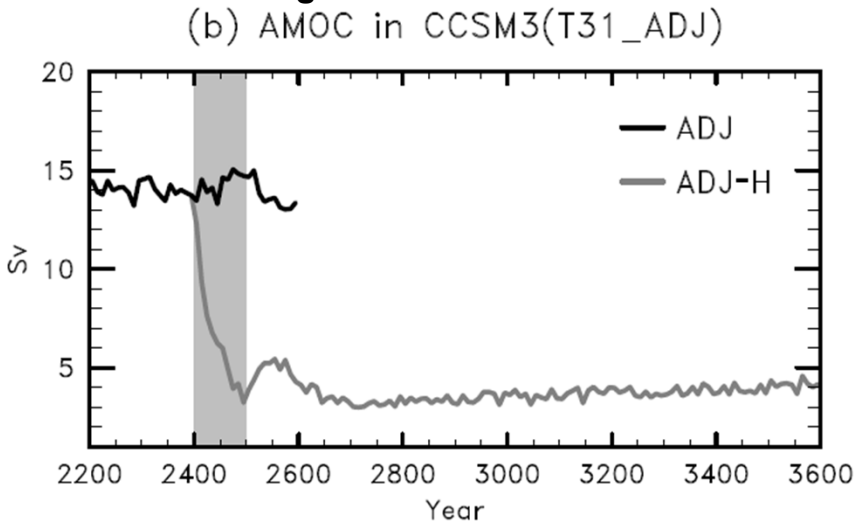


Liu and Liu, 2012

CTRL hosing



ADJ hosing

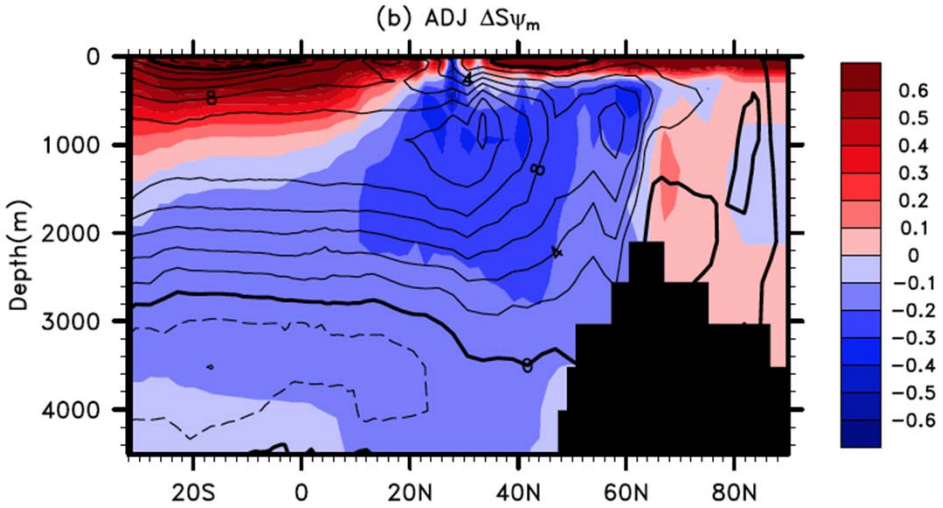


Liu et al., 2014

Attribution of climate bias on MovS

Surface Bias **Ψmean, ΔS**

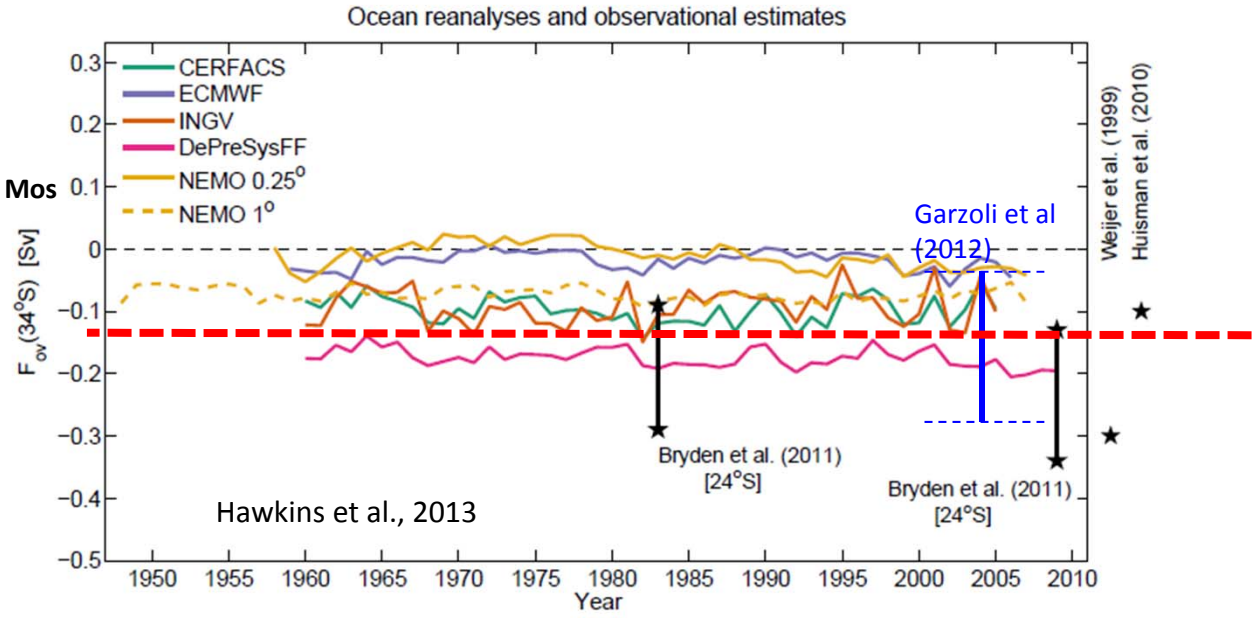
ADJ-CTL



But, tropical bias is not the whole story….
Tropical adjustment, ….

Liu W. et al., 2014

ΔM_{ov} for Real World: Weakly Bistable



Mn
Serreze et al., 2006

Publication	MovS (Sv)	MovN (Sv) Serreze et al., 2006 (total transport)	ΔMov (Sv) Weakly bistable	Data
Bryden et al., 2010	-0.09 -- -0.34	-0.16	+0.07 -- -0.18	24oS, 1983 (16 Sv), 2009 (21 Sv) two hydrographic sections
Garzoli et al., 2012	-0.05-- -0.28	-0.16	+0.11 -- -0.12	35S, XBT, CDT, ARGO, 2002-2011 (14-27Sv, 0.5 PW)
Hawkins et al., 2013	-0.0-- -0.20	-0.16	+0.16 -- -0.04	Ocean reanalysis

AR4 CGCM Climate Bias and AMOC Stability: Monostable

Stability Indicator

	M_{ovS}	M_{ovN}	ΔM_{ov}
Observation	-0.3 – -0.1	-0.16	**-0.14 – +0.06**
No Flux Adjustment			
BCCR-BCM2.0 (Norway)	0.023	-0.127	**0.150**
CCSM3(T85) (USA)	0.078	-0.185	**0.263**
CNRM-CM3 (France)	0.290	-0.097	**0.387**
CSIRO-MK2.0 (Australia)	-0.030	-0.465	**0.435**
UKMO-HadCM3 (UK)	0.359	-0.013	**0.372**
IPSL-CM4 (France)	-0.008	-0.128	**0.120**
MIRCO3.2(medres) (Japan)	-0.004	-0.110	**0.106**
CCSM3(T31) (USA)	-0.013	-0.127	**0.114**
Ensemble Mean	0.1	-0.16	**0.26**
Flux Adjustment			
CGCM3.1(T63) (Canada)	-0.118	-0.082	**-0.036**
MRI-CGCM2.3.2 (Japan)	-0.080	-0.160	0.080
ECHO-G (Germany-Korea)	0.046	-0.009	0.055
CCSM3(T31_ADJ) (USA)	-0.197	-0.095	**-0.102**
Ensemble Mean	-0.1	-0.086	**-0.01**

No Flux Adj: mono-stable; Flux Adj: bi-stable!

Liu . et al., 2014

Summary

ΔM_{ov} seems to work!

- **Real World AMOC is likely weakly bi-stable**
- **Most CGCMs are mono-stable, because of, partly, the tropical bias in the Atlantic.**

Uncertainty
Indicator…
Data…

Implications
Future projection: Biased CGCMs are underestimating abrupt climate change in the future! (?)

Obs Network: Freshwater transports (associated with AMOC) in both the southern and northern boundaries are important!