Climate thresholds and abrupt climate change:

What are research needs?

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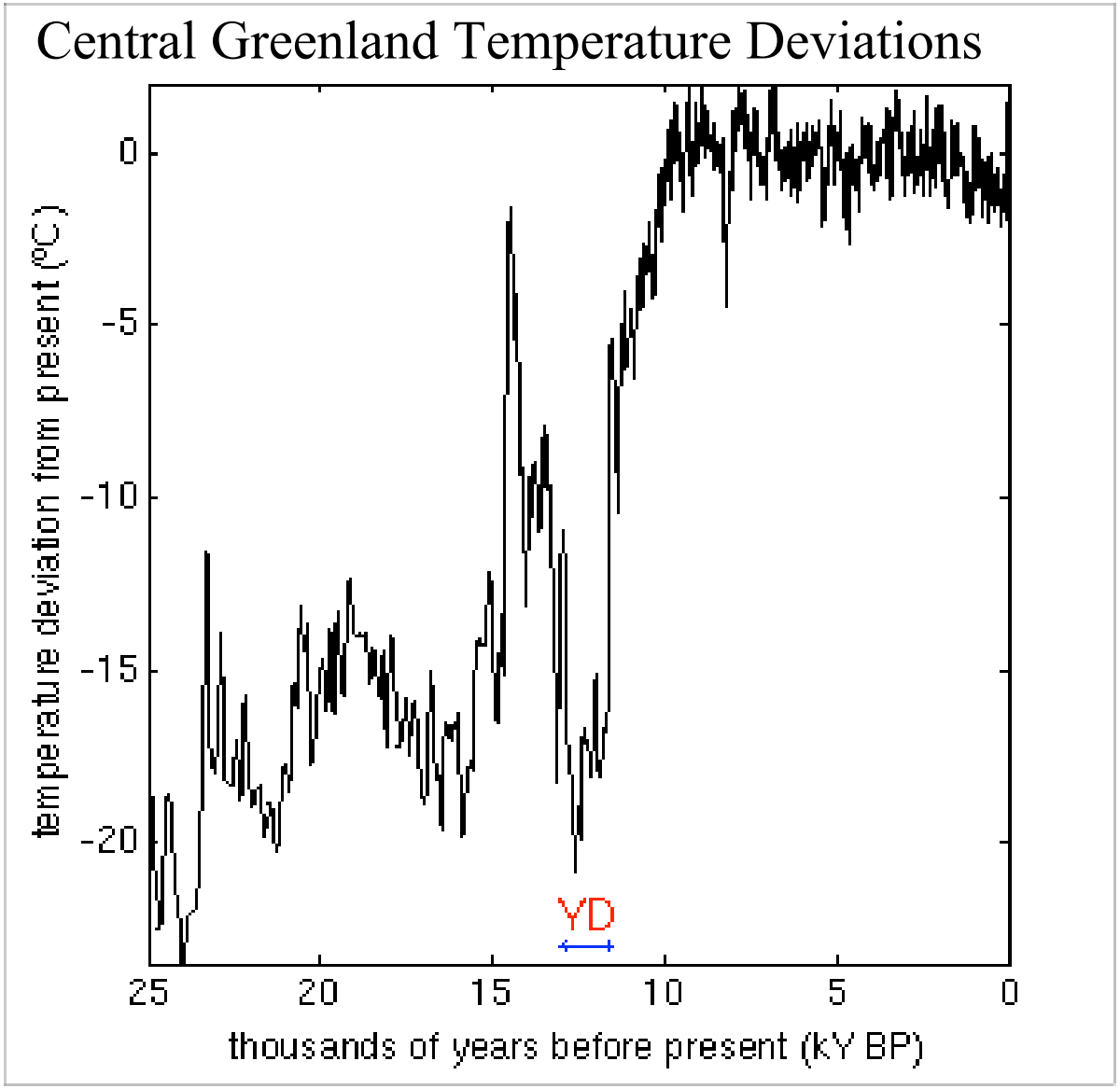
Climate Change can be abrupt

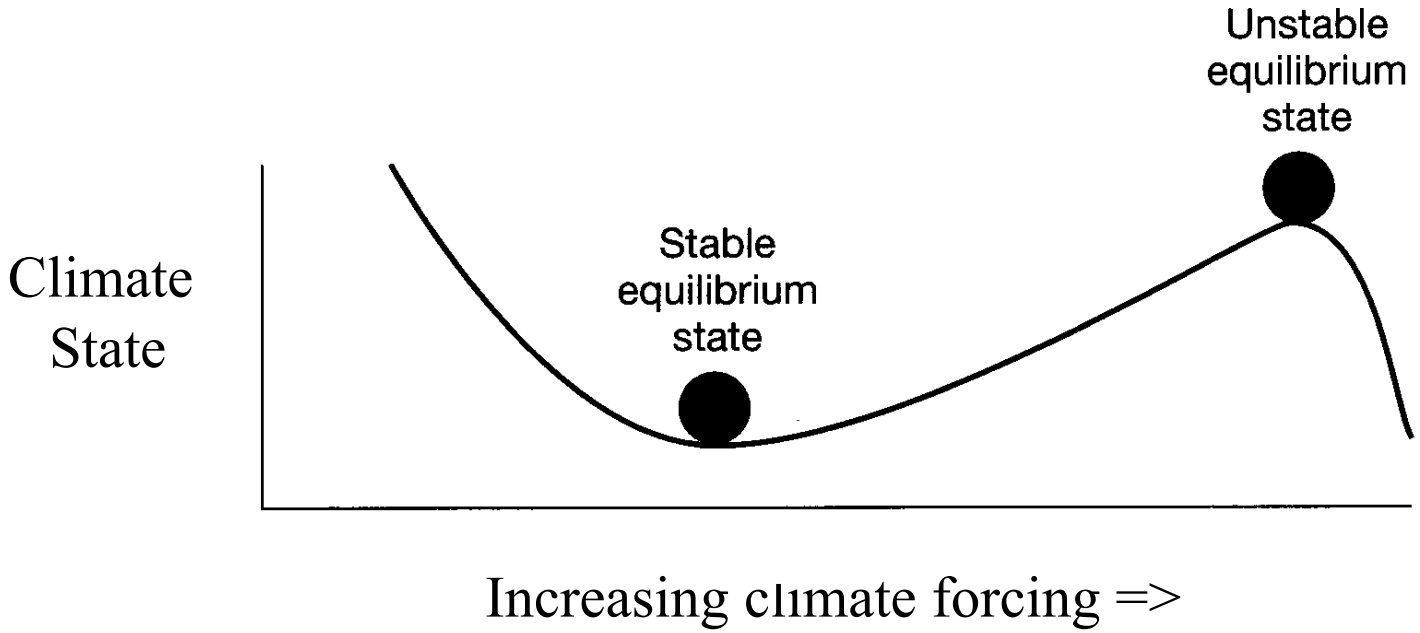
- Is this ACC associated with crossing of climate thresholds?
- What is a climate threshold?
- Where are these thresholds located in climate space?
- Would we see it coming?
- What are sound climate policies in the face of such uncertain climate thresholds?



Data from Meese *et al.* (1994) and Stuiver *et al.* (1995).
20 year running mean, δO^{18}-temp conversion based on Cuffey *et al*, 1995

What is a climate threshold?

- A negative feedback switches to a positive feedback loop.
- Potentially several basins of attraction.
- Changes can occur abruptly.



modified from Kump *et al* (2003)

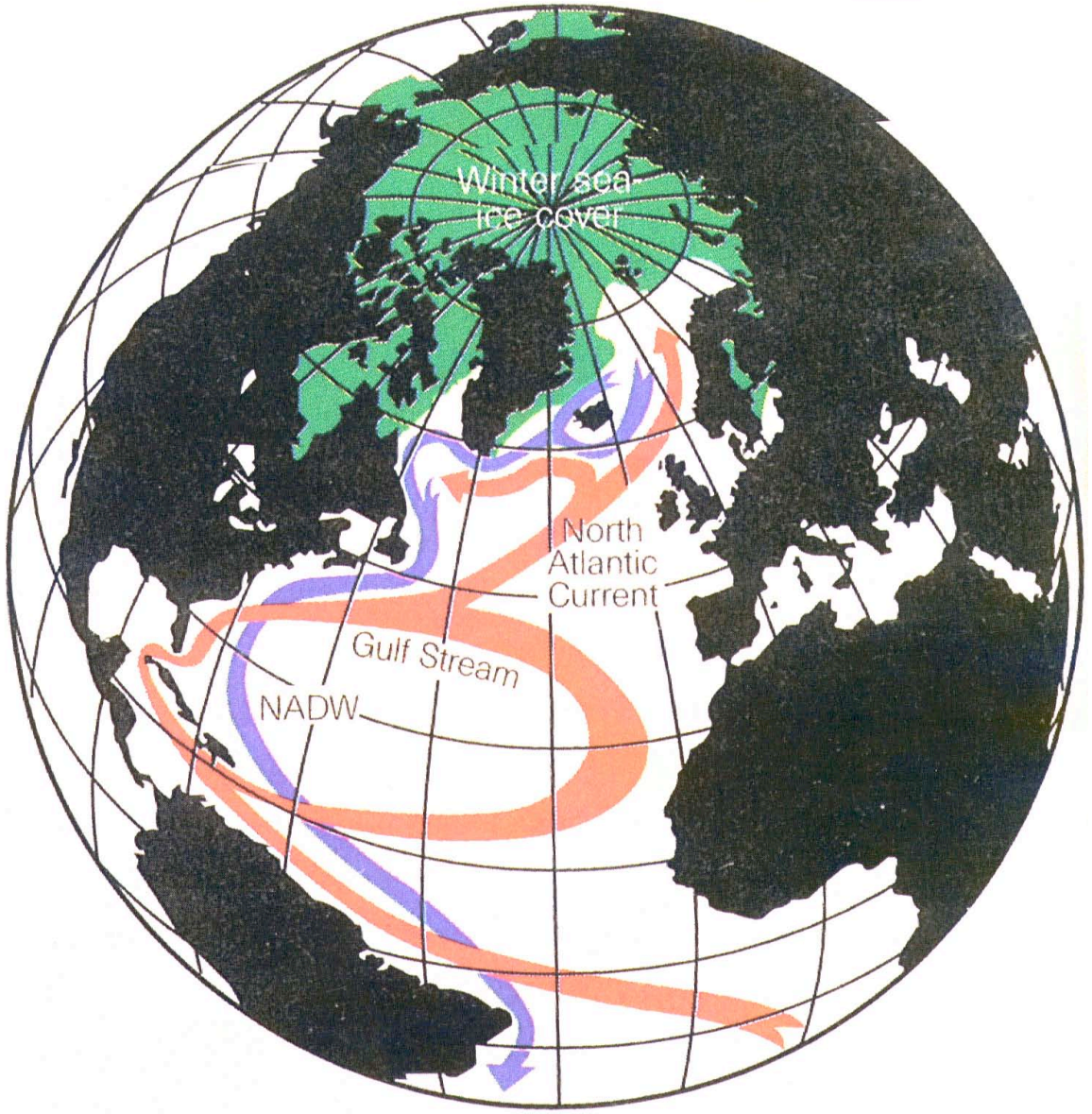
The main points

1) *Crossing climate thresholds* may be interpreted as "*dangerous anthropogenic interference with the climate system*".

2) Decisions to address climate thresholds have to be made under deep uncertainty.

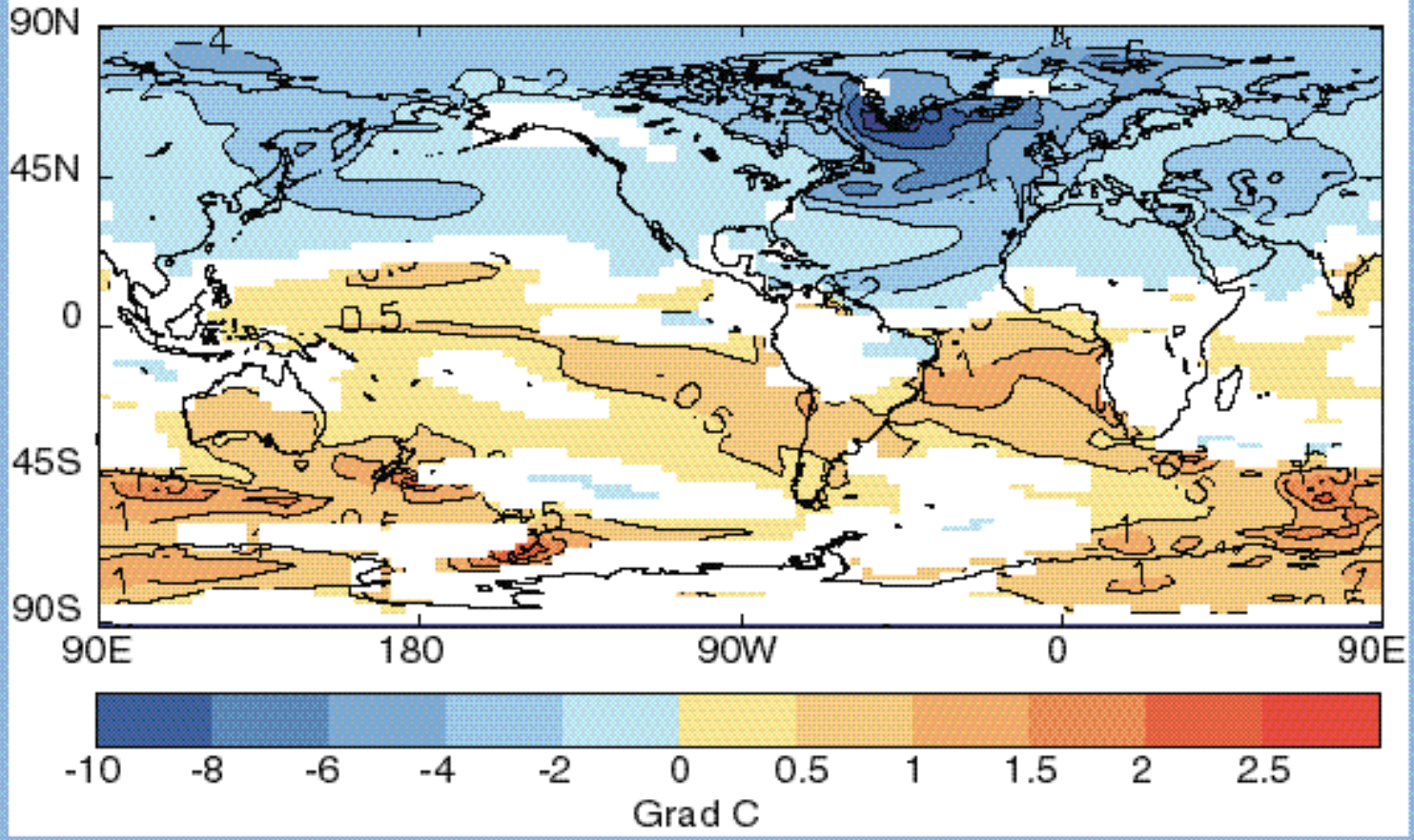
3) Important issues require more attention.
   - Where are the climate thresholds located?
   - Is a confident early detection (and maybe even prediction) possible?
   - What are the effects of potential overconfidence?
   - What decision-criterion should be used?

Example 1: The North Atlantic meridional overturning circulation (MOC) may collapse in a threshold response



Rahmstorf (1997)

Change in surface air temperature after a collapse of the thermohaline circulation in the North Atlantic



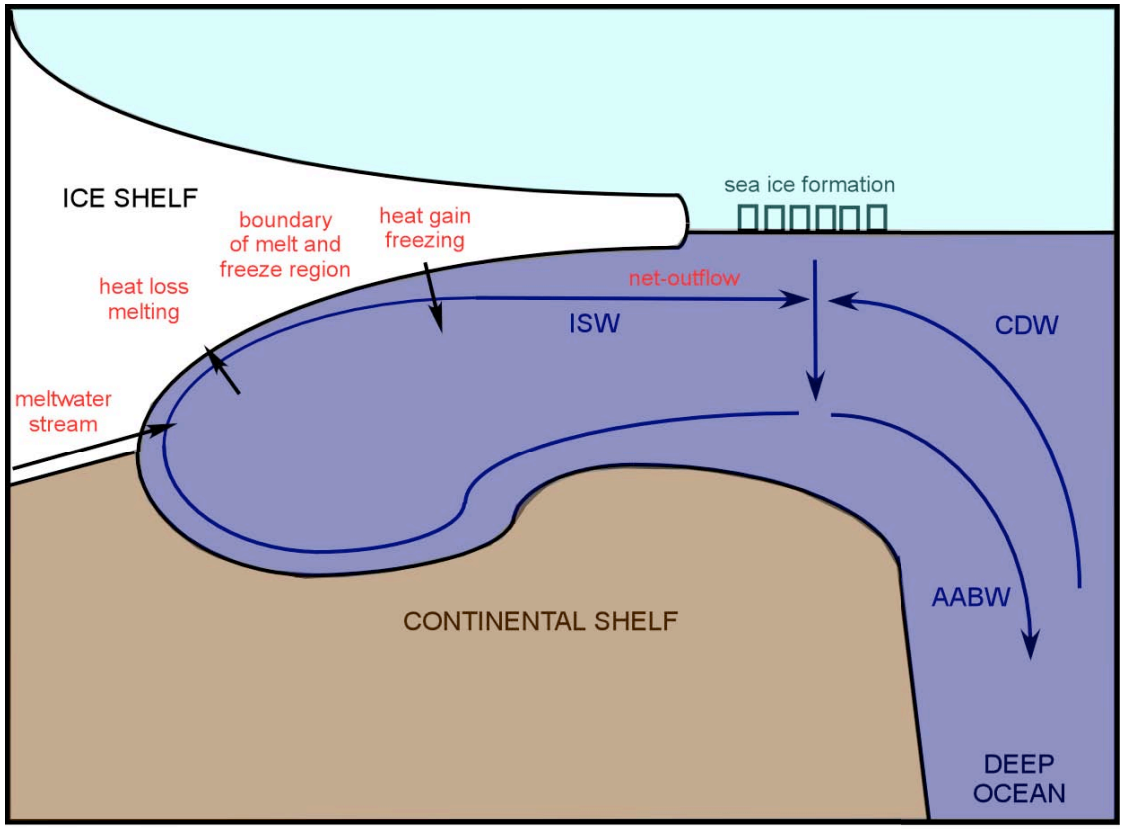
Average change of annual mean surface air temperature over the years 50-100 after a collapse of the THC in HadCM3. Areas with temperature differences that fall within the natural variability of the control run (at the 95% confidence level) appear as white. (courtesy of Michael Vellinga).

Example 2: A potential disintegration of the West Antarctic Ice Sheet (WAIS)

• The WAIS may disintegrate in response to anthropogenic greenhouse gas emissions (*cf.* Oppenheimer 1998).

• An anthropogenic warming of 2.5 °C has been interpreted as a WAIS climate limit.

• The consequences of a WAIS collapse *could* include a global sea level rise of around 6 meters and a disruption of global oceanic circulation patterns.



Key:
AABW: Antarctic Bottom Water
CDW: Circumpolar Deep Water
ISW: Ice Shelf Water

Based on hypotheses and observations of Holland et al (2003), Weppering et al (1996), and Smethie (pers. com.).

Two possible positive feedbacks:

- slip rate ↑ -> bottom temperature ↑ -> slip rate ↑
- temp. ↑ -> melting rate ↑ -> height ↓ -> temp. ↑

Abrupt climate change, hysteresis response, and climate thresholds

- Abrupt climate change:
  The climate response is faster than the forcing.

- Hysteresis response:
  The system does not return to the original state after the forcing is removed (over a relevant time period).

- Climate threshold:
  The location where either abrupt climate change sets in or a hysteresis response starts.

- Dangerous anthropogenic interference with the climate system may be interpreted as anthropogenic radiative forcing causing distinct and widespread climate change associated with the crossing of climate thresholds.

The main points

1) *Crossing climate thresholds* may be interpreted as "*dangerous anthropogenic interference with the climate system*".

2) Decisions to manage climate thresholds have to be made under deep uncertainty.

3) Important issues require more attention.
   - Where are the climate thresholds located?
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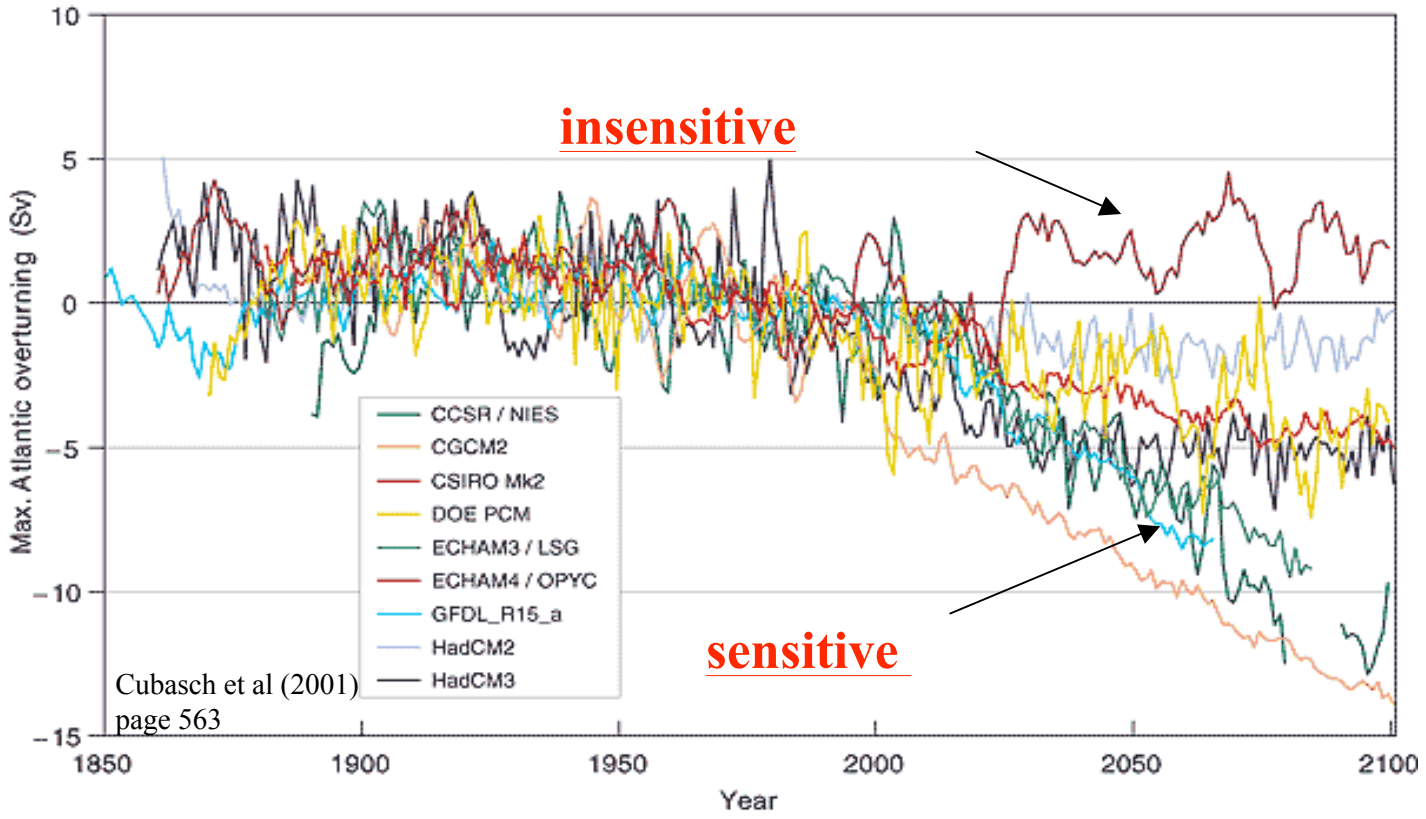
Predicted MOC changes are uncertain due to model uncertainties and missing observations



MOC changes detected

MOC collapsed in very sensitive models

Which of these models approximates reality the best?
Seemingly simple task: add data points to this plot..

Predictions about WAIS changes are uncertain due to model uncertainties and ambiguous paleo-constraints

- Numerical models incorporating some of the positive feedback mechanisms show sporadic WAIS collapses (MacAlley 1992), but these models lack important processes (Bindschadler and Bentley, 1997).
- Sea level *may* have been 2-6 m higher during the last interglacial
  - Ambiguous evidence based on coral stands and erosion patterns (*cf.* Neumann and Hearty, 1996 *vs.* Kindler and Strasser, 1997).
  - Global mean temperature was only 1-2^{o}C warmer at that time compared with now (Petit et al. 1999).
- Diatoms in the muddy beds of the ice-sheet indicate potential open water conditions in the last 1.3 million years (Scherer, 1998).

The main points

1) *Crossing climate thresholds* may be interpreted as "*dangerous anthropogenic interference with the climate system*".

2) Policies addressing climate thresholds have to be made in a situation of deep uncertainty.

3) Important issues require more attention.
   - What decision-criterion should be used?
   - Where are the climate thresholds located?
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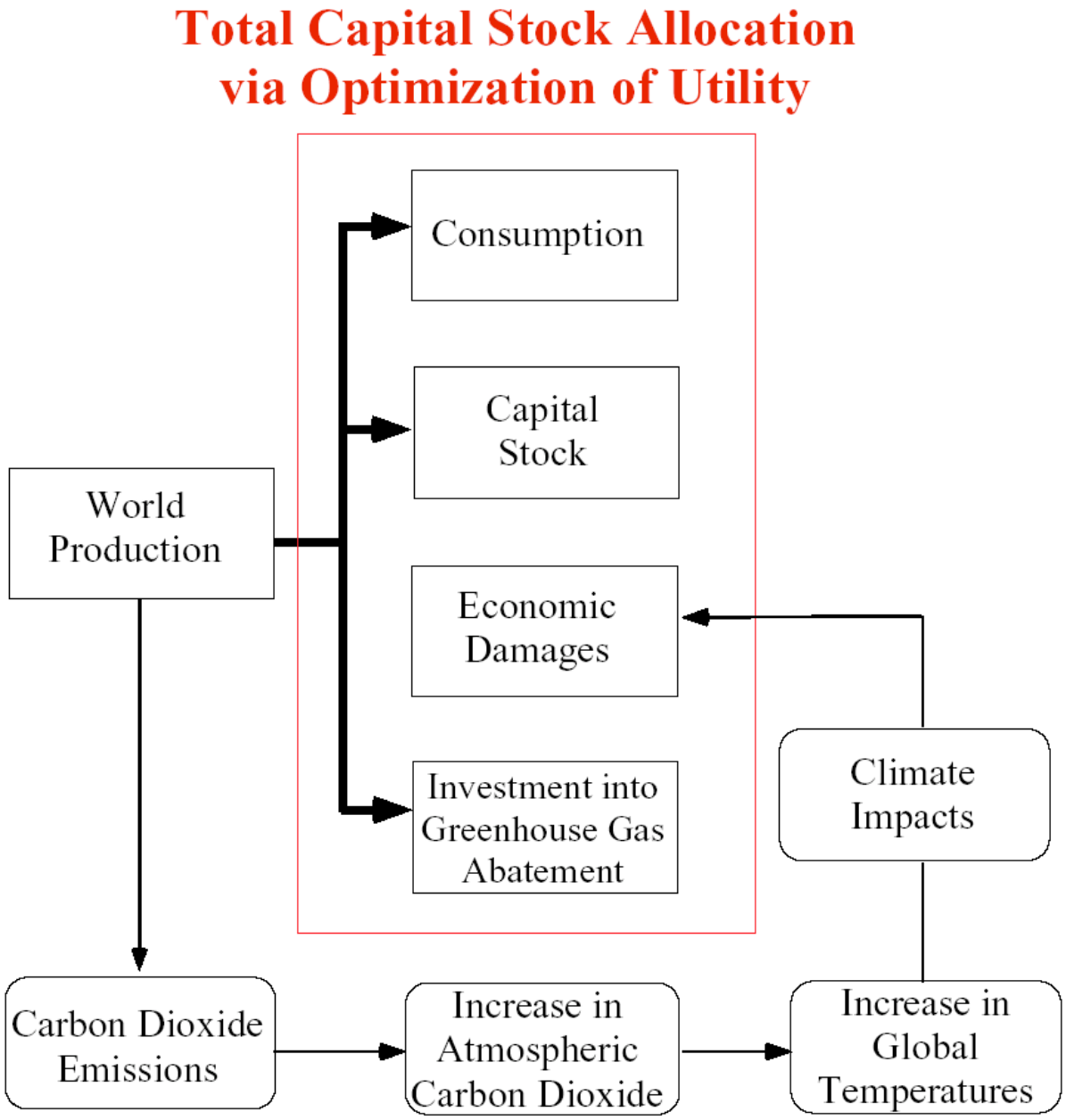
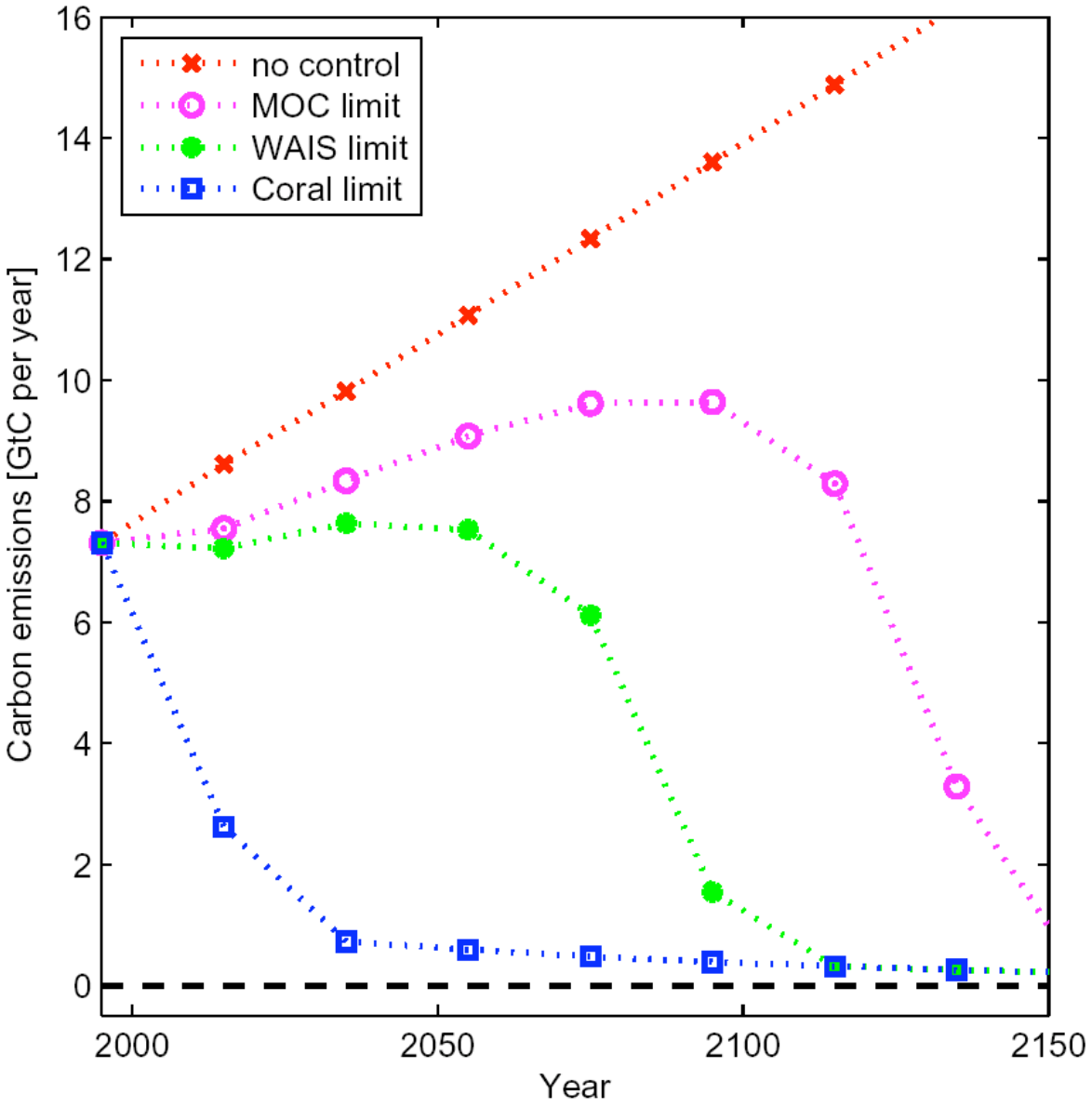
A simple model of economic optimal climate management



Simple extension of the Nordhaus and Boyer (2000) model
(*cf.* Keller *et al.*, 2005)

Reducing the risk of crossing the climate limits implies reductions in greenhouse gas emissions.



Key issues:

- Feasibility?
- Procrastination and regrets.
- What are the effects of uncertainty?

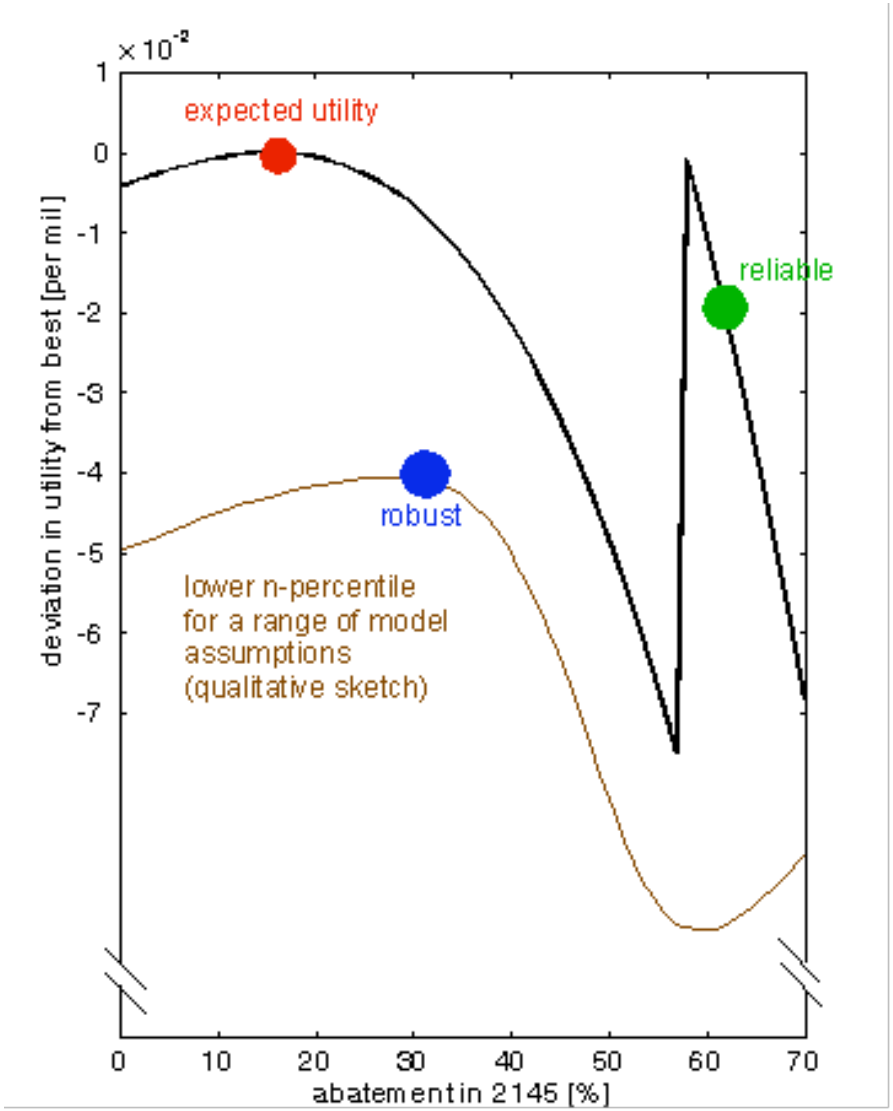
Keller *et al* (2005a)

Alternative framings of the decision problem yield different solutions

–"expected utility"
(*e.g.,* Nordhaus and Popp, 1997).

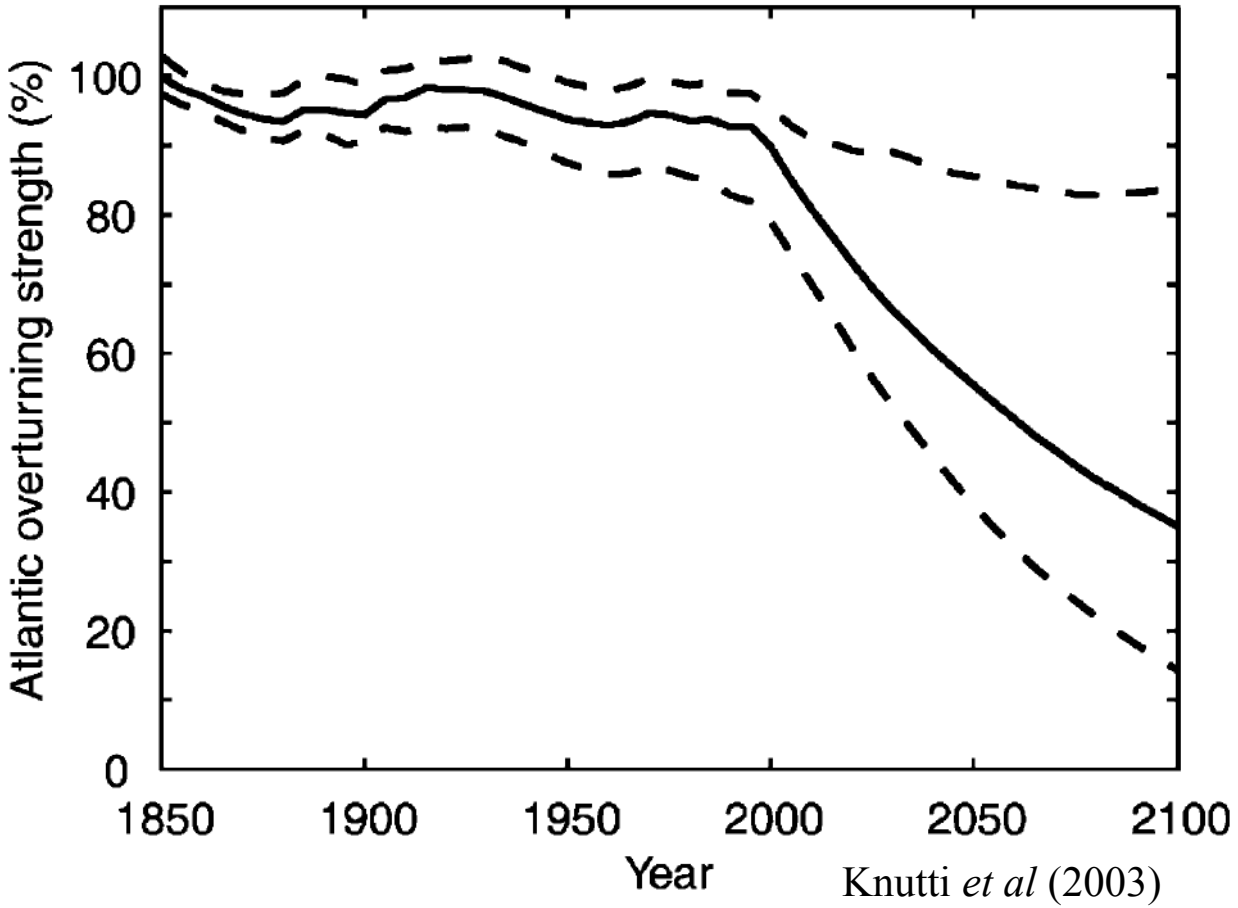
–"reliable"
expected utility maximization constrained to avoid the threshold with a required reliability (*e.g.,* Keller *et al*, 2000).

–"robust"
Assumes a range of probabilities (*e.g.,* $0 < p < 1$ for sensitive and $1 > (1\text{-}p) > 0$ for insensitve models) and identifies policies that perform well over a range of possible futures (*e.g.,* Lempert *et al*, 2004).



Probabilistic predictions based on a single model structure may be overconfident

Uncertainty analysis based on "history matching" of a few selected oceanic constraints and Bayesian analysis of a simple (and statistically approximated) climate model.



Knutti *et al* (2003)

Conclusions

1) Crossing climate thresholds may be interpreted as "dangerous anthropogenic interference with the climate system".

2) Policies addressing climate thresholds have to be made in a situation of – often deep – uncertainty.

3) Important issues (*e.g.,* apparent. overconfidence, effects of alternative decision-criteria) require more detailed attention.