Cascading climate tipping events and can society prevent them?

1. (Cascading) tipping risks due to global warming overshoots

2. Can society prevent climate tipping?

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‘Earth’s critical organs’: Climate tipping elements

Armstrong McKay, et al. (2022, Science)
Interacting climate tipping elements

Interactions among the Greenland Ice Sheet, West Antarctic Ice Sheet, AMOC, and Amazon rainforest

\[
\frac{dx_i}{dt} = -x_i^3 + x_i + \frac{\sqrt{4/27}}{T_{\text{limit},i}} \cdot \Delta \text{GMT} + \frac{d}{10} \sum_{j \neq i} s_i (x_j + 1) \frac{1}{\tau}
\]

- Tipping Element
- Nonlinear Earth system components
- Tipping element including Global Feedback on GMT
- Nonlinear Earth system components including Global Feedback on GMT

Critical parameters
- \( T_{\text{limit},i} \)
- \( \Delta \text{GMT} \)
- \( s_i \)
- \( \tau \)

Tipping times
- \( t_{\text{GRS}} = 1,000 - 15,000 \) yrs
- \( t_{\text{RIS}} = 500 - 13,000 \) yrs
- \( t_{\text{AMOC}} = 15 - 300 \) yrs
- \( t_{\text{AMAX}} = 50 - 200 \) yrs

Wunderling/vonderHeydt et al., 2023, ESDD (in review)
Potential risk of climate domino effects under global warming?

Roles of tipping elements in Cascades in this model:
- Ice sheets: Initiators
- AMOC: Transmitter

Critical temperature ranges:
- Increase for Greenland
- Decrease for all other TEs

Overall: Interactions destabilize the climate system
Characterising overshoot trajectories

1. Slow tipping elements (GIS, WAIS): Tipping risks independent of overshoot peak

2. Fast tipping elements (AMOC, Amazon rainforest): Tipping risks increase with overshoot peak
Safe overshoots (safe climate landing zones)

**High climate risk zone: tipping risk > 33%**

1. Convergence temp.: Smaller today’s levels of global warming: \(<1.2\,^\circ\text{C}\) of global warming
2. Peak temperatures: Smaller \(3.0\,^\circ\text{C}\) of global warming
3. Convergence times: Shorter than 300 years (depends on peak temperature)

**Key result:**
Safe climate landing zones don’t exist between the guardrails of \(T_{\text{Conv}} = 1.5–2.0\,^\circ\text{C}\).
Climate tipping risks under policy-relevant overshoot pathways

Overshoot pathways:
1. Based on PROVIDEv1.1 scenarios from IPCC AR6 scenarios. Emission pathways span a range of assumptions including:
   - Current policies (CurPol)
   - Current NDC-aligned pledges (ModAct)
   - Net-Zero-GHG emission (NZGHG)
   - Paris Agreement consistent (e.g. Neg)

2. Including climate system uncertainties
e.g. climate sensitivity, carbon-cycle feedbacks

In cooperation with
Climate tipping risks under policy-relevant overshoot pathways

Achieving net zero greenhouse gas emissions critical to limit climate tipping risks!
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Work in Progress
(Very) conceptual and coupled socio-climate model

\[
\frac{dx_i}{dt} = -x_i^3 + x_i + \frac{\sqrt{4/27}}{T_{\text{limit},i}} \cdot \Delta \text{GMT} + \frac{1}{10} \sum_{j \neq i}^N s_{ij} (x_j + 1) \frac{1}{\tau_i}
\]

Wunderling et al. (ESD, 2021)
The coupled socio-climate model summarized

Effectstakenintoaccount:
1. Political actions without taking into account tipping points: (Business-as-usual, Strong/Intermediate emission reduction)
2. Societal pressure $\vartheta$ to not cross tipping points
3. Science: Poor/effective cooperation due to scientific uncertainty in tipping points
Effective strategy to minimise tipping risks

Results:
1. Greenland & West Antarctica **save** AMOC & Amazon rainforest © Reason: different tipping time scales
2. Caring about not crossing any tipping point **is better** than caring about fastest tipping elements
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Thank you!

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RECEIPT/CASCADES conference
17.10.2023
Back-Up
Construction of temperature overshoot profiles

Overshoot temperature profile
rate of global warming in the recent past
final convergence temperature
current global warming
determination of peak temperature and convergence time

\[ \Delta \text{GMT}(t) = T_0 + \gamma t - \left[ 1 - e^{-(\mu_0 + \mu_1 t)} \right] \cdot \gamma t - (T_{\text{conv}} - T_0). \]
Climate tipping risks under policy-relevant overshoot

Möller/Högner, Schleussner, Rockström, ..., Wunderling (in review)
Avoiding tipping risks effectively

1. Strong political actions: Business-as-usual $\rightarrow$ Strong emission reduction
2. High societal pressure due to climate tipping elements: $\vartheta = 0 \rightarrow \vartheta = 24$
3. High scientific efforts to minimize tipping point uncertainties: Poor $\rightarrow$ Effective cooperation

Tipping risks can be limited when politics, society, and science work hand in hand.
Feedback from the socio-political acceptability

1. Available knowledge $\gamma$ about crossing tipping points

\[
\gamma = \frac{GMT}{GMT_{crit, closest}}
\]

2. Societal pressure $\vartheta$ about crossing tipping points:
   - Free parameter with the possibility of no pressure ($\vartheta = 0$) to high pressure values ($\vartheta = 24$)

3. Effort $\varepsilon$ due to uncertainty: Poor/Effective cooperation

![Diagram showing the relationship between carbon balance, socio-political acceptance, and clean energy investments and production.](image-url)
Effect taken into account

1. **Political actions** without taking into account tipping points: (Business-as-usual, Strong/Intermediate emission reduction)
2. **Societal pressure** to not cross tipping points
3. **Science:** Poor/effective cooperation due to scientific uncertainty in tipping points
Exemplary timelines of the four interacting tipping elements
Time to reach safe temperatures

It is not enough to stop emissions at 1.5 or 2.0°C above pre-industrial and then keep temperatures constant!

Armstrong McKay, et al. (2022, Science)
Tipping risks dependent on the peak temperature and the time to reach net zero emissions
The small role of interactions between the tipping elements (reason: interactions need time)
Reason for societal pressure – lowest $T_{\text{crit}}$ (separated)

Critical temperatures

- $T_{\text{limit, GIS}}$: $0.8 - 3.0 \, [^\circ C]$  
  McKay et al. (2022)

- $T_{\text{limit, WAIS}}$: $1.0 - 3.0 \, [^\circ C]$  
  McKay et al. (2022)

- $T_{\text{limit, AMOC}}$: $1.4 - 8.0 \, [^\circ C]$  
  McKay et al. (2022)

- $T_{\text{limit, AMAZ}}$: $2.0 - 6.0 \, [^\circ C]$  
  McKay et al. (2022)
Reason for societal pressure – fastest TE (separated)

<table>
<thead>
<tr>
<th>Tipping times</th>
<th>Tipping with the lowest threshold</th>
<th>McKay et al. (2022)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{GIS}$</td>
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Idea for future research

**Emergent constraints**
- $x$: Observable
- $y$: Description of the Earth system under global warming
- Functional dependence of $x$ on $y$
  $$y = f(x) + \epsilon$$

**Emergent constraints in social or socio-climate (socio-ecological) systems?**

But how to do measurements:
- surveys?
- online data?
- your ideas ...
Further examples for emergent constraints

(g) ECS versus Variability (CMIP5)

(h) TCR versus Trend (CMIP6)

Williamson et al. (Rev. Mod. Phys., 2021)