Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems

Stockholm University

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PIK

Risk analysis approach for tipping cascades and domino effects in the Earth system under global warming

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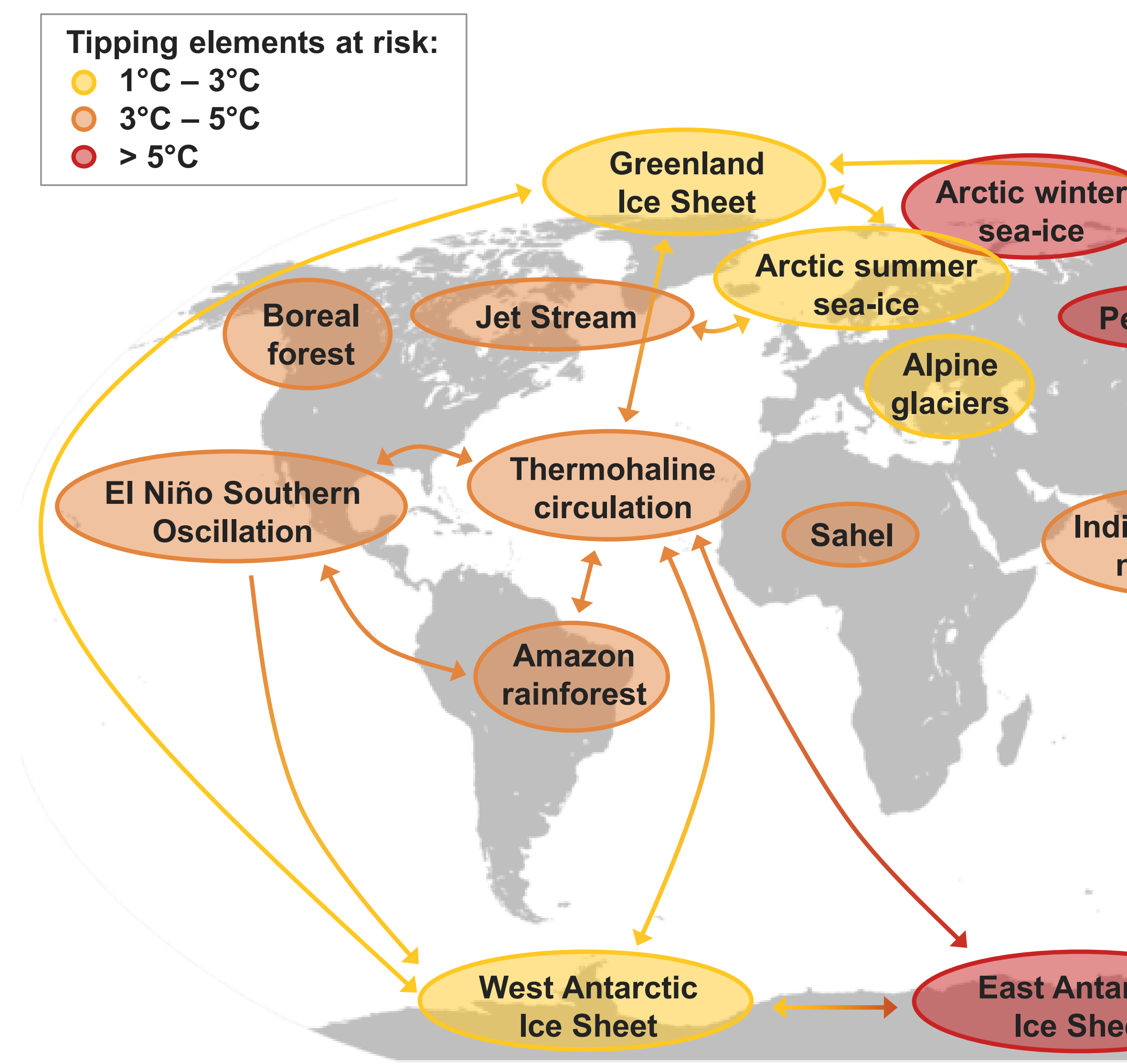

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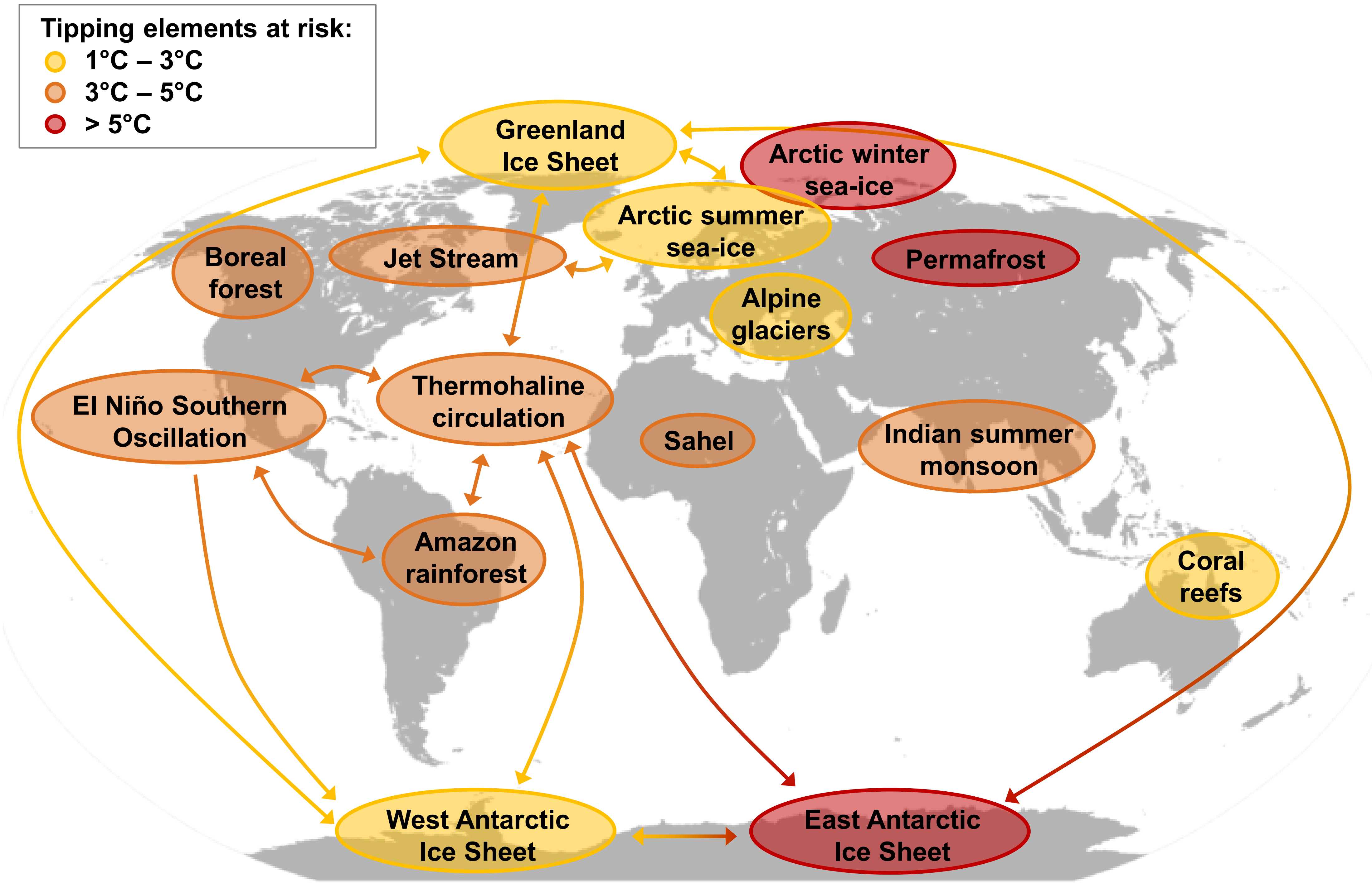
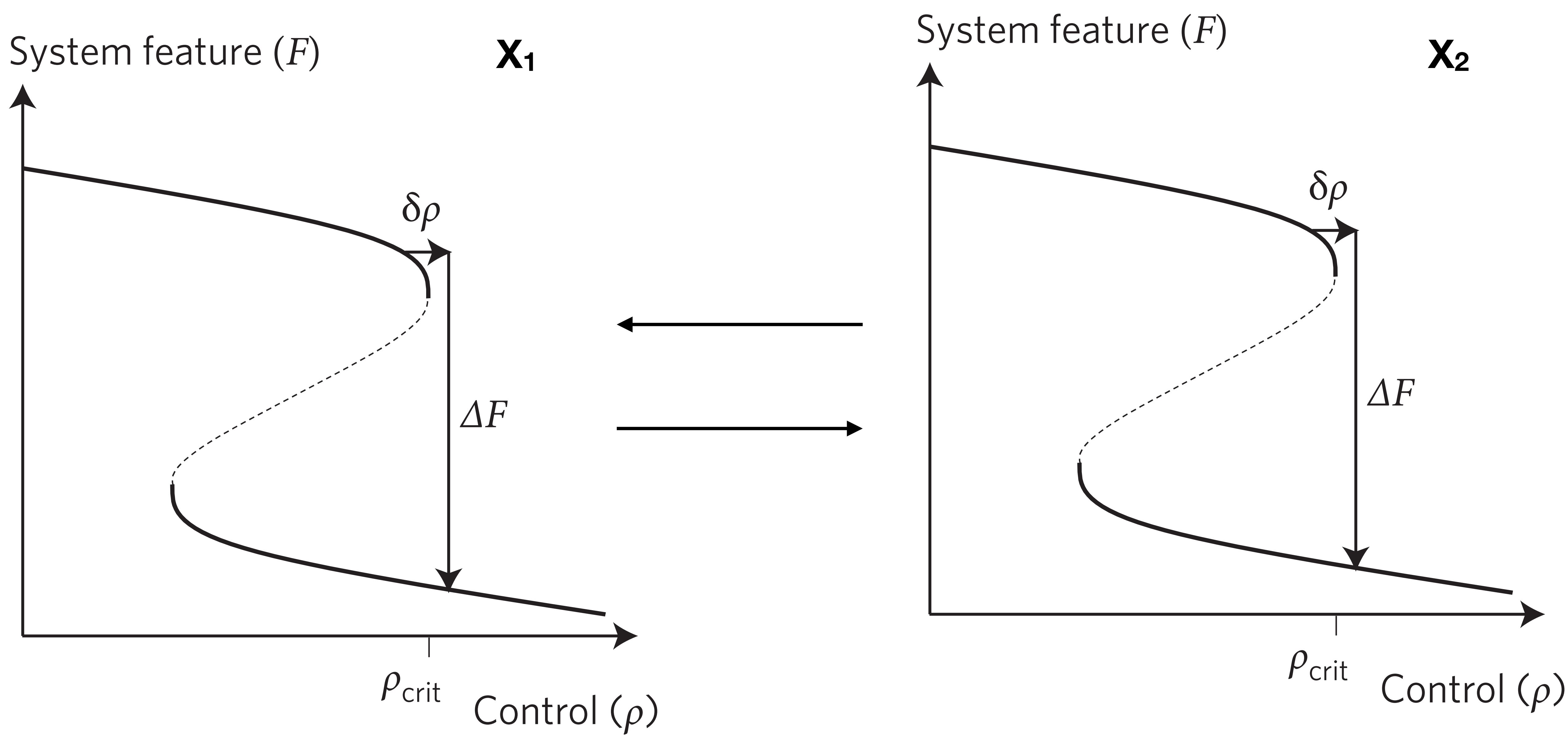
EGU 2020, 6 May 2020

There is evidence for tipping points in the climate system, but what is the risk for tipping cascades due to interactions?



Steffen et al., PNAS (2018)

Interactions between climate tipping elements: start with stylised modelling, because current Earth system model do not capture this well or are too slow

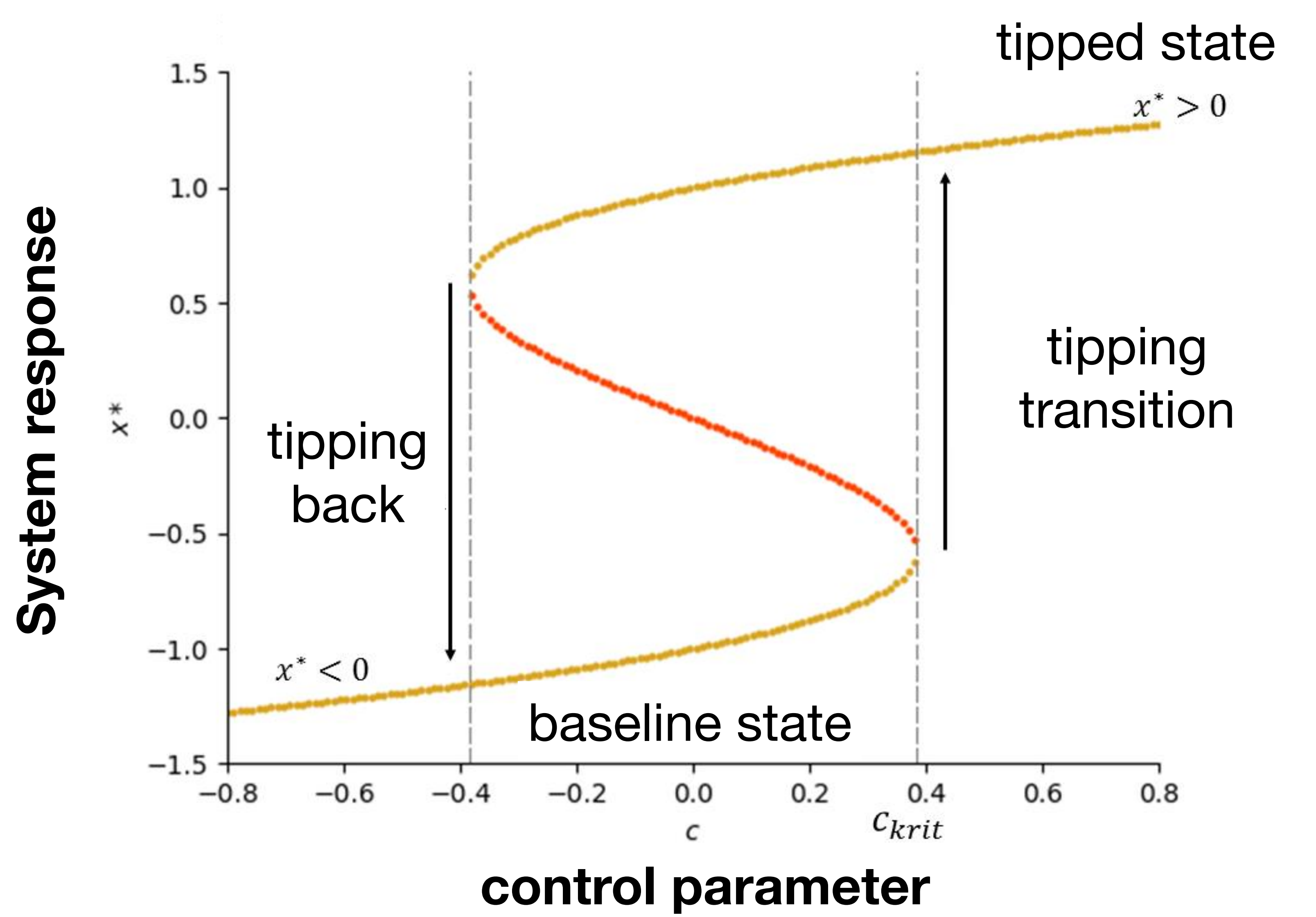


Model of a generalised tipping element with fold bifurcation

Stylised model of an isolated tipping element:

$$\frac{\partial x_i}{\partial t} = a_i x_i - {x_i}^3 + c_i$$

—> Two connected saddle-node bifurcations



Abraham (1990), Brummit et al. (2015), …

Interacting generalised tipping elements

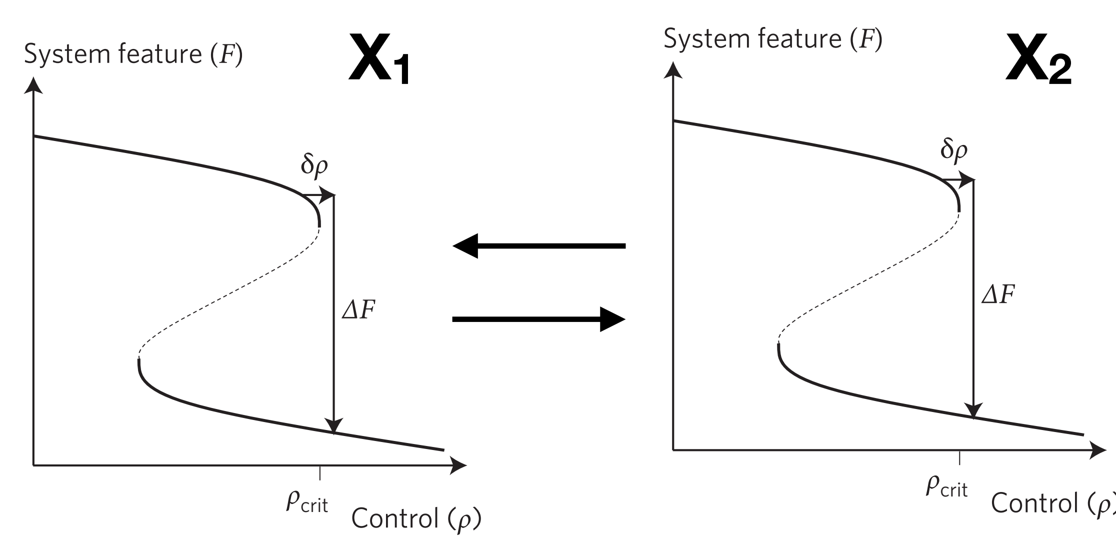
General form:

$$\frac{\partial x_i}{\partial t} = a_i x_i - {x_i}^3 + c_i + C_i(x_1, \dots, x_{i-1}, x_{i+1}, \dots, x_n)$$

Two interacting tipping elements:

$$\frac{\partial x_1}{\partial t} = x_1 - {x_1}^3 + c_1 + C_{x_1}(x_2, x_1)$$

$$\frac{\partial x_2}{\partial t} = x_2 - {x_2}^3 + c_2 + C_{x_2}(x_1, x_2)$$



Klose et al. (in review), arXiv:1910.12042,
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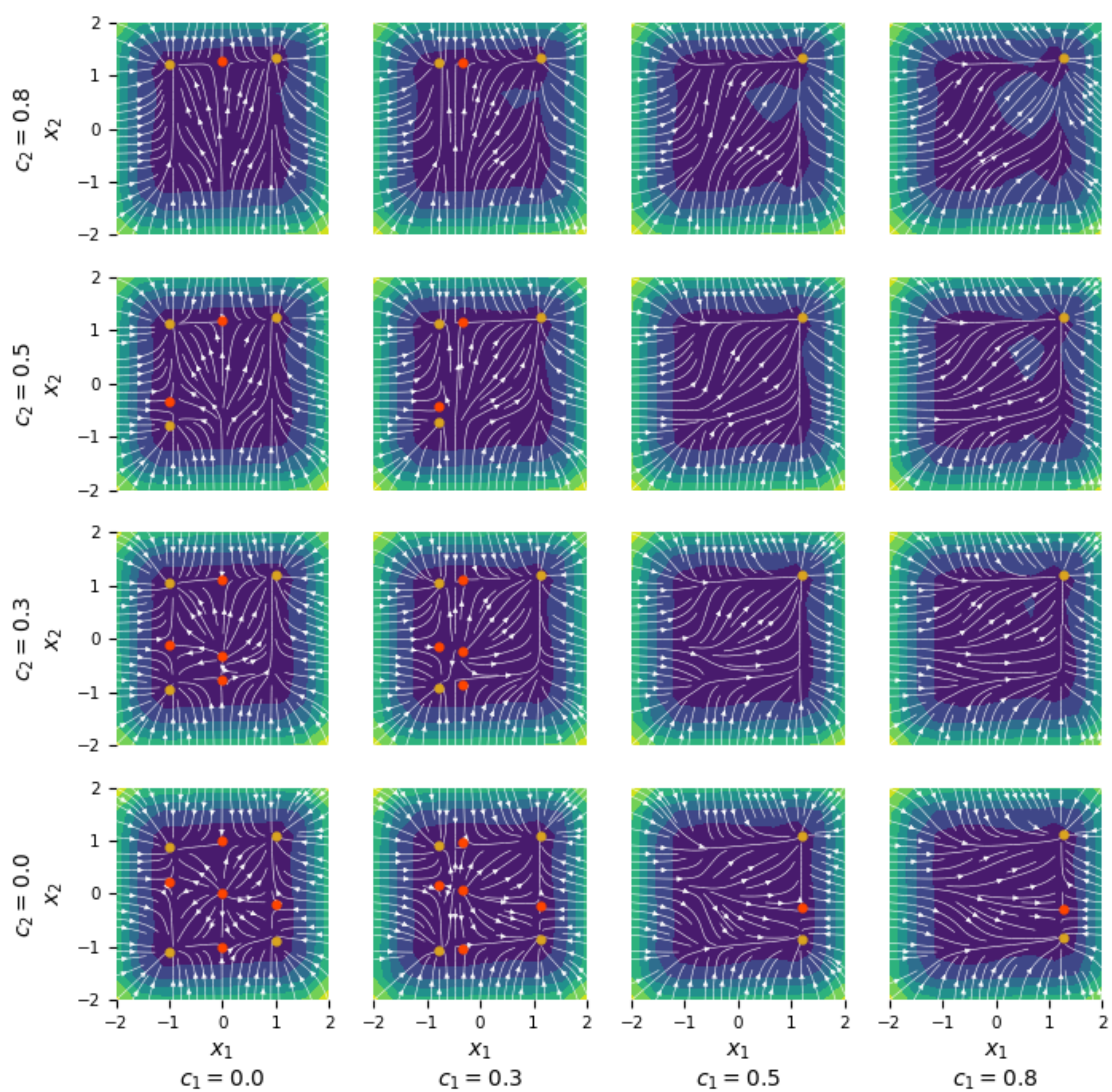
Unidirectional coupling $X_1 \rightarrow X_2$

e.g. chain of lakes connected by river



Coupling functions:

$$C_{x_1}(x_2, x_1) = 0$$

$$C_{x_2}(x_1, x_2) = d_2 x_1$$

$$d_2 > 0.$$

Effective tipping points c_2:

$$\pm\sqrt{\frac{4}{27}} = c_2 + d_2 {x_1}^*$$

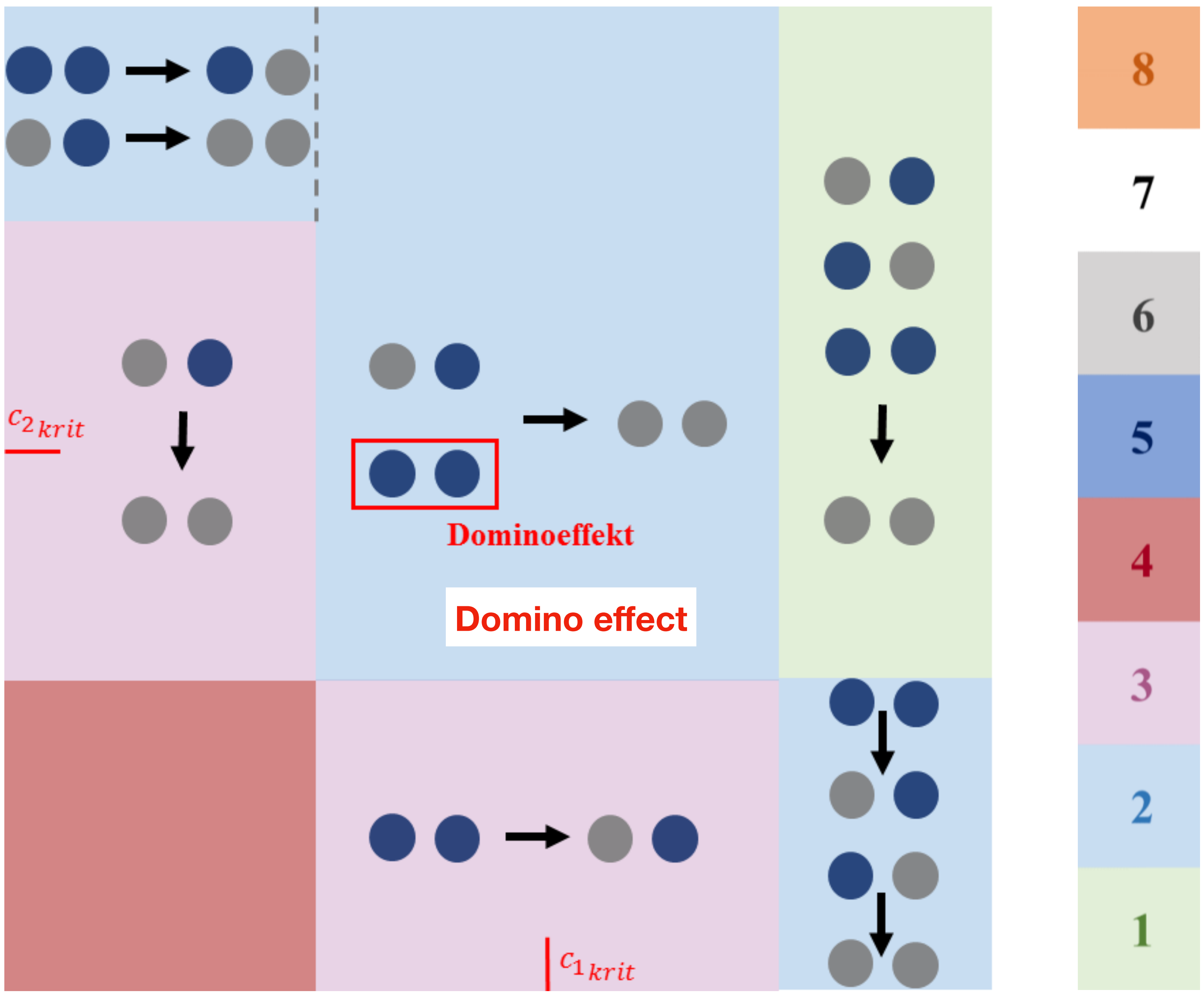
Klose et al. (in review), arXiv:1910.12042,
EGU2020-4490

Stable fixed points
Unstable fixed points

Bidirectional coupling with negative feedback

$$X_1 \overset{\rightarrow}{\underset{\leftarrow}{}} X_2$$

e.g. Greenland ice sheet and thermohaline circulation



Coupling functions:

$$C_{x_1}(x_2, x_1) = d_1 x_2$$

$$C_{x_2}(x_1, x_2) = d_2 x_1$$

Coupling strengths:

$d_1 < 0 \qquad d_2 > 0.$

$|d_1| \approx |d_2|$

Klose et al. (in review), arXiv:1910.12042,
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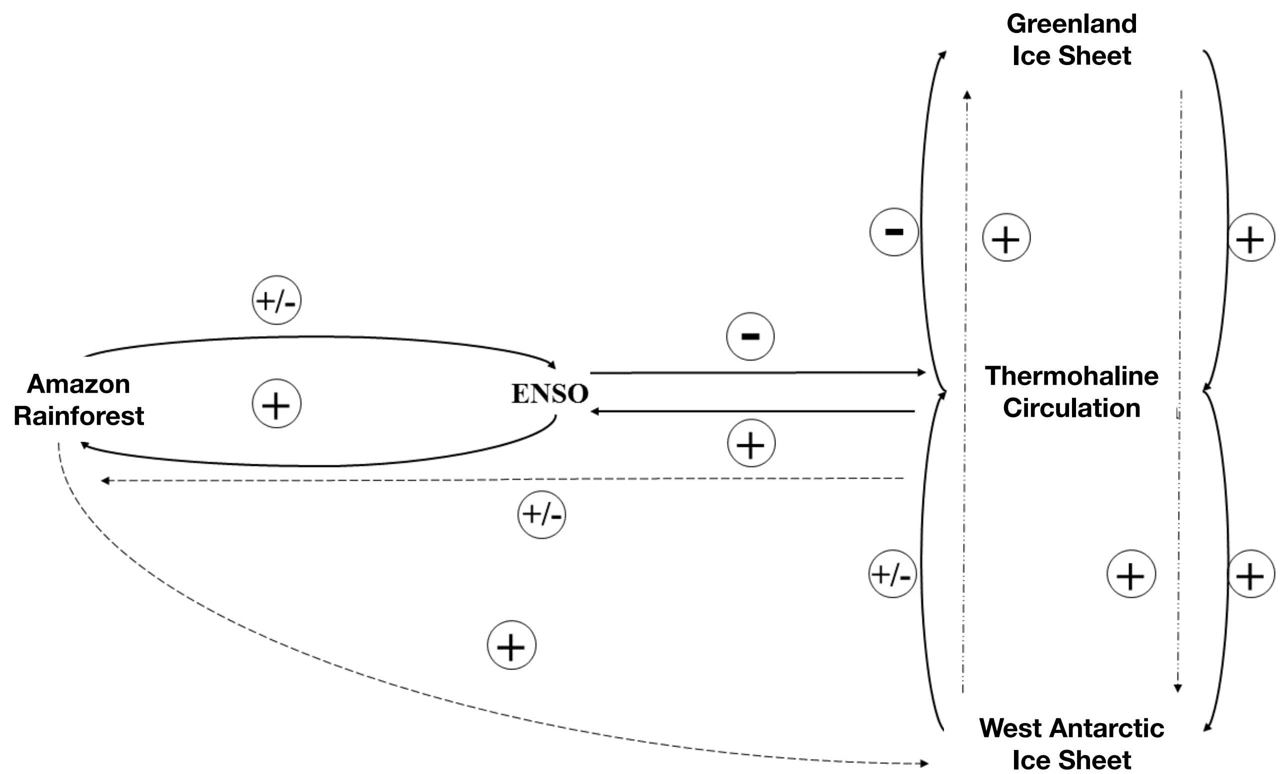
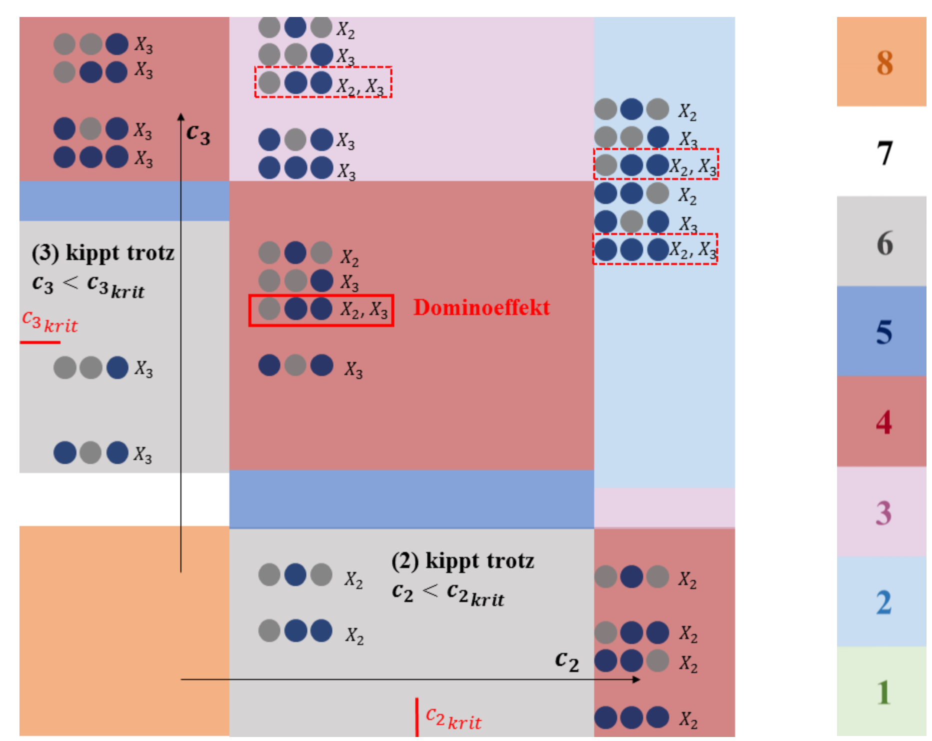
Baseline state
Tipped state

Extensions to larger networks of tipping elements

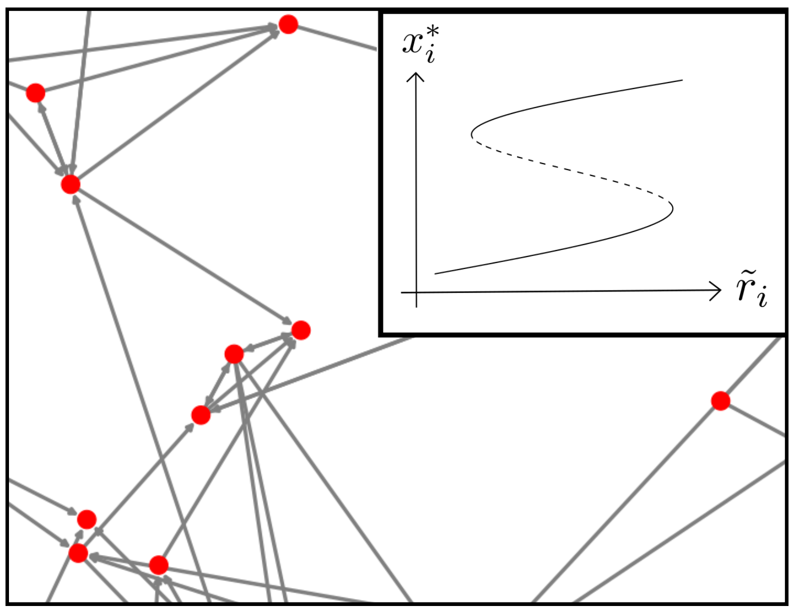
e.g. interacting climate tipping elements



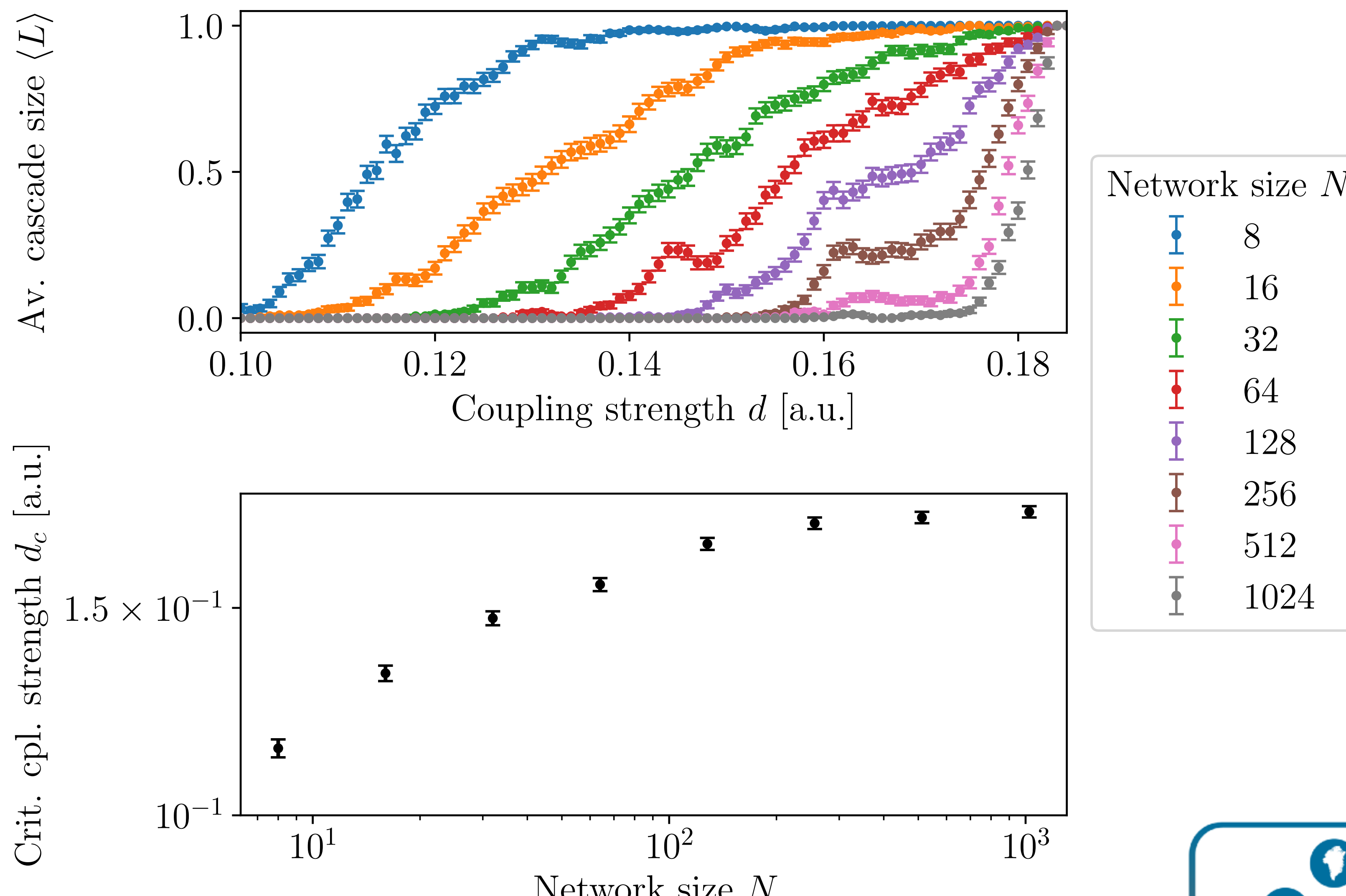


Klose et al. (in review), arXiv:1910.12042,
EGU2020-4490

Tipping cascades in general complex networks



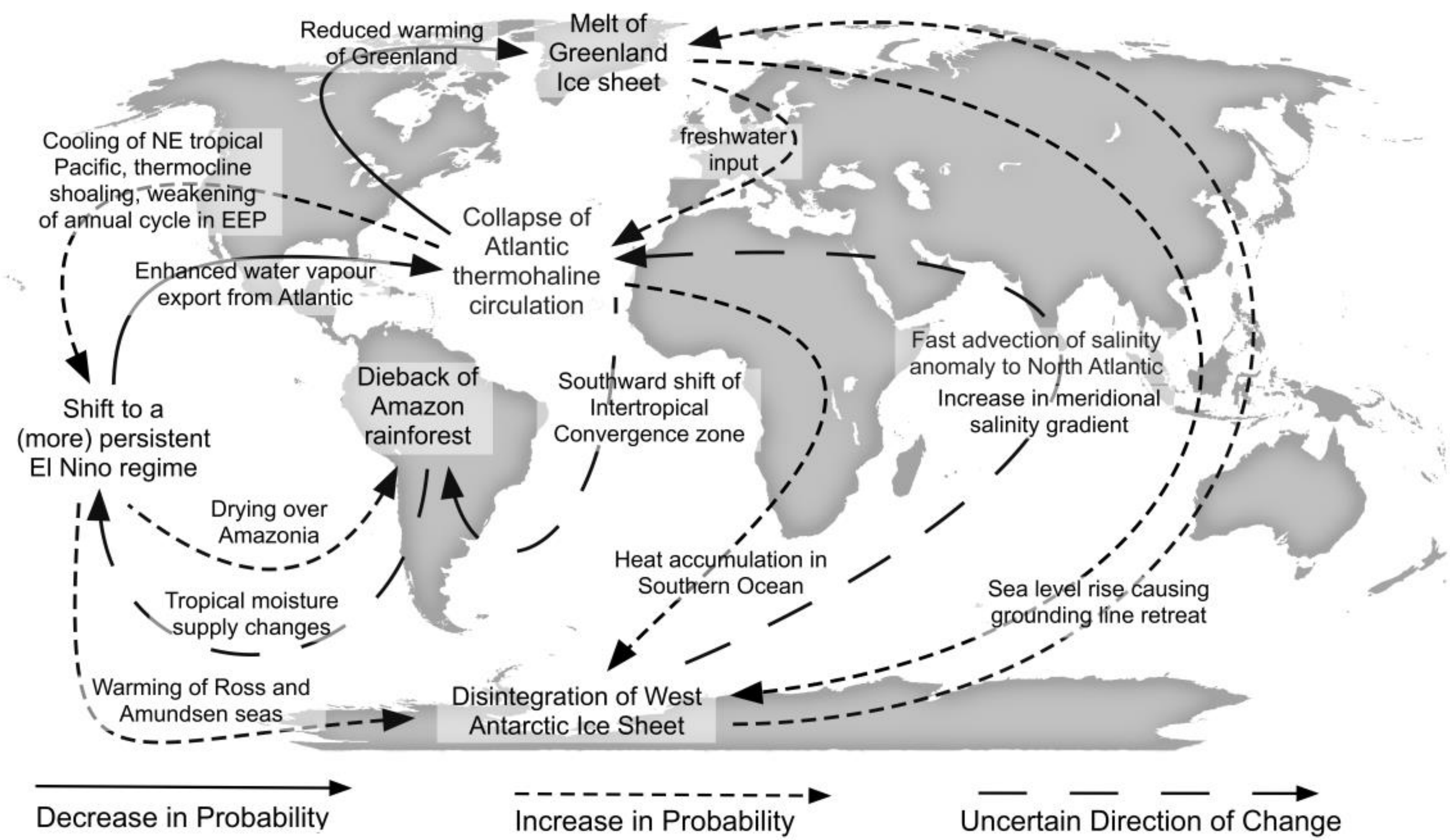
Network of generalised tipping elements



Typical cascade size on networks

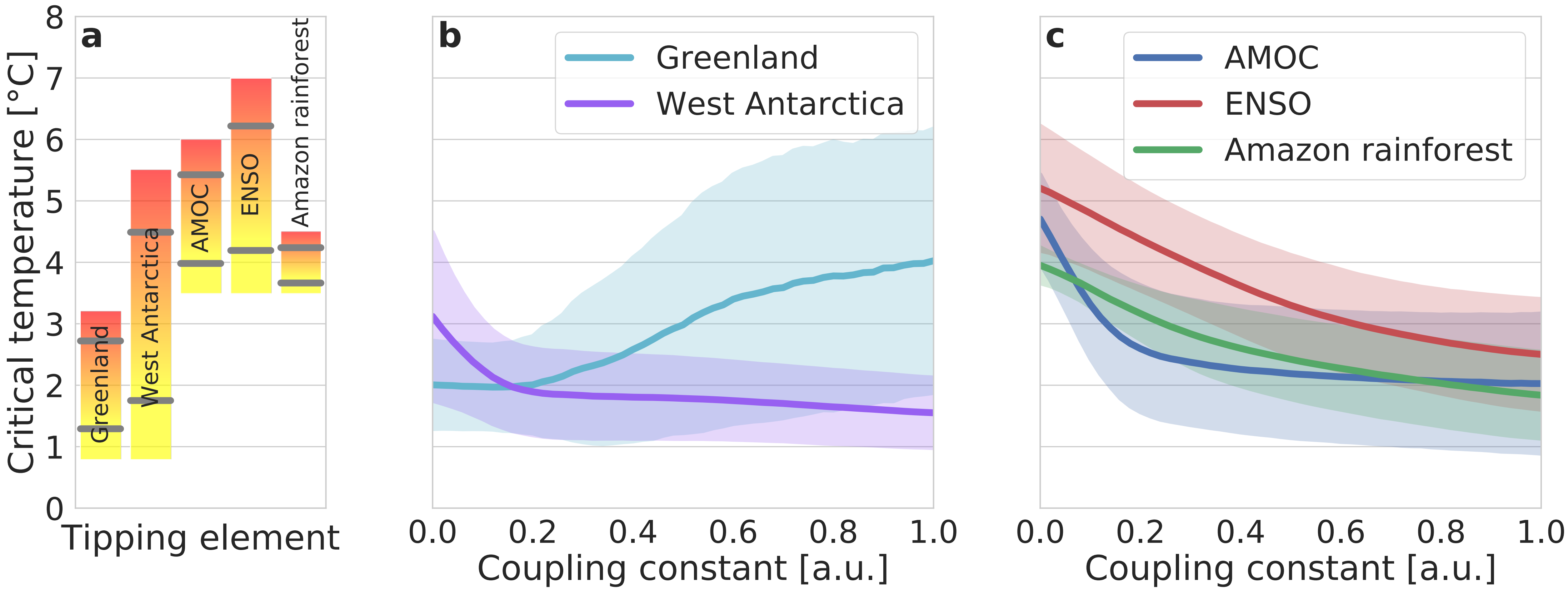
Krönke et al., Physical Review E (2020), arXiv:1905.05476;
Wunderling, Stumpf et al., Chaos (2020), arXiv:2001.02169

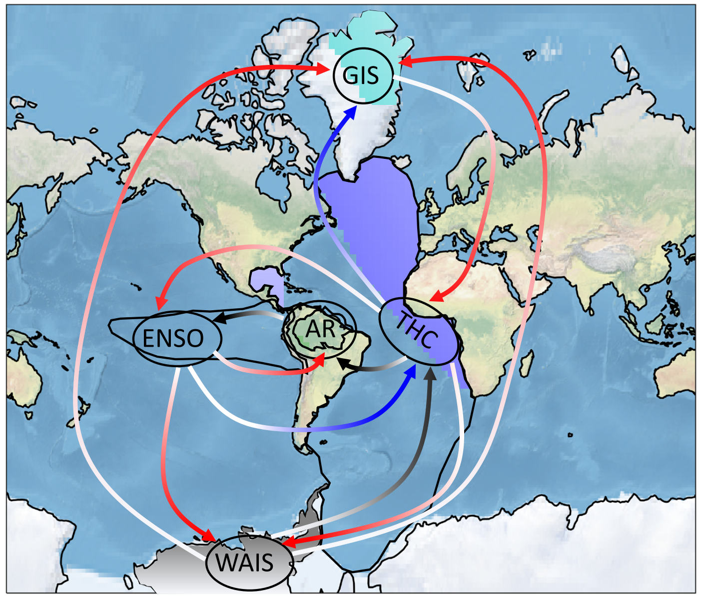
Network of interacting climate tipping elements: study potential cascading dynamics using stylised network model



Cai et al. (2016) after Kriegler et al. (2009)

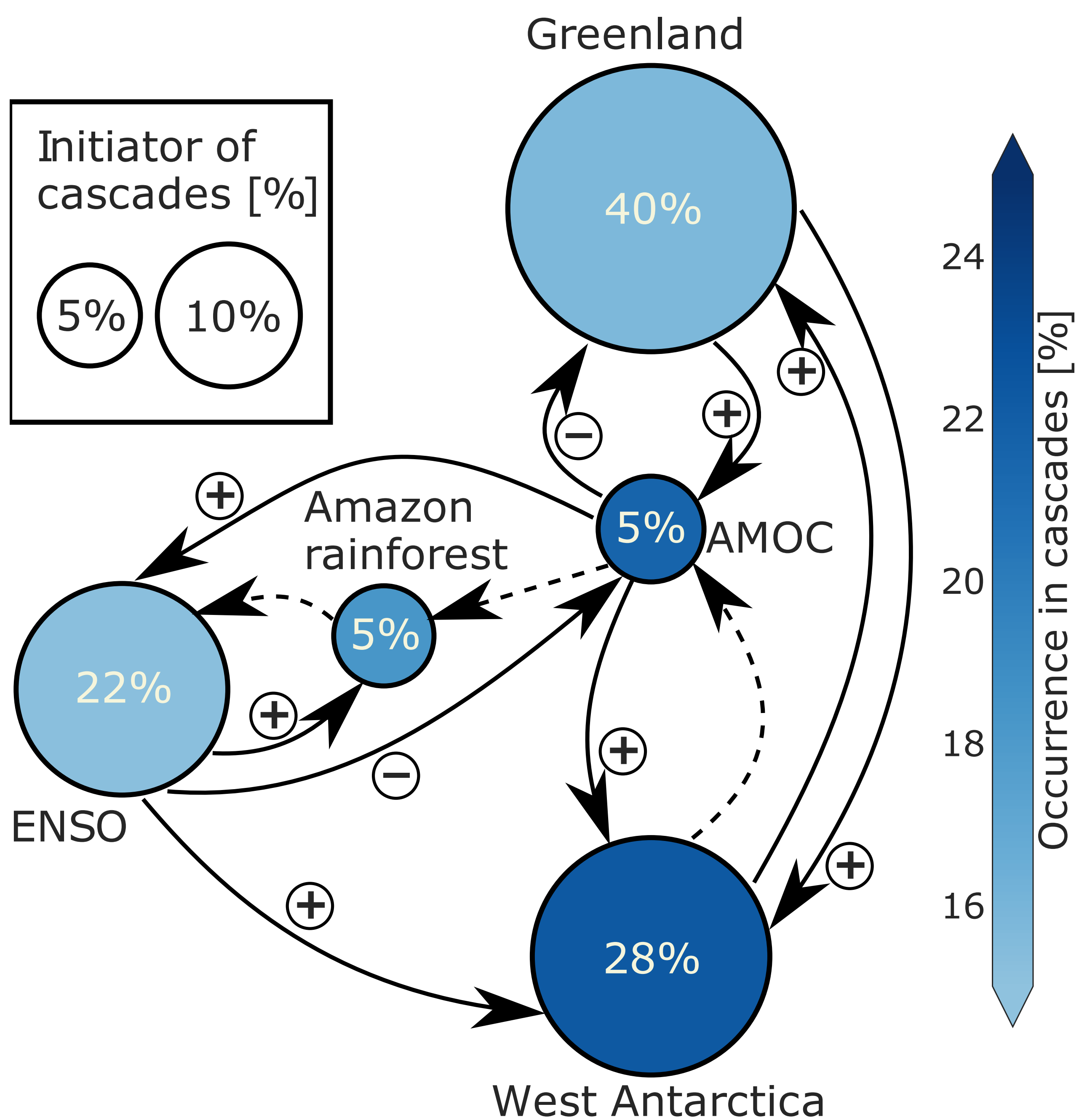
Shifts of critical thresholds due to tipping element interactions

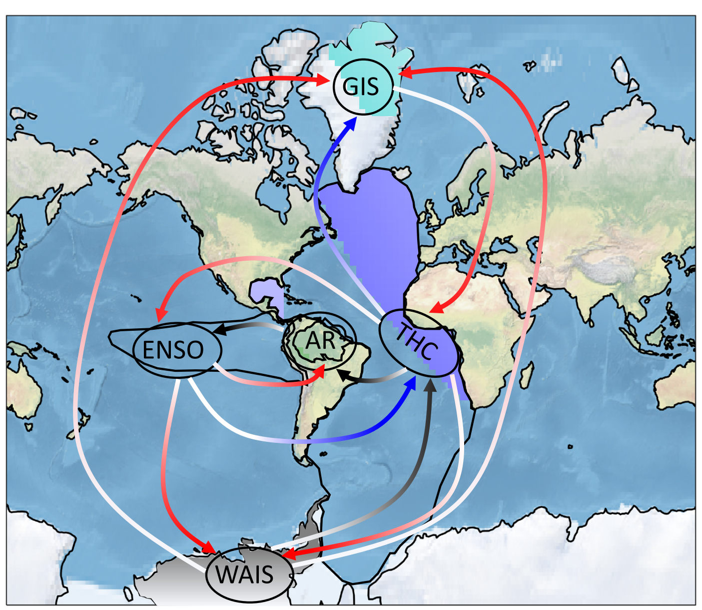




Wunderling et al., ESD Discussions (2020)

Roles of tipping elements in cascades: ice sheets appear as main initiators of cascades, AMOC is an important transmitter of cascades in this model





Wunderling et al., ESD Discussions (2020)

Summary

1. Important to study dynamics of tipping elements under global warming due to large potential impacts on human societies

2. Interactions of tipping elements and potential for domino effects are still understudied and large uncertainties exist in various parameters and interaction structure

3. Risk analysis approach based on stylised network model and Monte Carlo propagation of uncertainties to guide more detailed analysis with process-based models

Thank you

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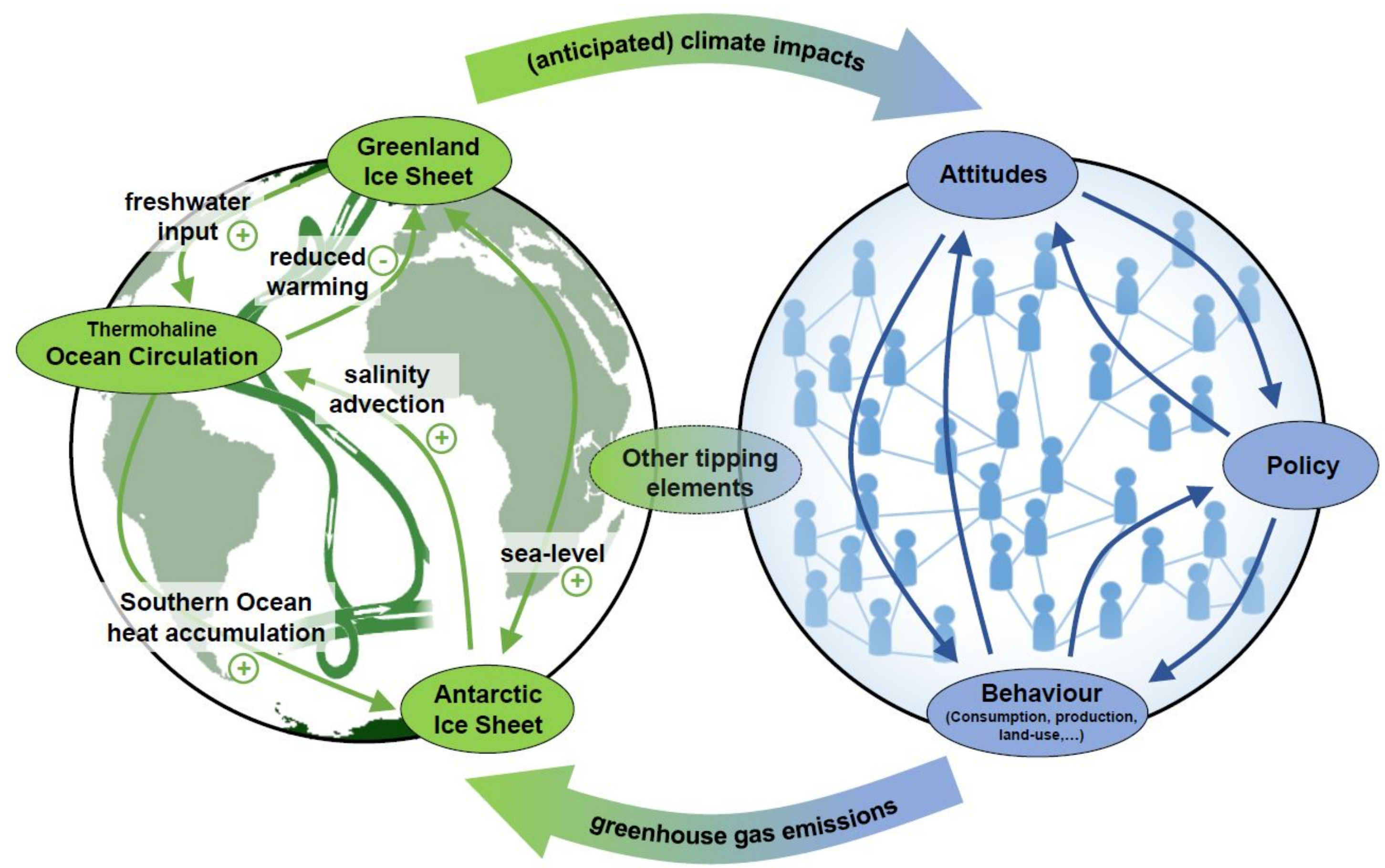

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