The World Climate Research Programme

High Impact events and tipping dynamics: how robust is our understanding

WCRP TipSci Group
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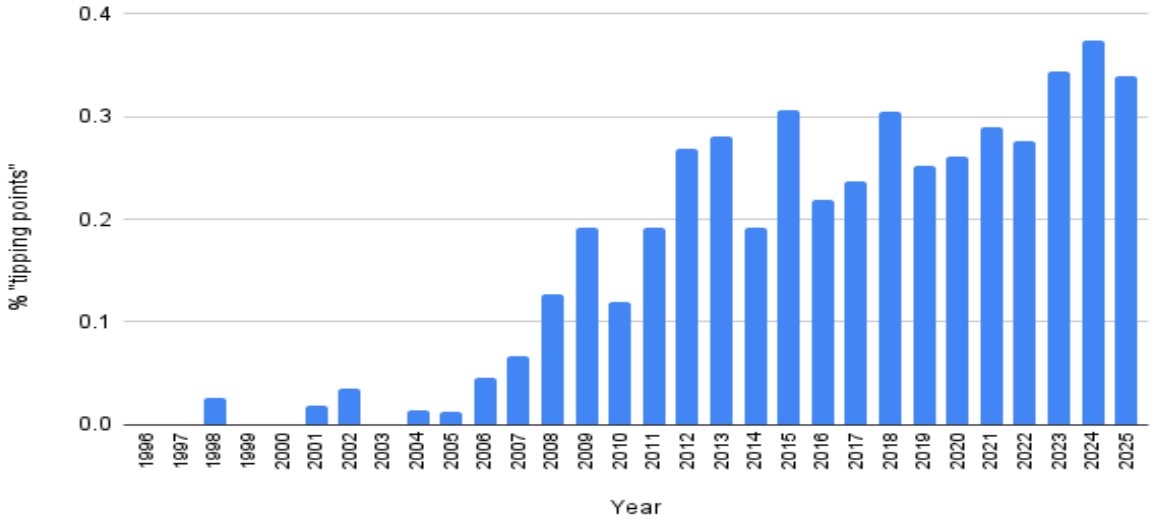
plus ca **70 specialist section co-authors**

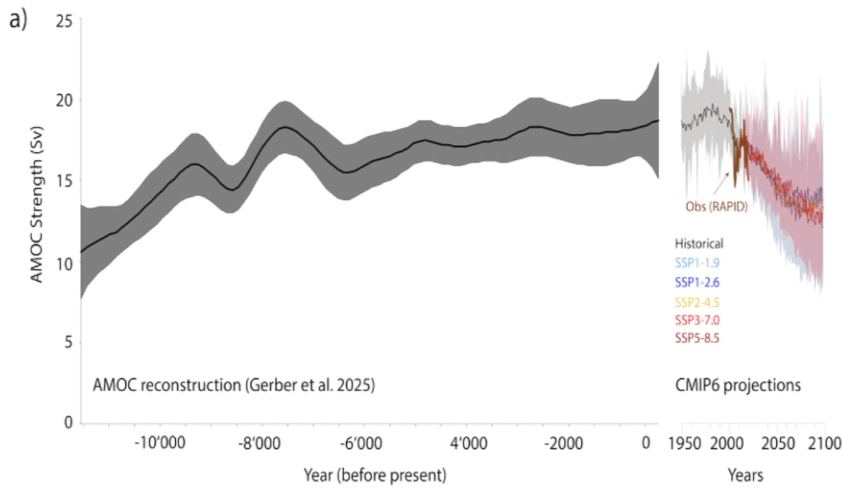
Why the Assessment paper

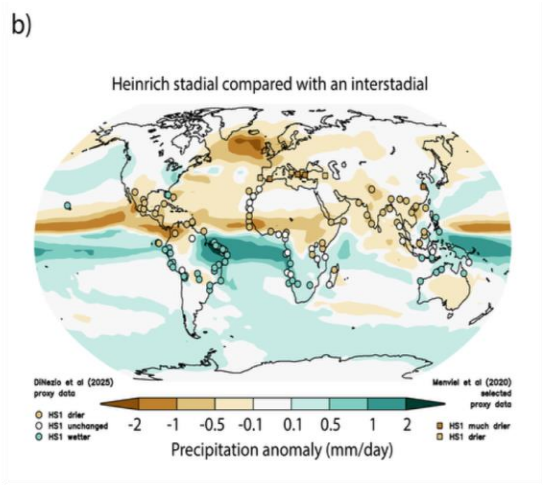


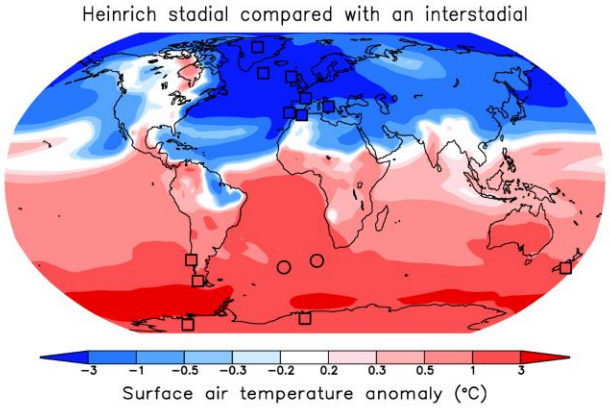
- Rapid expansion of literature on tipping points, although somewhat controversial discussion (figure: fraction of papers on climate change that include tipping points and climate)
- Goal: Consensus building across the research community on level of scientific understanding across this topic
- Key question: which high impact events and tipping points are we most concerned about and how can we better constrain that risk using information from past climates, present observations and modelling?
- Plan: Submit as single review paper, with paper proposal submitted to reviews in Geophysics.
- Key outcome: Inform IPCC AR7 and support consensus building

Guiding questions

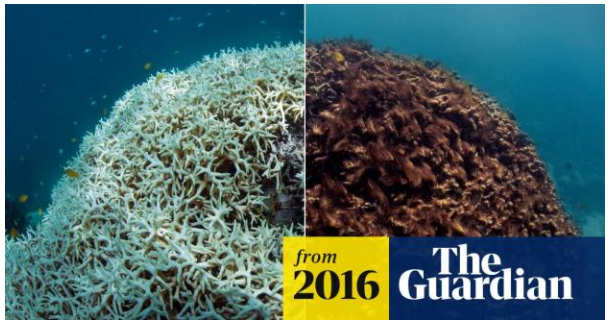
- What large-scale climate-driven events or changes can lead to the most severe consequences, and what do we know about their risk and impacts?
- Are processes involved in tipping dynamics represented reliably in ESMs? Does palaeoclimate evidence or other observations constrain models?
- What thresholds need to be considered and simulated well enough for enable study of nonlinear, severe impacts; and what are limitations in our understanding
- What are the carbon cycle consequences of crossing tipping points or long-lasting transitions?
- What can climate science do to better enable early warning and predicting risk of tipping dynamics and irreversibility?







2: Ocean tipping points and high impact events - DRAFT



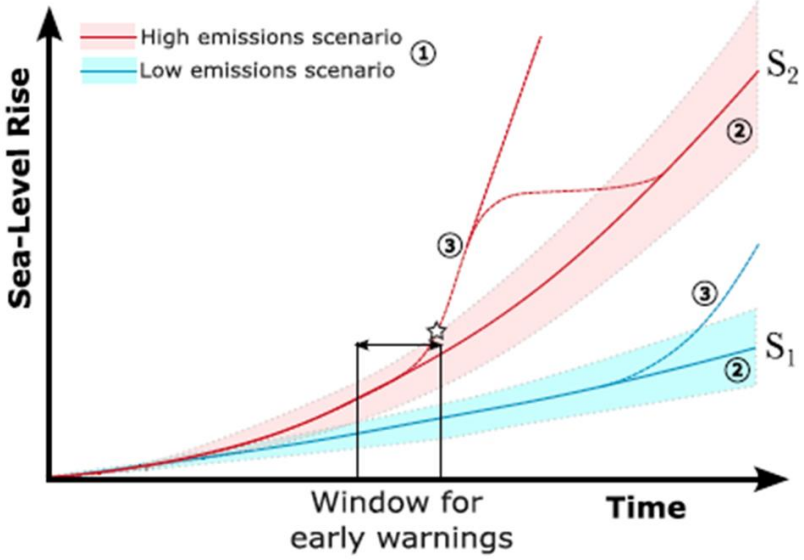
Leads: Anastasia Romanou and Thomas Froehlicher

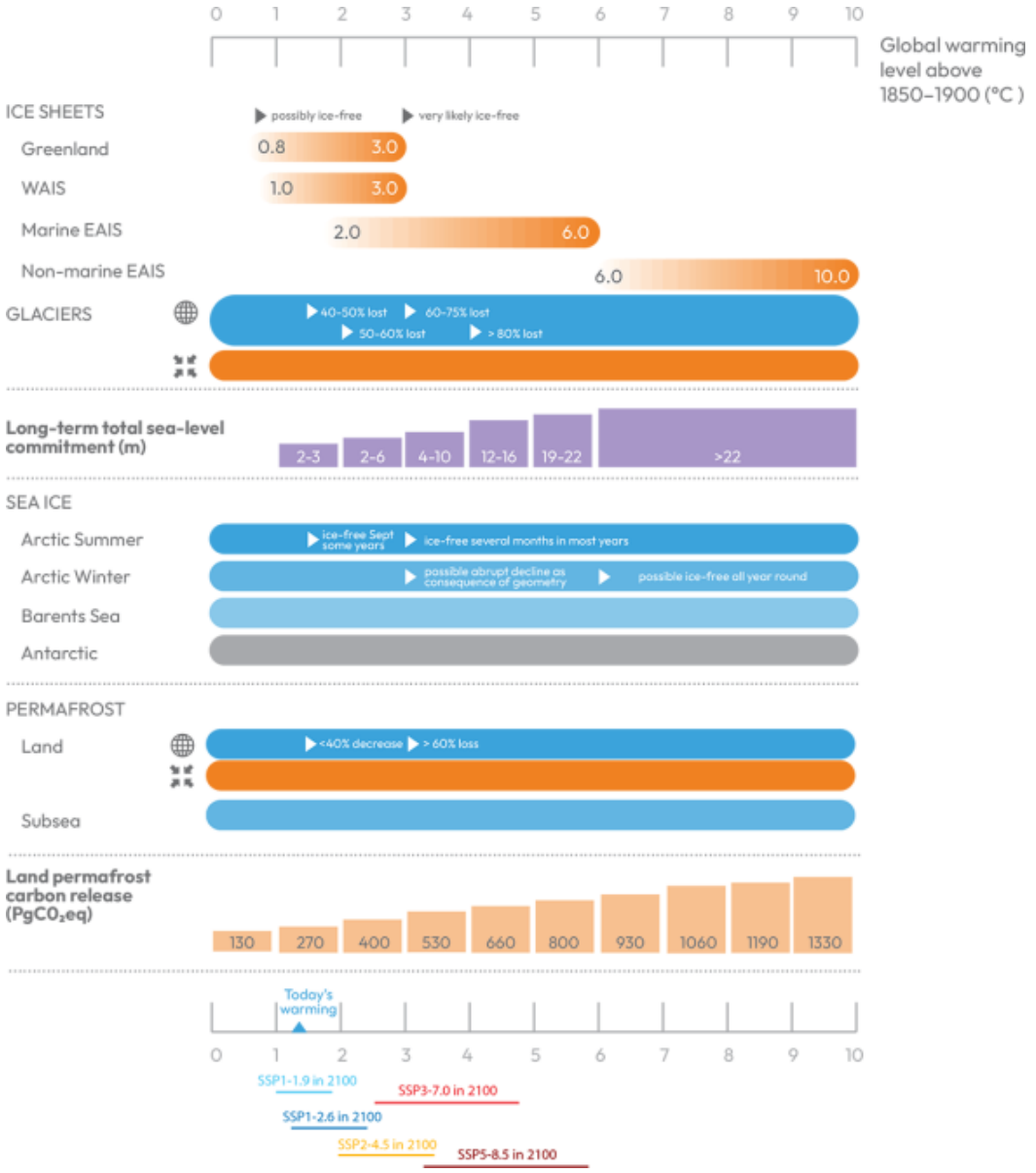
- AMOC collapse (confidence language – high confidence will weaken, medium confidence it will not collapse beyond 21st century);
- SPG and Southern Ocean Abyssal circulation
- Corals and biogeochemical extremes

3. Tipping dynamics of the cryosphere: ice in a warming world - DRAFT

Leads: Florence Colleoni, Ricarda Winkelmann and Tim Naish

- Characteristics of tipping dynamics, long latency and severe impacts
- Ice sheet instability can accelerate collapse





4 and 5: Permafrost and tropical and boreal forest systems - DRAFT

Leads: Victor Brovkin and Annett Bartsch; Lina Trekkentrup and Laibao Liu

Events with potential high impact :

- Permafrost, impacts of loss directly, and carbon feedback
- Boreal forest (southward retraction - northward advance) some evidence at present
- Monitoring of changes insufficient particularly for permafrost and processes too simple in models

- mass tree mortality in tropical forests. This risk is high at higher global warming levels but already significant. Possible coexistence of the forest and savanna biome after transition reduces land carbon uptake and water recycling
- Tropical peatland abrupt changes due to declining water table also release carbon and methane into the atmosphere a risk that is poorly quantified and considered.
- West African monsoon system changes and overall monsoon changes

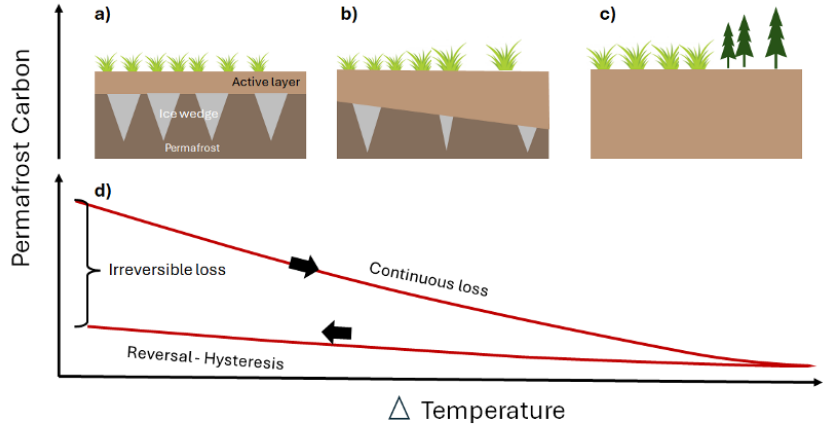
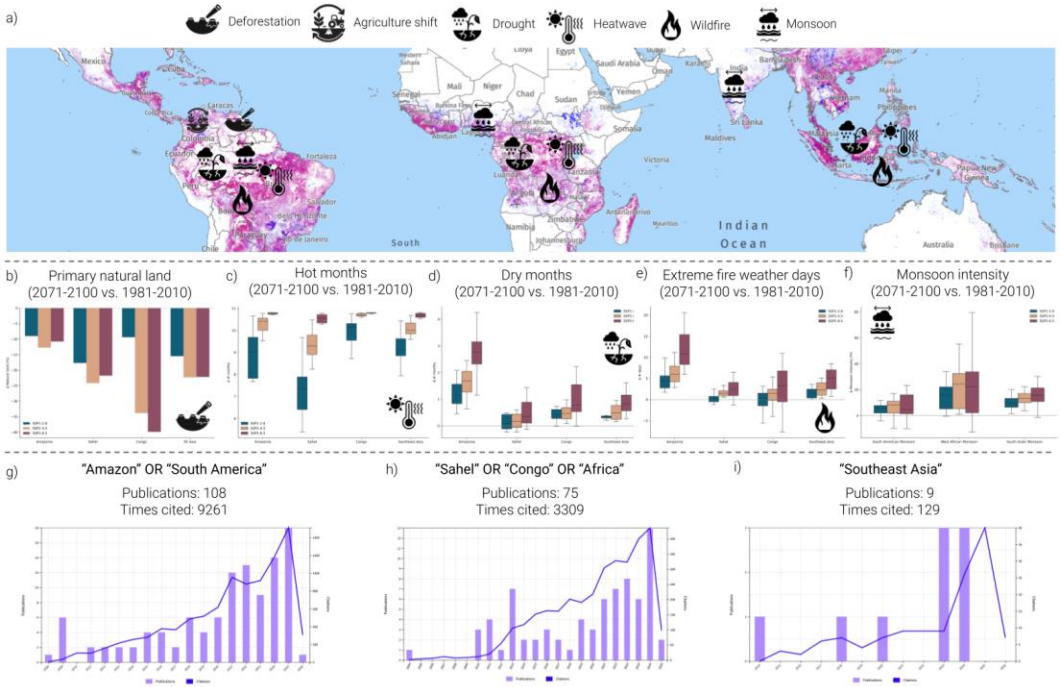


Fig 2 Conceptual global permafrost changes. **a)** undisturbed permafrost system; **b)** gradual warming; **c)** no permafrost state; **d)** permafrost carbon hysteresis. *Same for ground ice (Jan's suggestion)*
Gustaf



7: Threshold breaching / tipping in impacts - DRAFT

- Lead: Alaa Al Khourdajie and Jonathan Moyer;

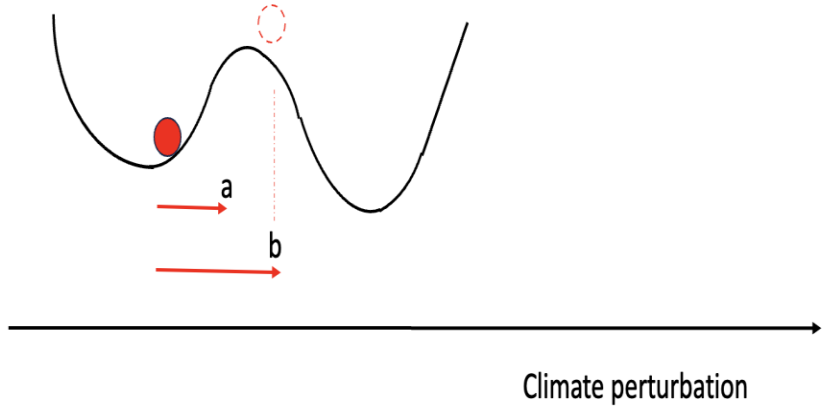
	Socioecological systems cross a critical threshold or reach a tipping point	**Socioecological systems remain in a (largely) linear response regime**
Climate systems tipping points (TPs) occur	Category A "Cascade" pathways	Category B: "Propagation" pathways
Gradual climate system change	Category C: "Socioecological Thresholds" pathways	Category D: "Incremental" pathways

Examples:
Health – dangerous and life threatening heat; Dengue fever
Food system
Financial system

Recommendations for research

- **Monitor** –e.g. permafrost – monitor response and recovery from extreme events and other indicators of loss of stability.
- **Improved integration of process understanding from multiple lines of evidence:** Models, observations (palaeo, instrumental, satellite retrieval, modelling across hierarchy of complexity).
- **Improved ESMs and targeted simulations:**
  - interactive coupling in ESMs and subcomponents to resolve feedbacks (e.g. prognostic ice sheets/glaciers, links to ocean biogeochemistry and dynamics, land vegetation, climate, fire, AQ; soil/climate/carbon interactions; permafrost interactions…. (where possible)
  - Higher resolution will address some issues, e.g. some long-standing model biases (?) but long timescales and sampling of extreme events needed (i.e. need tools to bridge – emulators? ML?)
  - Use coordinated model experiments to evaluate robustness of response (e.g., TipMIP, Winkelmann et al., 2026). Imposed tipping where models may not be able to reliably simulate tipping dynamics
- Improved **precursors and 'early warning**' of tipping dynamics (ESMs as training ground; ML etc)
- **Carbon cycle response to tipping dynamics**
- **Consider irreversibility in impacts on the biosphere, biodiversity and society**; improve understanding of interaction between human and climate system (incl by modelling) to anticipate limits to adaptation.
- **Governance approaches** needed; and flexible approach for adaptation to climate change (e.g. signposts and decision triggers leaving room for adjustment of adaptation strategies).

1: Definitions and Scope - DRAFT



Lead: Hannah Liddy and myself

Informed by literature, and WCRP/IPCC workshop on high impact events and Tipping points in Paris, 11/2025: **tipping system' is a large-scale (regional to sub-continental) component of the Earth (+ society) system that**

1. Has plausible pathway to *high-impact consequences* that may cascade through physical, biophysical, biogeochemical, socioecological systems

and exhibits **some or all of** :

2. *self-reinforcing (positive) feedbacks* that become self-sustaining when a *critical threshold* is crossed
3. Occurs *abruptly,* relative to the typical time scale of variability in the system
4. Effectively *irreversible:* returning to the original state would require substantially different forcing or much longer timescales (also *hysteresis)*, this maybe be rapid or slow timescales relative to human systems

Additional common characteristics:

5. *latency* between the time of irreversible commitment and the full realization of system responses
6. *deep uncertainty* in the presence, likelihood, magnitude, thresholds, or timing of tipping dynamics