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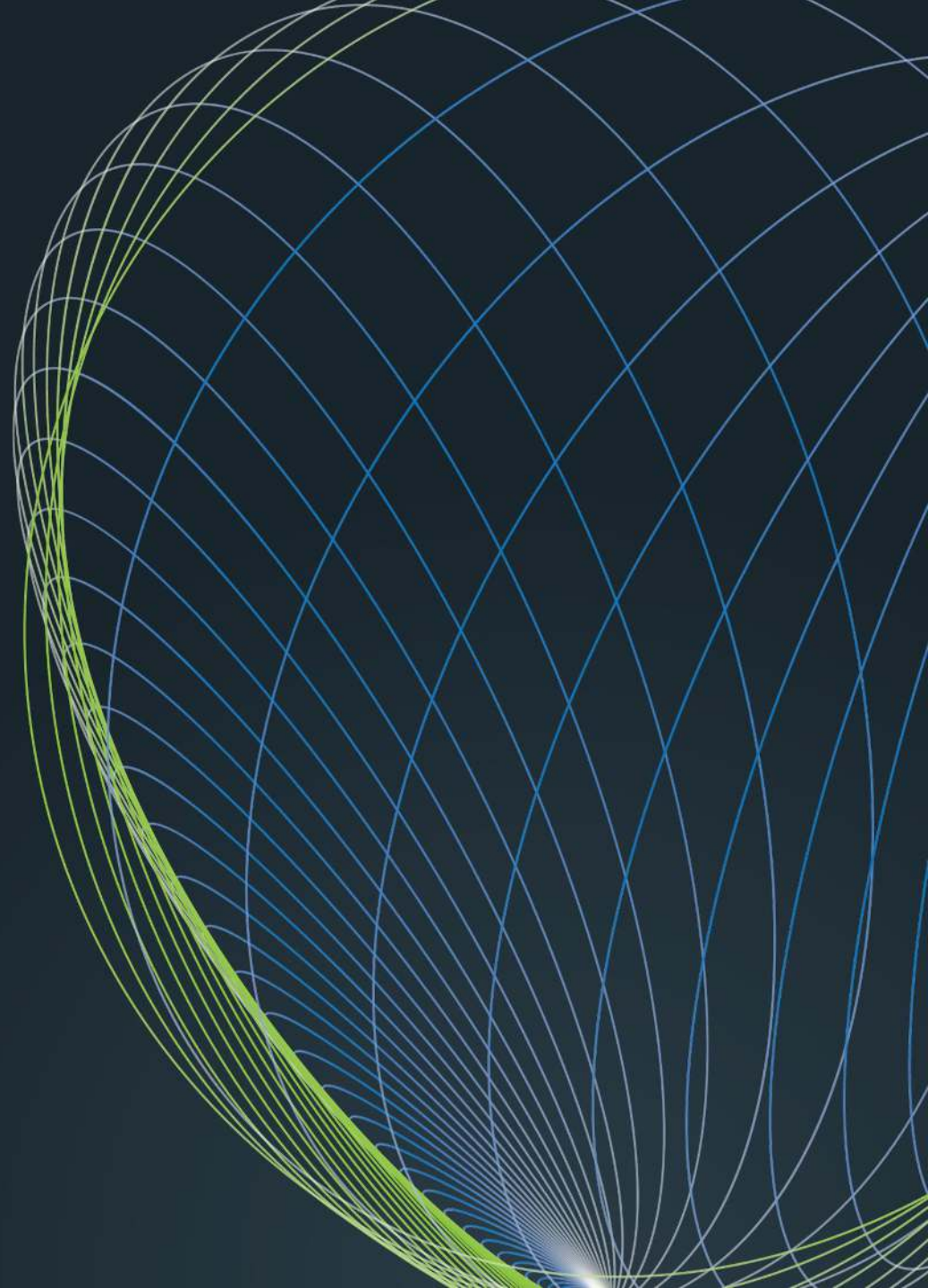
Investigating the risk of abrupt /irreversible changes in the coupled Earth system

Tim Lenton

Director, Global Systems Institute, University of Exeter
t.m.lenton@exeter.ac.uk

exeter.ac.uk/**gsi**

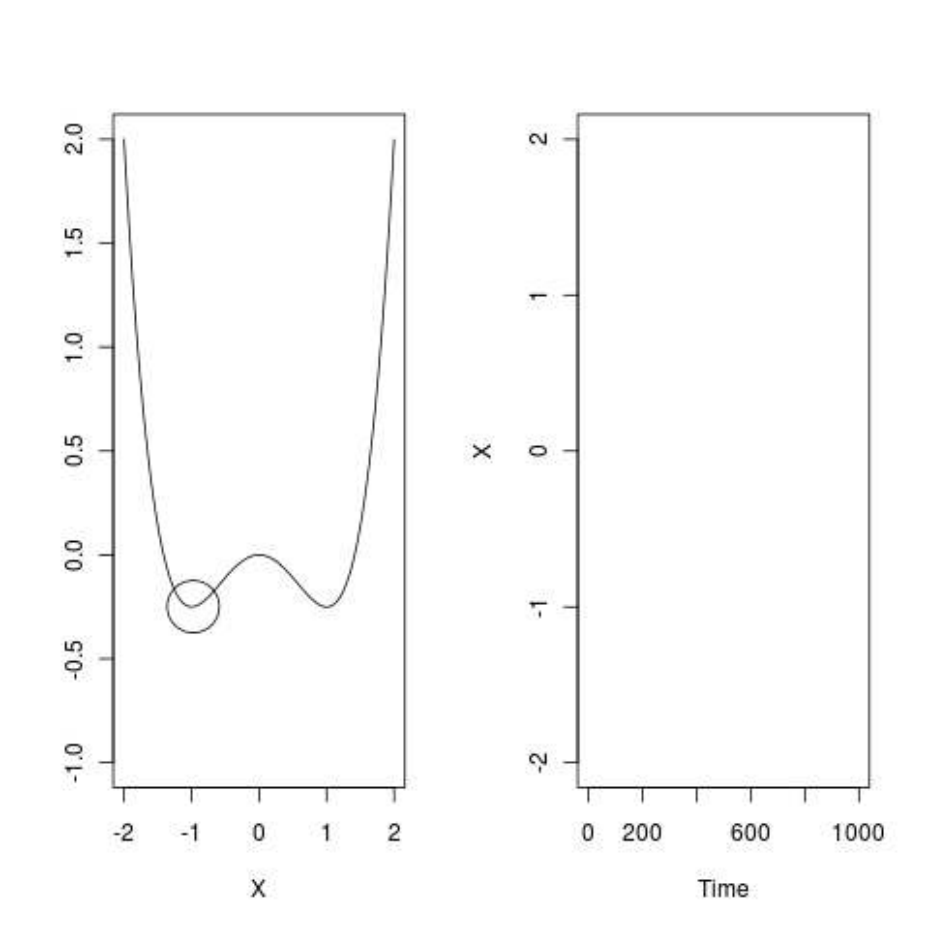


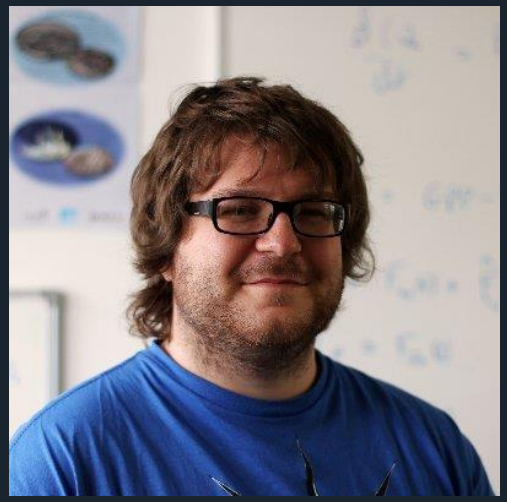
Outline

- "abrupt, potentially irreversible changes" (in the Earth system) = tipping points

- What is the current state of knowledge?
- What is amenable to investigation with ESMs?
- What are the key requirements of models to be helpful/useful?

Generic example of passing a tipping point





Thanks to Chris Boulton for the animation

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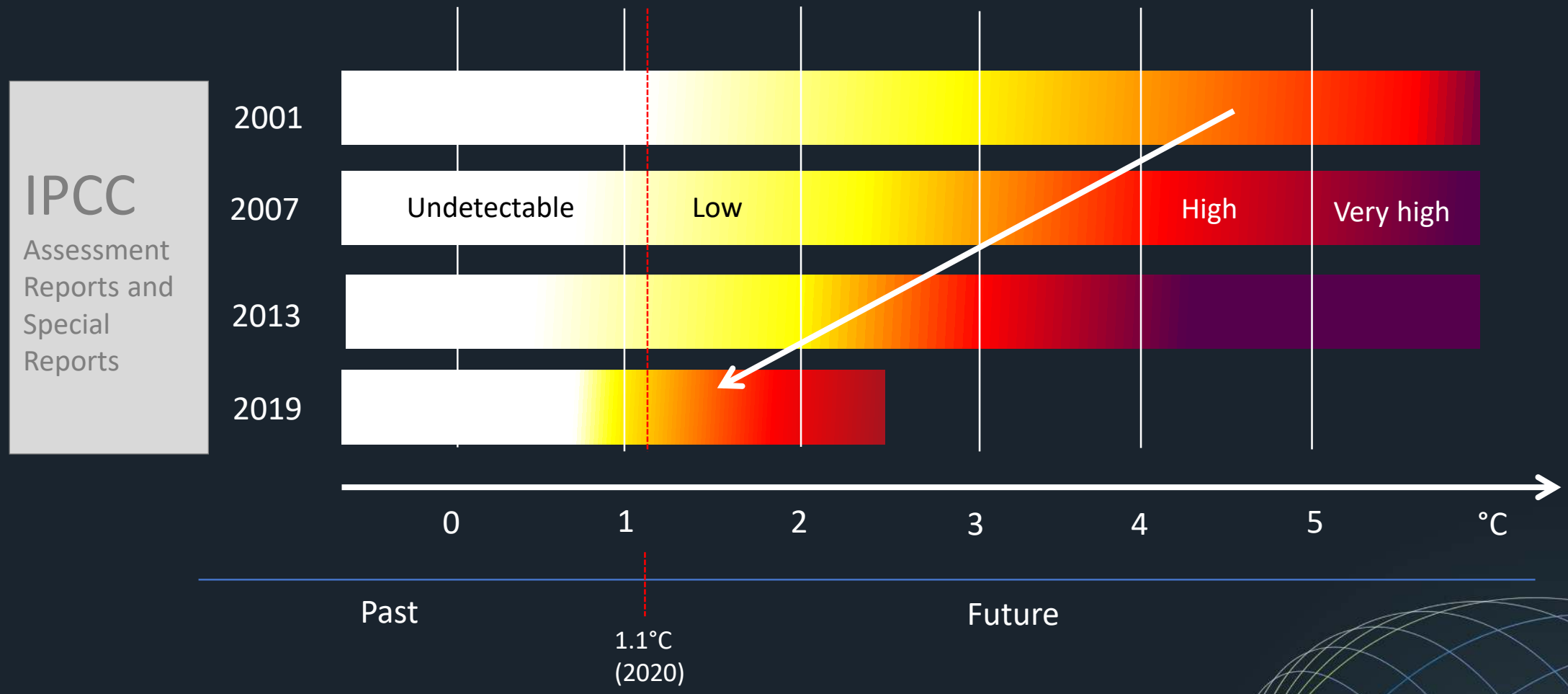
Changing risk assessment of climate tipping points



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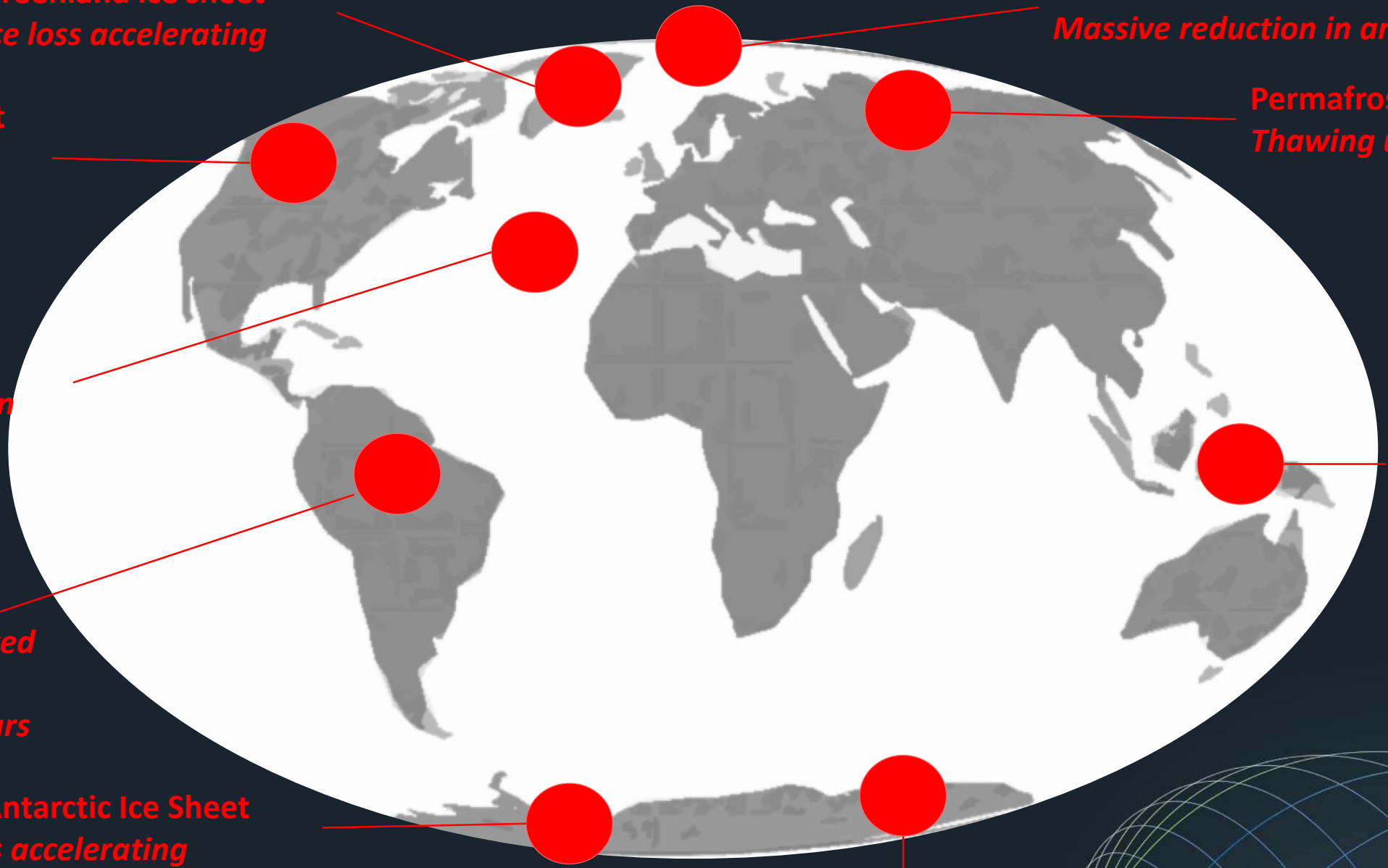

Greenland ice sheet
Ice loss accelerating

Arctic sea ice
Massive reduction in area

Boreal forest
Fire regime changing

Permafrost
Thawing underway

Atlantic circulation
15% slowdown since 1950s

Coral reefs
Massive die offs

Amazon rainforest
Unprecedented droughts in last 15 years

West Antarctic Ice Sheet
Ice loss accelerating

Wilkes basin, East Antarctica
Ice loss accelerating

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Risk = likelihood x impact

Use ESMs to assess TP likelihood

- Represent key processes
- Reproduce past abrupt changes
- Calibrate stability regime against observations
- Detect abrupt shifts in models
- Assess coupling effects

Use ESMs to assess TP impacts

- Examine detected abrupt shifts
- Test for reversibility
- Force tipping point(s) to occur
- Assess consequences
- Test observation-based early warning methods

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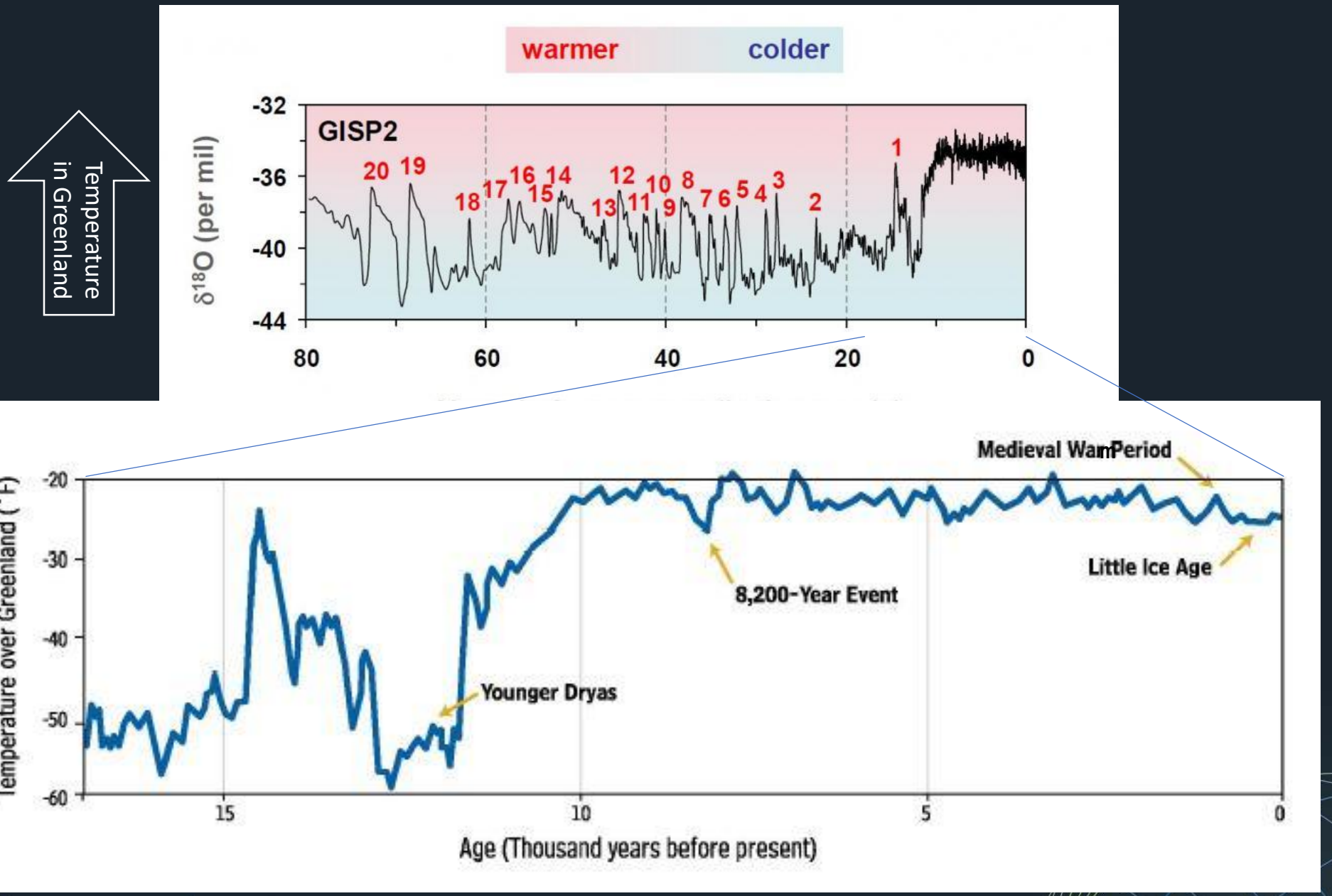
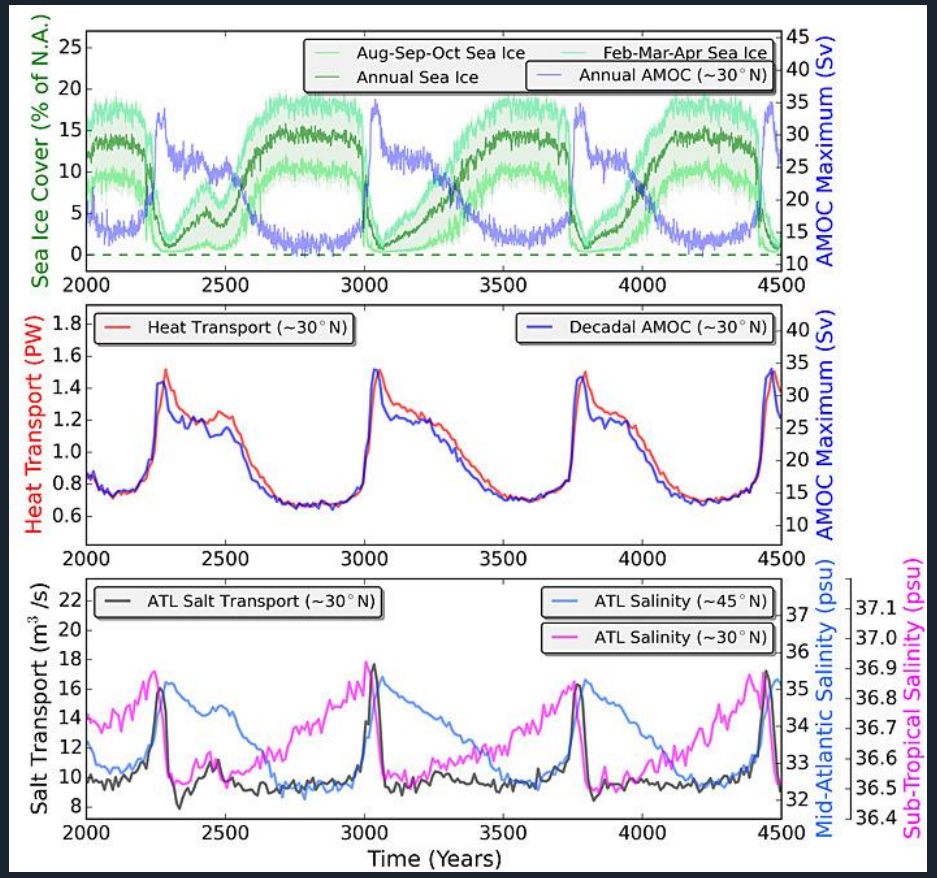
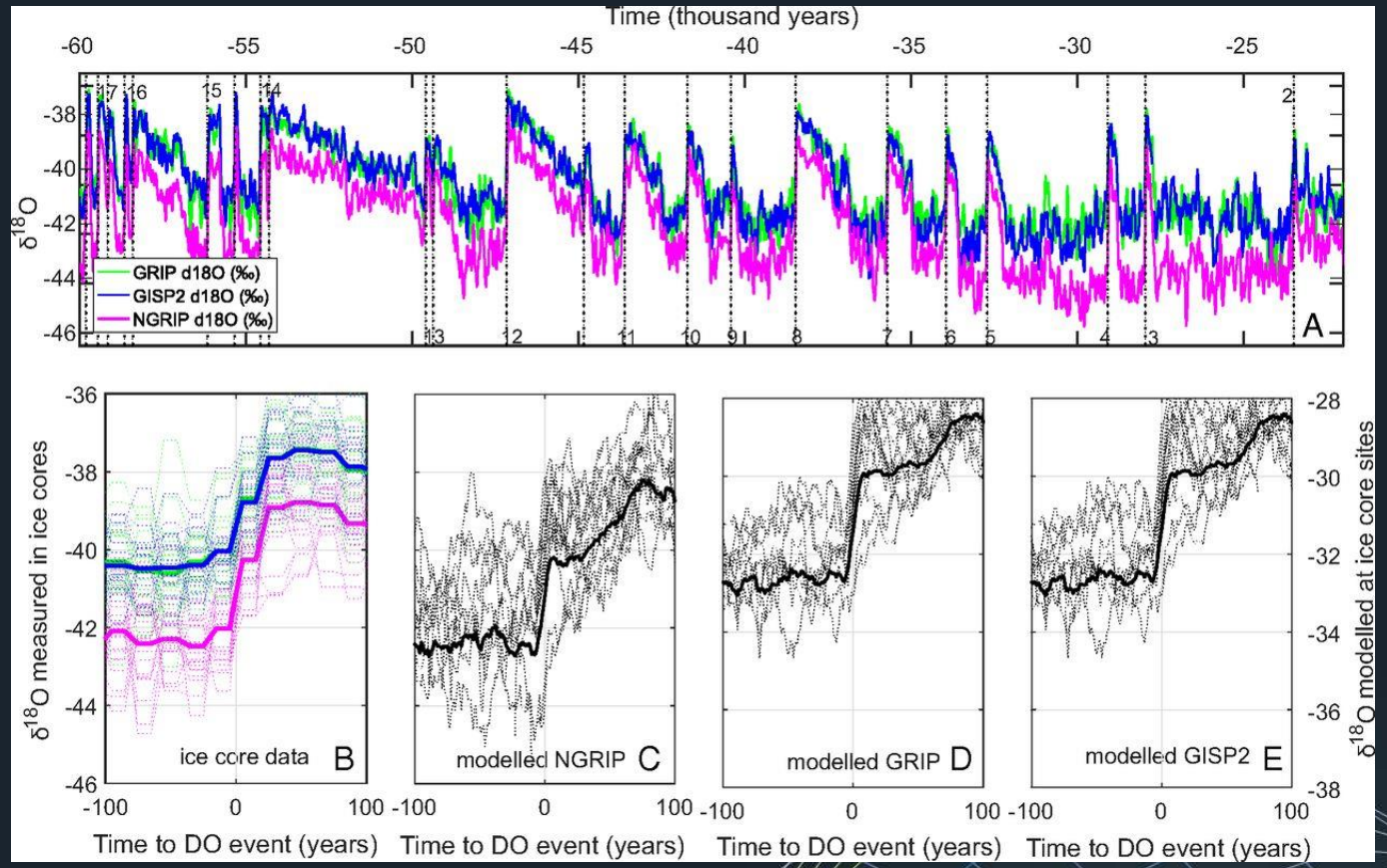

warmer
colder
Temperature in Greenland
GISP2
$\delta^{18}O$ (per mil)
-32
-36
-40
-44
80
60
40
20
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Temperature over Greenland (°F)
-20
-30
-40
-50
-60
15
10
5
0
Age (Thousand years before present)
Medieval Warm Period
Little Ice Age
8,200-Year Event
Younger Dryas

Can ESMs reproduce past abrupt climate changes?

CESM1 (Peltier & Vettoretti 2014 *GRL*)



HadCM3 (Sime et al. 2019 *PNAS*)



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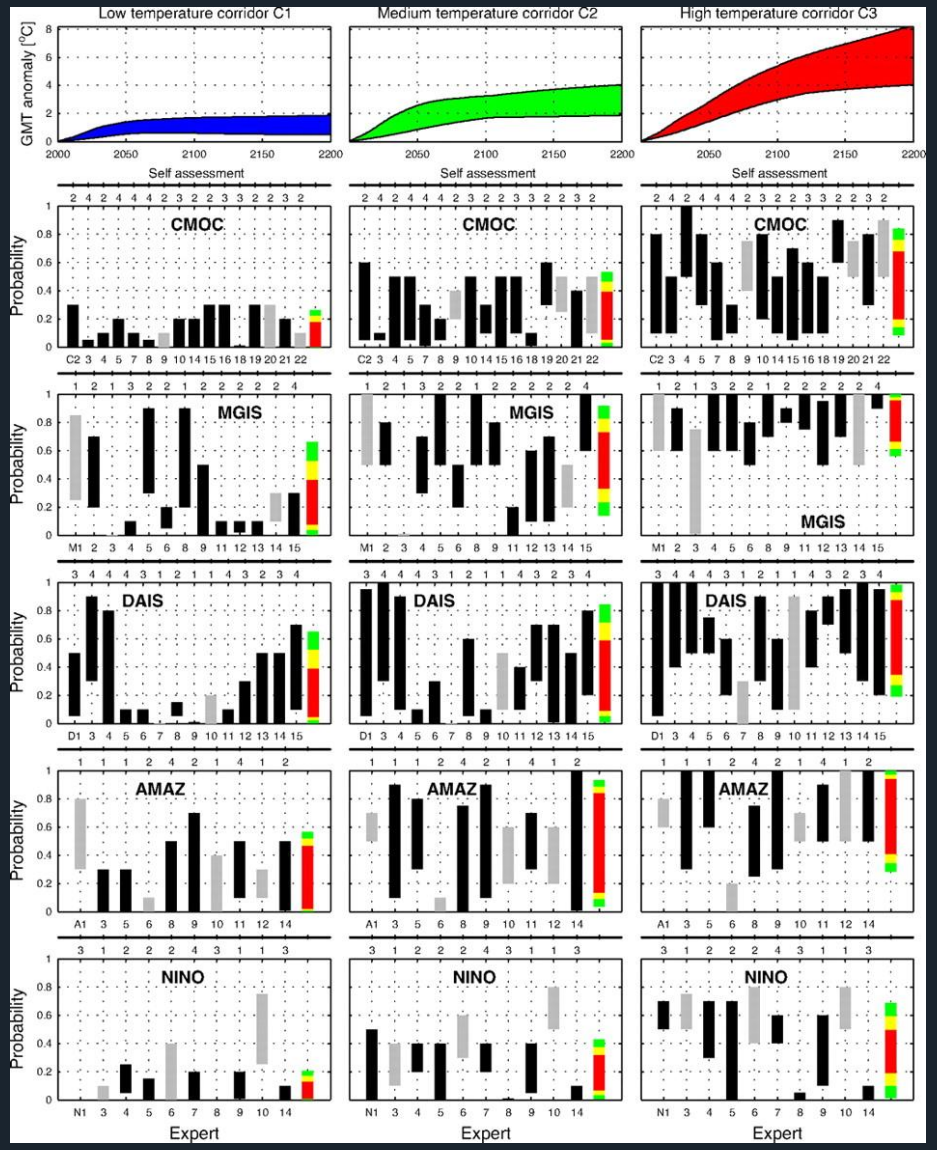
Likelihood of tipping points (expert elicitation)

- 2-4 °C warming: >16% probability of passing at least one tipping point
- >4 °C warming: >56% probability of passing at least one tipping point



Atlantic

Greenland

Antarctica

Amazon

El Niño

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

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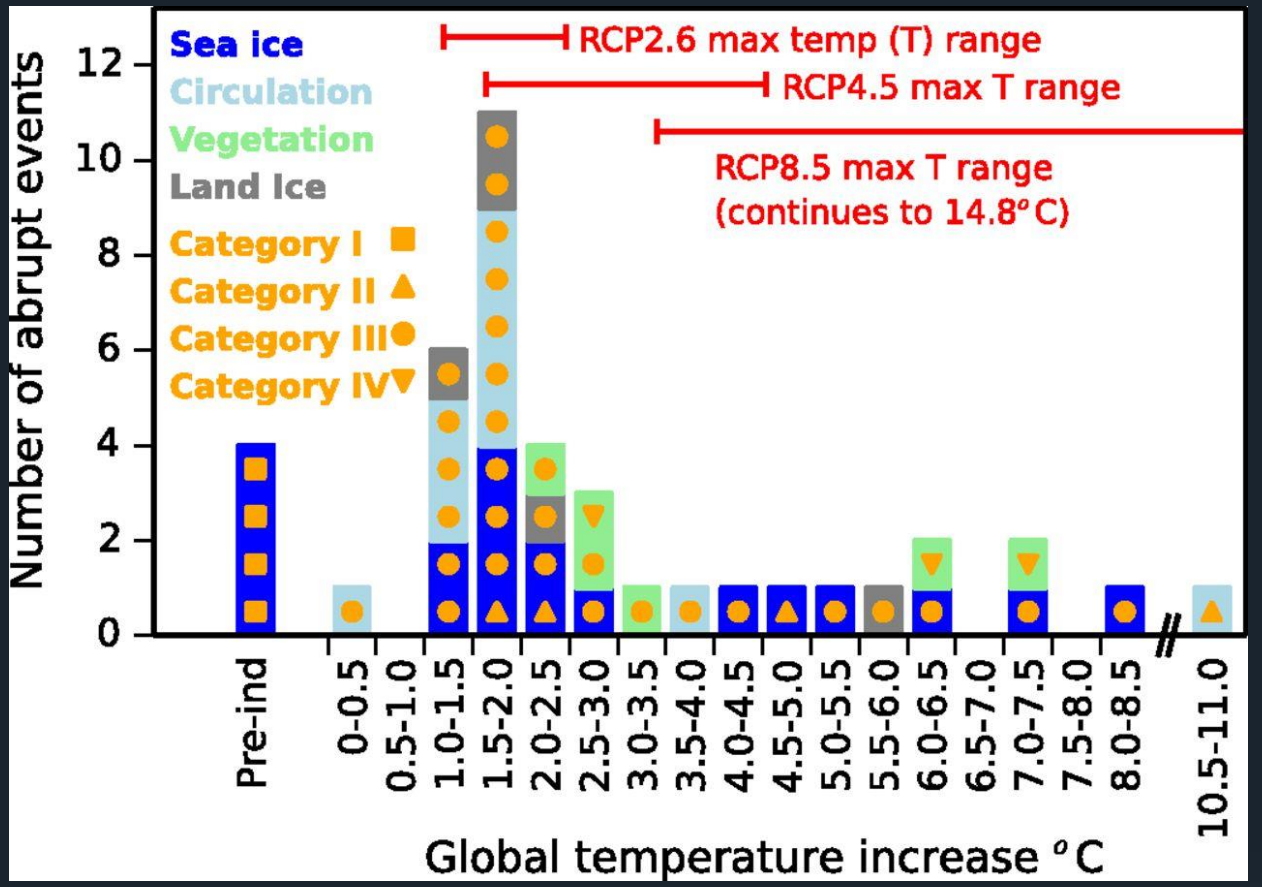
Abrupt changes detected in CMIP5 models



Drijfhout et al. (2015) *PNAS* 112(43): E5777-E5786

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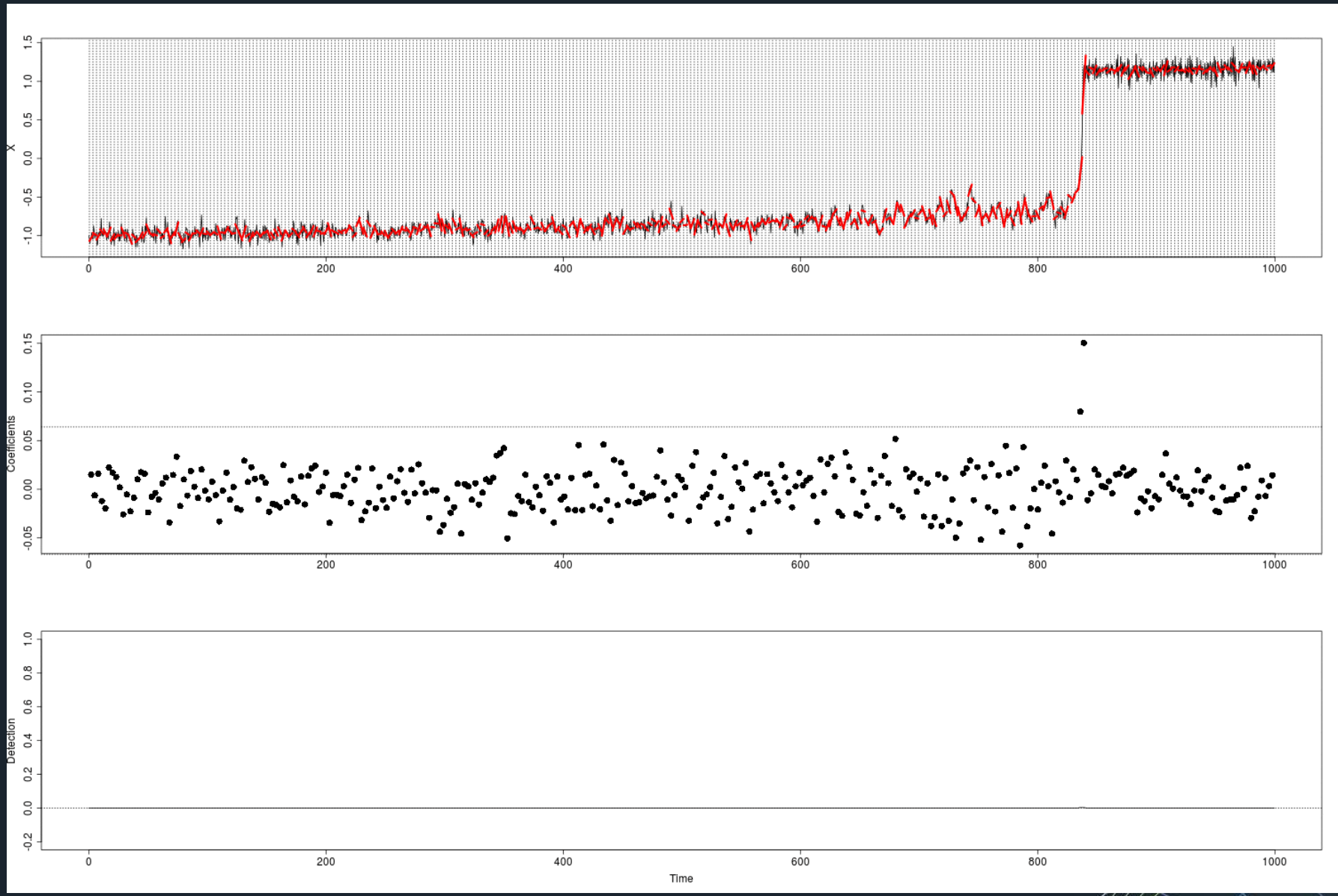

Boulton & Lenton (2019) A new method for detecting abrupt shifts in time series, f1000research, 8:746

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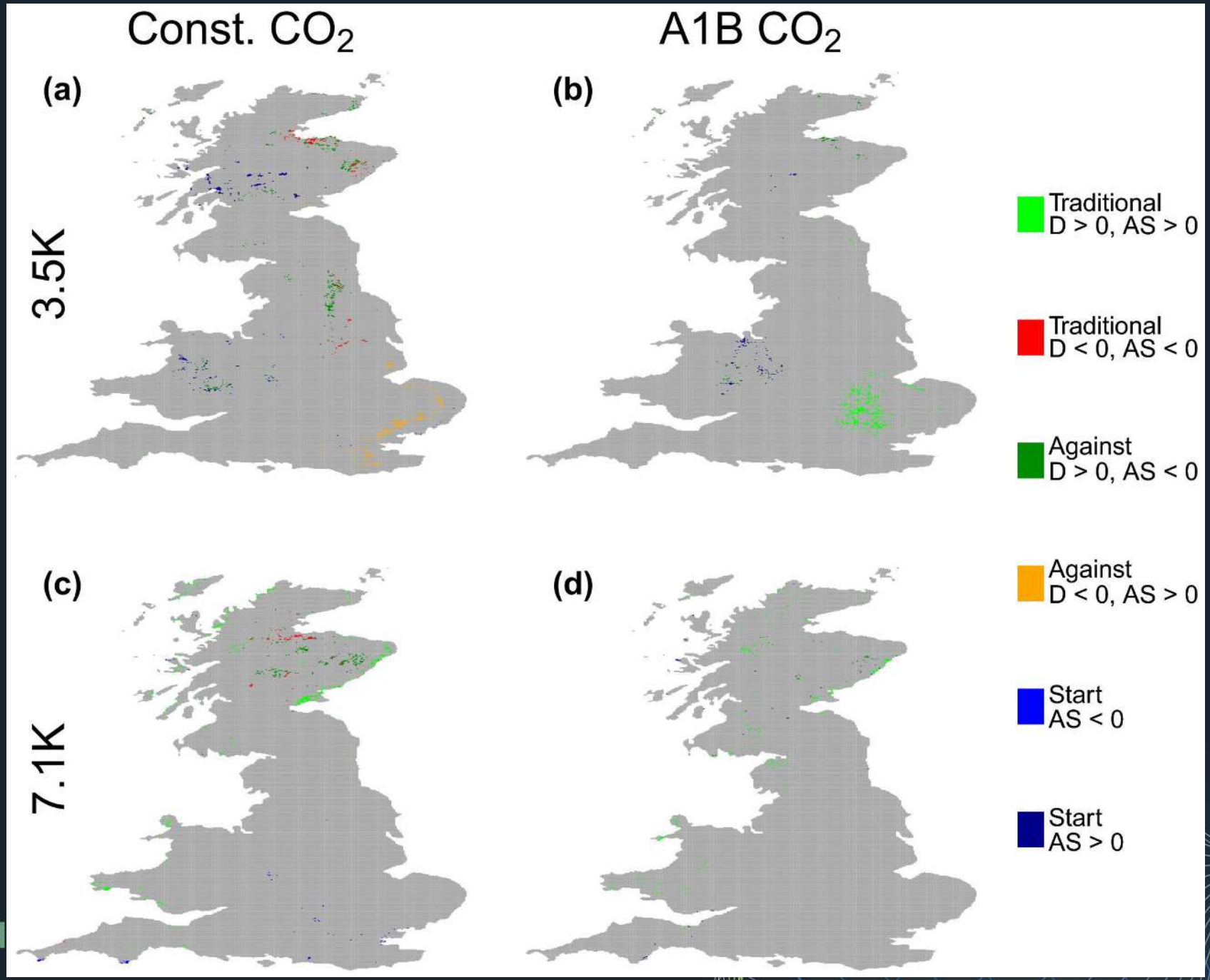
Abrupt shifts in vegetation carbon in JULES



Boulton, Ritchie & Lenton (2020)
Global Change Biology

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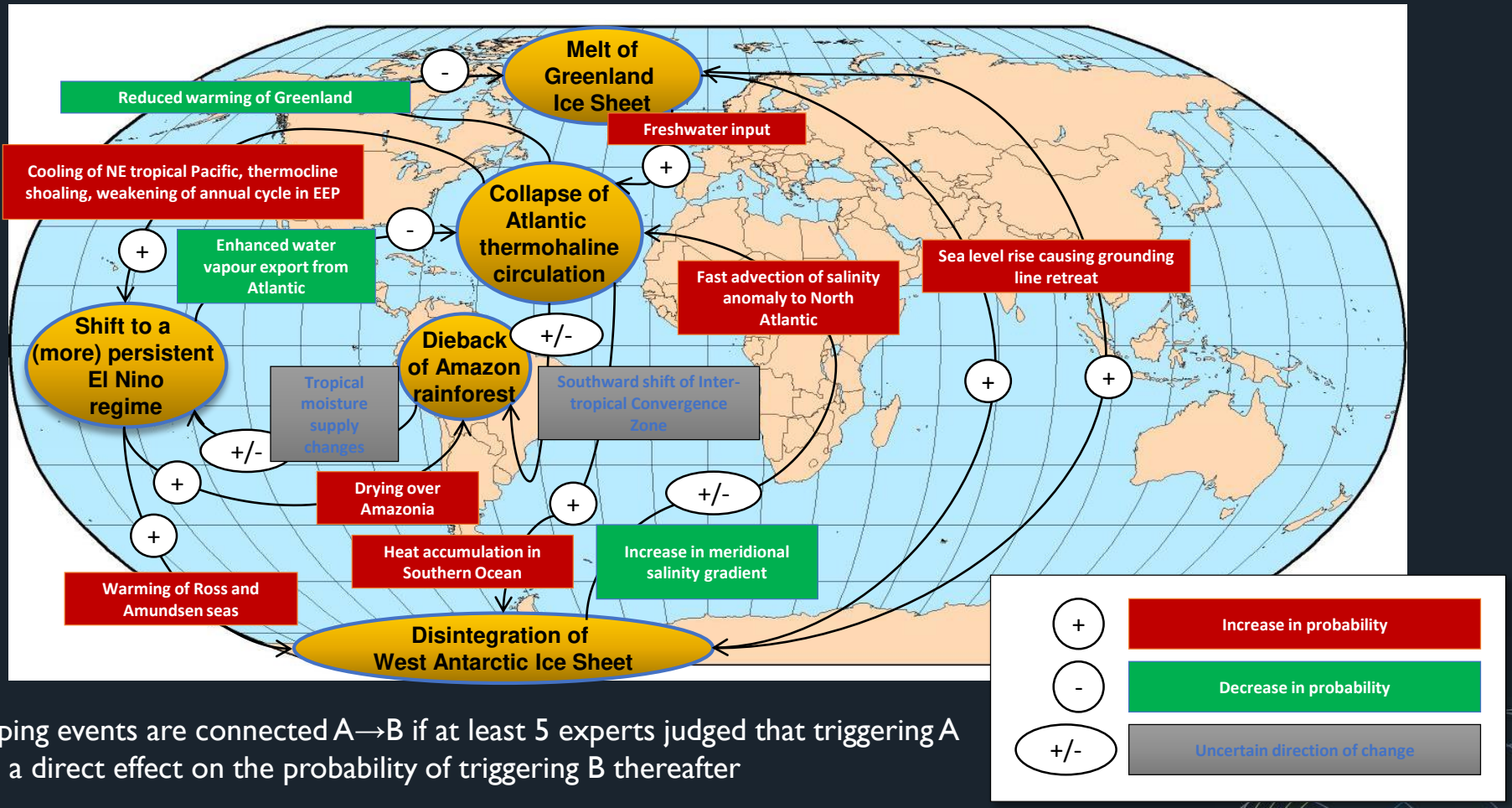
Interactions between tipping events



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

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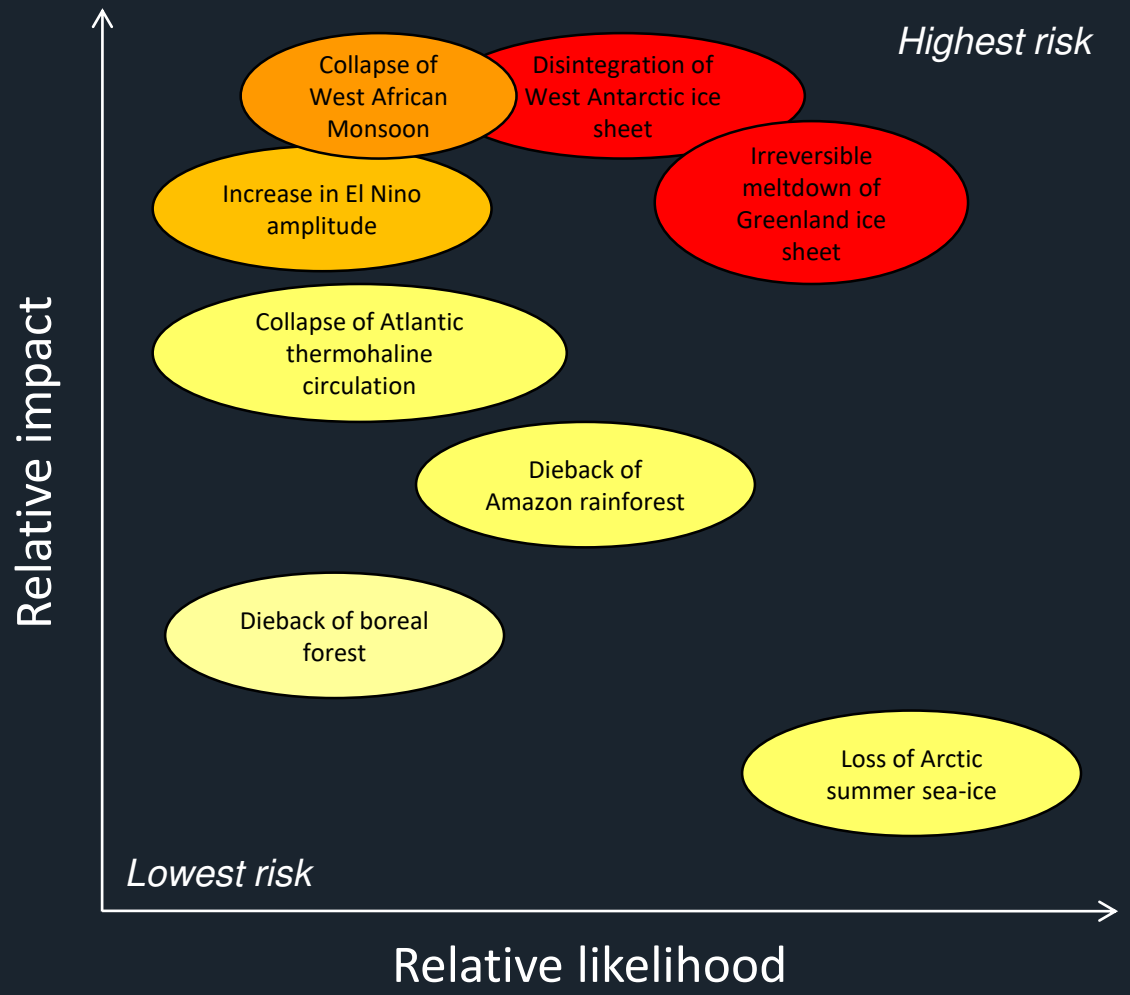
Kriegler et al. (2009) *PNAS* **106**(13): 5041-5046

Risk knowledge



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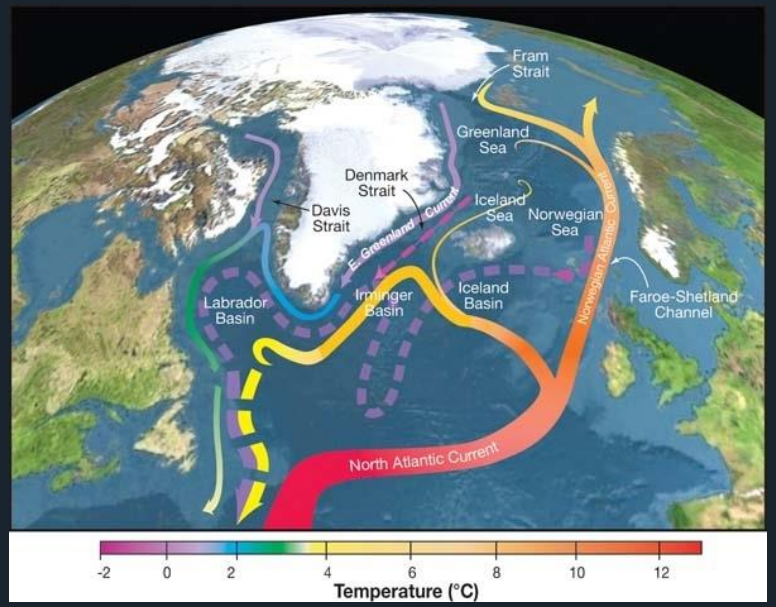
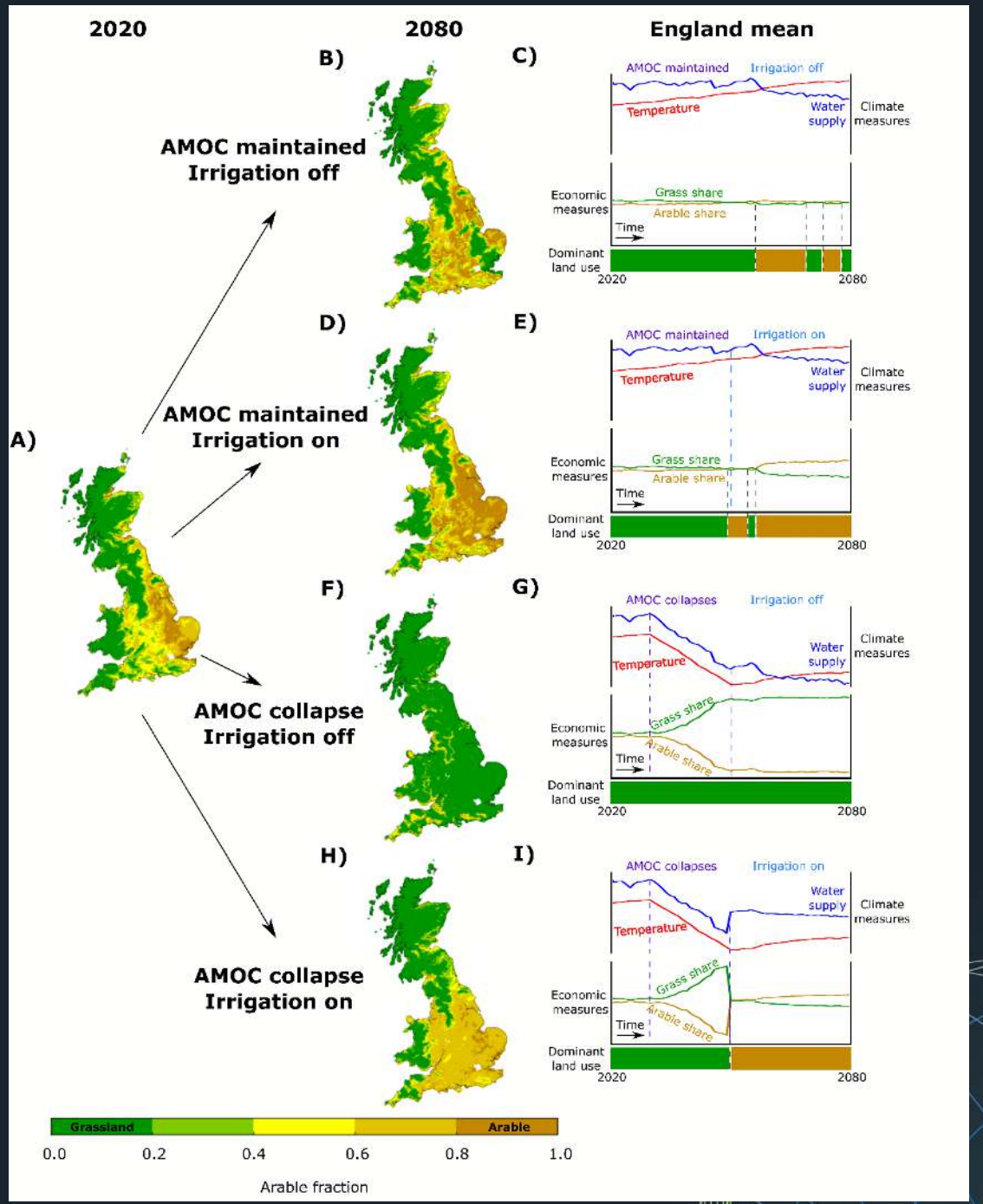
Lenton (2011) *Nature Climate Change* 1: 201-209

Effect of a climate tipping point on GB agriculture

Collapse of the Atlantic Meridional Overturning Circulation (AMOC)





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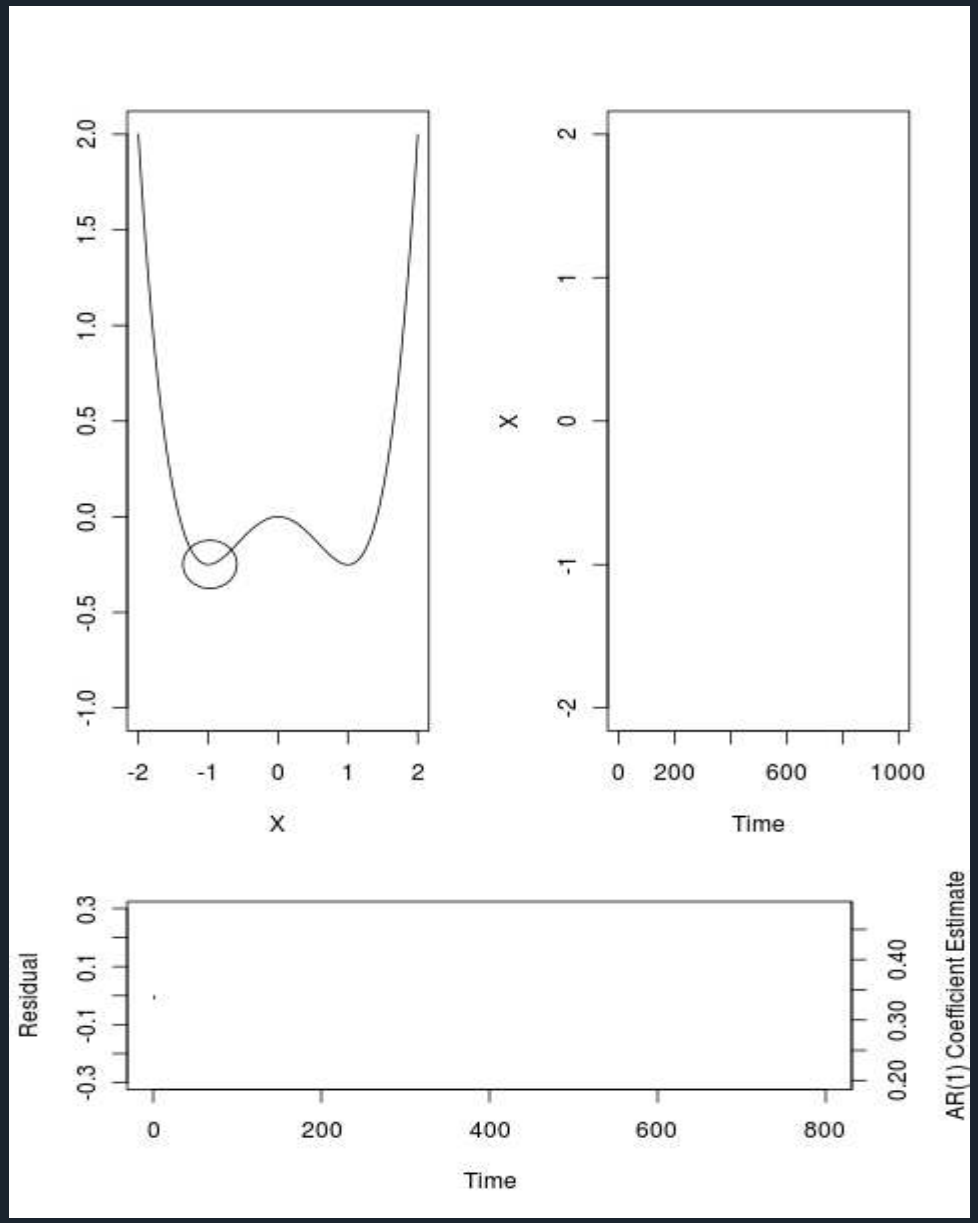
Ritchie, *et al.* (2020) *Nature Food*

Tipping point early warning



Early warning indicator

Thanks to Chris Boulton for the animation

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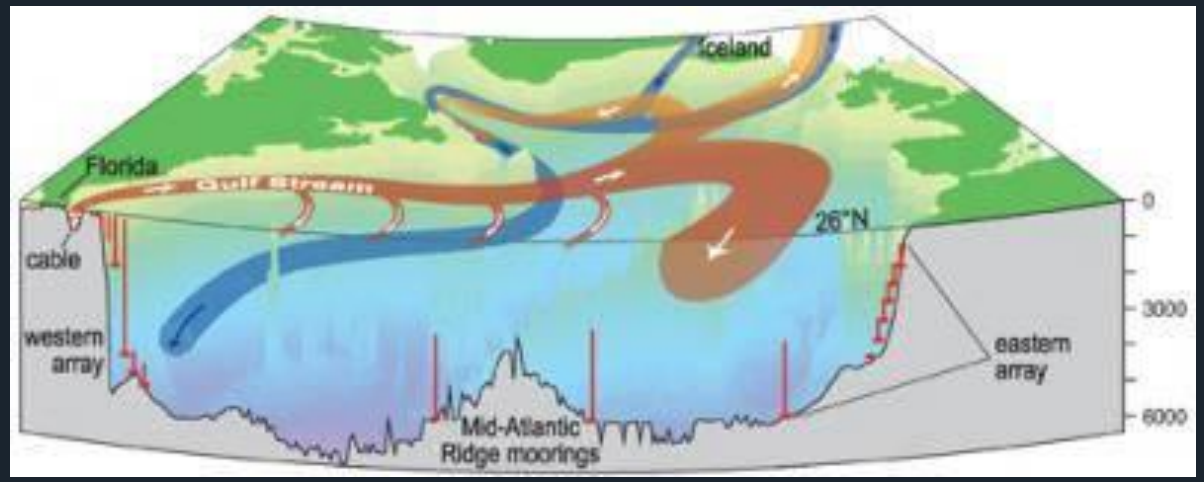
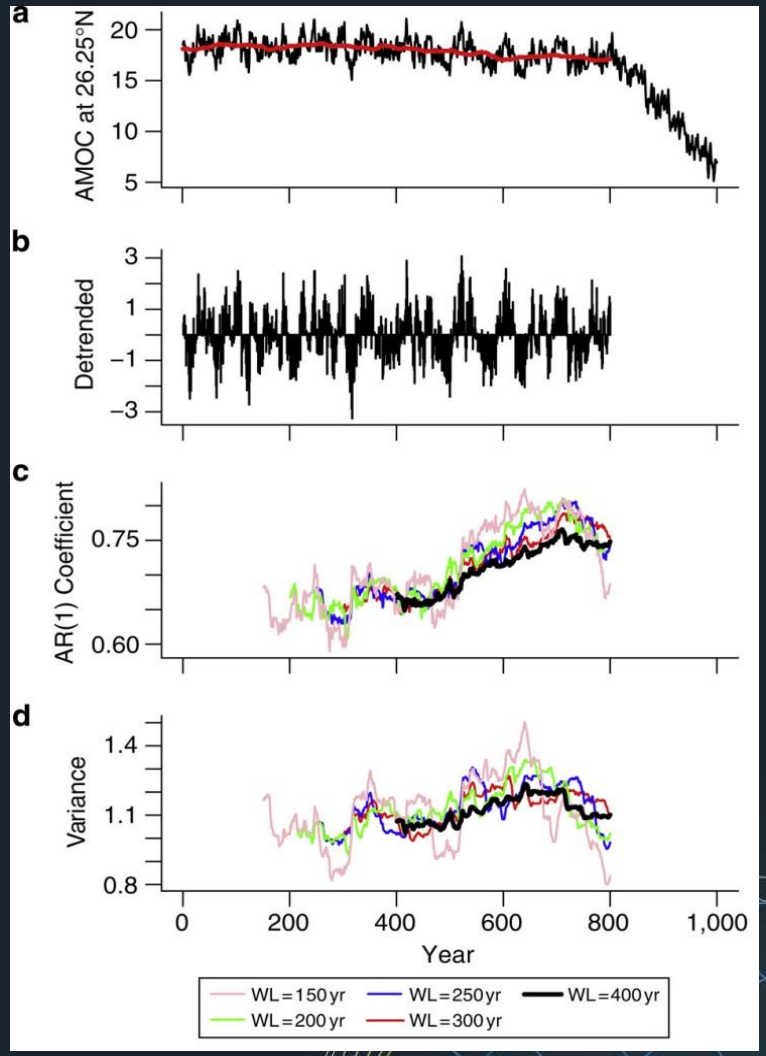
Early warning of AMOC collapse in FAMOUS



- Atlantic Meridional Overturning Circulation (AMOC) is currently monitored at 26ºN
- In a climate model we can collapse the AMOC and see if there are early warning signals at 26ºN



Early warning indicator

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

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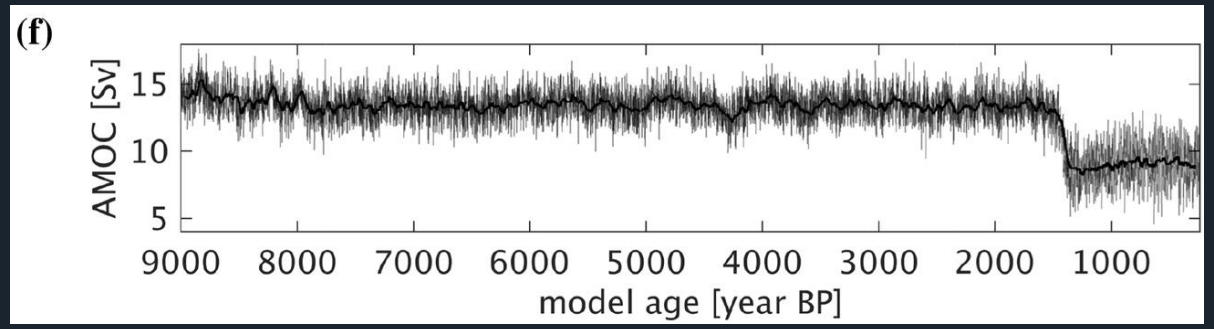
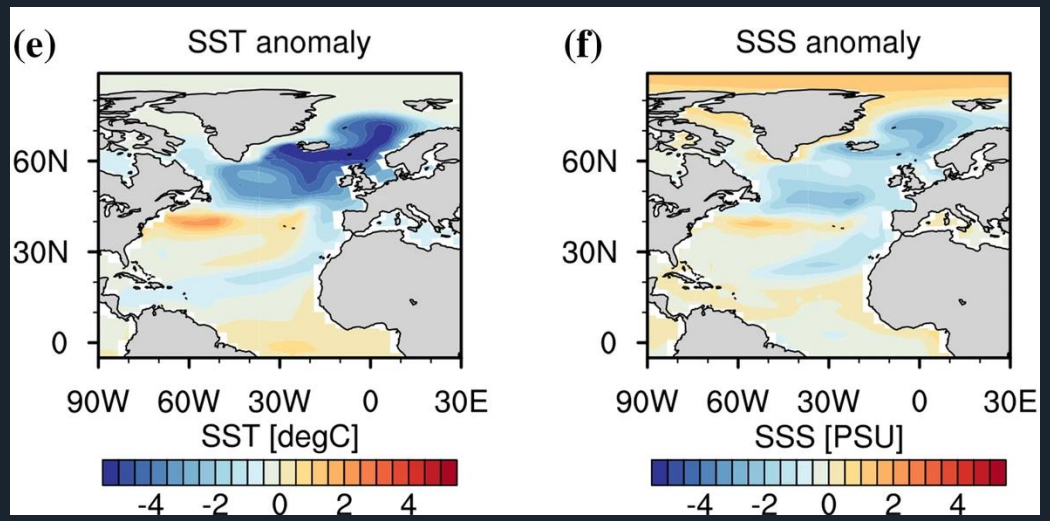
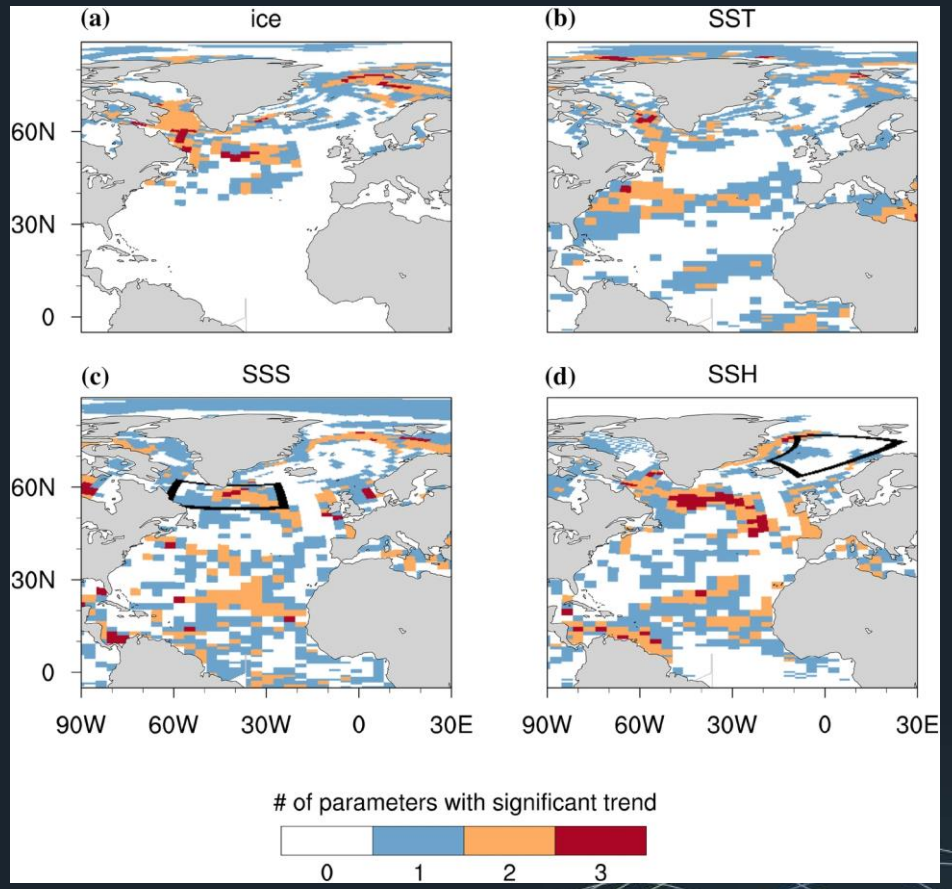
Early warning of AMOC collapse in CCSM3







Klus et al. (2019) *Climate Dynamics* 53: 97-113

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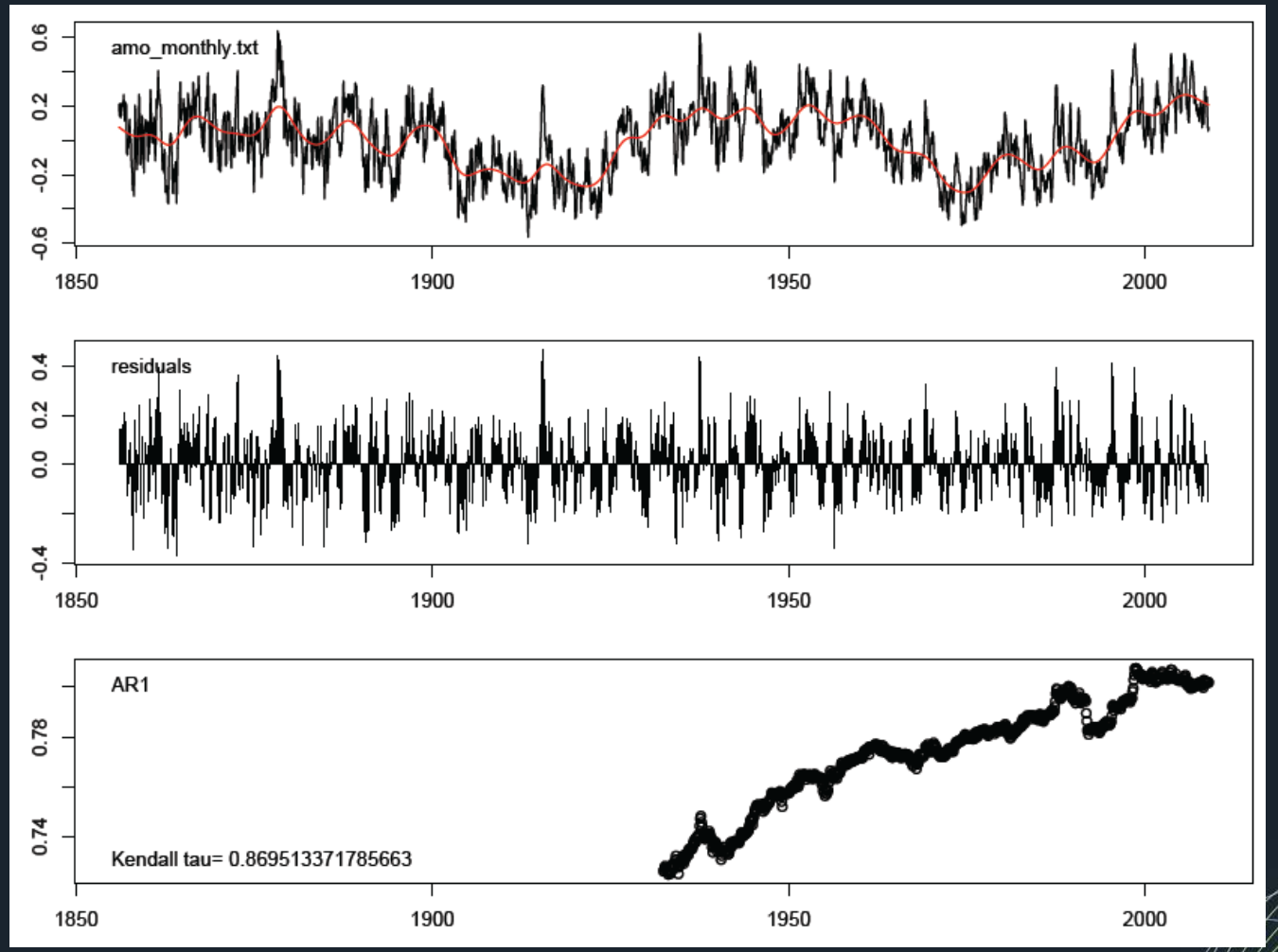
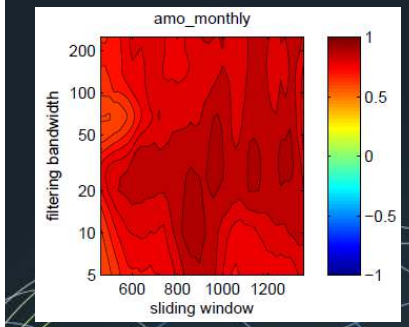
Atlantic Multi-decadal Oscillation (AMO)

AMO from SST data

Detrended data

Early warning indicator





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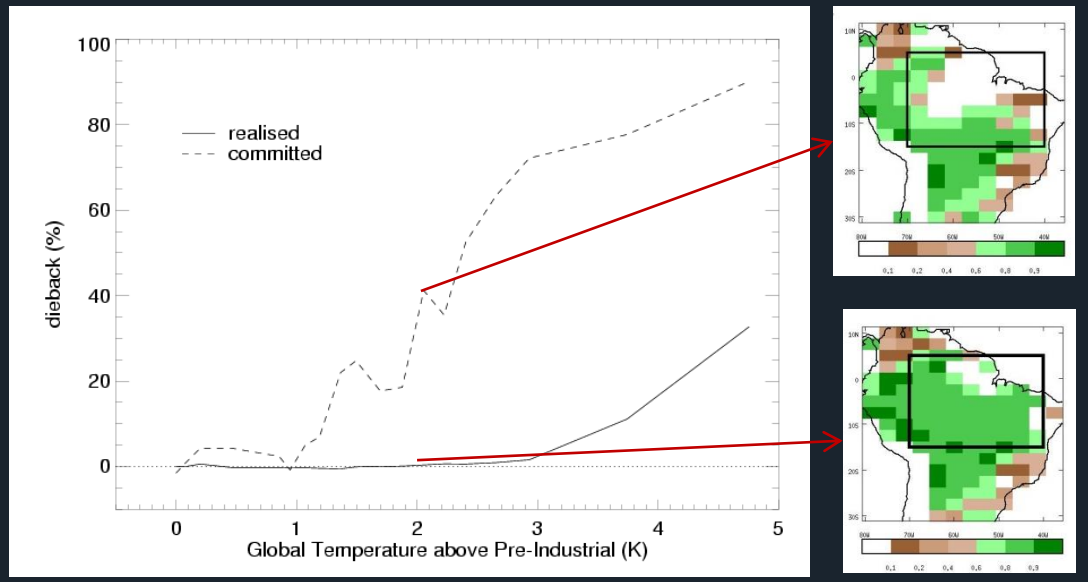
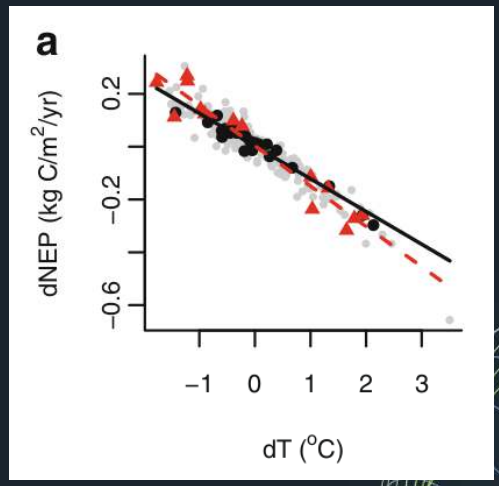
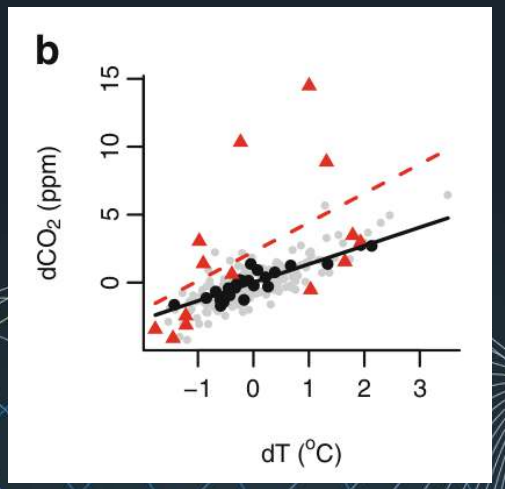
Early warning of Amazon rainforest dieback?

- 'Generic' early warning signals fail despite vegetation equations exhibiting a bifurcation
- Rapid climate forcing of the forest destroys the generic early warning signals
- But system-specific early warning works…
  - Sensitivity of Net Ecosystem Productivity (NEP) to temperature anomalies becomes more negative as temperature increases
  - Sensitivity of CO_2 anomalies to temperature also robustly increases
  - *These are observable variables*







Boulton *et al.* (2013) *Theoretical Ecology* 6: 373-384.

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