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Can increasing greenhouse gases cause tipping of the AMOC?

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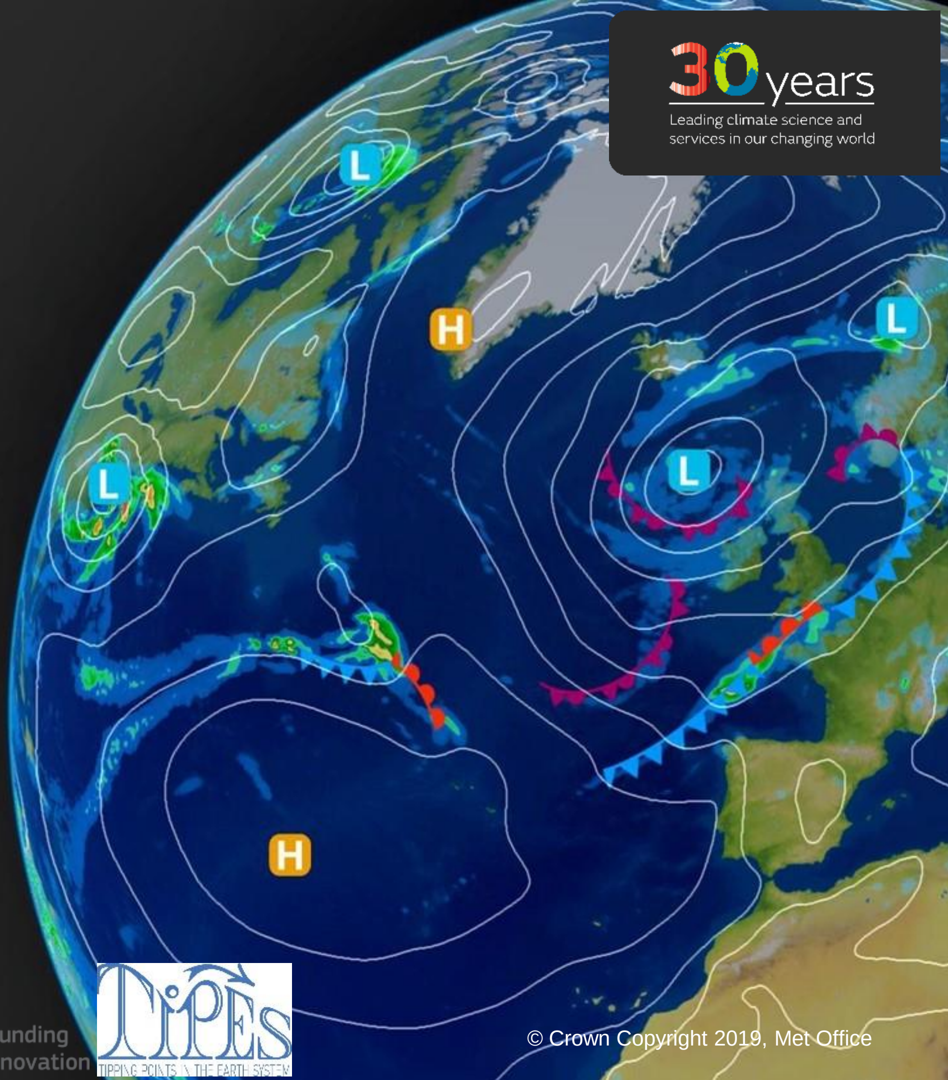

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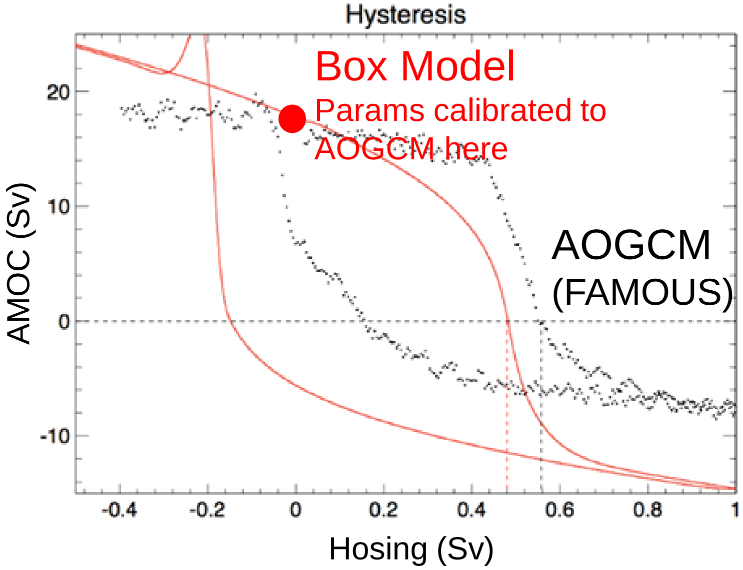
TIPPING POINTS IN THE EARTH SYSTEM

Summary

- Climate models show the possibility of AMOC tipping in response to fresh water forcing (‘hosing’)
- Fresh water forcing on its own is highly idealised. What about a more realistic case of warming *and* fresh water forcing?
- In an *equilibrated* climate at 2x pre-industrial CO_2, *more* hosing is needed to tip the AMOC than at $1xCO_2$. Stronger atmospheric water cycle in a warmer climate makes the Atlantic more evaporative and favours stability.
- What about *transient* warming scenarios?
- A simple model, *tested against GCM results*, can capture the key processes and allow us to explore safe mitigation pathways. Shows possibility of rate-dependent tipping in response to transient CO_2 increase.

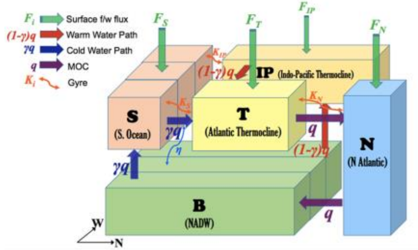
A simple box model captures the dynamics of AMOC hosing hysteresis in an AOGCM

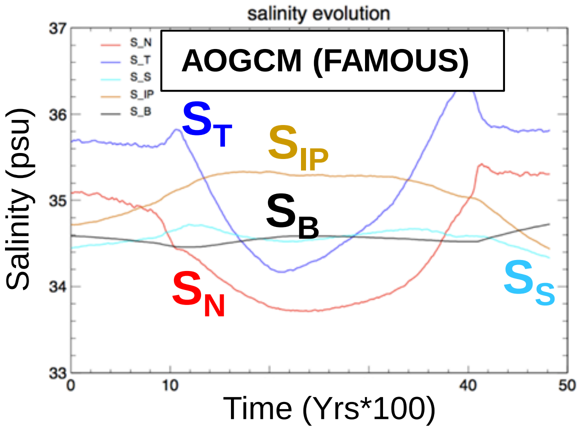


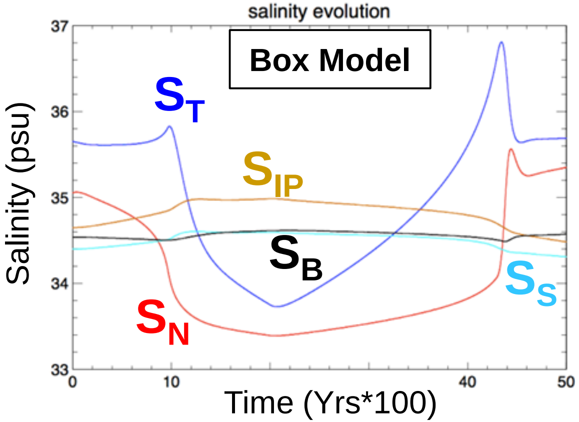
Box model has salinity dynamics only (fixed temperatures in North Atlantic and S. Ocean)

Captures dynamics of AMOC tipping in hosing (water forced) expts.

But what about a global warming scenario?







Wood et al. Clim. Dyn., 2019

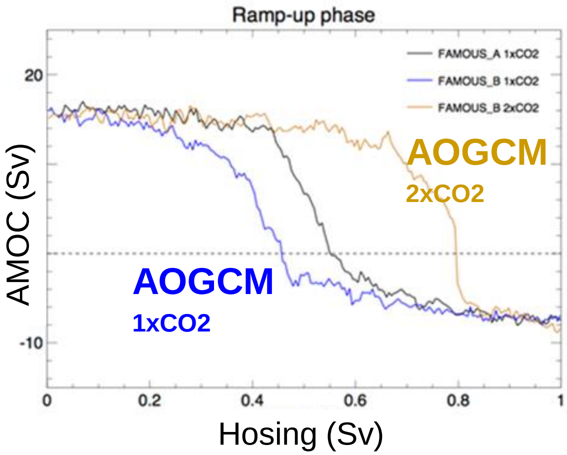
Warming scenarios Step 1: In a warmer (equilibrated) climate, *more* fresh water is needed to tip the AMOC!

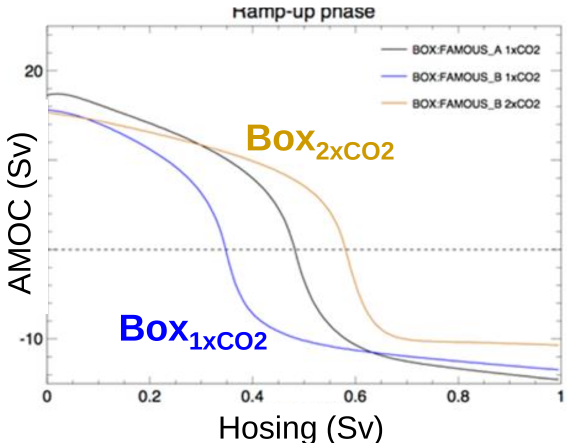
A hosing experiment is run with the AOGCM spun up at 1 x pre-industrial CO_2. The AMOC collapses at about 0.45Sv hosing.

The AOGCM is spun up for 920 years with 2 x pre-industrial CO_2. Then the hosing experiment is repeated. The AMOC collapses at about 0.8Sv hosing.

More hosing is needed to tip the AMOC at increased CO_2. Why?

The box model parameters are re-calibrated to the 1xCO2 and 2xCO2 AOGCM states, then the hosing experiments are repeated. Again more hosing is needed at $2xCO_2$





Wood et al. Clim. Dyn., 2019

Warming scenarios Step 1: Why is more hosing needed to tip the AMOC in a warmer climate?

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We use the change in box model parameters (calibrated to the AOCGM 1xCO_2 and 2xCO_2 states) to see why more hosing is needed.

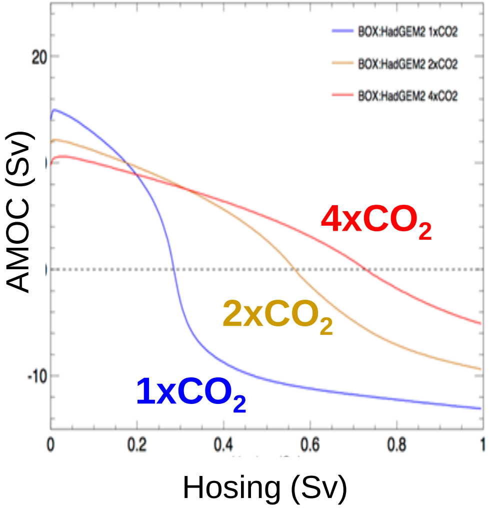
Three factors drive the tipping point to higher hosing at increased CO_2:

a. Strengthening water cycle in warmer climate. Atlantic basin becomes more evaporative.
b. Increase in the thermal driving of the AMOC.
c. Changes in the gyre fresh water transports.

Of these, (a) is a robust feature of climate change simulations, (b) may be robust (but really needs a model with an active heat variable – see next slide), and (c) is model-dependent.

We see the same response calibrating to a different AOGCM (Figure).

Box model calibrated to HadGEM2-ES



Wood et al. Clim. Dyn., 2019

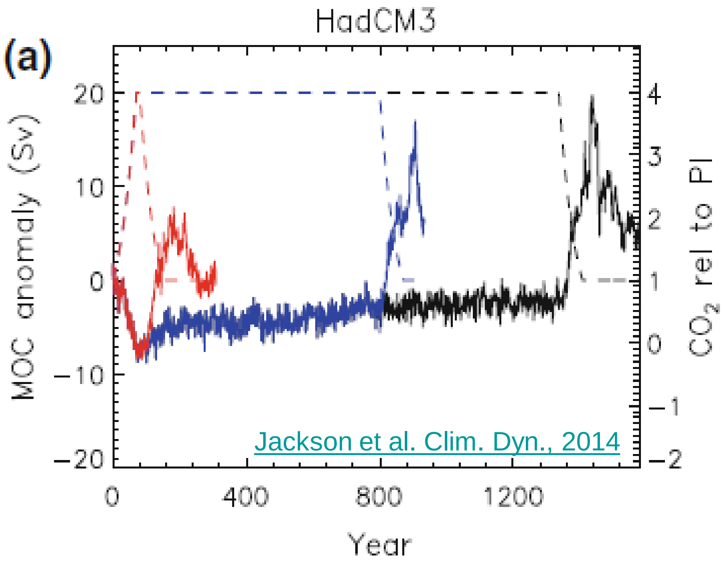
Warming scenarios Step 2: Can *transient* warming cause tipping?

Transient CO_2 increase/warming causes AMOC to weaken, but if CO_2 is then stabilised the AMOC generally recovers (e.g. Figure, seen in many AOGCMs)

Recovery is usually due to stored salty anomalies in the subtropics, but differential warming rates in N Atlantic and S Ocean can also contribute

Can transient CO_2 increase that is large/fast enough trigger a quasi-permanent collapse?

Extend box model to include active temperature variables and energy cycle, linked to an atmospheric water cycle and Greenland melt that strengthen with warming temperature…



Warming scenarios Step 2: Rate-dependent tipping in response to transient CO_2 increase

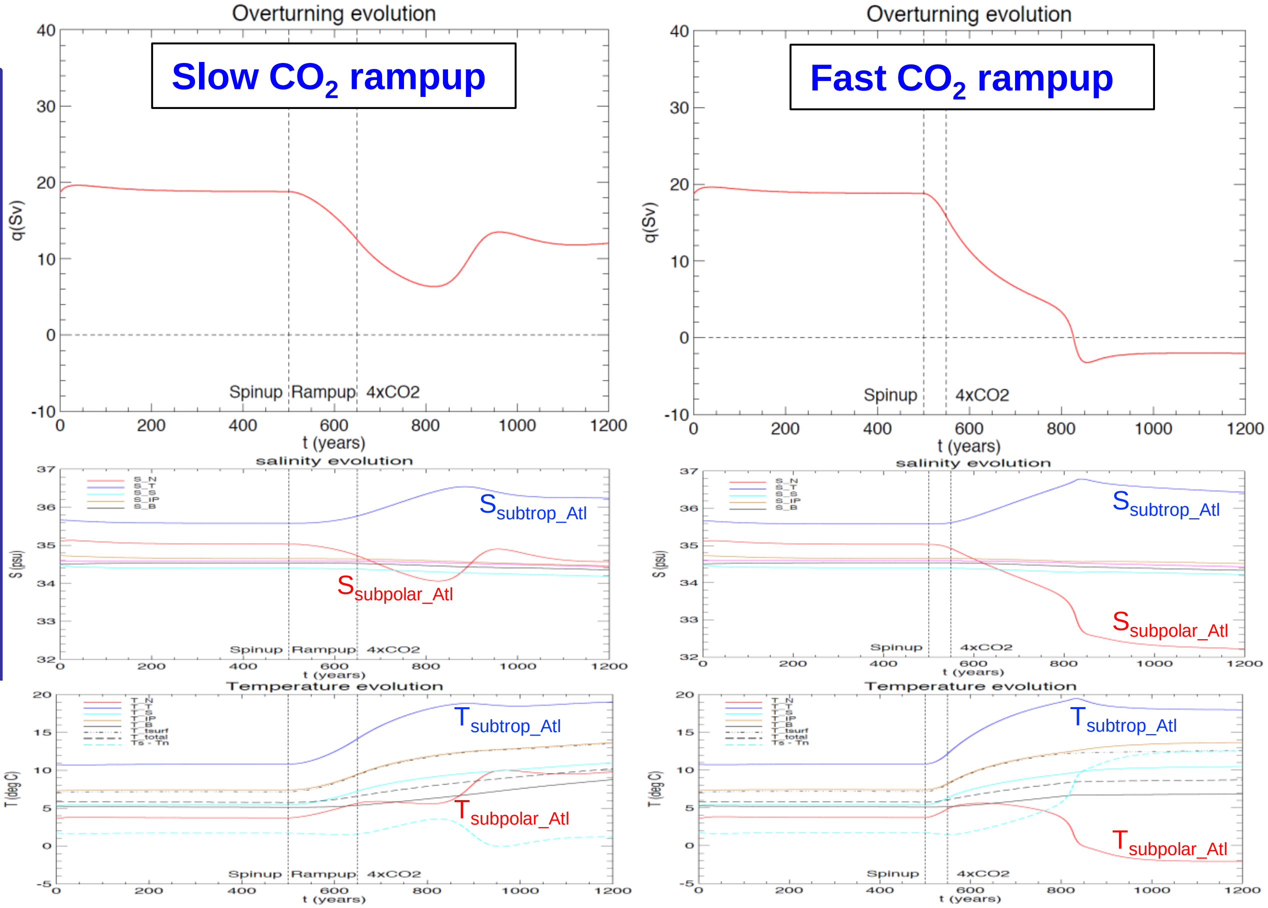
Thermohaline box model:

Spinup (500 yrs) + Ramp up to $4xCO_2$ (R yrs) + Stabilise @ $4xCO_2$

Slow ramp up (150 yrs): AMOC weakens then partly recovers

Fast ramp up (50 yrs): AMOC collapses

Use this to explore 'safe' mitigation pathways?



(cf.Stocker & Schmittner, Nature 1997)

References

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This work. Box model, traceability to AOGCM, and response of threshold to increased CO_2:
Wood, R.A., J. Rodriguez, R.S. Smith, L.C. Jackson and E. Hawkins, 2019: Observable, low-order dynamical controls on thresholds of the Atlantic Meridional Overturning Circulation. *Climate Dyn.*, **53**, 6815-6834, https://doi.org/10.1007/s00382-019-04956-1

Examples of AMOC recovery following stabilization of CO_2 in AOGCMs:
Jackson, L.C., N. Schaller, R. S. Smith, M. D. Palmer and M. Vellinga, 2014: Response of the Atlantic meridional overturning circulation to a reversal of greenhouse gas increases. *Climate Dyn.*, **42**, 3323–3336, https://doi.org/10.1007/s00382-013-1842-5

A (the?) previous example of rate-dependent AMOC tipping in response to CO2 increase:
Stocker, T.F. and A. Schmittner. 1997: Influence of CO2 emission rates on the stability of the thermohaline circulation. *Nature*, **388**, 862-865