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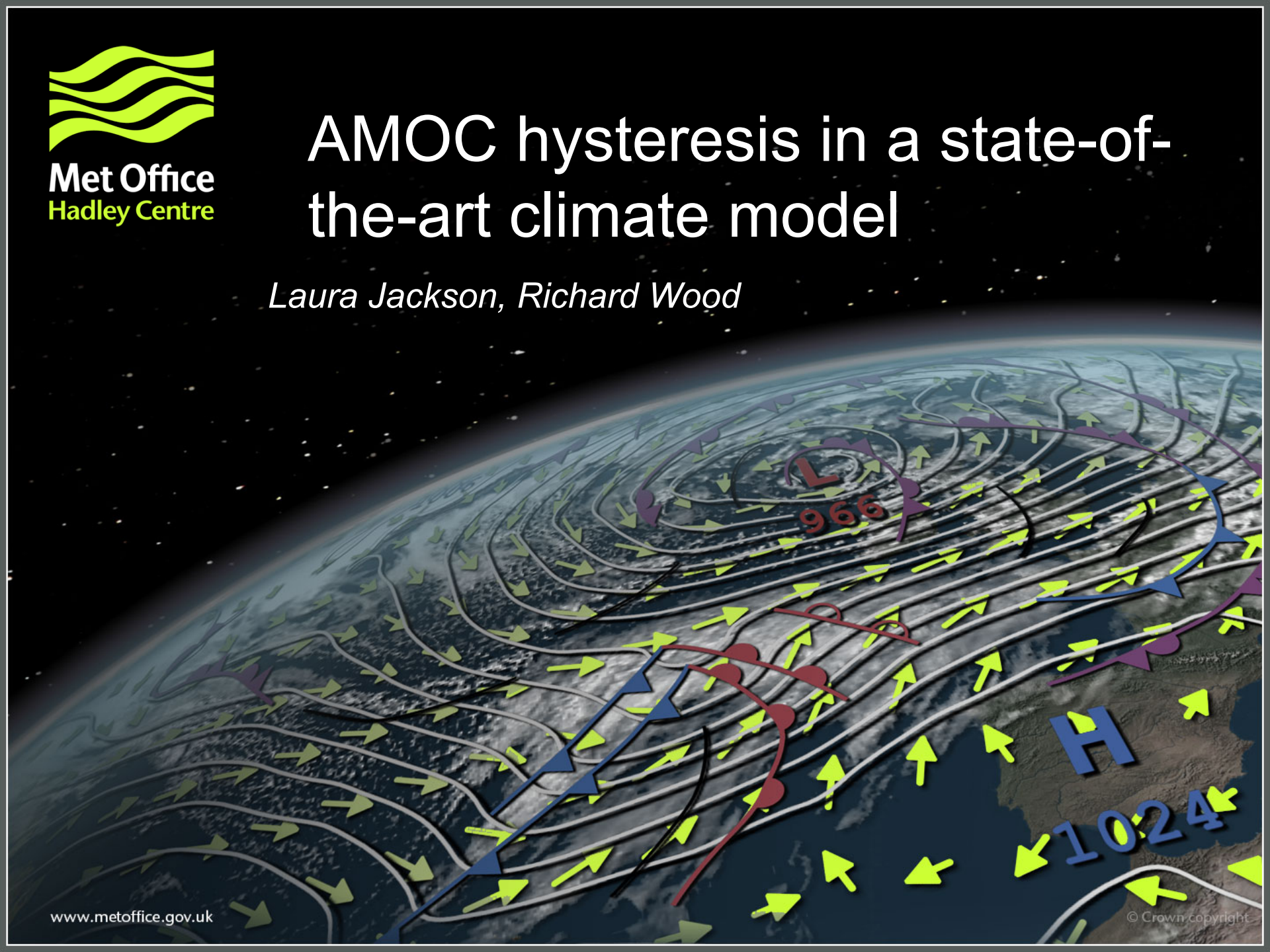
AMOC hysteresis in a state-of-the-art climate model

Laura Jackson, Richard Wood



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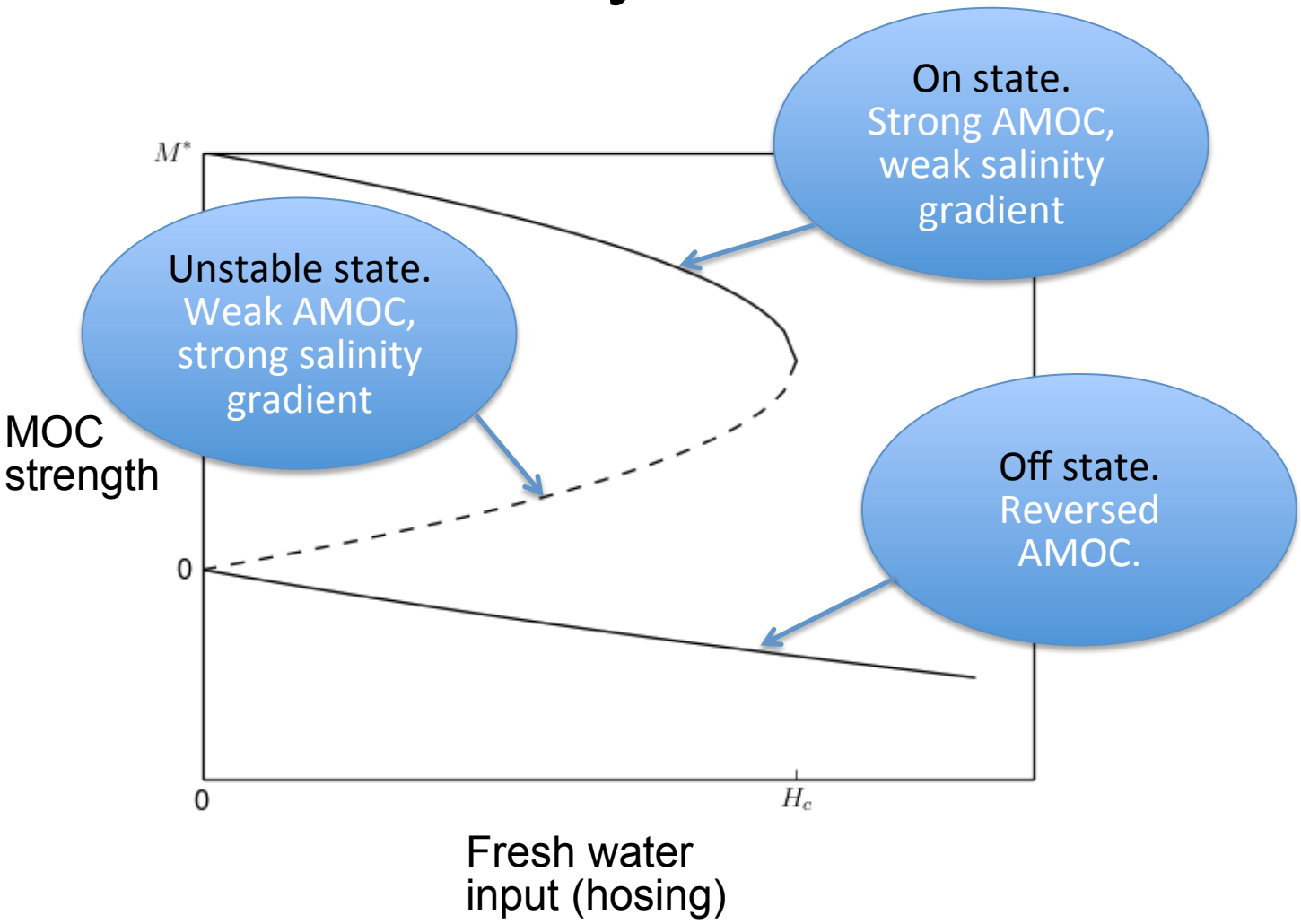
Stommel Theory



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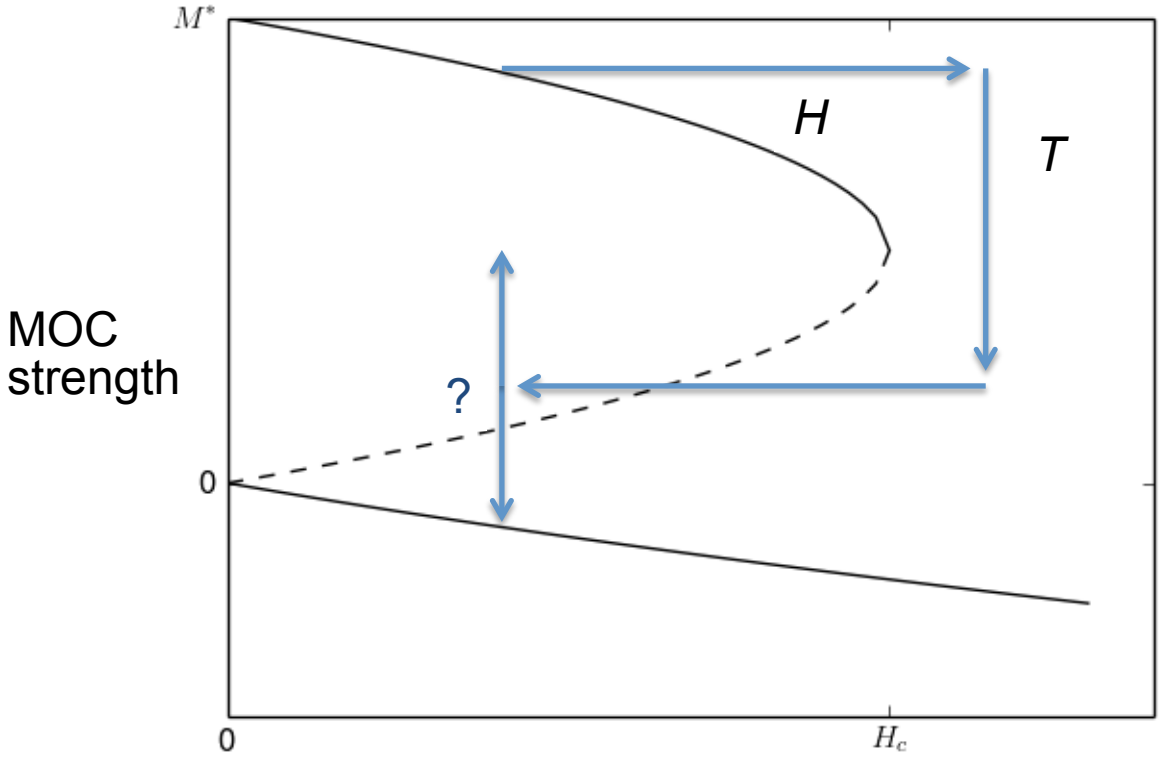

MOC strength

Fresh water input (hosing)

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GCM

- HadGEM3-GC2 (pre CMIP6 model)
- NEMO ocean model
- Fully coupled atmosphere, ocean and sea ice.
- 'Eddy-permitting' - nominally 0.25^{o} with 75 levels
- No GM

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.

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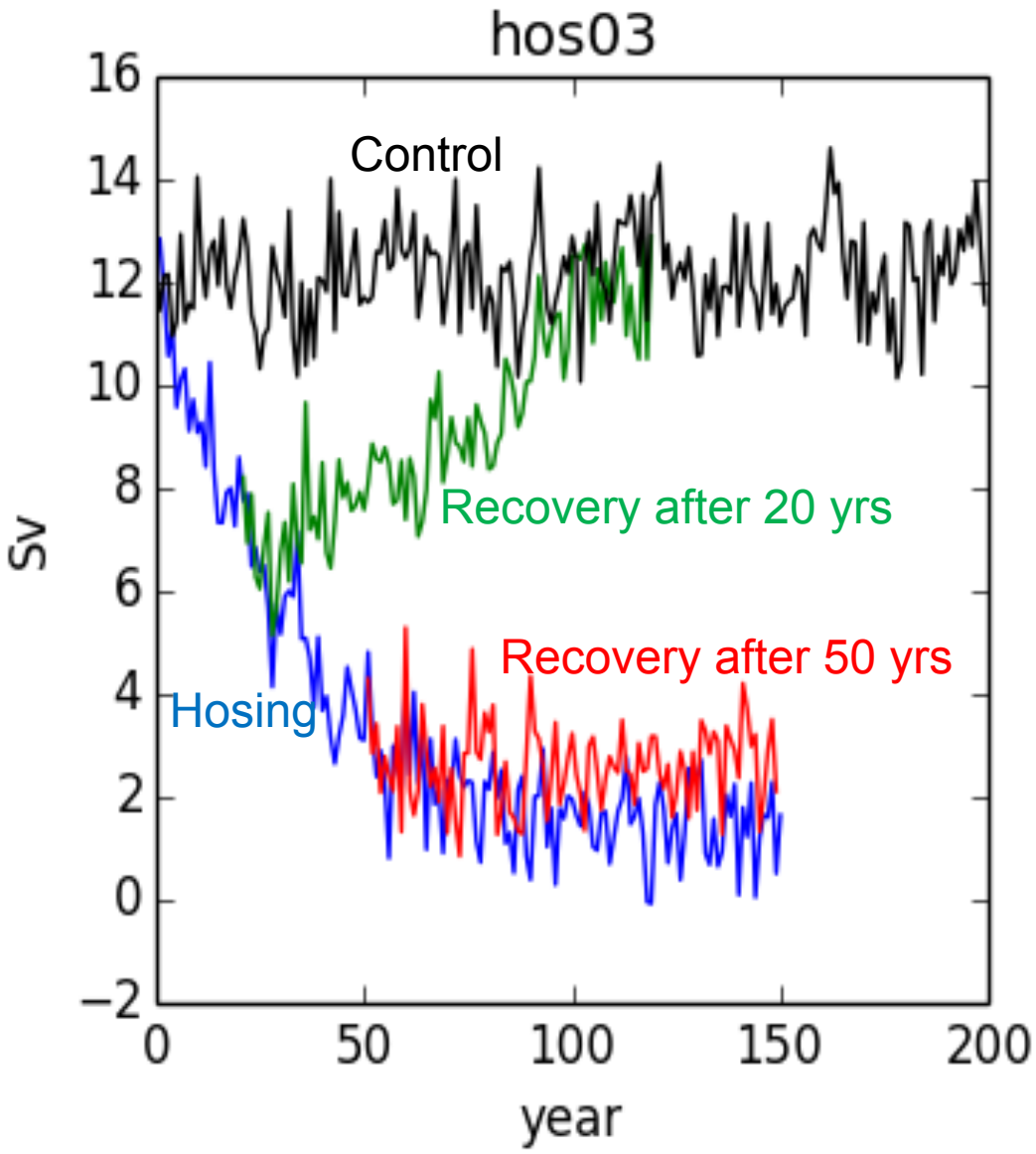

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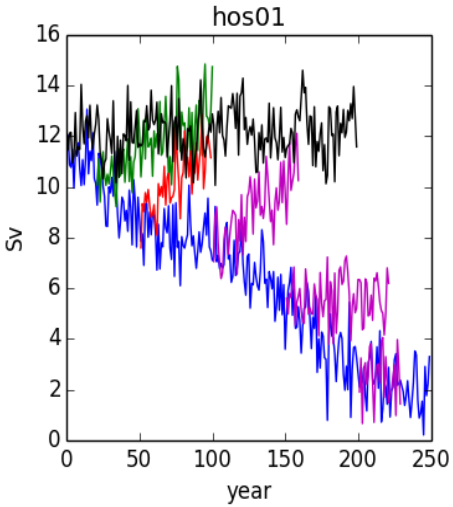

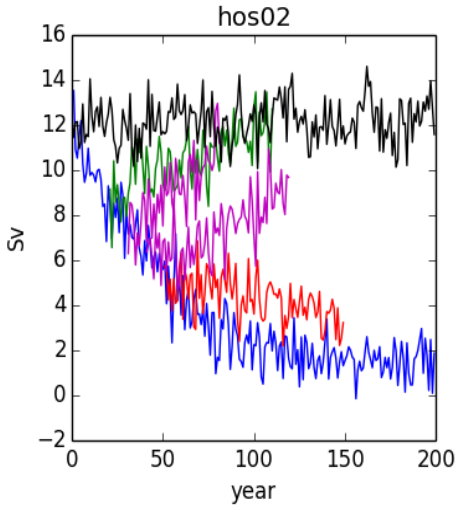

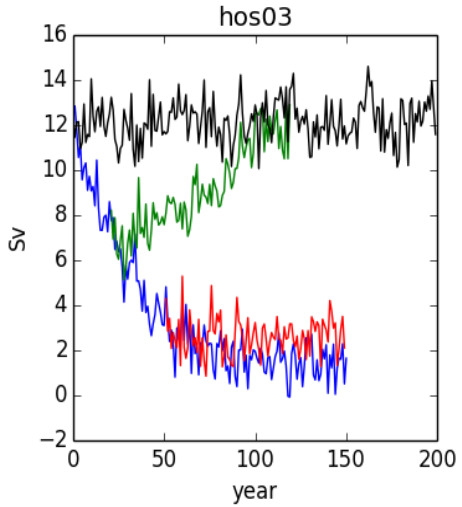

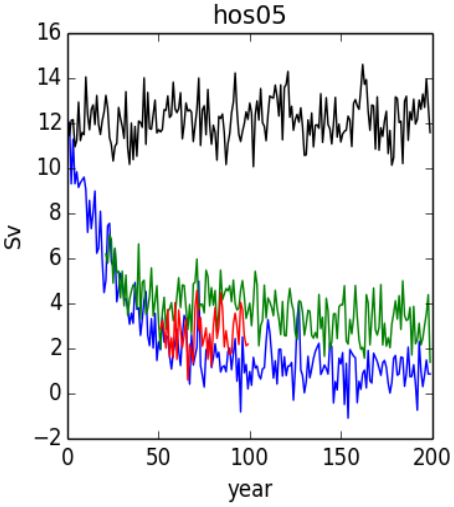

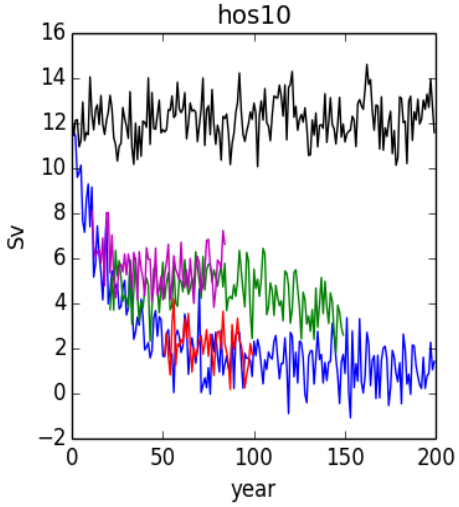

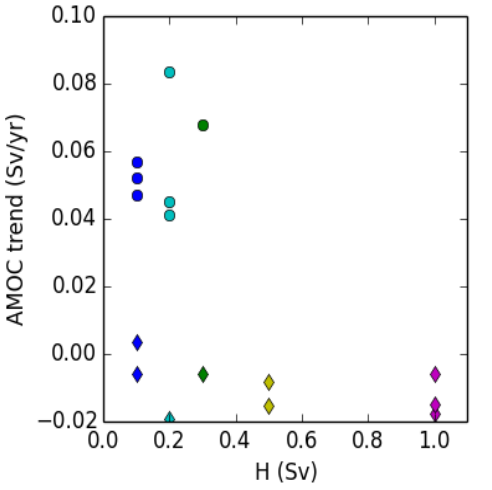

Control
Hosing
Recovery after 20 yrs
Recovery after 50 yrs
Other Recoveries

Bistability	?
Hysteresis	✓
Threshold	✓

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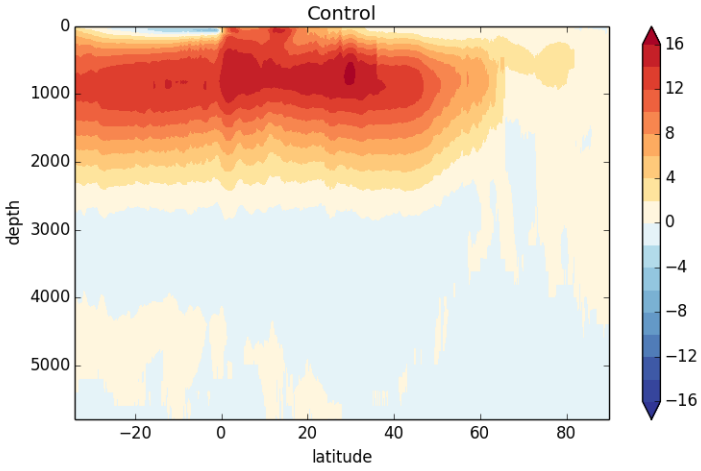
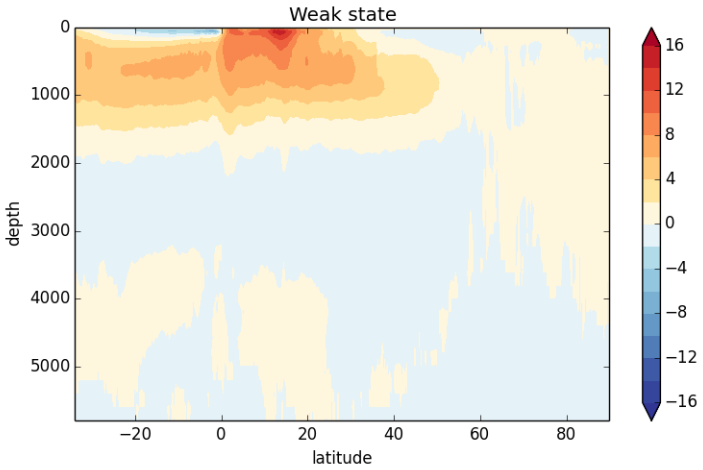
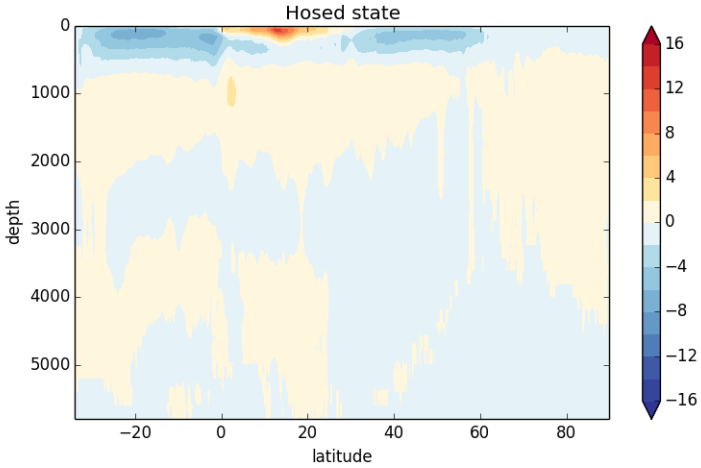






Hosed state

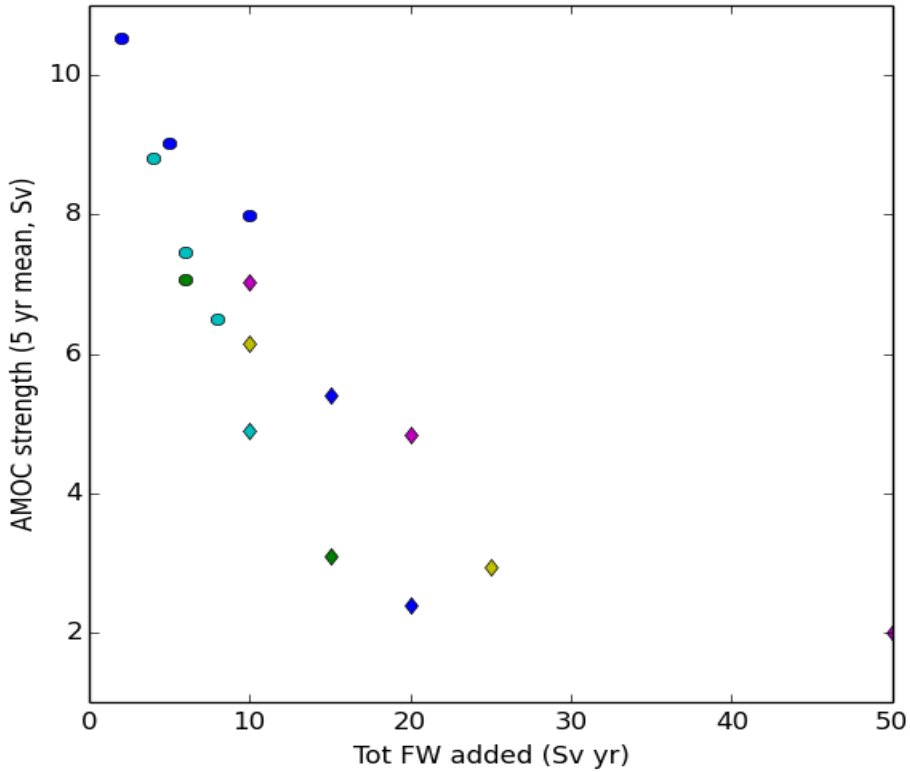
No AMOC

Reverse cell in upper ocean (Ekman+AAIW?)

No change to AABW cell

Weak state

AMOC cell is weaker, shallower and extends less far north



Generally, AMOC recovers if:

- AMOC has not weakened below 7Sv
- Total fresh water added is less than 10 Sv years

HOWEVER

This is not exact – in particular expect different response from small hosing for long time to large hosing for short time

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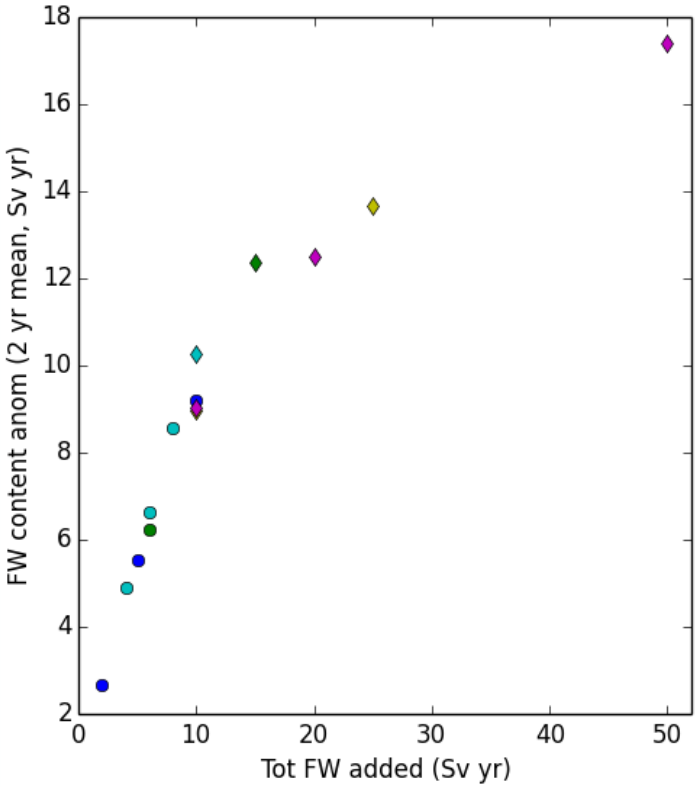

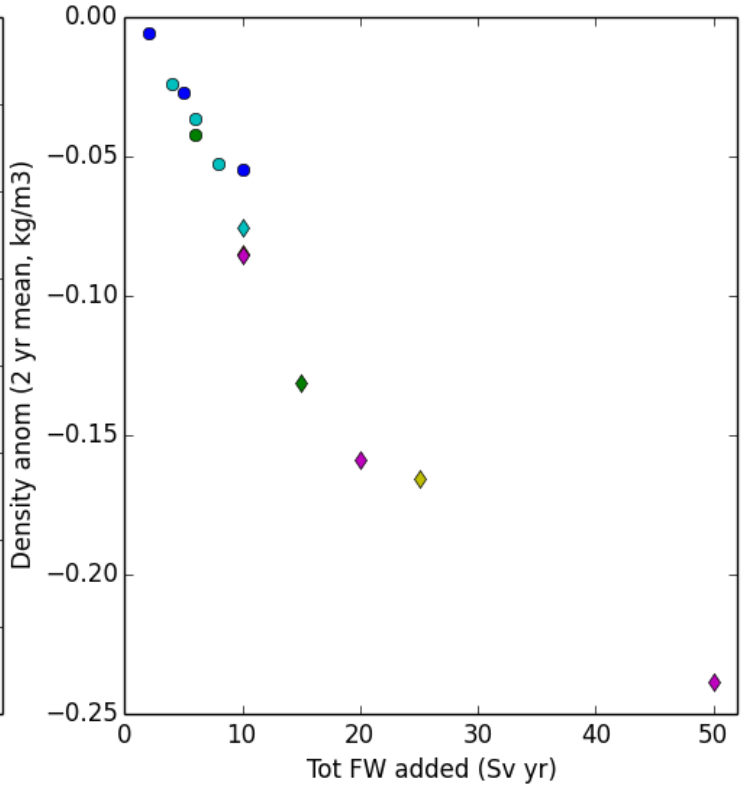

Total FW change accounts for different FW loss but still no clear division.

Density change does show clear division

Exact numbers are likely to be model and scenario dependent

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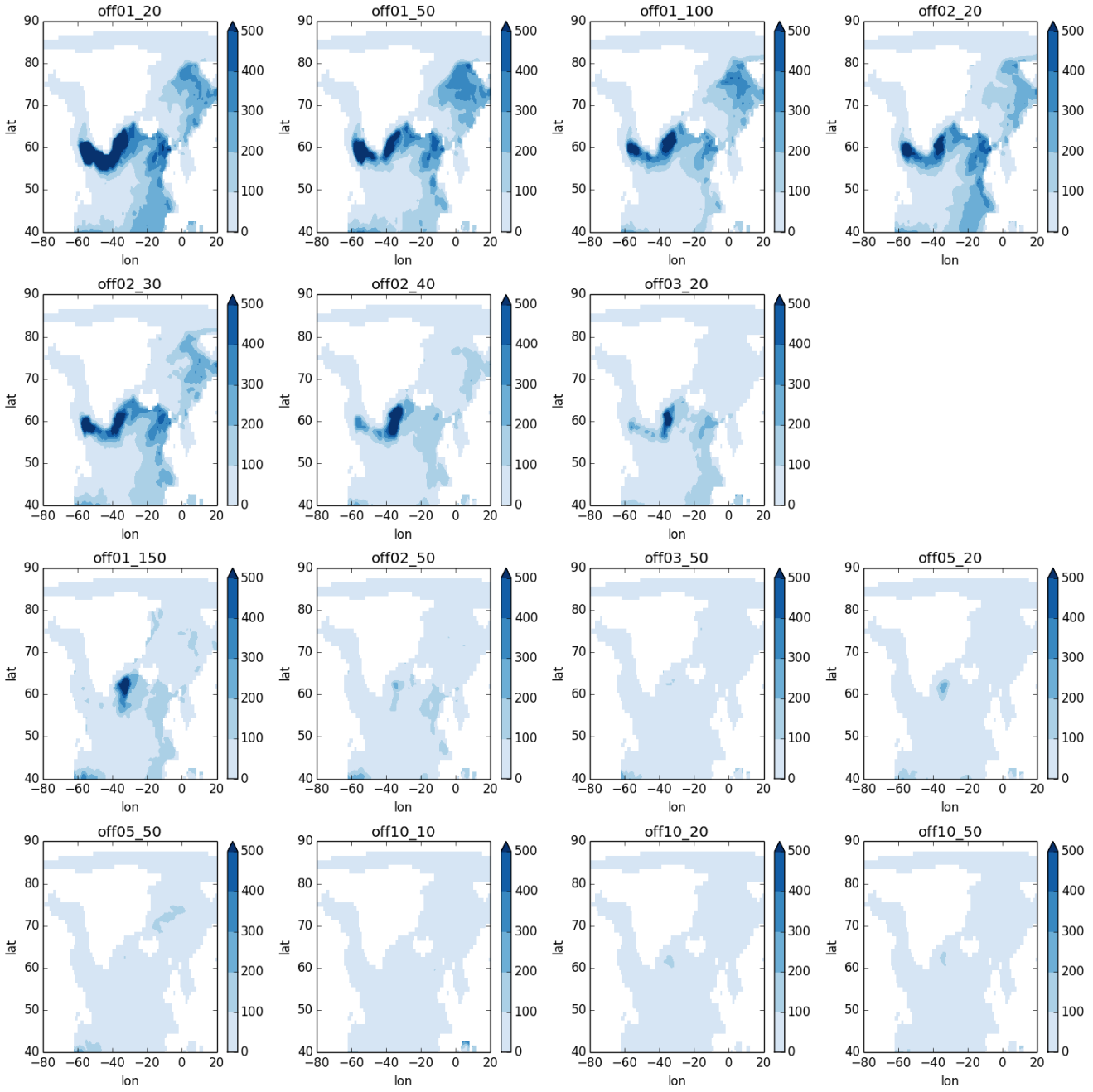

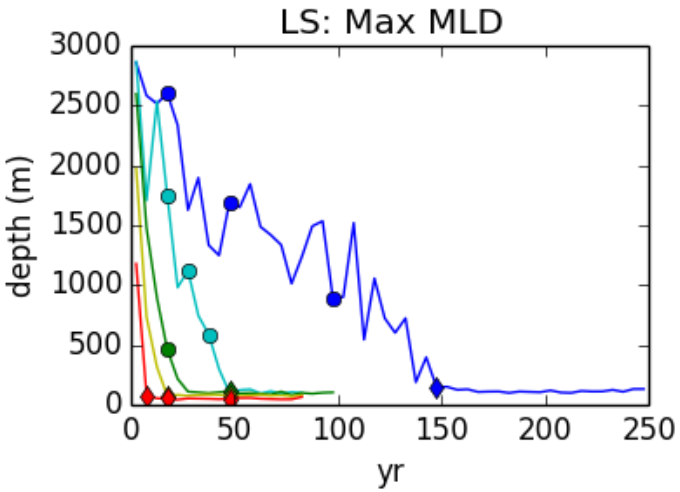

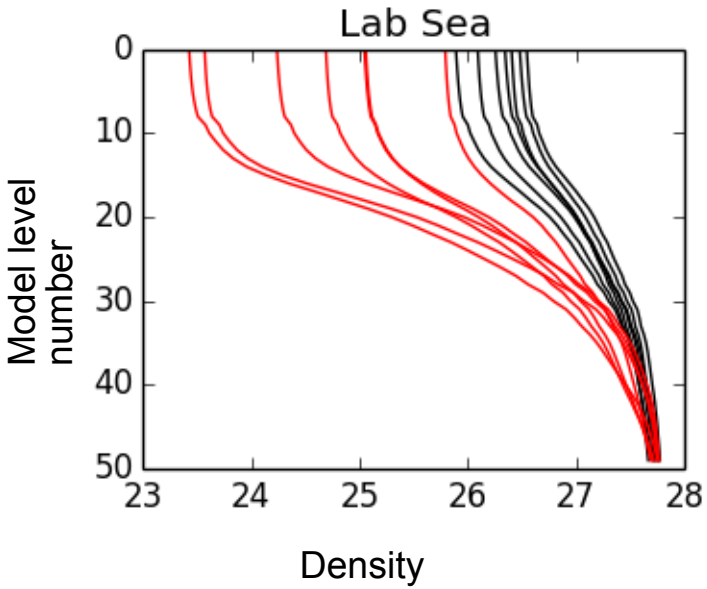

Does this mean that when the Lab Sea becomes sufficiently stratified and deep convection switches off that convection and the AMOC can't recover?

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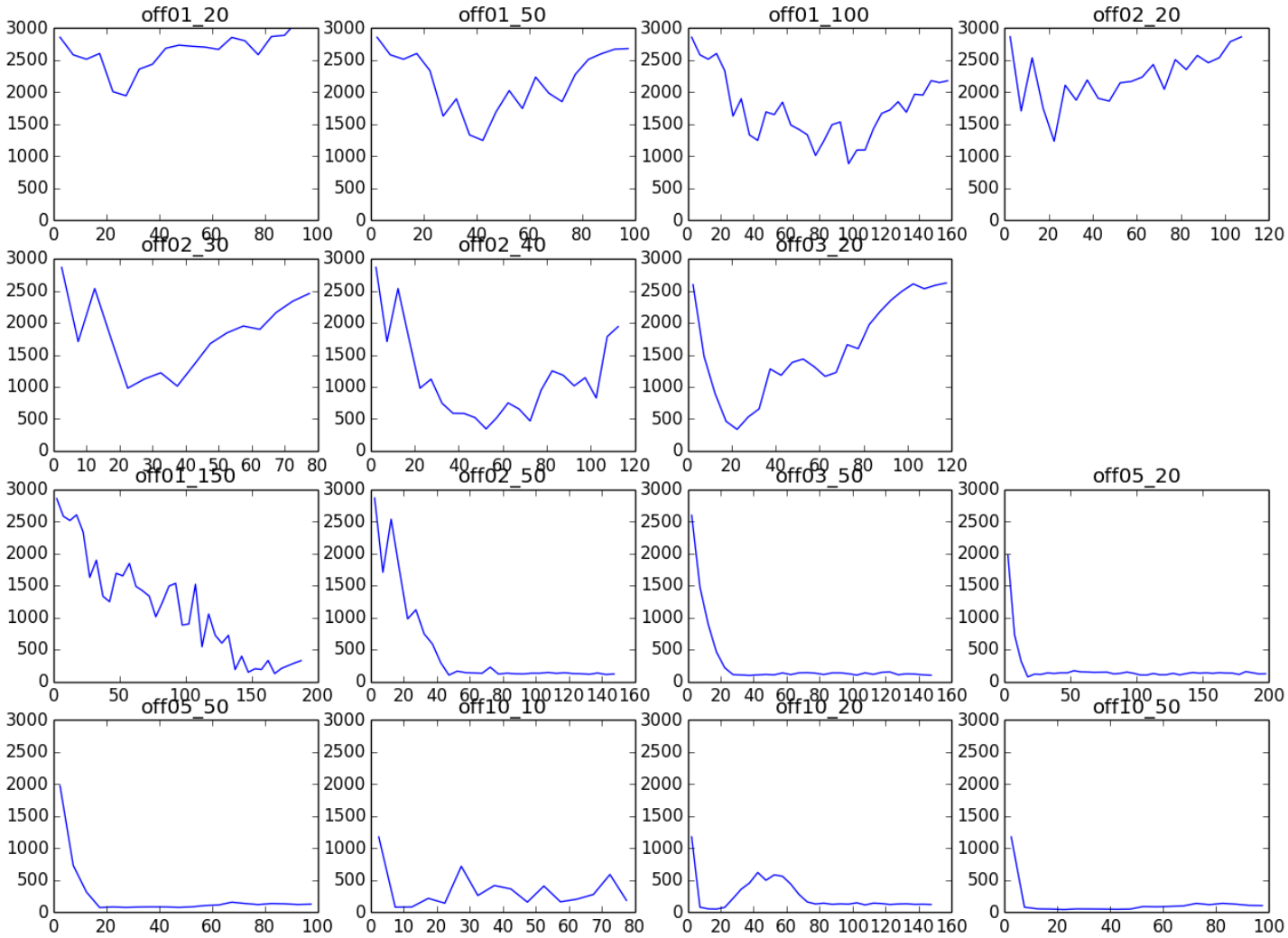

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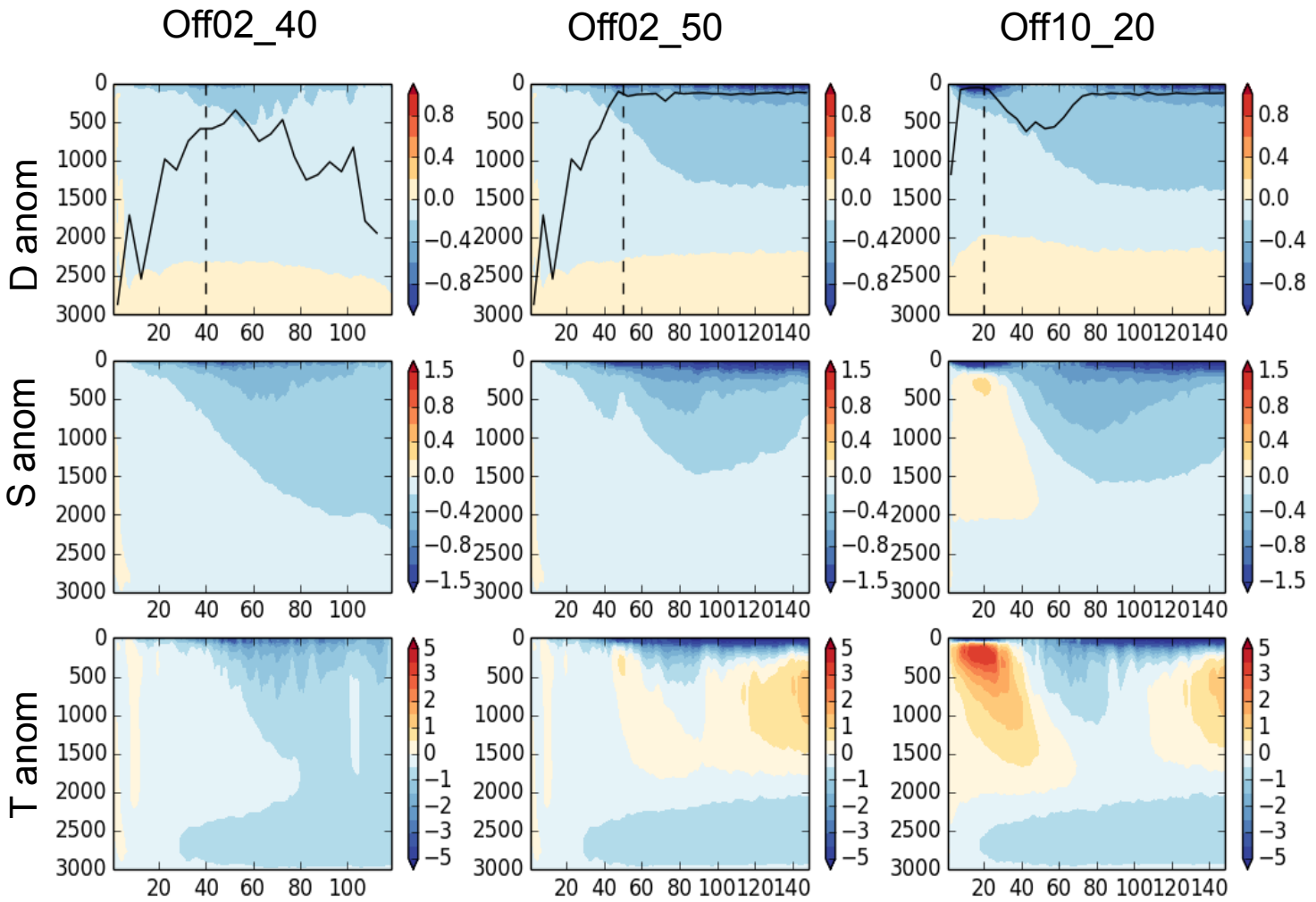

During hosing gets lighter/fresher and MLD decreases.

Off02_40: density and MLD recover. Deep convection mixes T,S

Off02_50: density and MLD do not recover. Cold and fresh at surface, no convection so heat gain at depth

Off10_20: Convection starts temporarily, before again getting fresher

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Open Questions

What determines the threshold (whether the AMOC recovers or not)?

What happens in a more realistic scenario/with increased greenhouse gases?

Why does this model behave differently from other GCMs?

- Resolution? – highest resolution (eddy permitting) used for such a study
- No Gent-McWilliams?
- ...?

And is it more representative of the real world?!

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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, this freshens the tropical N Atlantic, overcoming salinification from surface flux feedbacks.

Hence no saline anomalies advected northwards into sinking region

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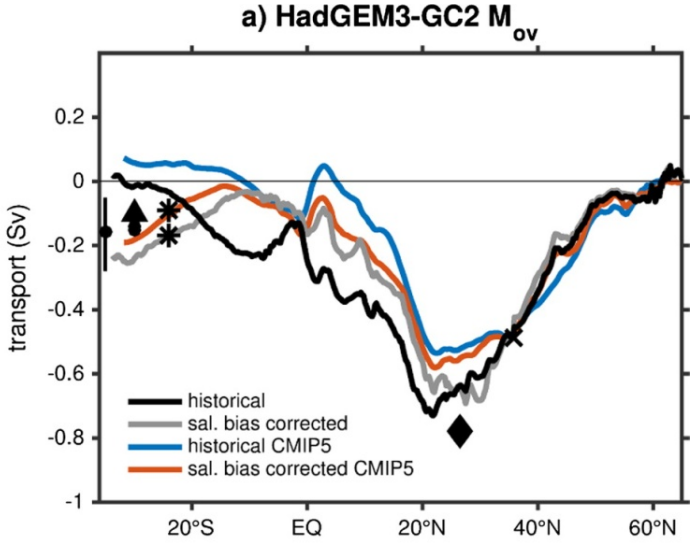

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Conclusions

AMOC exhibits hysteresis

There appears to be a threshold beyond which the AMOC does not recover.

- Less likely to recover when the AMOC weakening is greater
- Less likely to recover when the total FW input is greater

Appears to be a relationship with the convection in the Labrador Sea.

It is unclear why HadGEM3-GC2 has this behaviour, although one candidate is the increased, eddy-permitting, resolution

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Thanks.
Any questions?

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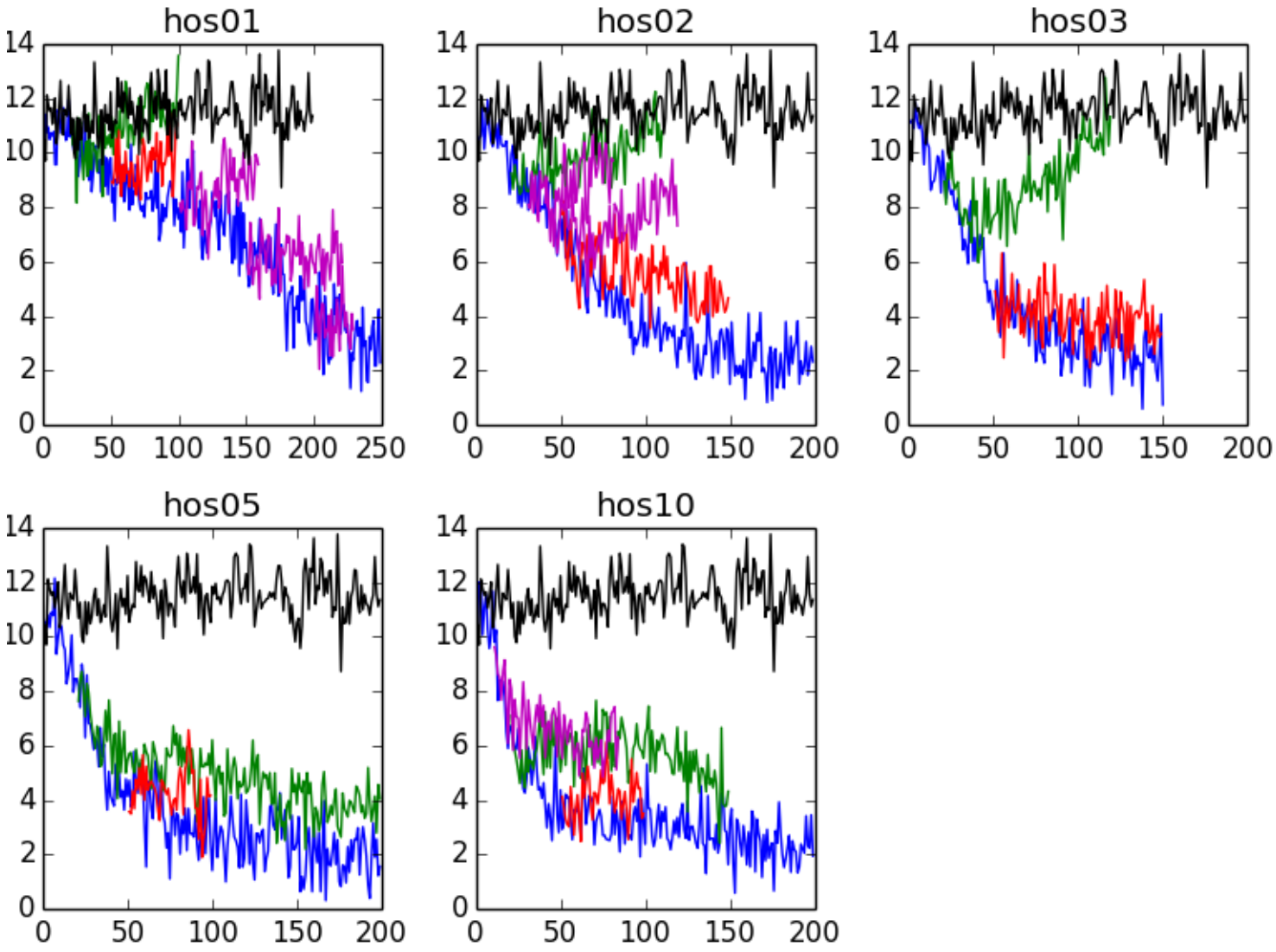

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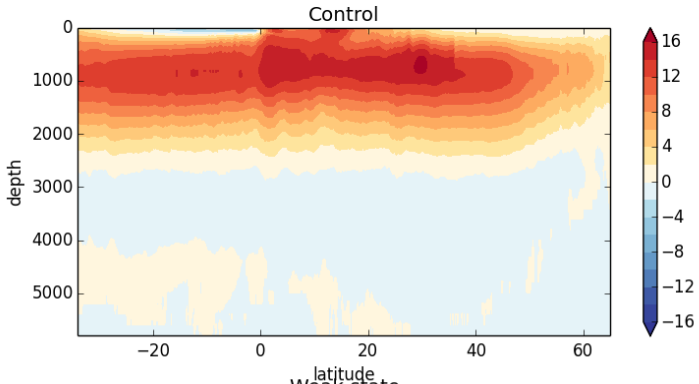

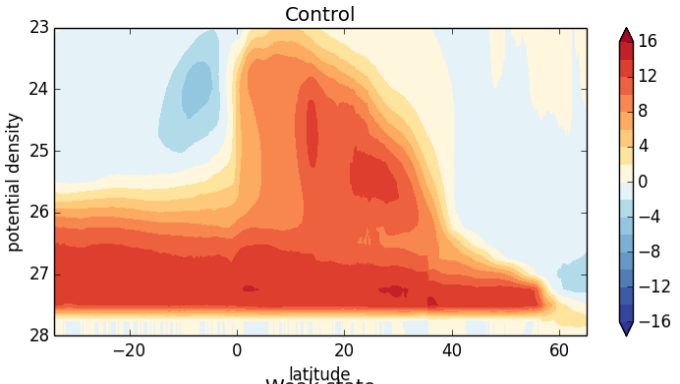

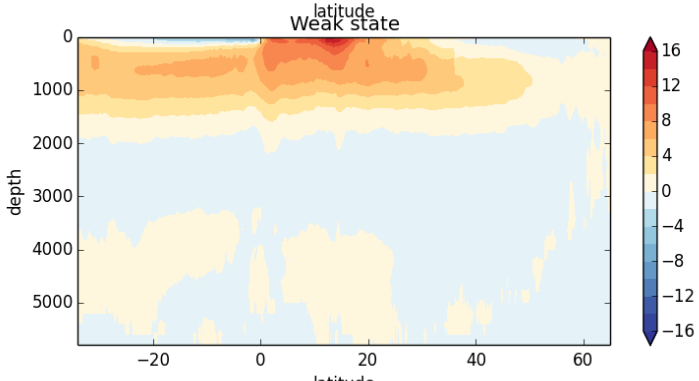

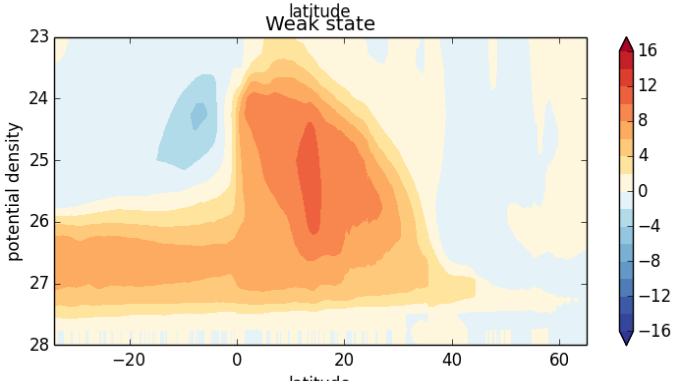

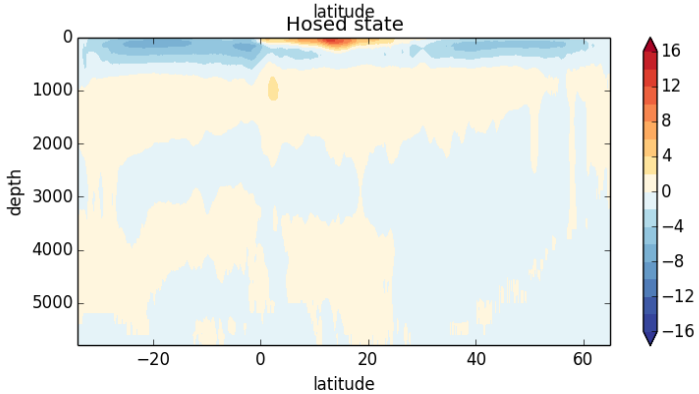

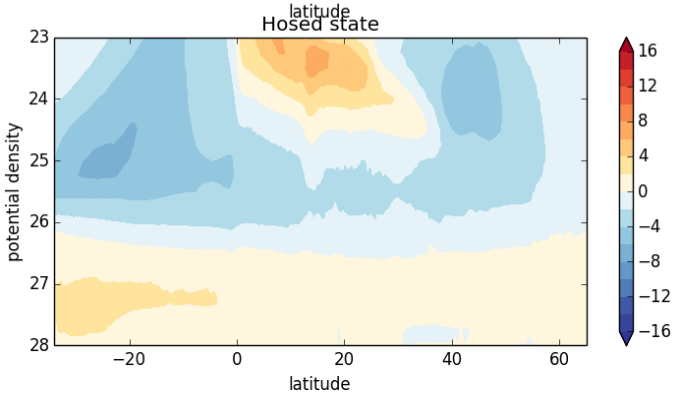

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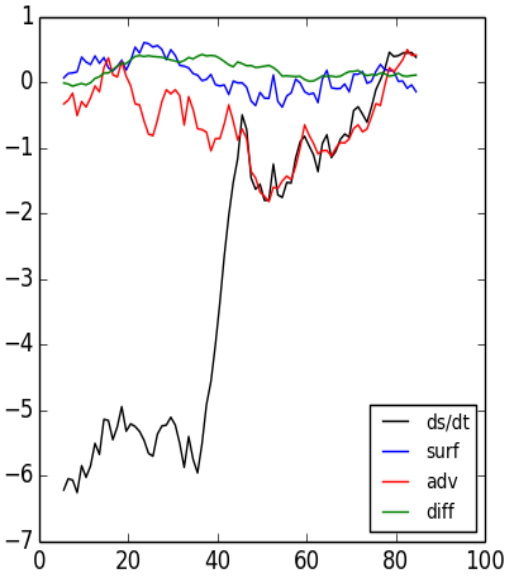
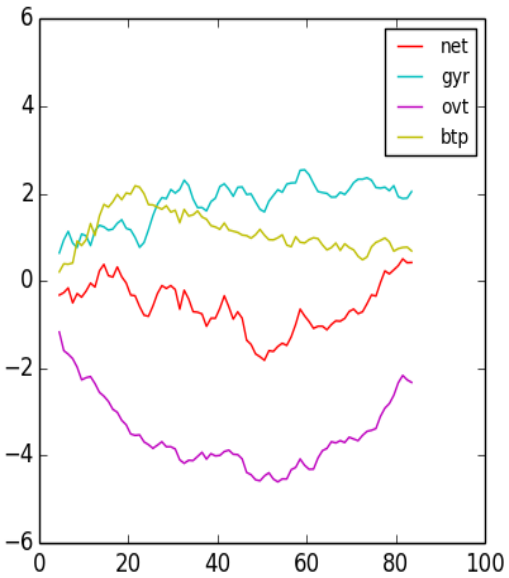
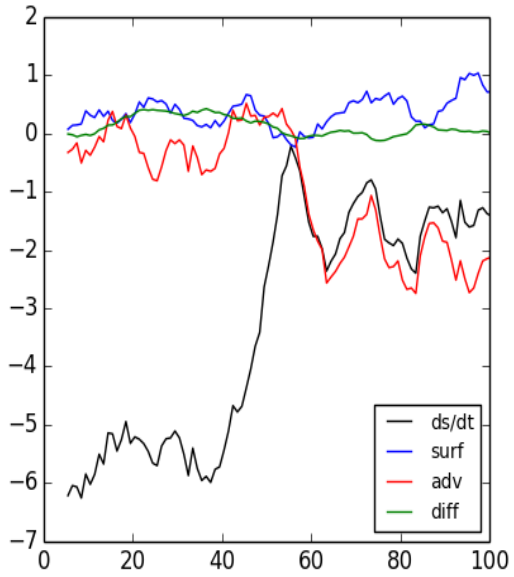
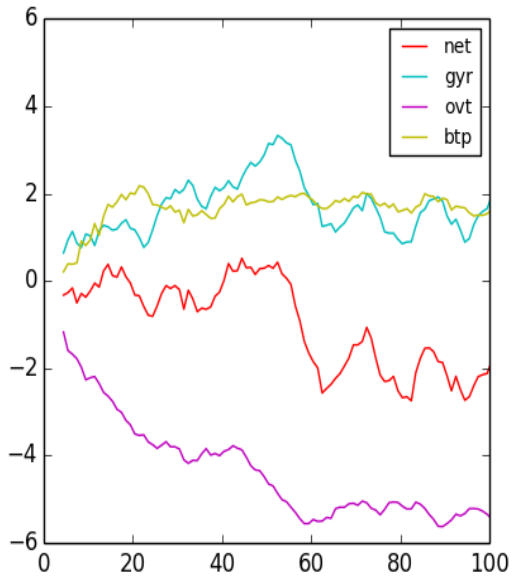
AMOC recovers





AMOC stays weak





During hosing, the freshening is opposed by the gyre (removing fresh anoms) and reinforced by the weakening AMOC (less import of saline water).

When the AMOC starts to recover it imports saline water, so density increases => positive feedback

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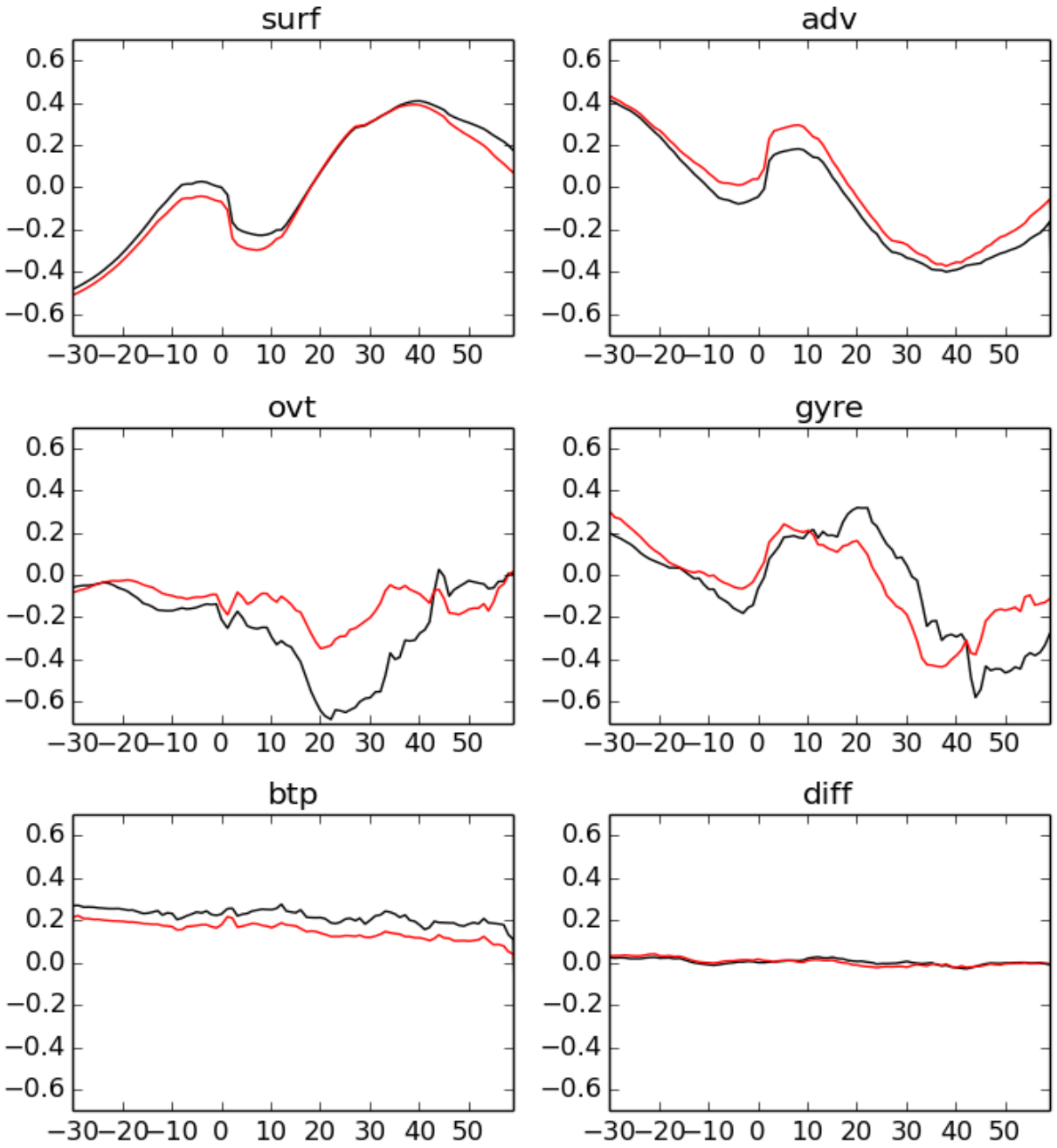

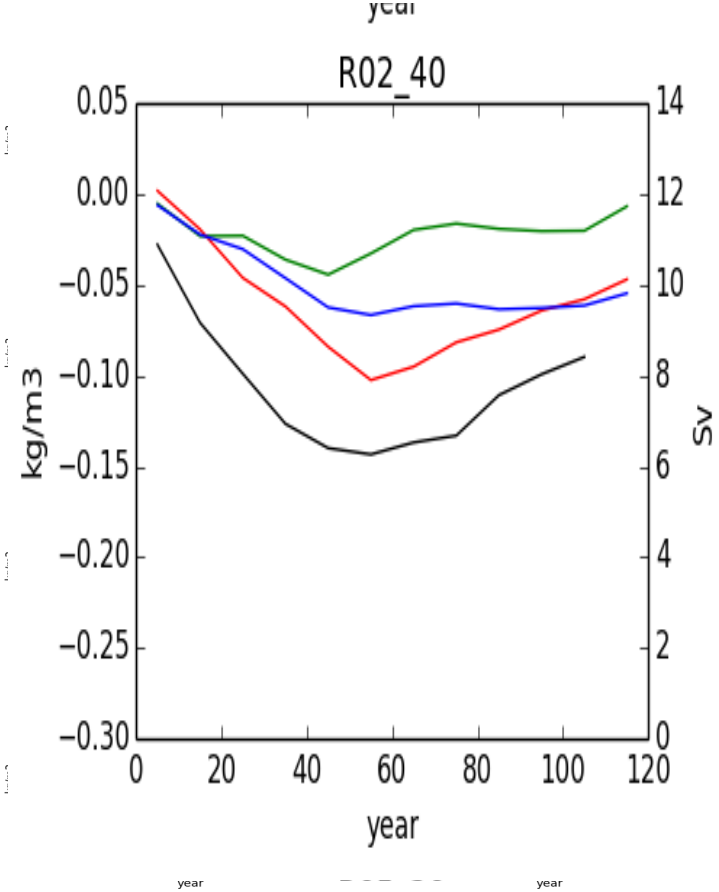

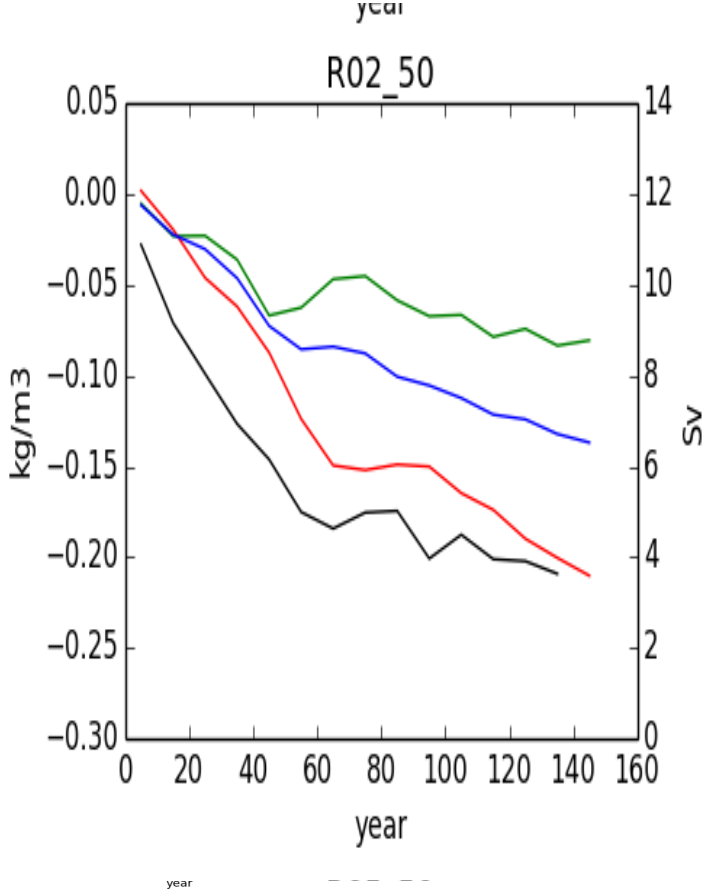

Surface density change (green, divided by 10) immediately starts to recover in both

Subsurface density only recovers in R02_40

In experiments when the AMOC does not recover, increasing surface salinity/density does not affect deeper salinities/ densities or the AMOC.

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