Monitoring/sustained observation of the Atlantic MOC: a climate modelling perspective

Richard Wood, Michael Vellinga, Peili Wu

Hadley Centre, Met Office, Exeter, UK

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Why monitor the MOC?

- Detect changes – link to climate on interannual, decadal, centennial timescales
- Attribute changes – understand (?) what's happening
- Initialise interannual-decadal forecasts (including early warning of major MOC change)
- Provide focused tests to sort out reliable and unreliable model predictions

Note 1: Assume MOC variations are important for climate

Note 2: Only the first of these requires a MOC-ometer

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Monitoring the MOC at 26°N

Joint NERC RAPID / NSF project

Continuous monitoring of MOC 2004-2008

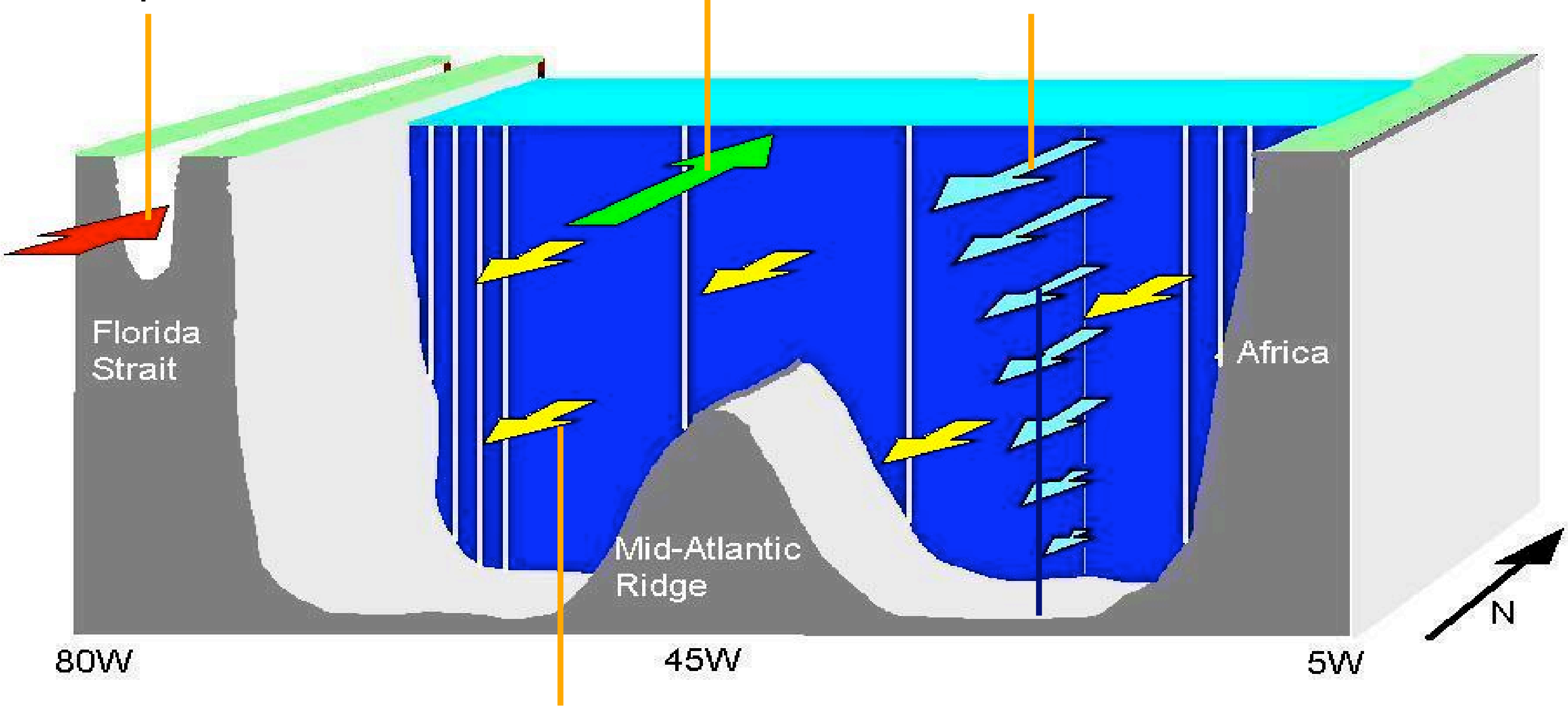
Deployed Feb/Mar 04

(Hirschi et al. *GRL* 2003)

Florida Strait transport

Ekman

Thermal wind



Spatially constant correction for the velocity field to ensure mass balance

Designing a cost-efficient, sustained MOC observing system

- At some point we may wish to establish a long-term, sustained MOC observing system
- Want to know that limited money is being spent on the 'right' observations
- If the results are going to be used to input to decisions on mitigation of anthropogenic climate change, we need them soon!

(Vellinga & Wood, GRL 2001)

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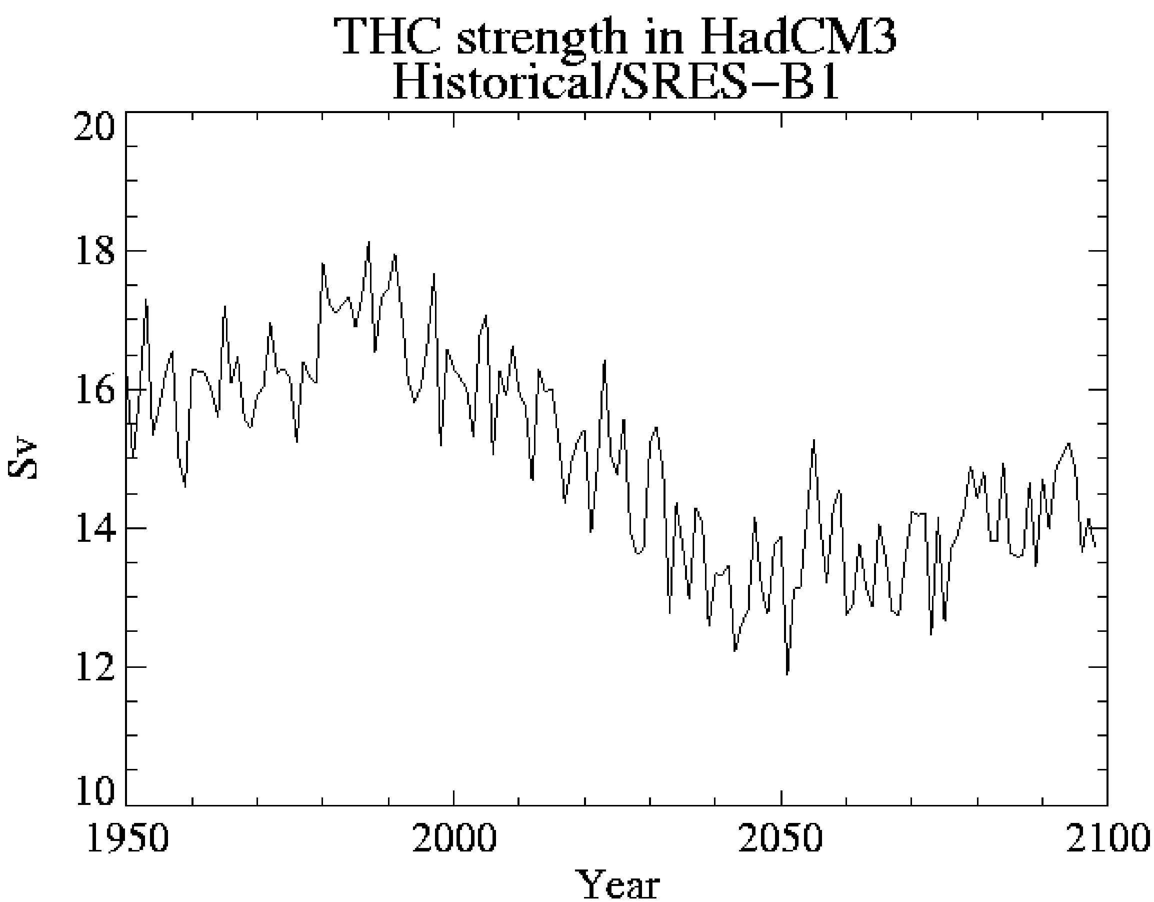
Simulated MOC at 26°N



What's the chance of detecting a trend with 10 years of observations? With 40 years?

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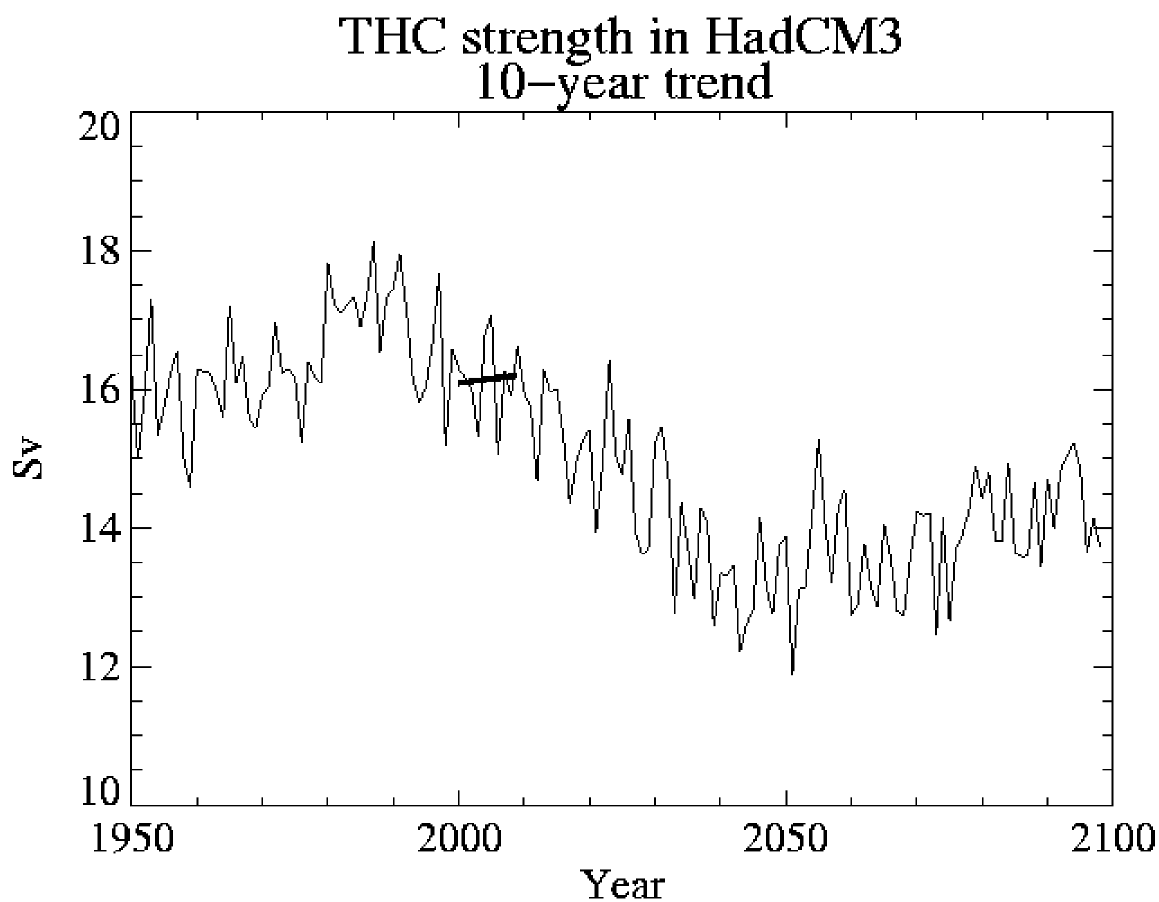
Simulated MOC at 26°N



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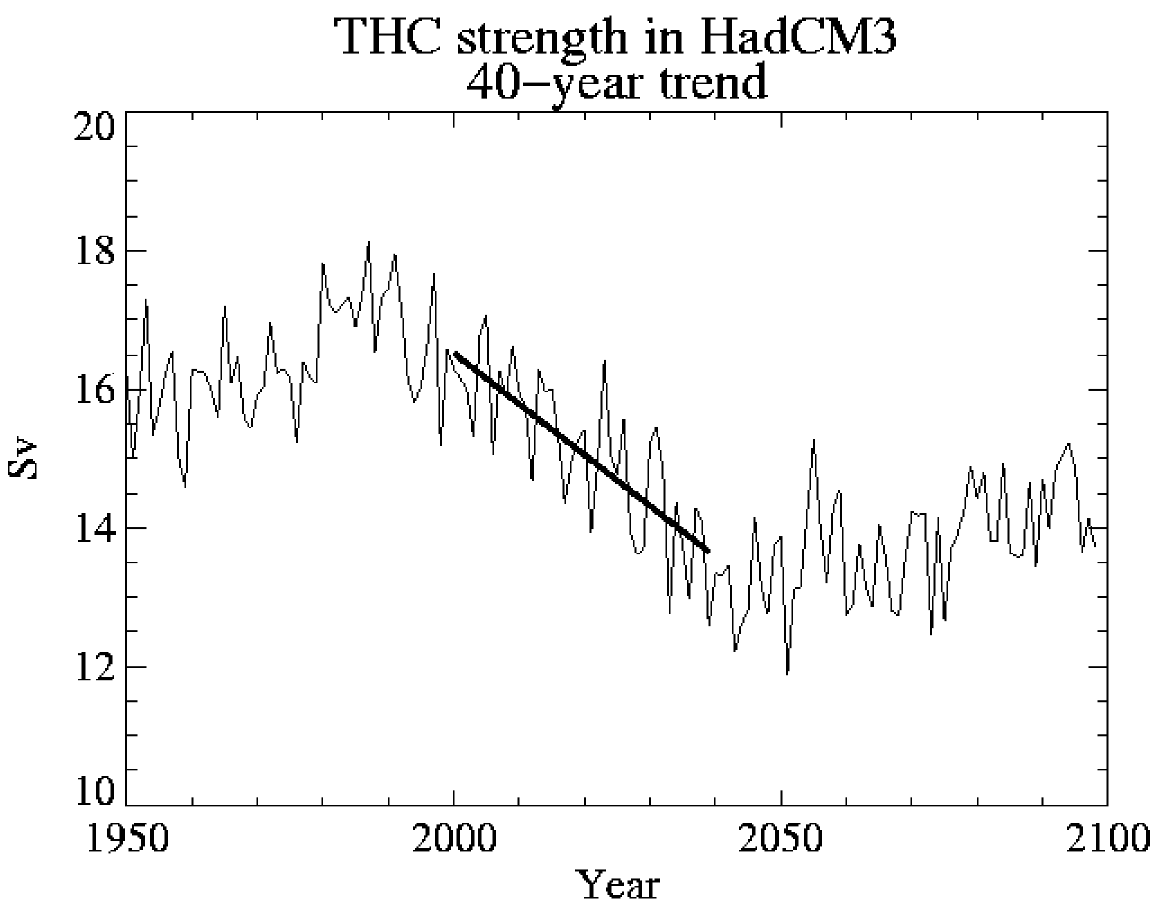
Simulated MOC at 26°N



Can we add supplementary observations to improve signal to noise and hence give earlier detection?

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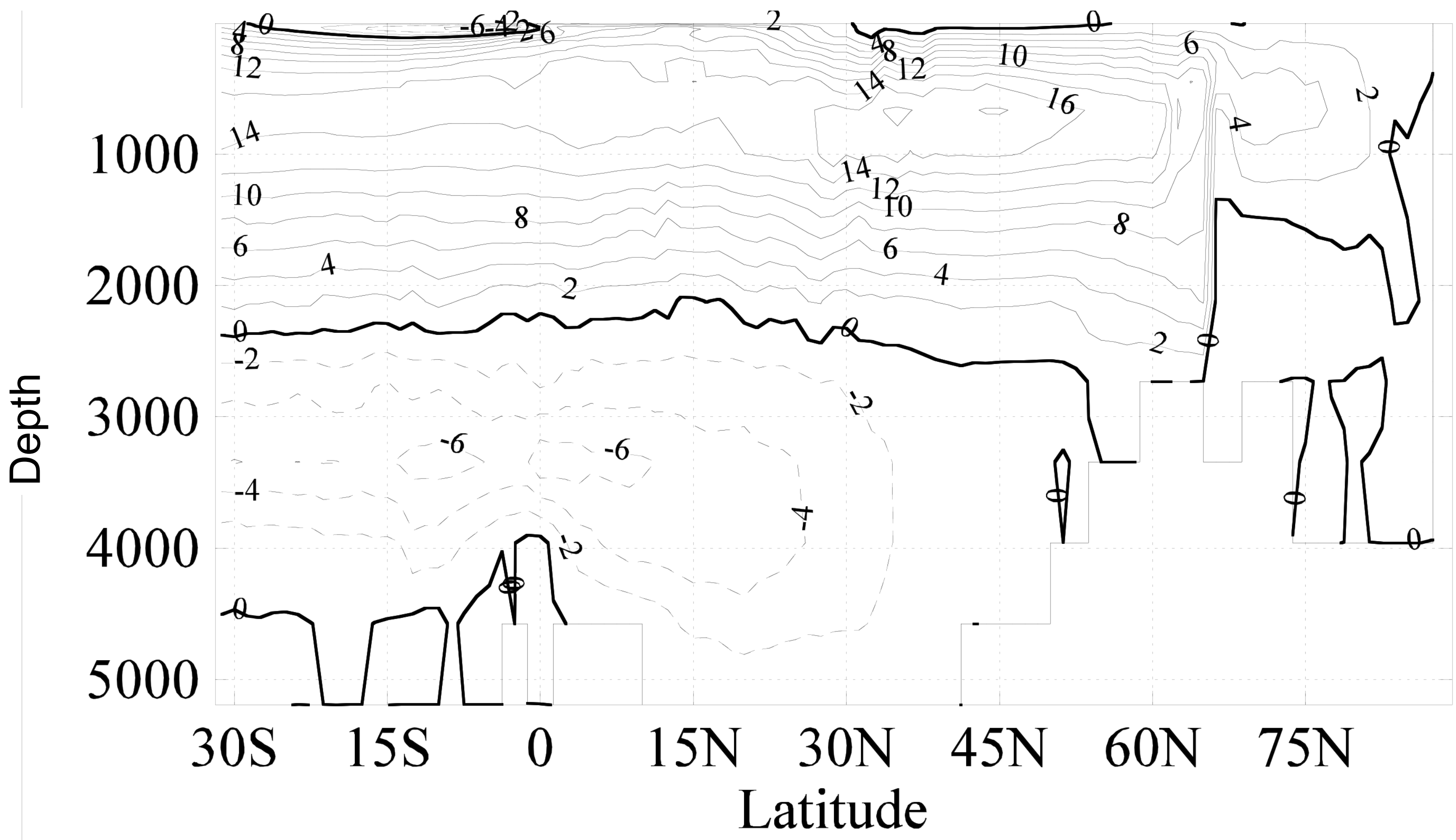
HadCM3 meridional overturning circulation



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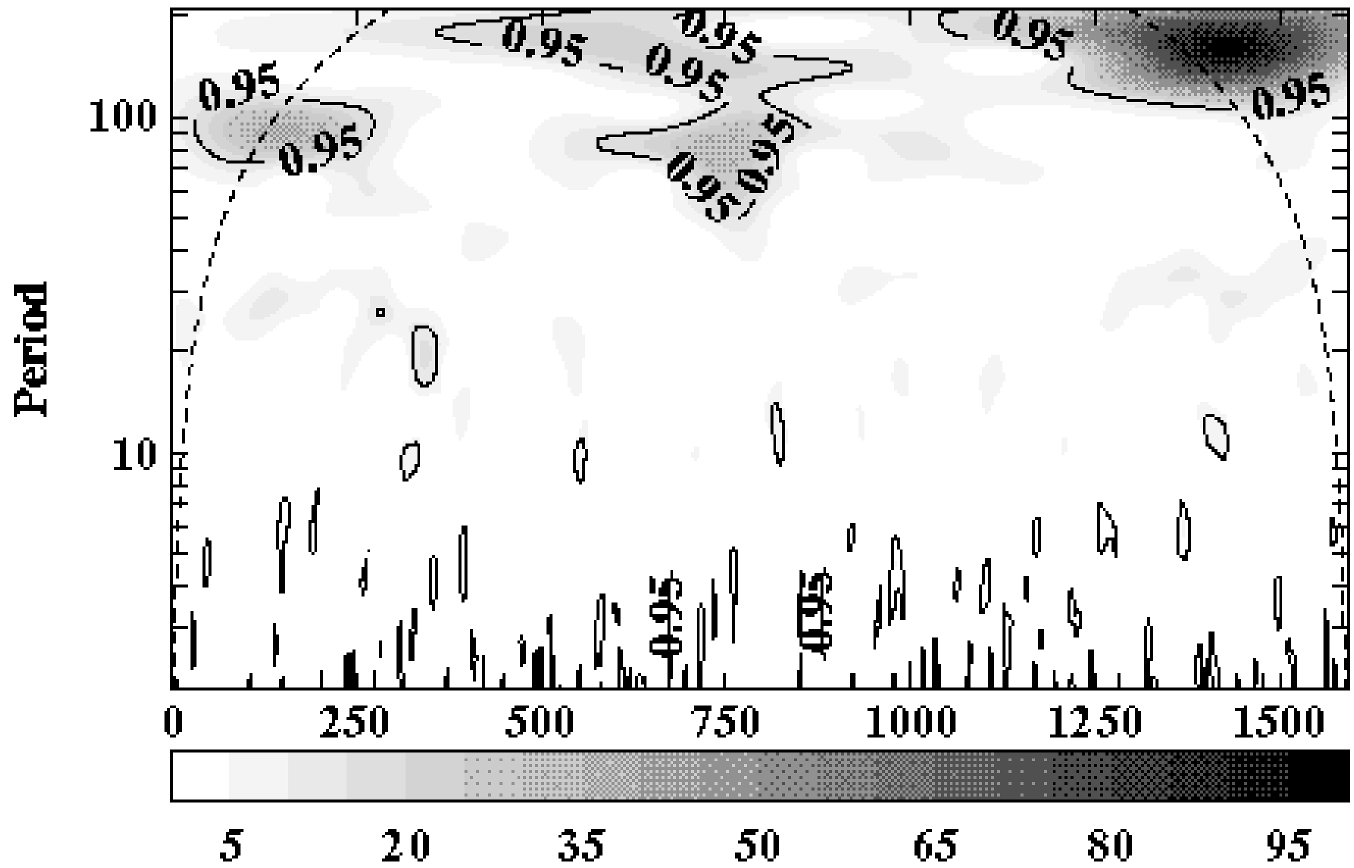
Modes of MOC variability in HadCM3



Tropical-extratropical

Subpolar gyre

NAO

ENSO

(Vellinga and Wu, *J. Climate* 2004)

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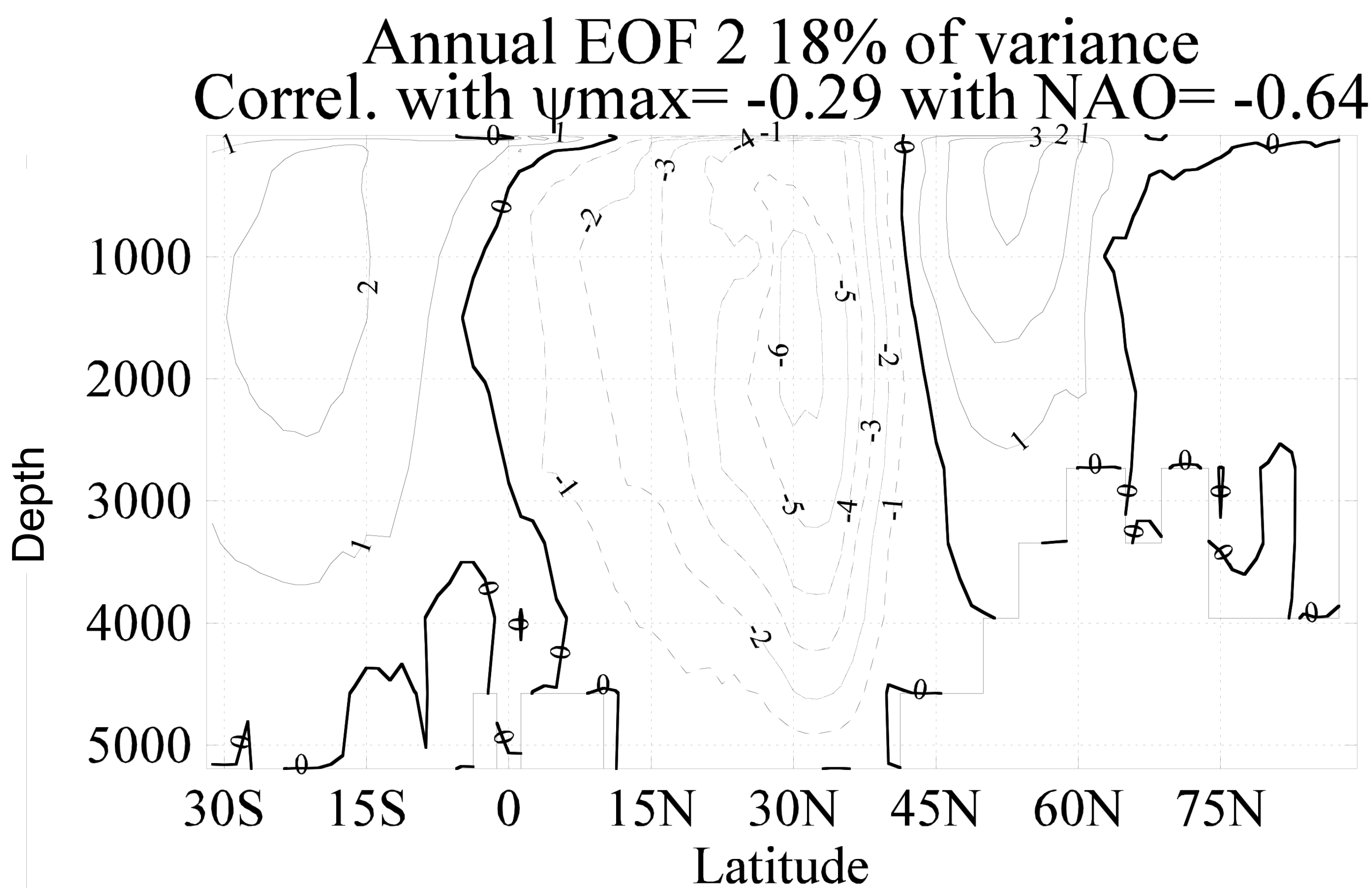
EOF2 of overturning stream function



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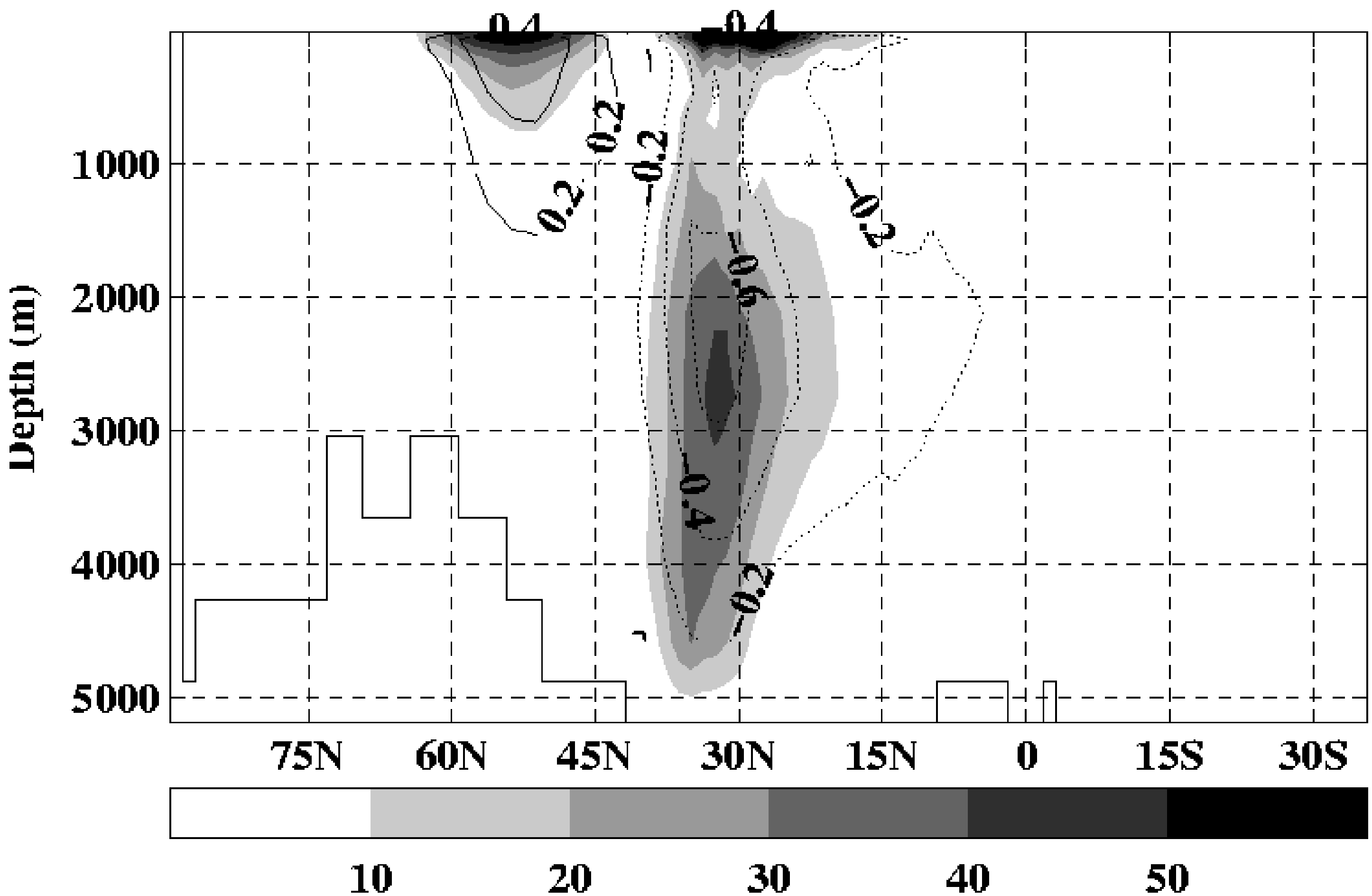
MOC response to surface winds at 30°N

Annual data



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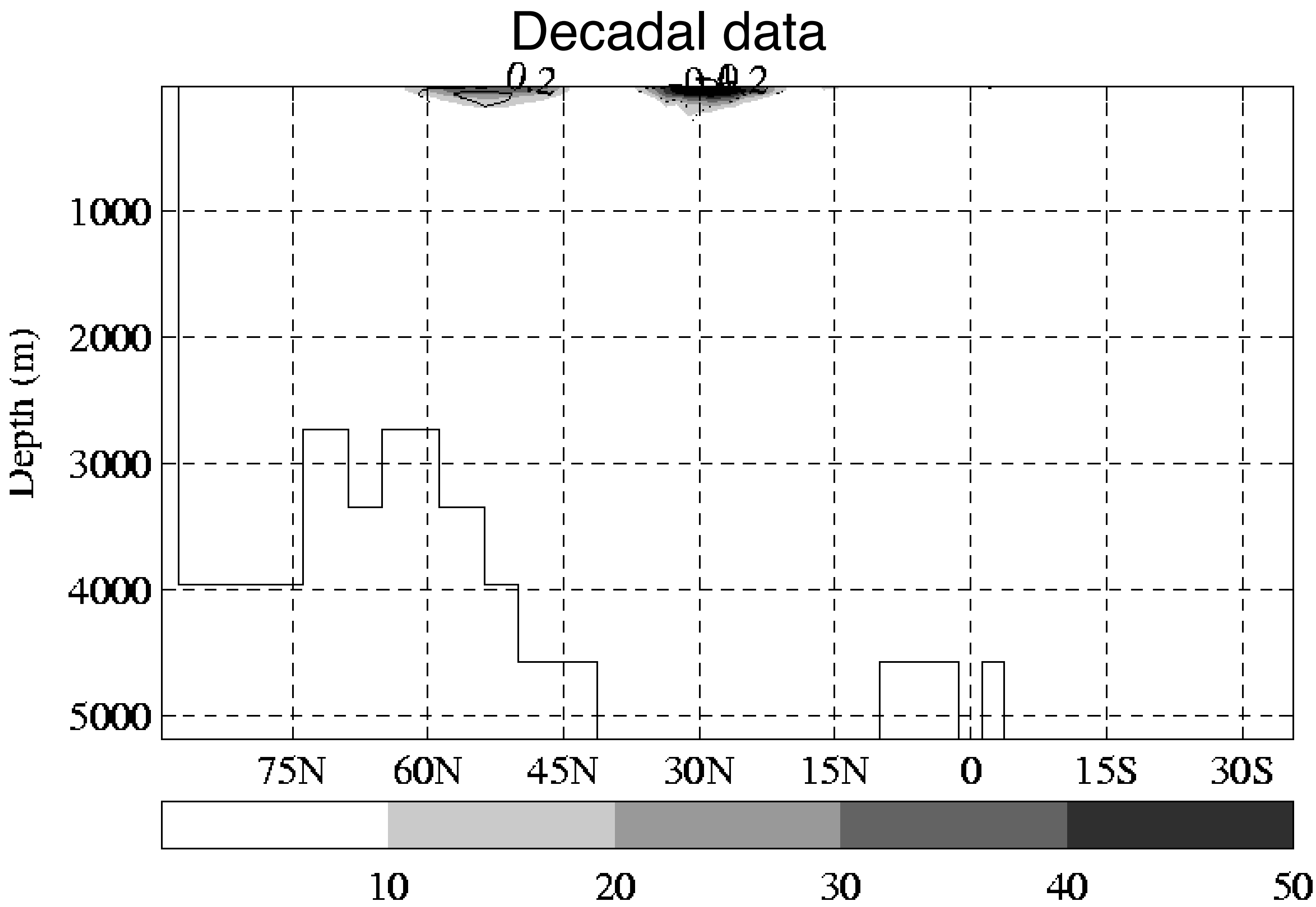
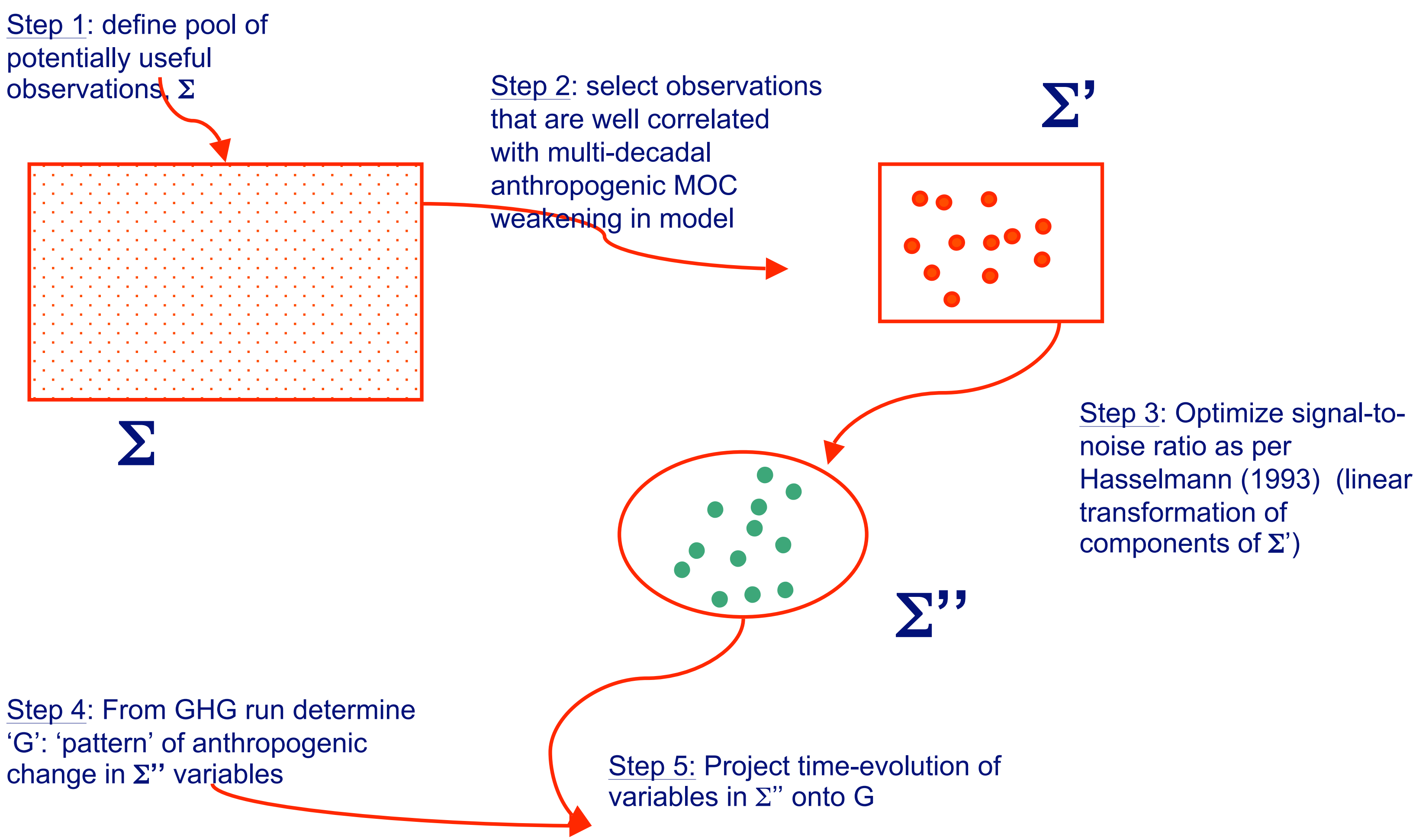
Response to surface winds at 30°N



Approach



$$\langle \underline{X}(t) \square \underline{G} \rangle \equiv d(t)$$

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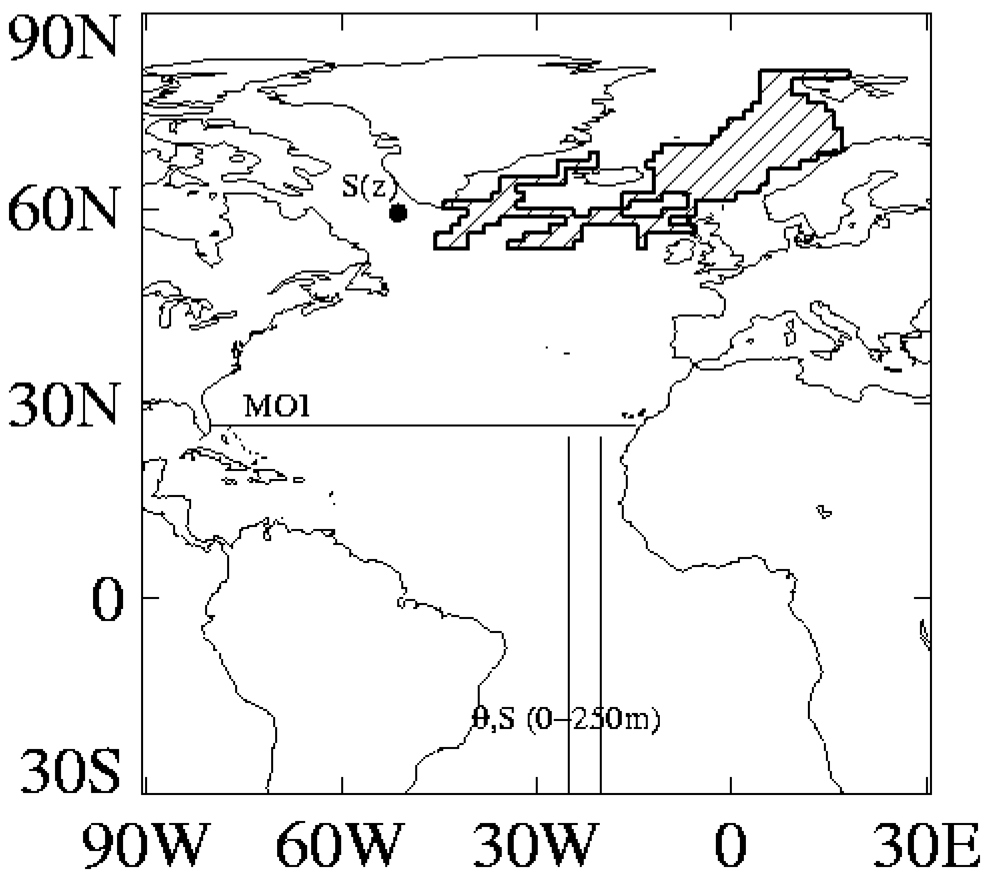
Observing additional variables…



Most useful observations Σ'

	Description	Correl. With MOI in ANT	CON
1	Maximum overturning at 26N		
2	Potential temperature ('θ') at potential density ('σ_θ')=28 in Norwegian Sea	0.94	0.46
3	Salinity ('*S*') at Faroe-Shetland overflow	-0.91	-0.44
4	*S* at σ_θ=27.9 in Norwegian Sea	0.92	0.61
5	θ at σ_θ=28.0 in Greenland-Norwegian Sea	0.93	0.43
6	Vertical *S* profile in Labrador Sea	-0.80	-0.44
7	*S* at Iceland-Faroe overflow	-0.91	-0.49
8	*S* in Denmark Strait overflow	-0.83	-0.25
9	*S* at σ_θ=27.9 in Greenland-Norwegian Sea	0.90	0.58
10	*S* at σ_θ=28 in Greenland-Norwegian Sea	0.92	0.51
11	*S* along east-west section in subpolar gyre	-0.92	-0.59
12	θ at layer σ_θ=26-26.5 (25ºW, 30ºS-30ºN)	-0.90	0.03
13	θ between 0-250*m* (20ºW, 30ºS-30ºN)	-0.92	0.03
14	θ at σ_θ=27.9 in Norwegian Sea	0.92	0.56
15	θ between 0-250*m* (25ºW, 30ºS-30ºN)	-0.91	0.07
16	*S* at layer σ_θ=26-26.5 (25ºW, 30ºS-30ºN)	-0.89	0.04

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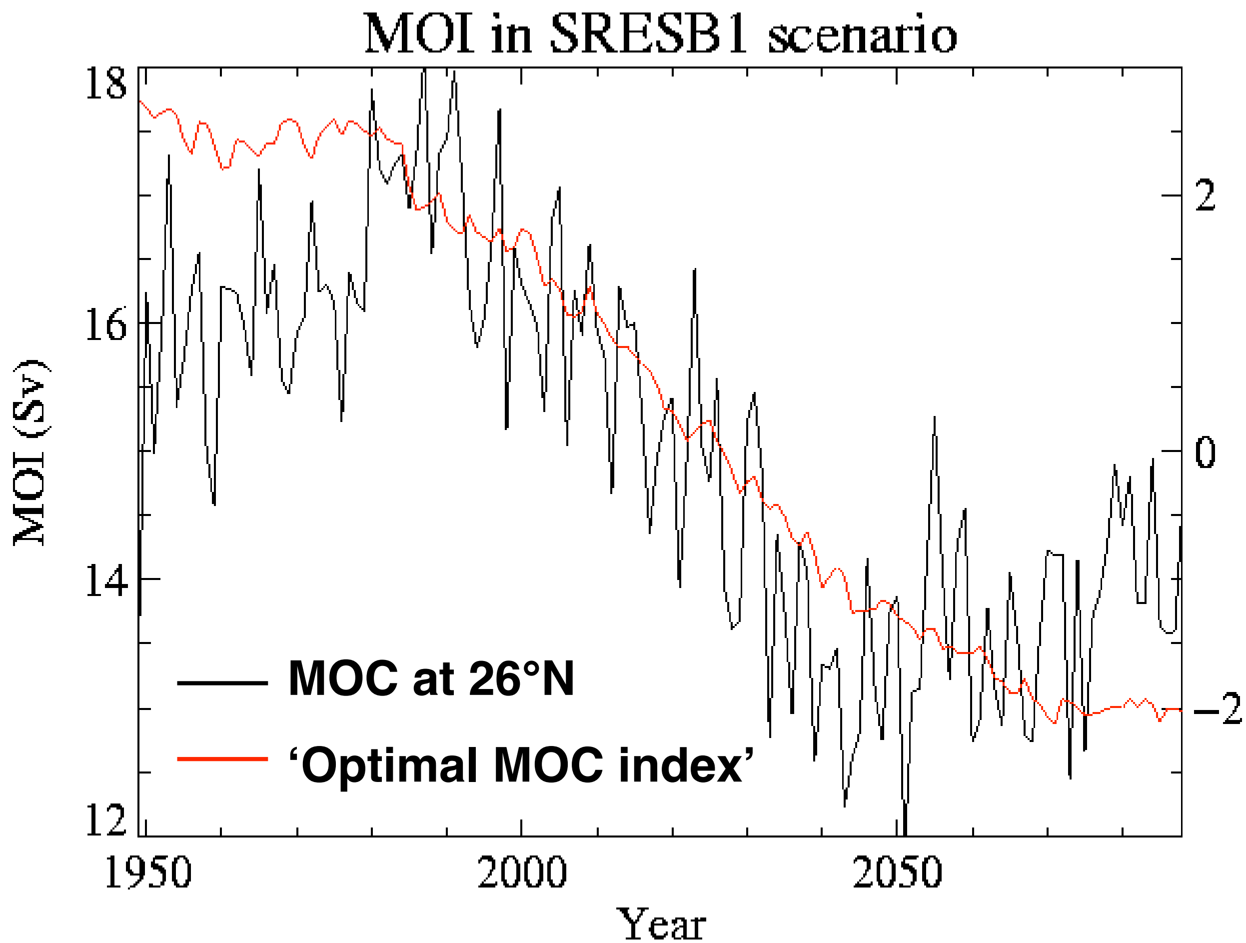
Detector variable has improved S/N



(…and maybe gives you a little attribution)

(Vellinga & Wood GRL 2004)

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Optimal MOC detection system - summary

- A system can be designed (from a prior set of possible observations) to give improved signal to noise and hence improve chances of early detection of anthropogenic MOC change
- Caveat: system is tested on the model it was trained on. Need to:
  - Train on one model/scenario and test on others
  - Understand physical reasons for selection of observables
- Look at redundancy in system

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Attribution of changes: a digression

Optimal MOC detection system appears to give some attribution also

'Detection and attribution' of observed climate 'changes' traditionally tests a null hypothesis: observed changes are due to internal variability of the climate system

Important for policy, but just because null hypothesis isn't rejected doesn't mean it's true. And null hypothesis relies on knowing the unknown internal variability!

What we really want to know is the most likely explanation for what's been observed

Better: use models for hypothesis *generation* – i.e. to produce physically consistent stories about the (undersampled) observations (which could then be tested against further observations) [e.g. palaeo]

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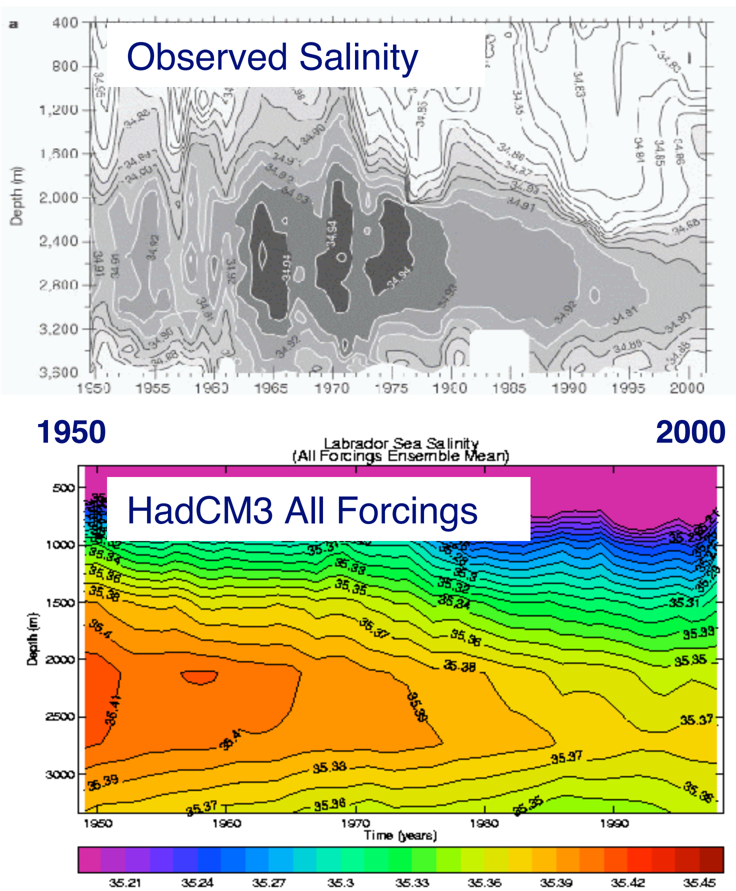
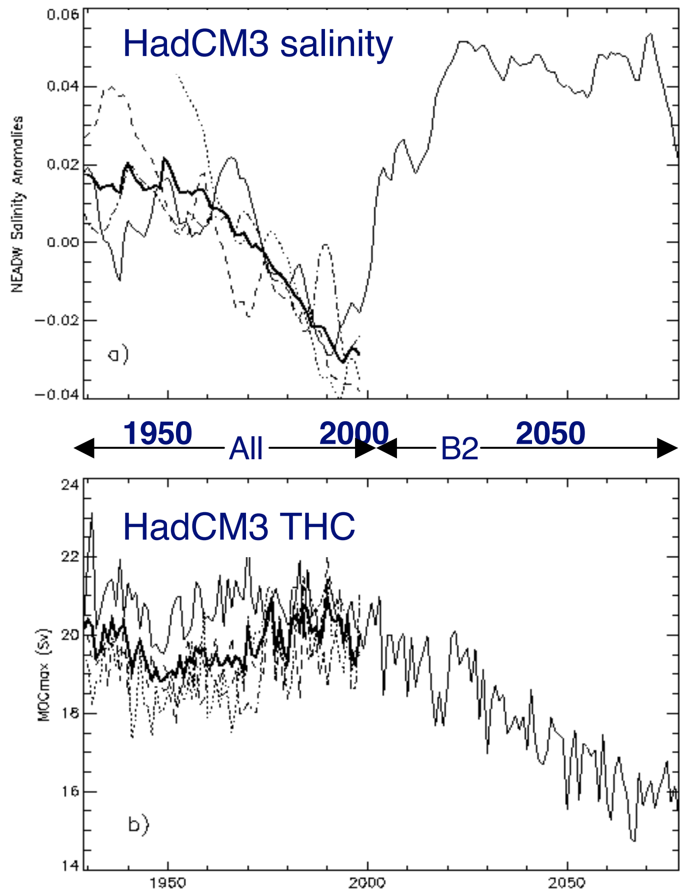
Example: Deep NW Atlantic freshening

Hypothesis (N.B. not by Dickson et al or by Wu et al.!!): Atlantic has been freshening – so maybe the MOC has been weakening.

Use of a model to generate a more plausible hypothesis:





(Dickson et al. *Nature* 2002, Wu et al. *GRL* 2004)

What about the attribution question?

Wu et al. 2005

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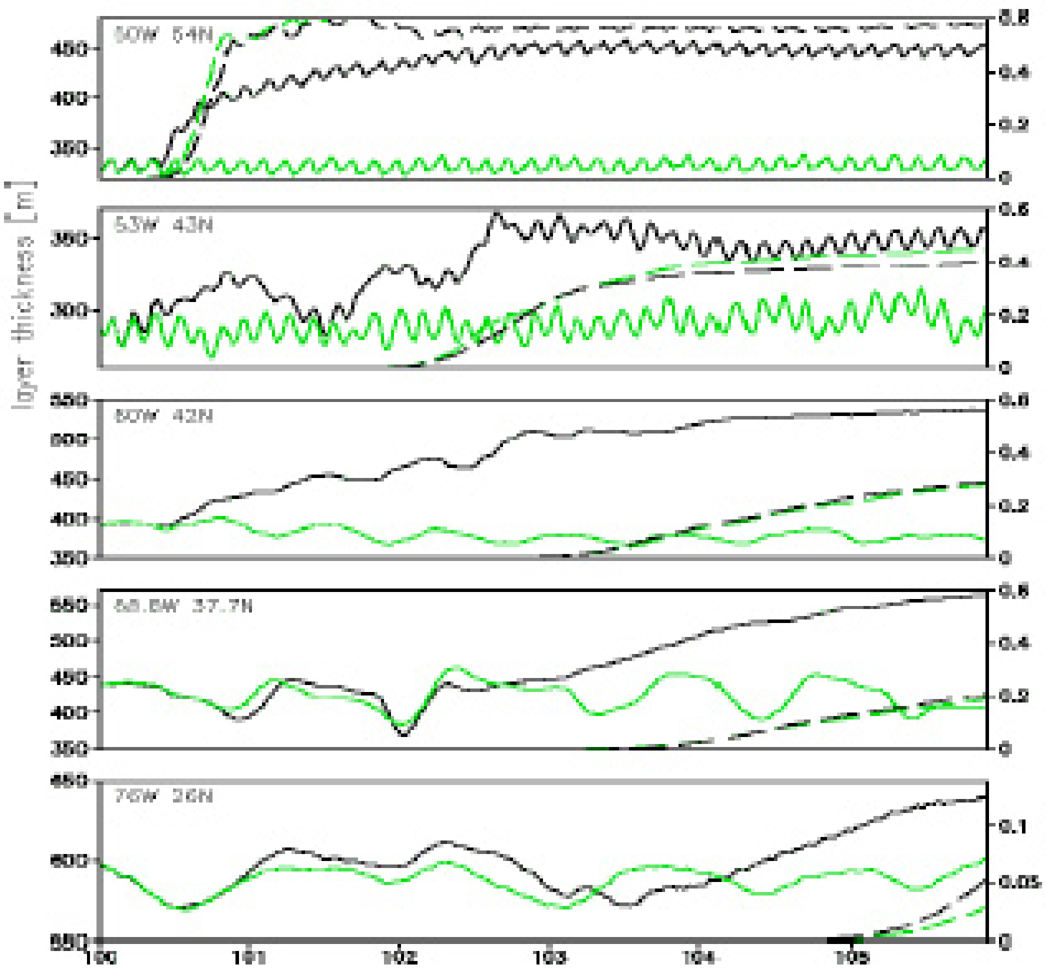
Response of DWBC to high-latitude buoyancy forcing



54N (Labrador Sea)

43N (Grand Banks)

42N

38N

26N

Solid: layer thickness

Dashed: tracer

(Hughes et al. RAPID project)

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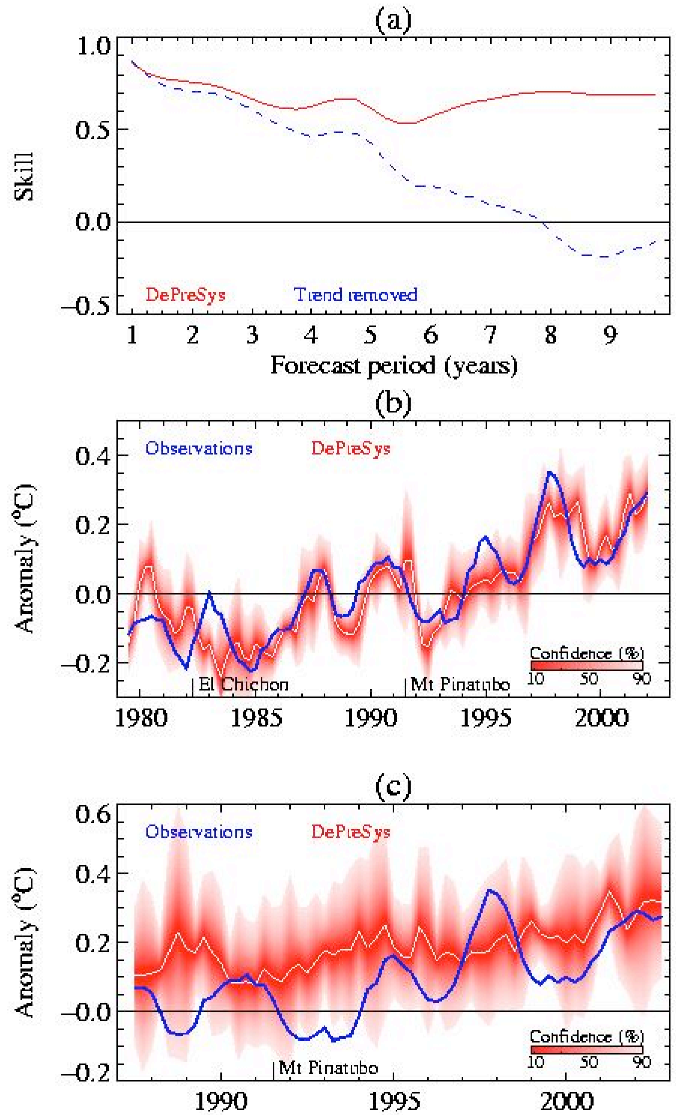
Prototype decadal prediction system



Skill (global mean temperature)

1-year forecast

10-year forecast

Most skill at longer lead times comes from forcing (not initial conditions)

Both the observations and the method of assimilation are almost certainly non-optimal

(Courtesy Doug Smith et al., Hadley Centre)

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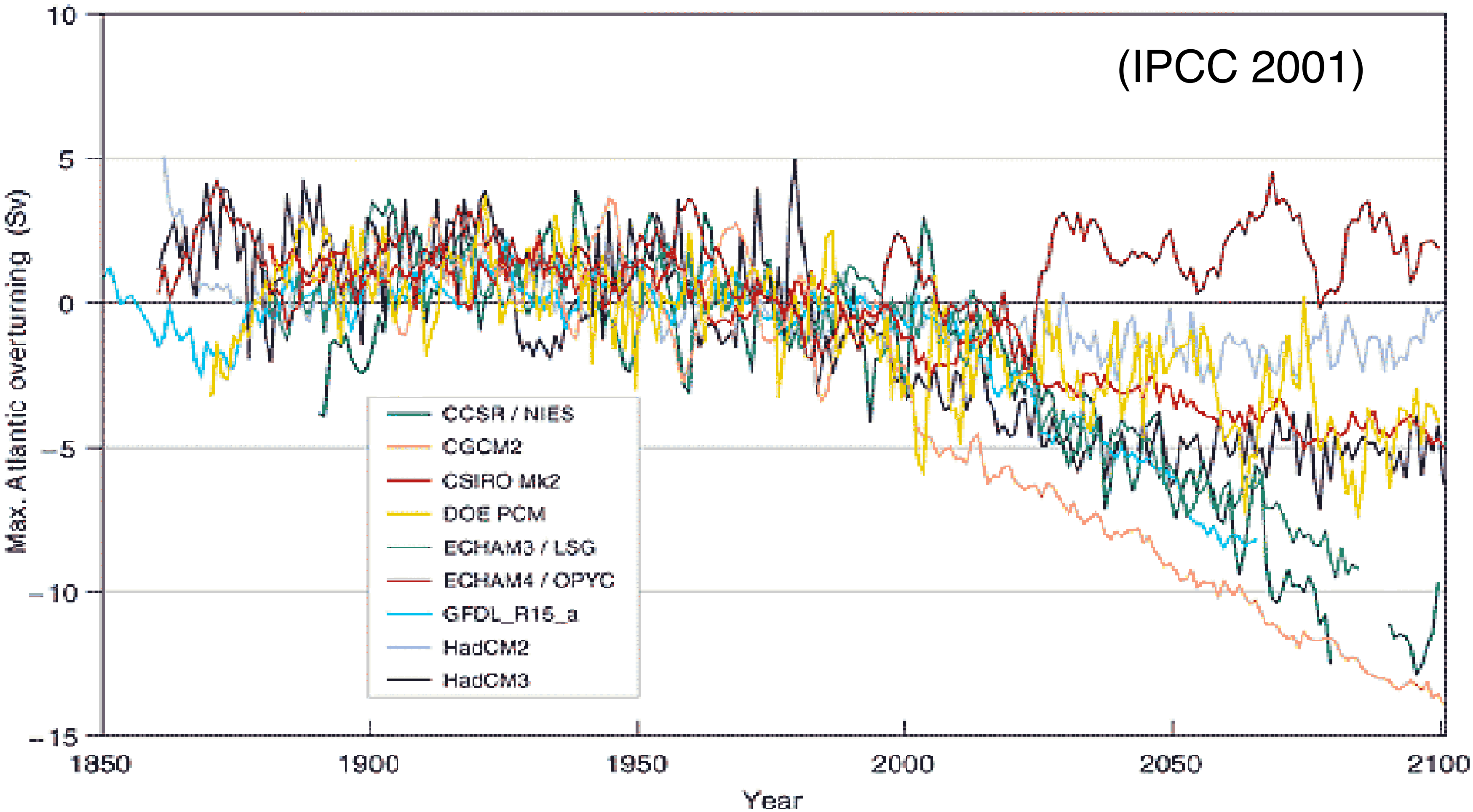
Why do all the models have different THC response?



Various model MOC responses to IS92a

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Some bad reasons to compare models and observations

(a) 'To see if the model is right' ('~~validation~~')
(b) 'To prove the model is wrong' ("~~These models~~…")

Choose some arbitrary set of observations and compare with some model runs. Then either ignore the differences (and get on with using the model to predict a THC shutdown, which is what we were always going to do anyway) or complain about them (and never predict anything).

All models are imperfect sketches of the real world. We already know this. So what?

And yet we all continue to do this, because we have no idea how to do better.

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A better reason to compare models and observations

(c) To weight model predictions, especially when there is a large ensemble of models to choose from

More sophisticated version of (a) and (b). Note both weighting method and choice of observations to compare are still arbitrary. [e.g. is good simulation of NPDW a necessary condition to simulate MOC evolution in 21st Century?]

Overall, we are currently almost totally ignorant about how to use observations to determine uncertainty in climate predictions. But the community is starting to think about this.

2 ways to make them less arbitrary:

(i) Deploy physical understanding, e.g. ‘good’ simulation of present sea ice distribution is probably important for simulating high latitude temperature change because of albedo feedback. Can we quantify the relationship between the error in the observational test and the error in the prediction?

(ii) Use ‘perfect model’ approach to build statistical model of error propagation (needs large ensemble).

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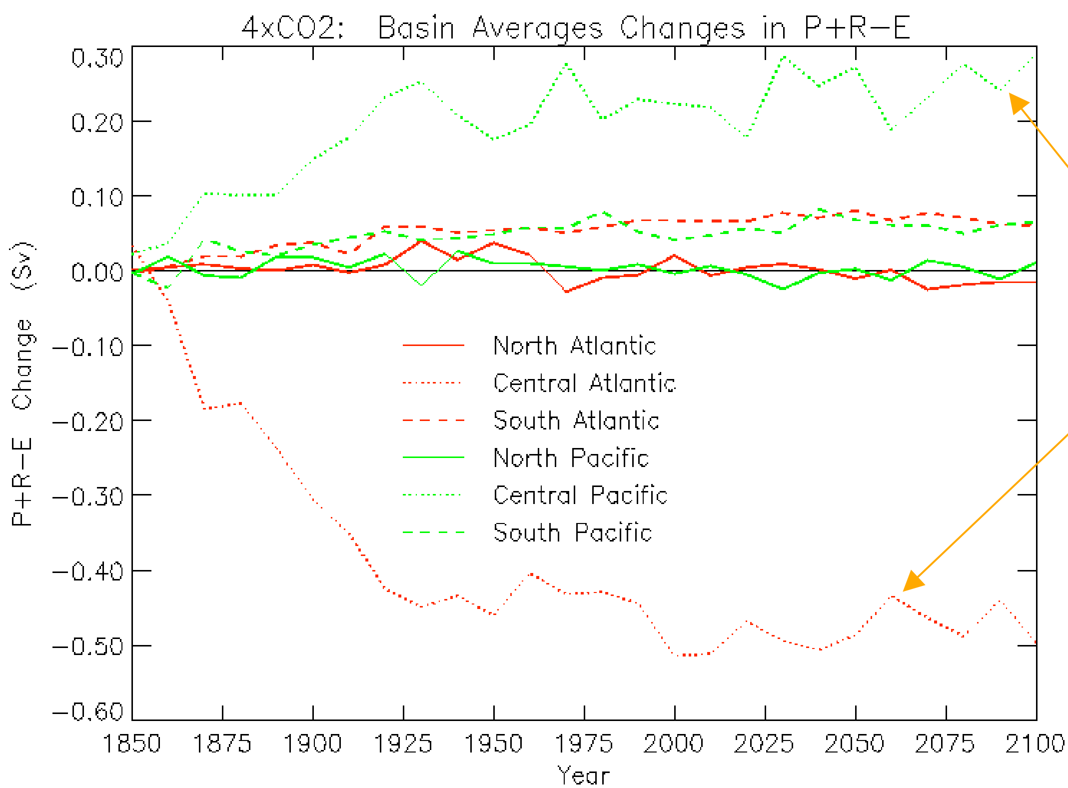
Tropical fresh water response stabilises the THC in HadCM3



Global warming leads to enhanced water transport from tropical Atlantic to tropical Pacific, salting the tropical Atlantic

+ve Atlantic salinity anomalies transported northwards from subtropics to subpolar regions, stabilising THC

(Thorpe at al., *J. Climate* 2001)

So: to establish credibility of model responses we need observational tests of the 'hydrological sensitivity' (an atmospheric parameter!)

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Why monitor the MOC?

- Detect changes/*trends* – add extra observations to detect on policy-relevant timescales
- Attribute changes – understand what's *probably* happening
- Initialise interannual-decadal forecasts (including early warning of MOC change) – look upstream?
- Provide focused tests to sort out reliable and unreliable model predictions – no idea at present: maybe atmospheric observations?

Note 1: Assume MOC variations (at 26N) important for climate

Note 2: Only the first of these requires a MOC-ometer