Reducing the Risk of a Collapse of the Atlantic Thermohaline Circulation

U.S. Climate Change Science Program Workshop:
Climate Science in Support of Decisionmaking

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Michael Schlesinger

Climate Research Group, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign

Mass Transport (Sv = 10^6 m^3/sec) of the Atlantic Ocean Simulated by the UIUC Coupled Atmosphere-Ocean General Circulation Model (CGCM)

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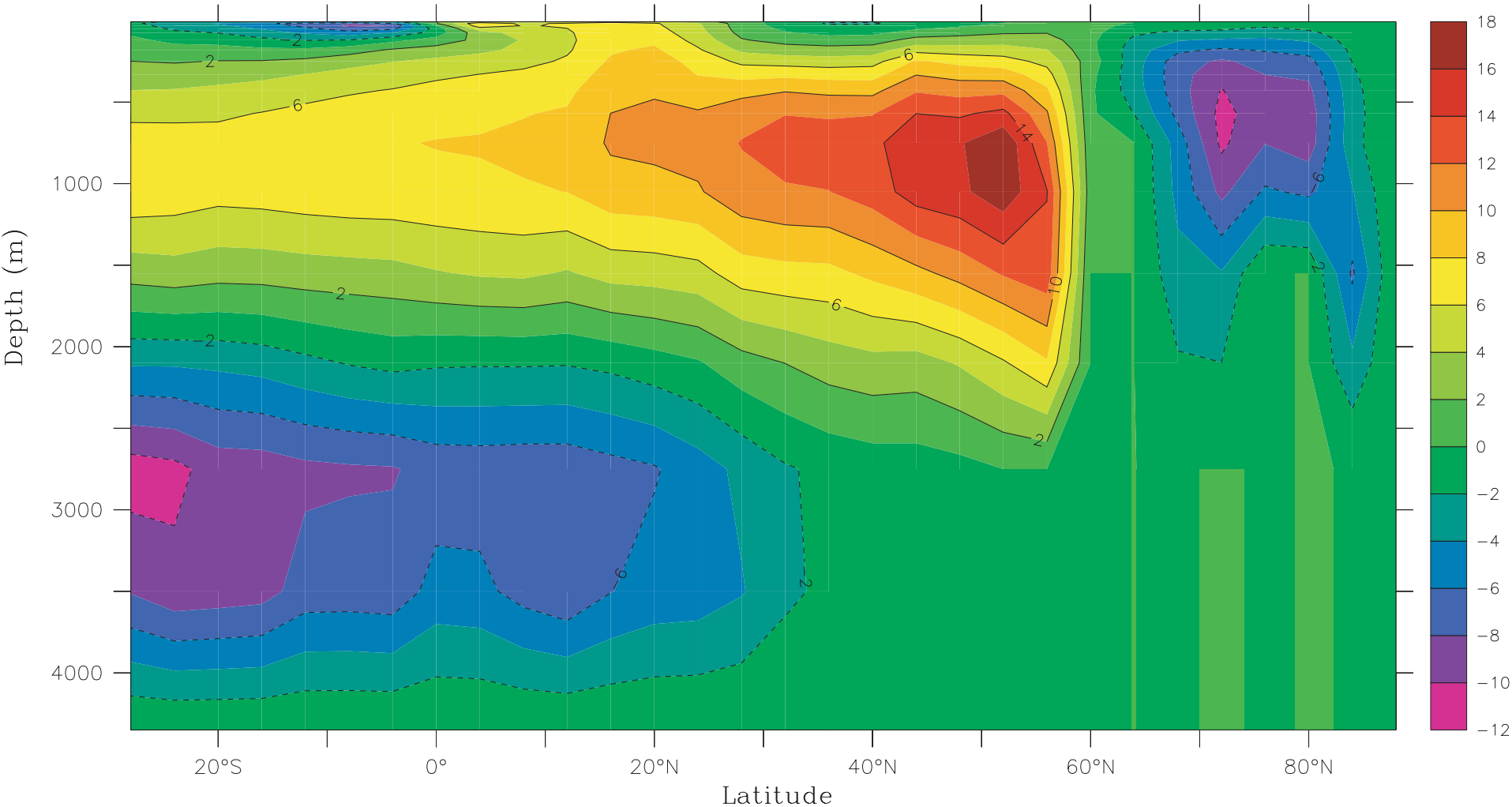

Ocean Currents in the Atlantic Ocean Simulated by the UIUC CGCM

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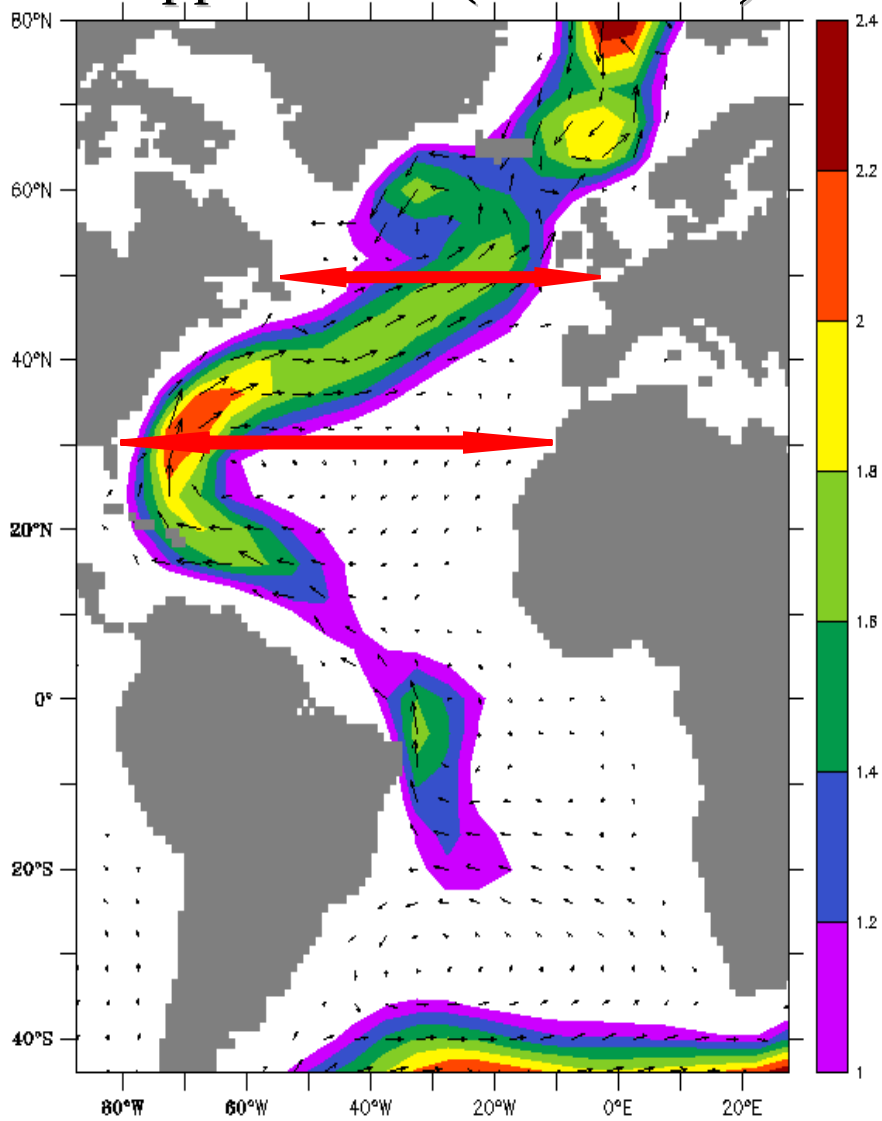
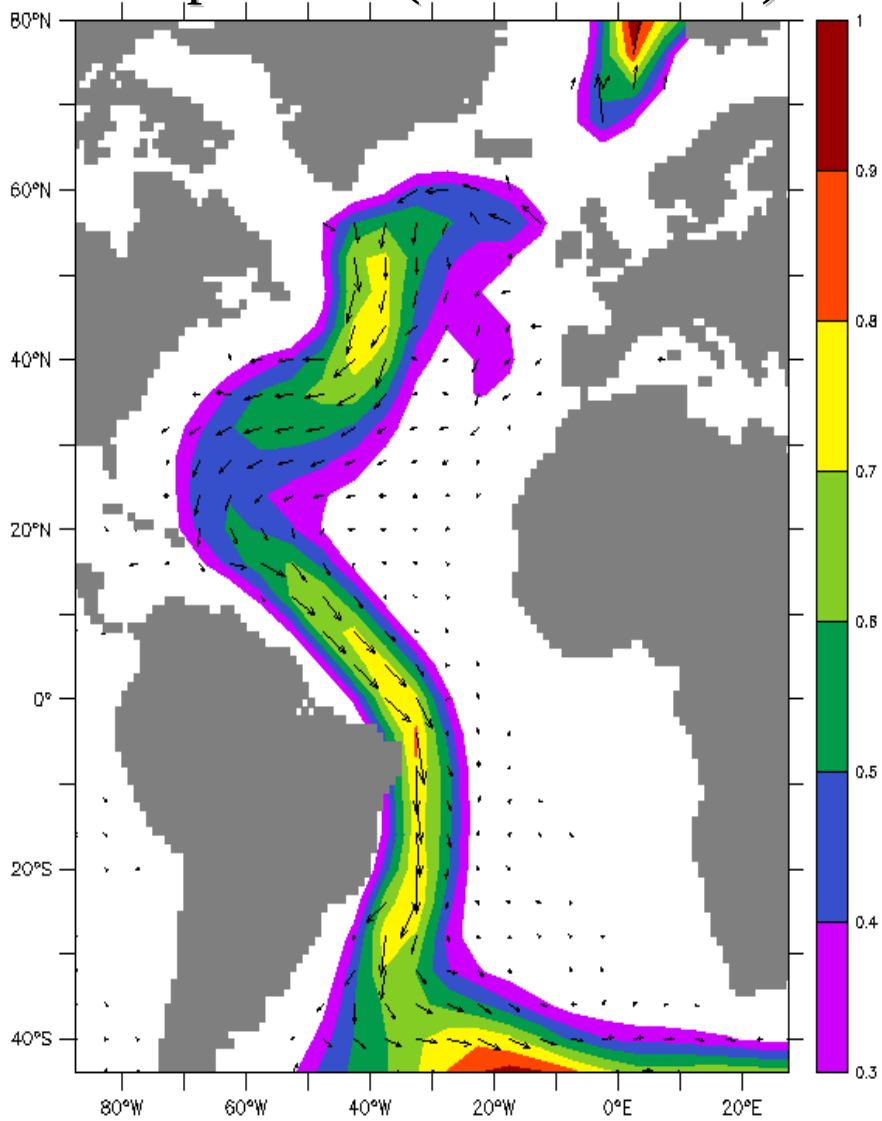
Upper ocean (0~1000 m)

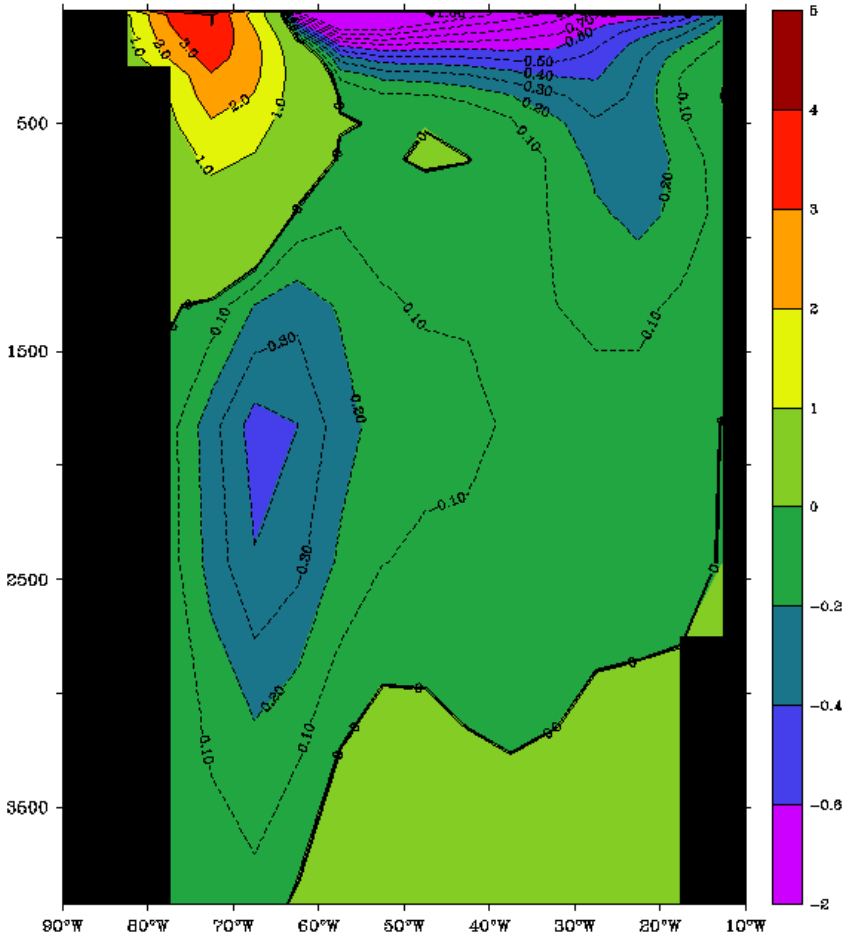


Deep ocean (1000~3000m)



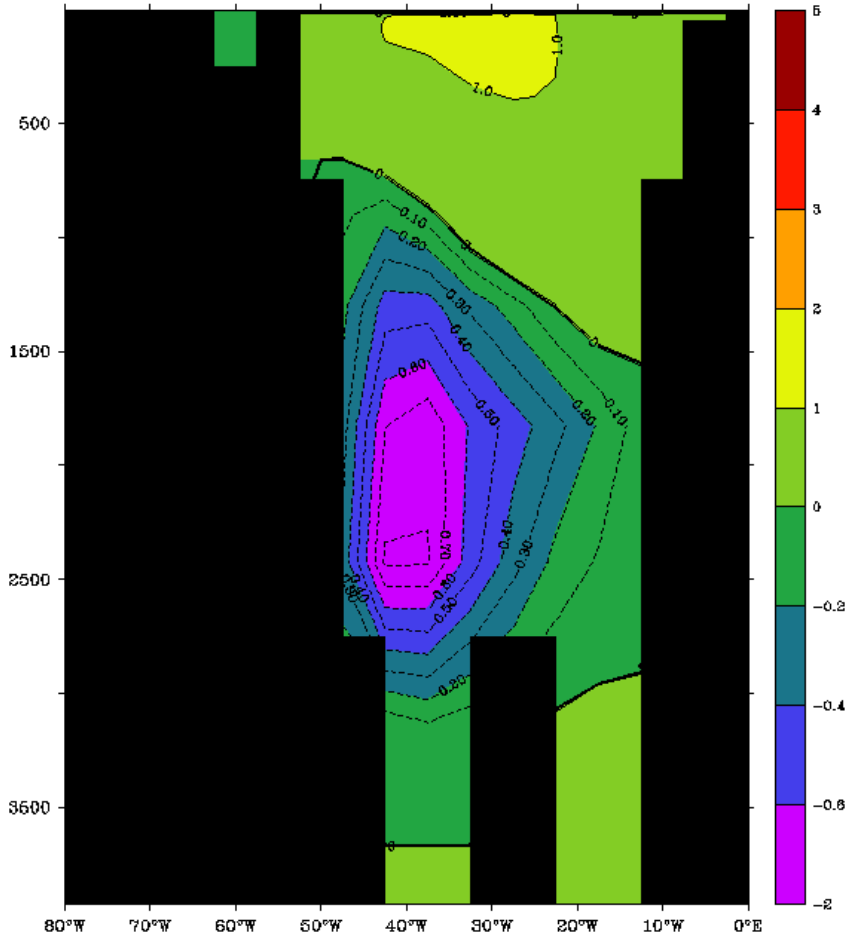
Longitude-Depth Cross-sections of currents (cm/s) in the North Atlantic Simulated by the UIUC CGCM

30° N



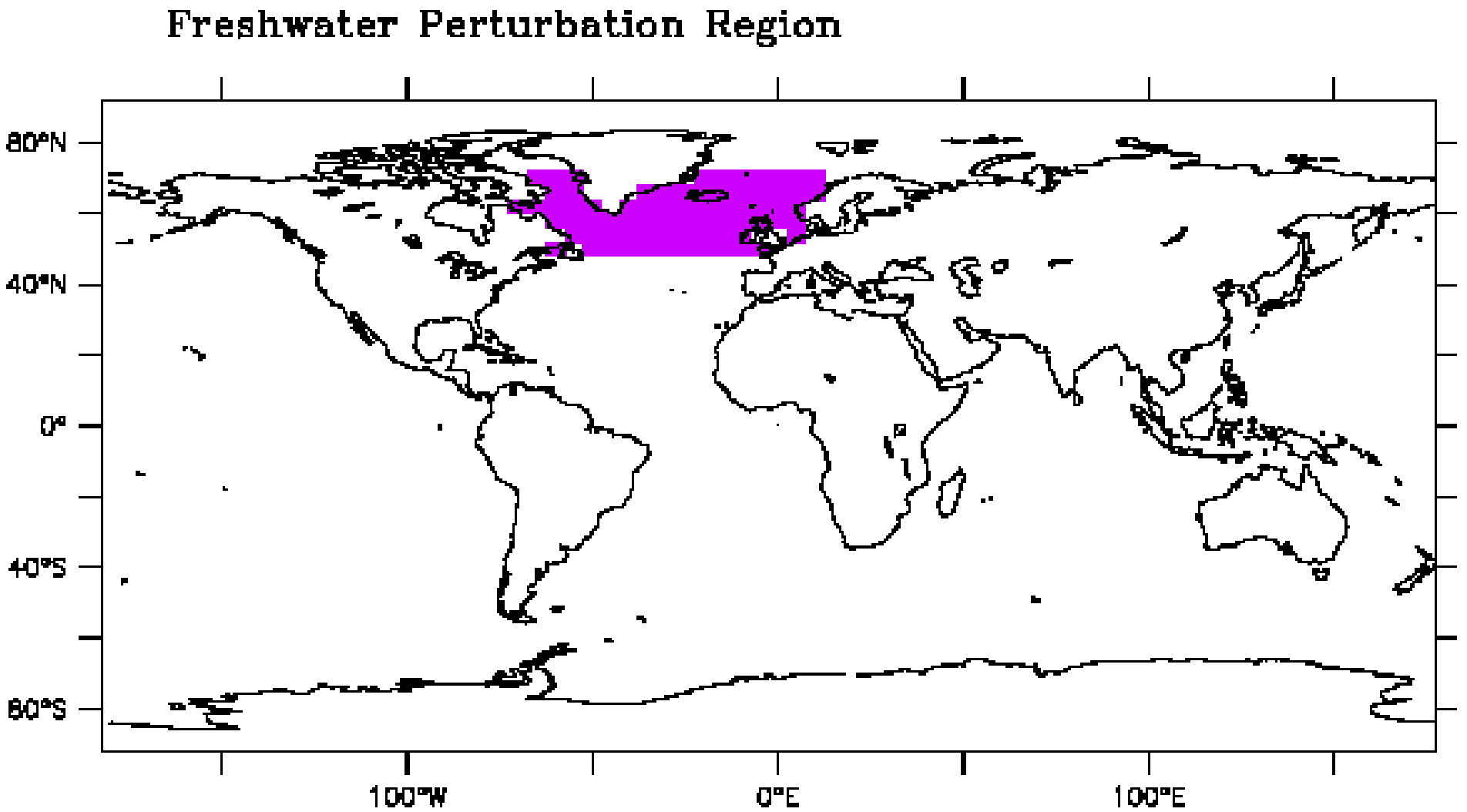
N. America Europe

50° N

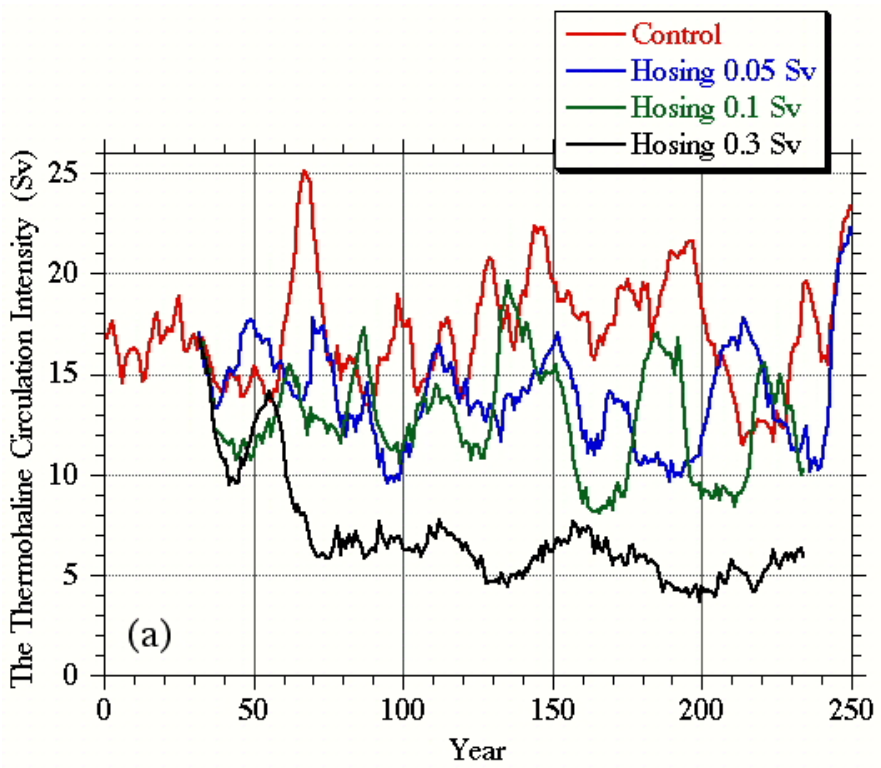


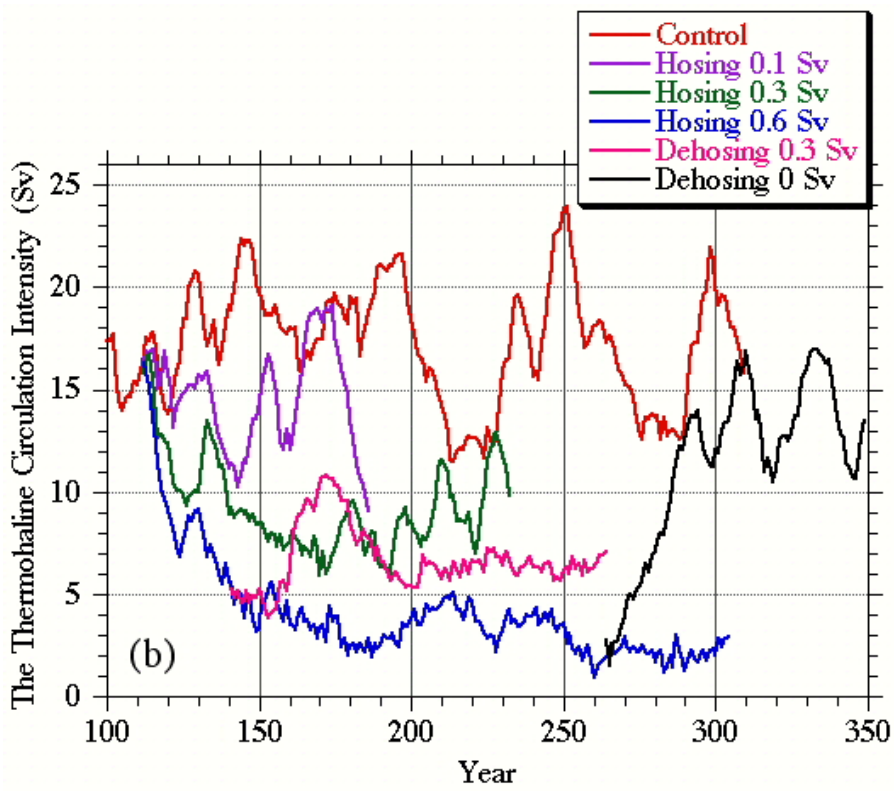
N. America Europe

Region of the North Atlantic Ocean Where Freshwater Is Added



Intensity of the Thermohaline Circulation (THC, Sv) Versus Time as a Function of the Amount of Freshwater Added





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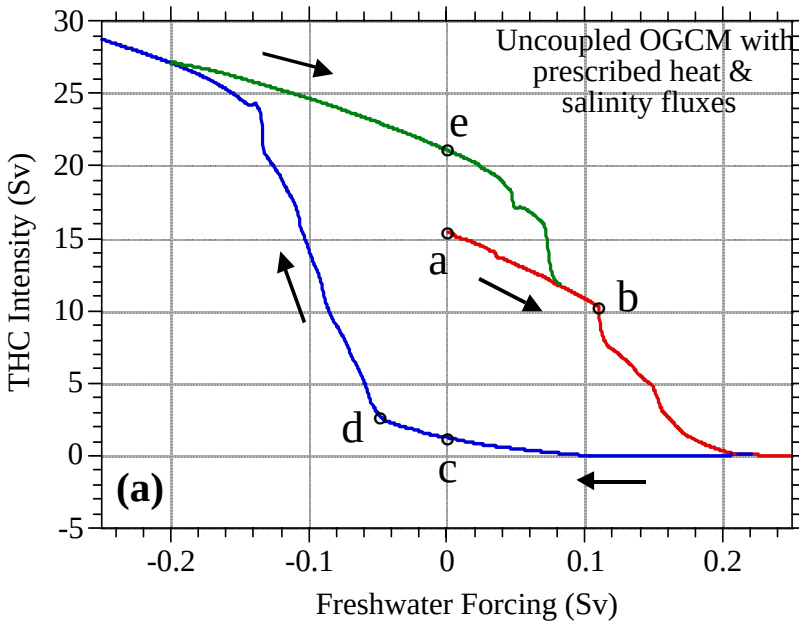
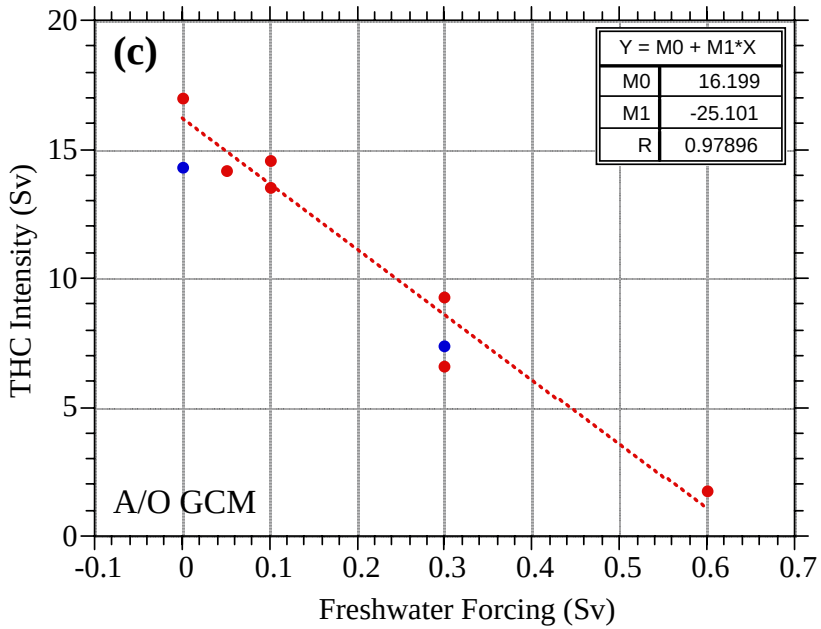
THC Intensity As Freshwater Is First Added (Hosing) to and then Removed from (De-hosing) the from the North Atlantic Ocean





The Uncoupled Ocean GCM shows hysteresis and thus an irreversible Shutdown of the THC

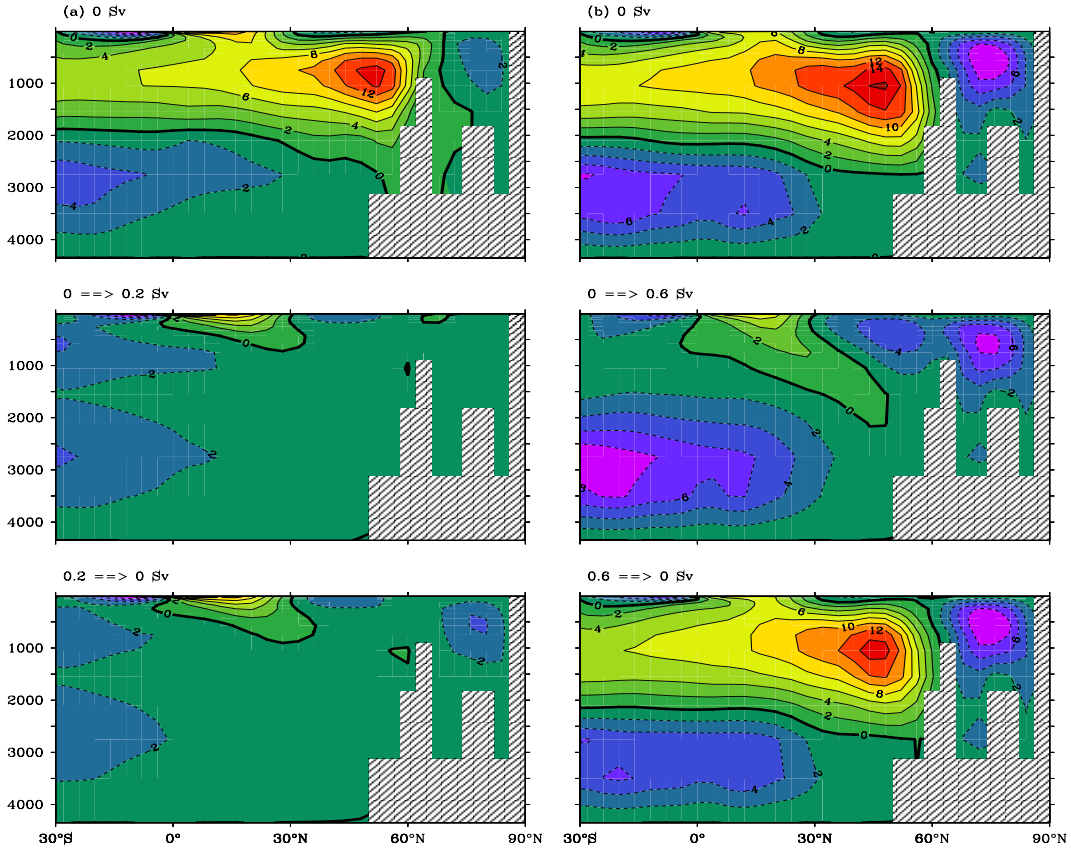
The Coupled Atmosphere-Ocean GCM shows no Hysteresis and thus a reversible shutdown of the THC

THC Intensity in Uncoupled OGCM (left) & CGCM (right)

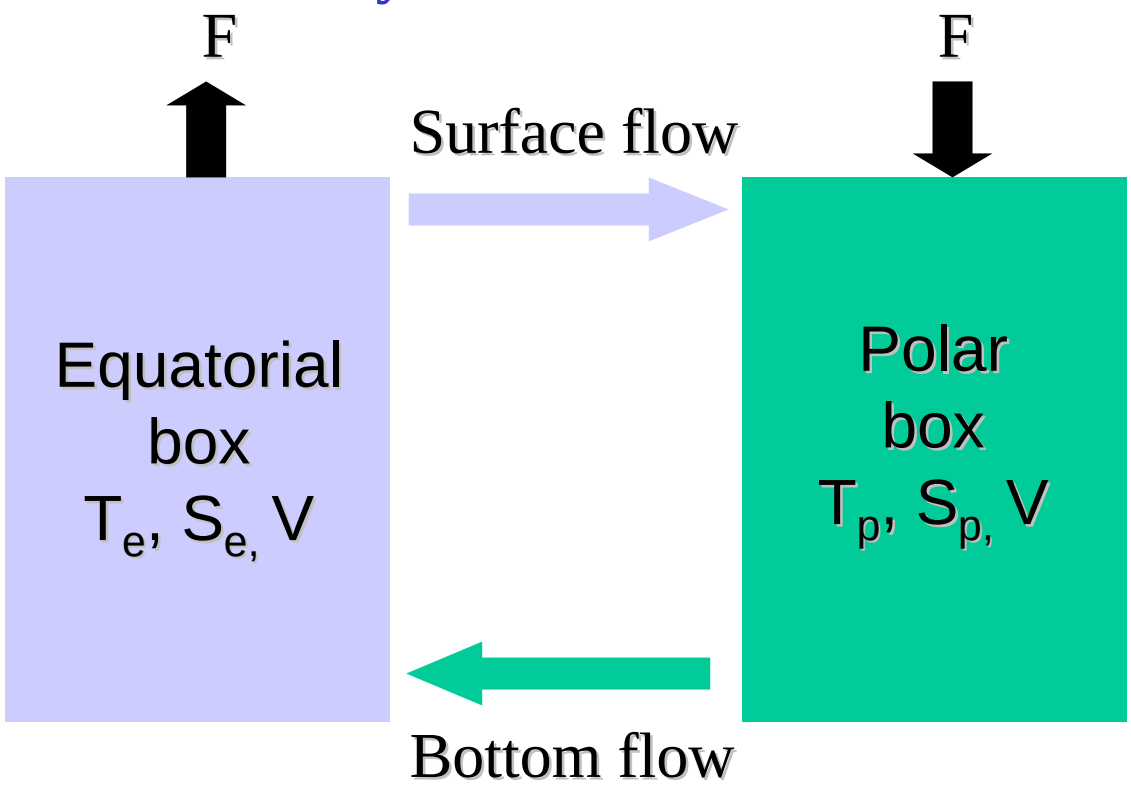
With no freshwater added

With enough freshwater added to shutdown THC

With Removal of freshwater addition

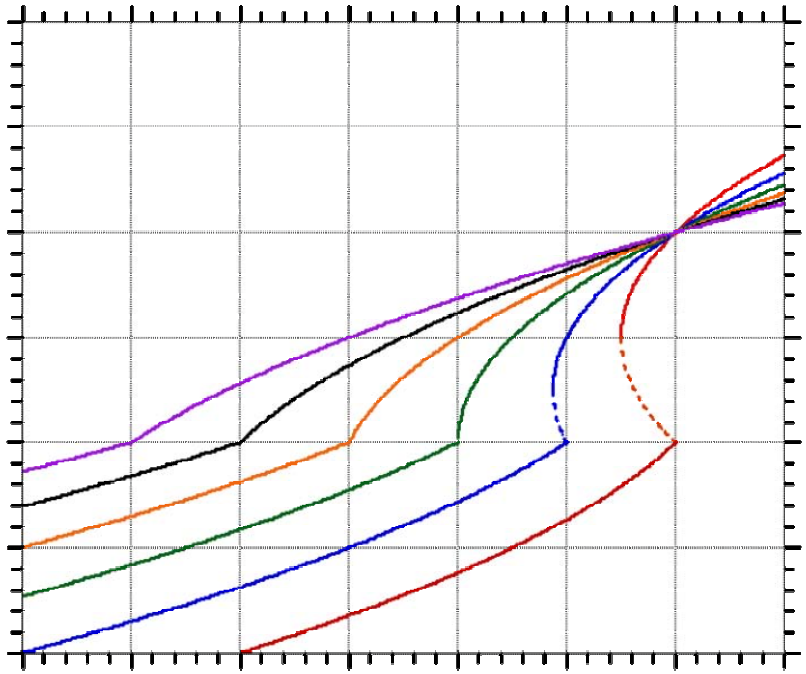


The Stommel Two-Box Model (1961) of the THC Generalized to Include Salt Transport by the Ocean Gyre and Eddies

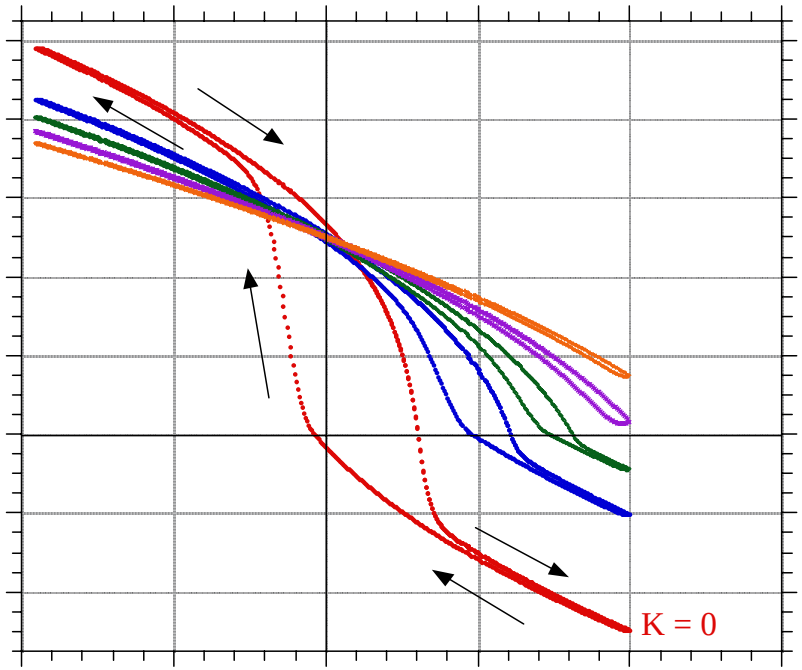


K is the ratio of the transport coefficient for the gyre circulation and eddies, to that for the THC.

Stability (left) and Dynamics (right) of the Generalized Stommel Model



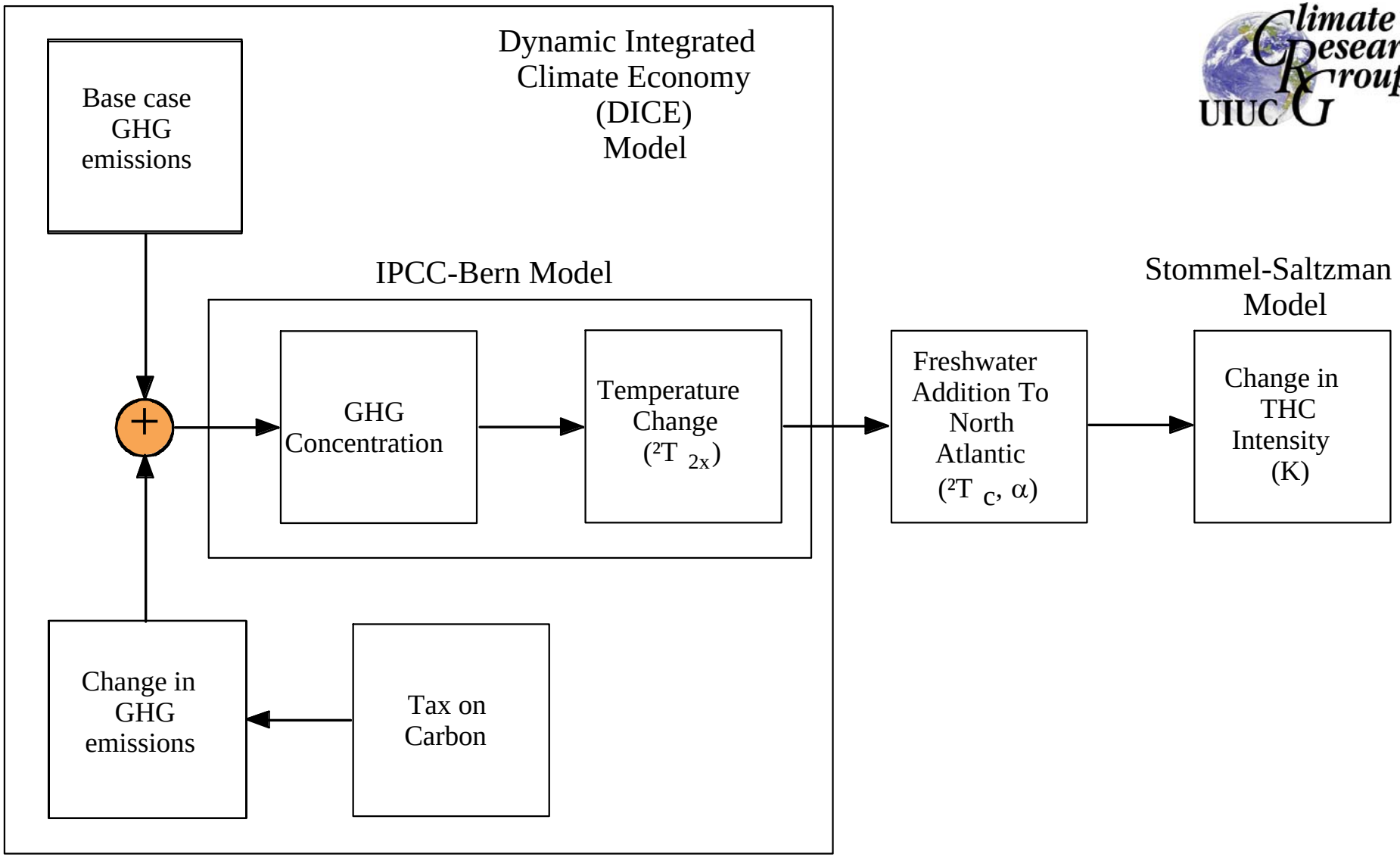
Stability Diagram



Hosing/De-Hosing

The generalized Stommel model reproduces the nonlinear Dynamics of both the uncoupled OGCM and CGCM

Integrated Assessment Model Together With The Generalized Stommel Model



Uncertain Quantities in the Model

ΔT_{2x}, climate sensitivity: 9 values from 1.5°C to 9.0°C taken with probability p_i , i = 1, …, 9 given by Andronova & Schlesinger (2001, Geophys Res. Let.);

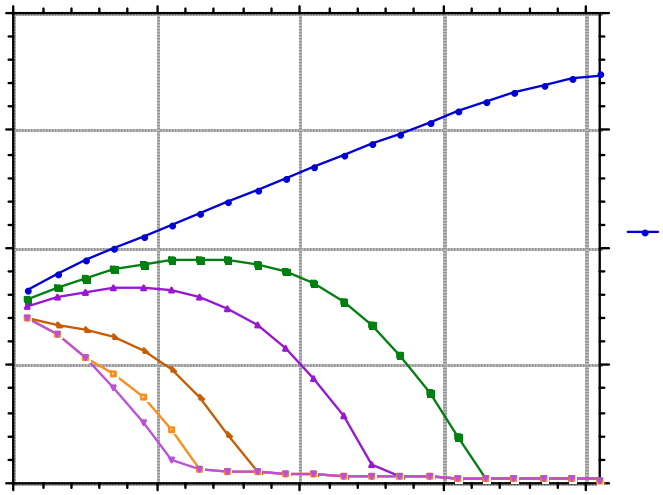
ΔT_c, threshold of temperature change since 1856 for onset of a THC slowdown: 7 values taken from 0°C and 0.6°C in 0.1°C increments, each with equally likely probability;

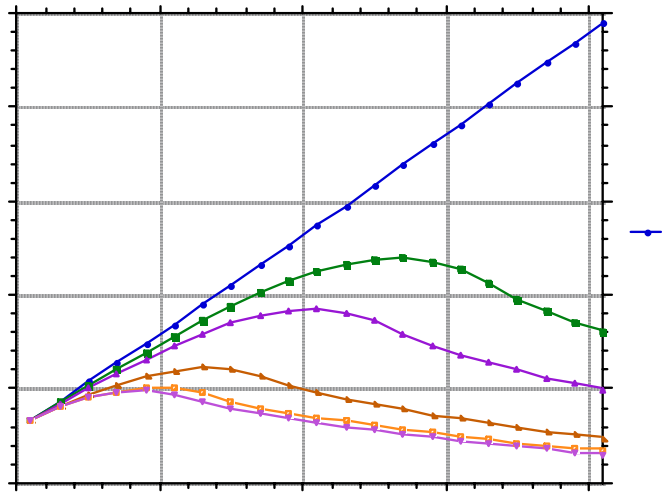
α, hydraulic sensitivity – amount of freshwater added to North Atlantic per degree of global warming: 5 values from 0.2 to 1.0 in 0.2 increments, each with equally likely probability;

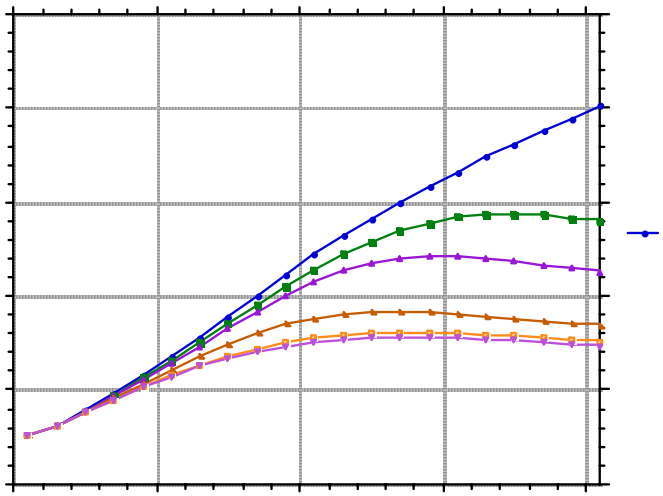
K, ratio of poleward salt transport by non-THC (gyre & eddies) to that by THC: 5 values from 0 to 2.5 in 0.5 increments, each with equally likely probability;

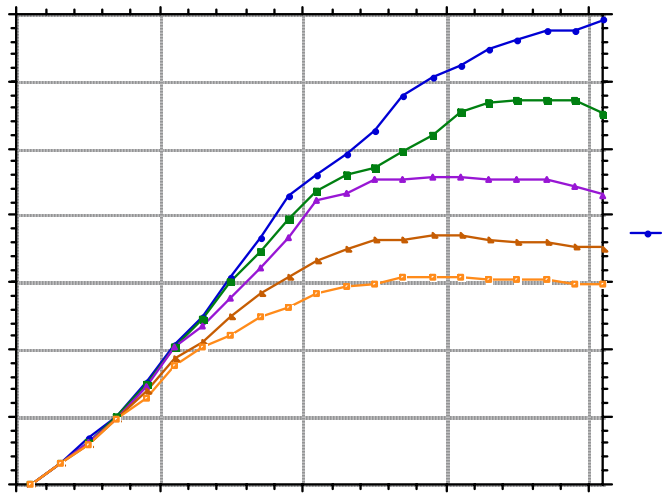
All 9x7x5x5 = 1575 combinations run. The relative likelihood of any combination depends on the underlying ΔT_{2x} according to $\{p_i/1575\}$.

CO_2 Emission & Concentration, Temperature Change & Likelihood of a THC Shutdown Versus Time for a Reference Basecase and for an Initial Carbon Tax Which Grows with Time

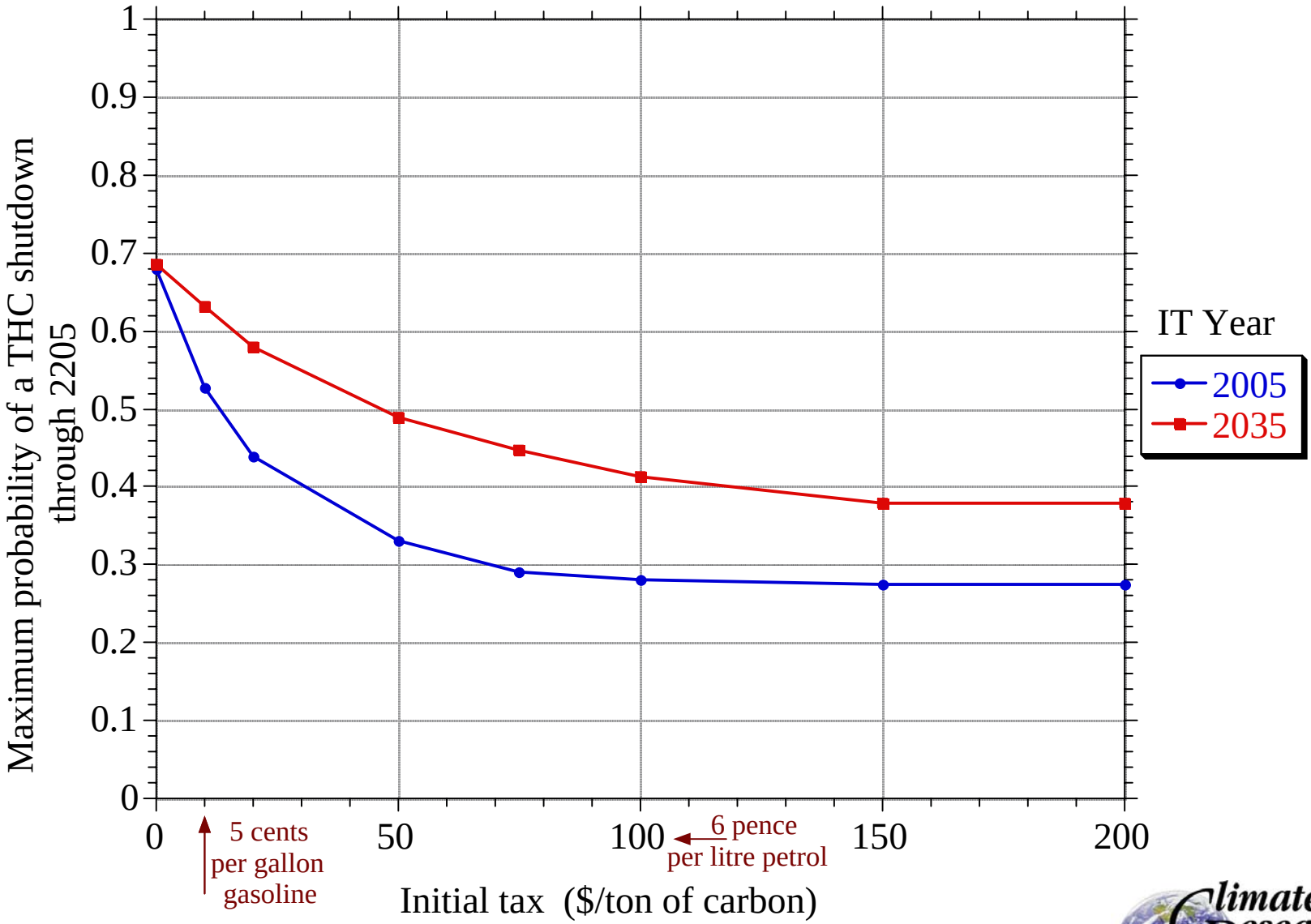








Maximum Probability of a THC Shutdown Versus Initial Tax Starting in Either 2005 or 2035



Conclusions

- Absent climate policy, the likelihood of a THC collapse sometime over the next 200 years is more than 2 chances in 3.
- The likelihood declines with mitigation, but even the most rigorous immediate climate policy would leave a 1 in 4 chance of a THC collapse.
- Waiting 30 years to act increases the odds to more than 1 chance in 3.

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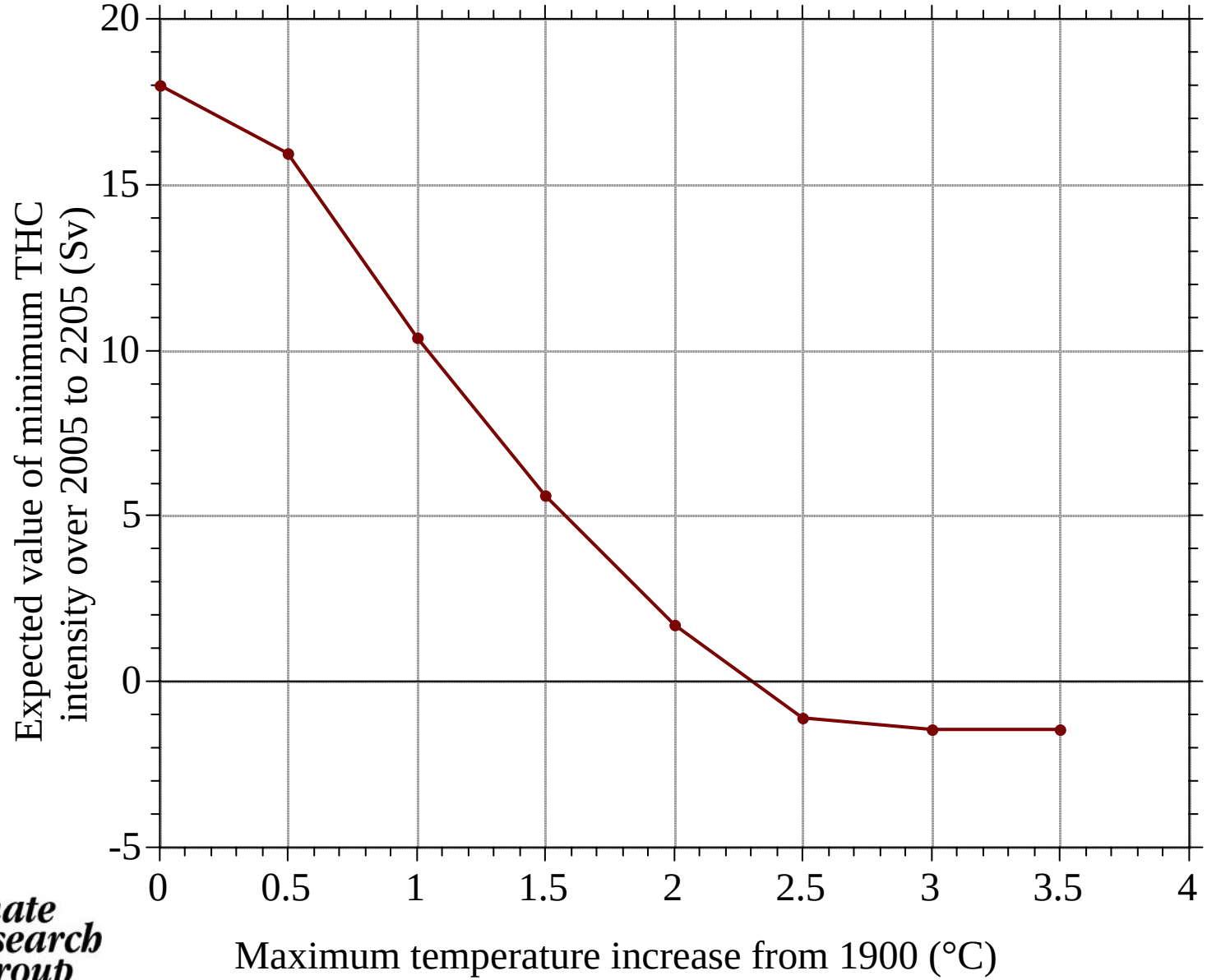
Expected Value of Minimum THC Intensity Versus Maximum Temperature Increase from 1900



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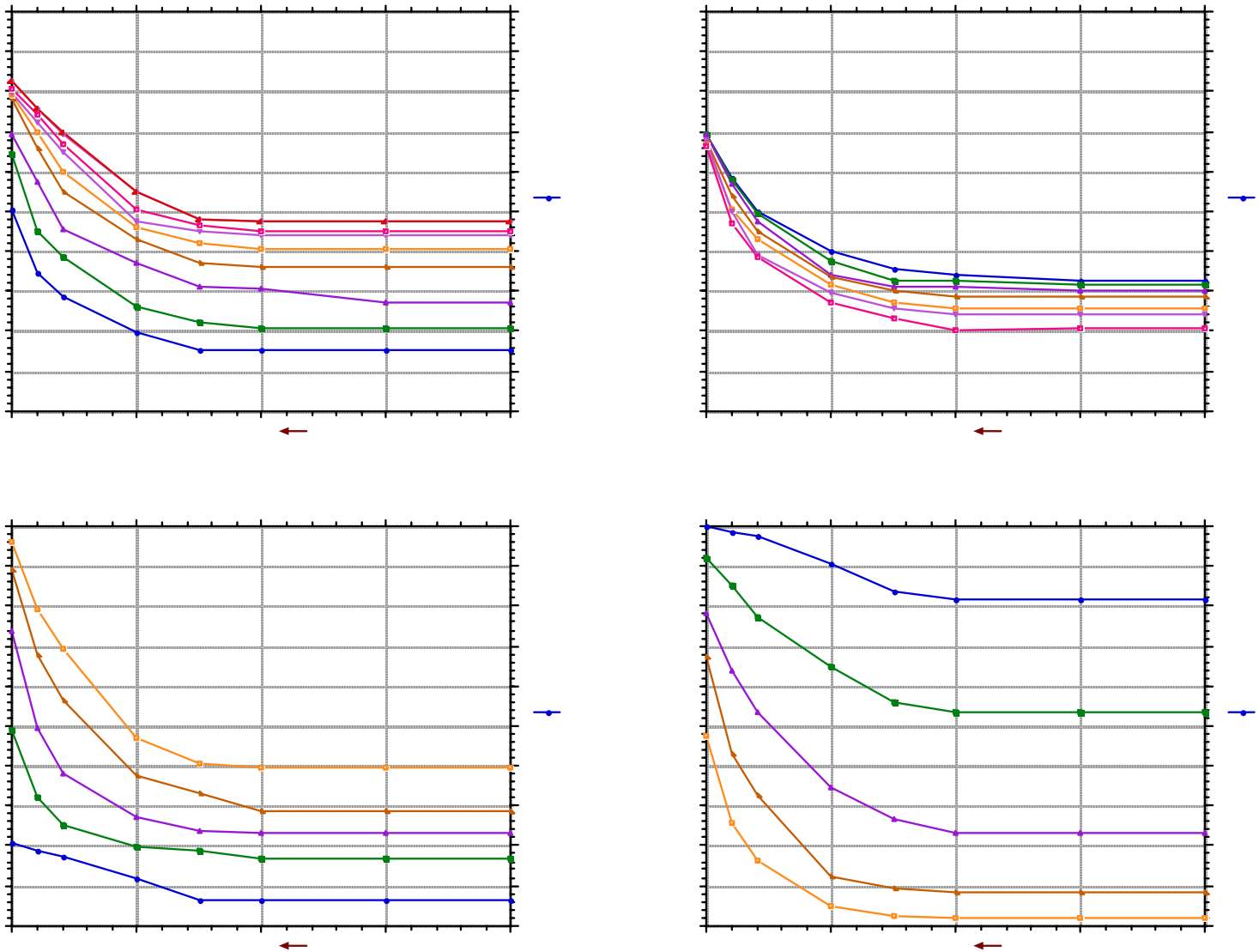
Sensitivity of the Probability of a THC Shutdown to the Uncertain Parameters



THC Shutdown Probability Very Sensitive to K, α and ΔT_{2x}

Conclusions

- Climate model simulations display large differences in the future change in the intensity of the ATHC and in the climatic changes resulting therefrom.
  - As Yogi Berra said: “Prediction is difficult, particularly about the future”.
- Thus it is useful/necessary to test/evaluate climate models by simulating past abrupt THC-induced climate changes, in particular the Younger Dryas and 8.2 ka event, and compare the results with the paleoclimate record.

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Conclusions

- This is the objective of the Paleo-hosing Modeling Intercomparison Project (PhMIP) directed by the author under the auspices of the Paleoclimate Modeling Intercomparison Project 2 (PMIIP) and the Worldwide Universities Network (WUN) Arctic Climates and Environments (ACE) initiative.
- 15 climate modeling groups worldwide are participating in the PhMIP (ECBilt-CLIO (Netherlands), FRCGC/JAMSTEC (Japan), Freij University Amsterdam (Netherlands), GISS (US), Hadley Centre (UK), IAP (China), LSCE (France), MRI (Japan), NCAR (US), U. Bristol (UK), U. British Columbia (Canada), UIUC (US), UKMO (UK), U. Tokyo (Japan), U. Toronto (Canada)
- First results by September 2007