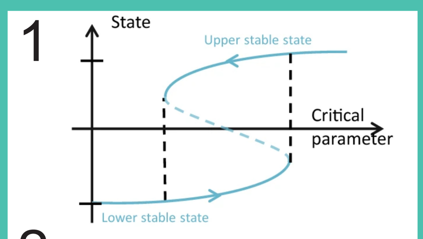
Polar ice sheets decisive for tipping risks and cascading effects in the Earth system

Jonathan Rosser[1],[2],[3] - jpr57@cam.ac.uk,
Ricarda Winkelmann[4],[5],[6], Nico Wunderling[4],[7],[8]

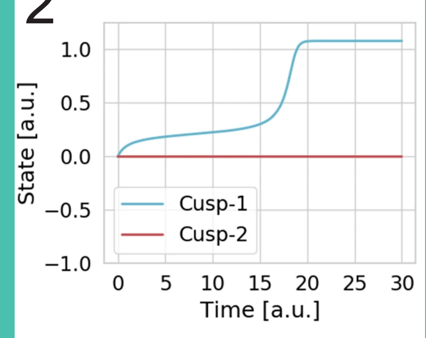
Introduction and Methods

- The Earth system consists of key components such as:
  - Amazon Rainforest (AMAZ),
  - Greenland Ice Sheet (GIS),
  - West Antarctic Ice Sheet (WAIS),
  - Arctic Summer Sea Ice (ASSI),
  - El Niño Southern Oscillation (ENSO)
  - Atlantic Meridional Overturning Circulation (AMOC).
- Some of these key components are suggested climate tipping elements, where beyond a critical threshold (tipping point), a small perturbation may qualitatively alter their state.
- Tipping points and large qualitative changes in key Earth system components pose large risks to human societies.
- High uncertainty remains in the thresholds and timescales for tipping, and their interactions with other components.
- This study makes use of the Pycascades model to represent key elements of the climate system as:
  - simple cusp-like tipping points (AMOC,GIS,WAIS, AMAZ) shown in Figs 1 & 2 (State space and example evolutions of the components)
  - linearly responding climate elements (ENSO and ASSI) shown in Figs 3 & 4 (State space and example evolutions of the components)
- Each element is given a characteristic temperature threshold and timescale for tipping/variation, alongside interactions with other elements which can stabilise or destabilise them.
- The key included components are shown in Figs 5 and 6.

1

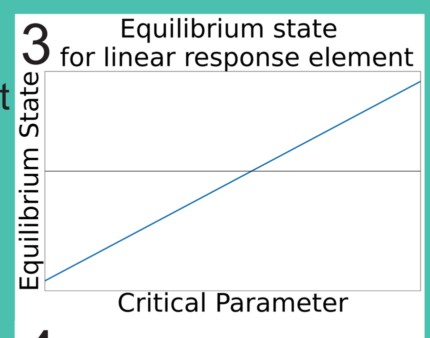


2

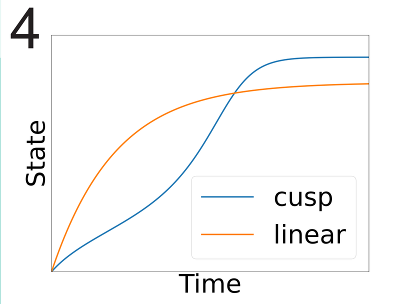


Wunderling, N., Krönke, J., Wohlfarth, V. et al. (2021)

3



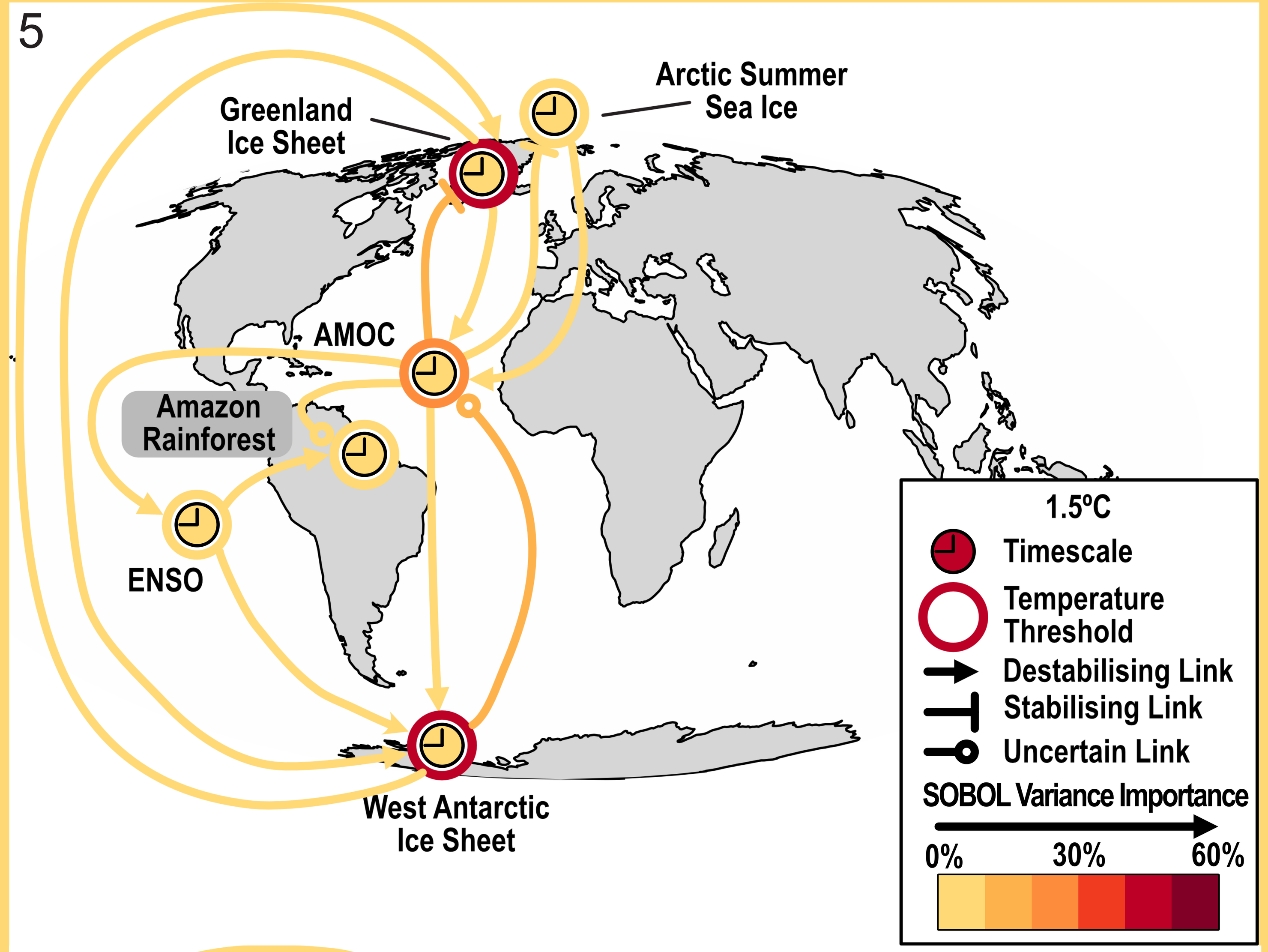
4



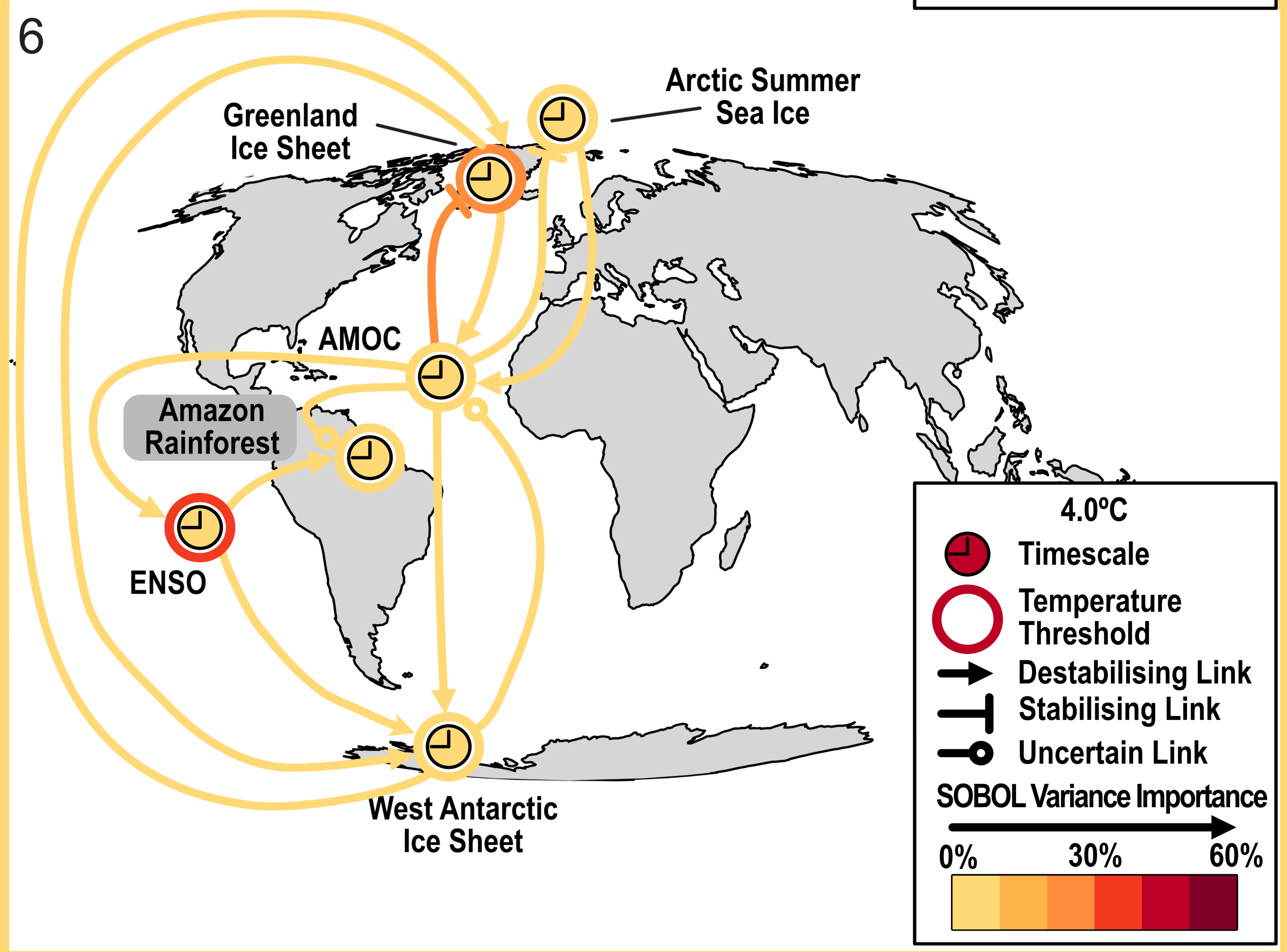
Which Climate Elements are most important for understanding our future climate state?

- Figs 5 and 6 highlight the importance of key climate elements and links for our future climate state using Sobol variance analysis.
- Sobol variance analysis calculates the contribution to overall variance in final tipping state due to variance/ uncertainty in each input parameter (temperature thresholds, timescales and interaction strengths),
- At 1.5C of global warming the key forcings are from elements with low-temperature thresholds, the GIS and WAIS.
- At 4.0C the key factors are the elements which do not tip, either due to having a high temperature threshold (e.g. ENSO) or stabilising links (GIS).
- At both temperature levels, the polar ice sheets are critical and so constraining the uncertainty in their behaviour and interactions is crucial to reducing uncertainty in the future climate state.

5



6

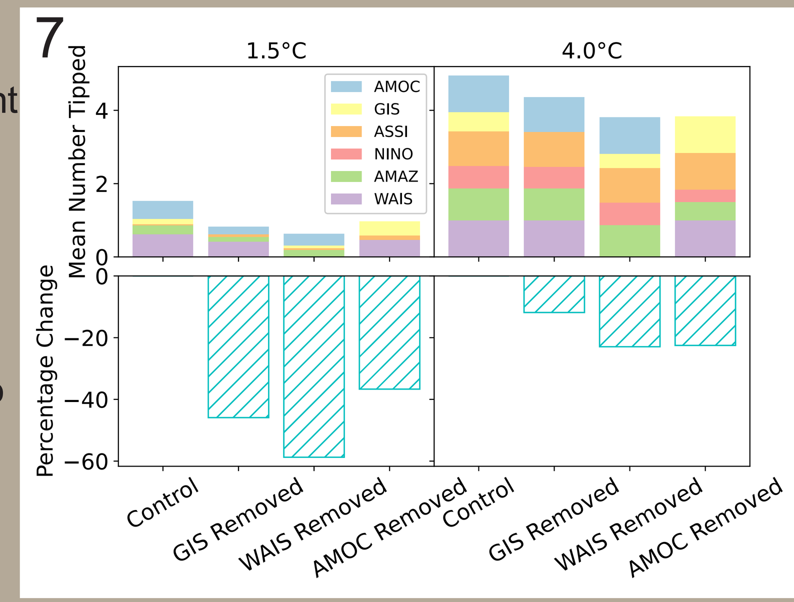


[1] British Antarctic Survey, [2] Department of Applied Mathematics and Theoretical Physics, University of Cambridge, [3] UK Met Office, [4] FutureLab Earth Resilience in the Anthropocene, Potsdam Institute for Climate Impact Research (PIK), [5] Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany, [6] Max Planck Institute of Geoanthropology, Jena, Germany, [7] Center for Critical Computational Studies (C^3S), Goethe University Frankfurt, Frankfurt am Main, Germany, [8] High Meadows Environmental Institute, Princeton University, Princeton, USA

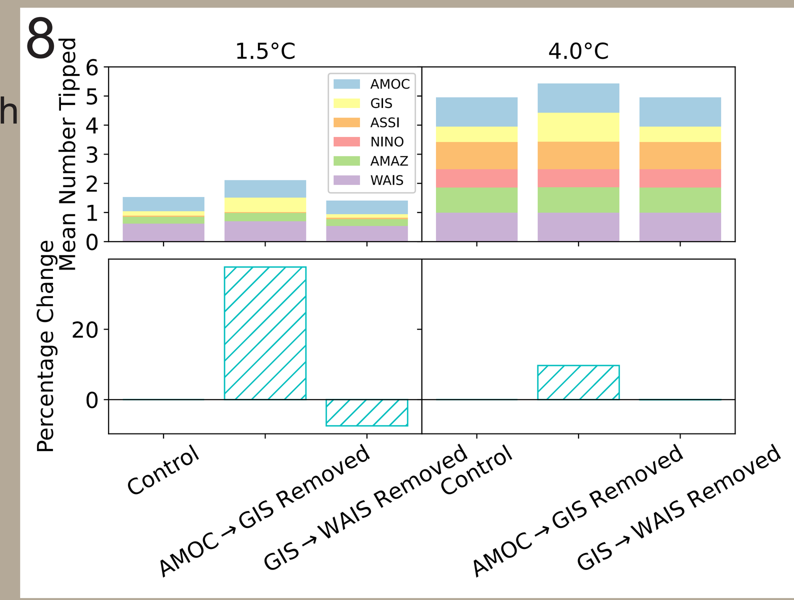
What is the impact of missing an element or interaction?

- Removing a node or link from our network of interacting Earth system components is analogous to an element of the climate system not being simulated or being neglected.
- The impact of removing a node or link can be seen in Figs 7 & 8 respectively.
- Removing the WAIS or GIS can lead to reductions of 58% or 46% respectively as they are strong initiators of cascades, influencing tipping in the AMOC and each other.
- Removing AMOC leads to a smaller reduction in tipping but a qualitatively different behaviour of the system as it leads to greater tipping of the GIS which it stabilises and different cascading impacts on AMAZ and ENSO.
- Changes in link removal can change tipping by up to 40%.
- If we miss a single link or node from our analysis, the results can differ from a more complete analysis by 20-60%.

7



8



Conclusions

- We must consider inherent uncertainty due to model structure and unknown unknowns in our model analysis
- If elements are missing our models simulate the climate badly in both qualitative and quantitative ways
- Because of this we should ensure that large climate models include as many components as possible
- Polar ice sheets contribute the critical uncertainty to our future tipping projections so more research is needed on them to reduce this uncertainty
- Get more details from the preprint!
- Ask me about my upcoming postdoc on climate tipping points and their economic impacts as well as uncertainty in climate ensembles

This presentation participates in OSPP
Outstanding Student & PhD candidate Presentation contest

- **Please get in touch! jpr57@cam.ac.uk**