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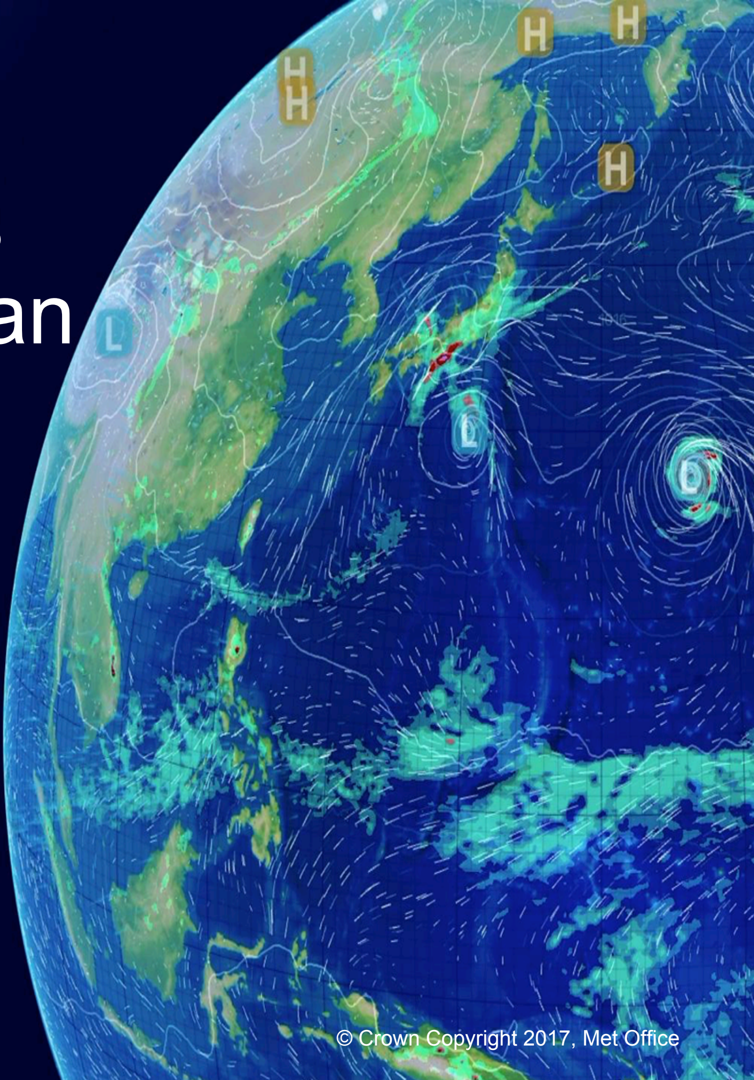
AMOC hysteresis and resilience in an eddy-permitting GCM

Laura Jackson and Richard Wood



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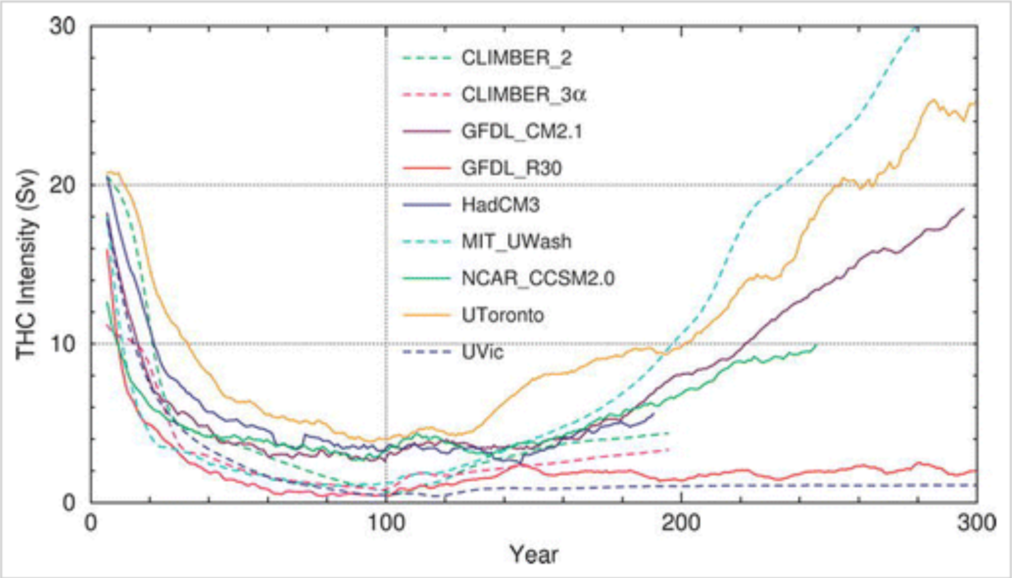

GCMs showed recovery after large freshwater input

Stouffer et al. 2005

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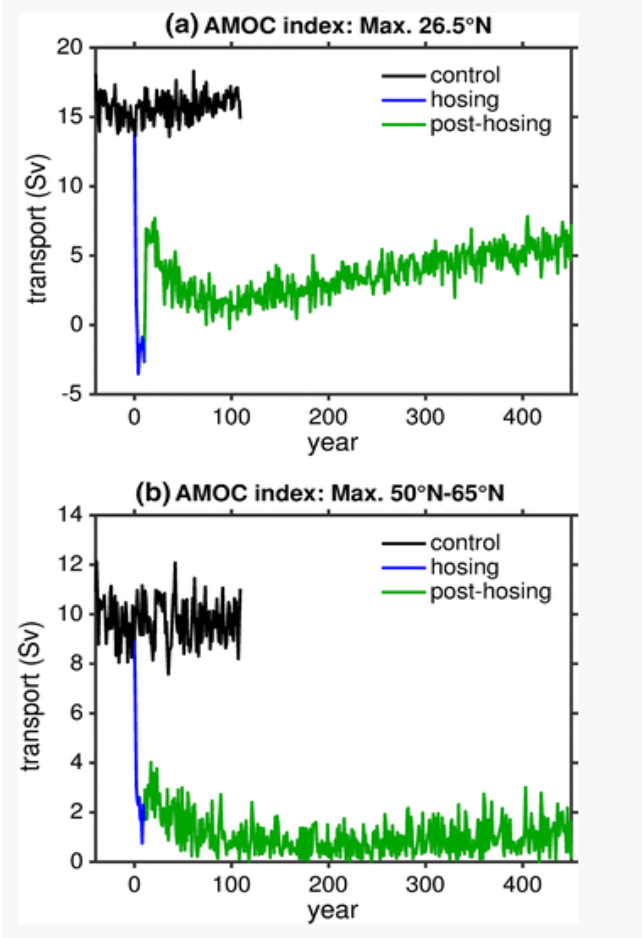
In HadGEM3 GC2 the AMOC remains in a weak state for hundreds of years following a large freshwater input (equiv to 10 Sv for 10 years)



Mecking et al. 2016

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Model

- HadGEM3-GC2 (pre CMIP6 model)
- Fully coupled atmosphere, ocean and sea ice (doesn’t include flux adjustment)
- NEMO ocean model
- ‘Eddy-permitting’ - nominally 0.25^{o} with 75 levels (highest resolution for such a study)
- No GM (sub-gridscale mixing)

Method

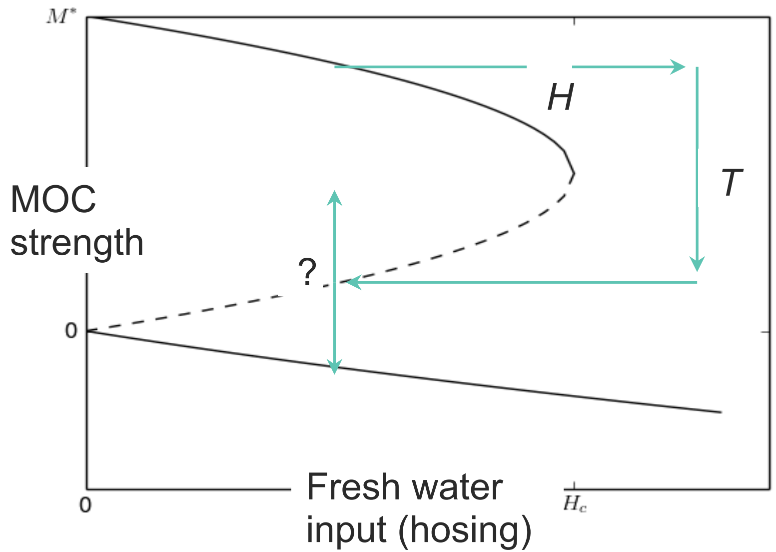
Hose (additional surface fresh water flux) from 50N-Bering Straits.

Use volume compensation to conserve fresh water

Hose at rate *H* for *T* years where:

> *H* = 0.1,0.2,0.3,0.5,1.0 Sv
>
> *T* = 20,50 years (plus others where needed)

Then stop hosing.



Methods

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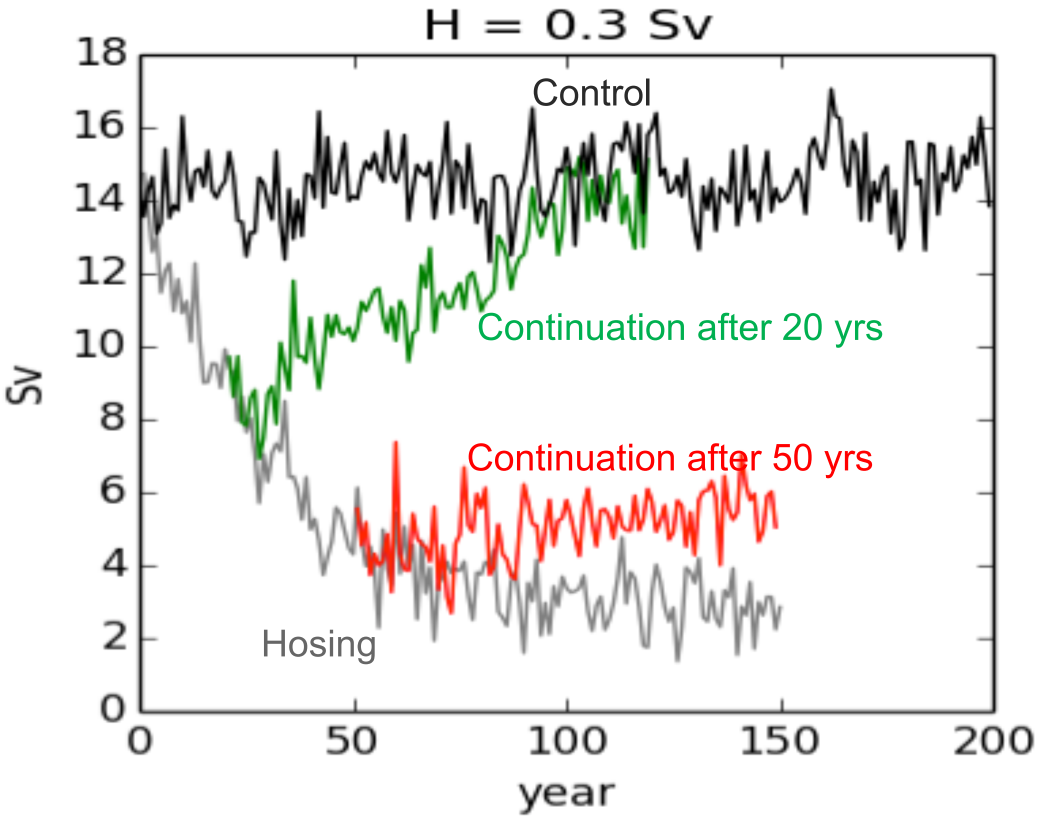
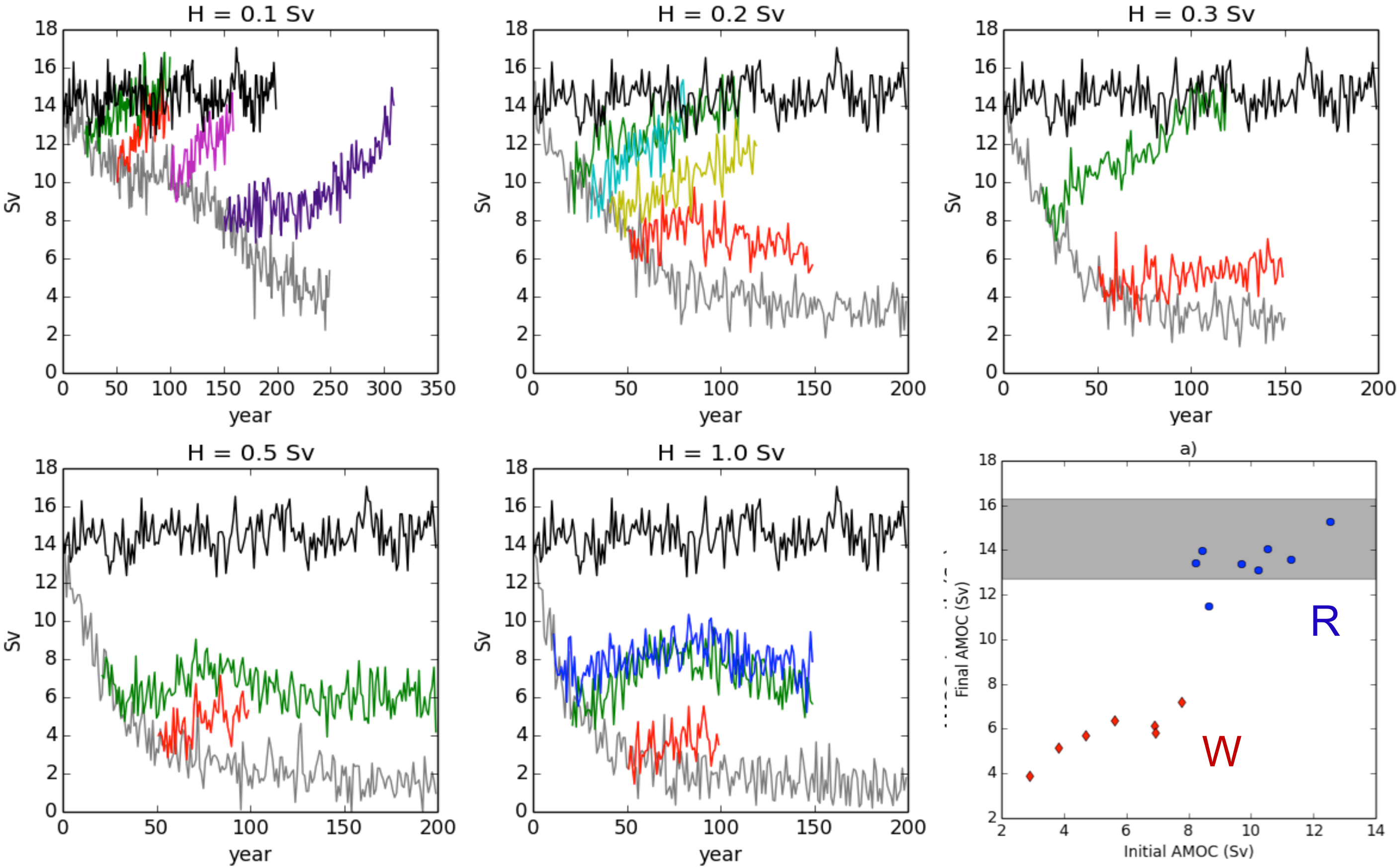
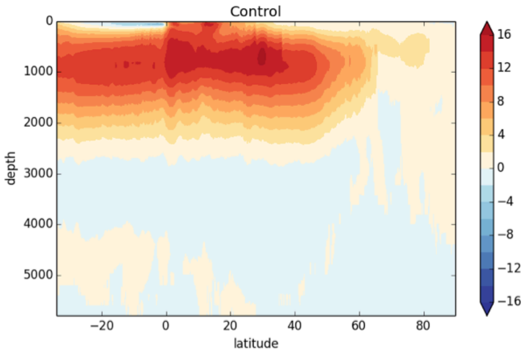
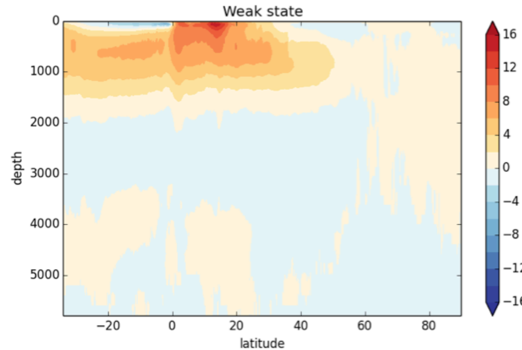
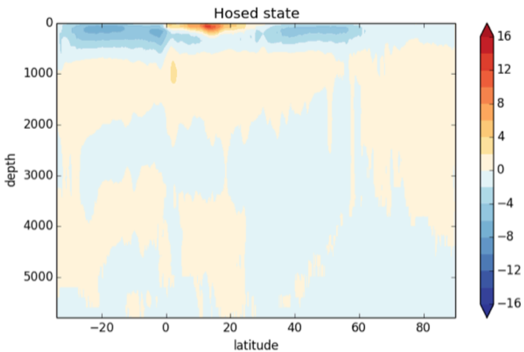



H = 0.1 Sv
H = 0.2 Sv
H = 0.3 Sv
H = 0.5 Sv
H = 1.0 Sv
Sv
year
a)
Final AMOC (Sv)
Initial AMOC (Sv)
R
W







<u>Hosed state</u>

No AMOC

Reverse cell in upper ocean (Ekman+AAIW?)

No change to AABW cell

<u>Weak state</u>

AMOC cell is weaker, shallower and extends less far north

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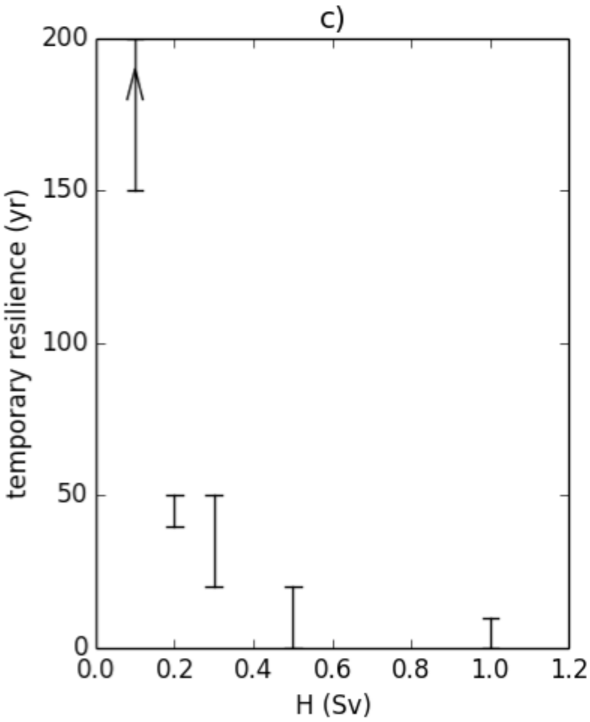
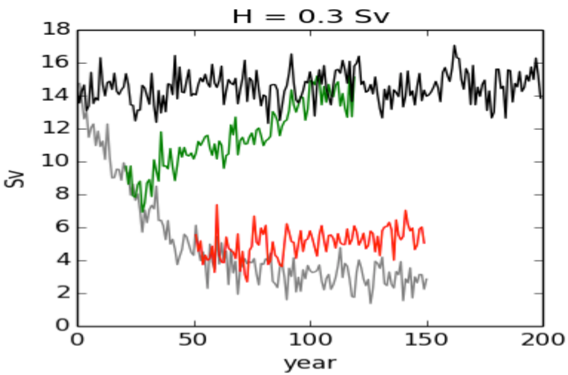
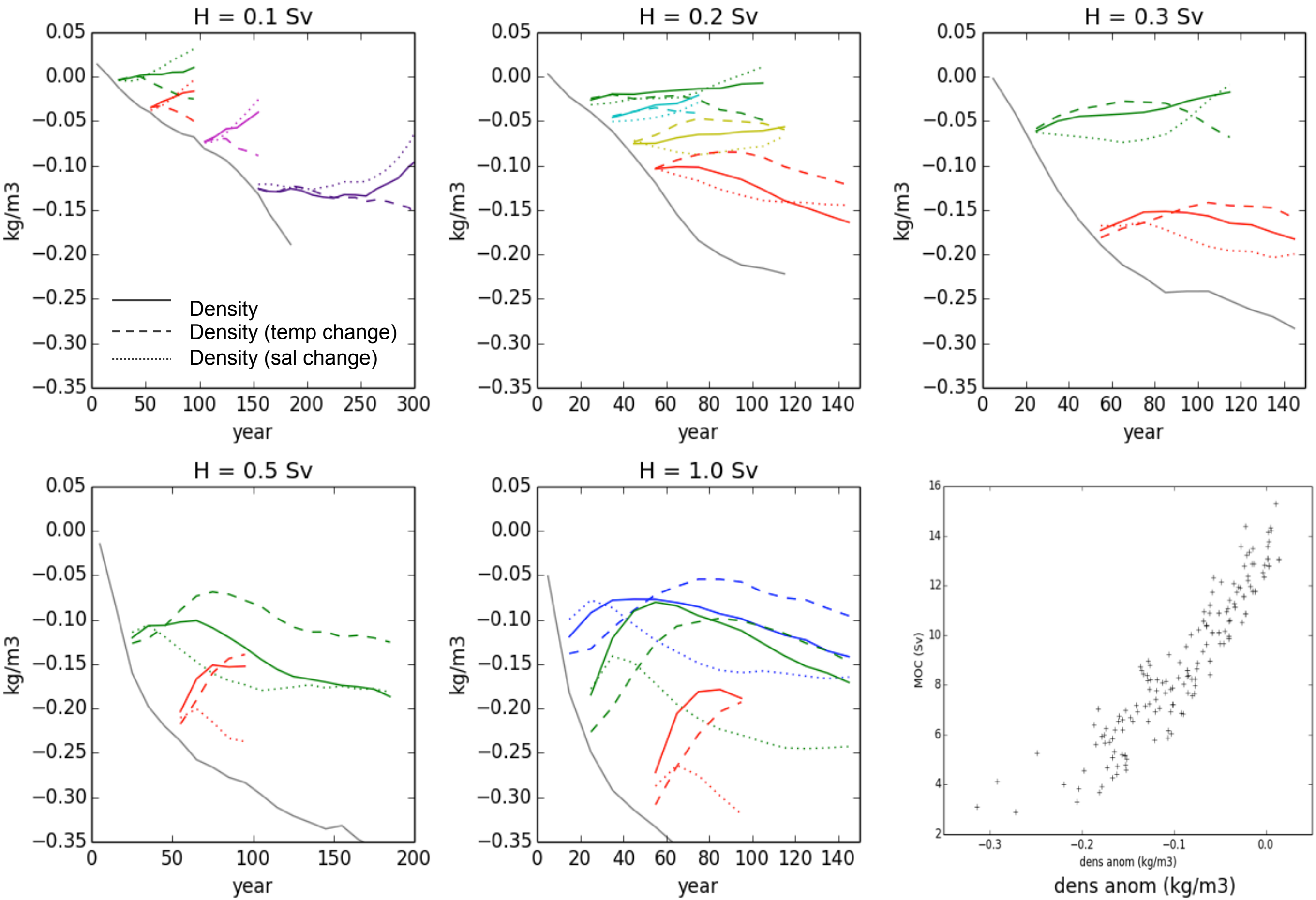
Temporary resilience





The AMOC is resilient for 20 years of H=0.3 Sv but not 50 years. Timescale of resilience 20 < t < 50



Results: Mechanisms

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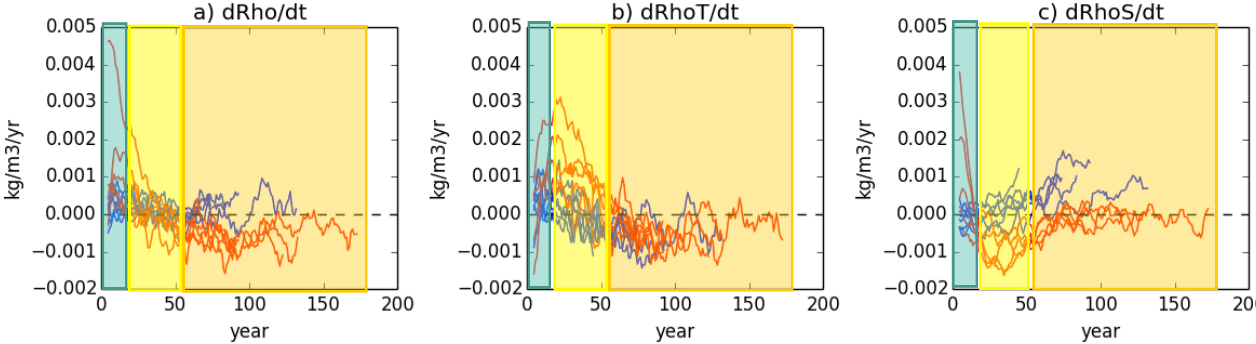
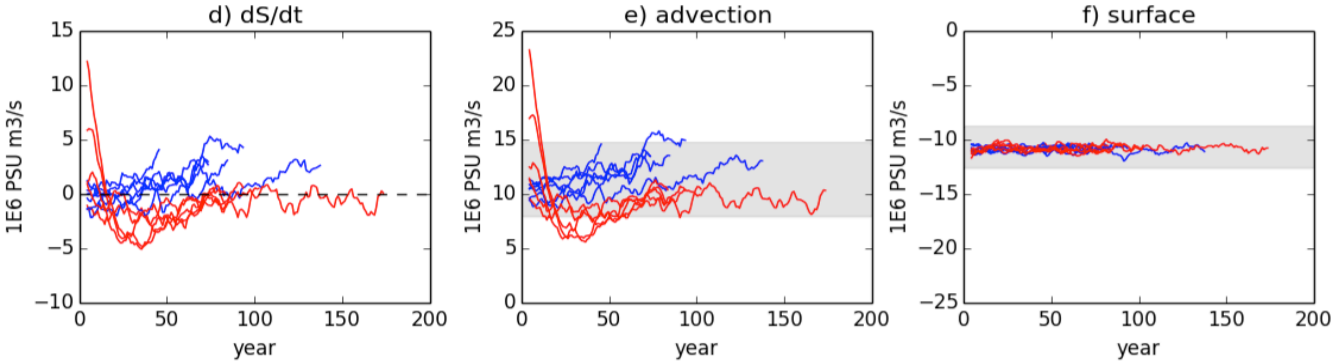
$d\rho(T,S)/dt$ $d\rho(T,S_0)/dt$ $d\rho(T_0,S)/dt$



- First 20 years – all see density increase from cooling. Some see large density increase from salinification
- Next 30 years – Similar density changes, though W experiments cool and freshen more than R experiments
- After – W experiments continue to see more freshening and see density decrease

Recovery determined by salinity changes

Salinity change = advection + surface fluxes (+...)



- Differences between R and W come from differences in advection
- Surface fluxes change little

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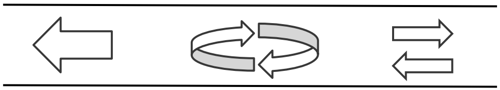
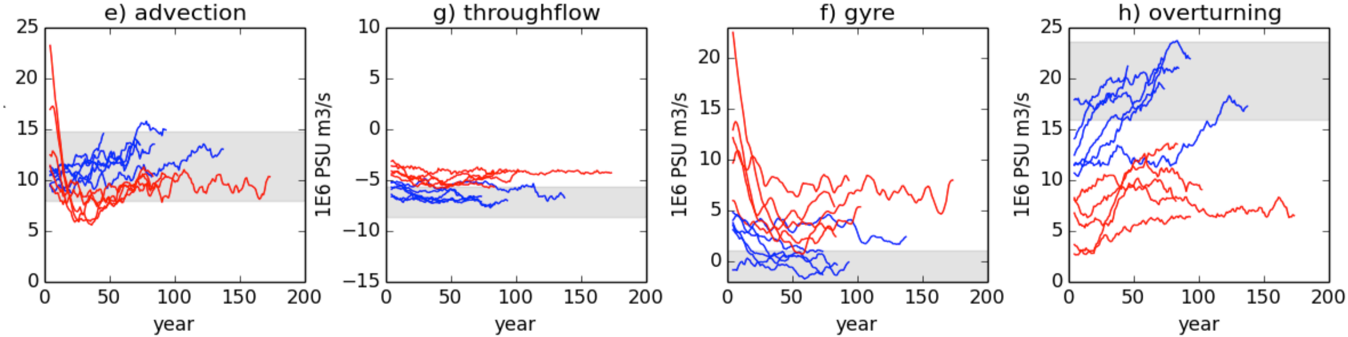


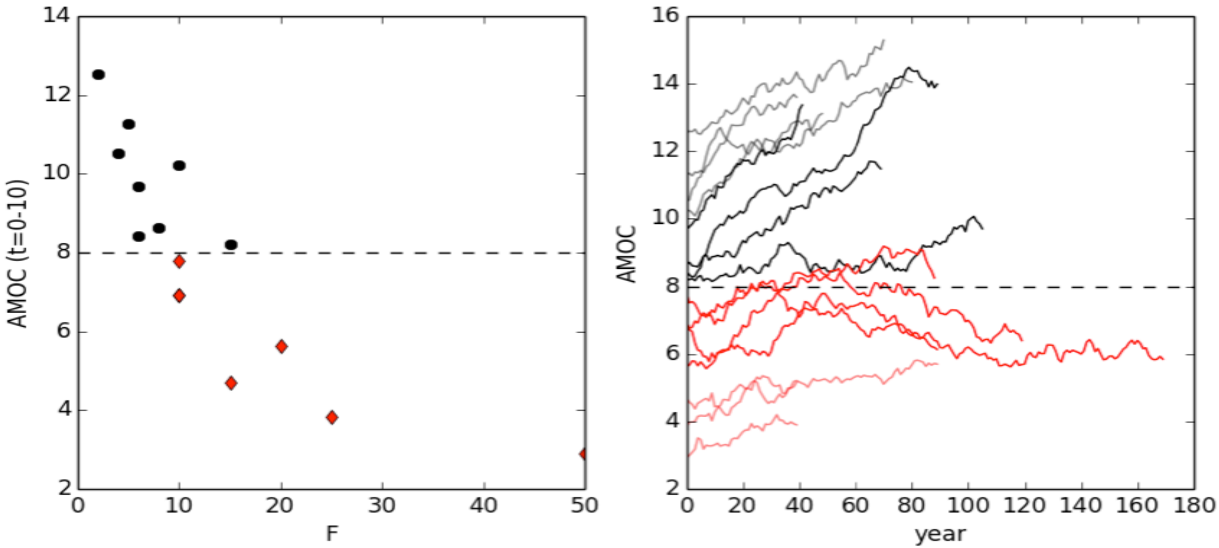
Advection = throughflow + gyre + overturning



Compared to control experiments after hosing see:

- Salinification from gyre exporting fresh anomalies
- Freshening from weaker AMOC

W experiments freshen more than R because of greater freshening from weaker AMOC – positive advective feedback.



AMOC limit of 8 Sv HOWEVER the cut off is not exact. In most extreme cases see partial recovery and then weakening.

If AMOC/MLD falls below the limit, there is a **high risk** of not recovering.

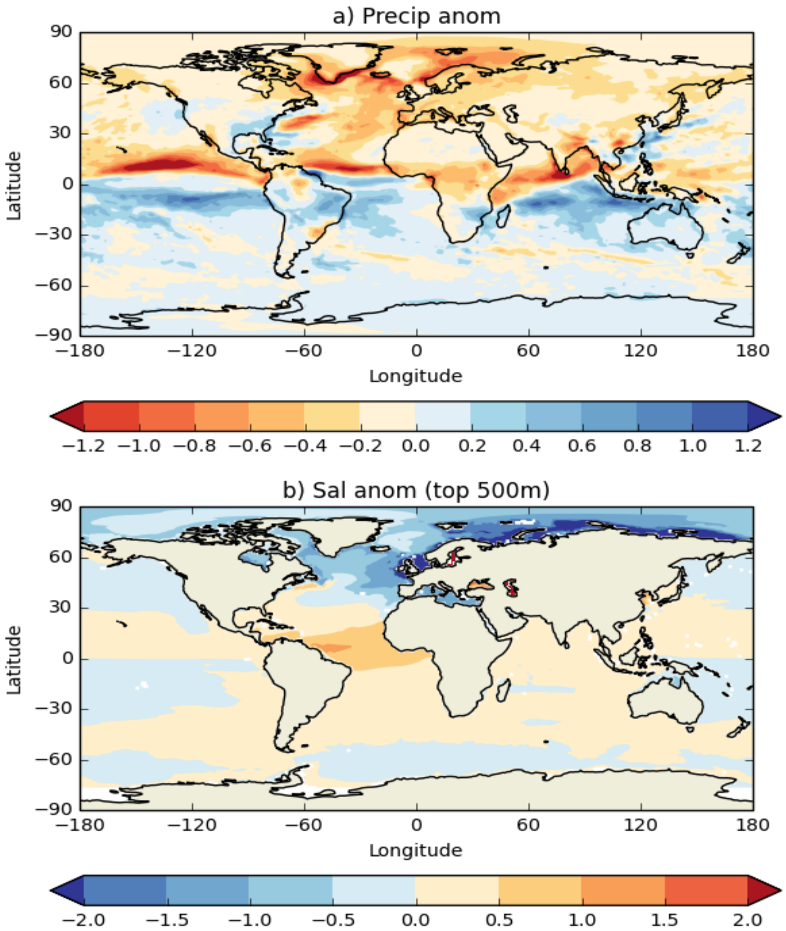
The limit is likely to be model (and maybe scenario) specific.

F (total amount of freshwater) is not very useful as an indicator

What is different in this model?

All coupled models find AMOC reduction causes a shift in Atlantic ITCZ. Can cause increase in tropical salinity.

Some models have shown that this can be advected north and cause AMOC to recover.



Mecking et al (2016): The AMOC in the same model didn't recover after a large salinity perturbation.

Attributed this to the strong salt transport by the AMOC.

- When the AMOC collapses, the lack of salt input freshens the N Atlantic
- Freshening is larger than salinification from ITCZ shift
- Stronger salt transport may be due to resolution?

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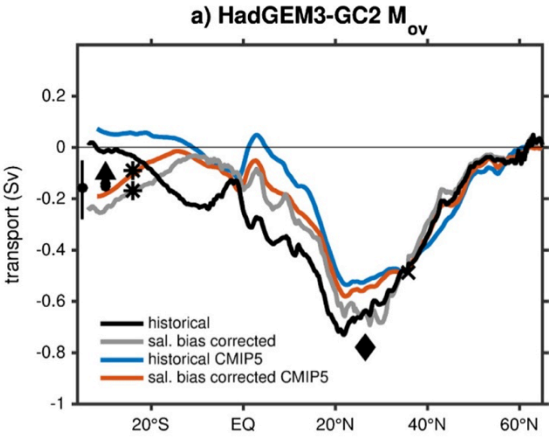

Conclusions

- AMOC exhibits hysteresis in GC2
- AMOC shows ‘temporary resilience’ – for ‘realistic’ levels of hosing would recover with < 100 years of hosing.
- There appears to be a limit beyond which the AMOC does not recover.
    - Less likely to recover when the AMOC weakening is greater
    - Less likely to recover when region of convection (MLD) is smaller.
- A weaker AMOC causes more freshening of the Atlantic and hence inhibits recovery more (positive advective feedback).
- This model may be different because of the strong advection of salt by overturning through basin (possibly because of more eddies/better resolution of boundary currents)

Future work

What would be the response to reversible ‘realistic’ hosing (+CO_2 scenario)?

Are there early warning indicators?

What is model specific and what is robust?

- Comparisons with other GCM hosing experiments
- Look at changes in freshwater transports and surface fluxes – what is the same/different?
- *Anyone interested in repeating some experiments/have any existing experiments to compare to?*

Paper just been published online with GRL

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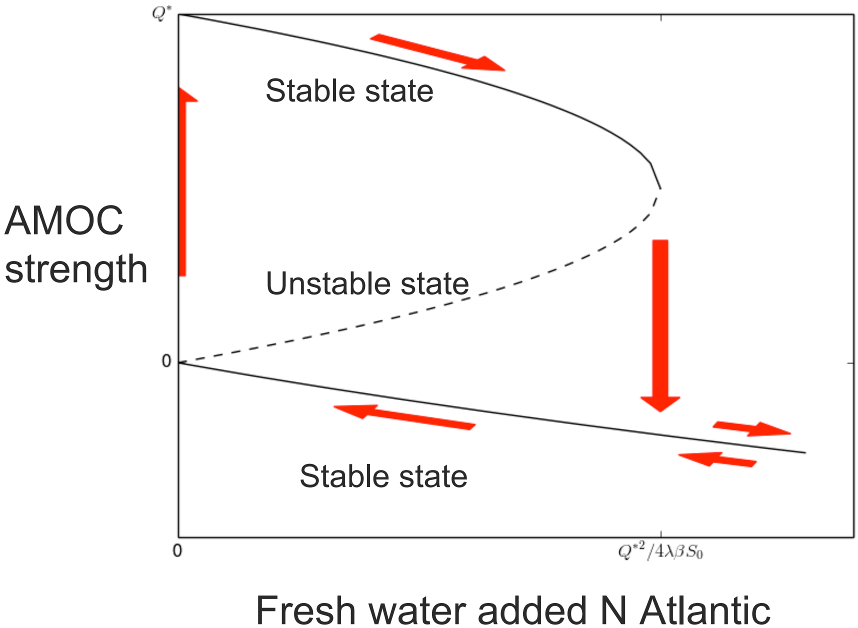
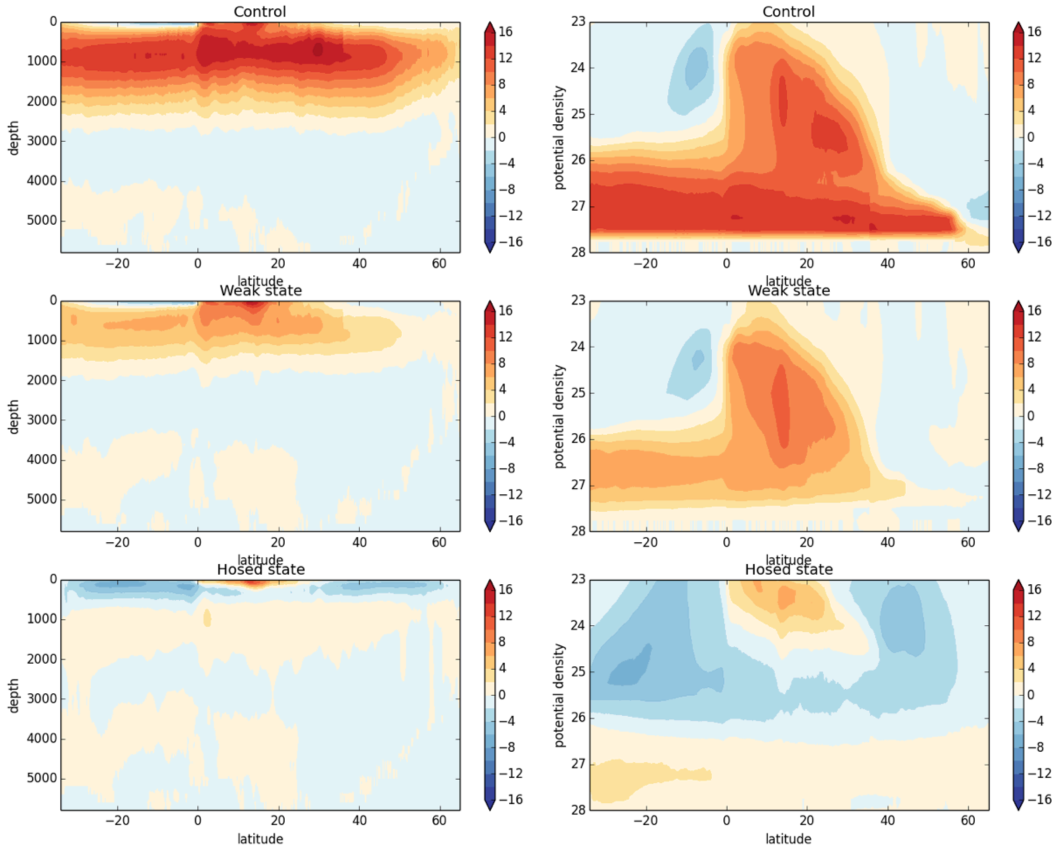
Thanks.
Any questions?

Stommel (1961) proposed a simple two box model for the AMOC





Control
Weak state
Hosed state
depth
potential density
latitude
0
1000
2000
3000
4000
5000
23
24
25
26
27
28
−20
0
20
40
60
16
12
8
4
0
−4
−8
−12
−16

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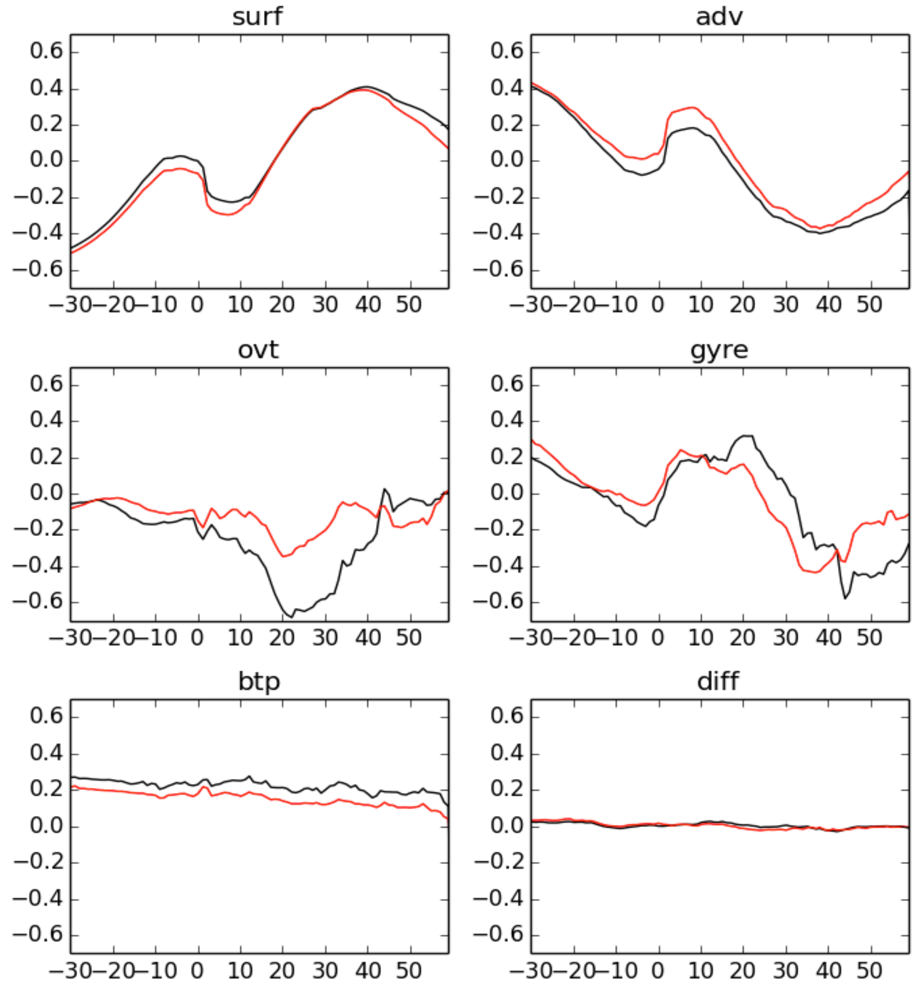
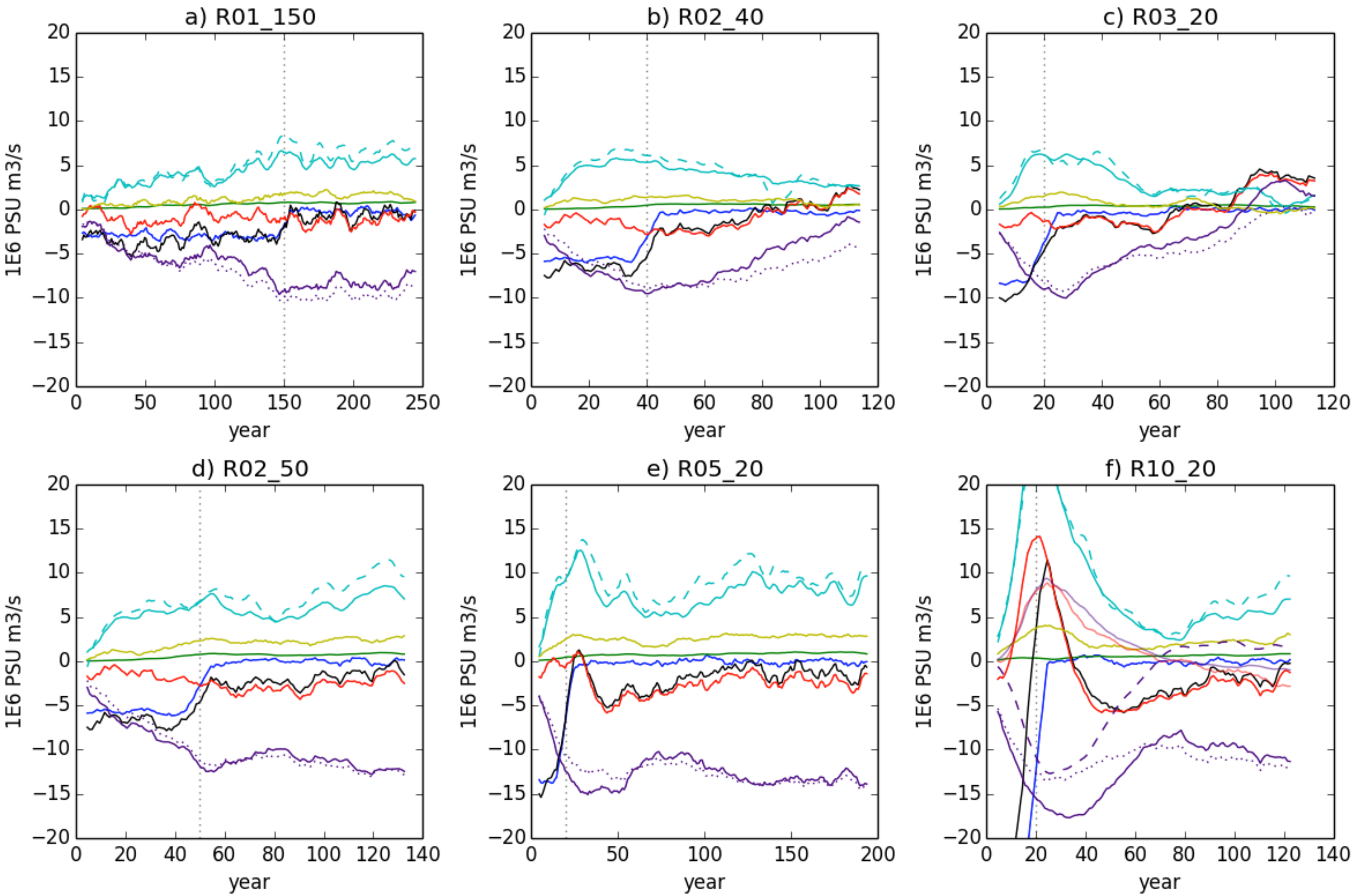
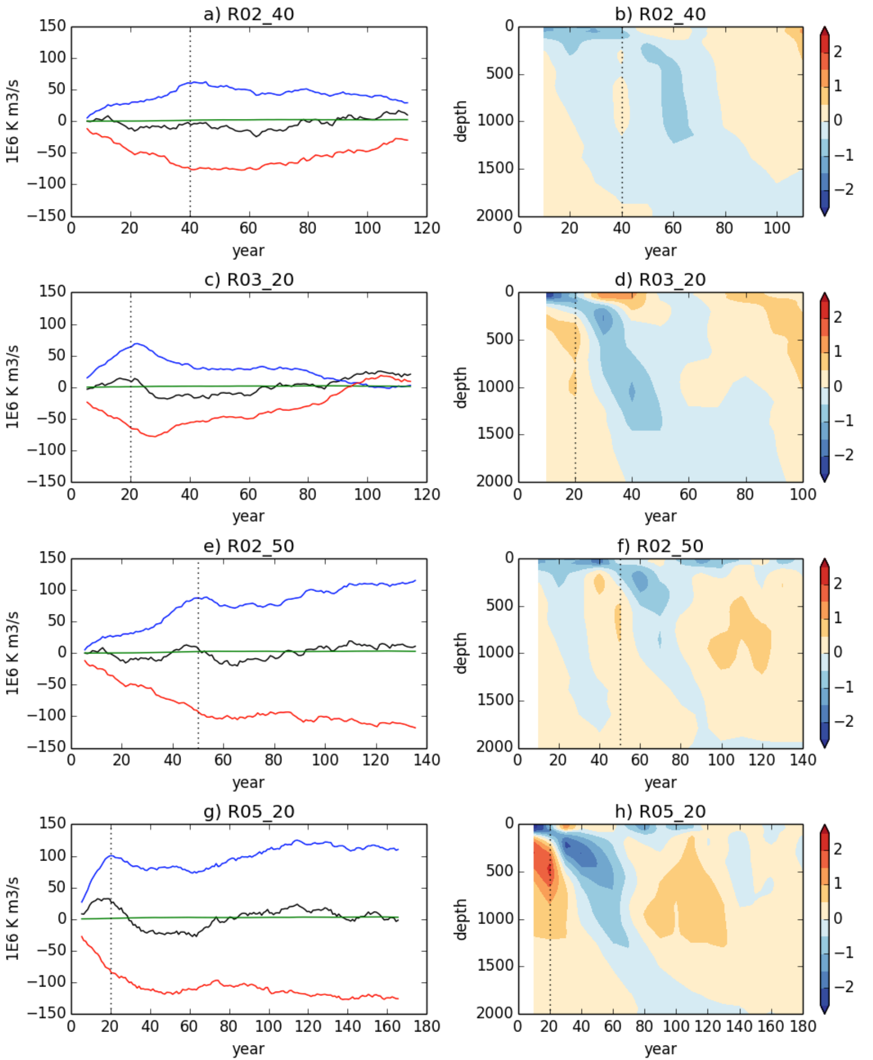
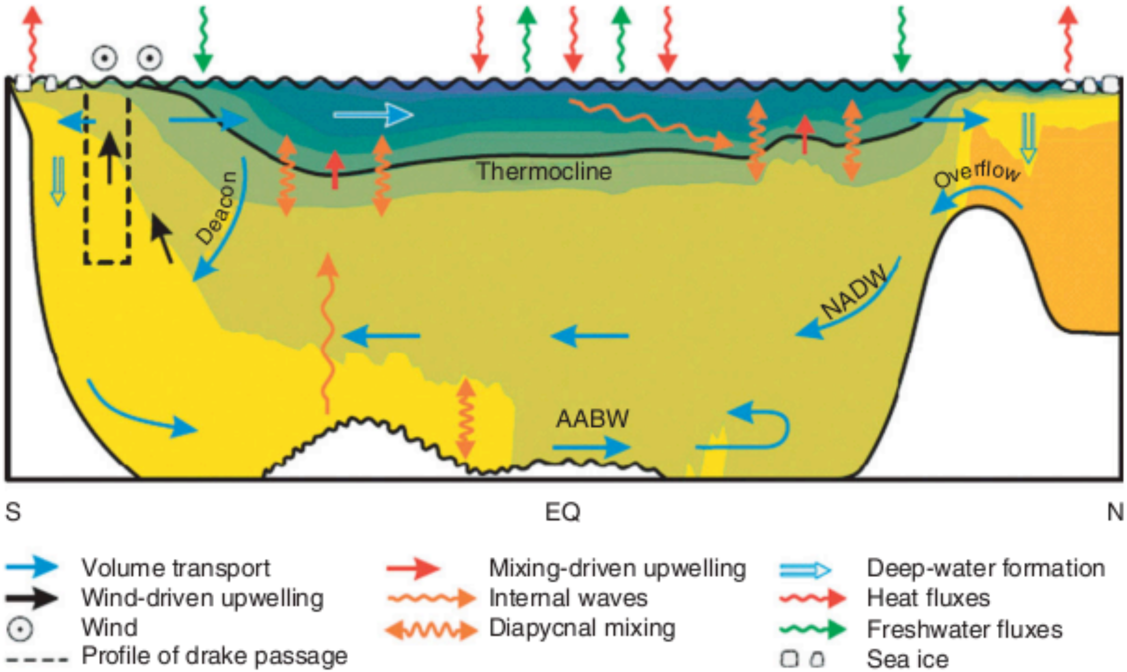



a) R01_150
b) R02_40
c) R03_20
d) R02_50
e) R05_20
f) R10_20
1E6 PSU m3/s
year



a) R02_40
b) R02_40
c) R03_20
d) R03_20
e) R02_50
f) R02_50
g) R05_20
h) R05_20
1E6 K m3/s
depth
year

Important AMOC processes



Cunningham and Marsh, 2010

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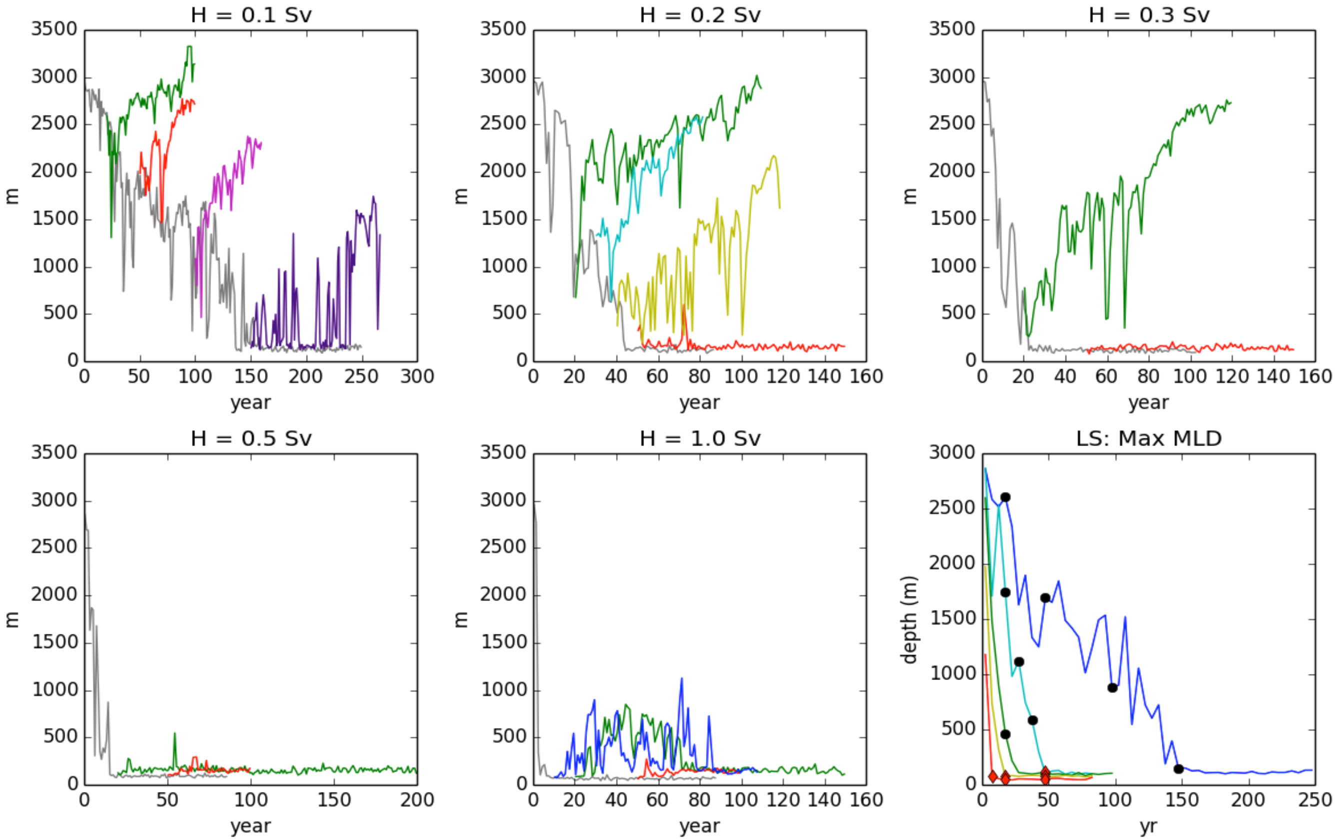

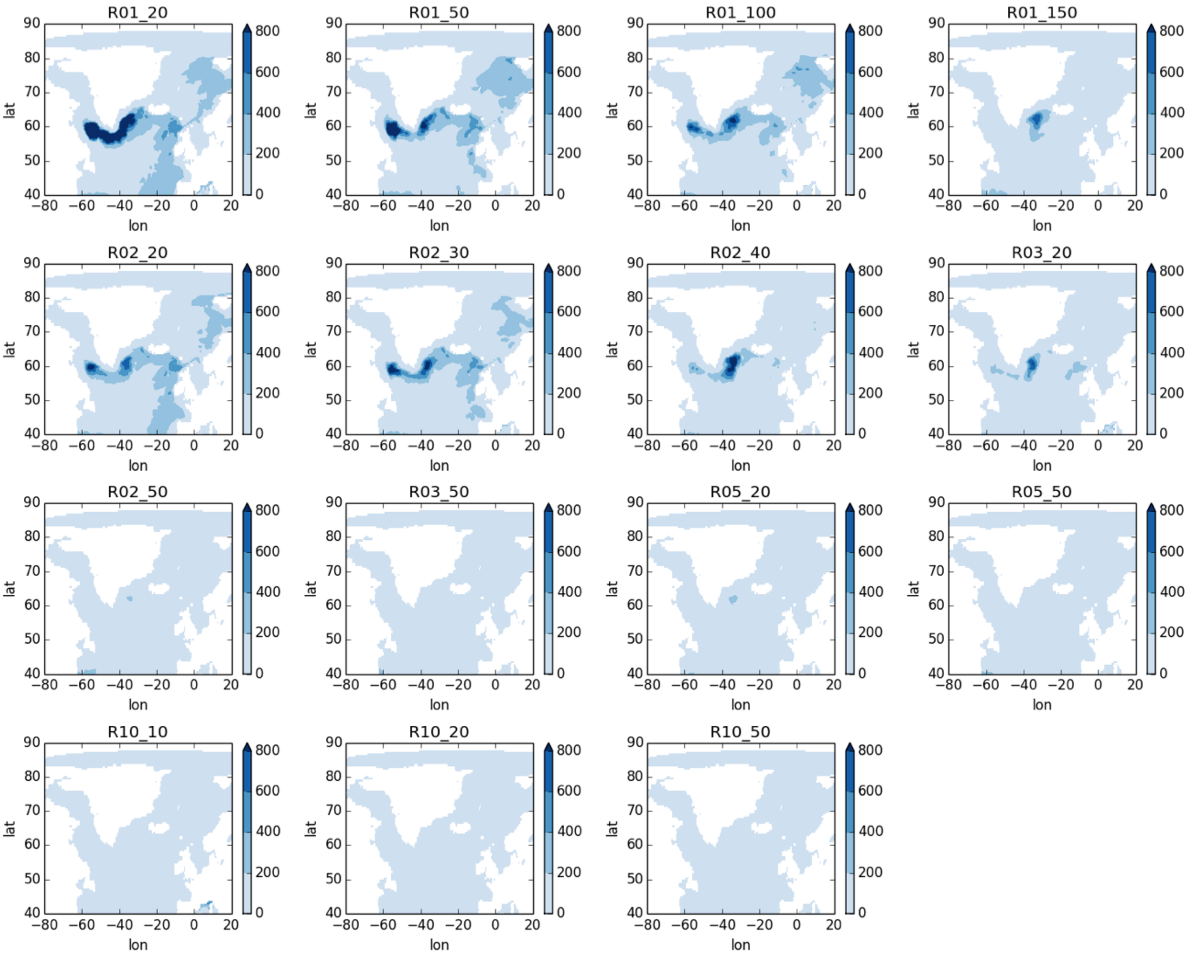
R01_20
R01_50
R01_100
R01_150
R02_20
R02_30
R02_40
R03_20
R02_50
R03_50
R05_20
R05_50
R10_10
R10_20
R10_50
lat
lon
800
600
400
200
0

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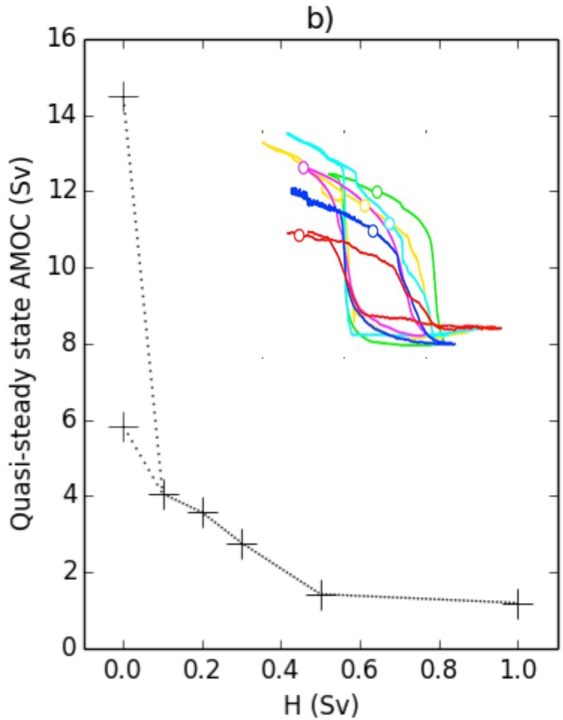
Hysteresis



Temporary resilience