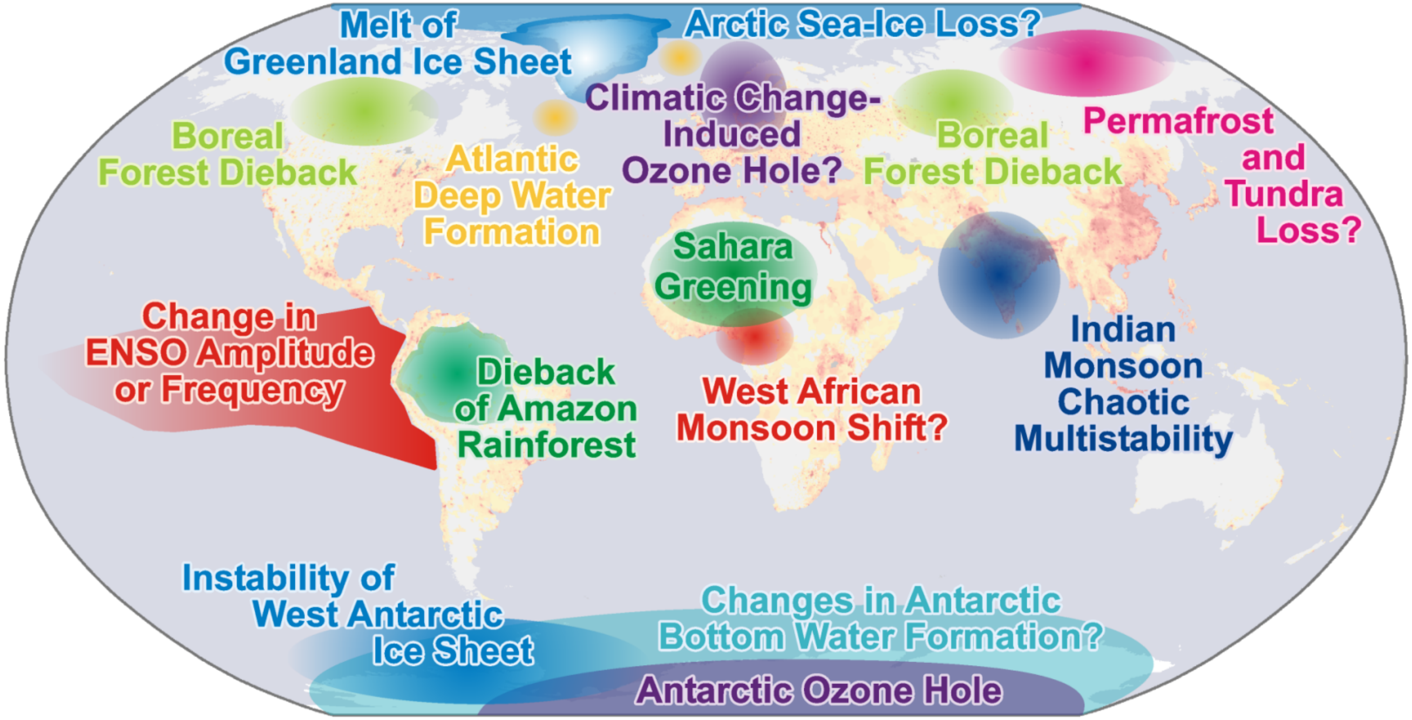
Current knowledge on climate tipping points: Should we change climate policy?



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Outline

- **Current knowledge on tipping points**

- **Implications for adaptation policy?**

Tipping point early warning potential

- **Implications for mitigation policy?**

Affect on the social cost of carbon

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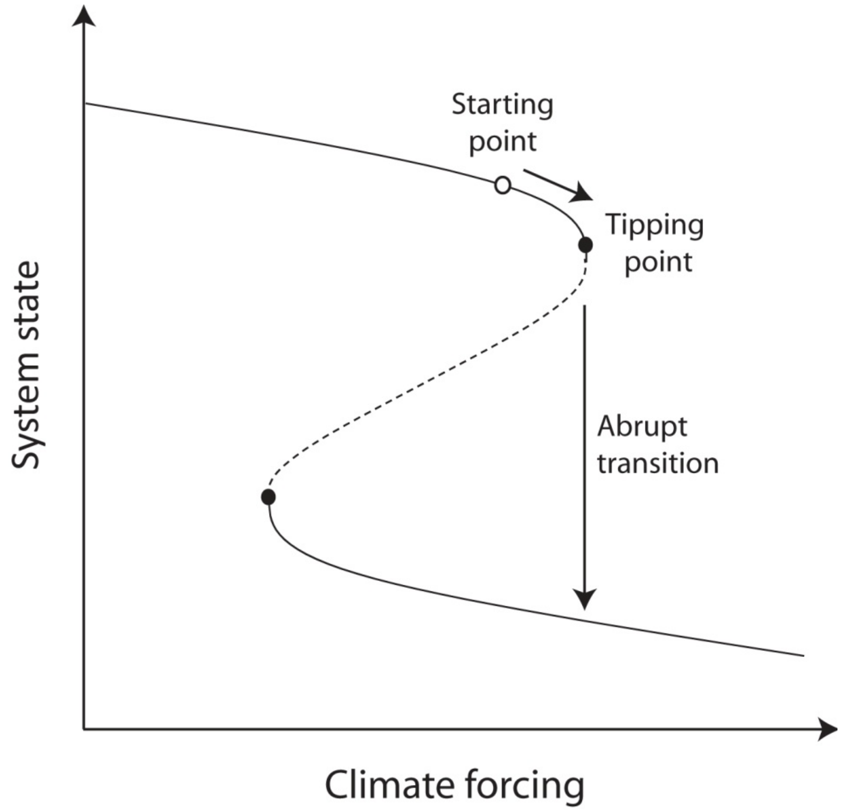
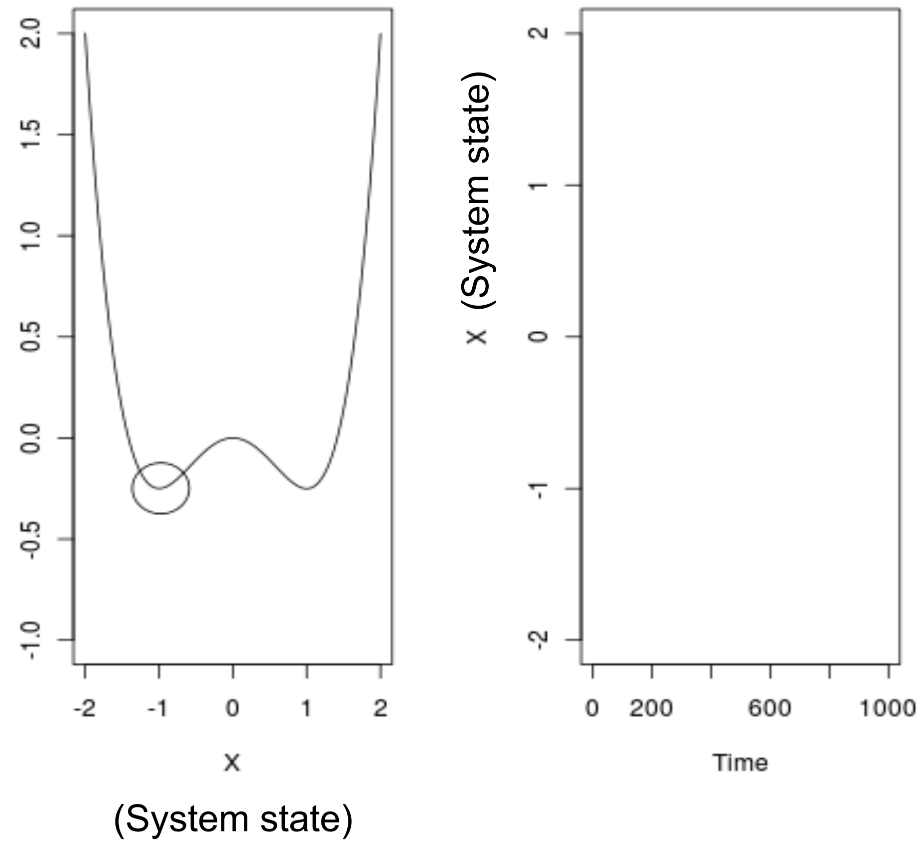
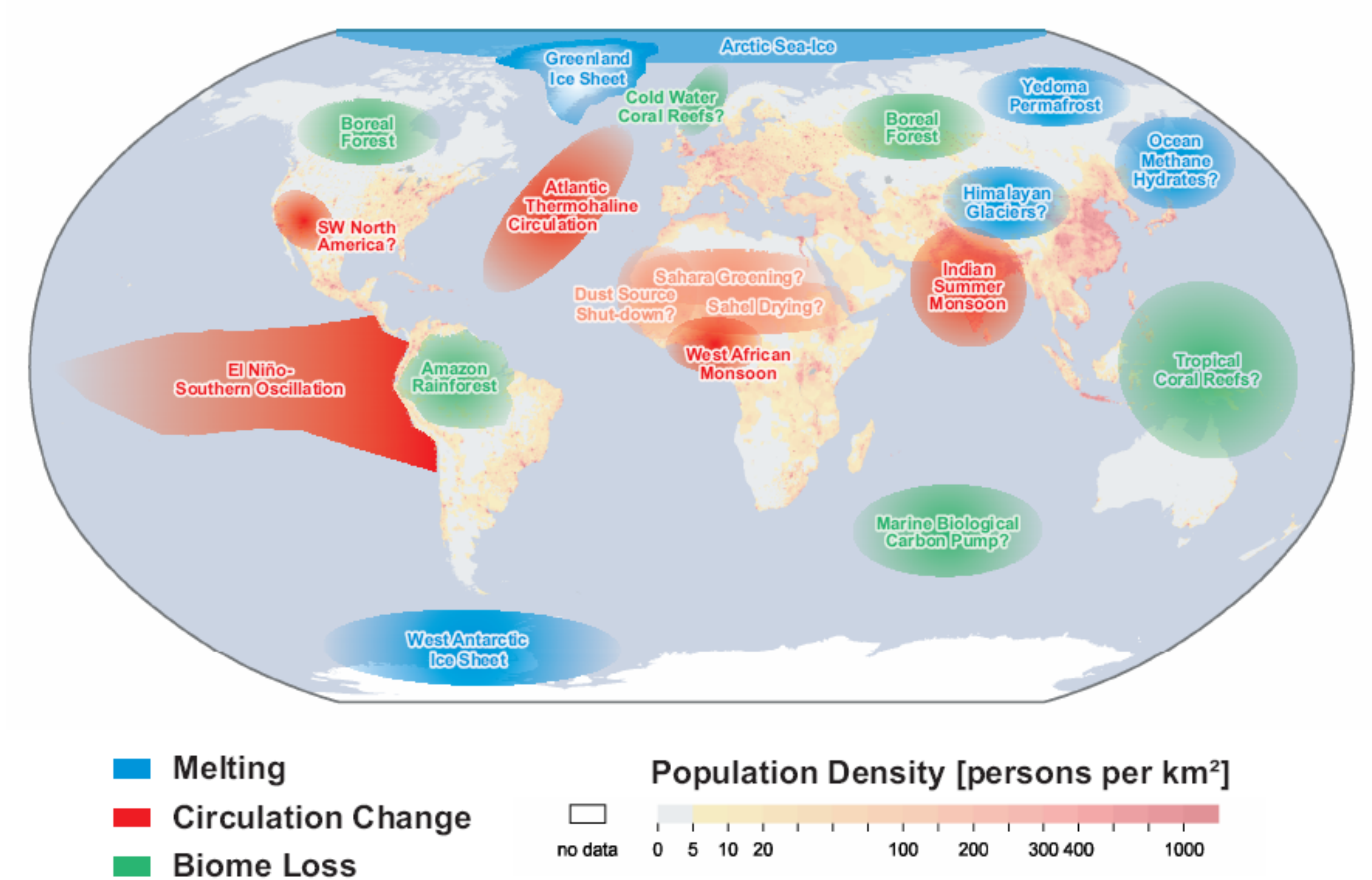
Bifurcation-type tipping point





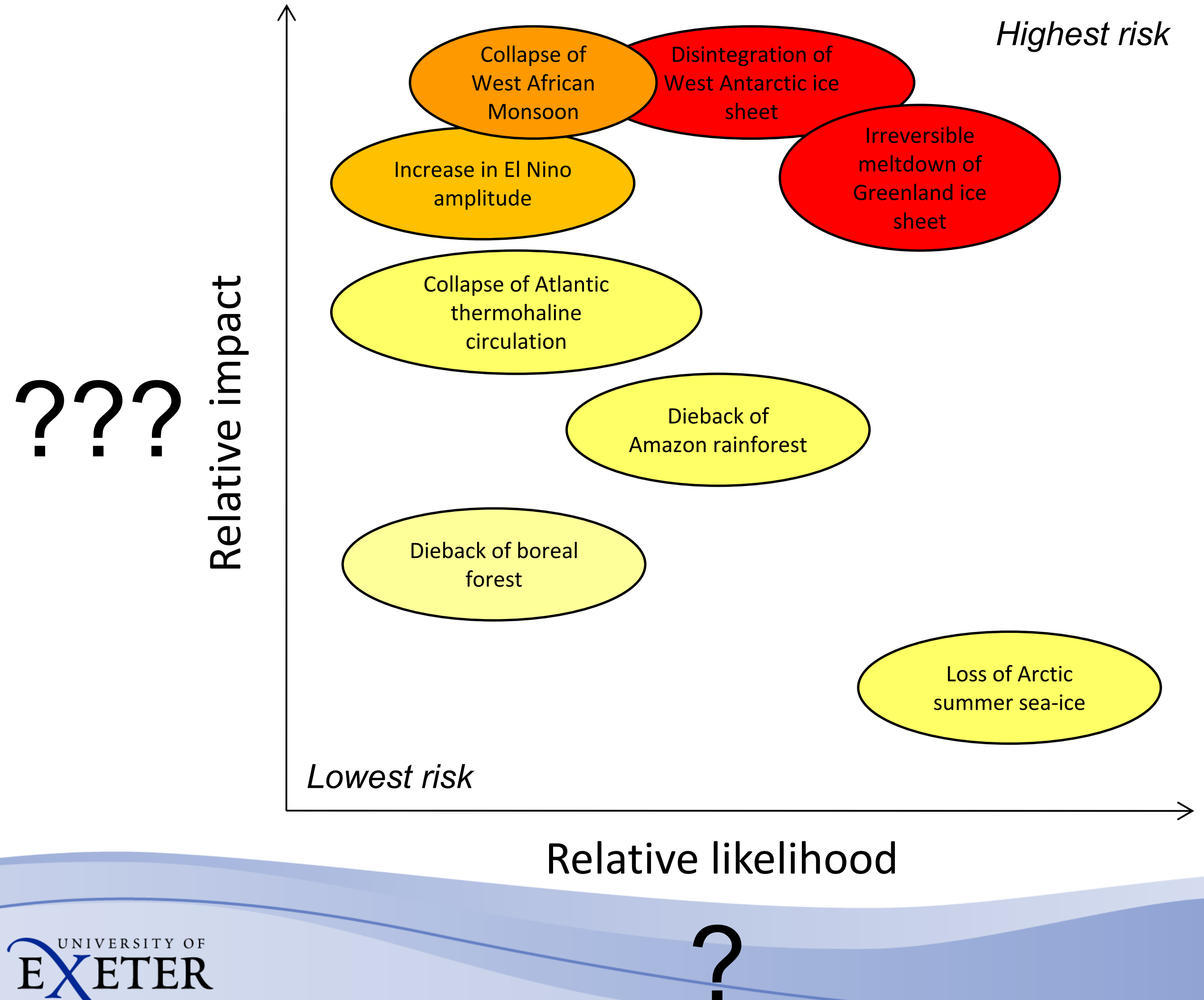
Thanks to Chris Boulton for the animation

Tipping elements in the climate system



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

Risk knowledge



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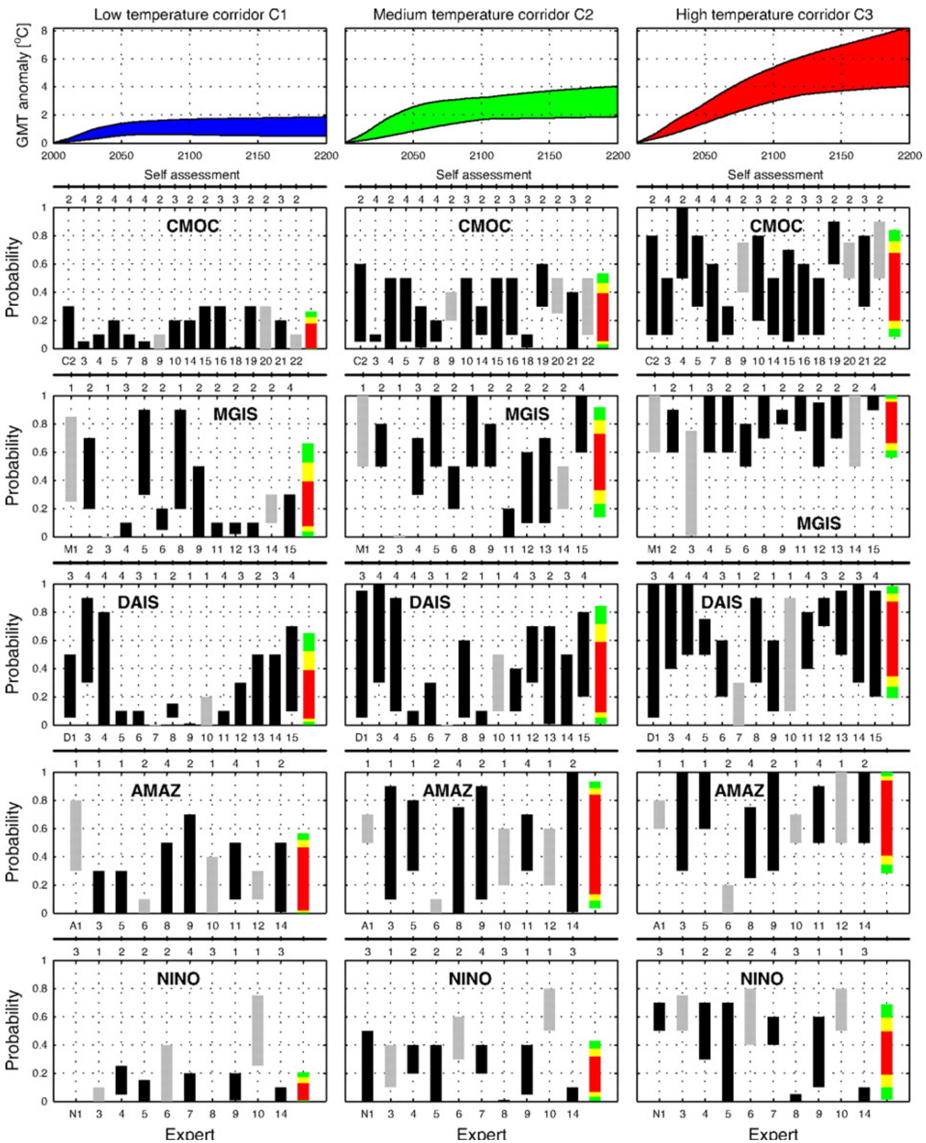
Lenton (2011) *Nature Climate Change* 1: 201-209

Likelihood of tipping points

- 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

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

Potential physical impacts of passing different climate tipping points

Tipping event	Temperature	Sea level	Precipitation	Atmospheric circulation	Ocean circulation	Biogeochemical cycles	Modes of variability	Extreme events
Arctic summer sea-ice loss	↑Arctic & N. Hem. warming	(minimal effect)	Local shift from snowfall to rainfall	↓polar vortex, shift in storm track	Intrusion of warm Atlantic waters	↑Permafrost thawing, ↑CO_2, CH_4	Shift in NAO centre of action	Cold winters in Europe
Greenland ice sheet meltdown	Local ↑	≤7 m global ≤0.5 m/century uneven	Local shift to rainfall	Less jet stream deflection?	↓THC, loss of Irminger Sea convection	Flooding of permafrost, ↑CO_2, CH_4	?	Storm surges, icebergs
West Antarctic ice sheet collapse	Local ↑	≤3.3 m abrupt ≤1 m/century uneven	Local shift	Uneven polar vortex?	↓or↑THC, Archipelago created	Flooding of permafrost, ↑CO_2, CH_4	?	Iceberg armadas storm surges
Atlantic thermohaline circulation (THC) shutdown	↓N. Atlantic ↑S. Hem.	Regional shifts ↑0.5m in parts of N. Atlantic	Drying of Sahel, collapse of WAM, wetting Amazonia	Southward shift of ITCZ, Atlantic storm track shift	Fundamental reorganisation	↑CO_2, biome changes	AMO ceases, ↑ENSO	Cold winters in Europe, hurricanes shift south?
ENSO increase in amplitude	↑S Asia, S Australia... ↓in NZ	Regional effects	↓SE Asia, E Australia, Amazon...	Walker circulation change	↑THC, warming Ross, Amundsen seas	↑CO_2, reduced land C storage	Coupled changes to PDO, AMO	Droughts, floods
Indian summer monsoon (ISM) weakening	Local ↑summer	-	↓ in India	[inherent]	?	?	Coupling to SO?	Drought in India, heatwaves
West African monsoon (WAM) collapse	↑in Sahel ↓coastal W. Africa	-	Sahel wetting/drying? (uncertain)	Inflow of moist air from Atlantic to W?	?	Possible greening of Sahel/Sahara	Coupling to THC?	Source region for Atlantic hurricanes
Amazon rainforest dieback	↑regional	-	↓regional	Walker circulation?	-	↑CO_2	Feedback to ENSO?	Droughts, fires, loss biodiversity
Boreal forest dieback	↓winter ↑summer	-	↓regional?	Regional effects?	-	↑CO_2	-	Fires, insect pests, biome loss

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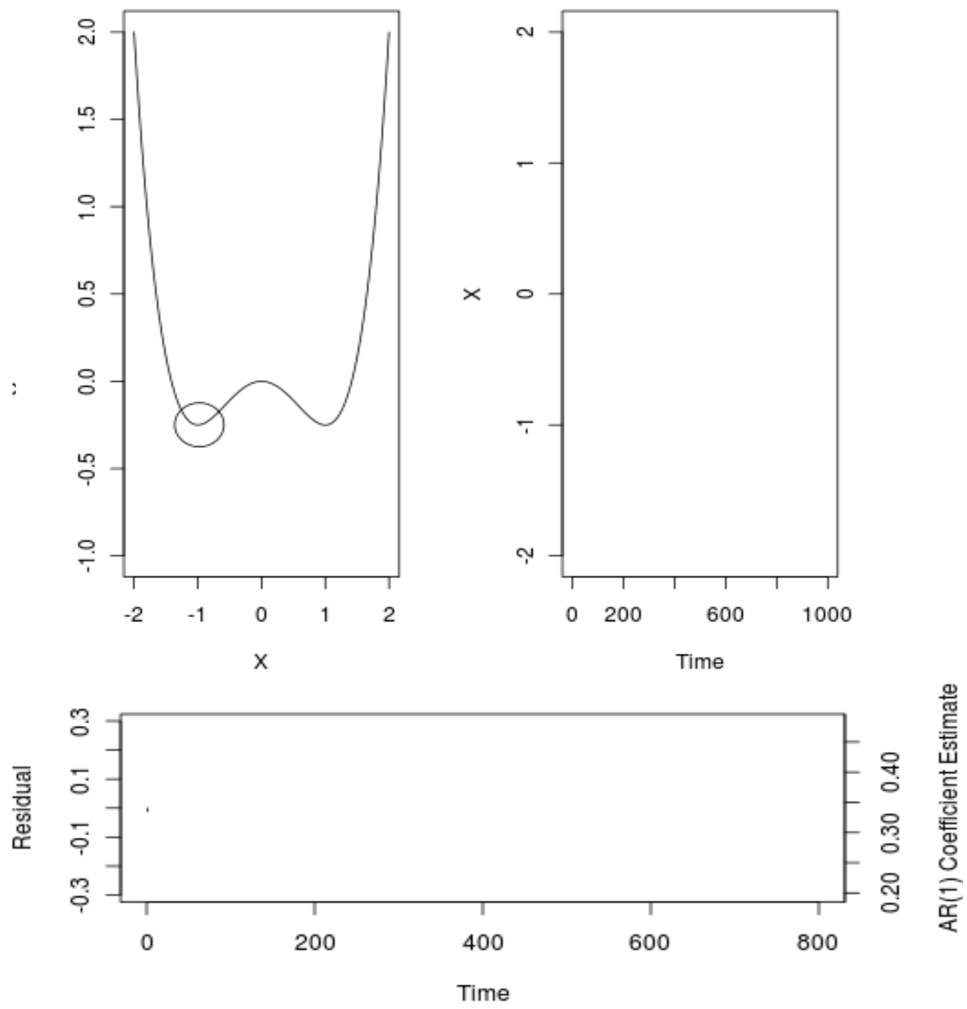
Lenton & Ciscar (2013) *Climatic Change* 117: 585–597

Tipping point early warning prospects



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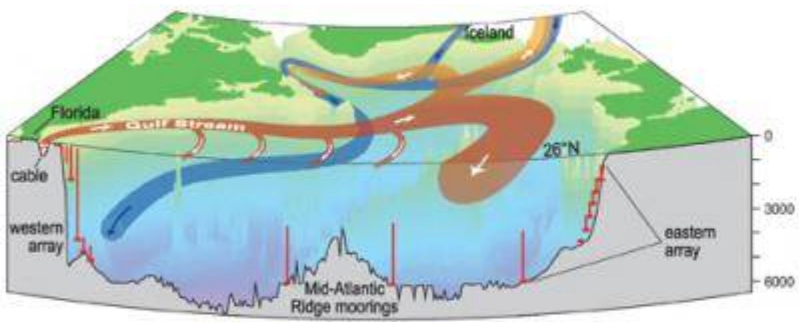
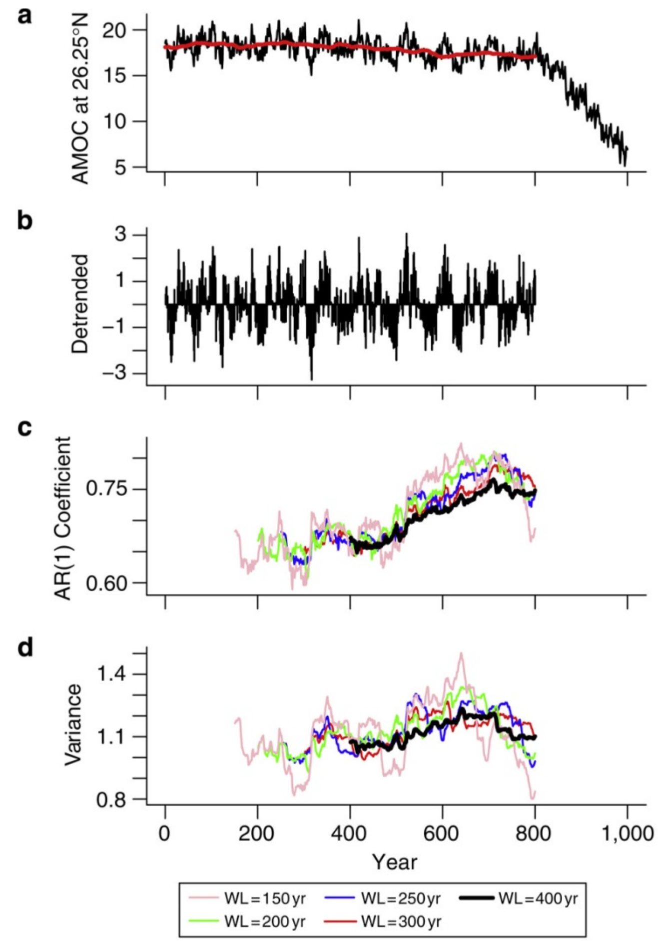
Thanks to Chris Boulton for the animation

Early warning of a modelled tipping point





- The Atlantic Meridional overturning circulation (AMOC) is currently monitored at 26°N
- Freshwater forcing of the 'FAMOUS' ocean-atmosphere GCM causes collapse of the AMOC
- There are early warning signals

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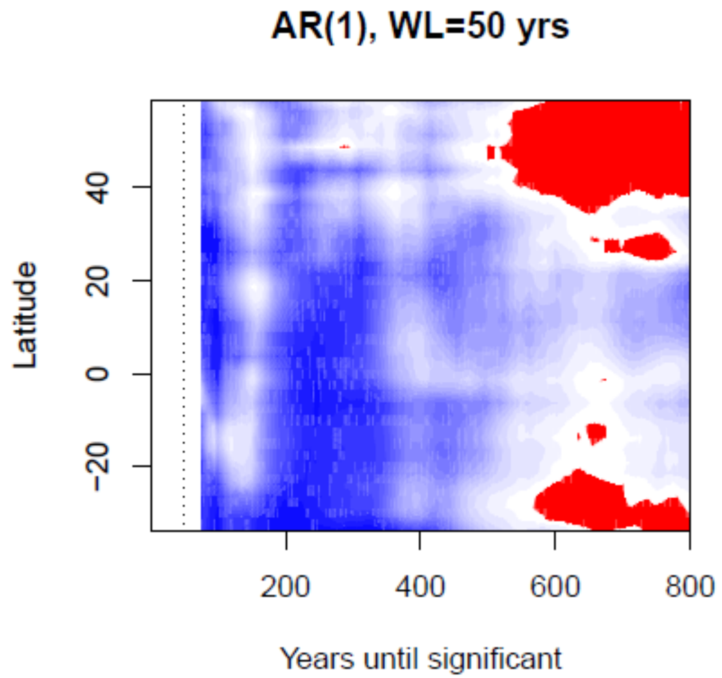
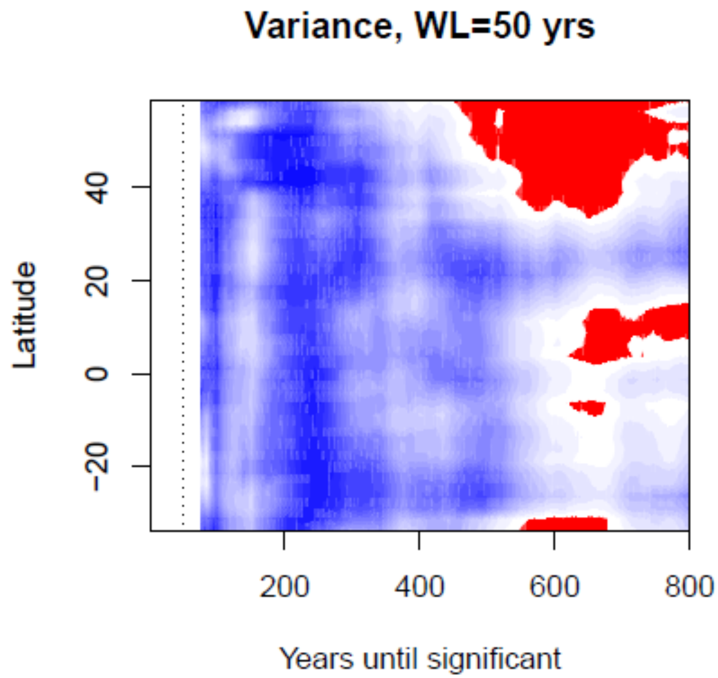
Boulton, Allison, Lenton (2014) *Nature Comms.* 5: 5752

Where are the best early warning signals? How early are they?





Red areas indicate early warning signals that are significant at $p<0.05$

from testing against 10,000 instances of a null model where the original data are bootstrapped to destroy their memory

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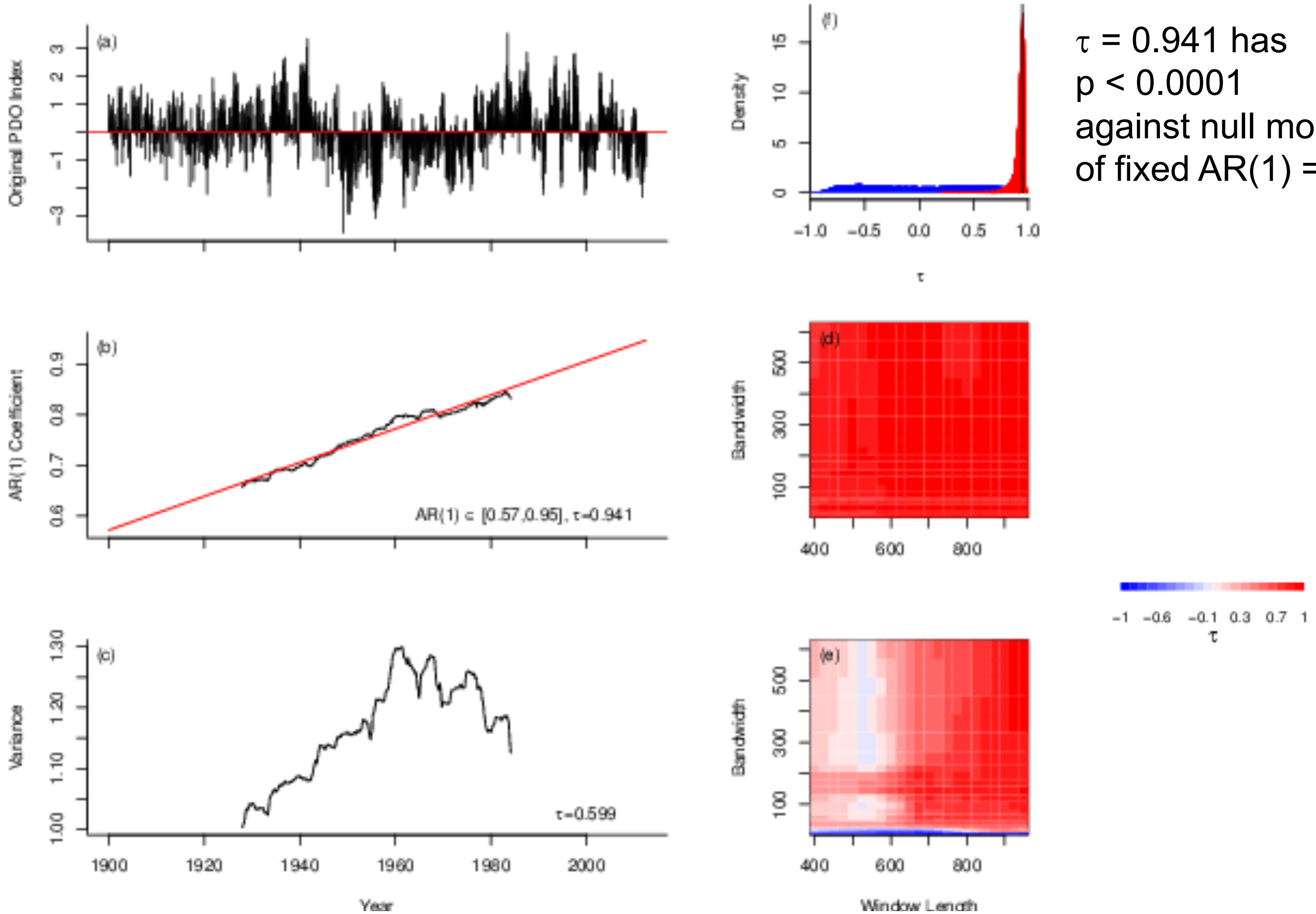
Boulton, Allison, Lenton (2014) *Nature Comms.* 5: 5752

Pacific Decadal Oscillation (PDO) index

n = 1343

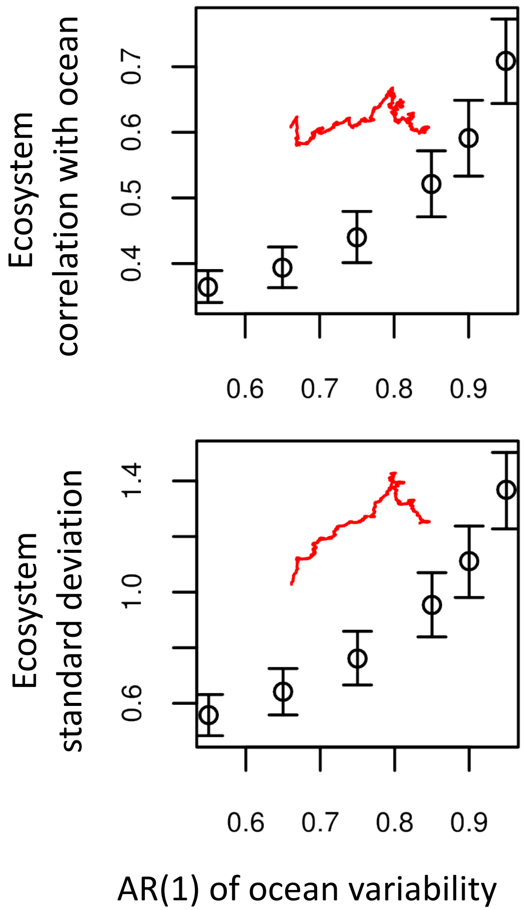


$\tau = 0.941$ has
$p < 0.0001$
against null model
of fixed AR(1) = 0.95

Boulton & Lenton (2015) *PNAS* 112(37): 11496-11501

Implications for marine ecosystems

- Marine ecosystems act as integrators of ocean sea surface temperature (SST) variability with their own characteristic damping timescale
- The surface ocean typically has a faster damping timescale (~6 months) than e.g. zooplankton populations (~2 years)
- Slowing down of ocean SST variability causes marine ecosystems to become more correlated with it, more variable, and more likely to pass tipping points if they have them



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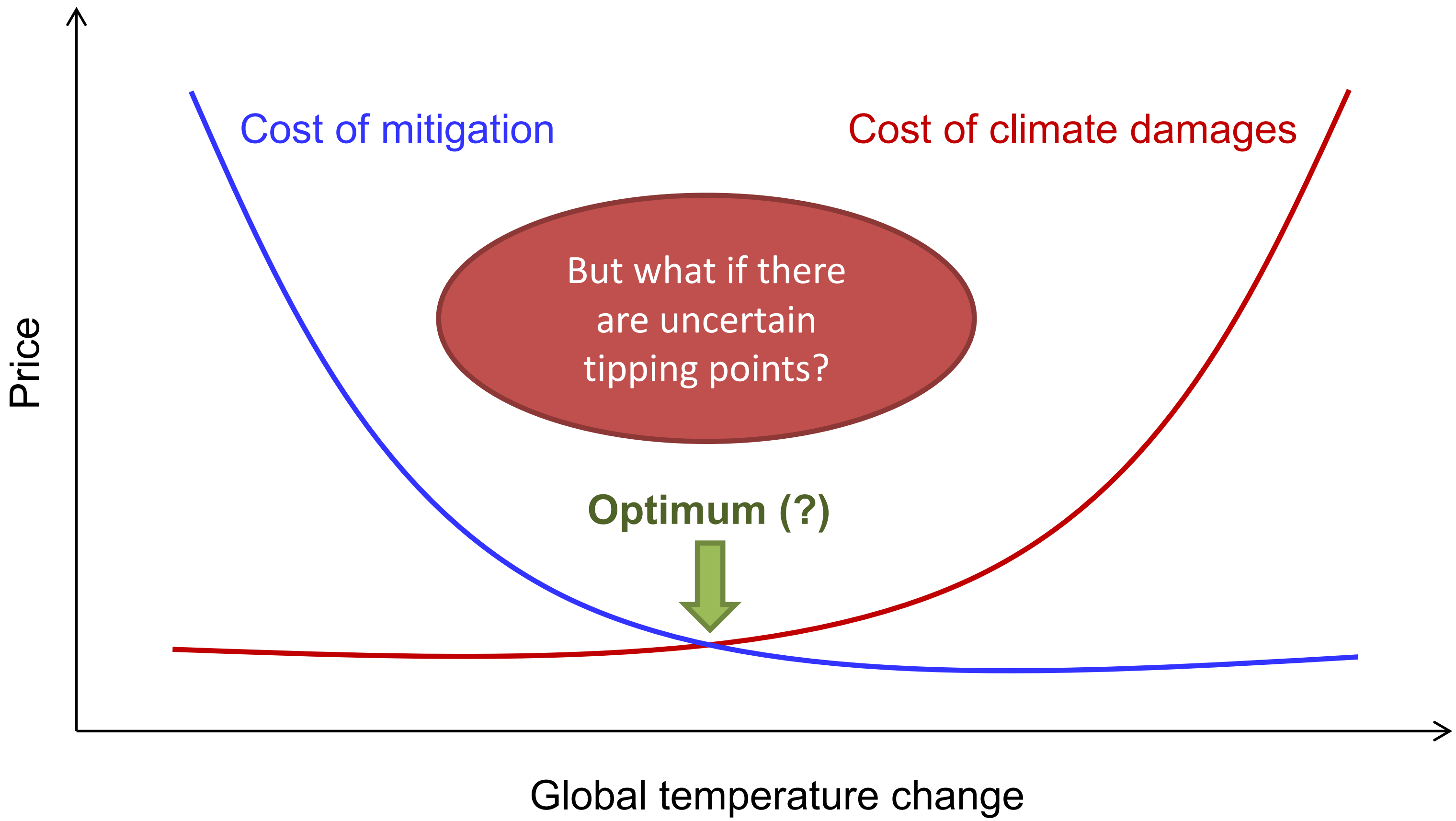
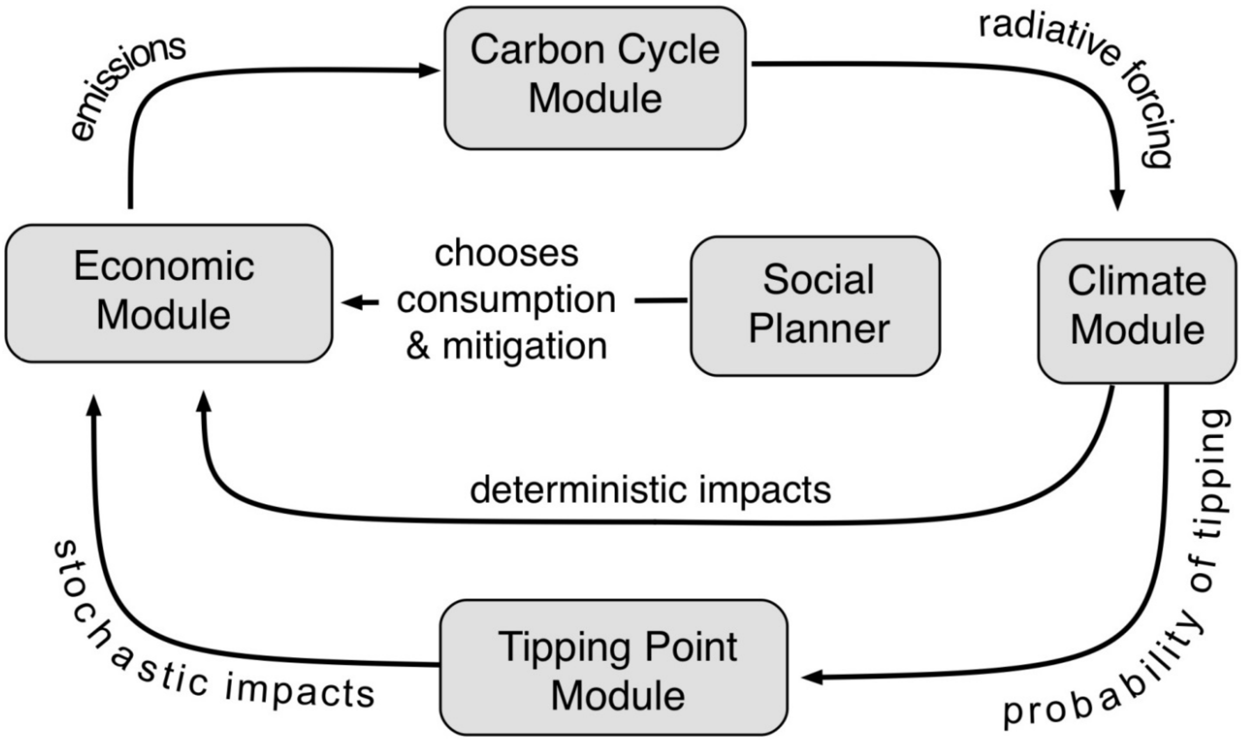
Boulton & Lenton (2015) *PNAS* 112: 11496-11501, adapting the model of Di Lorenzo & Ohman (2013) *PNAS* 110: 2496-2499

Conventional cost-benefit analysis



Adding uncertain tipping points to a widely-used integrated assessment model



The DSICE model – based on Nordhaus' DICE-2013 model
as used in US Federal Social Cost of Carbon estimates

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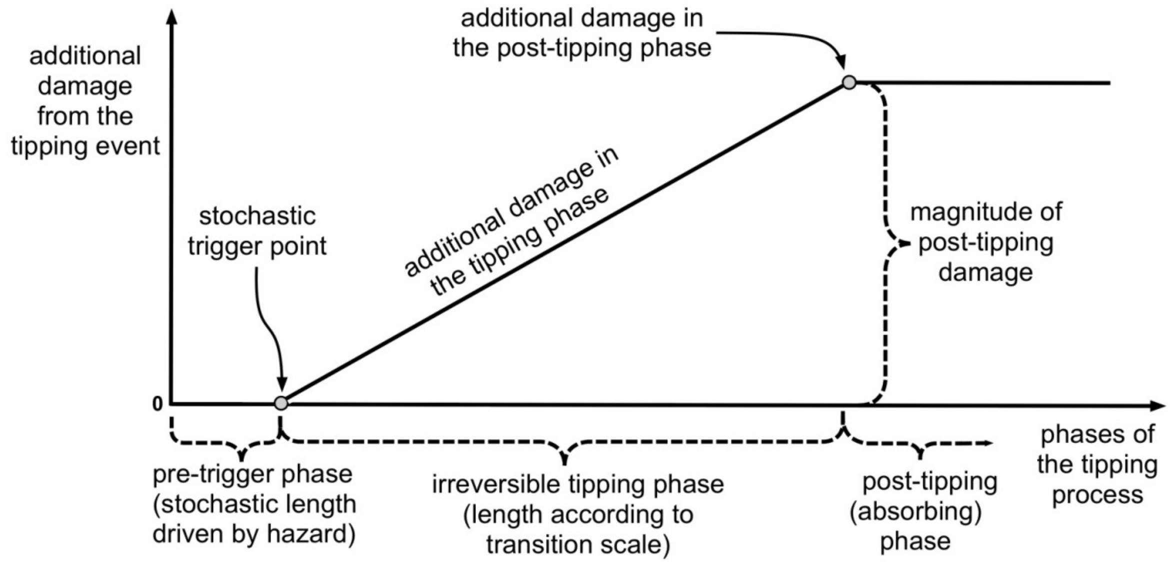
Lontzek, Cai, Judd, Lenton (2015) *Nature Climate Change* 5(4): 441–444

Representation of tipping points in DSICE



Tipping element	Hazard rate (%/yr/K)	Transition time (years)	Final damages (% world GDP)
Atlantic overturning (AMOC)	0.063	10-50-250	10-15-20
Greenland ice sheet (GIS)	0.188	300-1500-7500	5-10-15
West Antarctic ice sheet (WAIS)	0.104	100-500-2500	2.5-5-7.5
Amazon rainforest (AMAZ)	0.163	10-50-250	2.5-5-7.5
El Nino (ENSO)	0.053	10-50-250	5-10-15

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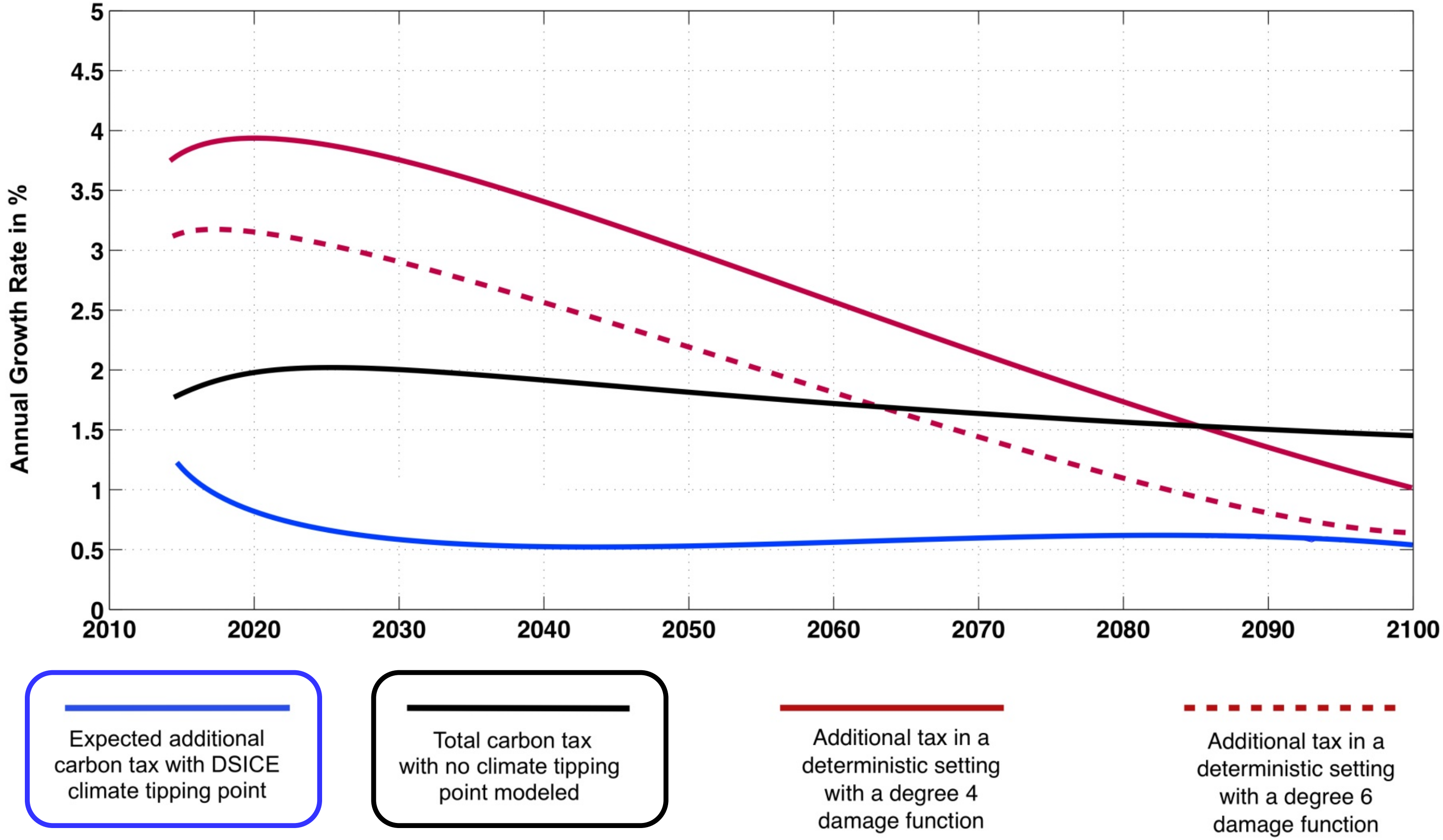
Lontzek, Cai, Judd, Lenton (2015) *Nature Climate Change* 5: 441–444; Cai, Lenton, Lontzek (2016) *Nature Climate Change*

Effect on carbon tax growth rate (equivalent to discount rate)



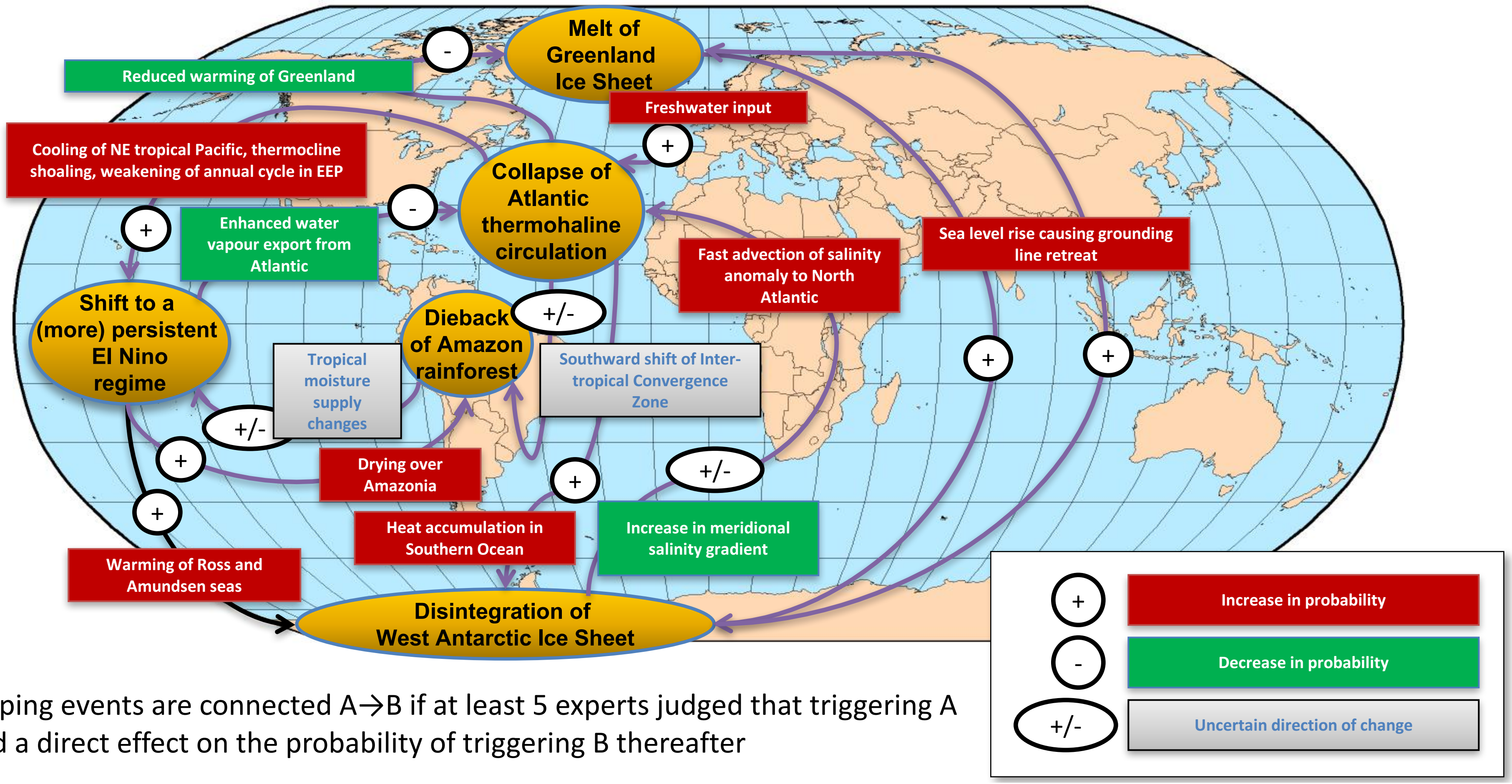
Lontzek, Cai, Judd, Lenton (2015) *Nature Climate Change* 5(4): 441–444

Why the low discounting of tipping point damages?

- Stochastic uncertainty over future damages produces a variance on expected future consumption (as well as a direct negative impact upon it)
- The 'social planner' (policymaker) wants to reduce the variance on future consumption (as well as try and limit the reduction in magnitude of future consumption)
- This leads to a precautionary, insurance-type policy response: we discount future impacts much less and hence are willing to pay a high premium now to try and avoid future tipping points

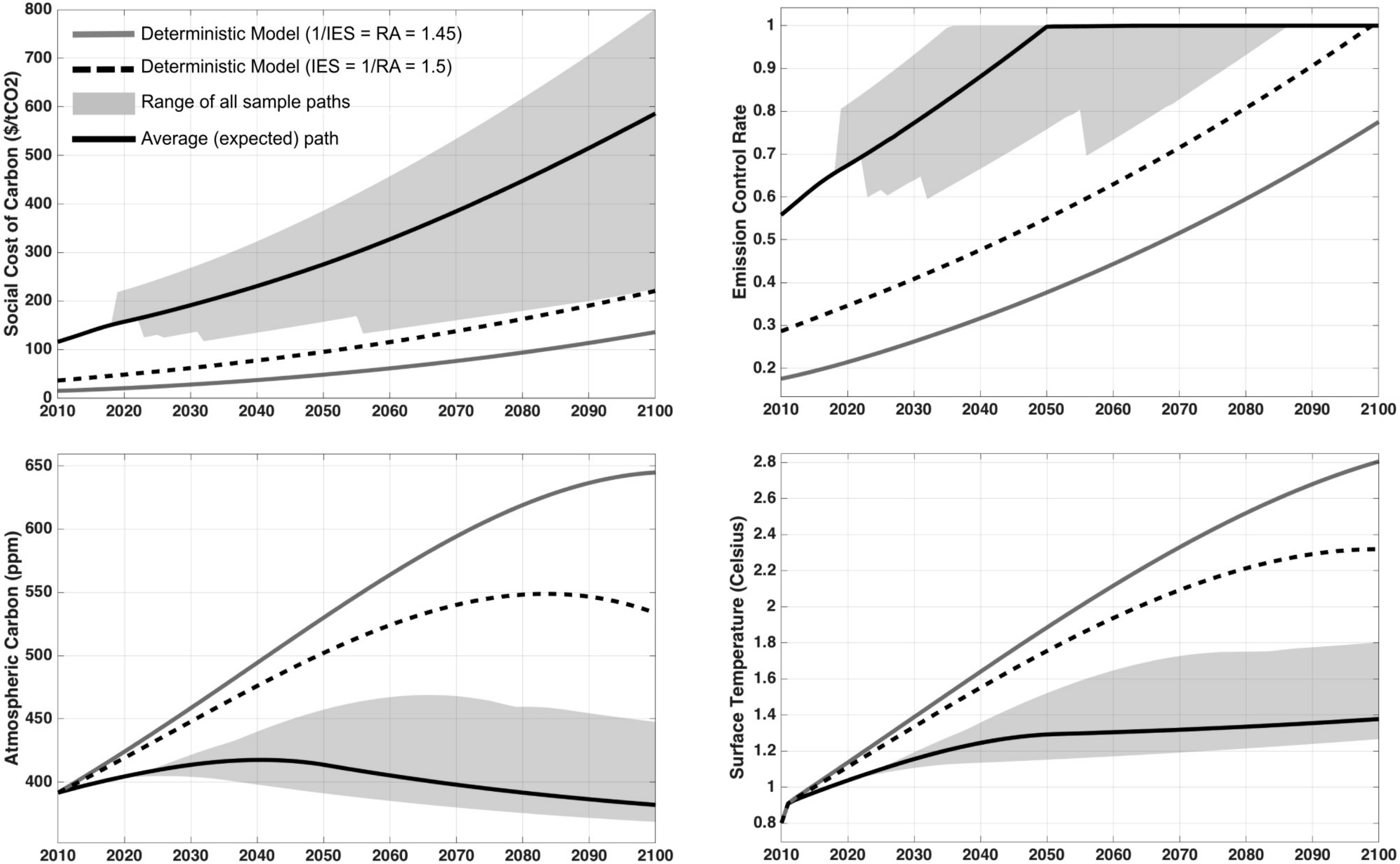
Lontzek, Cai, Judd, Lenton (2015) *Nature Climate Change* 5(4): 441–444

Tipping events and their causal interactions



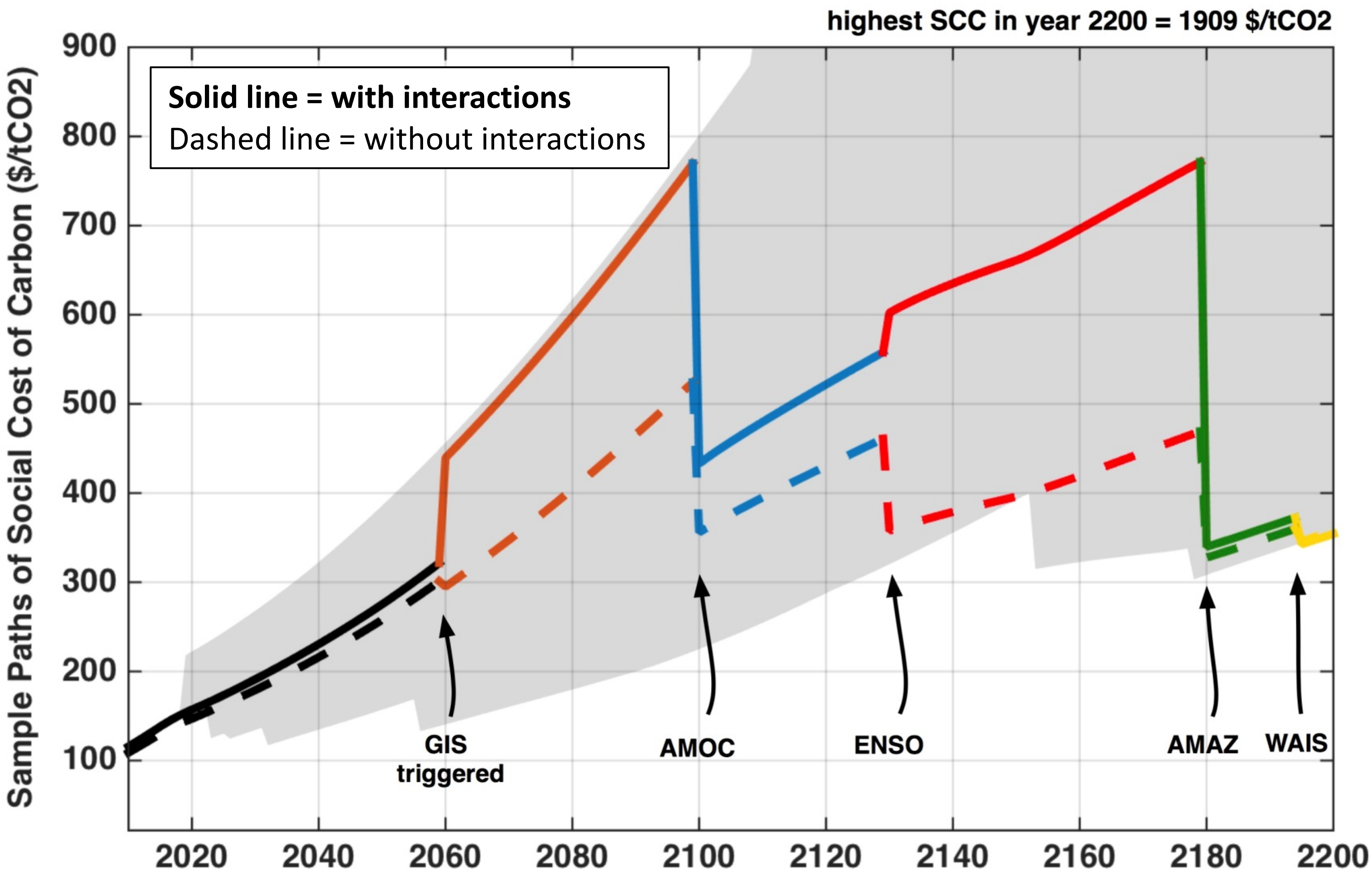
Tipping events are connected A→B if at least 5 experts judged that triggering A had a direct effect on the probability of triggering B thereafter

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



Cai, Lenton, Lontzek (2016) *Nature Climate Change* 6(5): 520–525

Effect of interactions in a tipping point cascade



Cai, Lenton, Lontzek (2016) *Nature Climate Change* 6(5): 520–525

Conclusion: We should change policy

- If business-as-usual continues then climate tipping points are expected to become high impact *high* probability events
- Early warning methods exist for tipping points and have been successfully tested before past abrupt changes and in model scenarios
- Temperature fluctuations have slowed down across large regions of the ocean contributing to past marine ecosystem ‘regime shifts’
- Tipping point early warning systems could be developed as an aid to adaptation to forewarn societies and trigger pre-emptive action
- The threat of multiple, interacting, uncertain climate tipping points should be triggering stronger mitigation activity now to reduce their likelihood
- The risk of tipping points should *not* be discounted at market interest rates
- The optimal policy response from a standard cost-benefit model with a realistic specification of risk aversion is a carbon price today of >$100/tCO_2$