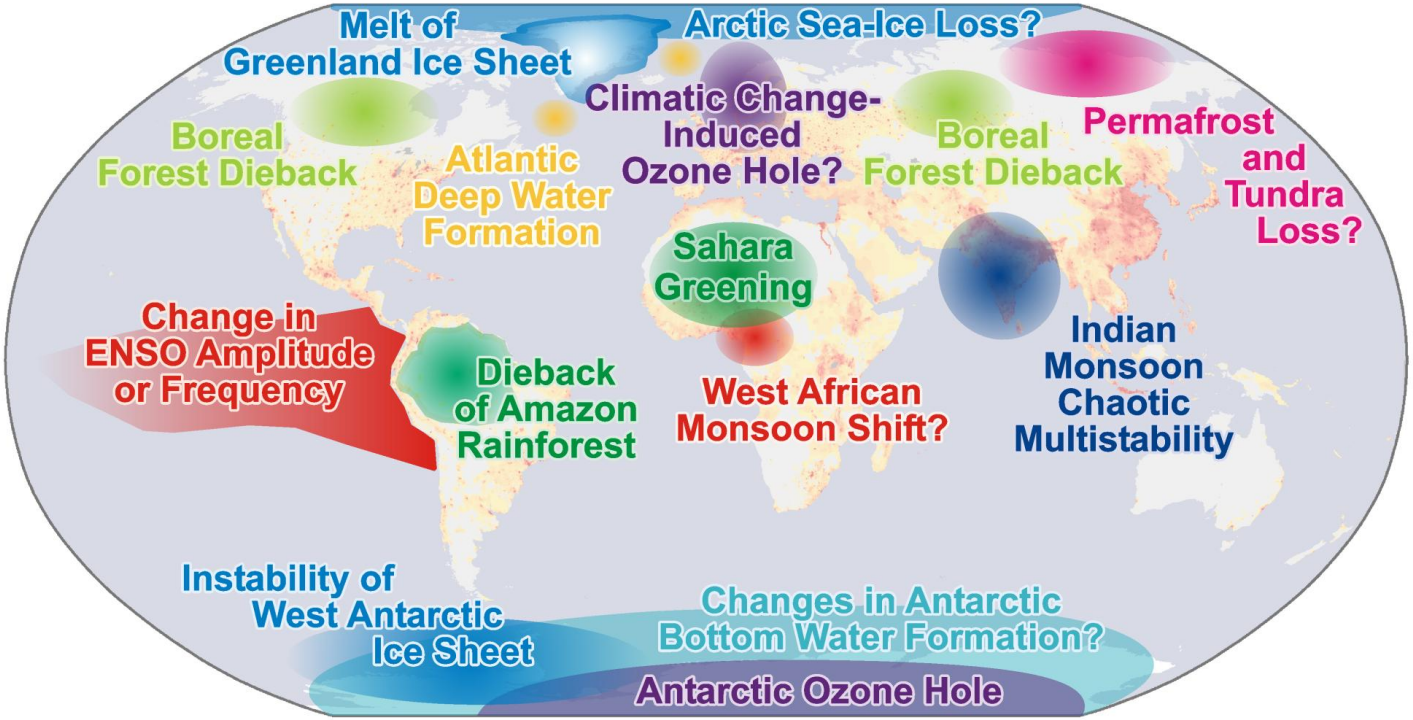
Earth system tipping points



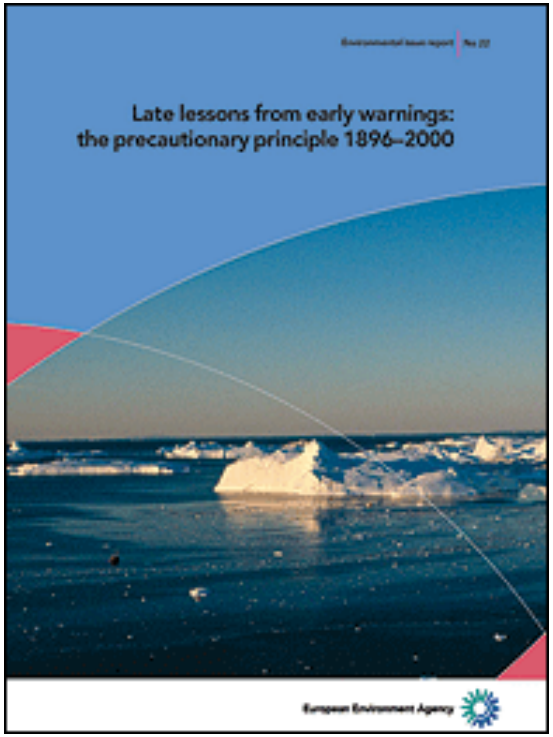
Tim Lenton

School of Environmental Sciences, University of East Anglia, Norwich, UK

Special thanks to John Schellnhuber, Valerie Livina, Elmar Kriegler, Jim Hall

Outline

- Evidence on tipping points
- Probability under different scenarios
- Early warning prospects



“Little things can make a big difference”

Lenton et al. (2008) *PNAS* 105(6): 1786-1793

Tipping element

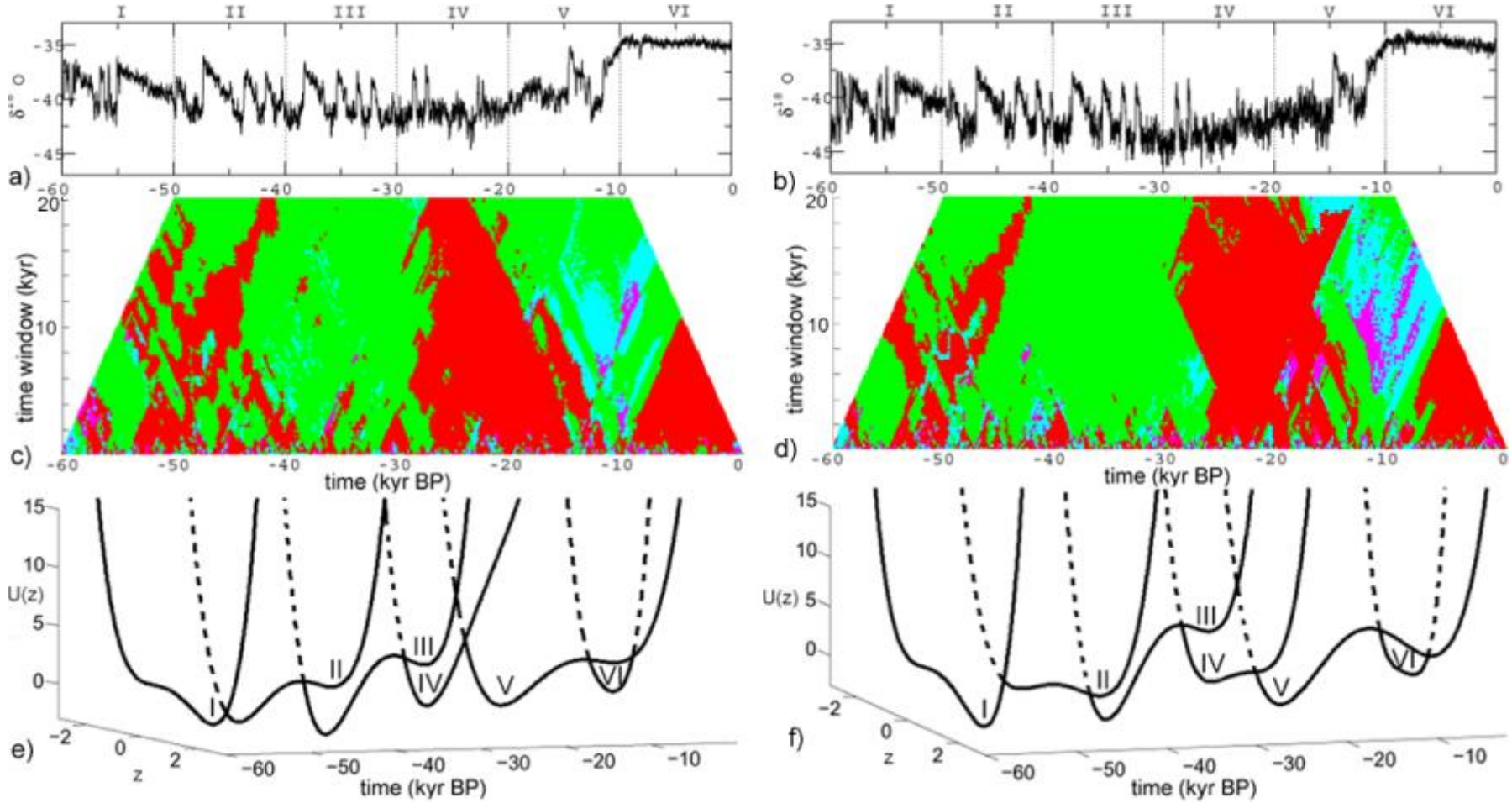
- A component of the Earth system, at least sub-continental in scale (~1000km), that can be switched – under certain circumstances – into a qualitatively different state by a small perturbation.

Tipping point

- The corresponding critical point – in forcing and a feature of the system – at which the future state of the system is qualitatively altered.

Changing climate states in the past

Livina, Kwasniok & Lenton (2010) *Climate of the Past,* 6: 77-82



Number of states: 1, 2, 3, 4

Policy relevant tipping elements

Lenton et al. (2008) *PNAS* 105(6): 1786-1793

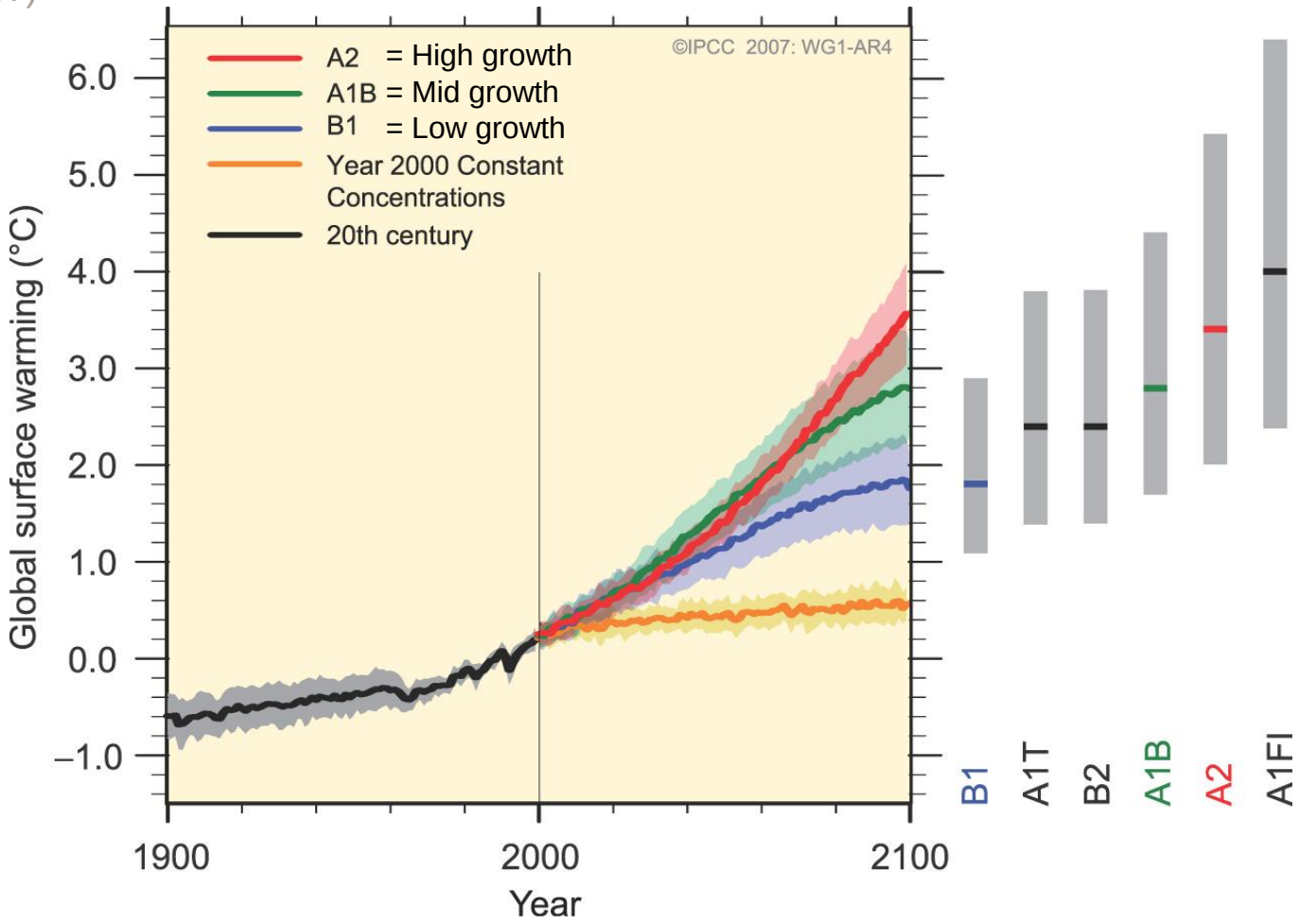
- Human activities are interfering with the system such that decisions taken within a “political time horizon” (~100 years) can determine whether the tipping point is reached.

- The time to observe a qualitative change plus the time to trigger it lie within an “ethical time horizon” (~1000 years).

- A significant number of people care about the fate of the system.

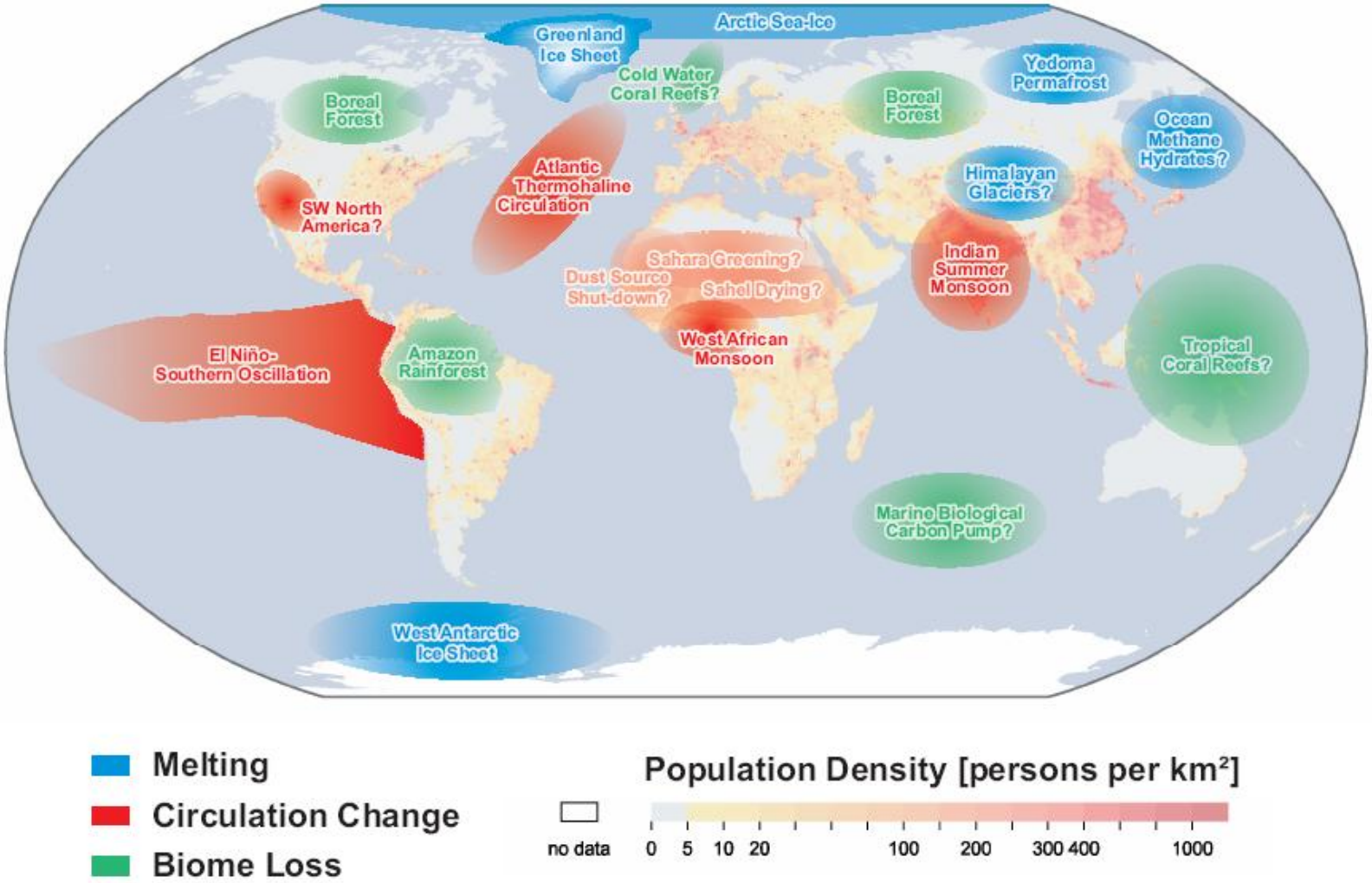
Policy-relevant forcing range

IPCC (2007)



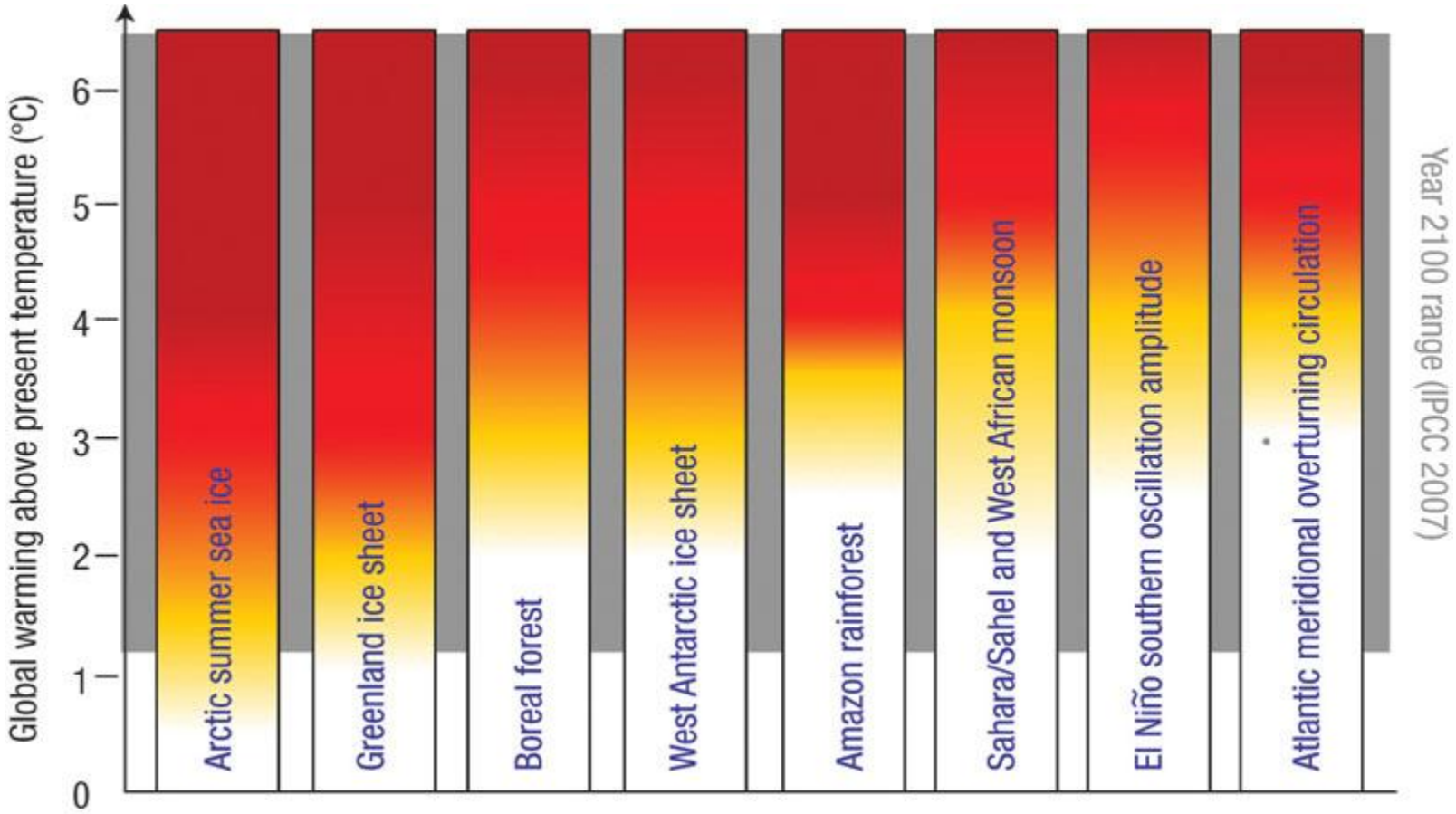
Tipping elements in the Earth system

Revised after Lenton *et al.* (2008) *PNAS* 105(6): 1786-1793



Estimates of proximity

Lenton & Schellnhuber (2007) *Nature Reports Climate Change*

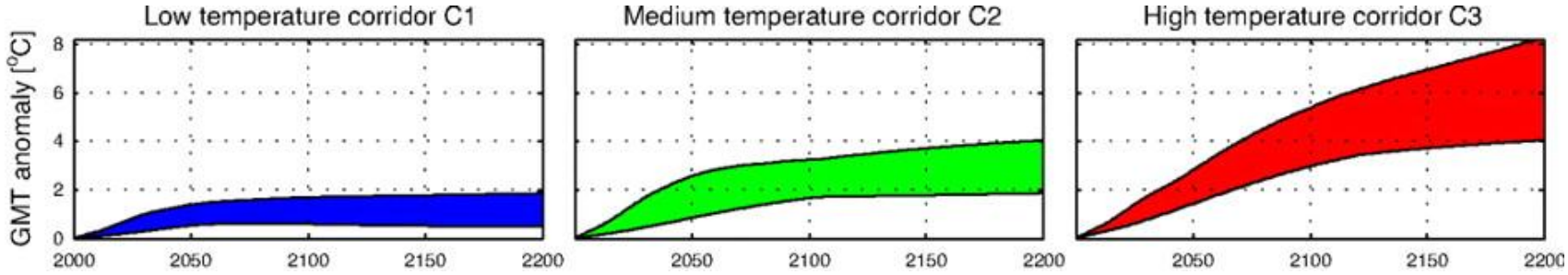


Results from literature review and workshop

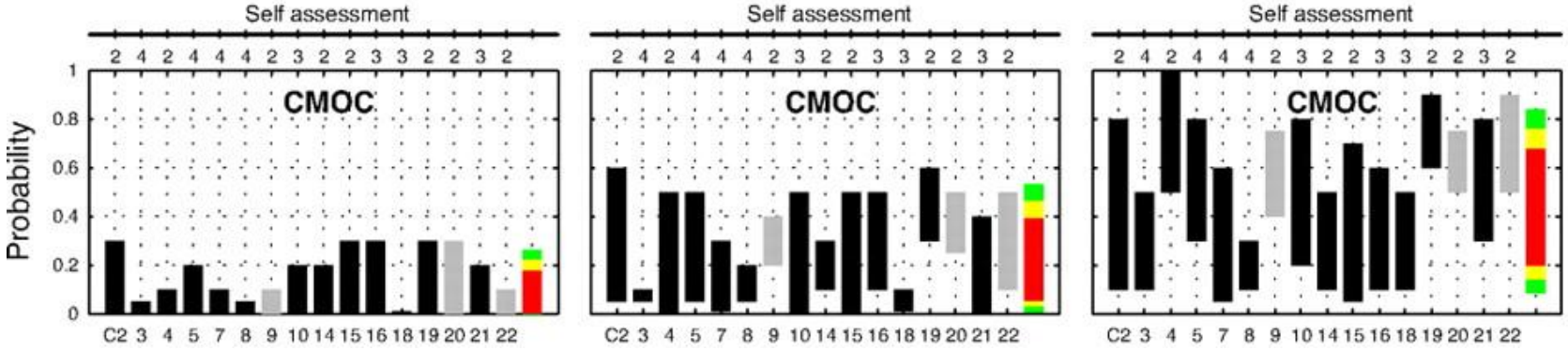
Probabilities under different scenarios

Kriegler et al. (2009) *PNAS* **106**(13): 5041-5046

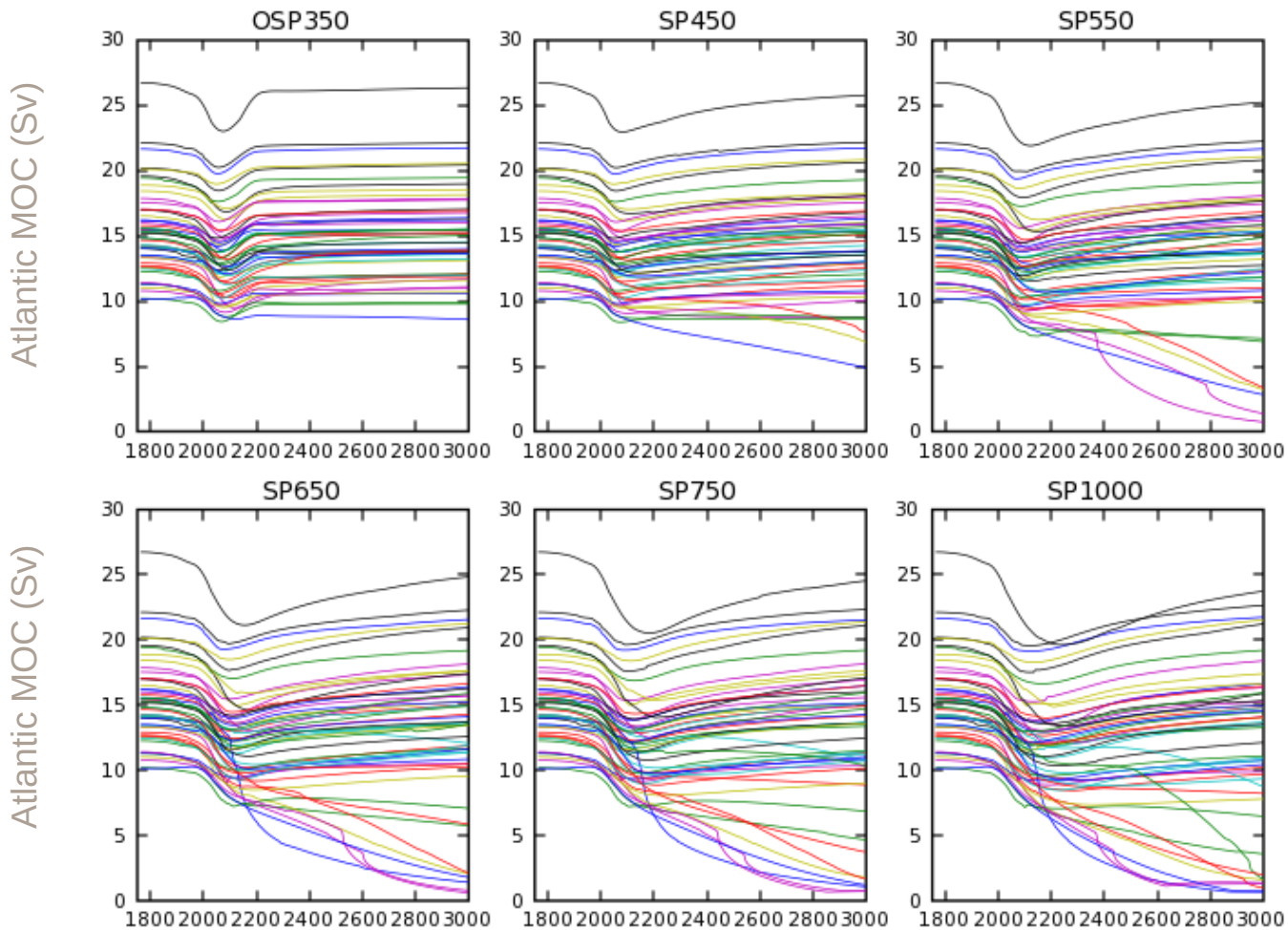
- Three different warming scenarios:



- Imprecise probability statements elicited from experts for tipping scenarios
- Example of collapse of Atlantic meridional overturning circulation:



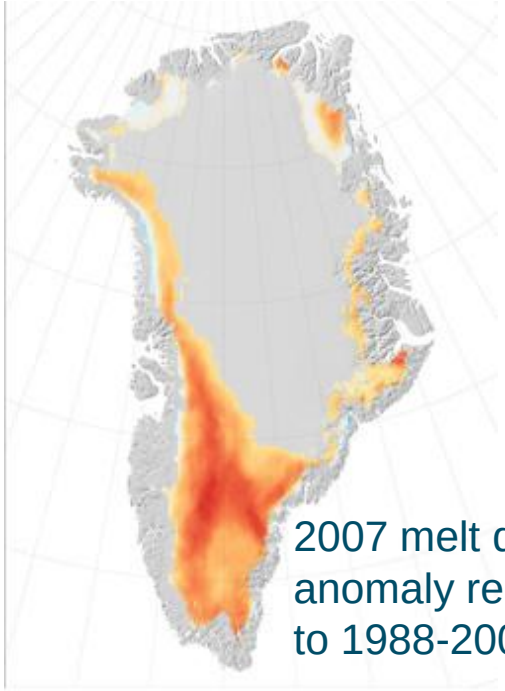
Atlantic meridional overturning circulation



GENIE-1 model, data assimilated with Ensemble Kalman Filter, for IPCC AR4, 3°C climate sensitivity

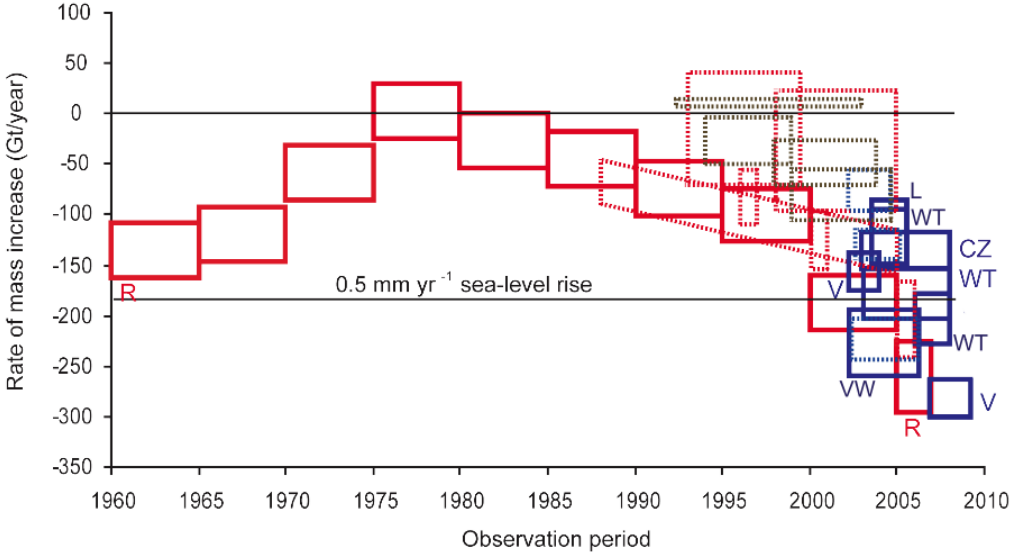
Greenland ice sheet

The Copenhagen Diagnosis (2009)

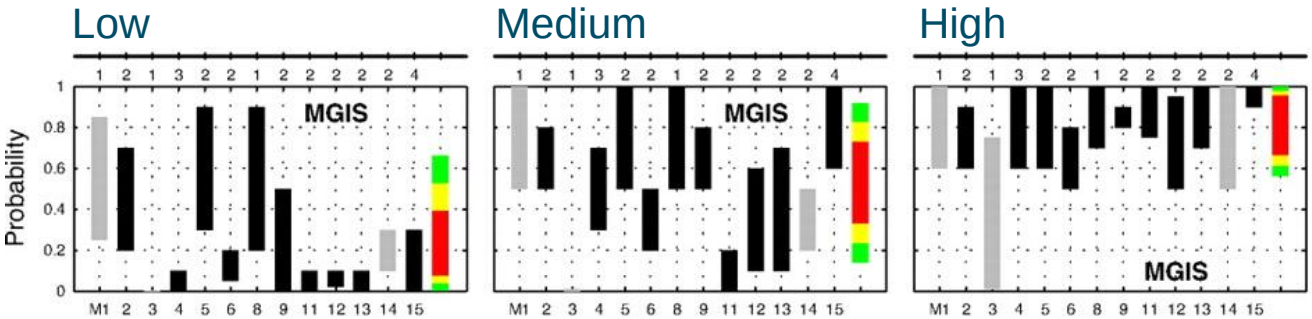


2007 melt days anomaly relative to 1988-2006

Net mass balance of Greenland ice sheet



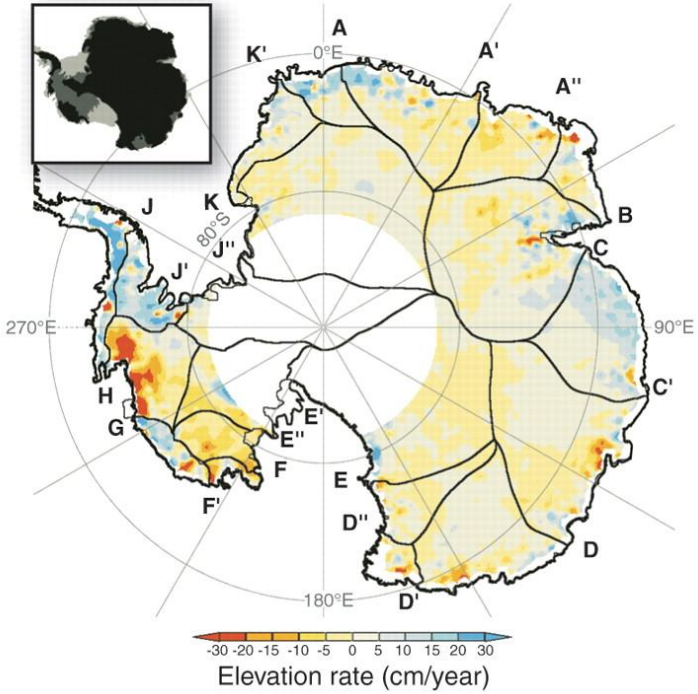
Expert elicitation for future warming scenarios:



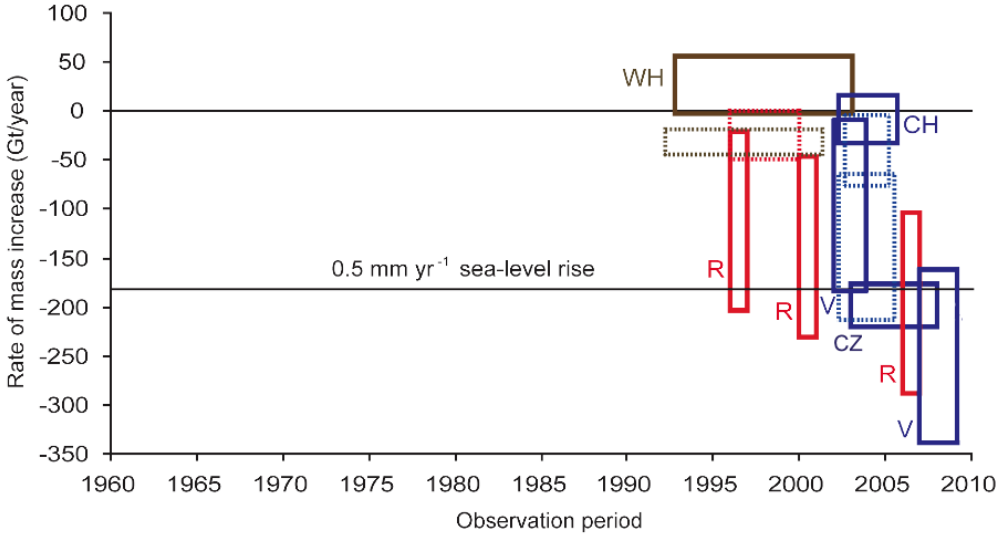
West Antarctic ice sheet

Shepherd & Wingham (2007) *Science* 315: 1529-1532

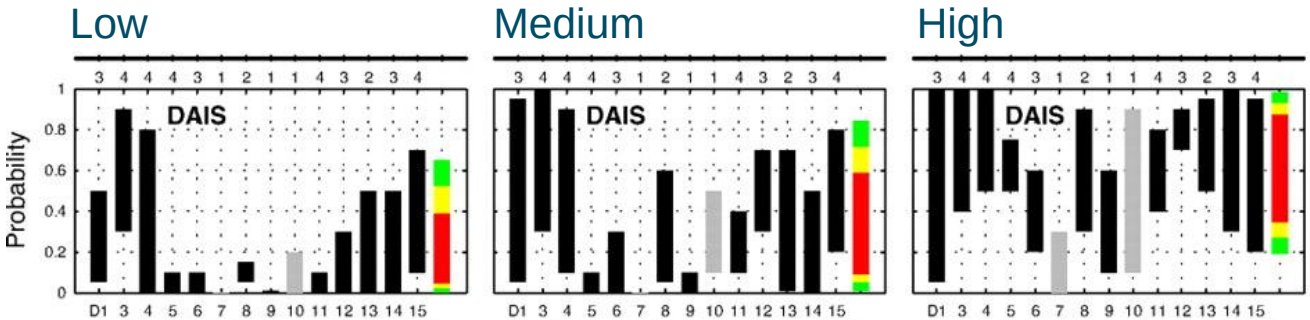
The Copenhagen Diagnosis (2009)



Net mass balance of Antarctic ice sheet



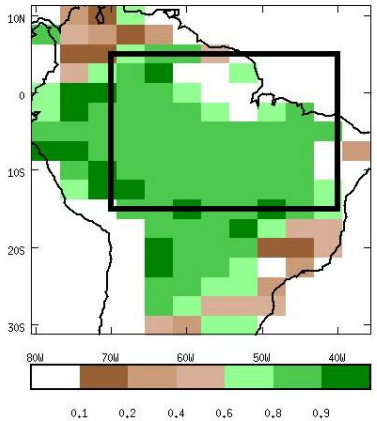
Expert elicitation for future warming scenarios:

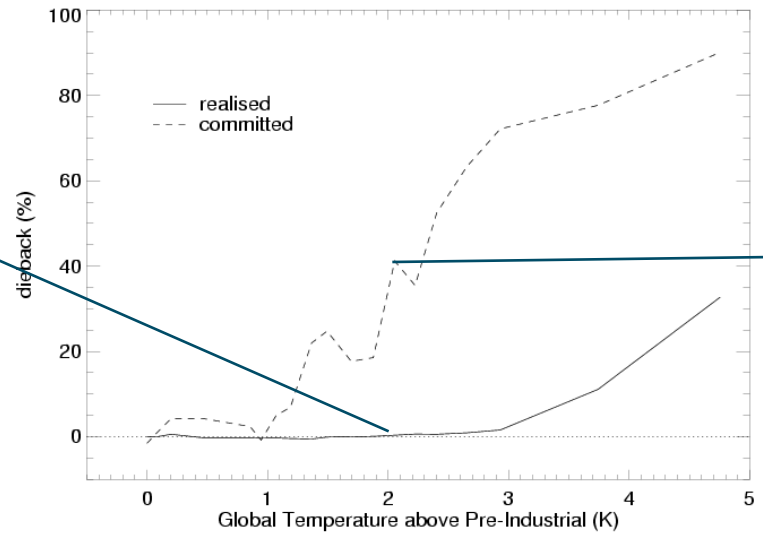


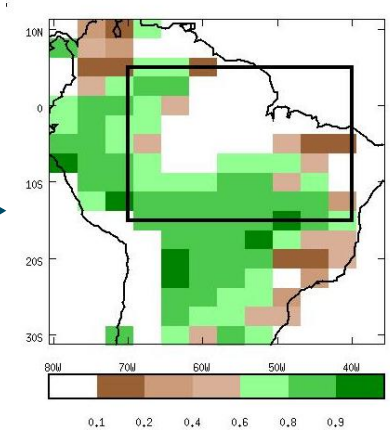
Amazon rainforest

Jones *et al.* (2009) *Nature Geoscience 2*: 484-487
Cook and Vizy (2009) *Journal of Climate*

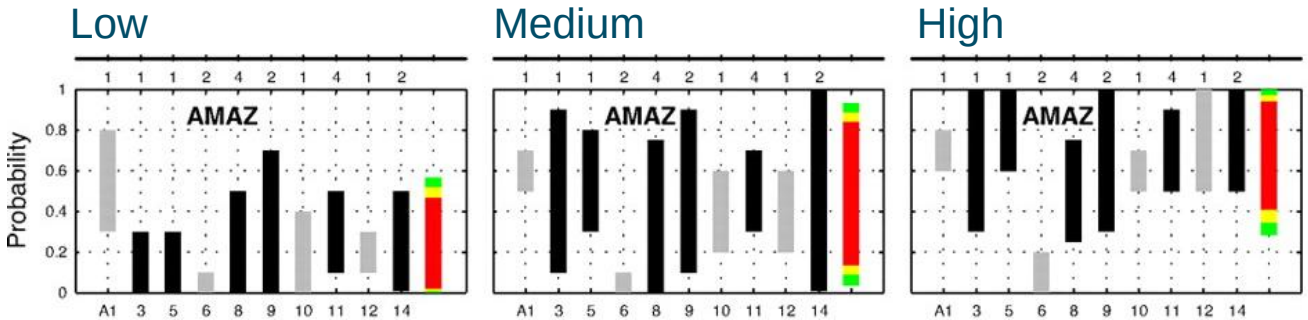
Cox *et al.* (2000) *Nature* 408: 184-187







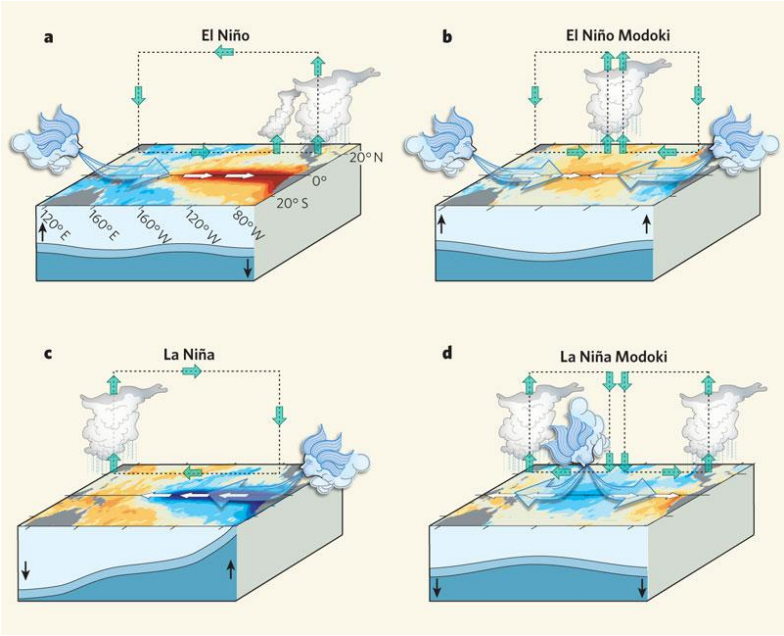
Expert elicitation for future warming scenarios:



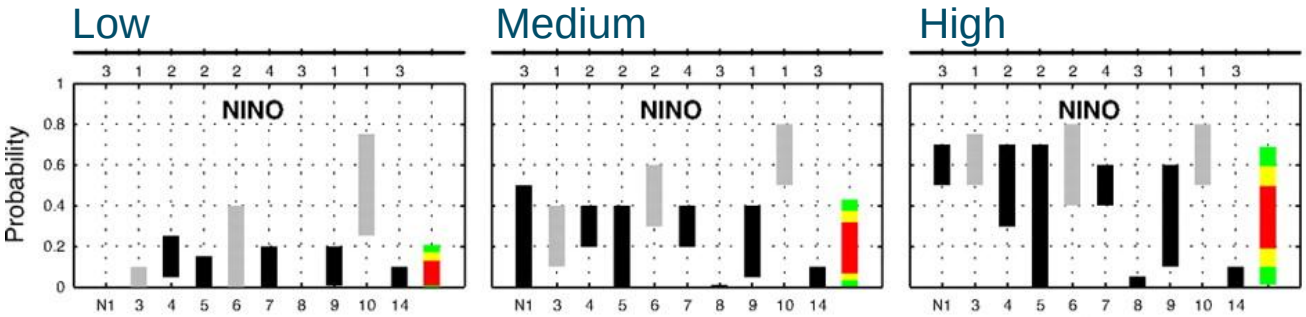
El Niño / Southern Oscillation

Guilyardi (2006) *Climate Dynamics* 26: 329-348, Yeh et al. (2009) *Nature* 461: 511-514

- Increase in ENSO amplitude in in most realistic models under 3-6°C warmer stabilised climate.
- No clear change in El Niño frequency
- Shift toward Central Pacific Modoki replacing classic East Pacific El Niño?



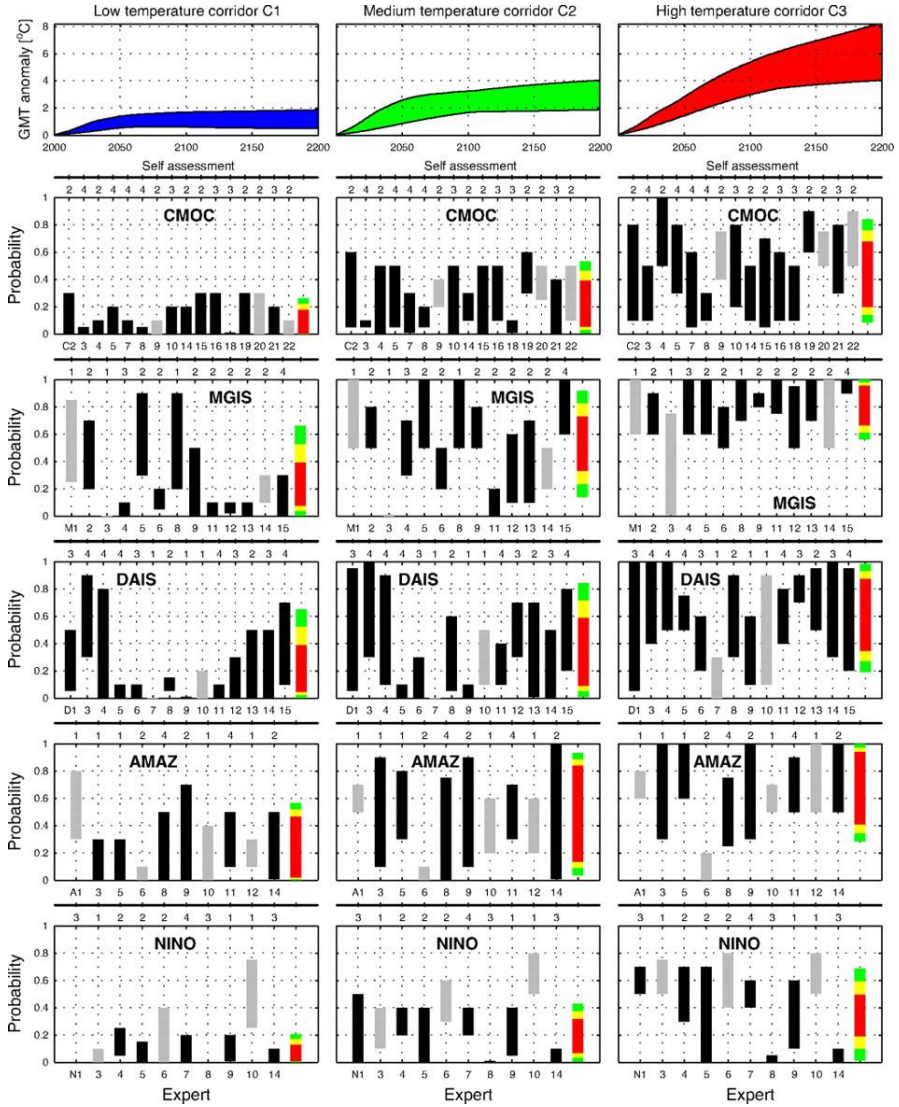
Expert elicitation for future warming scenarios:



Combined likelihood of tipping

Kriegler et al. (2009) *PNAS* **106**(13): 5041-5046

- Imprecise probability statements from experts formally combined
- Under 2-4 °C warming: >16% probability of passing at least one of five tipping points
- Under >4 °C warming: >56% probability of passing at least one of five tipping points



Atlantic

Greenland

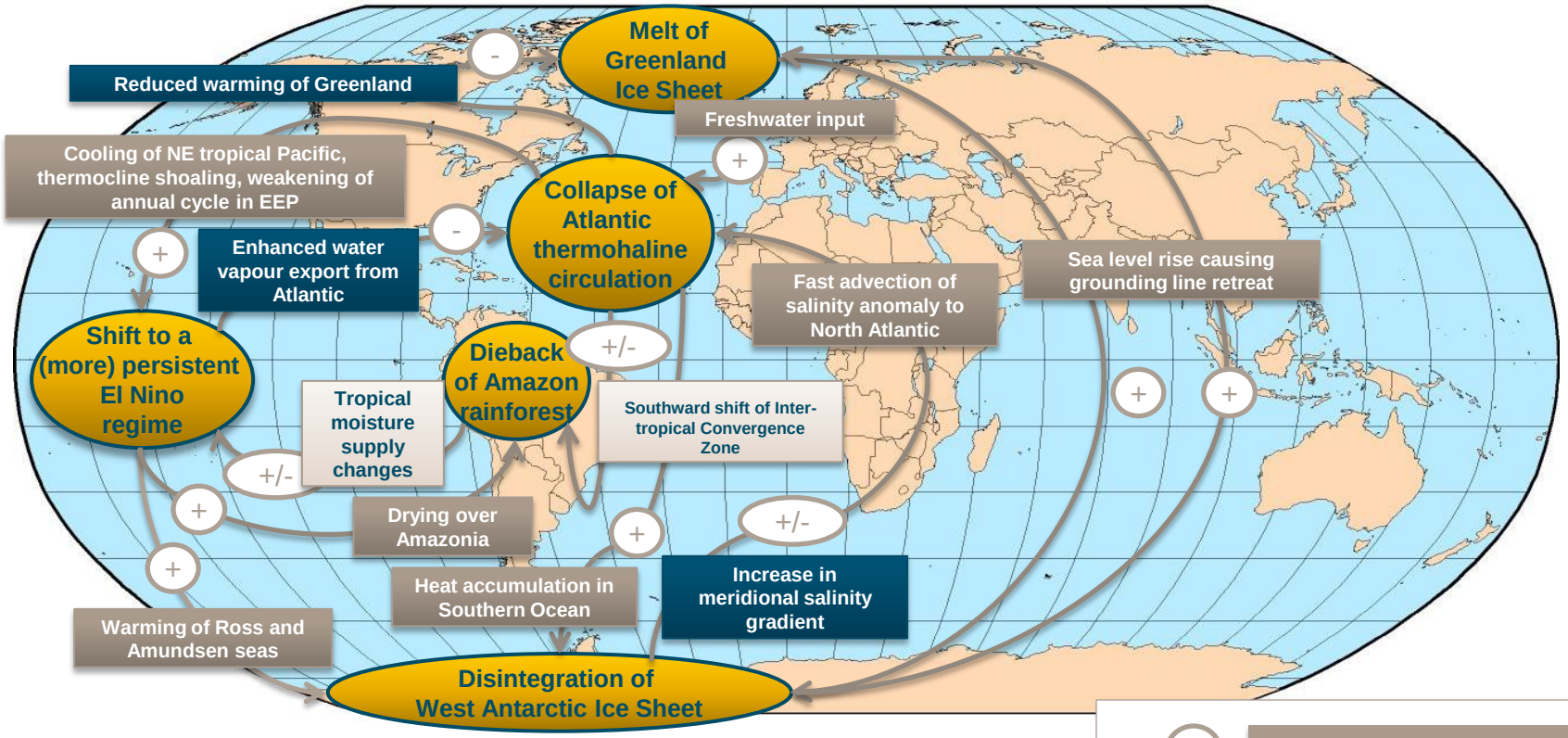
Antarctica

Amazon

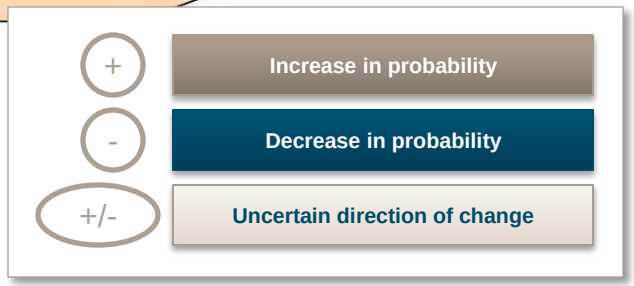
El Niño

Interactions between tipping events

Kriegler et al. (2009) *PNAS* **106**(13): 5041-5046



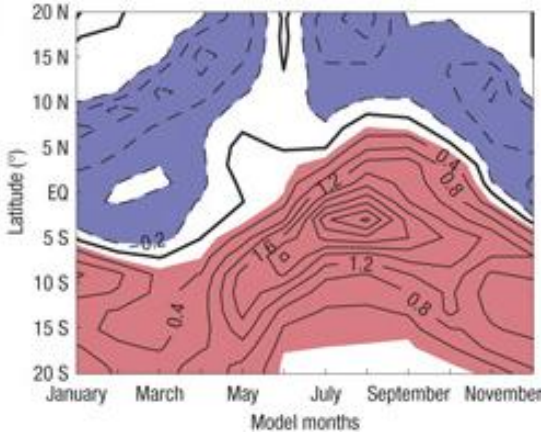
Tipping events are connected A→B if at least 5 experts judged that triggering A had a direct effect on the probability of triggering B thereafter

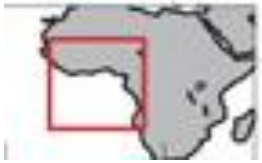


West African Monsoon

Chang *et al.* (2008) *Nature Geoscience* **1**: 444-448

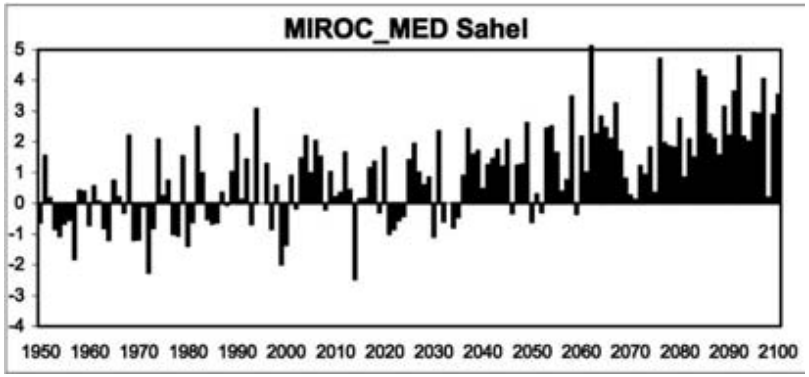
- Weakening of the Atlantic overturning circulation could trigger collapse of West African Monsoon (WAM)
- Collapse of the WAM could in turn cause increased inflow of moist air from West
- Requires ~3K warming of Gulf of Guinea SSTs
- Potential for increased food production in the Sahel region





Fractional change in annual precipitation cycle

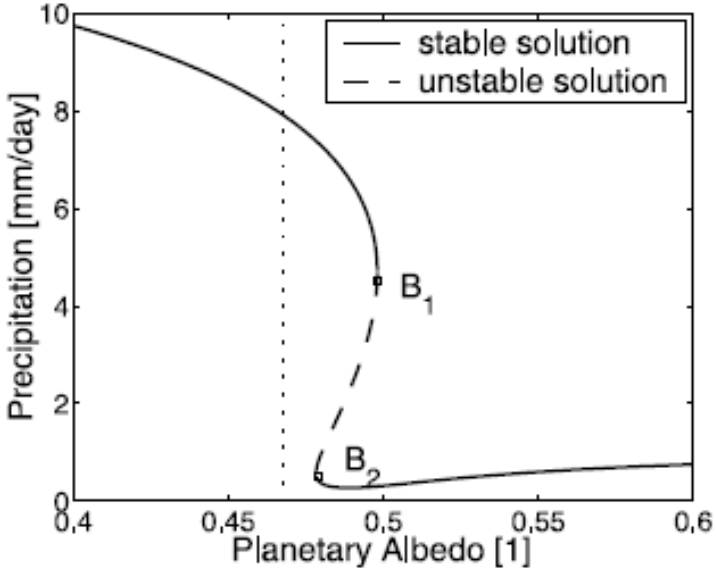
Sahelian JJAS precipitation change (mm day^{-1})

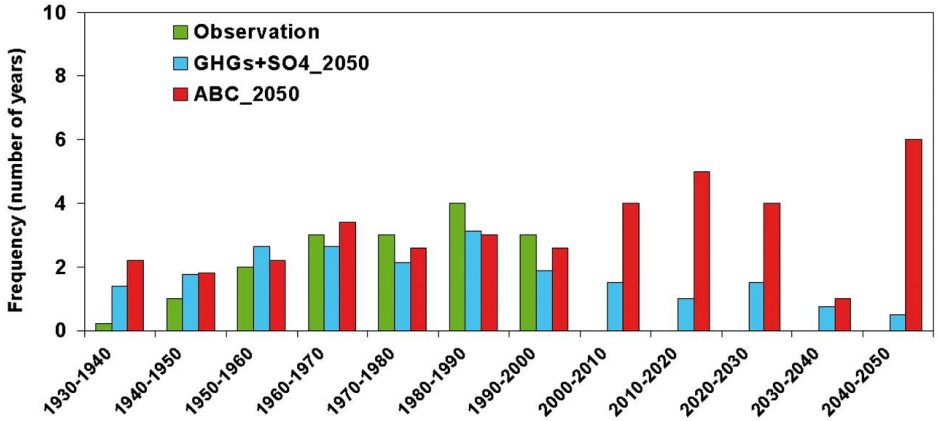


Cook and Vizy (2006) *Journal of Climate* 19: 3681-3703

Indian summer monsoon

Zickfeld, K. *et al.* (2005) *GRL* **32**: L15707; Ramanathan, V. *et al.* (2005) *PNAS* **102**(15): 5326



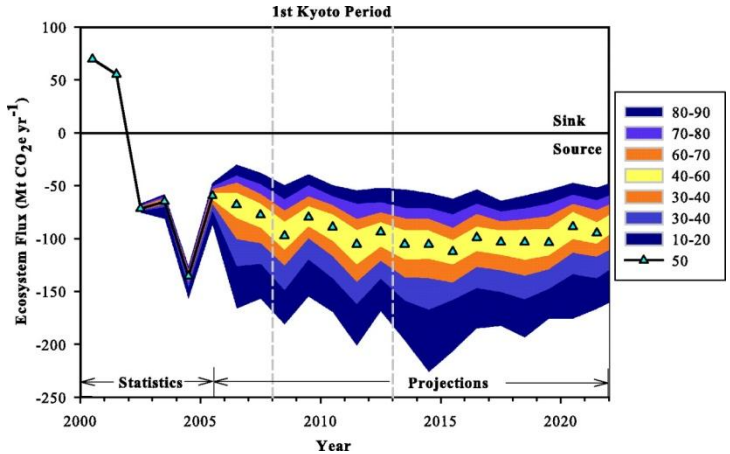


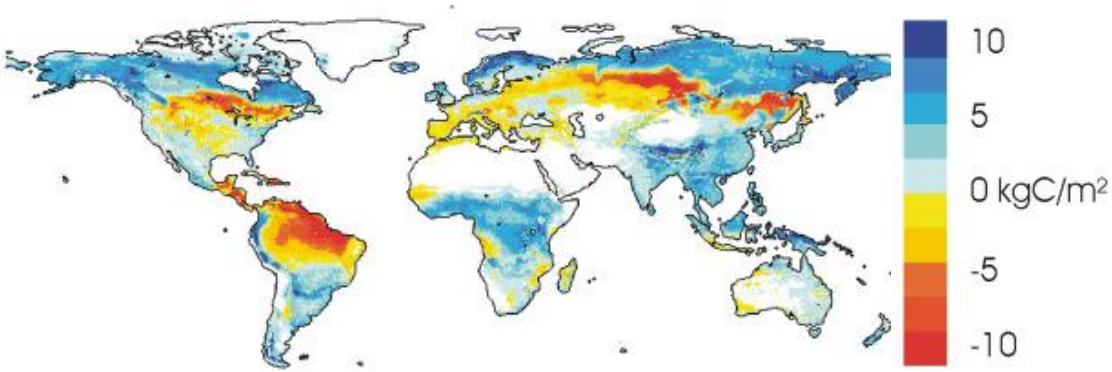
- Atmospheric brown cloud haze tends to weaken monsoon
- Greenhouse gas forcing tends to strengthen monsoon
- Potential “roller coaster” with huge societal impacts

Boreal forest

Lucht *et al.* (2006) *Carbon Balance and Management* 1: 6; Kurz et al. (2008) *PNAS* 105(5): 1551-5

- Canadian forests have recently switched from carbon sink to source due to insect outbreaks
- More widespread dieback forecast under ~3°C global warming (~7°C local warming)
- Map shows change in vegetation carbon content from 2000 to 2100
  - LPJ model forced with SRES A2 climate change from HadCM3





Yedoma permafrost

Khvorostyanov et al. (2008) *Geophysical Research Letters* **35, L10703**

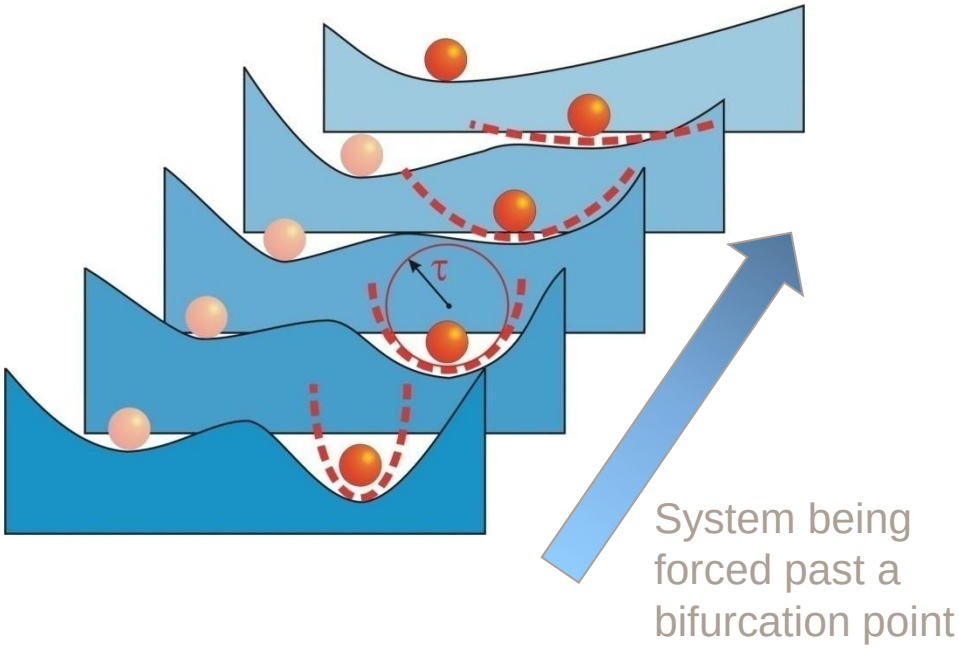
- Extent of permafrost melt forecast to be proportional to warming (*not* a tipping element)
- But Yedoma, containing up to 500 PgC, could undergo runaway meltdown due to biochemical heat release
- Estimated threshold is a 9 °C regional warming, but note this region warmed >3 °C in 2007

Prospects for early warning

Held & Kleinen (2004) *Geophysical Research Letters* 31: L23207
Lenton et al. (2008) *PNAS* 105(6): 1786-1793

Generic early warning signals:

- **Slowing down**
- Increasing variability
- Skewness of responses



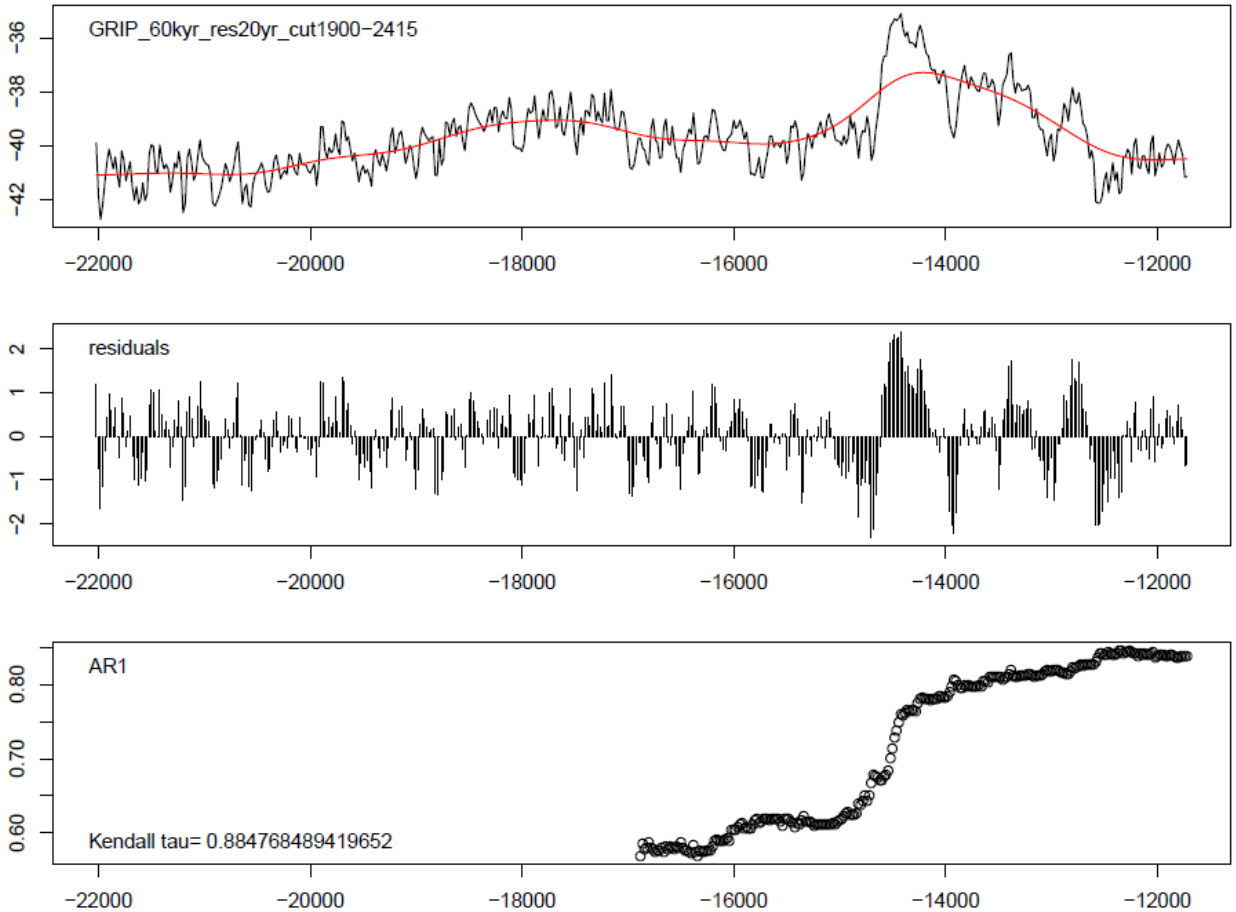
Slowing down at the end of the ice age

Lenton, Livina, Dakos *et al.* (in prep.) *Phil Trans A*

GRIP $\delta^{18}O$ data

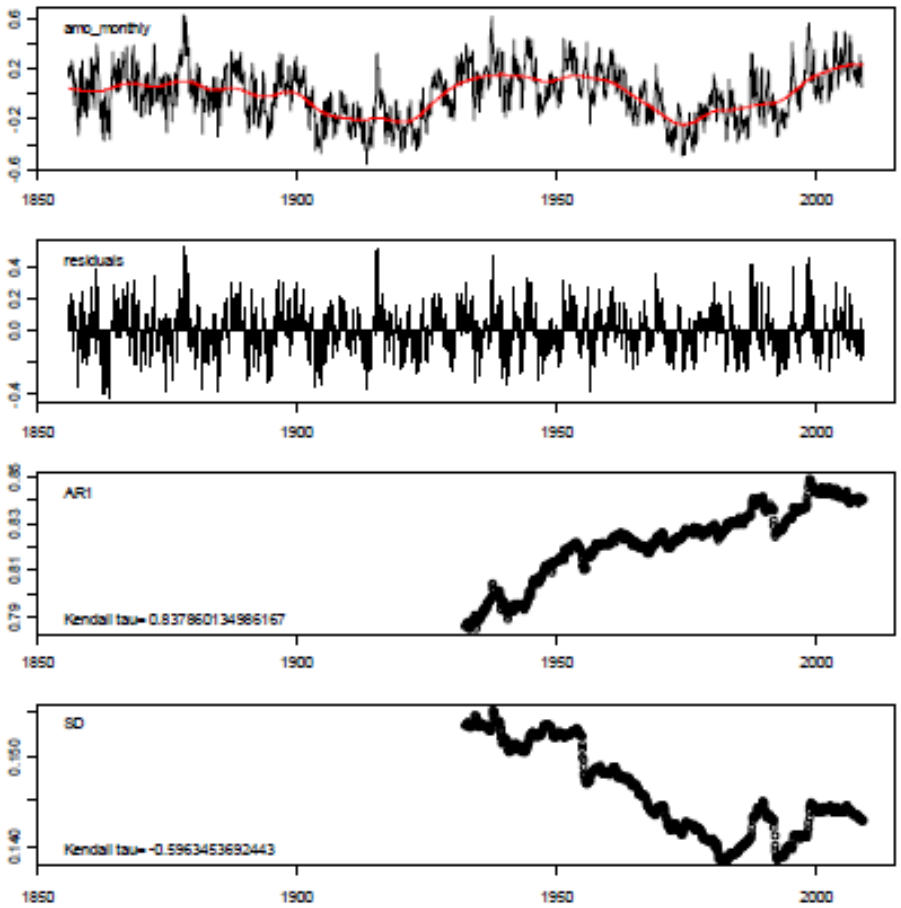
Detrended data

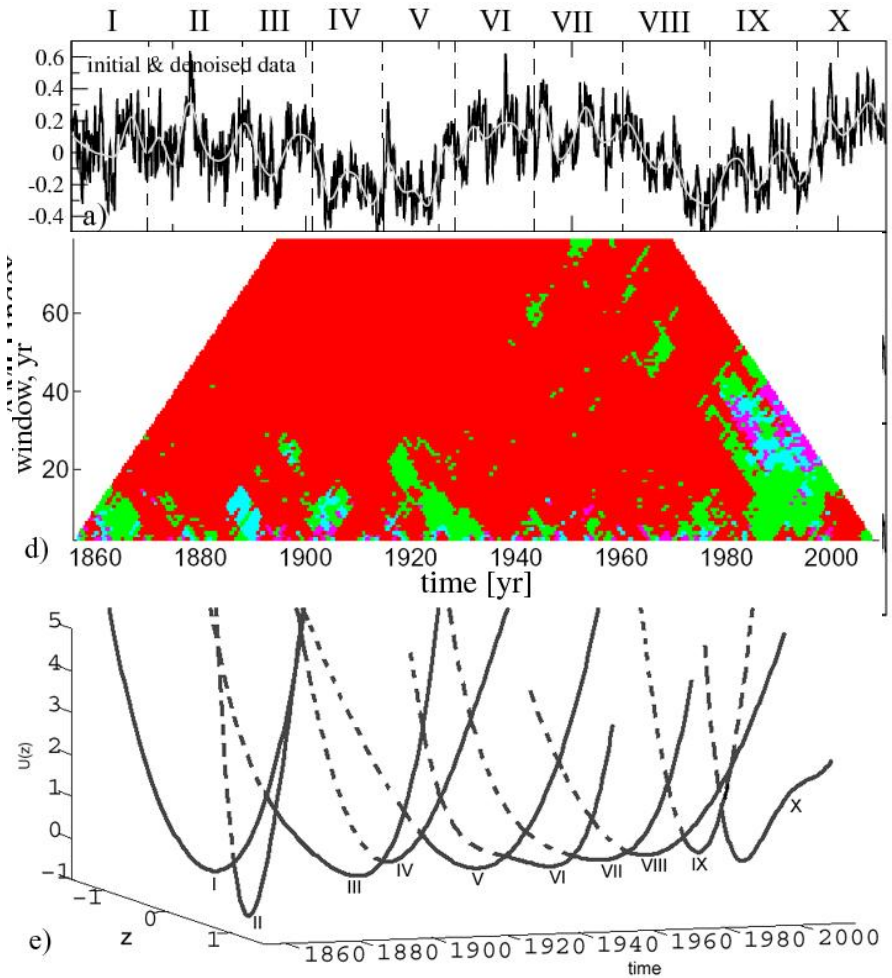
Early warning indicator



Atlantic Multi-decadal Oscillation index

Results from Vasilis Dakos and Valerie Livina





Number of states: 1, 2, 3, 4

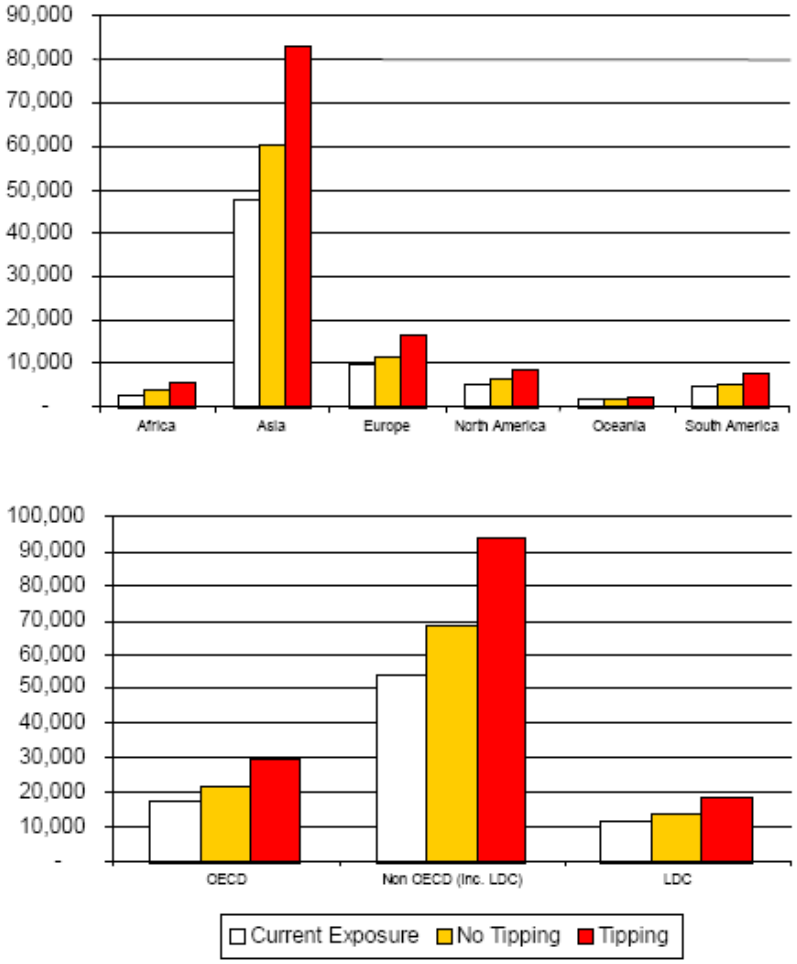
Impacts of tipping

Lenton, Footitt & Dlugolecki (2009)

Allianz / WWF report:

- Increased sea level rise
  - +$25,158 billion exposed assets in port megacities
- Amazon dieback and drought
- Indian summer monsoon disruption
- Aridification of southwest North America

Populations exposed to 1-in-100-yr flood events



http://knowledge.allianz.com/climate_tipping_points/climate_en.html

‘Straw man’ tipping point risk assessment

Tipping element	Likelihood of passing a tipping point (by 2100)	Relative impact** of change in state (by 3000)	Risk score (likelihood x impact)	Risk ranking
Arctic summer sea-ice	High	Low	3	4
Greenland ice sheet	Medium-High*	High	7.5	1 (highest)
West Antarctic ice sheet	Medium*	High	6	2
Atlantic THC	Low*	Medium-High	2.5	6
ENSO	Low*	Medium-High	2.5	6
West African monsoon	Low	High	3	4
Amazon rainforest	Medium*	Medium	4	3
Boreal forest	Low	Low-Medium	1.5	8 (lowest)

*Likelihoods informed by expert elicitation
**Initial judgment of relative impacts is my subjective assessment

Conclusion

- Tipping elements in the climate system could be triggered this century by anthropogenic forcing
- If business-as-usual continues we should expect to pass tipping points, i.e. high impact *high* probability events
- Early warning systems are conceivable and could help societies manage the risk posed by tipping points
- More research is needed on the corresponding impacts in order to do a proper risk assessment
- Then put that data in your integrated assessment model!