Interacting tipping elements increase risk of climate domino effects (Display D2308)

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Click below for details

- **1** Methods and Background
- **2** Structures of Vulnerability
- **3** Tipping cascades in the Earth system

This work is part of the IRTG 1740 (www.physik.hu-berlin.de/de/irtg1740) and the PIK FutureLab Earth Resilience in the Anthropocene (www.pik-potsdam.de/research/futurelas/earthresilience)

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Further displays on conceptualized tipping elements at EGU:

- Klose AK, Karle V, Winkelmann R, Donges JF: Display D 2300
- Donges JF, Wunderling N, Kurths J, Winkelmann R: Display D 2254

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Methods and Background

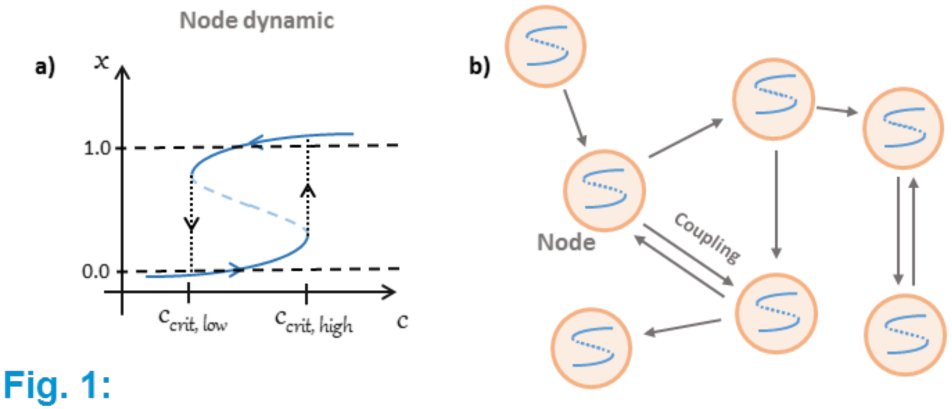

Fig. 1:
Bifurcation diagram of one paradigmatic tipping element **(a)**. The tipping element has a bistable regime. As soon as the critical parameter c of a certain tipping element surpasses a certain value $c_{crit,\,high}$, the respective tipping element transgresses into the tipped state. **(b)** Network of connected tipping elements that are linearly coupled. Since the tipping elements are interacting, the network structure can be decisive for the emergence of tipping cascades (see structures of vulnerability).

Conceptual tipping elements:
Each node represents a tipping element consisting of a non-linear differential equation with two stable states (**individual dynamics term**) linked via a saddle-node bifurcation. The tipping elements are coupled to others via linear couplings (**coupling term**)

$$\frac{dx_i}{dt} = \underbrace{-4(x_i - 0.5)^3 + (x_i - 0.5) + c_i}_{\text{Individual dynamics term}} + \underbrace{d \sum_{j,\, j \neq i} a_{ij} x_j}_{\text{Coupling term}}$$

x_i = state of tipping element
c_i = critical value
d = coupling strength
a_{ij} = 1 if connection between nodes exists, 0 otherwise

Go to Structures of Vulnerability

For more details: Krönke et al., 2020, PRE (accepted) "Dynamics of Tipping cascades on Complex Networks"

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Structures of Vulnerability: Network motifs

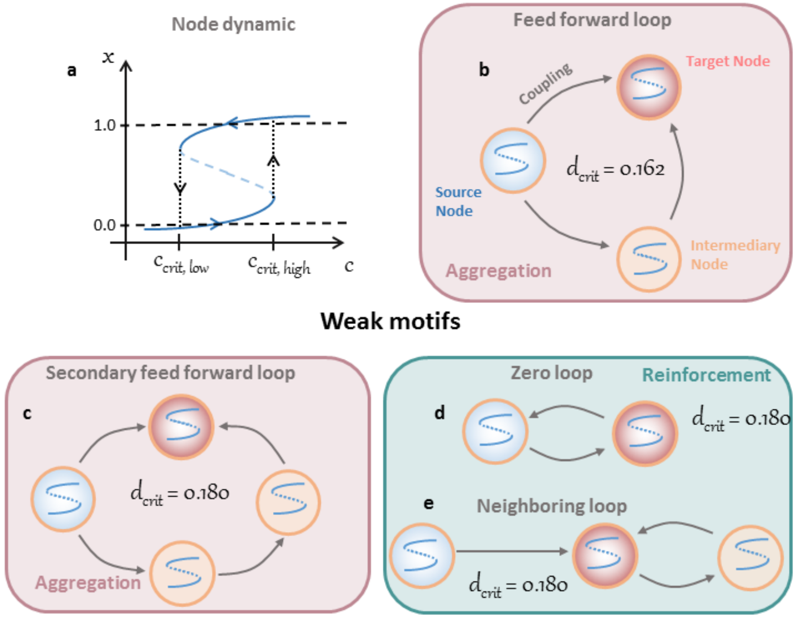

Fig. 2:
a) Dynamics of each node in the network, **b-e)** Micro structures (Motifs) within a larger network of tipping elements enhance its vulnerability.

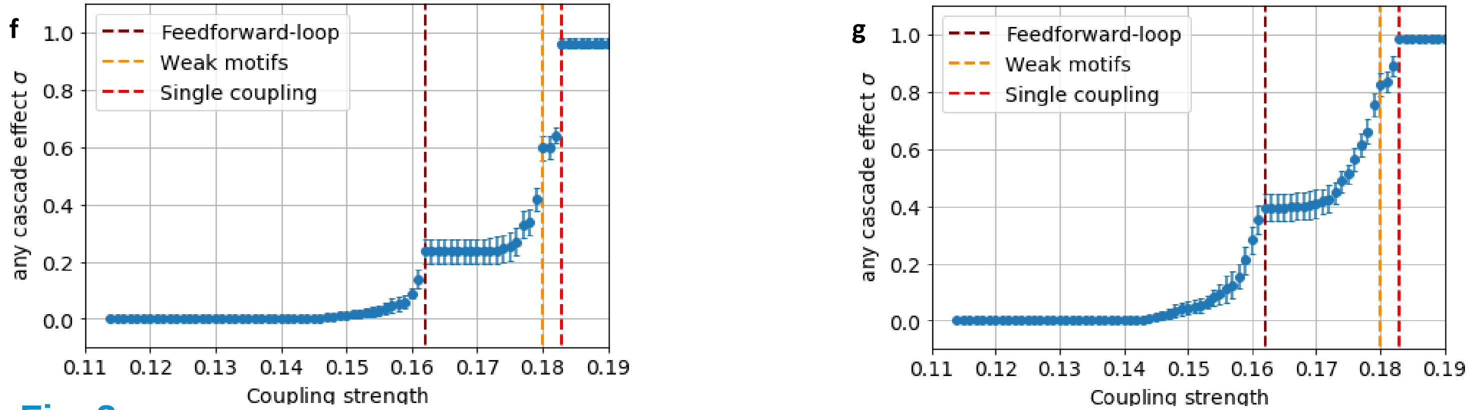

Fig. 2:
The effect of the coupling strength on the proportion of networks that show any cascading effect shown for an Erdös-Rényi network of 100 nodes and an average degree of three (panel **f)**) and four (panel **g**). Tipping cascades due to feed forward loops (dark red), weak motifs (orange) and due to no motifs (red line).

- **Local interaction structures (Motifs)** are responsible for the emergence of global cascades and the stability of the network as a whole (**Linking Micro to Macro**)

Go to Example: Amazon forest

More details: Wunderling, Stumpf et al., 2020, Chaos
"How motifs condition critical thresholds …: Linking micro- to macro-scales"

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Motifs in the moisture recycling network of the Amazon rainforest

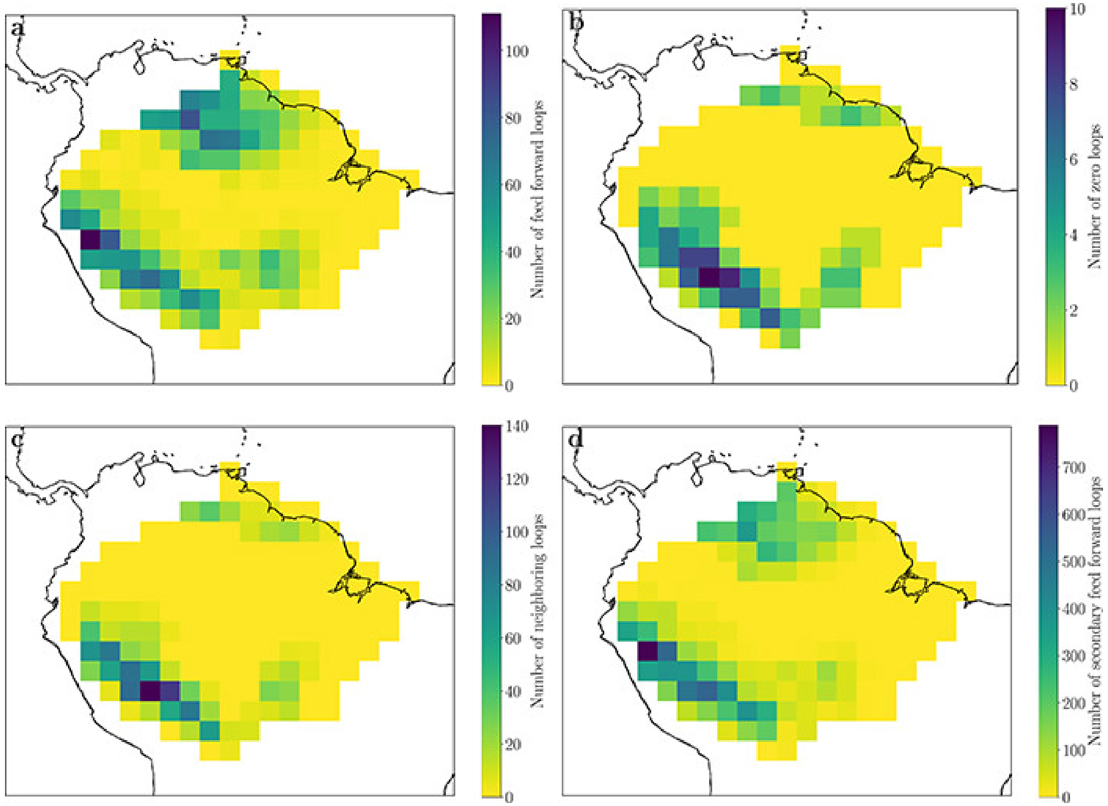

Fig. 3:
Number of motifs that point to a certain location in the 2x2 degree grid. Regions in the North, close to the Andes and in the South-East show an increased number of motifs. These are the regions where a decreased robustness due to tipping cascades can be expected. **a)** Feed forward loop, **b)** Zero loop, **c)** Neighboring loop, **d)** Secondary feed forward loop.

Take-home

1. Motifs can explain **Micro behavior** and emergence of **global cascades** in the network.
2. Motifs in the Amazon rainforest show spatial coherence of moisture-recycling network and might hint at increased vulnerability at these locations.

Go Back

Example 2: Climate tipping cascades

More details: Wunderling, Stumpf et al., 2020, Chaos “How motifs condition critical thresholds …”

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Tipping cascades in the Earth system

Go Back

Critical temperature ranges

Methods, Limitations & Merits

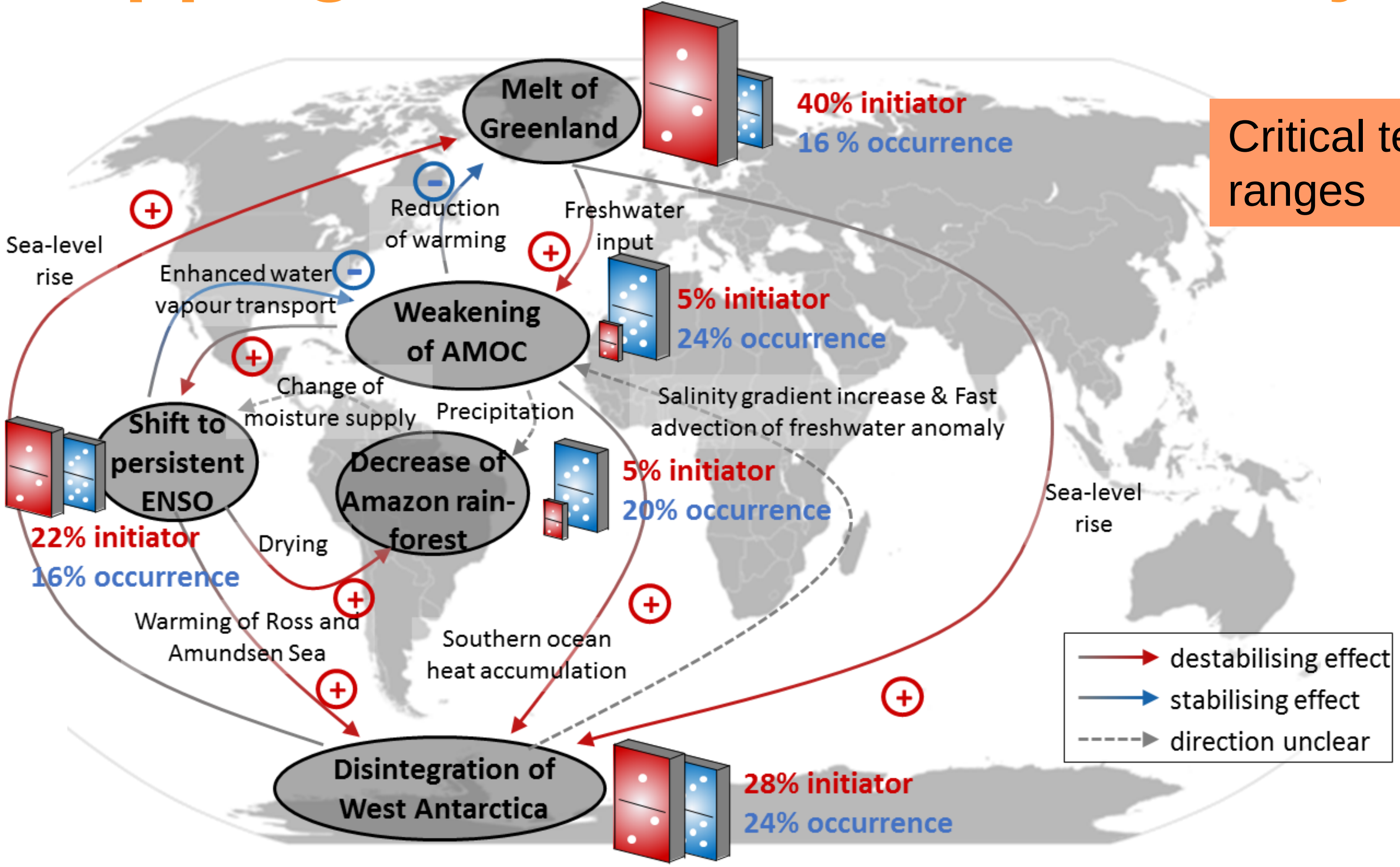

Fig. 4:
Interactions between climate tipping elements (from Kriegler et al., PNAS, 2009) and their roles in tipping cascades. The interactions are colour marked arrows: red for destabilising effects, blue for stabilising effects and grey for unclear direction. The size of the dominos indicates the relative frequency as an initiator of a tipping cascade (red domino) and its overall occurrence in cascades (blue domino). Our results seem to suggest that the polar tipping elements more often initiate tipping cascades, whereas the AMOC "mediates" such cascades in equatorial direction.

For details: Wunderling et al., ESD disc. (in review)
"Interacting tipping elements increase risk of climate domino effects under global warming"

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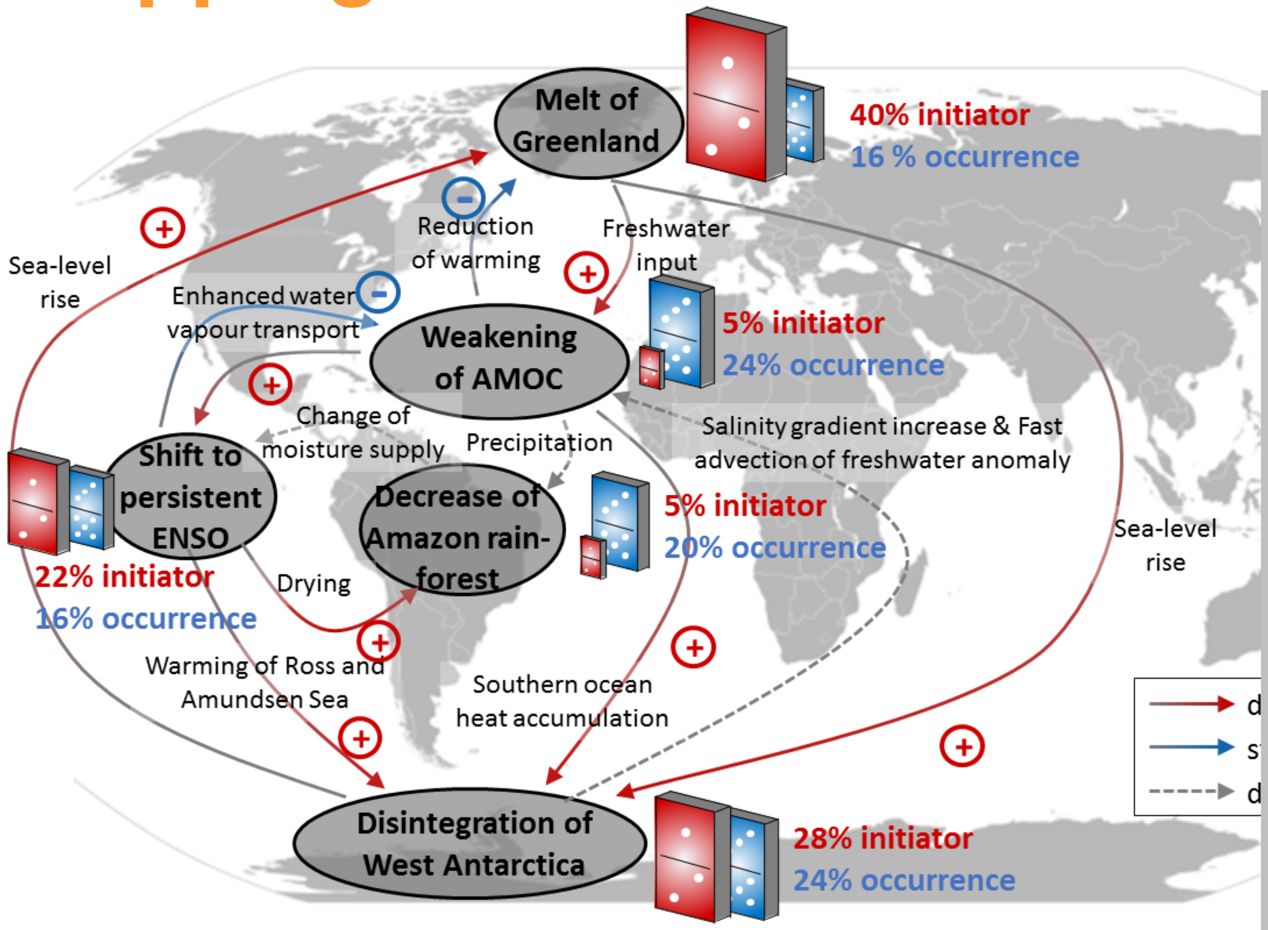

For details: Wunderling et al., ESD disc. (in review)

"Interacting tipping elements increase risk of climate domino effects under global warming"

Methods (see paper for details)

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

ΔGMT = Increase of global mean temperature
$T_{limit,i}$ = Critical temperature
d = Interaction strength
s_{ij} = Link weight
τ_i = Typical tipping time

Simulations

- Large scale Monte Carlo simulation (1.1 mio. ensemble members)
- All results are results from equilibrium simulations

Limitations

- Set of tipping elements and their interactions (strength) uncertain
- Conceptualised nature of tipping elements
- The role of ENSO

Merits

- Estimating tipping cascades in the Earth system consistently based on expert elicitation (Kriegler et al., PNAS, 2009)
- Large scale Monte Carlo ensemble propagates all uncertaintes (for details see paper)
- Comprehensive Earth system models cannot yet adequately represent all tipping elements and their interactions

Close

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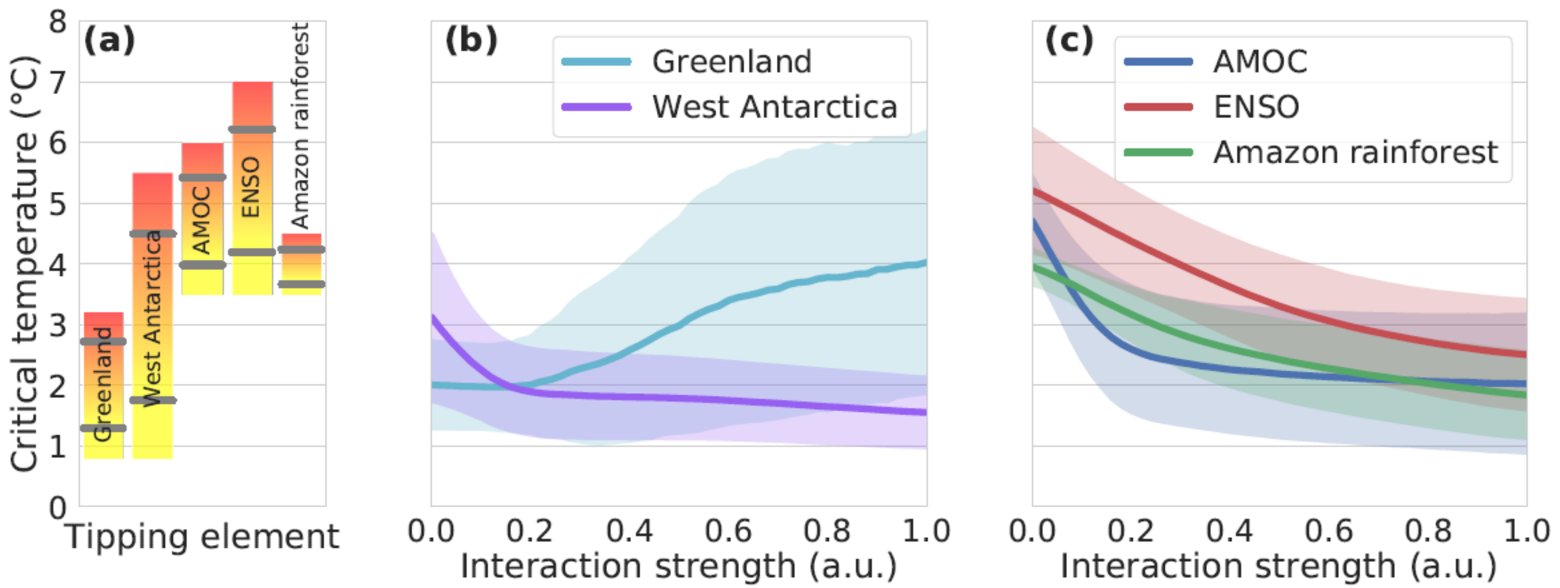

Fig. 5:

Shift of critical temperatures due to normalised interaction strength. **(a)** Critical temperatures as taken from the literature (Schellnhuber et al., NCC, 2016). **(b)** Critical temperatures for the polar tipping elements. **(c)** Critical temperatures for the equatorial tipping elements. The standard deviations are shown in shaded colours.

In general the temperature at which a critical transition occurs goes down with increasing interaction strength. For Greenland this is the other way round due to the strong negative feedback loop between Greenland and the AMOC.

Go back to Earth system

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Thank you!

Please comment and ask questions ☺

Sources

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- Schellnhuber, H.J., Rahmstorf, S. and Winkelmann, R., 2016. Why the right climate target was agreed in Paris. *Nature Climate Change*, *6*(7), p.649.
- Krönke, J., **Wunderling, N.,** Winkelmann, R., Staal, A., Stumpf, B., Tuinenburg, O.A. and Donges, J.F., 2020. Dynamics of Tipping Cascades on Complex Networks. *PRE (accepted).*
- **Wunderling, N**.*, Stumpf, B.*, Krönke, J., Staal, A., Tuinenburg, O.A., Winkelmann, R. and Donges, J.F., 2020. How motifs condition critical thresholds for tipping cascades in complex networks: Linking micro-to macro-scales. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *30*(4), p.043129. (*These authors equally contributed to this study)
- **Wunderling, N.,** Donges, J. F., Kurths, J., and Winkelmann, R.: Interacting tipping elements increase risk of climate domino effects under global warming, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2020-18, in review, 2020.

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