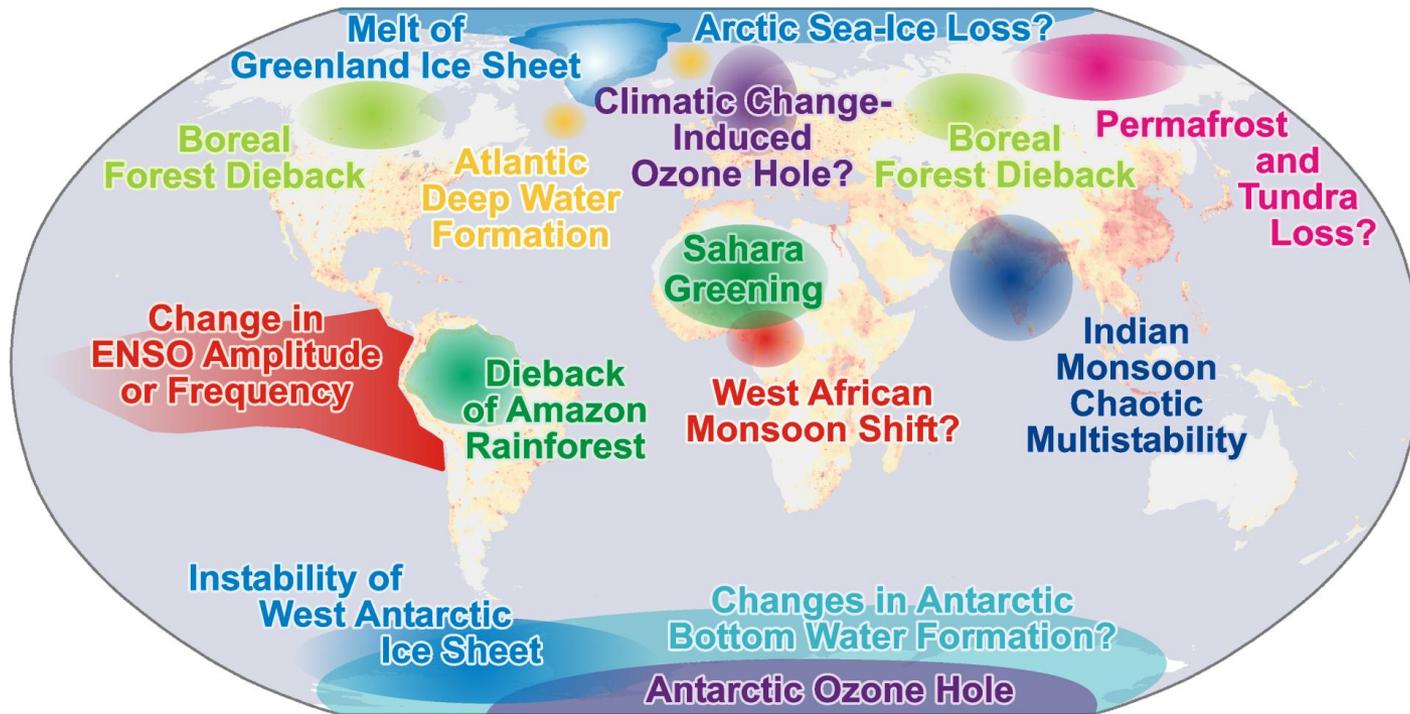


Early warning of climate tipping points



Tim Lenton

With thanks to John Schellnhuber, Valerie Livina, Vasilis Dakos, Marten Scheffer





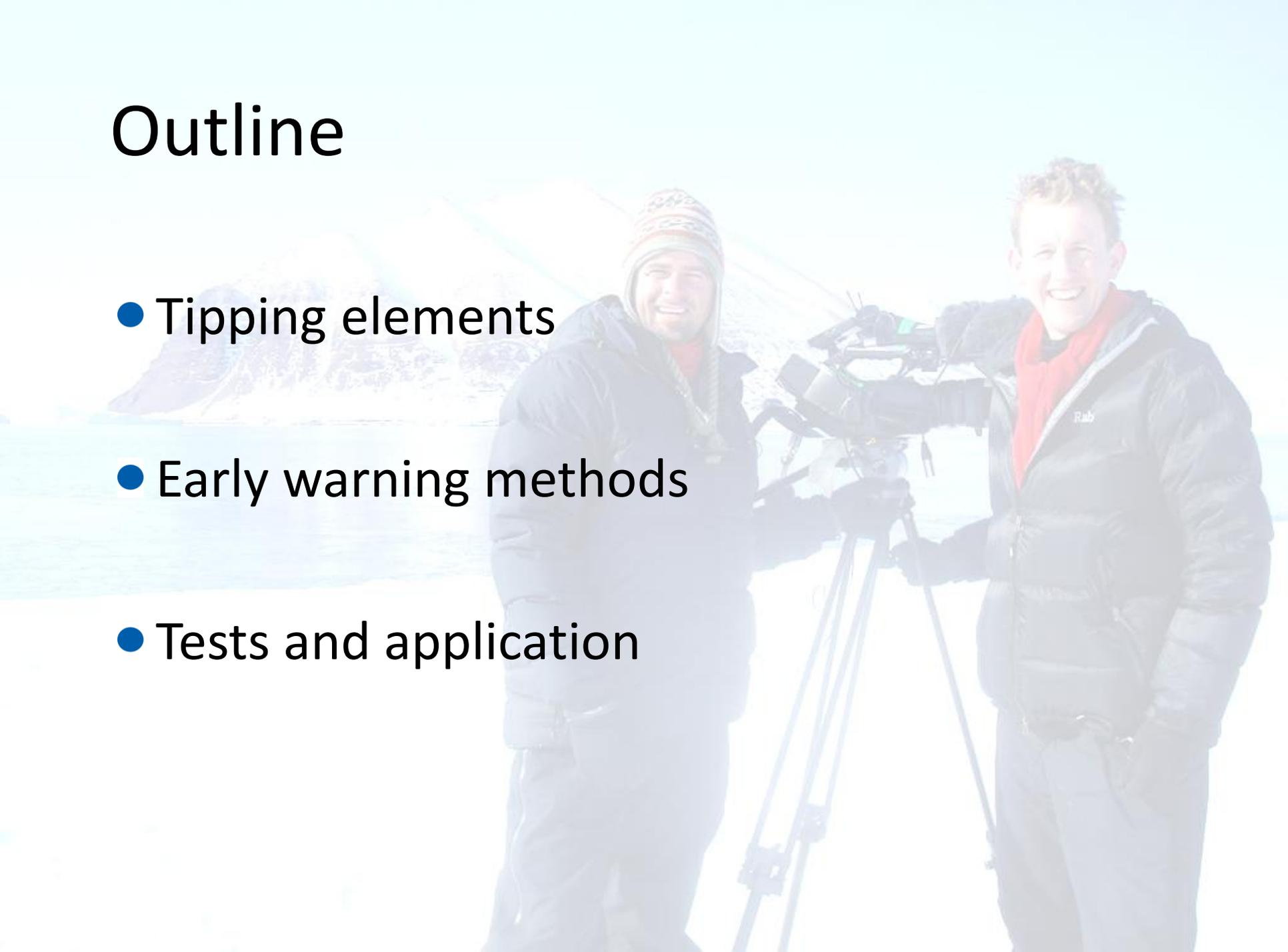
Fax: 32 68 50





Outline

- Tipping elements
- Early warning methods
- Tests and application



Little things can make a big difference

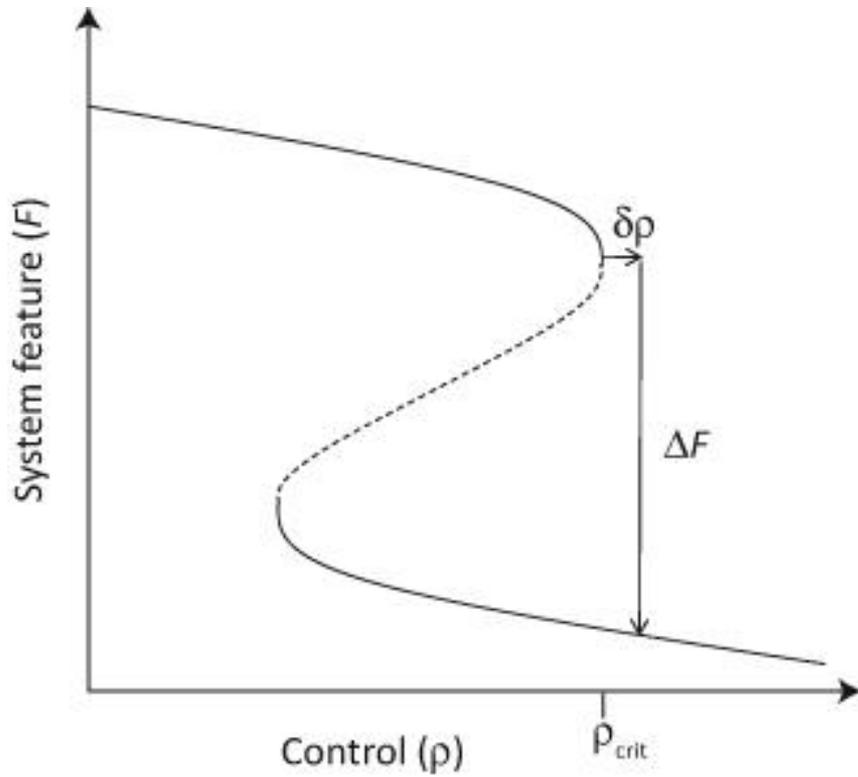
- **Tipping element**

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

- **Tipping point**

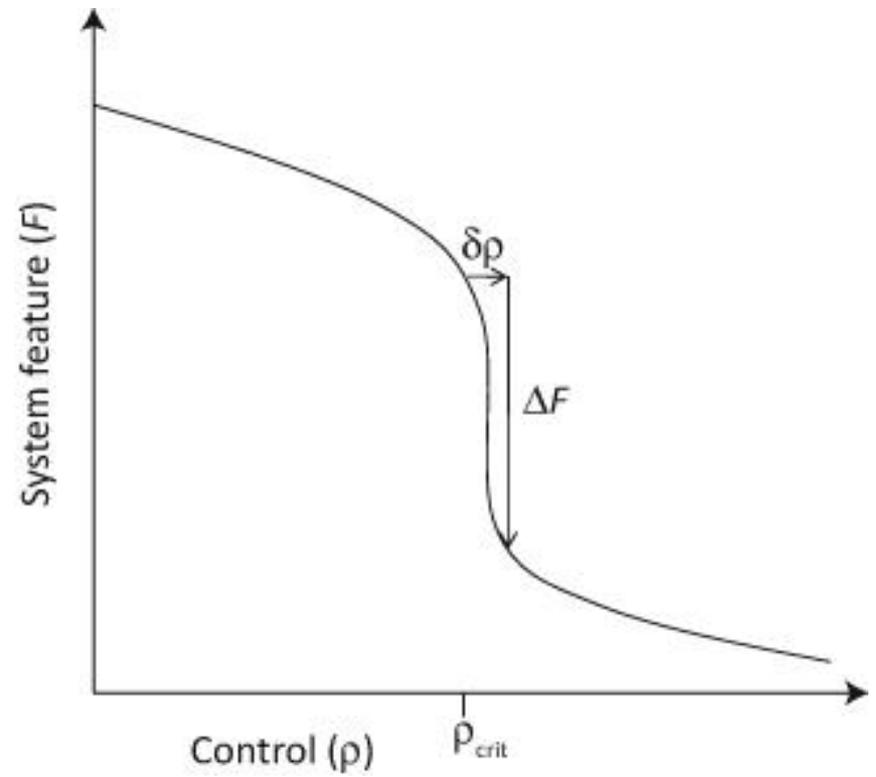
- The corresponding critical point – in forcing and a feature of the system – at which the future state of the system is qualitatively altered.

Bifurcation



Irreversible transition

No bifurcation

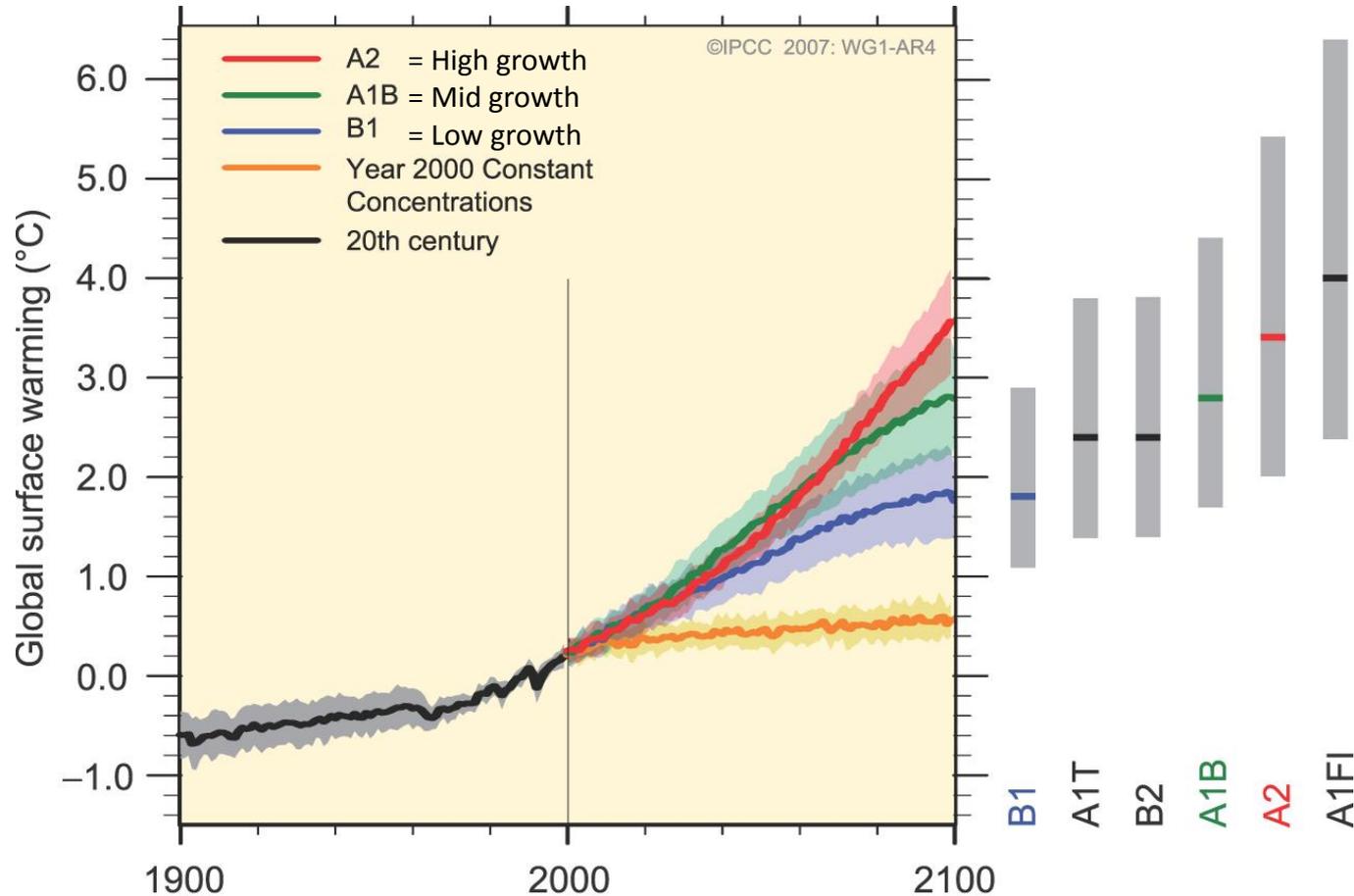


Reversible transition

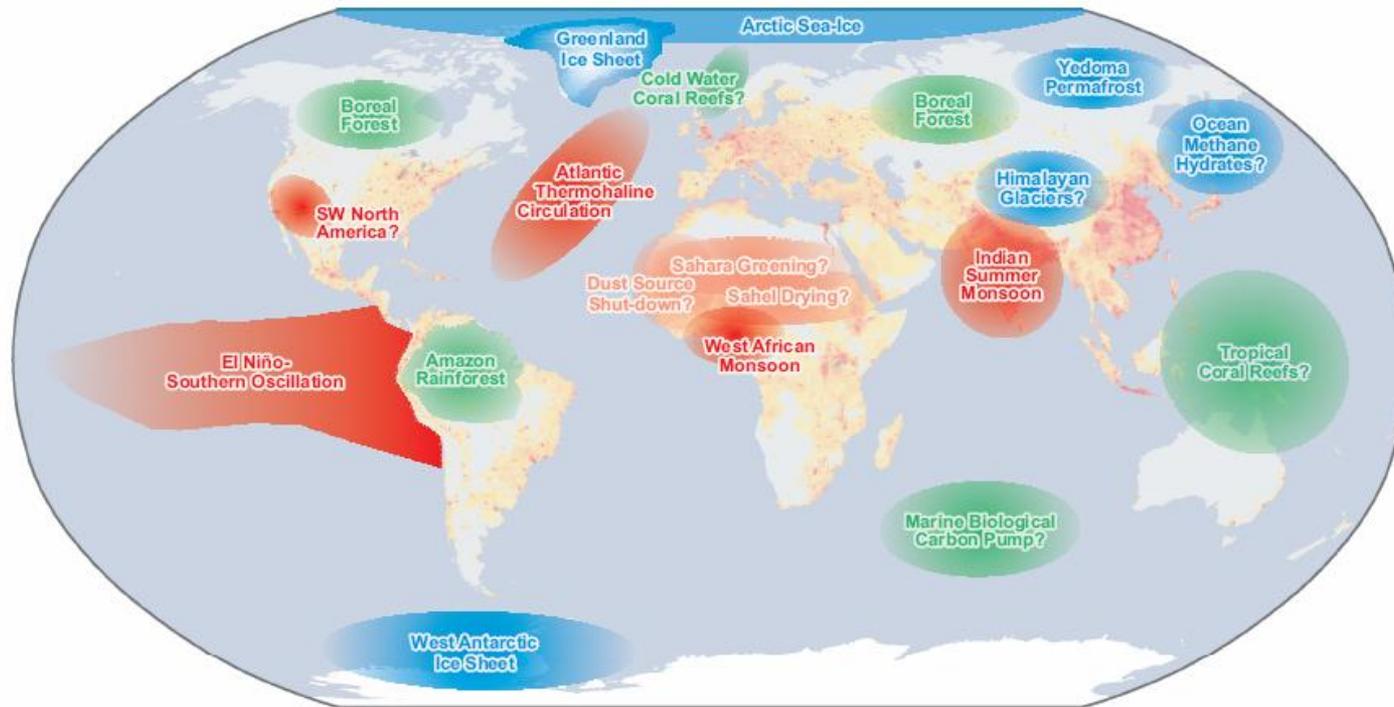
Policy relevant tipping elements

- 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.

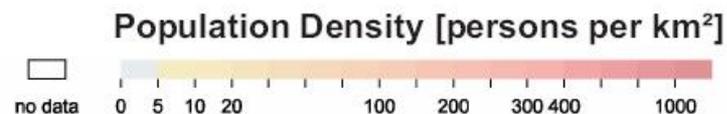
Observations & IPCC projections



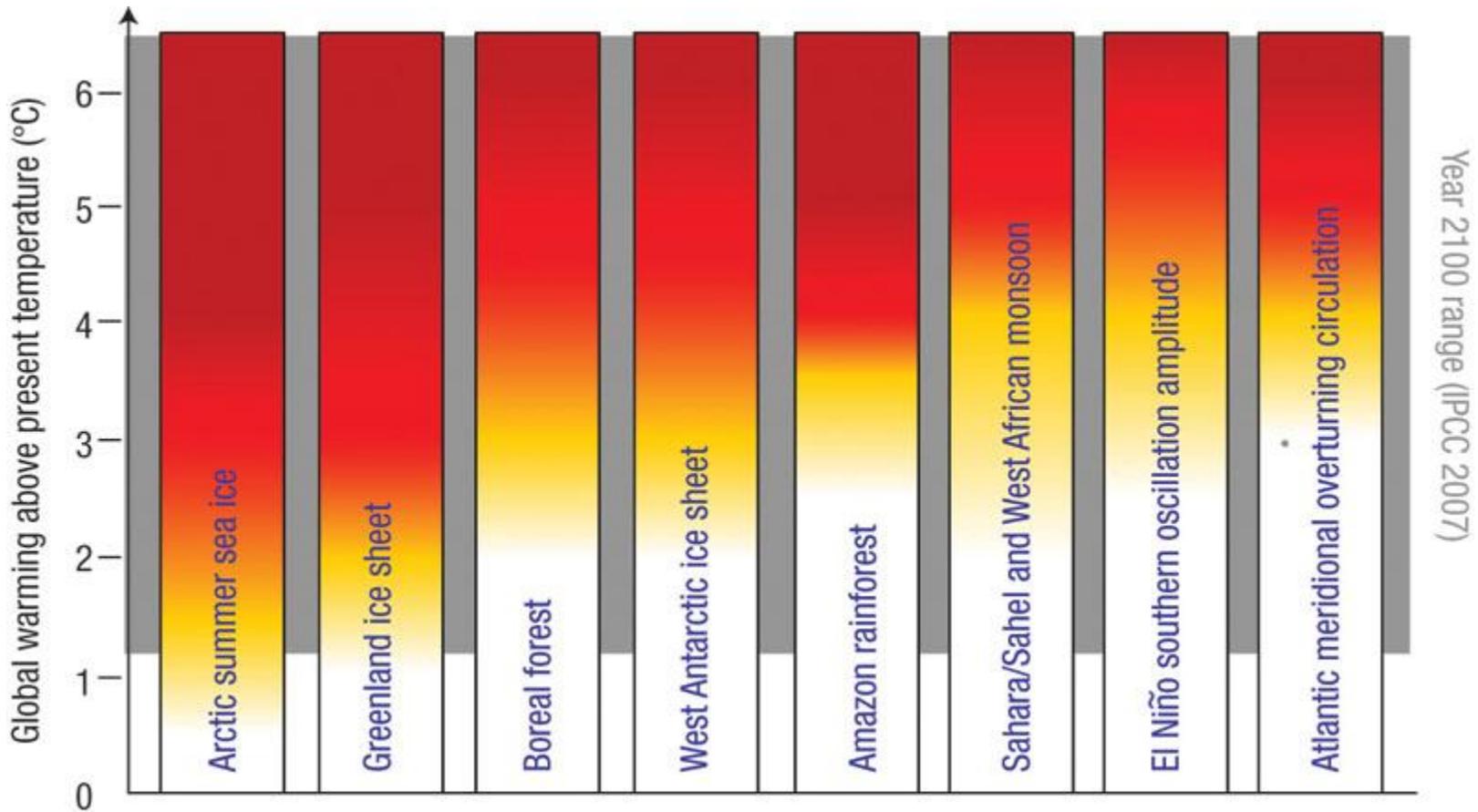
Tipping elements in the climate system



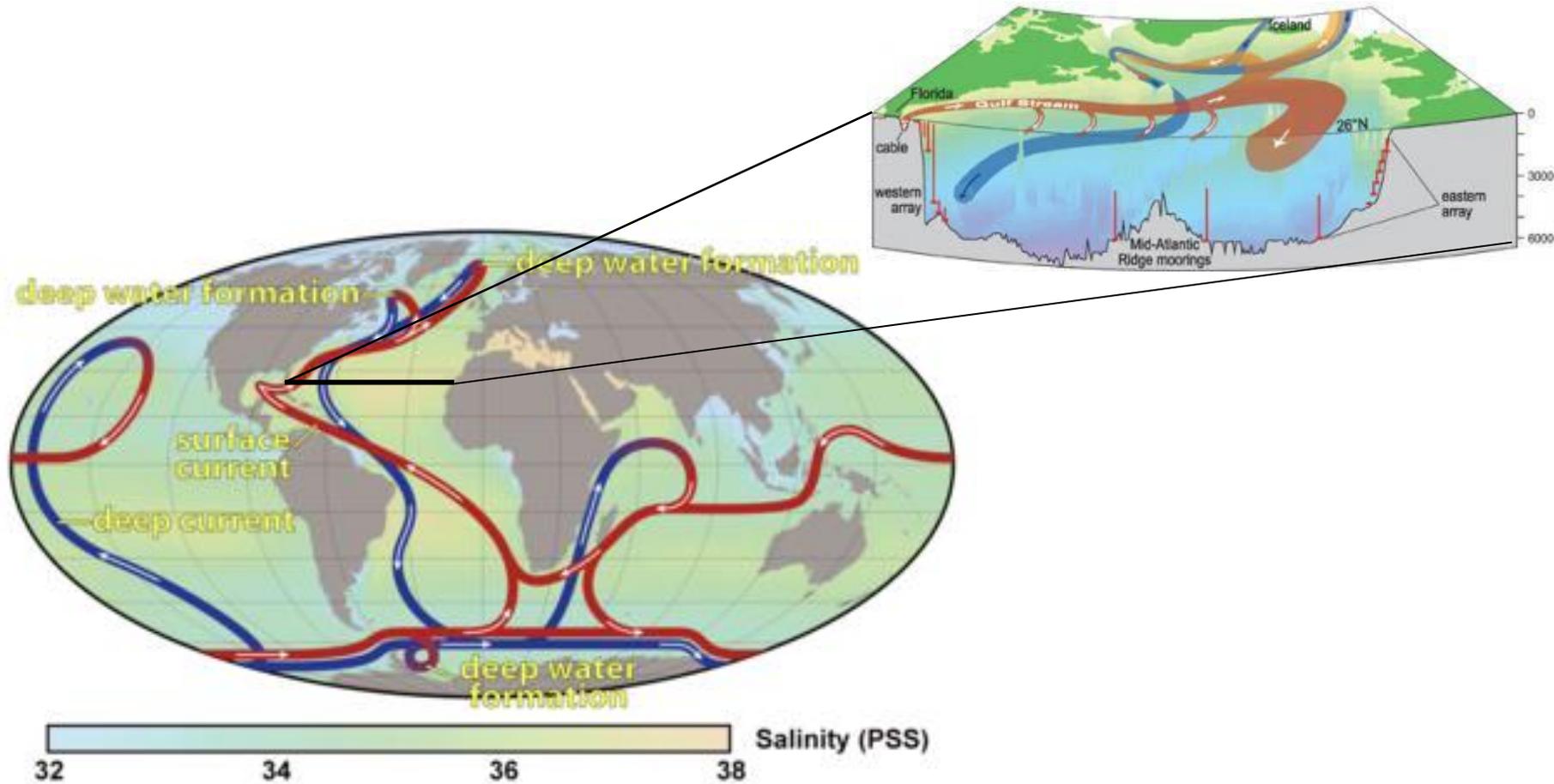
- Melting
- Circulation Change
- Biome Loss



Estimates of proximity

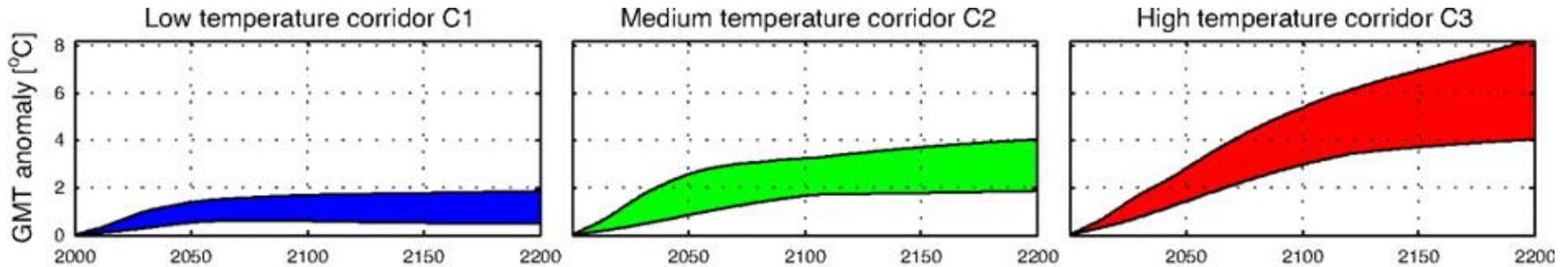


Atlantic overturning circulation



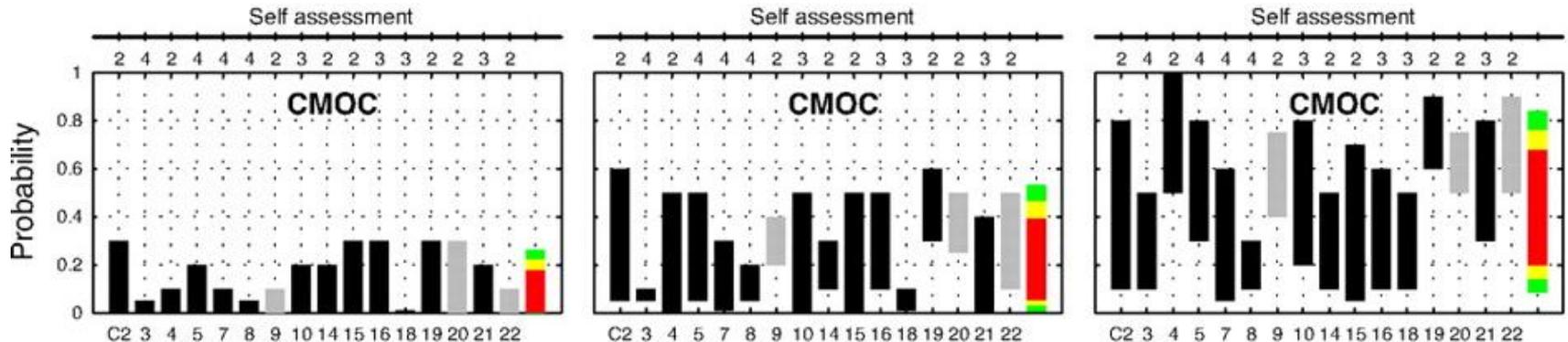
Probabilities under different scenarios

- Three different warming scenarios:

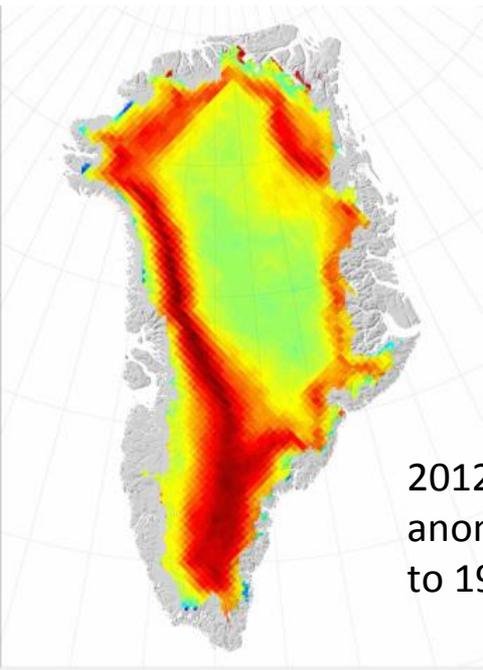


- Imprecise probability statements elicited from experts.

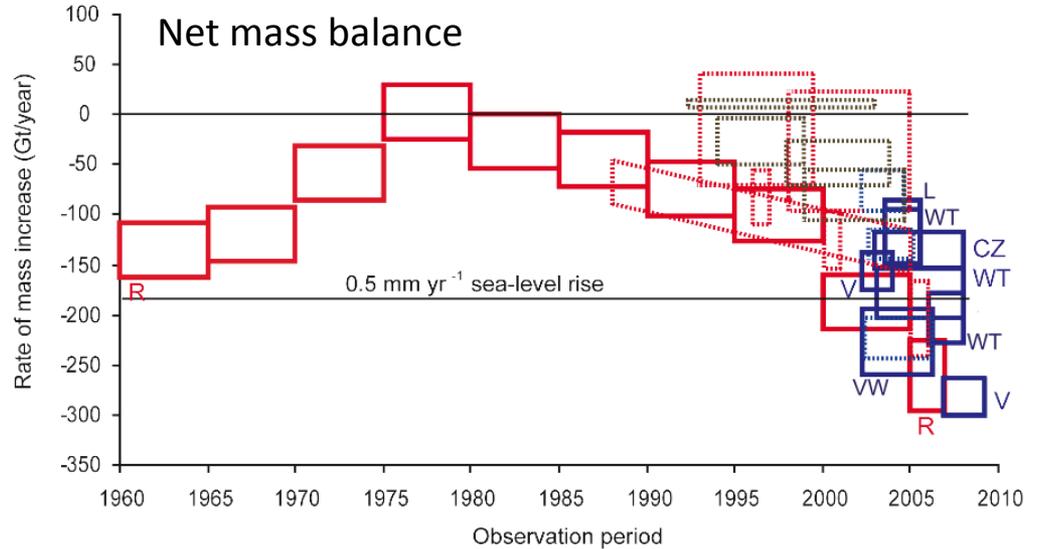
- Example of collapse of Atlantic meridional overturning circulation:



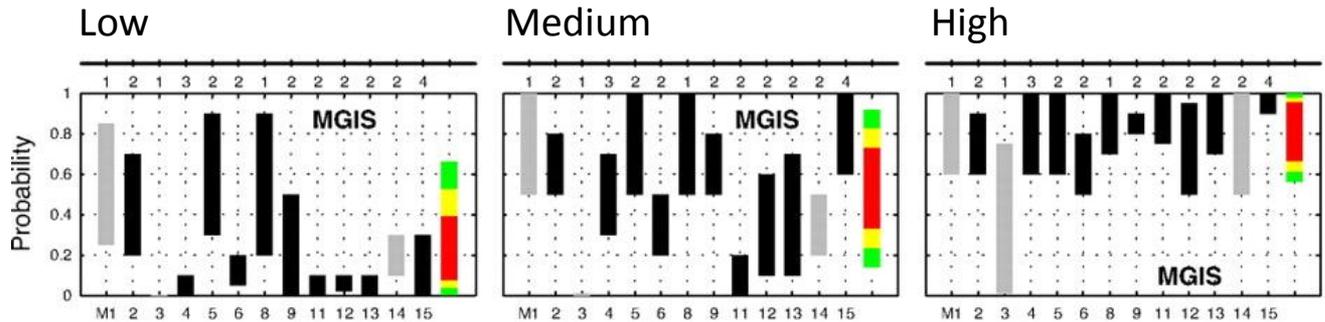
Greenland ice sheet



2012 melt days anomaly relative to 1980-1999

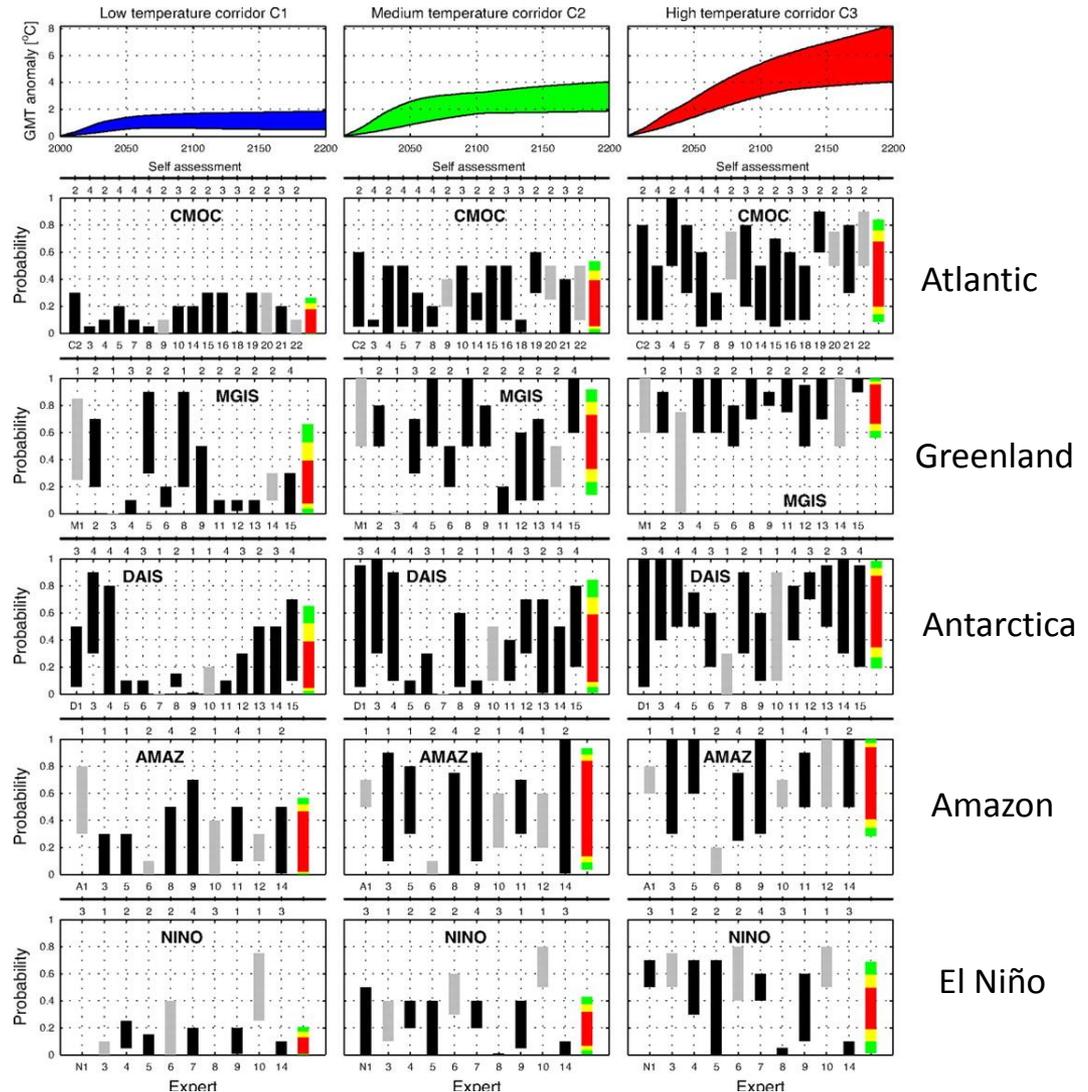


Expert elicitation for future warming scenarios:

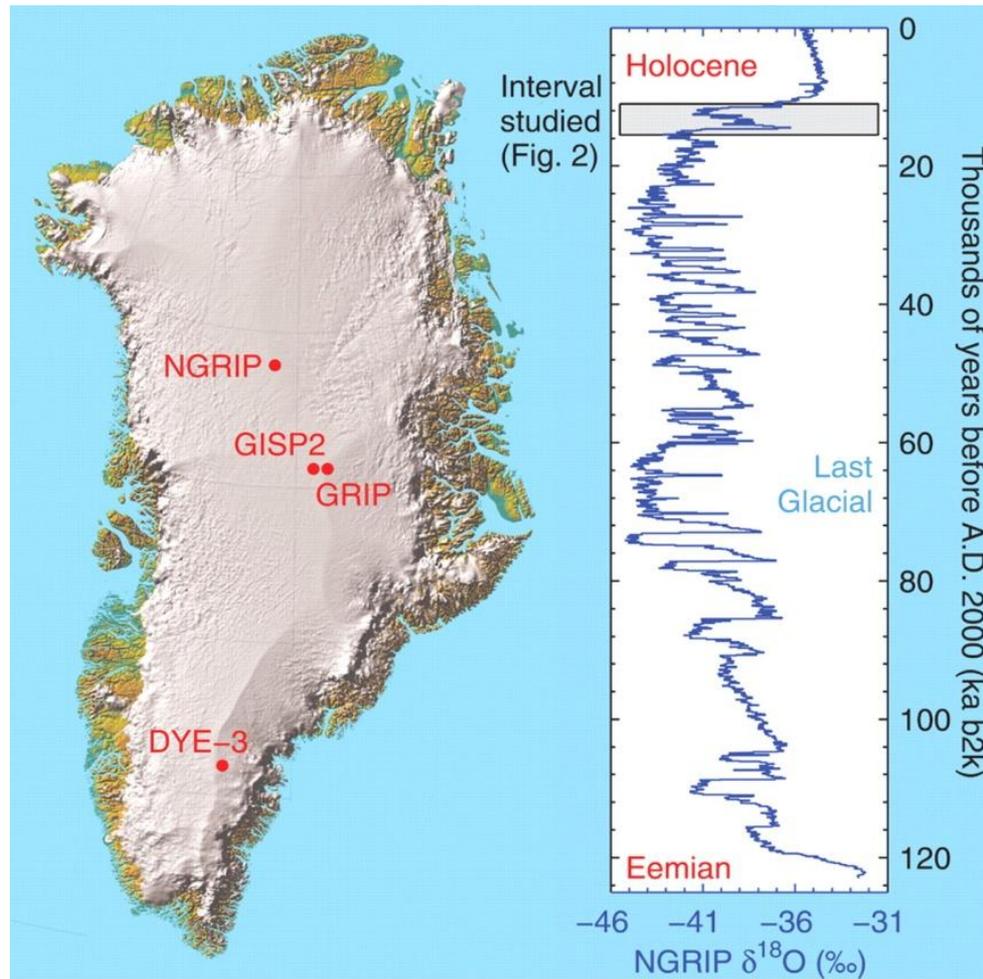


Likelihood

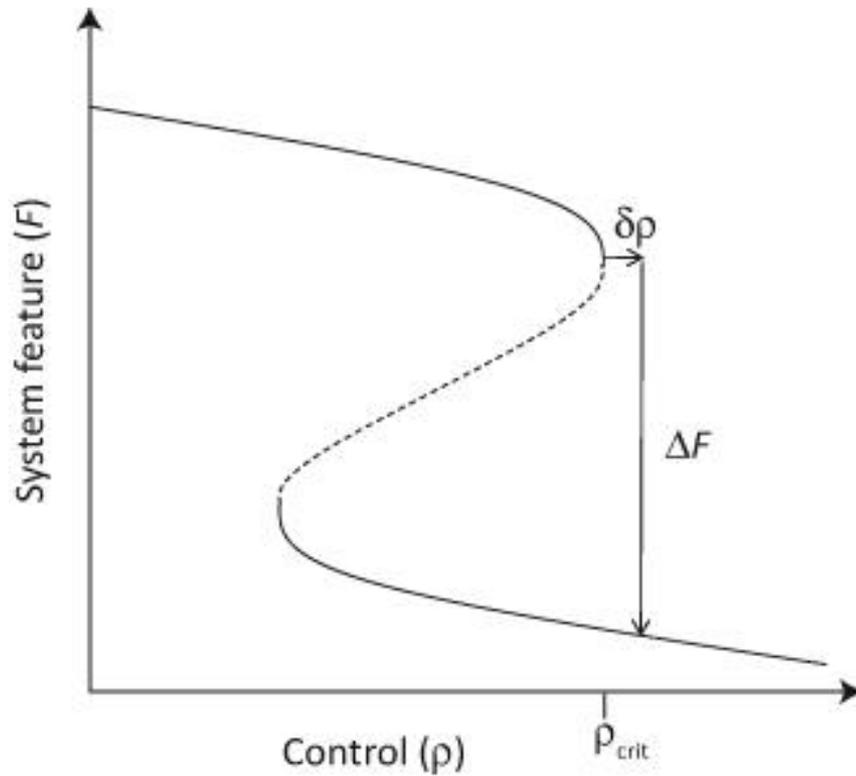
- ✦ Imprecise probability statements from experts formally combined
- ✦ Under 2-4 °C warming: >16% probability of passing at least one of five tipping points
- ✦ Under >4 °C warming: >56% probability of passing at least one of five tipping points



Past abrupt climate changes

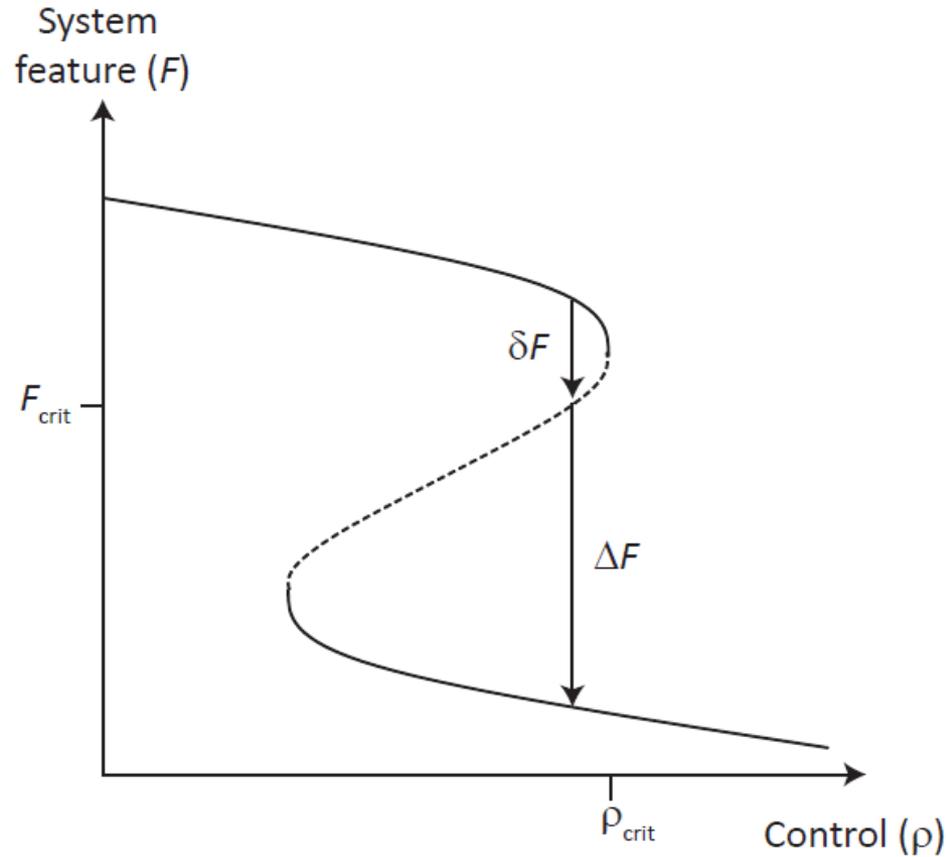


Bifurcation tipping



Early warning

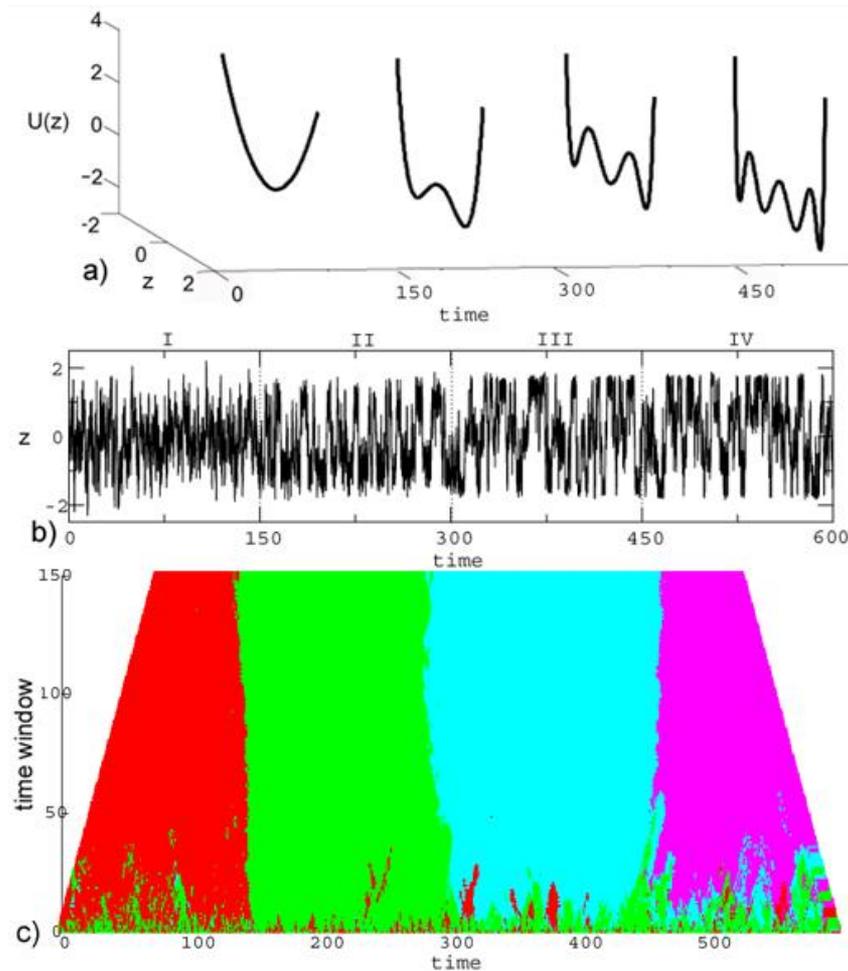
Noise-induced tipping



No early warning

Test of tipping point detection

Artificial data

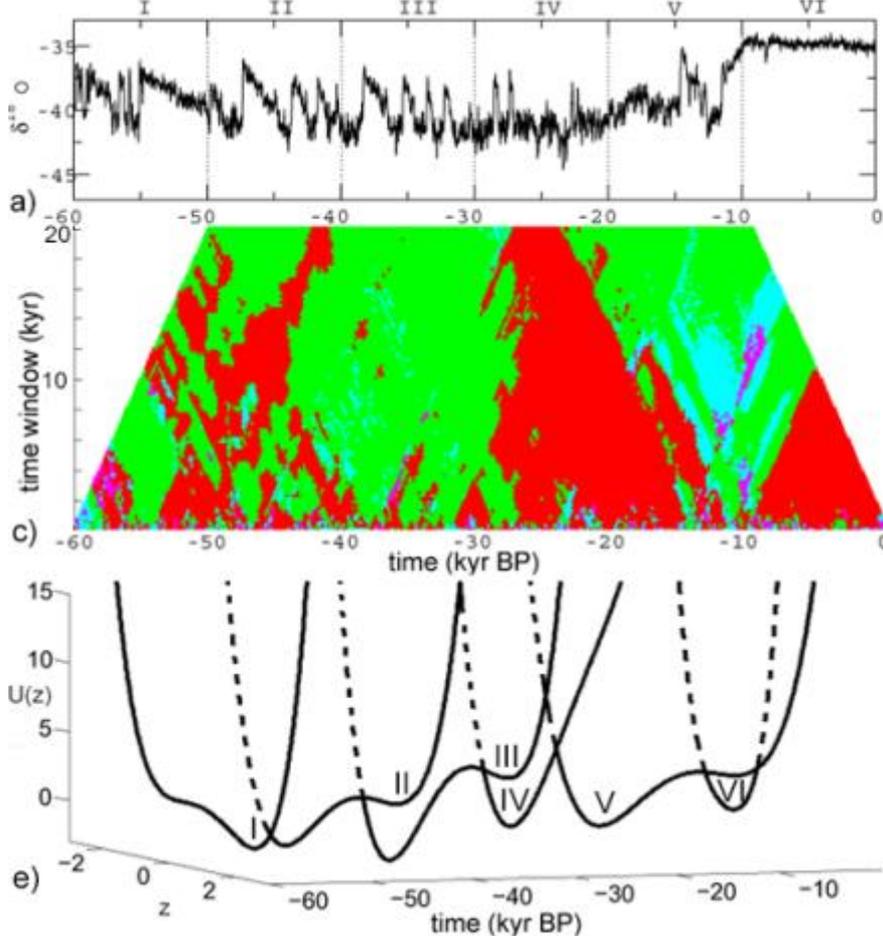


Number of states:

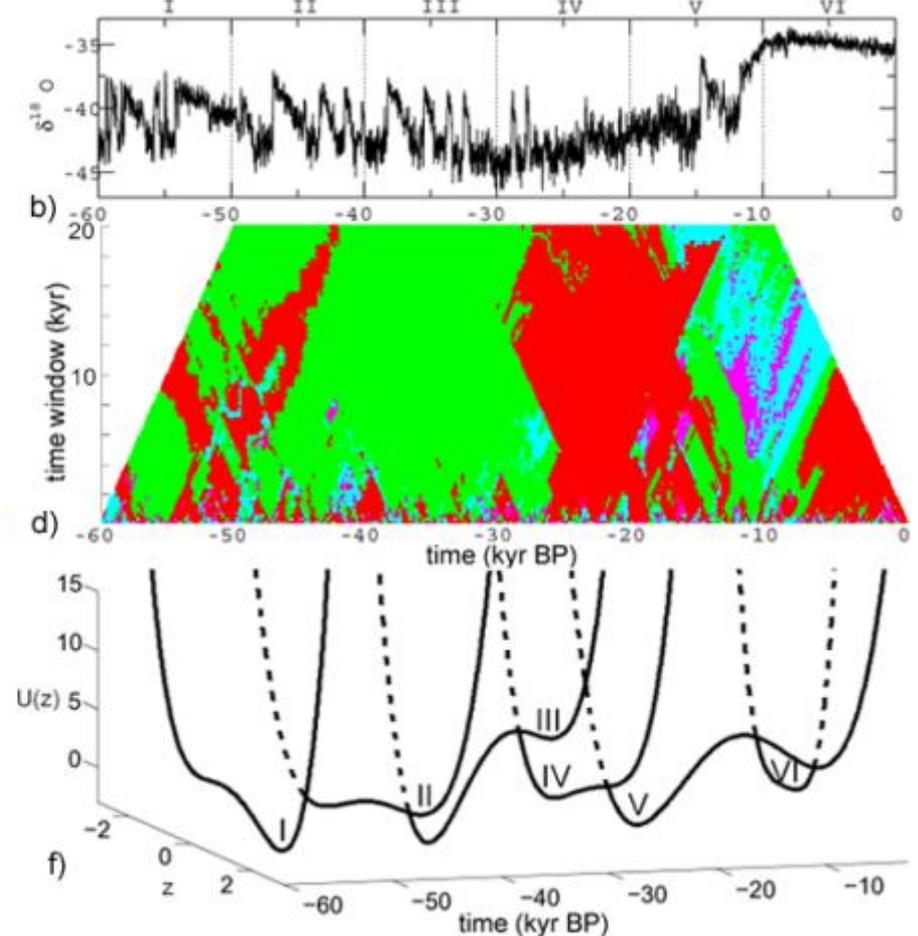
1, 2, 3, 4

Past climate tipping points

GRIP ice-core $\delta^{18}\text{O}$ proxy temperature

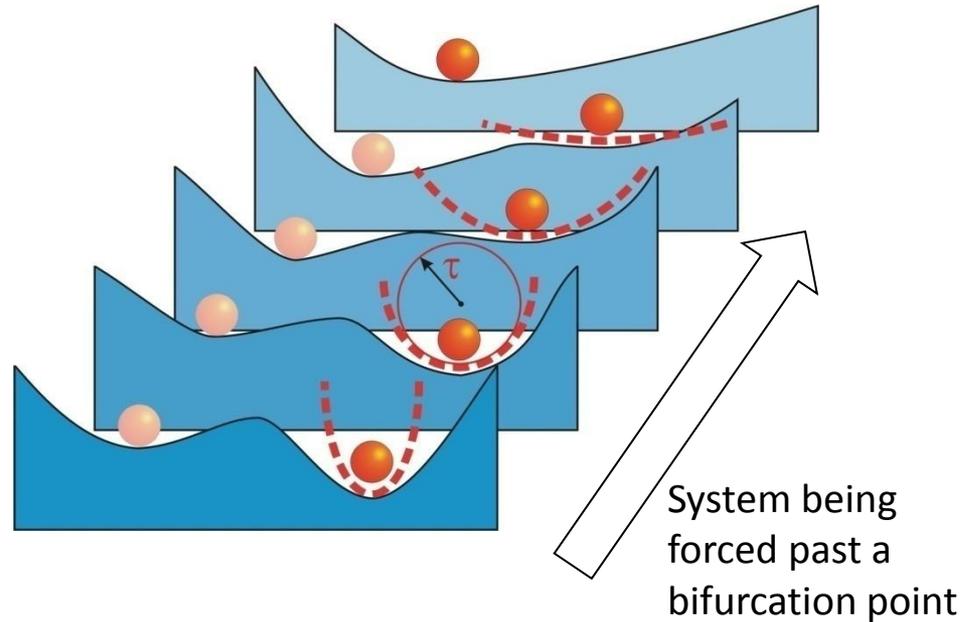


NGRIP ice-core $\delta^{18}\text{O}$ proxy temperature



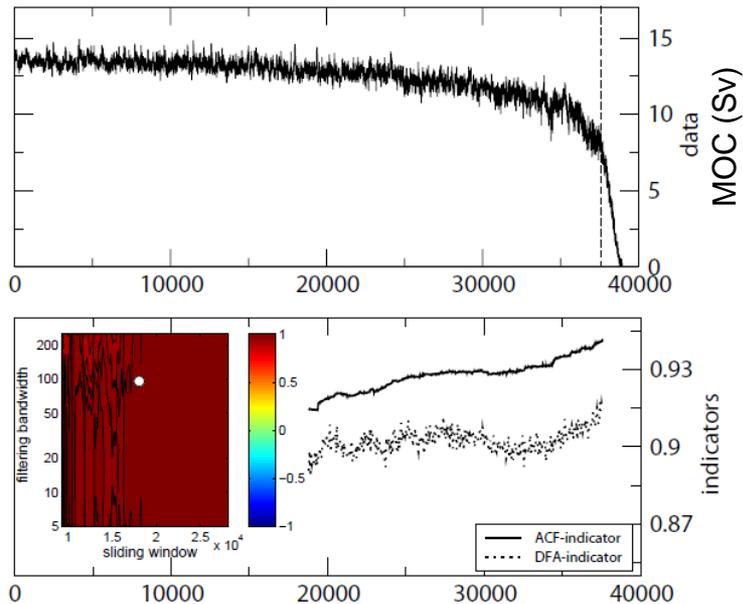
Number of states: 1, 2, 3, 4

Early warning prospects

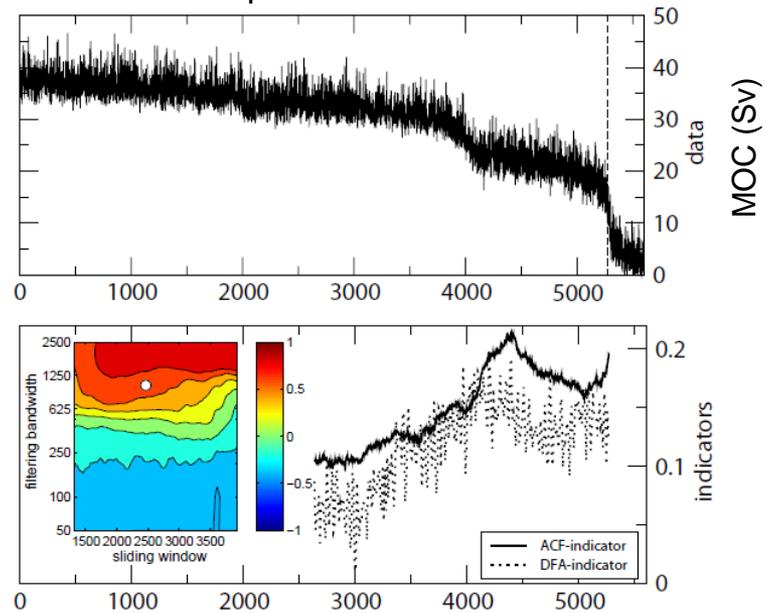


Model tests of early warning: Collapse of the thermohaline circulation

GENIE-1 intermediate complexity model

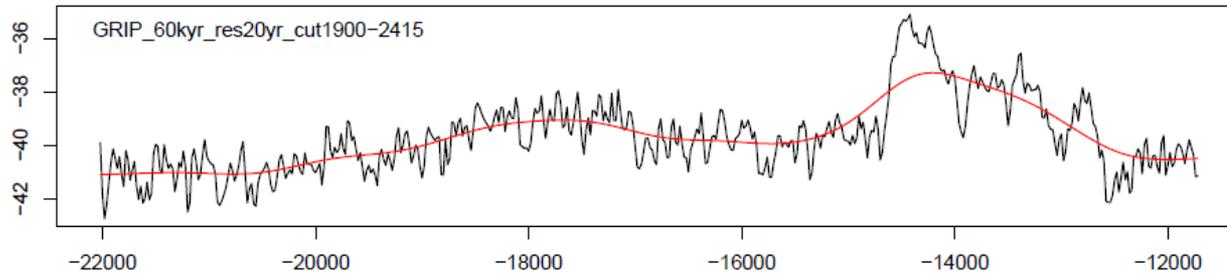


GENIE-2 atmosphere-ocean GCM

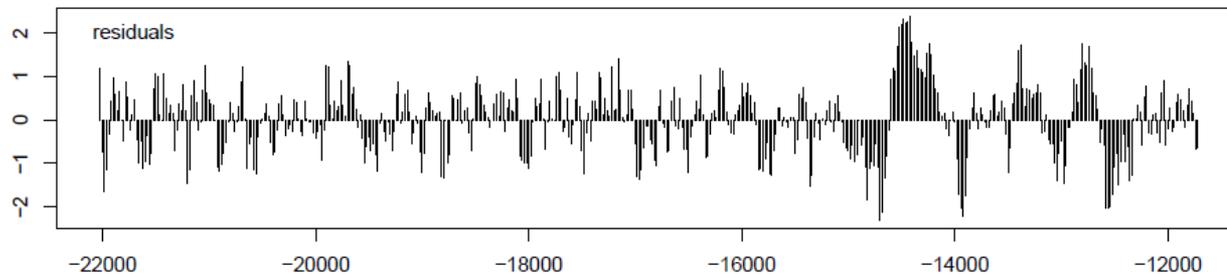


The end of the ice age in Greenland

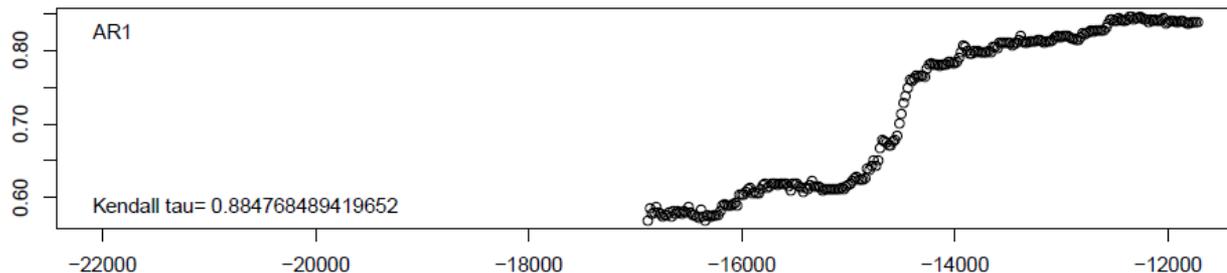
GRIP ice-core
 $\delta^{18}\text{O}$ proxy
temperature



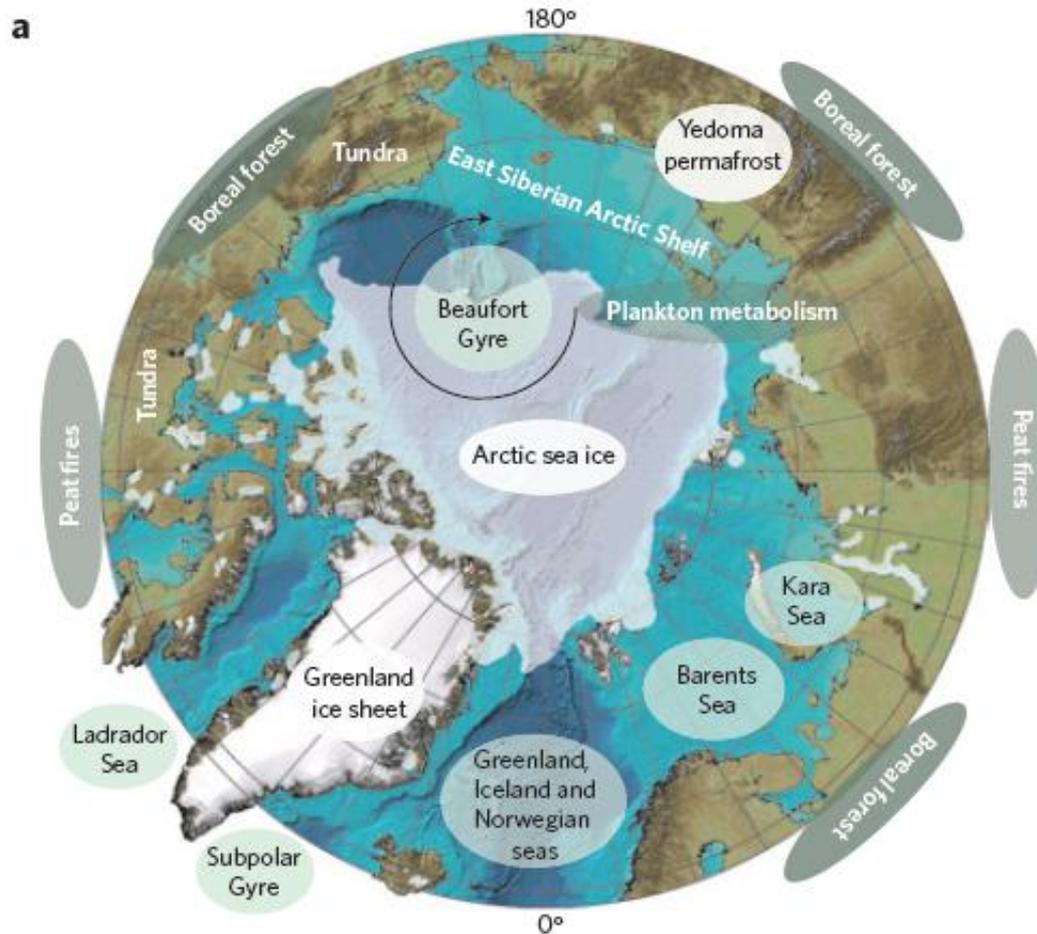
Detrended
data



Early
warming
indicator



Arctic climate tipping points

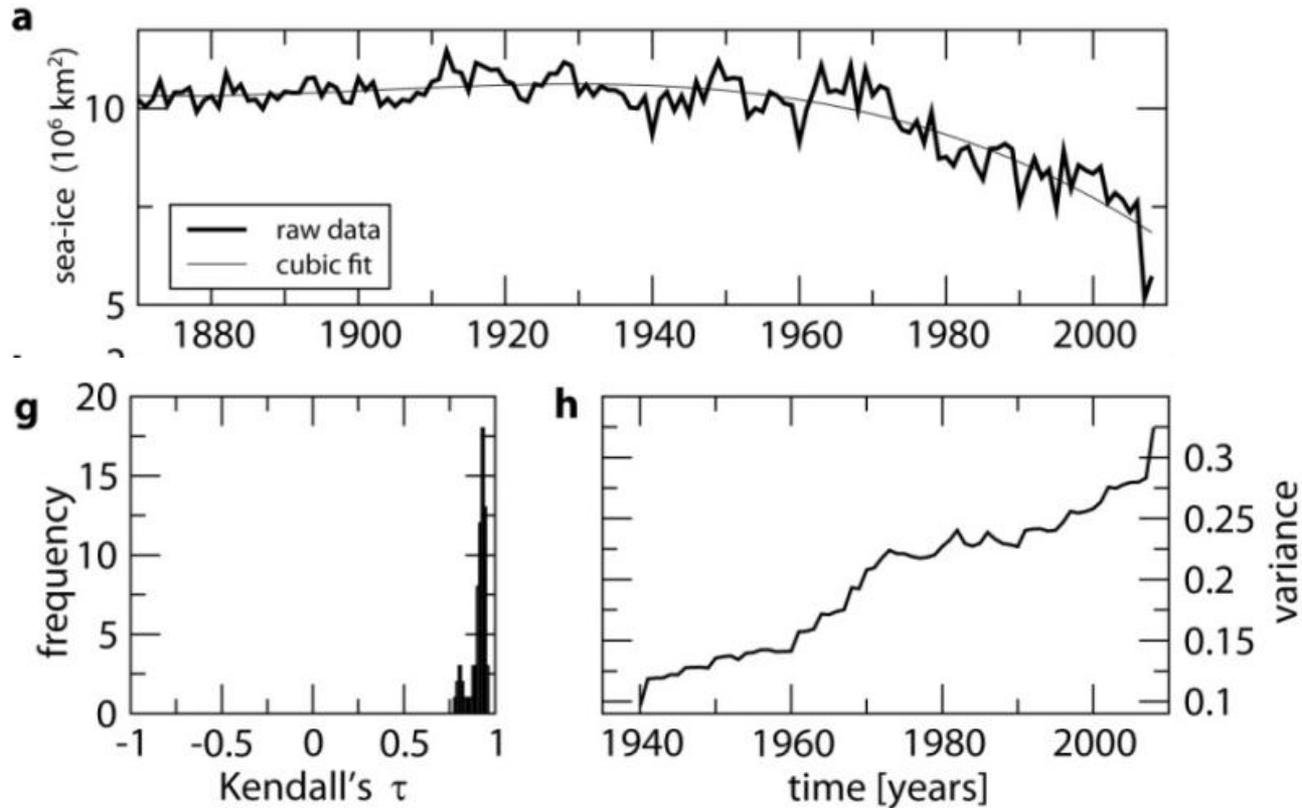


Arctic sea-ice

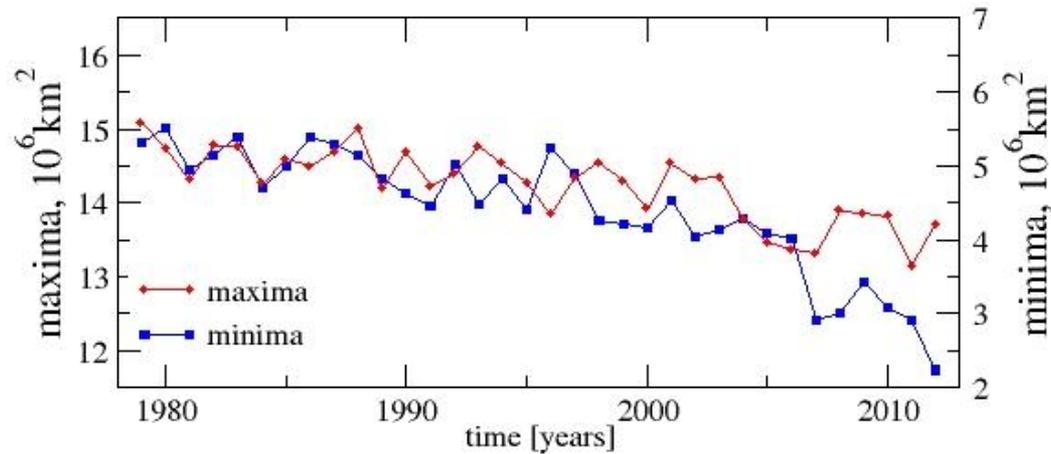
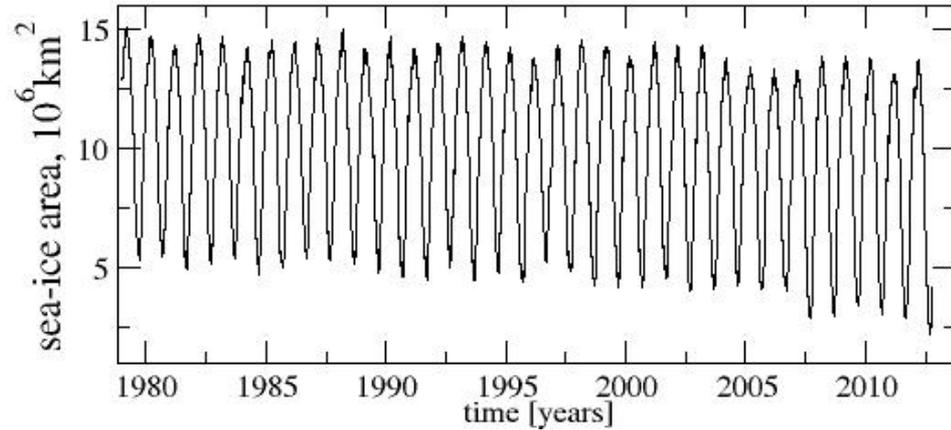


26 August 2012 compared to the 30 year average minimum (green line)

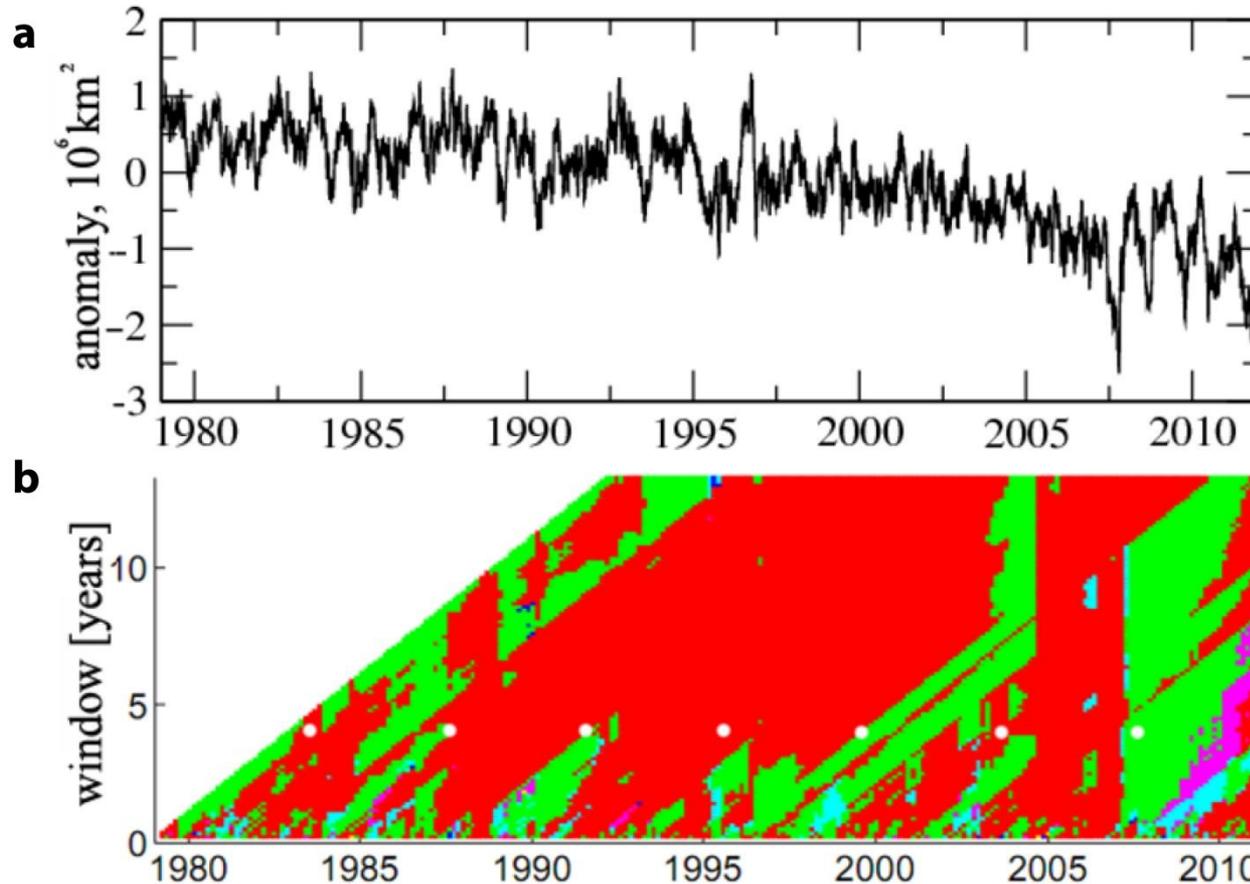
Inter-annual variability of Arctic sea-ice



Arctic sea-ice



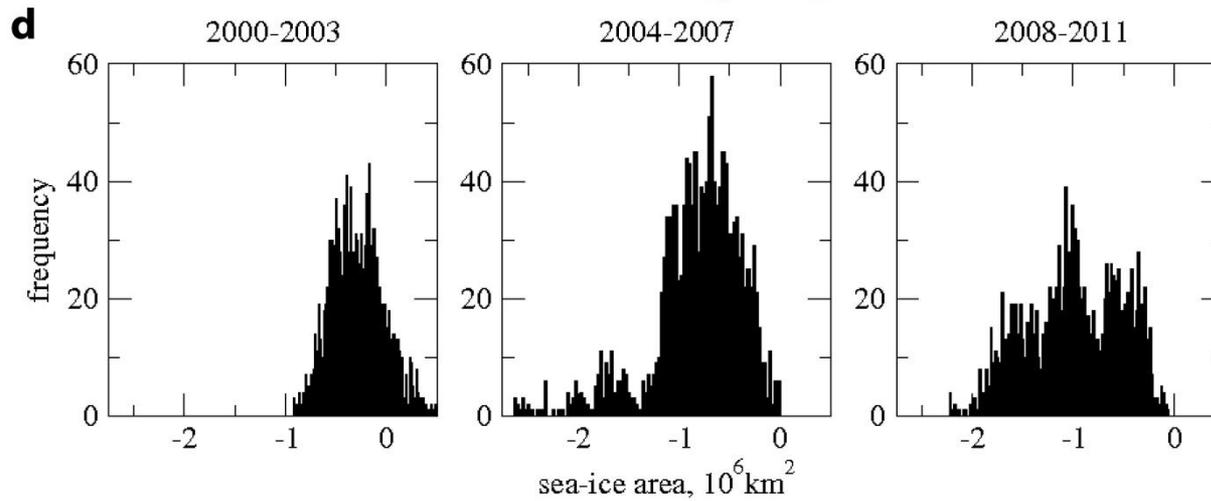
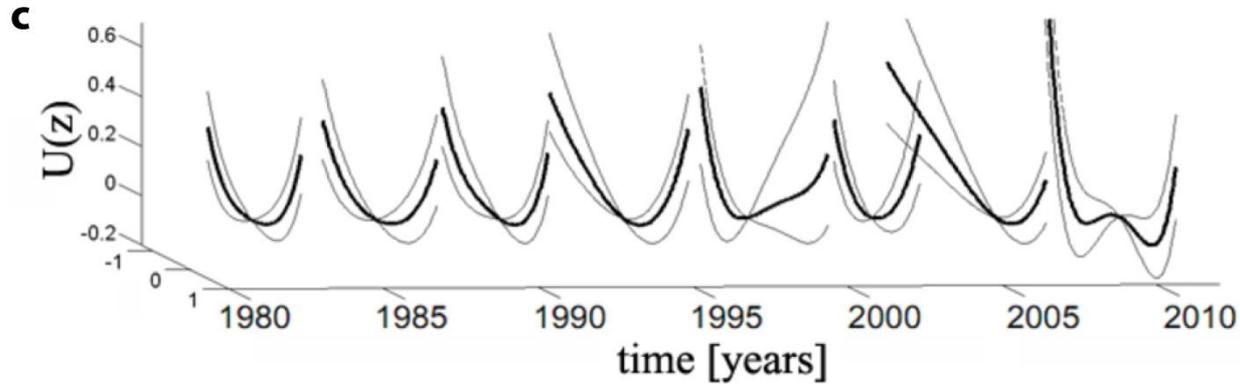
A new low Arctic sea-ice state appearing?



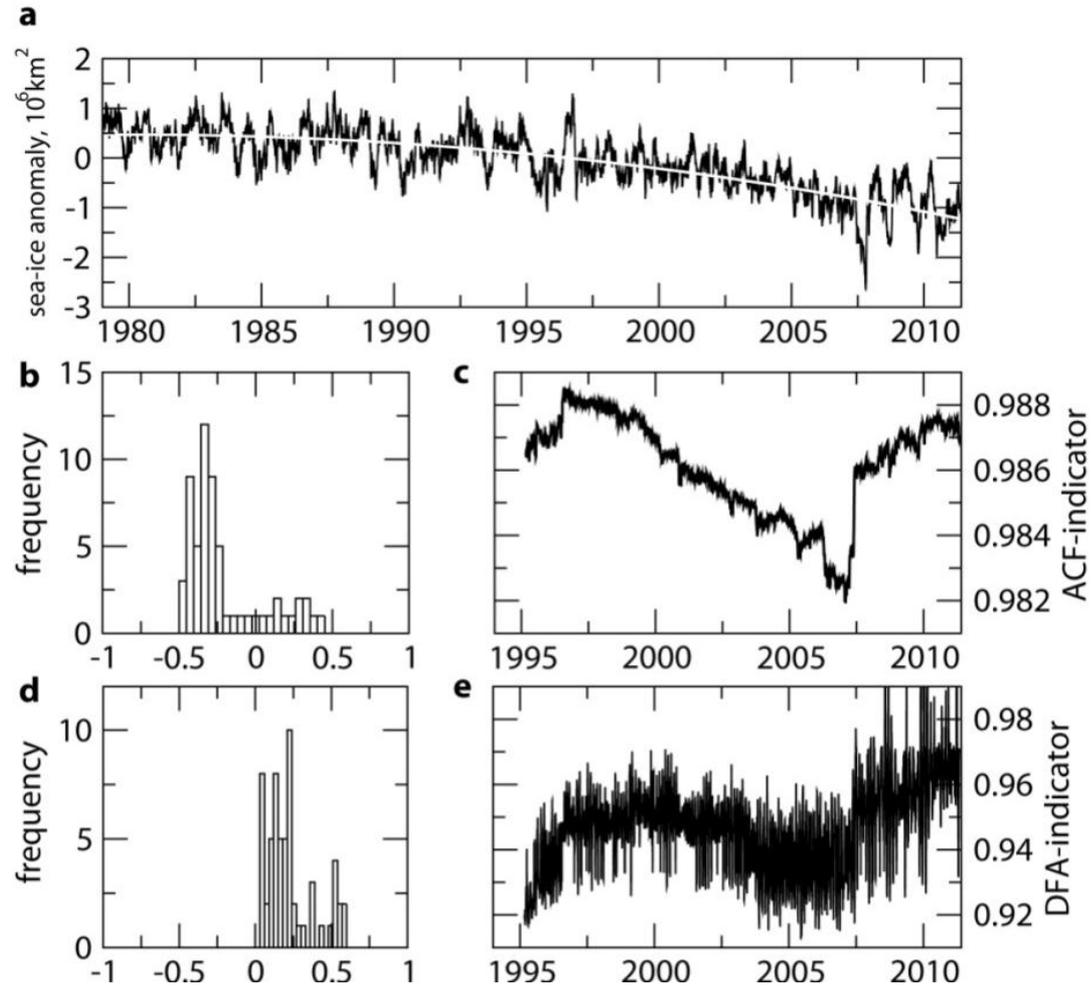
Number of
states:

1, 2, 3, 4

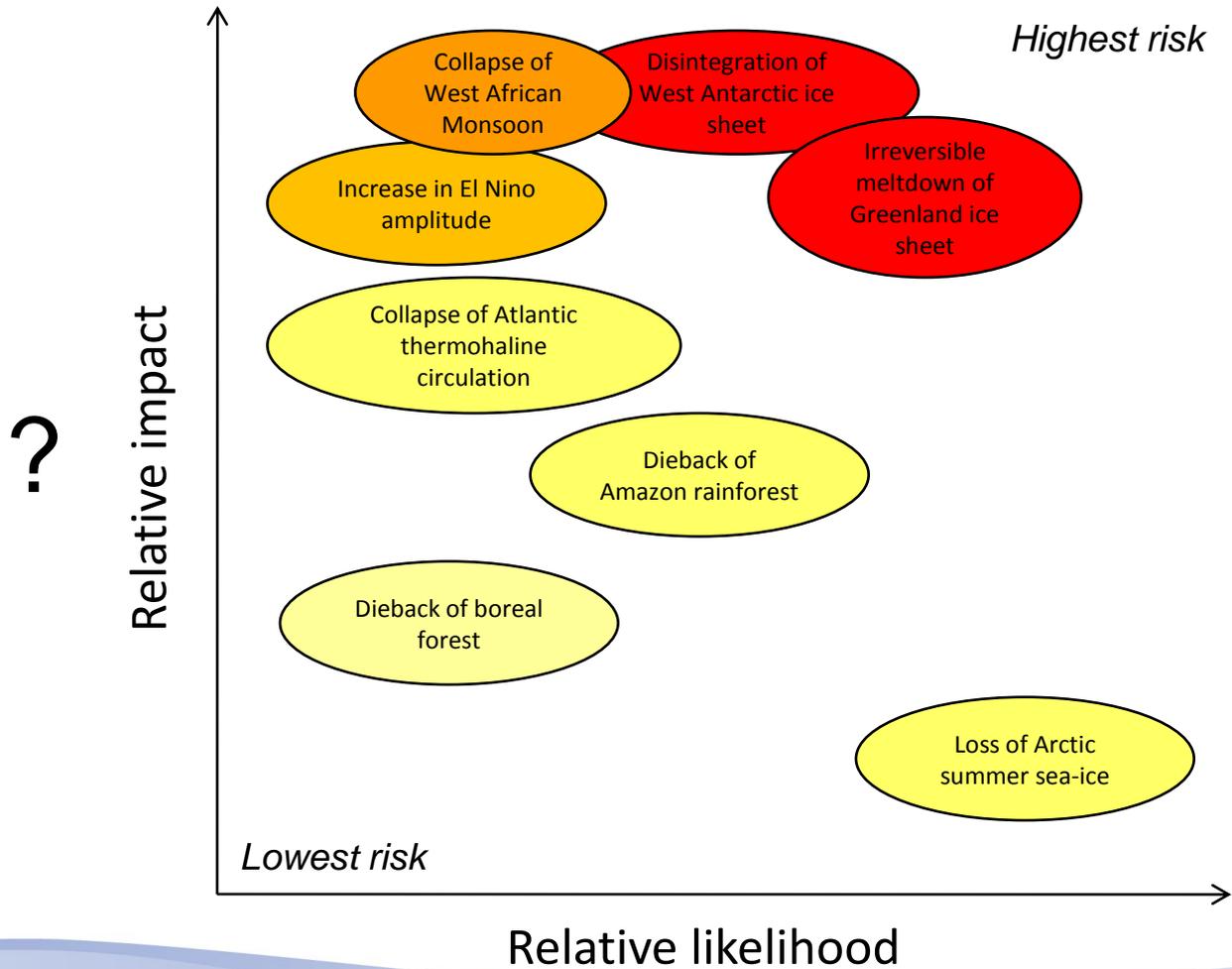
A new low Arctic sea-ice state appearing?



Early warning signals?



Risk matrix





Conclusion

- Several tipping elements in the climate system could be triggered this century by human activities
- Some could become high impact *high* probability events but we need improved information on their likelihood
- Early warning methods exist for some types of tipping points and these have been successfully tested
- The same methods suggest that the Arctic sea-ice cover has recently passed a tipping point
- The Greenland ice sheet could be very close to a tipping point

