Cascading climate tipping events and can society prevent them?

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

2. Can society prevent climate tipping?

RECEIPT/CASCADES conference
17.10.2023

Nico Wunderling
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Earth Resilience in the Anthropocene

Potsdam Institute for Climate Impact Research
Stockholm Resilience Centre
Sustainability Science for Biosphere Stewardship
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PRINCETON UNIVERSITY

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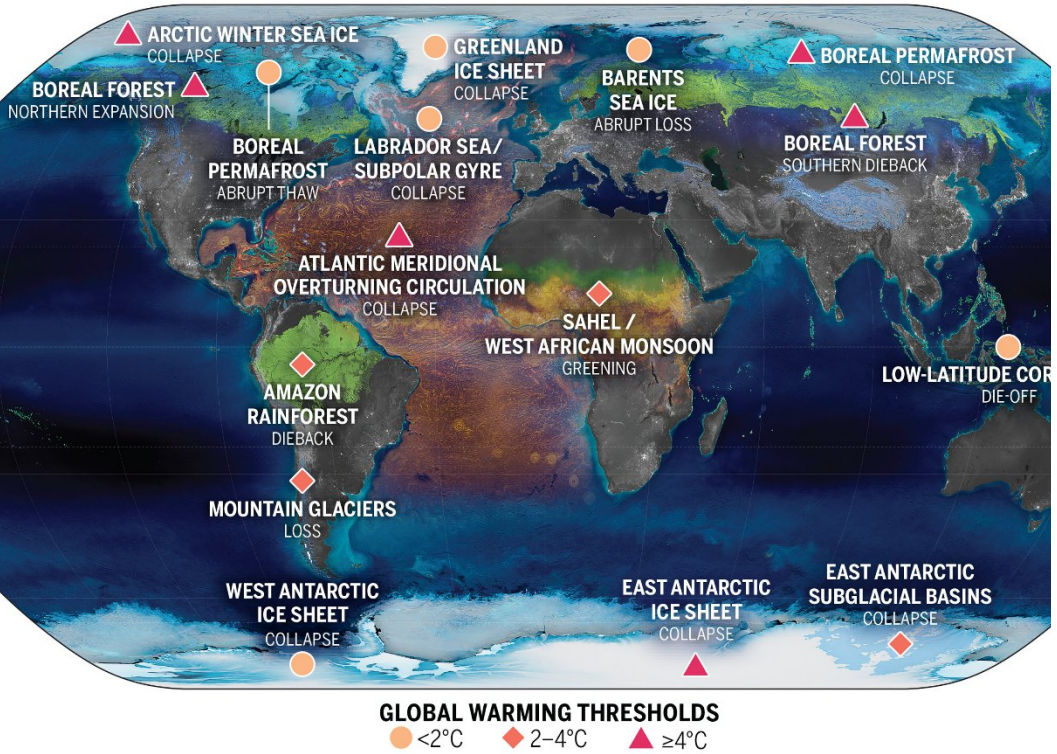
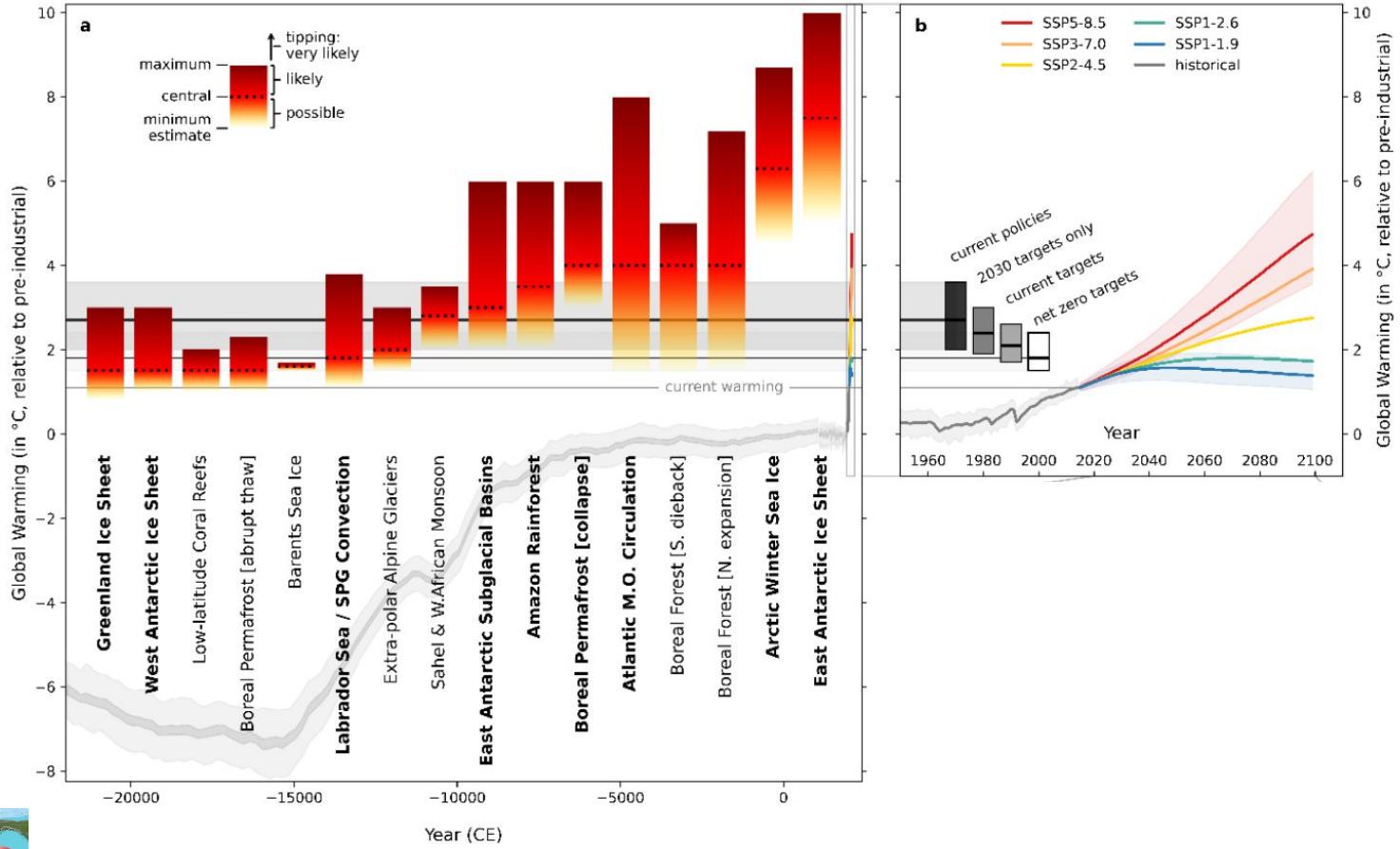
‘Earth’s critical organs’: Climate tipping elements



Armstrong McKay, et al. (2022, Science)



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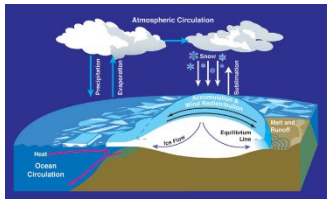
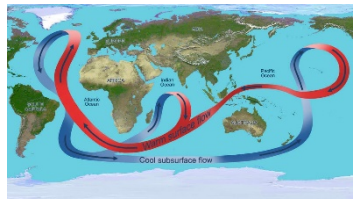
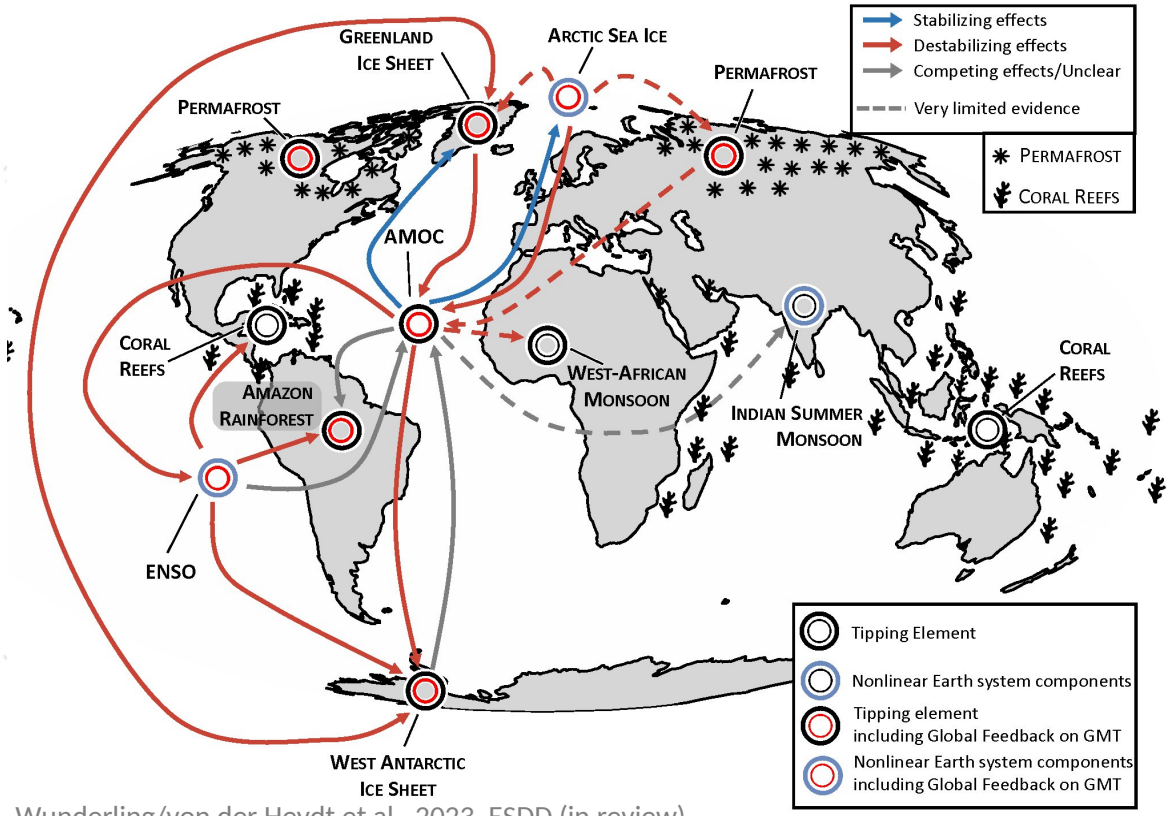
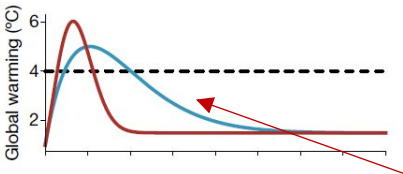




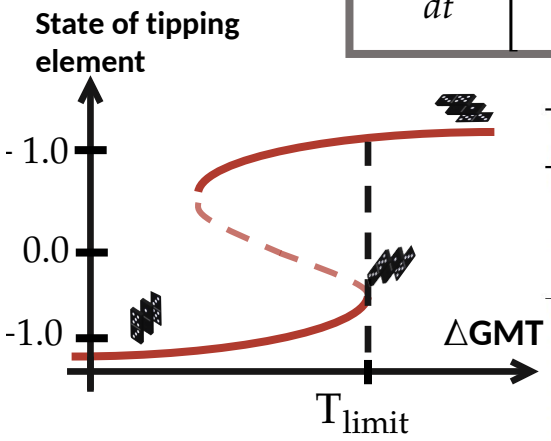
Interacting climate tipping elements



Wunderling/von der Heydt et al., 2023, ESDD (in review)



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

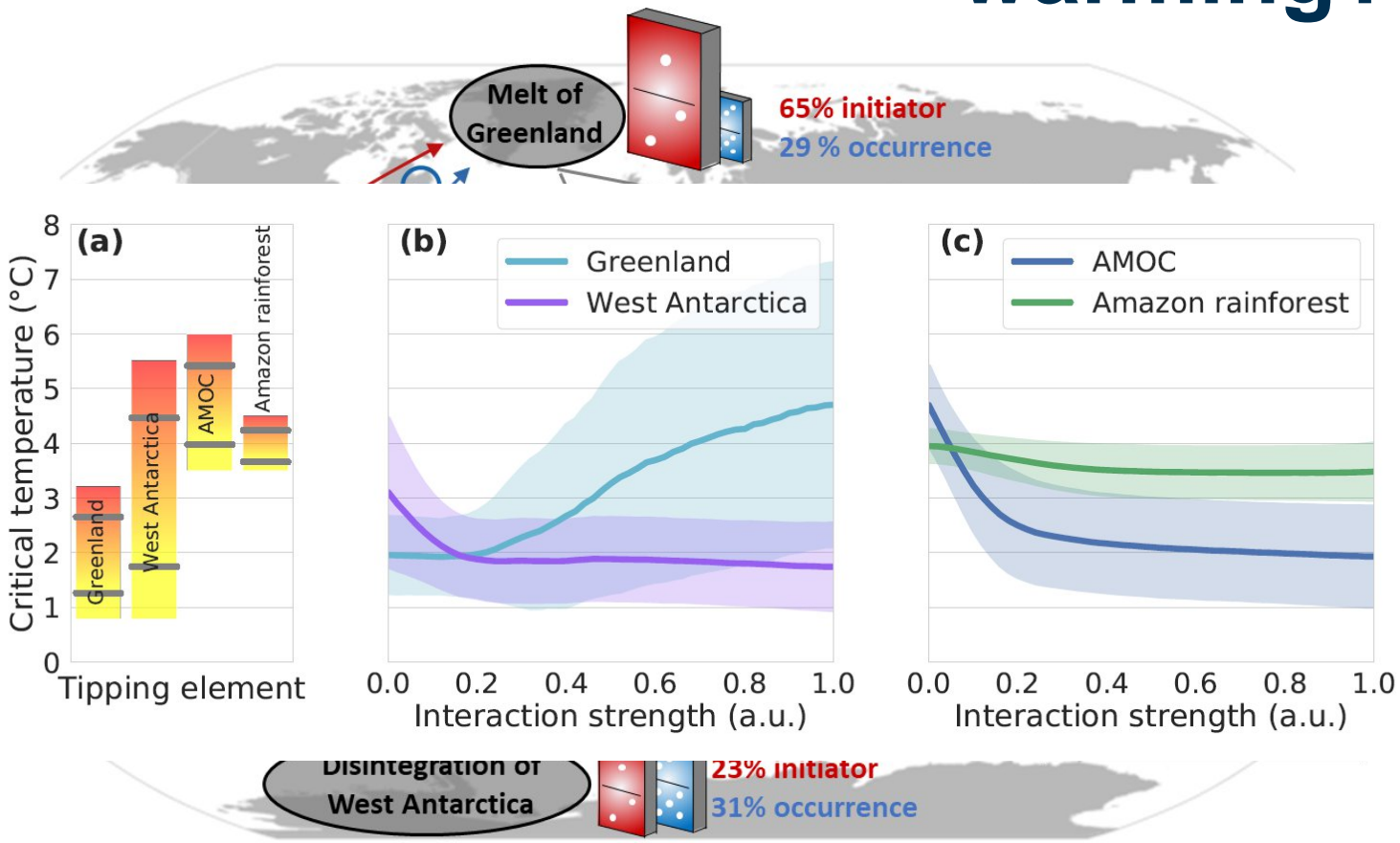


Uncertain parameter	Value	Literature reference
Critical temperatures		
$T_{\text{limit, GIS}}$	0.8 – 3.0 [°C]	McKay et al.(2022)[1]
$T_{\text{limit, WAIS}}$	1.0 – 3.0 [°C]	McKay et al.(2022)[1]
$T_{\text{limit, AMOC}}$	1.4 – 8.0 [°C]	McKay et al.(2022)[1]
$T_{\text{limit, AMAZ}}$	2.0 – 6.0 [°C]	McKay et al.(2022)[1]
Interaction strengths		
$s_{\text{GIS}\to\text{AMOC}}$	1 – 10 (pos.)	Wunderling et al.(2021)[2]
$s_{\text{AMOC}\to\text{GIS}}$	1 – 10 (neg.)	Wunderling et al.(2021)[2]
$s_{\text{GIS}\to\text{WAIS}}$	1 – 10 (pos.)	Wunderling et al.(2021)[2]
$s_{\text{AMOC}\to\text{AMAZ}}$	2 – 4 (unc.)	Wunderling et al.(2021)[2]
$s_{\text{WAIS}\to\text{AMOC}}$	1 – 3 (unc.)	Wunderling et al.(2021)[2]
$s_{\text{WAIS}\to\text{GIS}}$	1 – 2 (pos.)	Wunderling et al.(2021)[2]
$s_{\text{AMOC}\to\text{WAIS}}$	1 – 1.5 (pos.)	Wunderling et al.(2021)[2]
Tipping times		
τ_{GIS}	1,000 – 15,000 [yrs]	McKay et al.(2022)[1]
τ_{WAIS}	500 – 13,000 [yrs]	McKay et al.(2022)[1]
τ_{AMOC}	15 – 300 [yrs]	McKay et al.(2022)[1]
τ_{AMAZ}	50 – 200 [yrs]	McKay et al.(2022)[1]

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

P I K

Potential risk of climate domino effects under global warming?



Roles of tipping elements in Cascades in this model:

- Ice sheets: Initiators
- AMOC: Transmitter

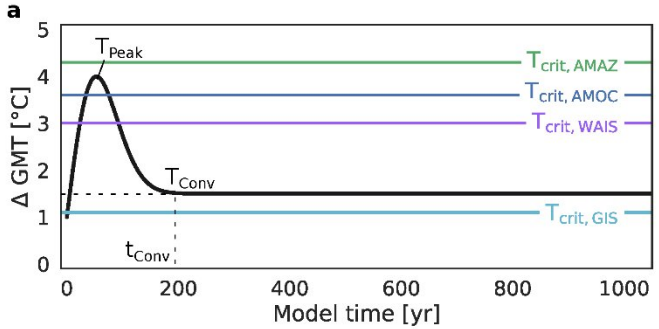
Critical temperature ranges:

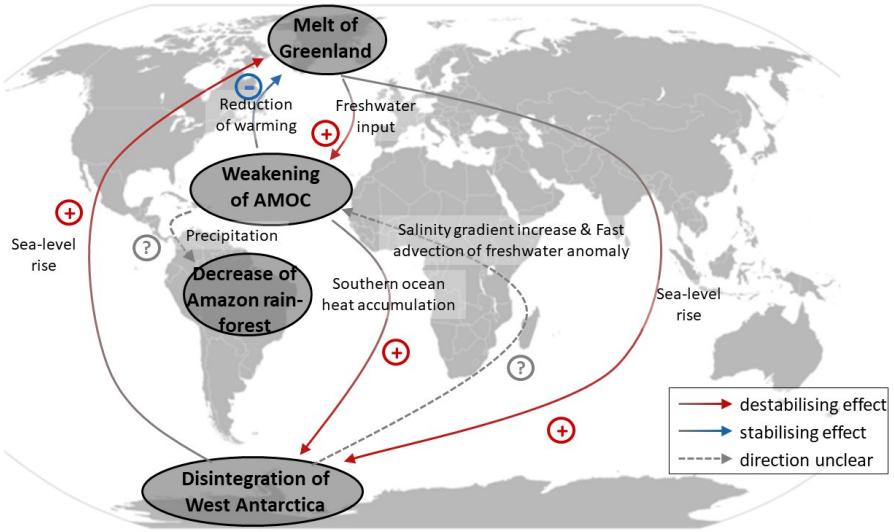
- Increase for Greenland
- Decrease for all other TEs

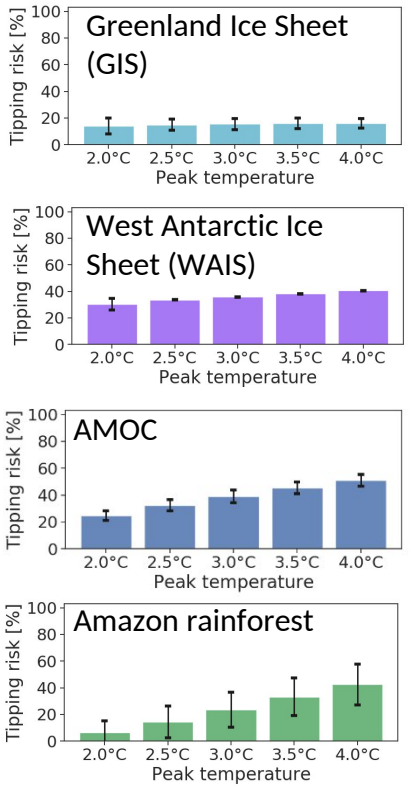
Wunderling, Donges, Kurths, Winkelmann, Earth System Dynamics (2021)
10 New Insights in Climate Science, 2021

Overall: Interactions destabilize the climate system

Characterising overshoot trajectories



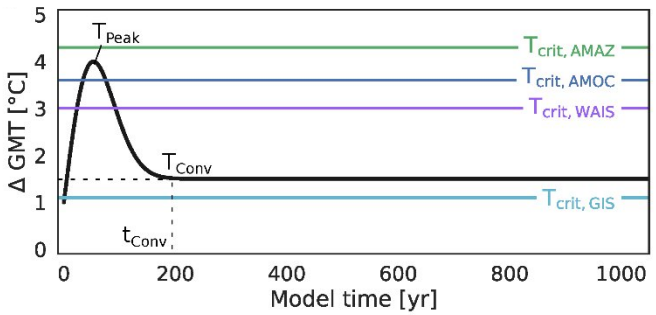


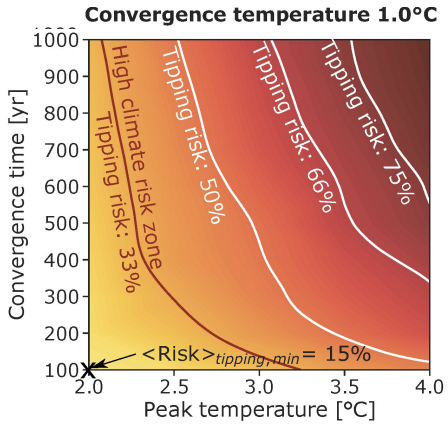


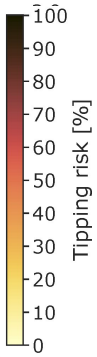
1. Slow tipping elements (GIS, WAIS):
   Tipping risks independent of overshoot peak

2. Fast tipping elements (AMOC, Amazon rainforest):
   Tipping risks increase with overshoot peak

Safe overshoots (*safe climate landing zones*)



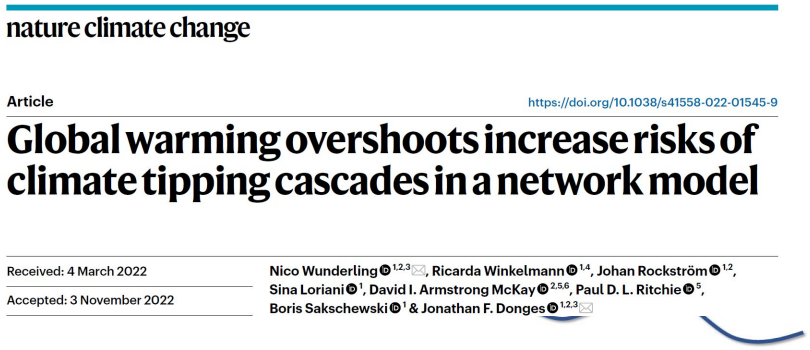




High climate risk zone: tipping risk > 33%

1. Convergence temp.: Smaller today's levels of global warming: **<1.2°C** of global warming
2. Peak temperatures: Smaller **3.0°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 $T_{Conv} = 1.5–2.0°C$.


nature climate change

Article https://doi.org/10.1038/s41558-022-01545-9

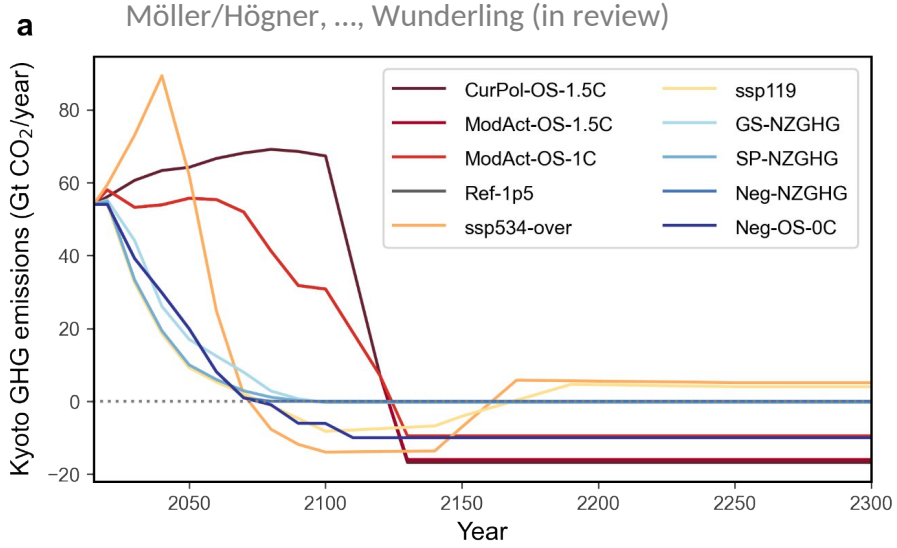
Global warming overshoots increase risks of climate tipping cascades in a network model

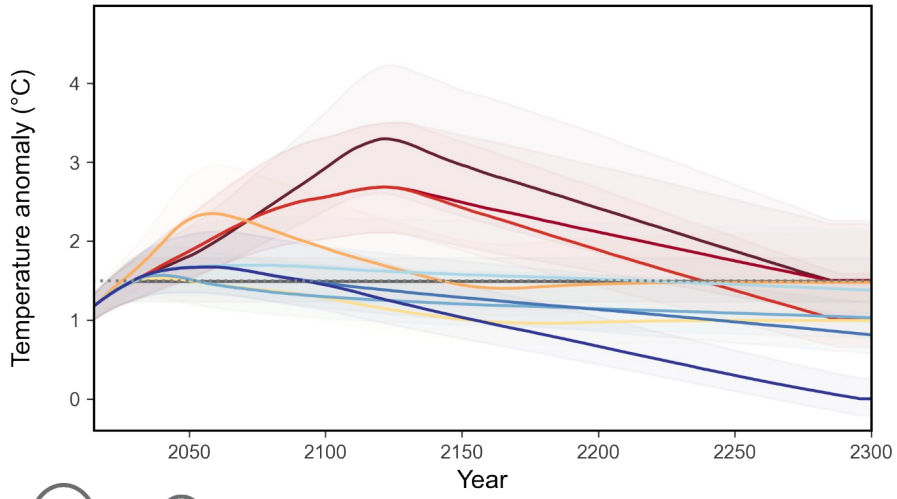
Received: 4 March 2022
Accepted: 3 November 2022

Nico Wunderling, Ricarda Winkelmann, Johan Rockström, Sina Loriani, David I. Armstrong McKay, Paul D. L. Ritchie, Boris Sakschewski & Jonathan F. Donges

Climate tipping risks under policy-relevant overshoot pathways

Möller/Högner, ..., Wunderling (in review)





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 ANALYTICS

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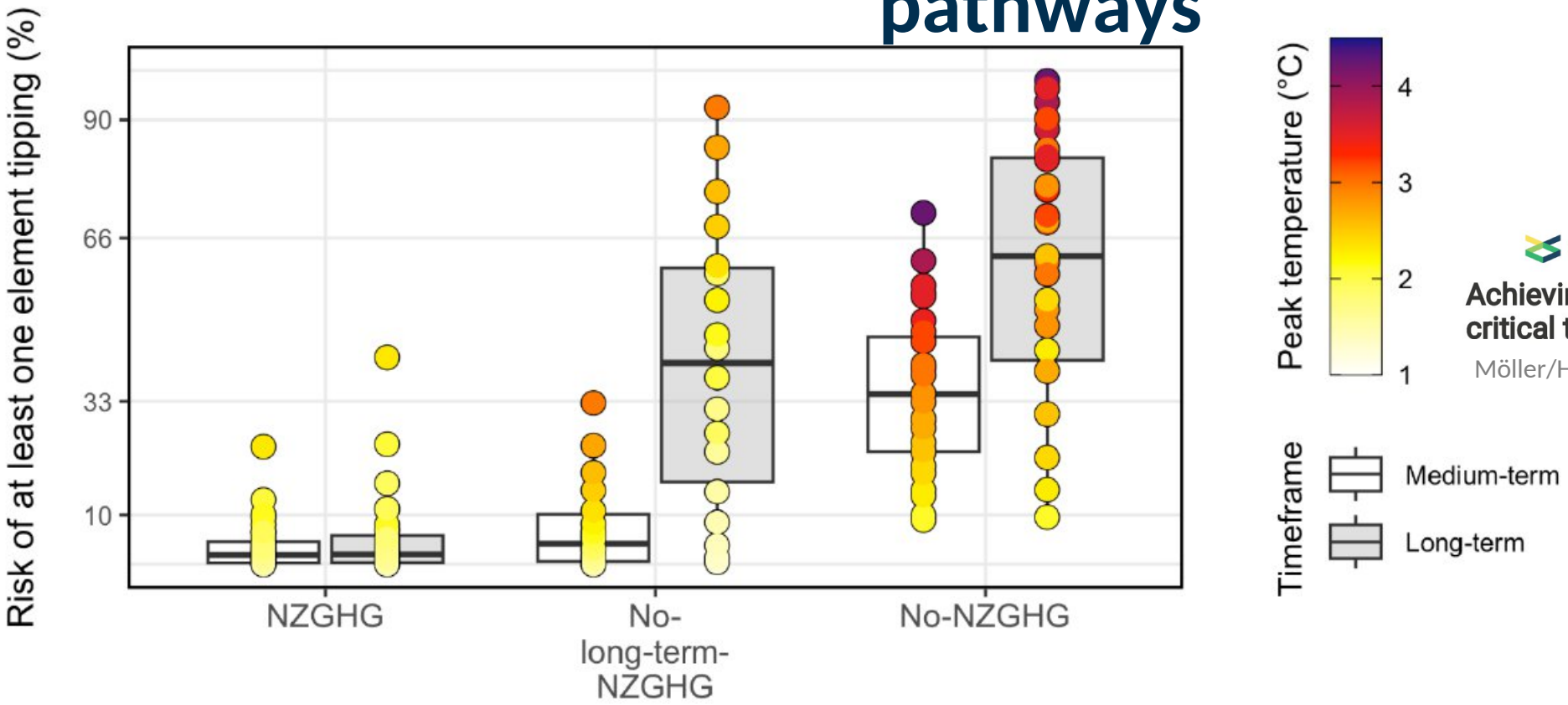
Climate tipping risks under policy-relevant overshoot pathways



Research Square

Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

Achieving net zero greenhouse gas emissions critical to limit climate tipping risks

Möller/Högner, ..., Wunderling (in review)

Achieving net zero greenhouse gas emissions critical to limit climate tipping risks!

In cooperation with

CLIMATE ANALYTICS

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Cascading climate tipping events and can society prevent them?

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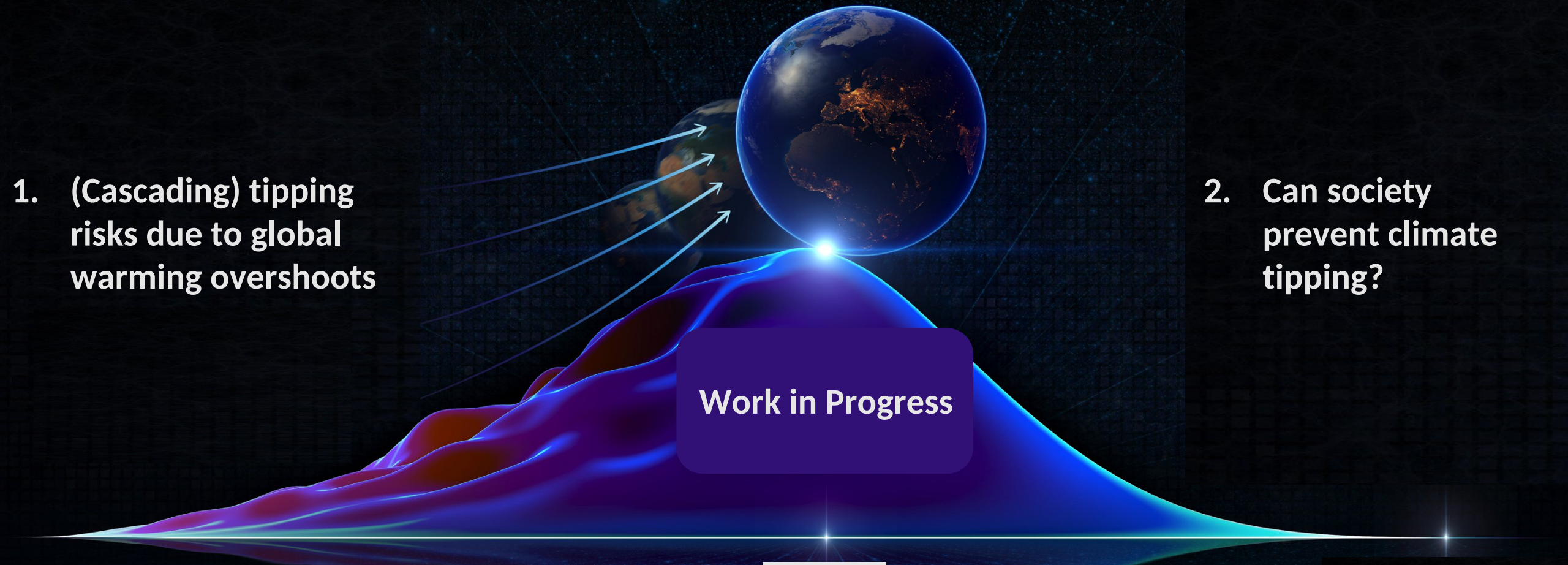
2. Can society prevent climate tipping?



Work in Progress

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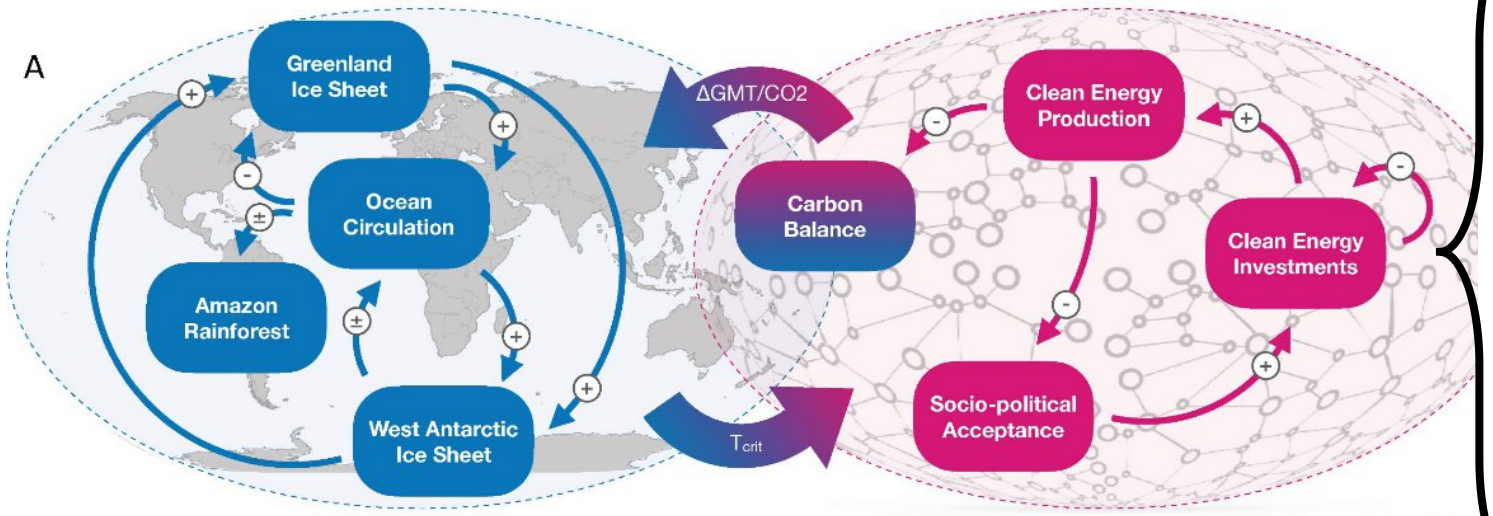
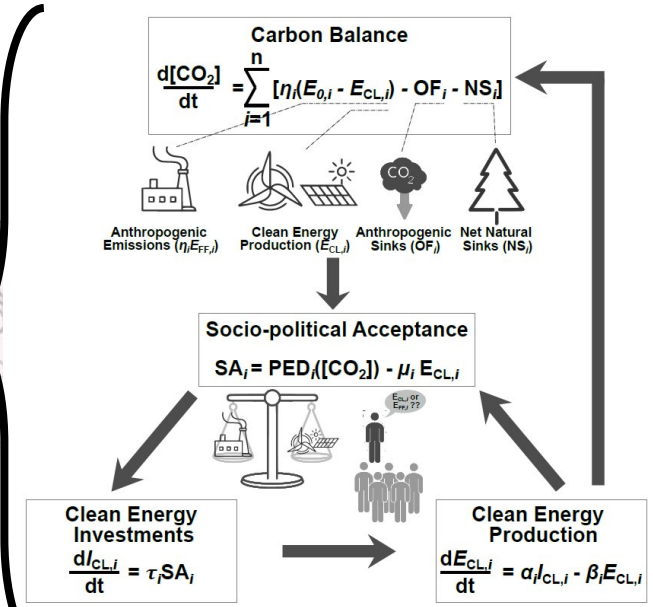
(Very) conceptual and coupled socio-climate model

Wunderling, Perri, Rockström, Levin, ..., Donges, Barfuss, 2023 (in progress)





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

Wunderling et al. (ESD, 2021)

One Earth

Article

Socio-political feedback on the path to net zero

Saverio Perri,[1,6,*] Simon Levin,[1,2] Lars O. Hedin,[1,2] Nico Wunderling,[3,4] and Amilcare Porporato[1,5]

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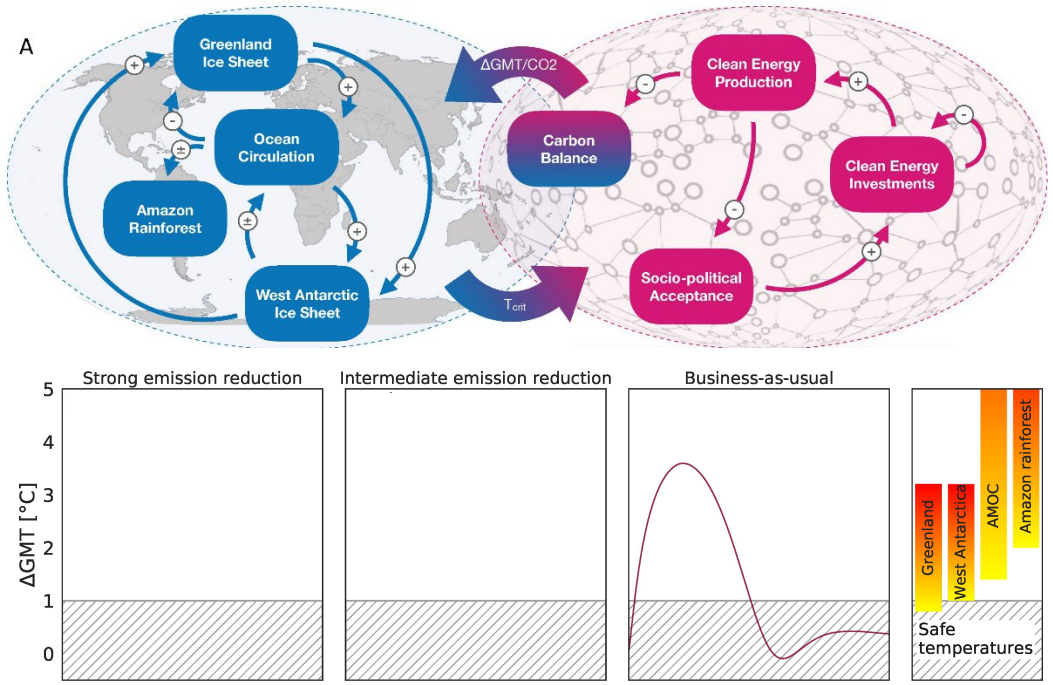
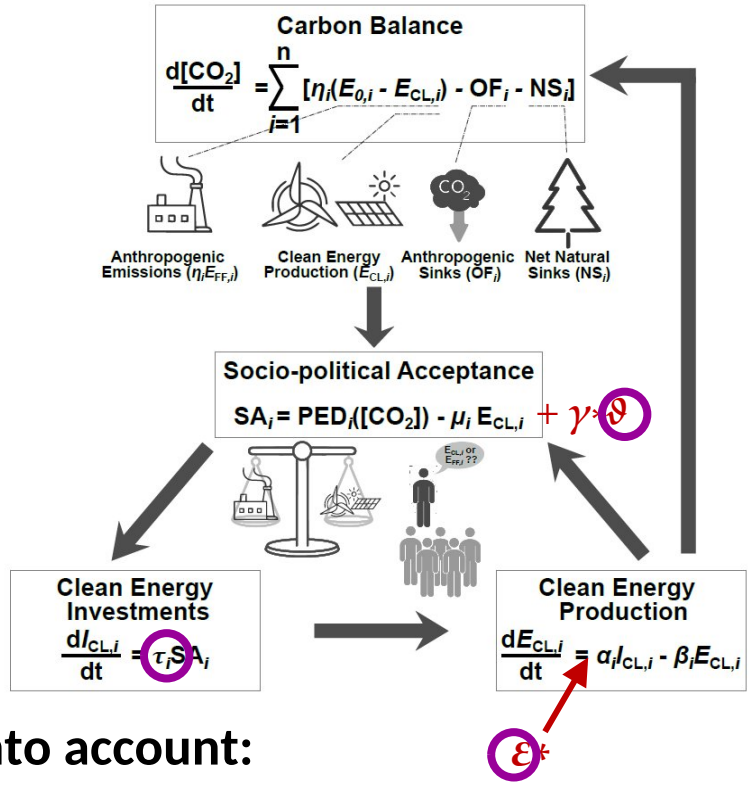
The coupled socio-climate model summarized

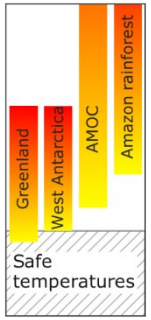




Effects taken into account:

1. **Political actions** without taking into account tipping points: (Business-as-usual, Strong/Intermediate emission reduction)
2. **Societal pressure ϑ** to not cross tipping points
3. **Science: Poor/effective cooperation** due to scientific uncertainty in tipping points

Effective strategy to minimise tipping risks



Tipping times	
τ_{GIS}	$1,000 - 15,000$ [yrs]
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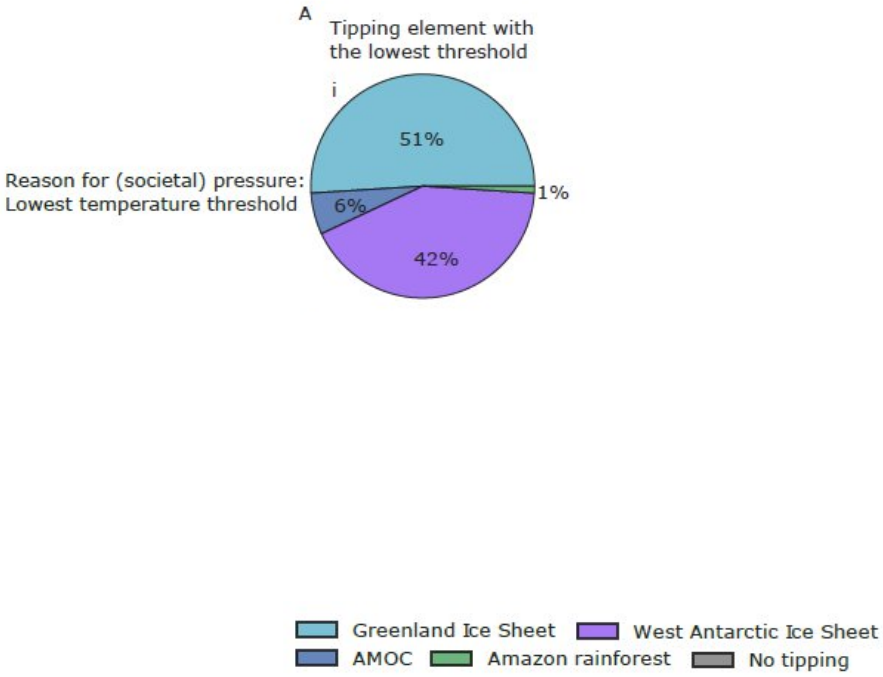
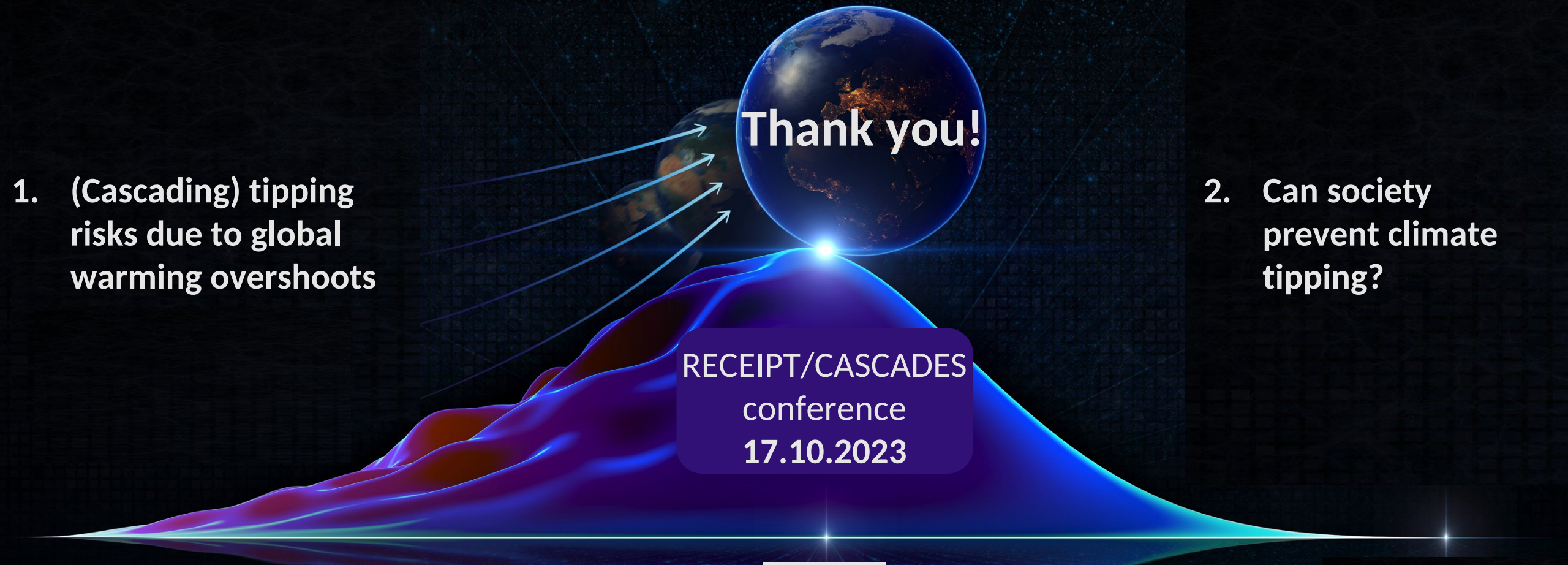


Wunderling, Perri, Rockström, Levin, ..., Donges, Barfuss, 2023 (in progress)

Results:

1. Greenland & West Antarctica **<u>save</u>** AMOC & Amazon rainforest Ⓟ Reason: different tipping time scales
2. Caring about not crossing any tipping point **<u>is better</u>** than caring about fastest tipping elements

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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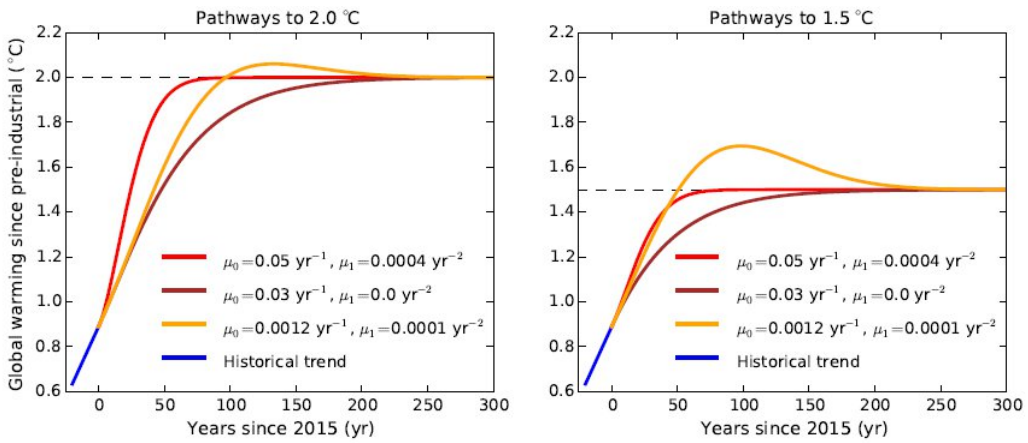
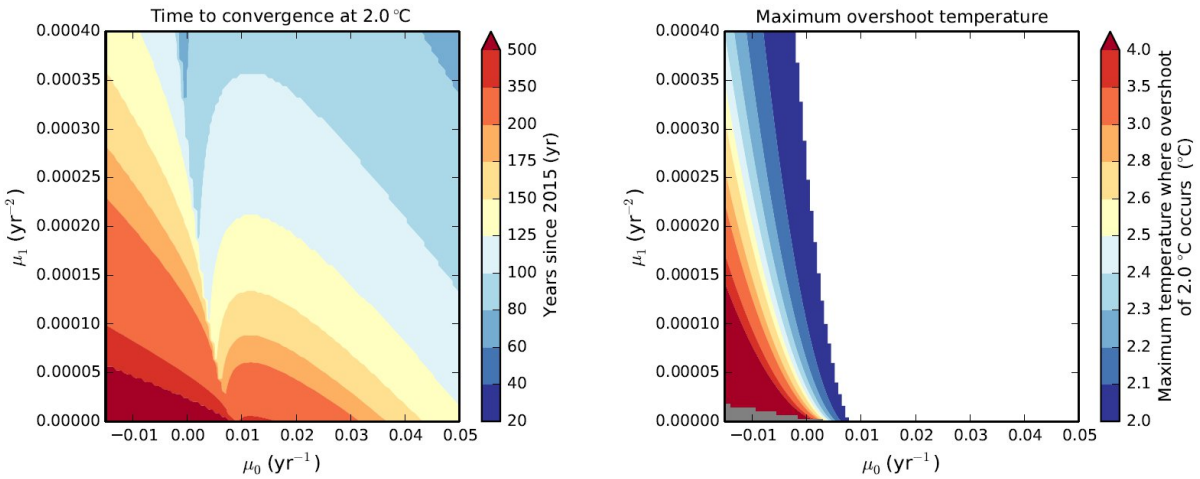
Princeton University

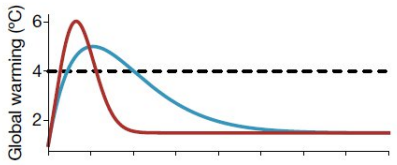
Back-Up

Construction of temperature overshoot profiles



Huntingford et al., 2017, ESD





Ritchie et al., 2021, Nature

Overshoot temperature profile

rate of global warming in the recent past

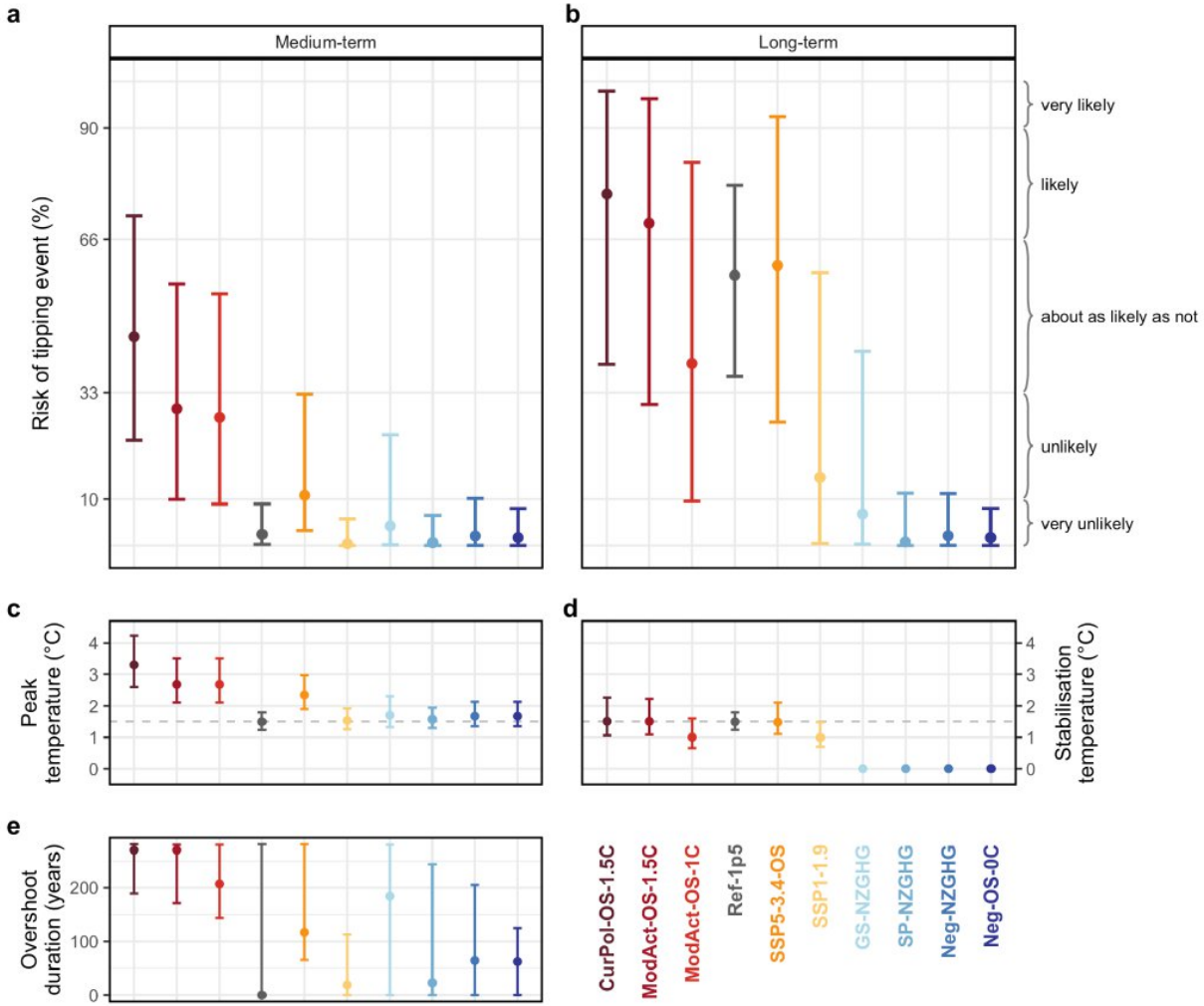
final convergence temperature

$$\Delta\mathrm{GMT}(t) = T_0 + \gamma t - \left[1 - \mathrm{e}^{-(\mu_0+\mu_1 t)t}\right]\left[\gamma t - (T_{\mathrm{Conv}} - T_0)\right].$$

current global warming

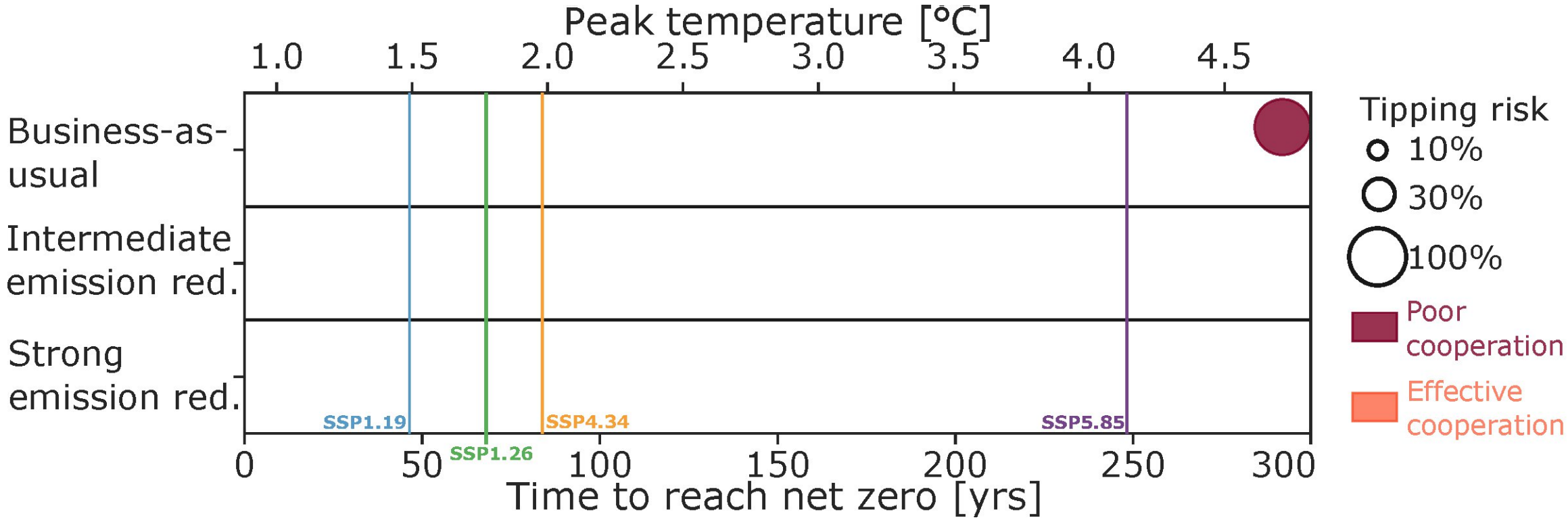
determination of peak temperature and convergence time

Climate tipping risks under policy-relevant overshoot



Möller/Högner, Schleussner, Rockström, …, Wunderling (in review)

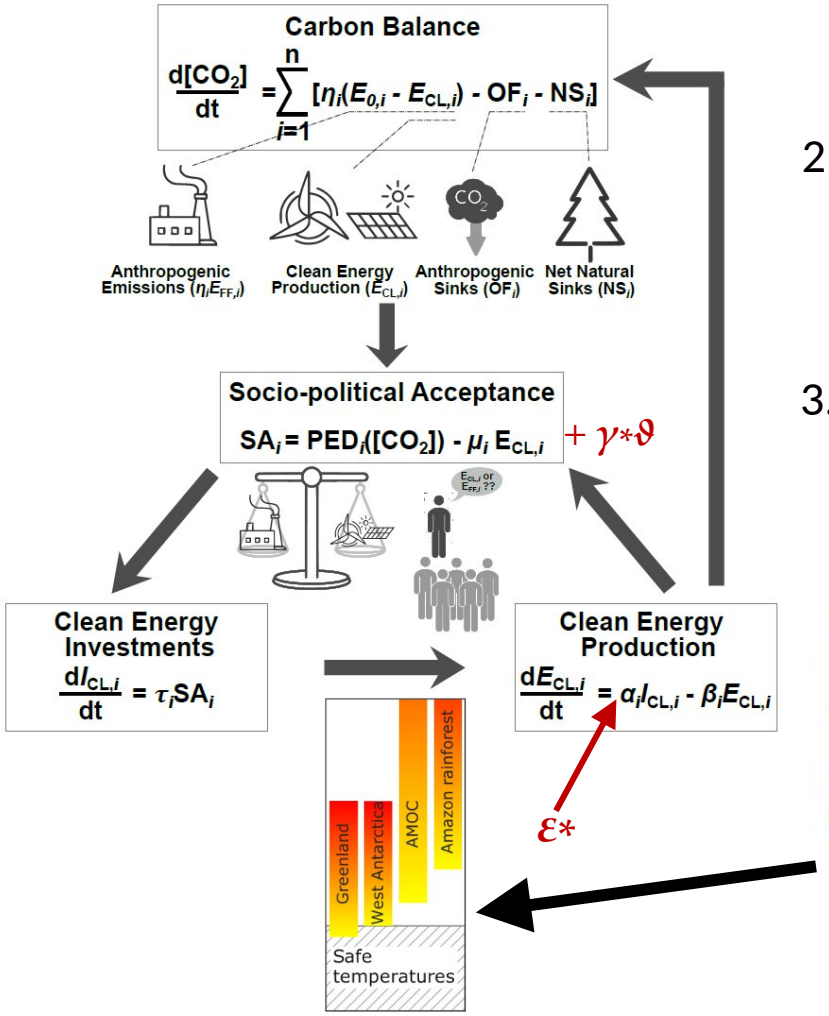
Avoiding tipping risks effectively



Tipping risks can be limited when
politics, society, and science work hand in hand

cooperation

Feedback from the socio-political acceptability

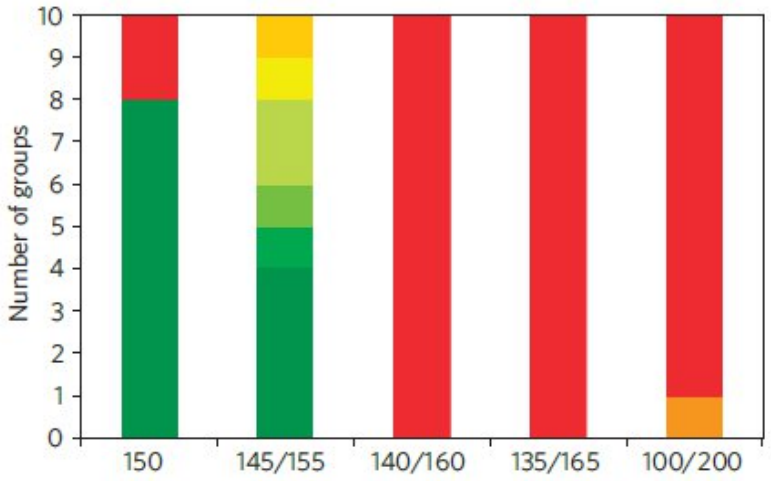


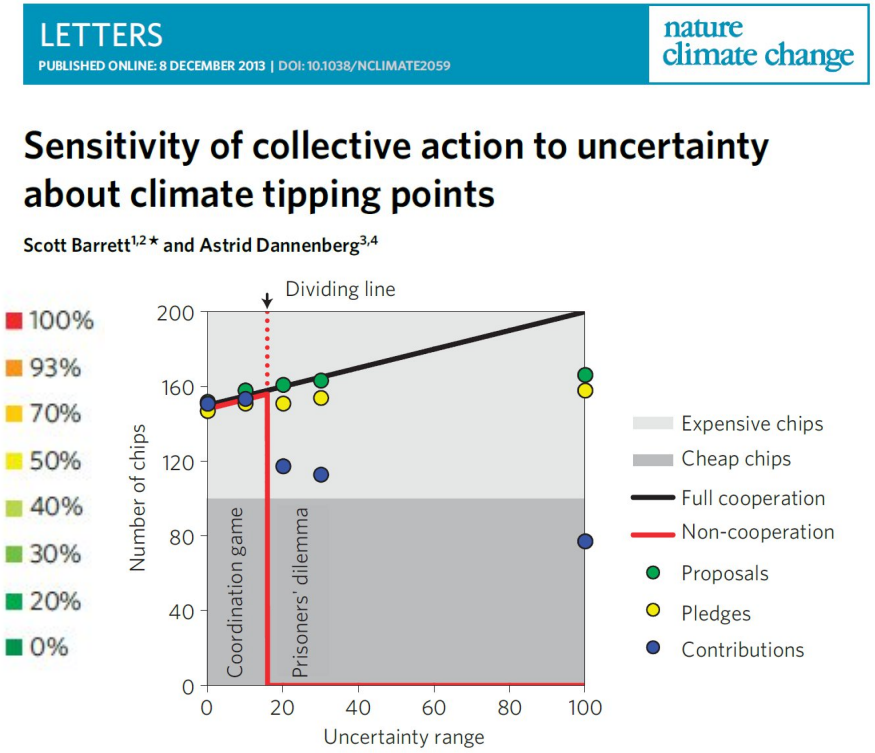
1. Available knowledge γ about crossing tipping points

$$\gamma = \frac{GMT}{GMT_{crit,\ closest}}$$

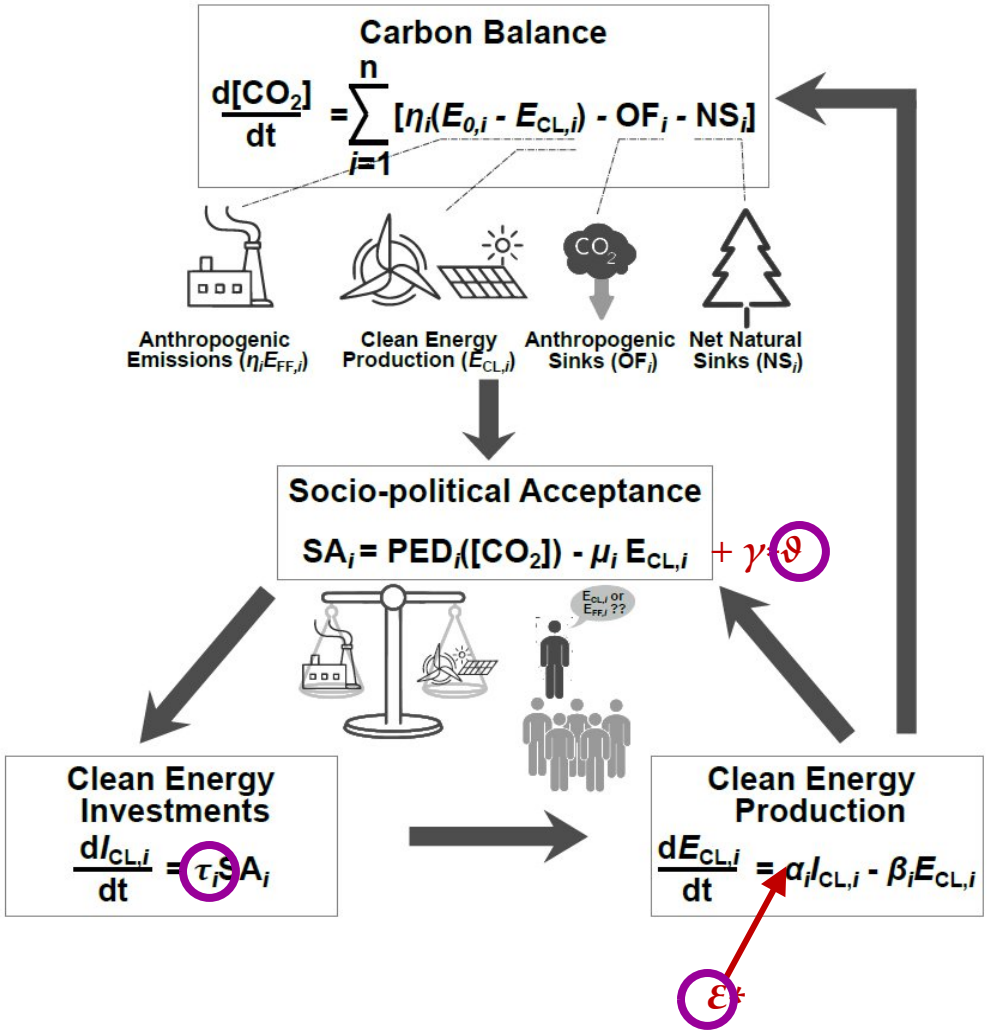
2. Societal pressure ϑ about crossing tipping points:
   - Free parameter with the possibility of no pressure ($\vartheta = 0$) to high pressure values ($\vartheta = 24$)

3. Effort ε due to uncertainty:
   Poor/Effective cooperation



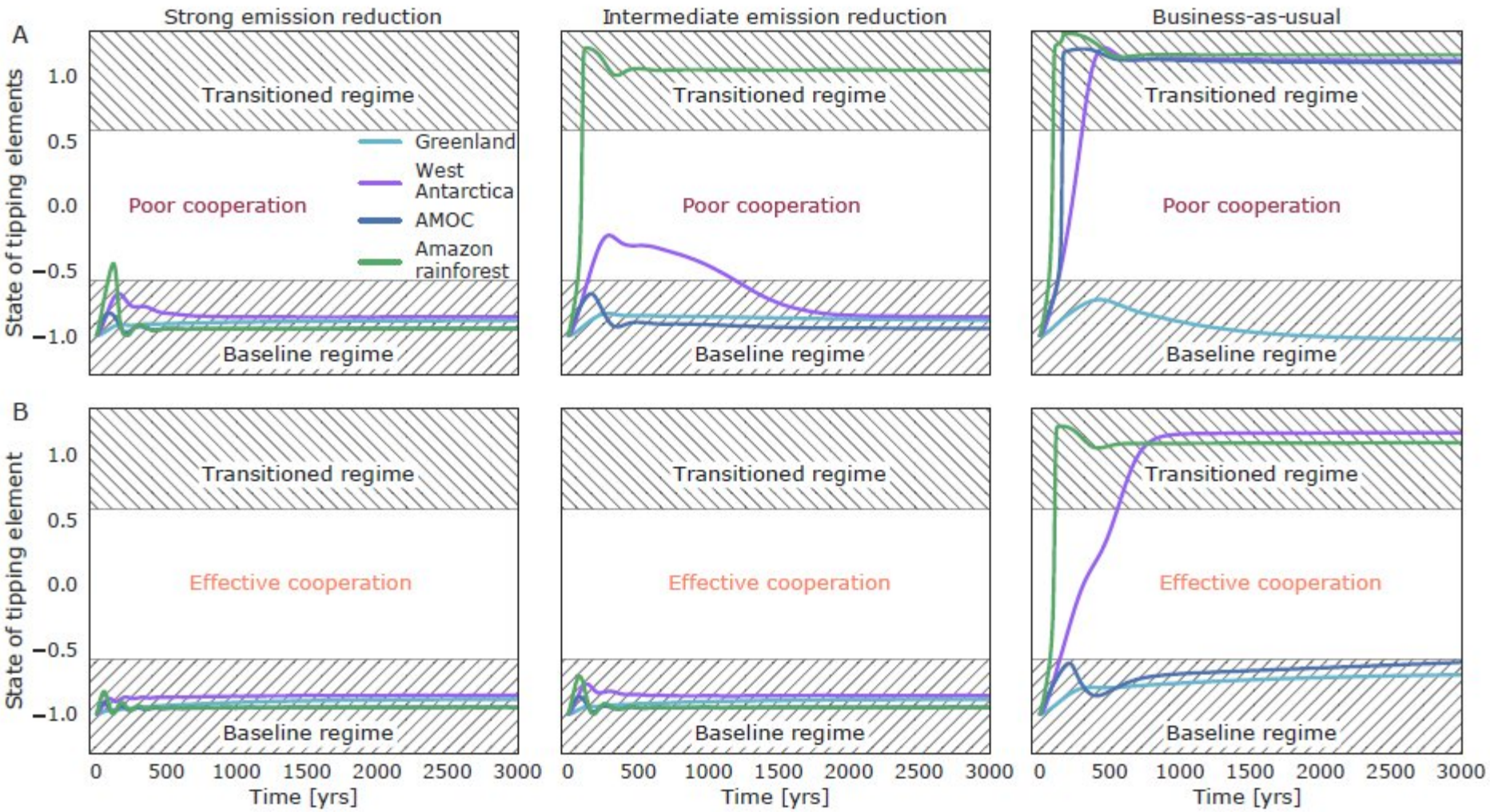


Effects taken into account

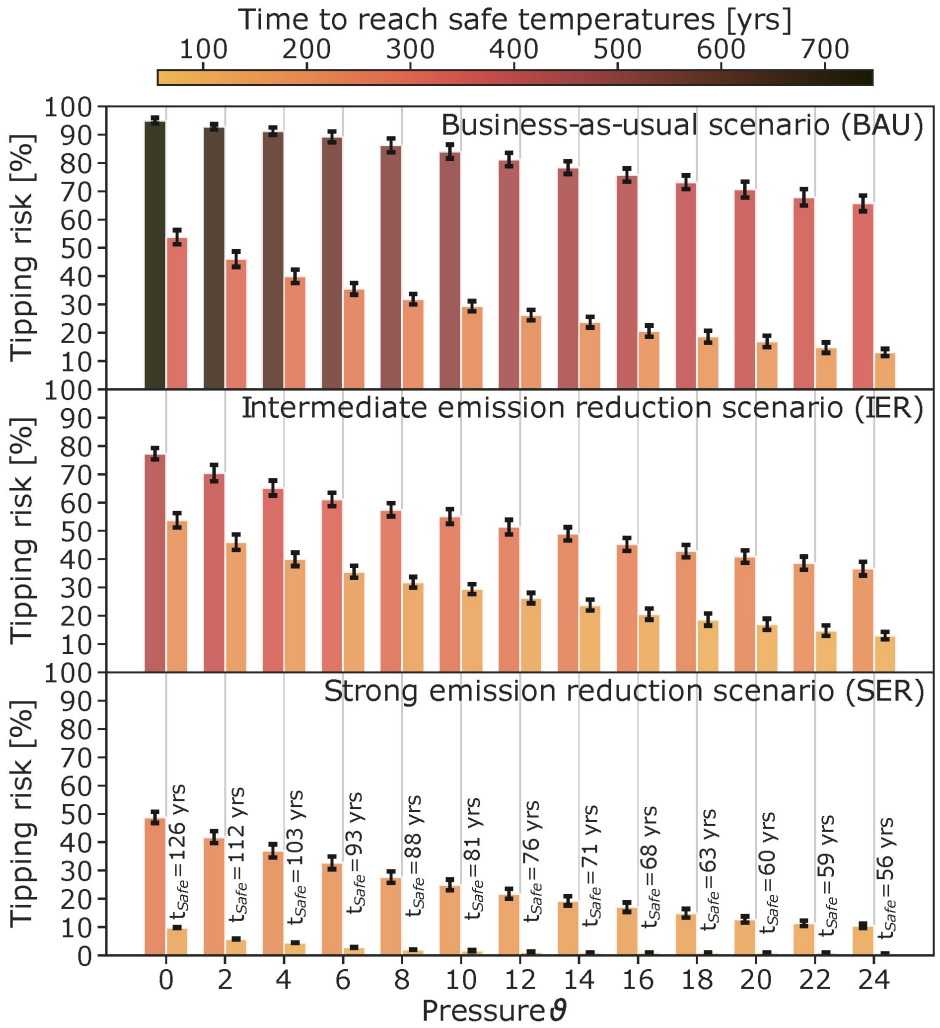


1. **Political actions** without taking into account tipping points: (Business-as-usual, Strong/Intermediate emission reduction)
2. **Societal pressure ϑ** to not cross tipping points
3. **Science: Poor/effective cooperation** due to scientific uncertainty in tipping points

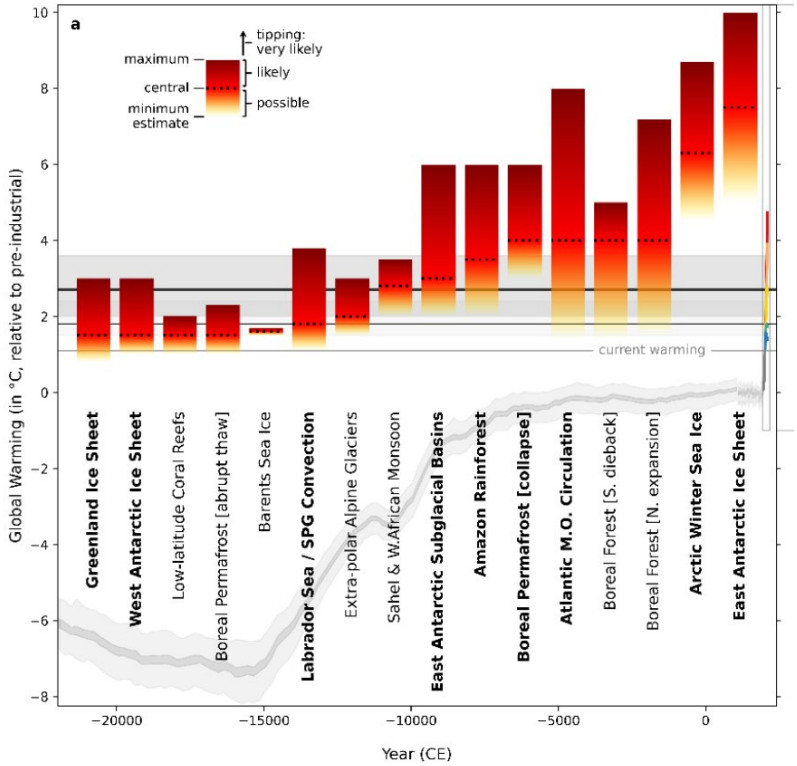
Exemplary timelines of the four interacting tipping elements



Time to reach safe temperatures

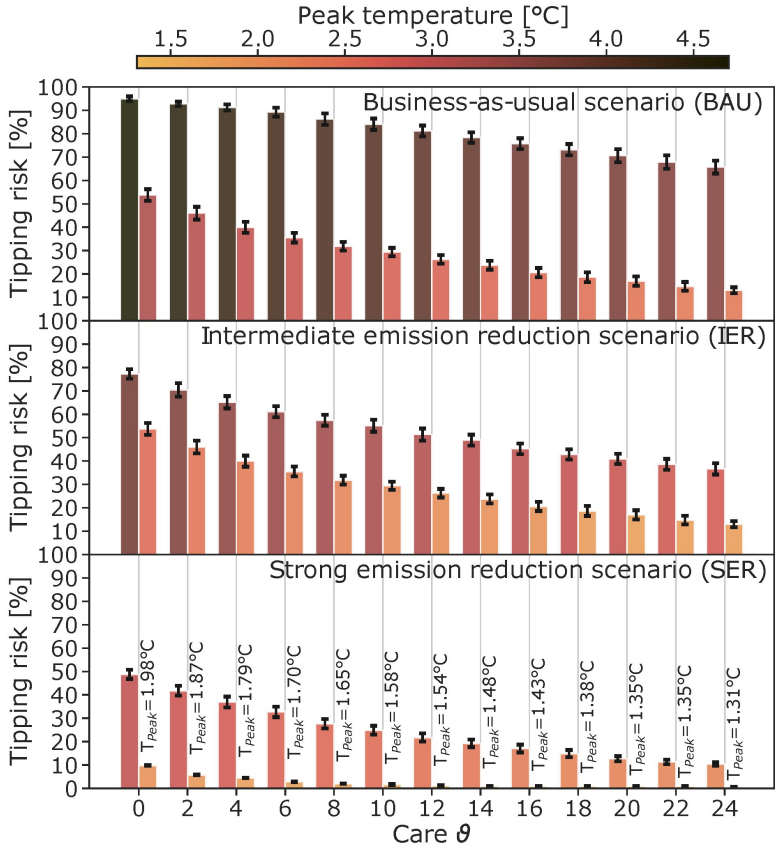


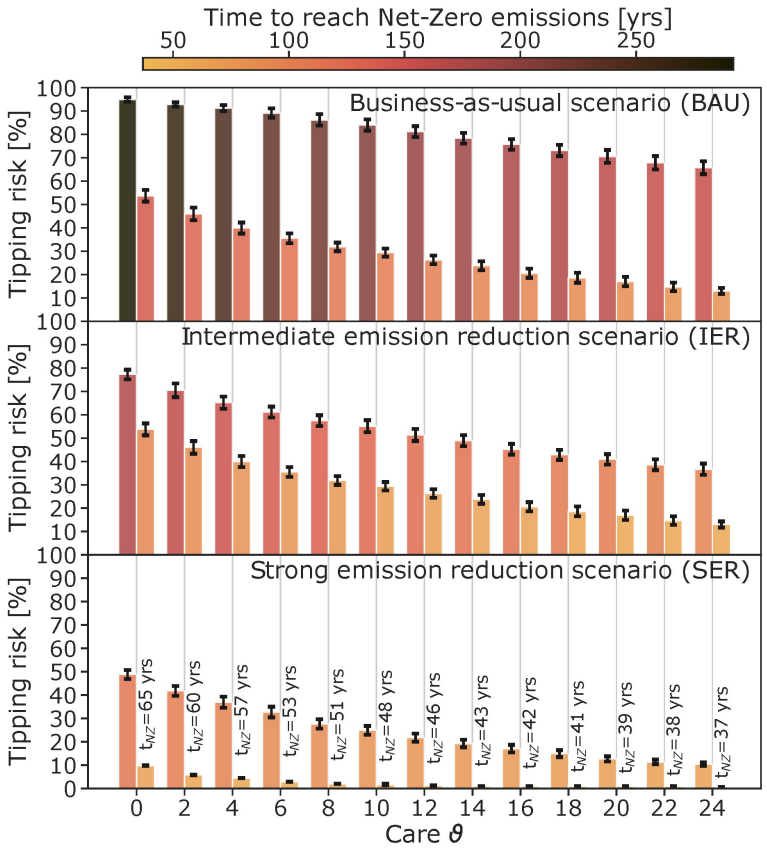
It is not enough to stop emissions at 1.5 or 2.0°C above pre-industrial and then keep temperatures constant!



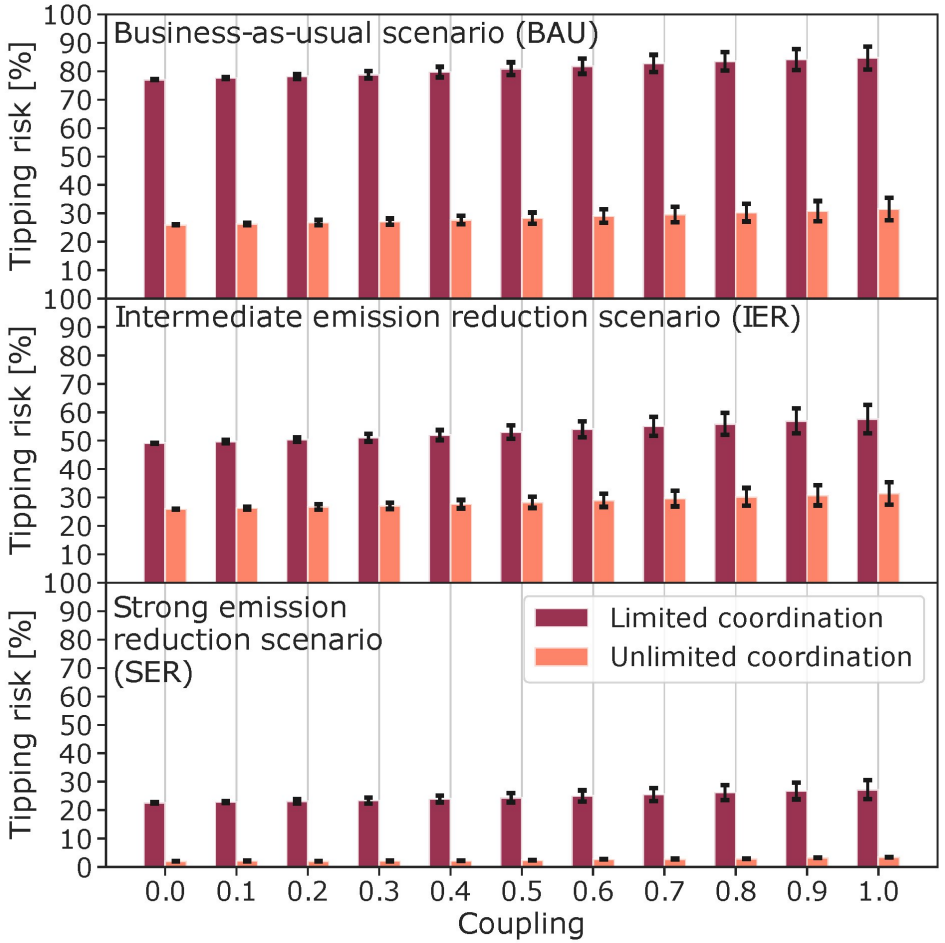
Armstrong McKay, et al. (2022, Science)

Tipping risks dependent on the peak temperature and the time to reach net zero emissions



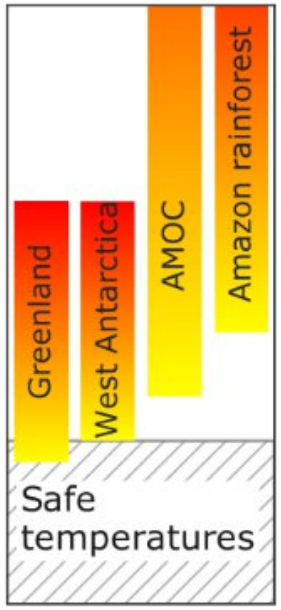


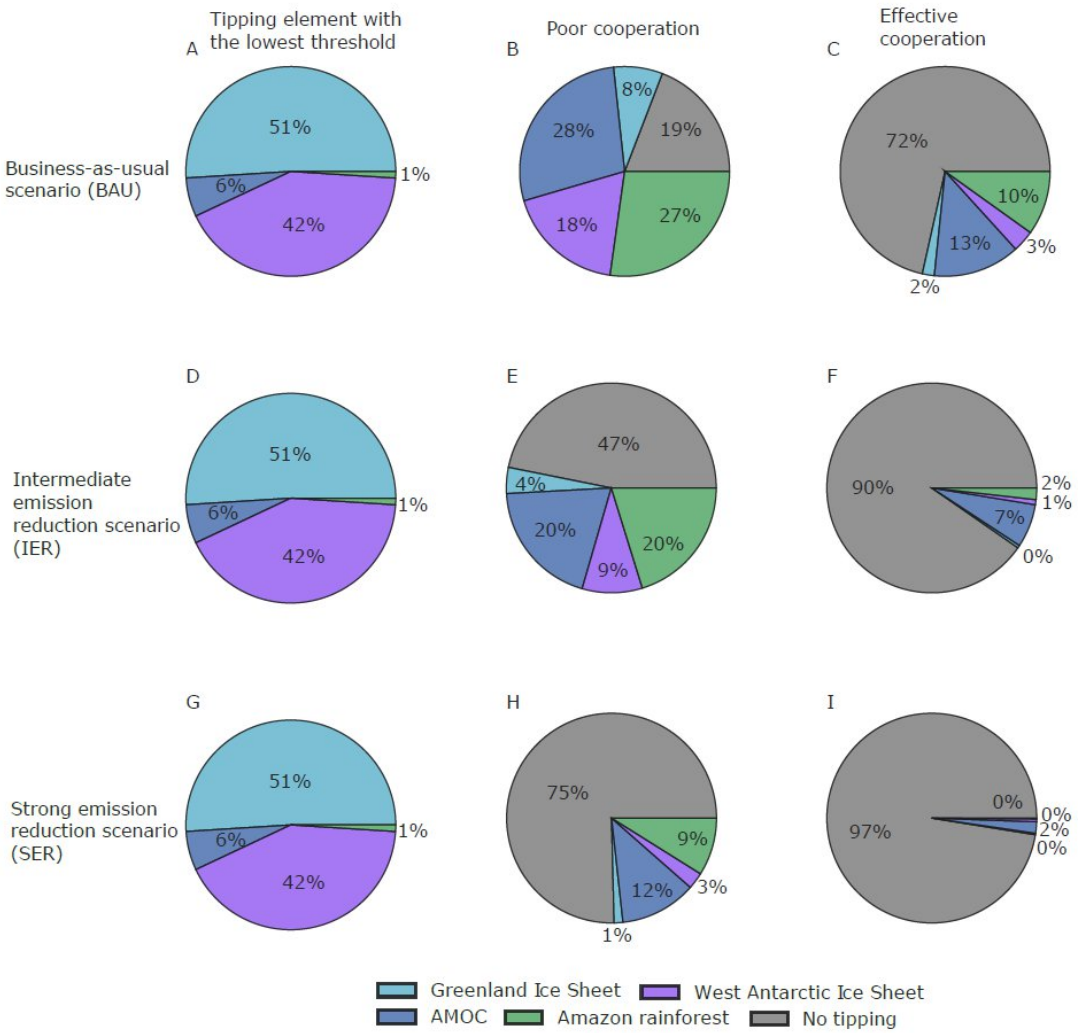
The small role of interactions between the tipping elements (reason: interactions need time)



Reason for societal pressure – lowest T_{crit} (separated)

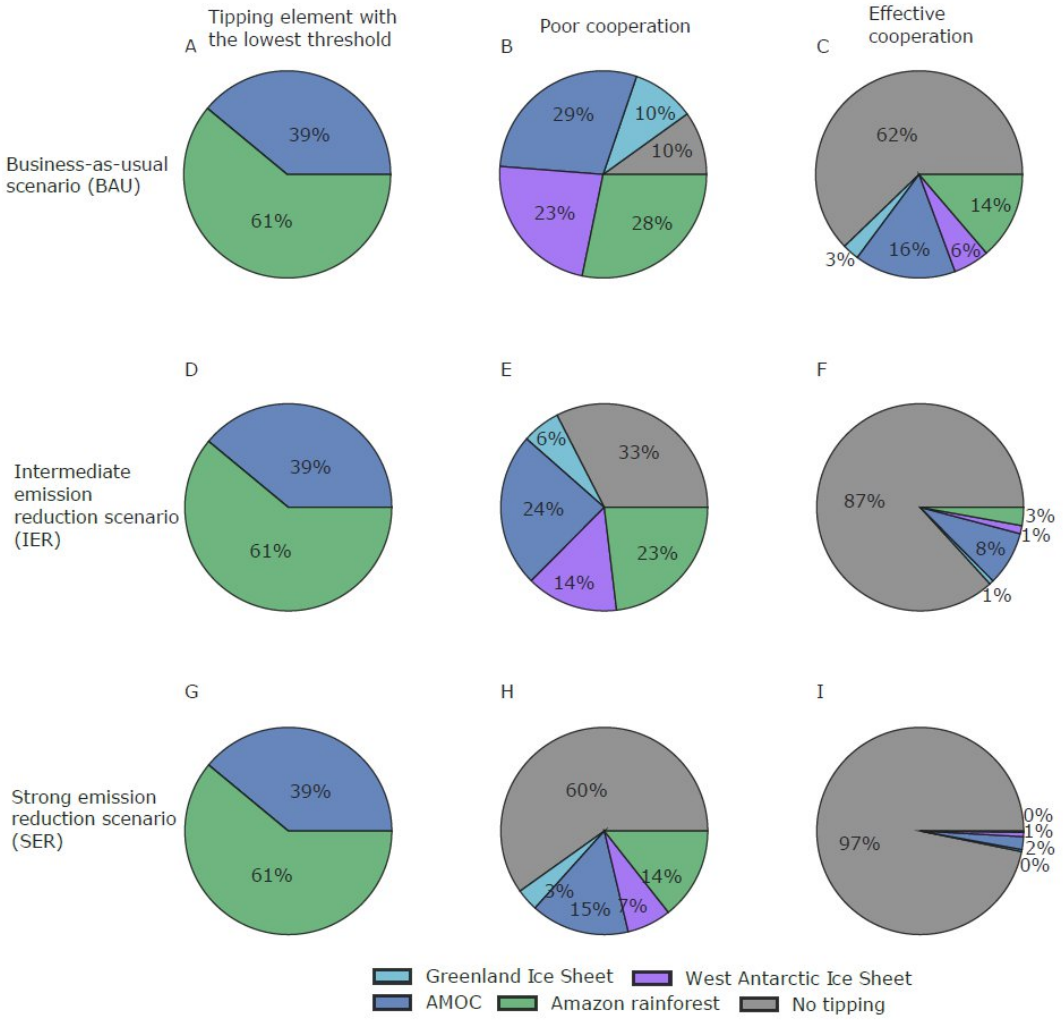
Critical temperatures		
$T_{\text{limit, GIS}}$	$0.8 - 3.0$ [°C]	McKay et al.(2022)[1]
$T_{\text{limit, WAIS}}$	$1.0 - 3.0$ [°C]	McKay et al.(2022)[1]
$T_{\text{limit, AMOC}}$	$1.4 - 8.0$ [°C]	McKay et al.(2022)[1]
$T_{\text{limit, AMAZ}}$	$2.0 - 6.0$ [°C]	McKay et al.(2022)[1]





Reason for societal pressure – fastest TE (separated)

Tipping times		
τ_{GIS}	$1,000 - 15,000$ [yrs]	McKay et al.(2022)[1]
τ_{WAIS}	$500 - 13,000$ [yrs]	McKay et al.(2022)[1]
τ_{AMOC}	$15 - 300$ [yrs]	McKay et al.(2022)[1]
τ_{AMAZ}	$50 - 200$ [yrs]	McKay et al.(2022)[1]

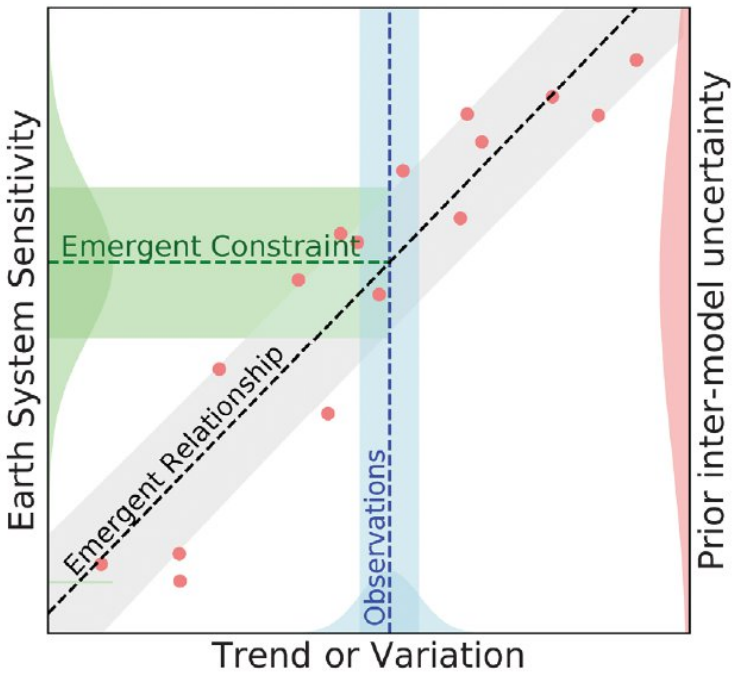


Idea for future research

Emergent constraints

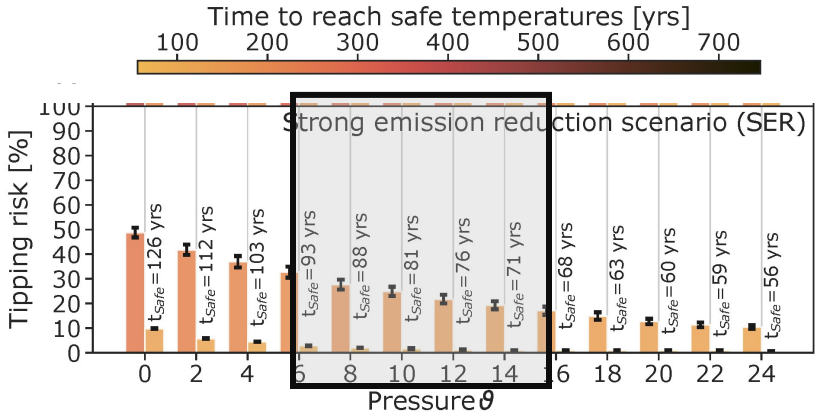
- x: Observable
- y: Description of the Earth system under global warming
- Functional dependence of x on y

$$y = f(x) + \varepsilon$$



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

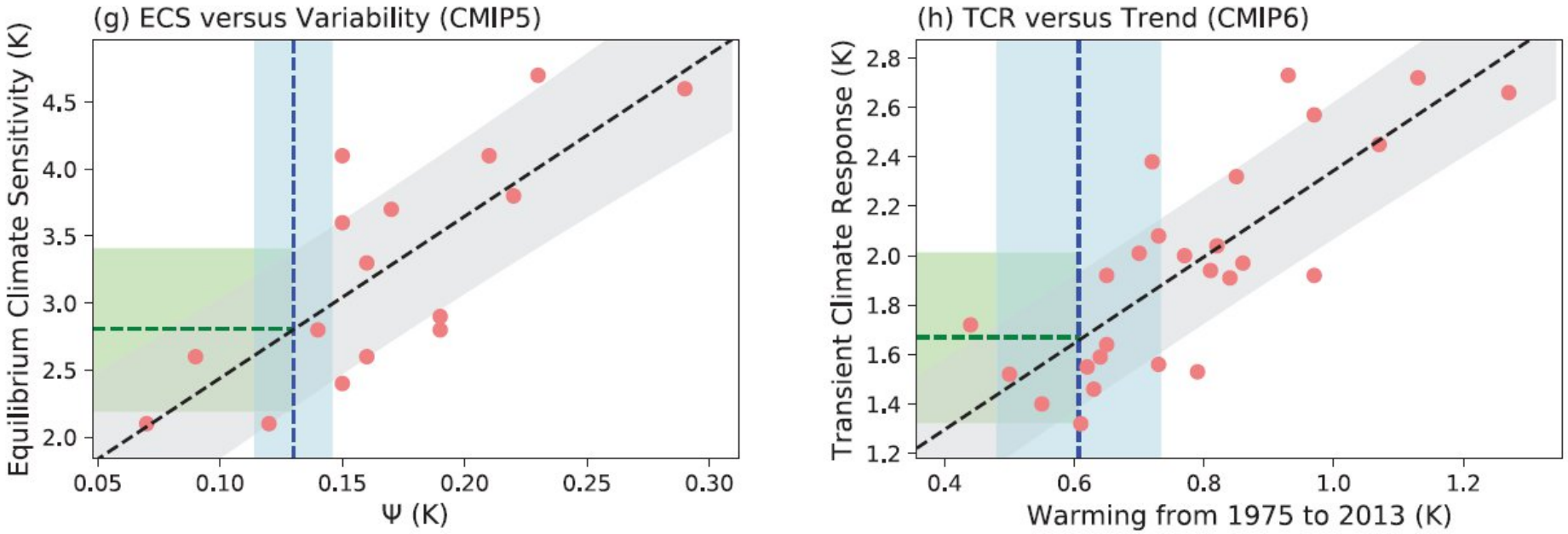
Emergent constraints in social or socio-climate (socio-ecological) systems?



But how to do measurements:

- surveys?
- online data?
- your ideas …

Further examples for emergent constraints



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