POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Dynamics of cascading failures on networks: Measuring vulnerability in connected systems

Environmental transformations in the Amazon rainforest

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era
Earth Resilience
in the Anthropocene

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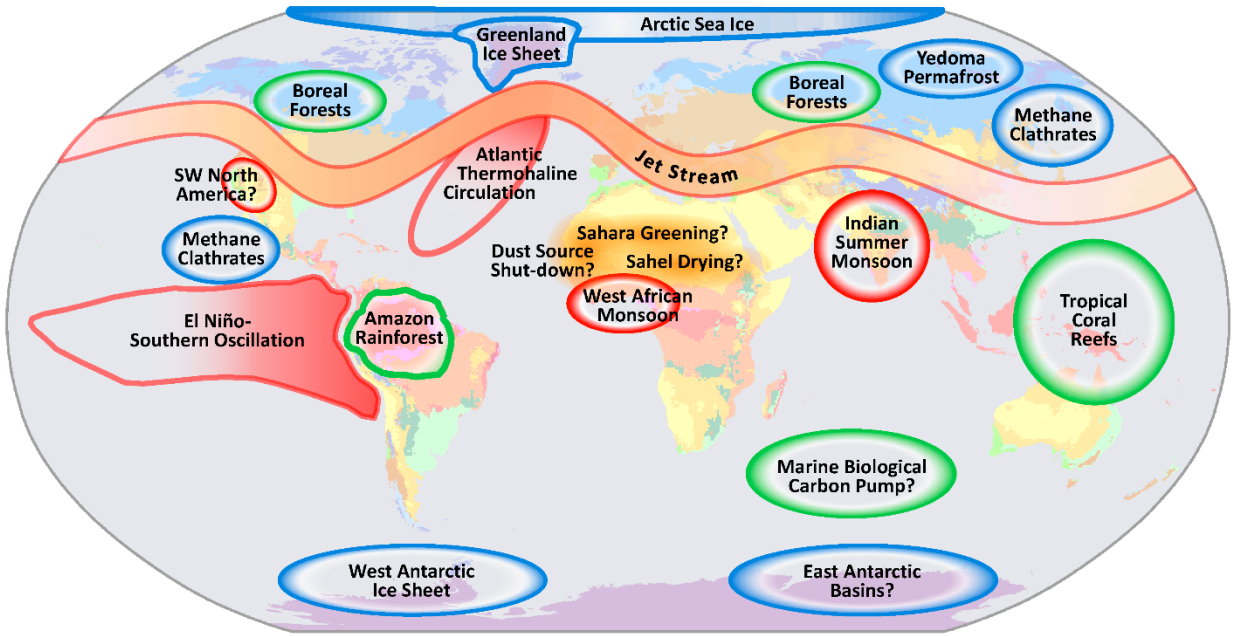
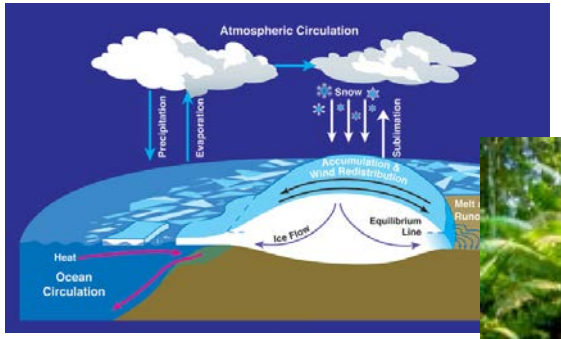
Tipping elements in the climate system

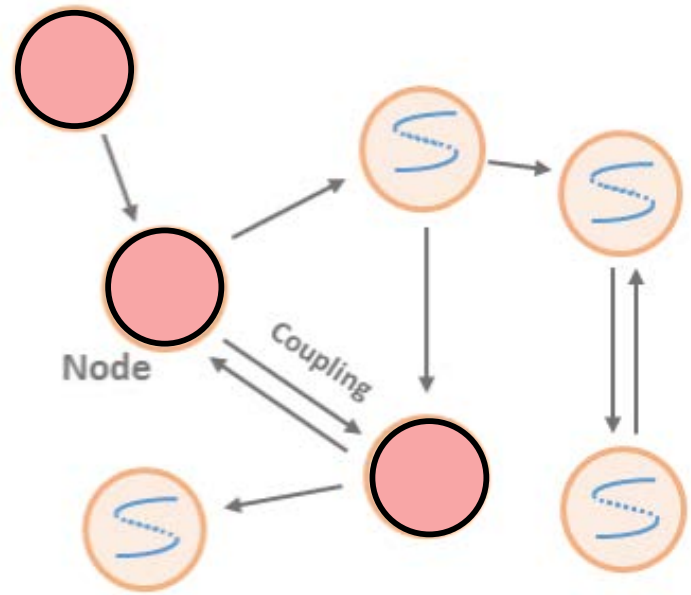


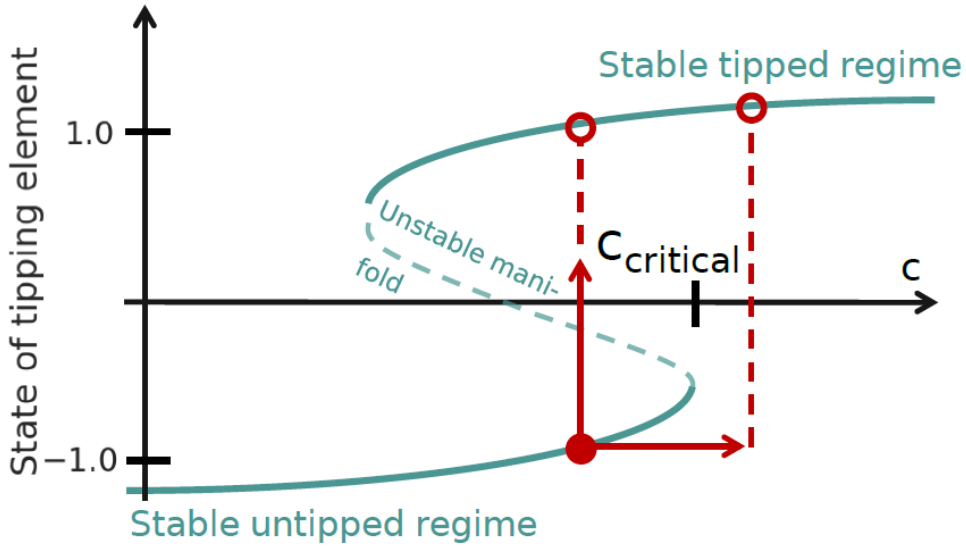
www.pik-potsdam.de/services/infodesk/tipping-elements



Tipping elements are systems, where a small perturbation can be sufficient to induce a qualitative change of the whole system as soon as a critical value (tipping point) is approached.

Networks of connected tipping elements





$$\frac{dx_i}{dt} = \underbrace{-a(x_i - x_0)^3 + b(x_i - x_0) + c_i}_{\text{Individual dynamics}} + \cdot$$

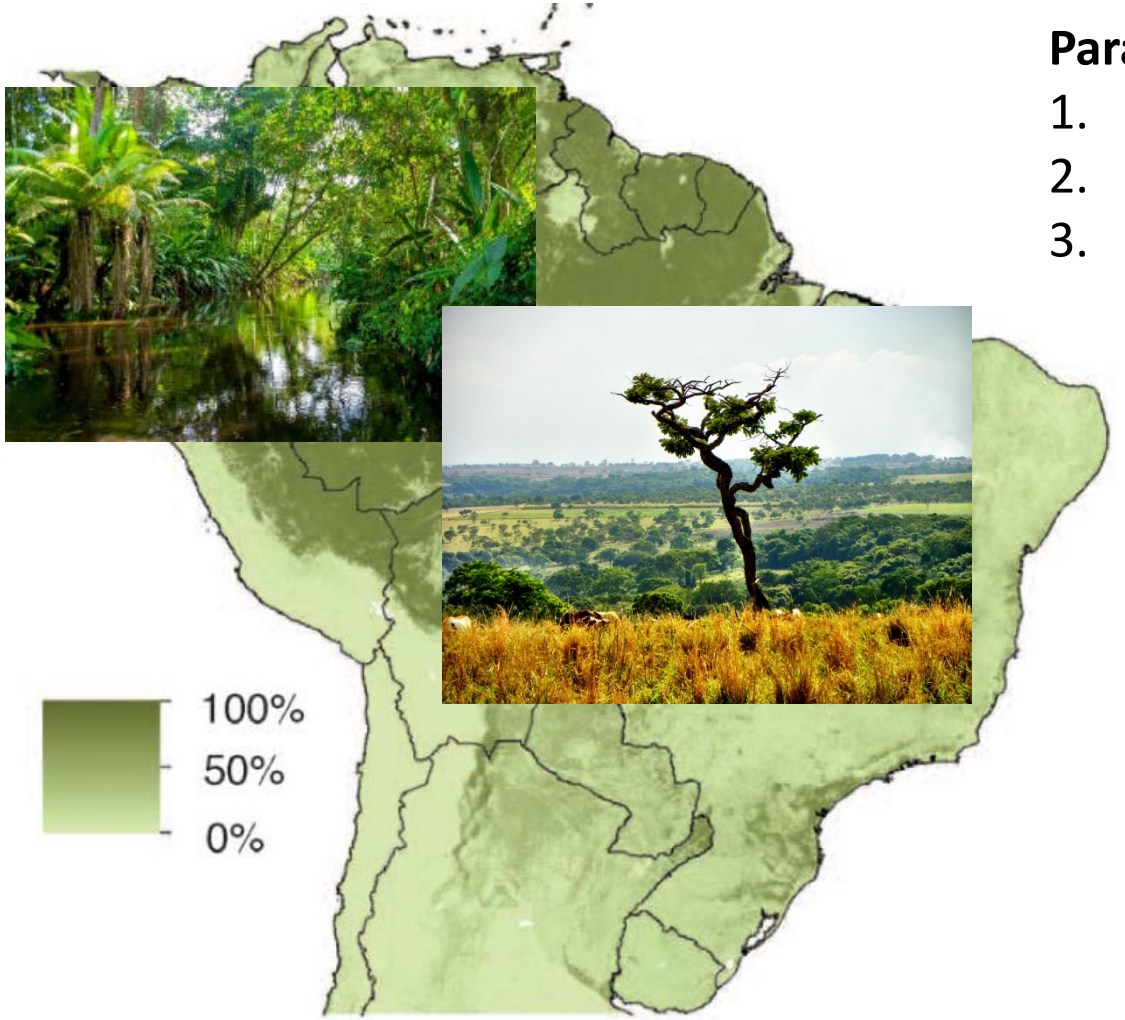
x_i= state of tipping element
x_0= shift
c_i= critical value
d = coupling strength
a_{ij}= 1, if connection between nodes exists, 0 otherwise

Krönke, **Wunderling** et al. (PRE, in review)

The Amazon rainforest as a tipping element: Network approaches to environmental transformations

Thanks to contributors:
A. Staal, B. Sakschewski, K. Thonicke, HMJ. Barbosa, JF. Donges & R. Winkelmann

The Amazon rainforest as a tipping element



Hirota, M., et al. (2011). *Science*

Parameters influencing the Amazon adversely (among others):

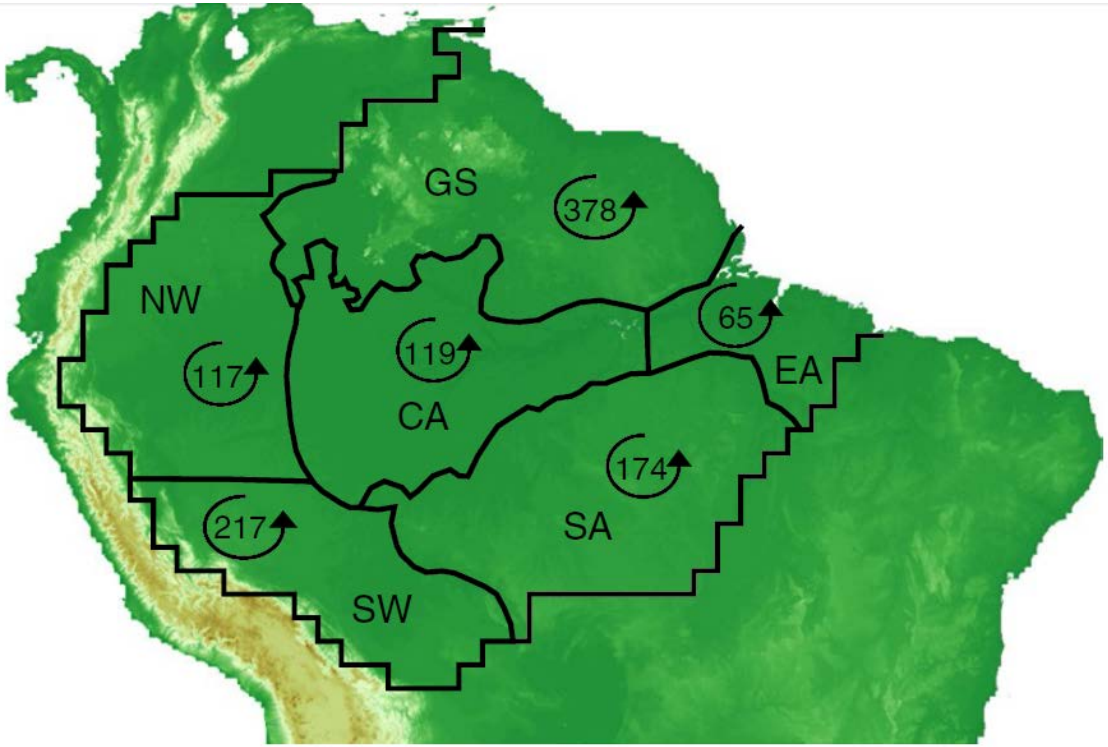
1. Droughts (Seasonal, Annual precipitation patterns)
2. Fire & Deforestation (Natural, Anthropogenic)
3. Climate Change (Adaptation to new environmental conditions)

Source: BBC (drought 2010)

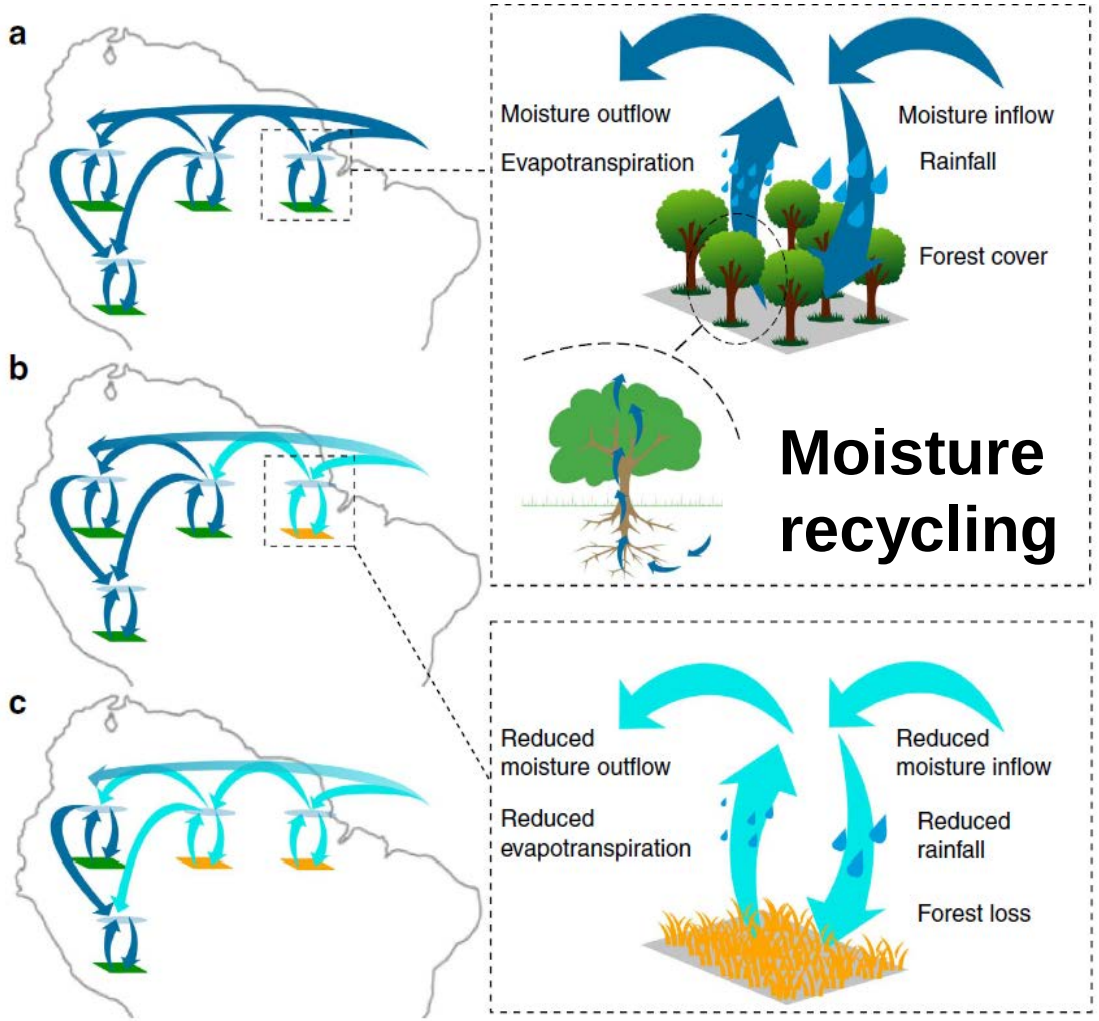
Source: BBC (forest fire 2019)

Source: BBC (deforestation 2019)

The Amazon rainforest as a tipping element



Staal, A., et al. (2018). *Nature Climate Change*

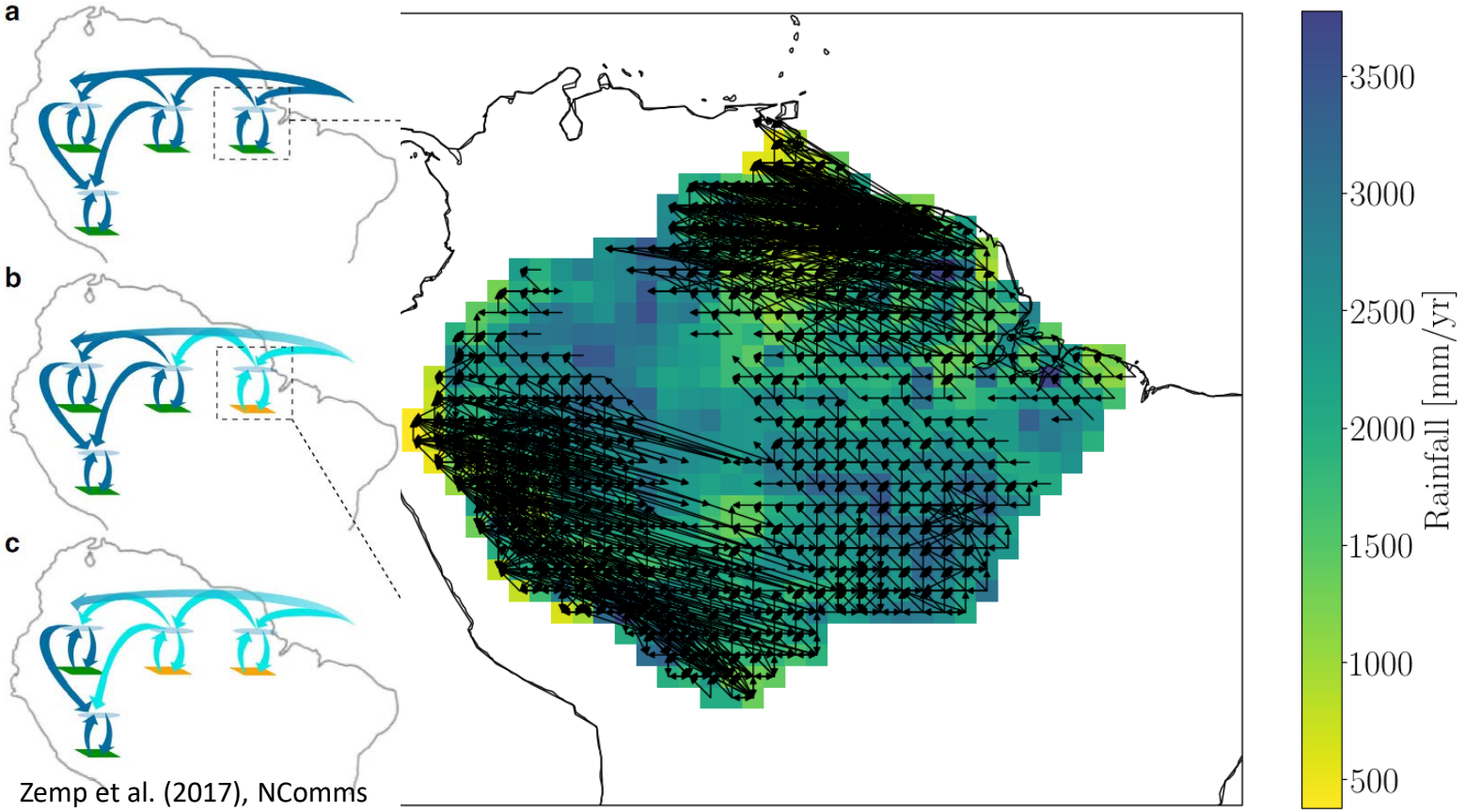


Zemp et al. (2017), Nature Communications

Note:

Regions within the Amazon are **dependent** on each other due to moisture transport

Networks of tipping elements



Zemp et al. (2017), NComms

Input:

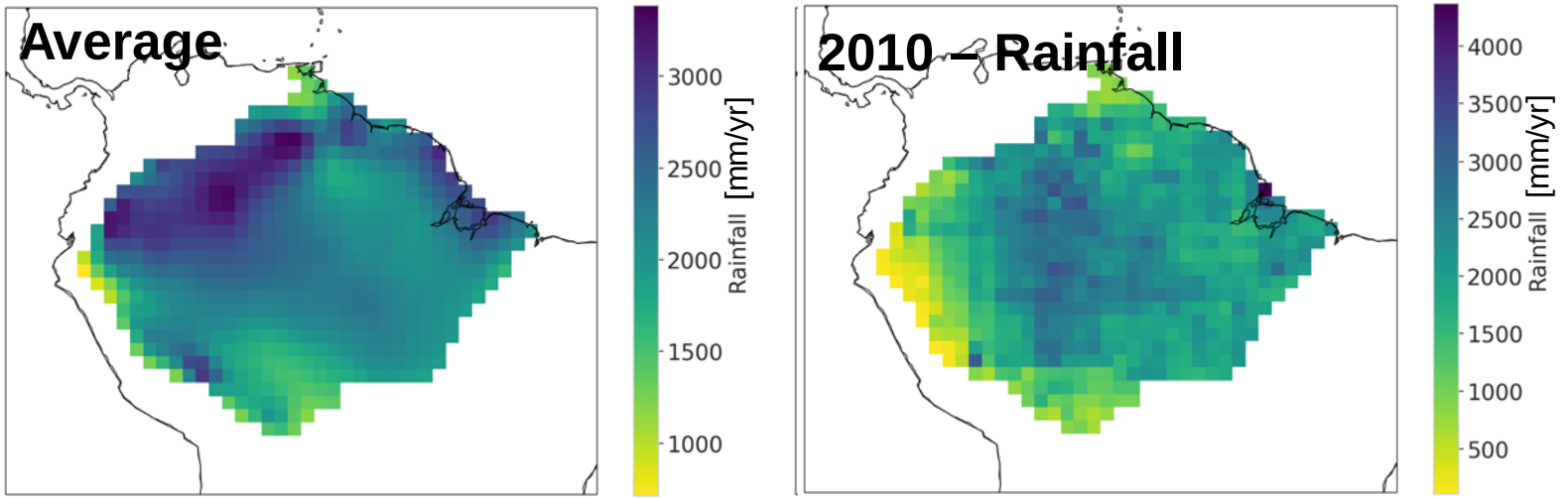
1. Rainfall of the specific cell
2. Moisture recycling network from GLDAS (2003-2014, Staal et al., 2018)

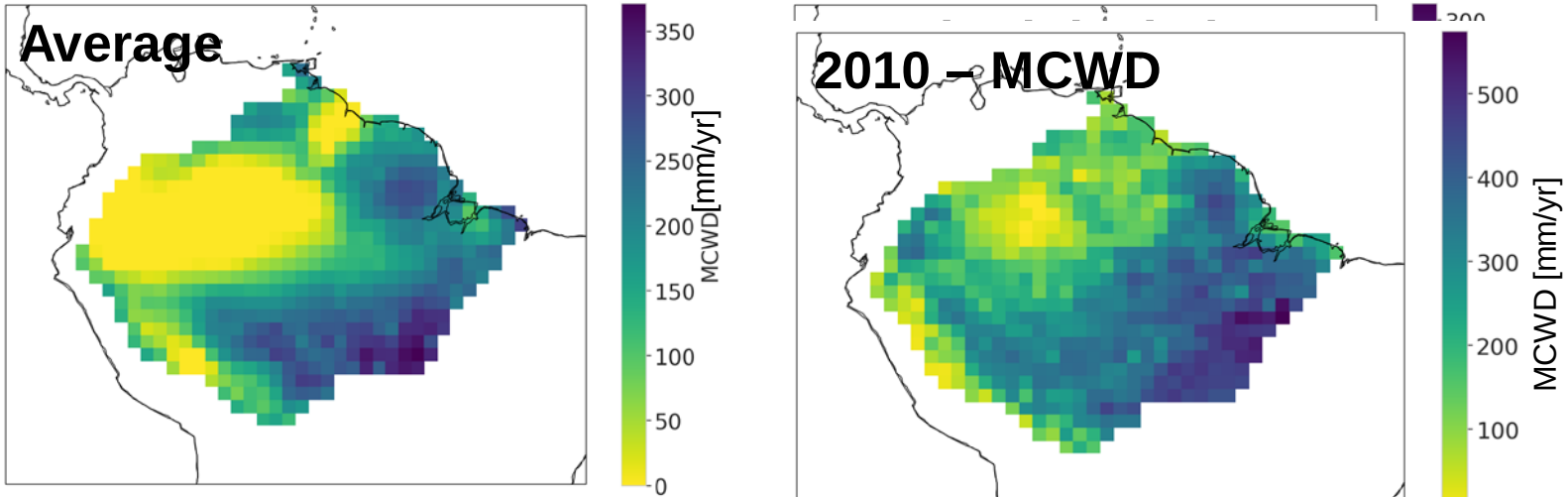
Which regions of the Amazon rainforest are most vulnerable?

Setup: Each node is a tipping element

1. Two stable states exist: Rainforest or a savanna/treeless state
2. Critical variables: Mean annual precipitation & drought index (MCWD)

Stability against droughts: When does the rainforest tip?





Assumption:
Rainforest is adapted to past conditions

Past conditions (from GLDAS 1973-2002):
- Mean annual precipitation (Rainfall)
- Drought index (MCWD)

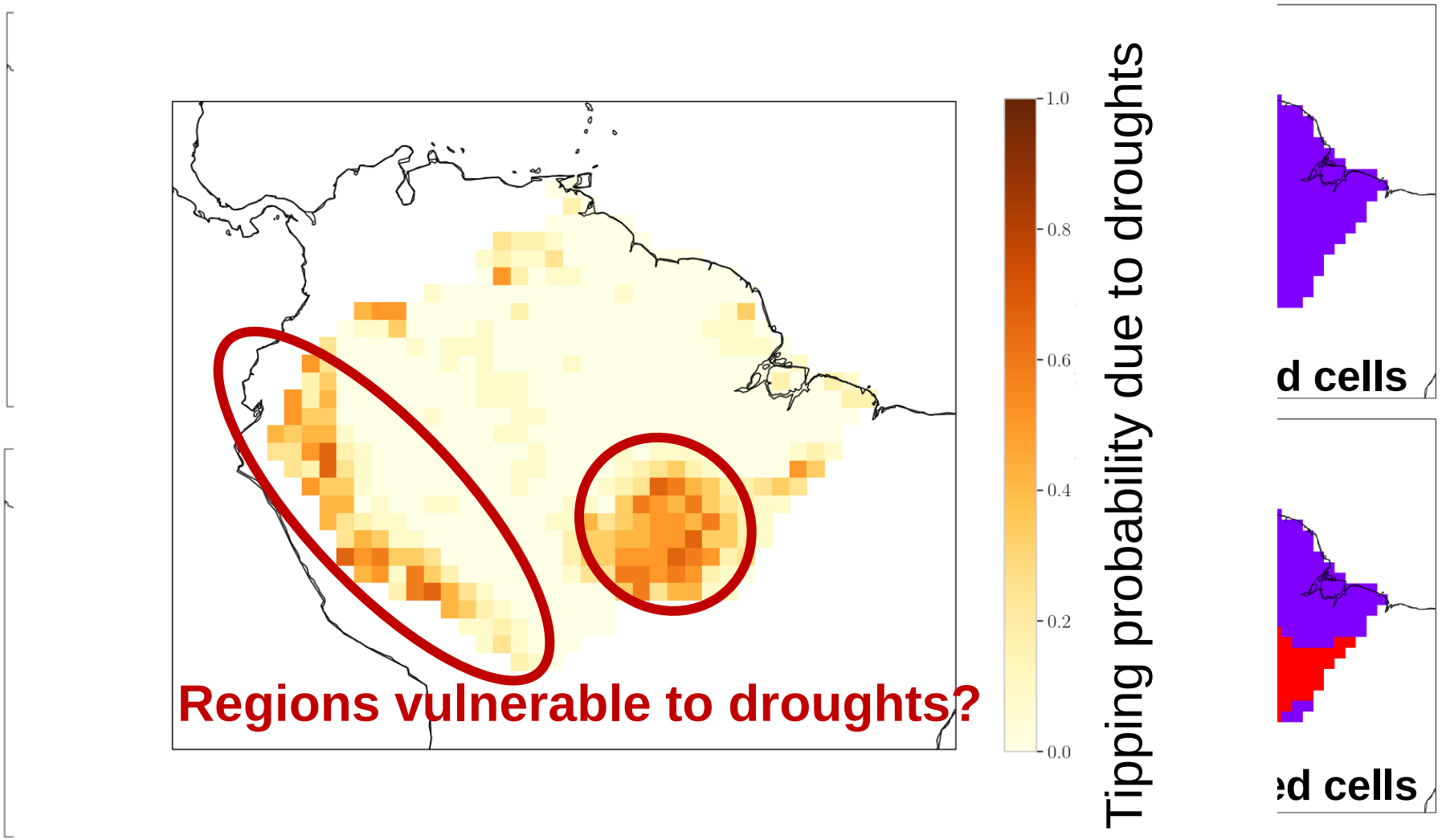
Tipping rule:

Average – 2 Standard Deviations

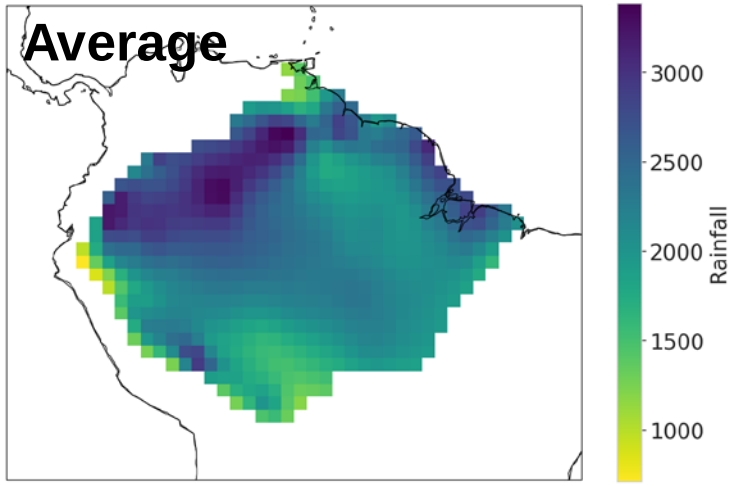
Evaluation data:

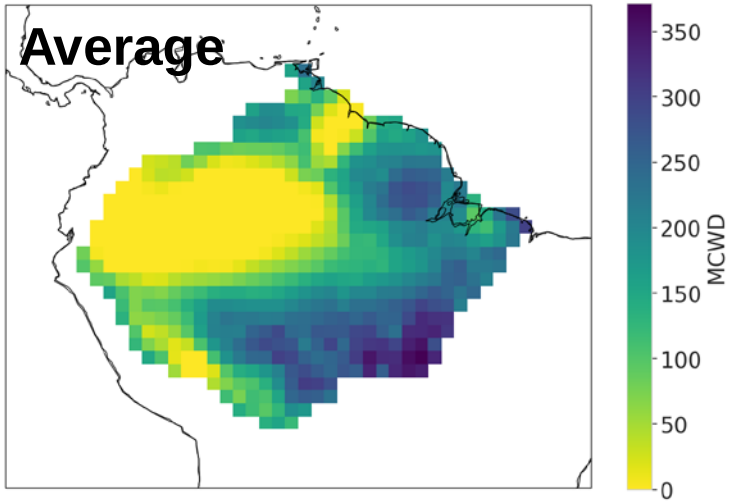
2003-2014:Rainfall, drought index, Moisture transport network

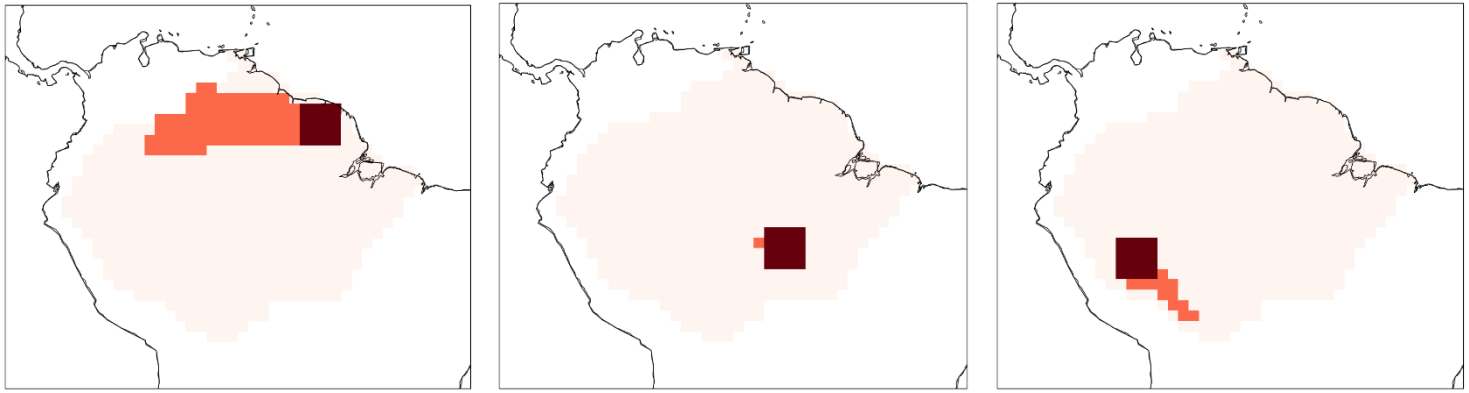
Stability against droughts: When does the rainforest tip?

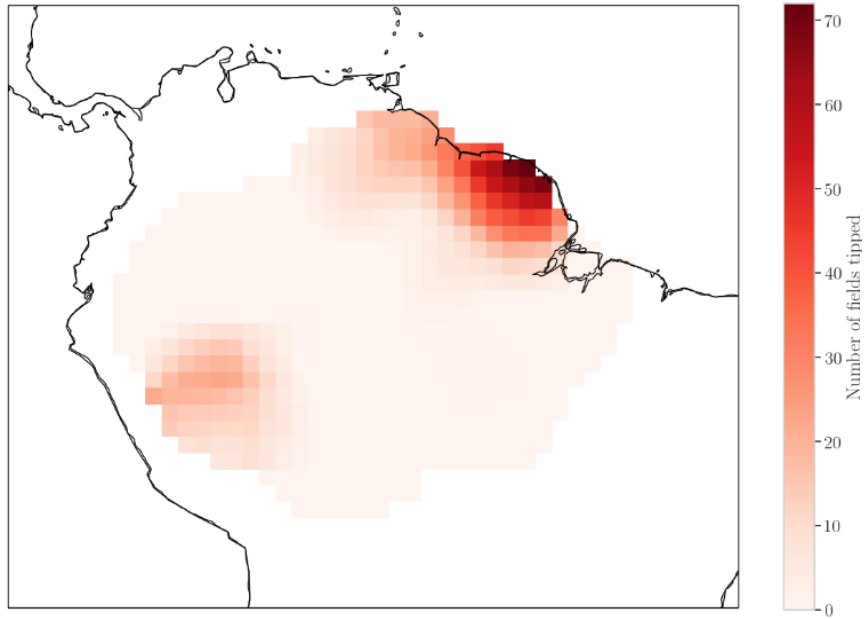


Stability against perturbations in forest cover?



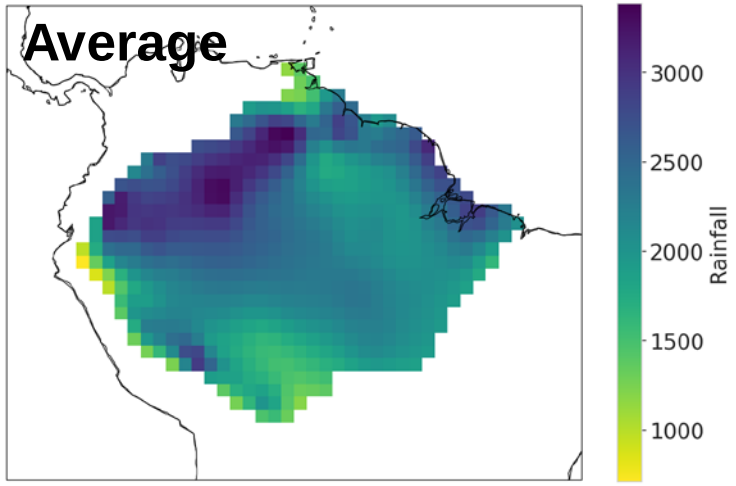


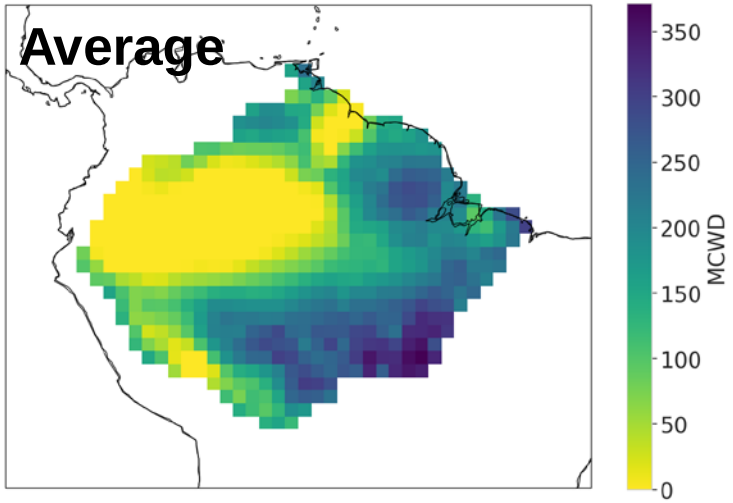




Vunerability map due to removal of forest patch

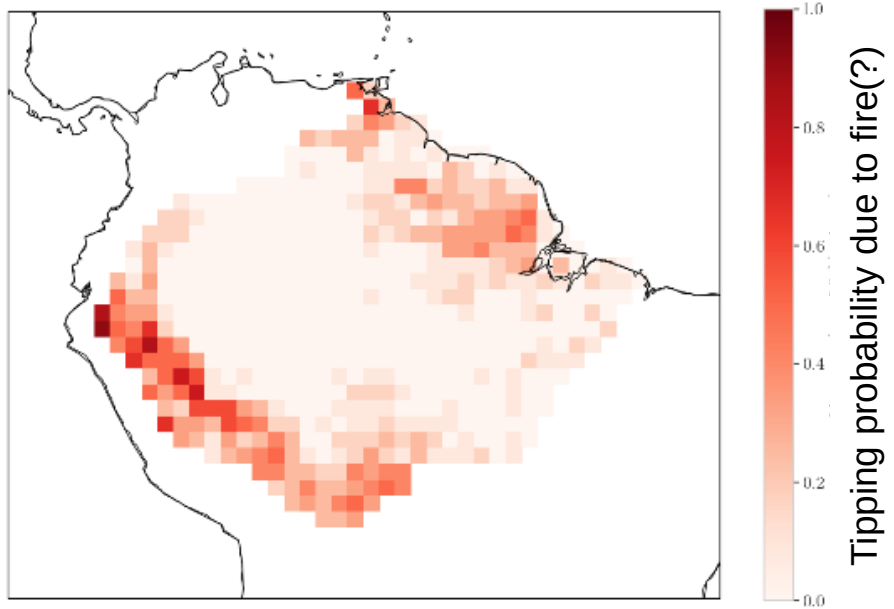
Stability against fixed thresholds





Old tipping rule:
Average – 2 Standard Deviations

New tipping rule:
i) Mean annual rainfall below 1000 mm/yr
ii) MCWD > 350 mm/yr

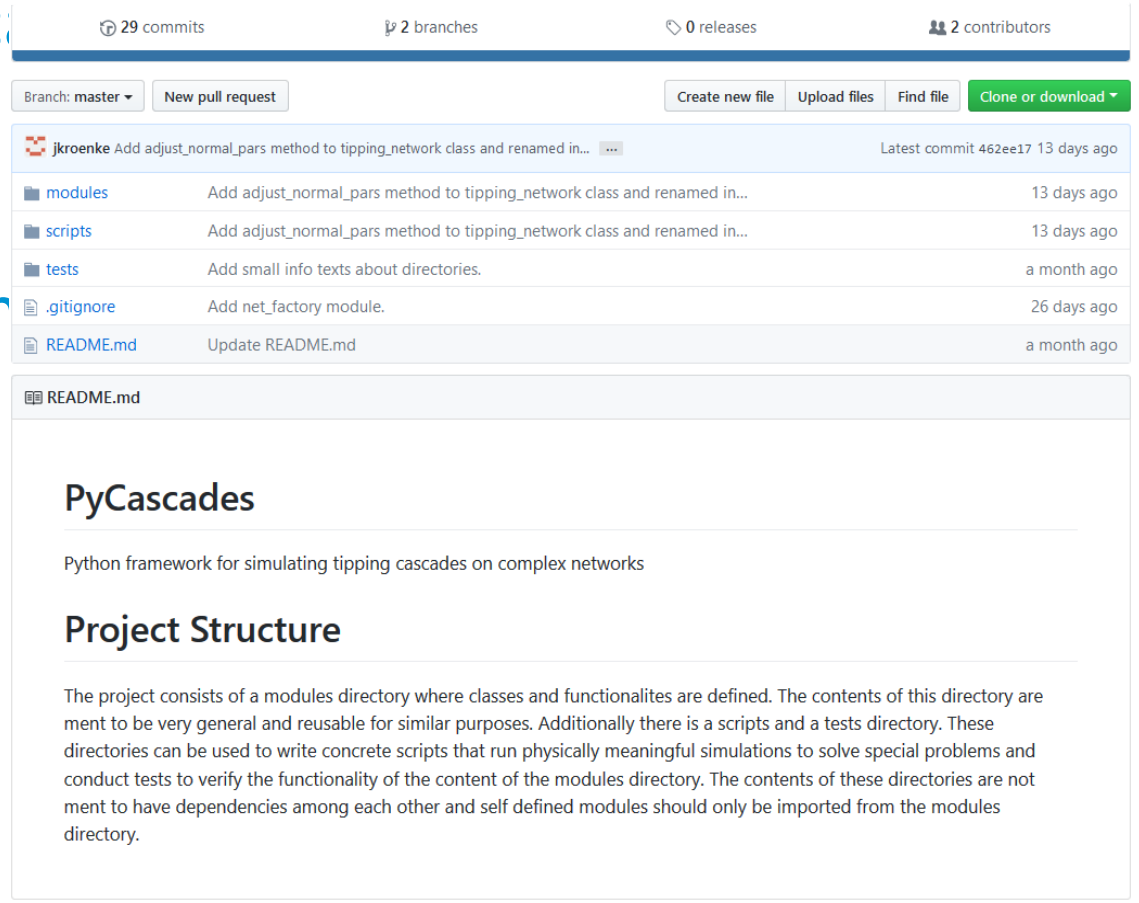



I think I got it,
but just in case
I will explain it
once more

Conclusion

1. Investigation of tipping casc
   the Amazon rainforest with
   to
- Adaptive thresholds (Drough
- Removal of forest cover
  (Deforestation?)
- Fixed thresholds (Fire?)

2. Github package available to simulate tipping cascades on networks



Github repository

The Amazon rainforest as a tipping element: Network approaches to environmental transformations

Thank you!

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FAPESP

PIK

IRTG 1740

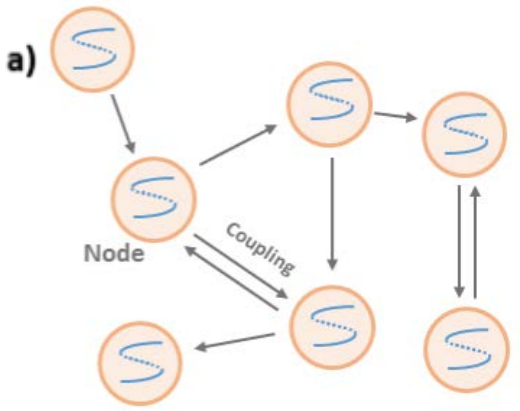
Literature

1. Krönke, J., **Wunderling, N**., Winkelmann, R., Staal, A., Tuinenburg, O., Donges, J.F., Dynamics of tipping cascades in complex networks (PRE in review)
2. **Wunderling, N.*,** Stumpf, B.*, Krönke, J., Staal, A., Tuinenburg, O., Winkelmann, R. & Donges, J.F., Linking Micro to Macro: How motifs condition critical thresholds in complex networks (Chaos, in review), *These authors share the first authorship
3. **Wunderling, N.,** Donges, J.F., Kurths, J., Winkelmann, R., Interacting tipping elements increase risk of climate domino effects (submitted)
4. Donges, J.F., **Wunderling, N.,** Kurths, J., Winkelmann, Risk analysis approach for tipping cascades and domino effects in the Earth system under global warming (in prep.)
5. **Wunderling, N.,** Staal, A., Sakschewski, B., Thonicke, K., Barbosa, H.M.J., Donges, J. F., Winkelmann, R., The Amazon rainforest – Vulnerability due to droughts (in prep.)

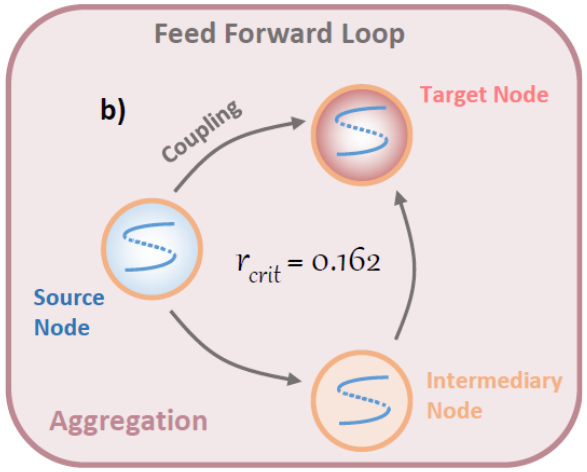
Further literature

1. Staal, A., Tuinenburg, O.A., Bosmans, J.H., Holmgren, M., van Nes, E.H., Scheffer, M., Zemp, D.C. and Dekker, S.C., 2018. Forest-rainfall cascades buffer against drought across the Amazon. *Nature Climate Change*, *8*(6), p.539.
2. Zemp, D.C., Schleussner, C.F., Barbosa, H.M., Hirota, M., Montade, V., Sampaio, G., Staal, A., Wang-Erlandsson, L. and Rammig, A., 2017. Self-amplified Amazon forest loss due to vegetation-atmosphere feedbacks. *Nature communications*, *8*, p.14681.
3. Hirota, M., Holmgren, M., Van Nes, E.H. and Scheffer, M., 2011. Global resilience of tropical forest and savanna to critical transitions. *Science*, *334*(6053), pp.232-235.
4. Lenton, T.M. and Williams, H.T., 2013. On the origin of planetary-scale tipping points. *Trends in Ecology & Evolution*, *28*(7), pp.380-382.
5. Kriegler, E., Hall, J.W., Held, H., Dawson, R. and Schellnhuber, H.J., 2009. Imprecise probability assessment of tipping points in the climate system. *Proceedings of the national Academy of Sciences*, *106*(13), pp.5041-5046.
6. 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.
7. Hirota, M., Holmgren, M., Van Nes, E.H. and Scheffer, M., 2011. Global resilience of tropical forest and savanna to critical transitions. *Science*, *334*(6053), pp.232-235.
8. Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J., 2008. Tipping elements in the Earth's climate system. *Proceedings of the national Academy of Sciences*, *105*(6), pp.1786-1793.

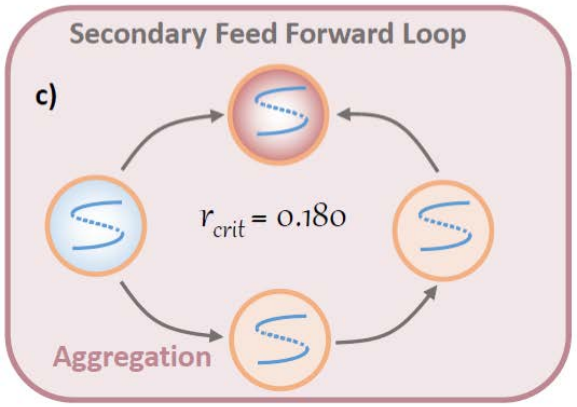
Structures of vulnerability: The notion of motifs

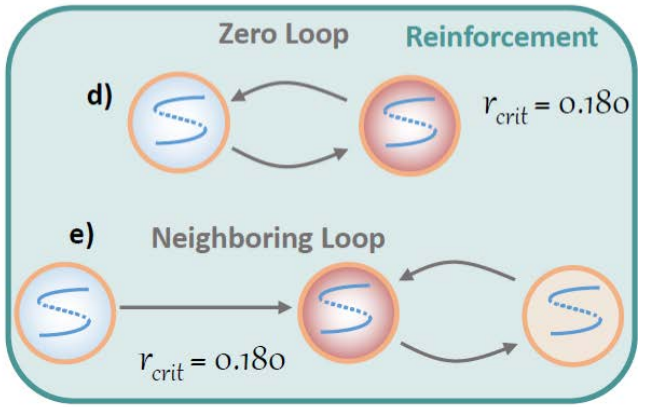


Wunderling, Stumpf et al. (Chaos, in review)

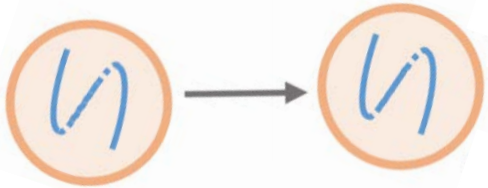


Weak Motifs

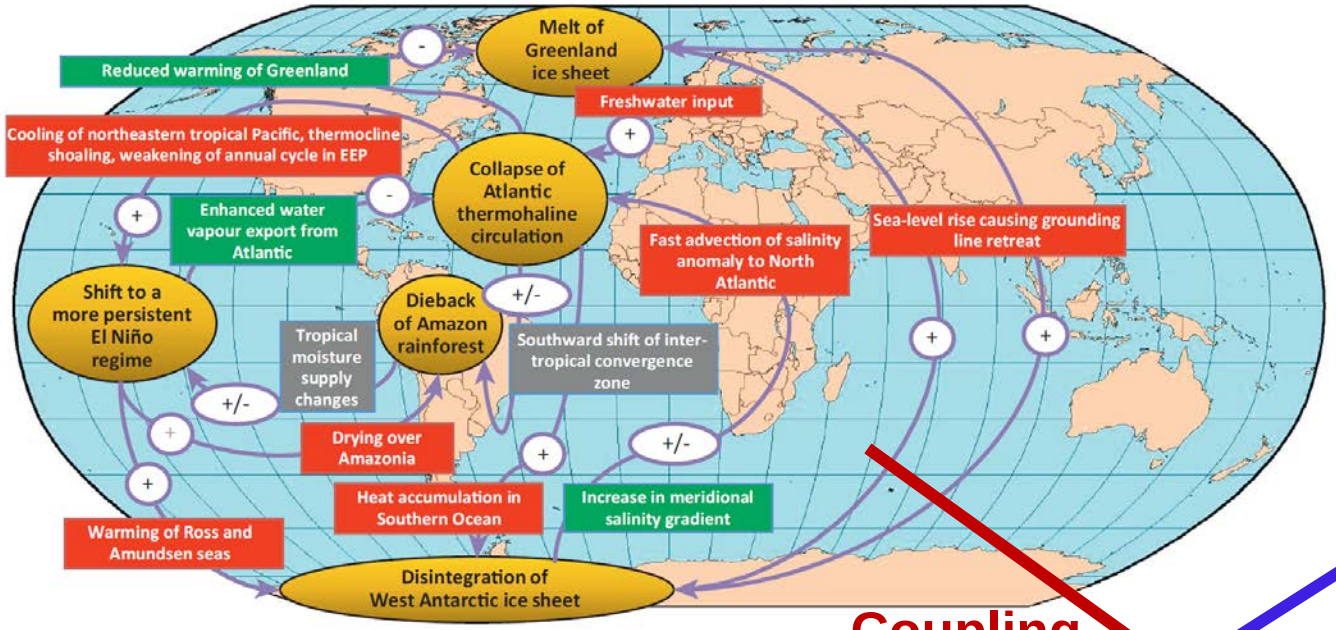




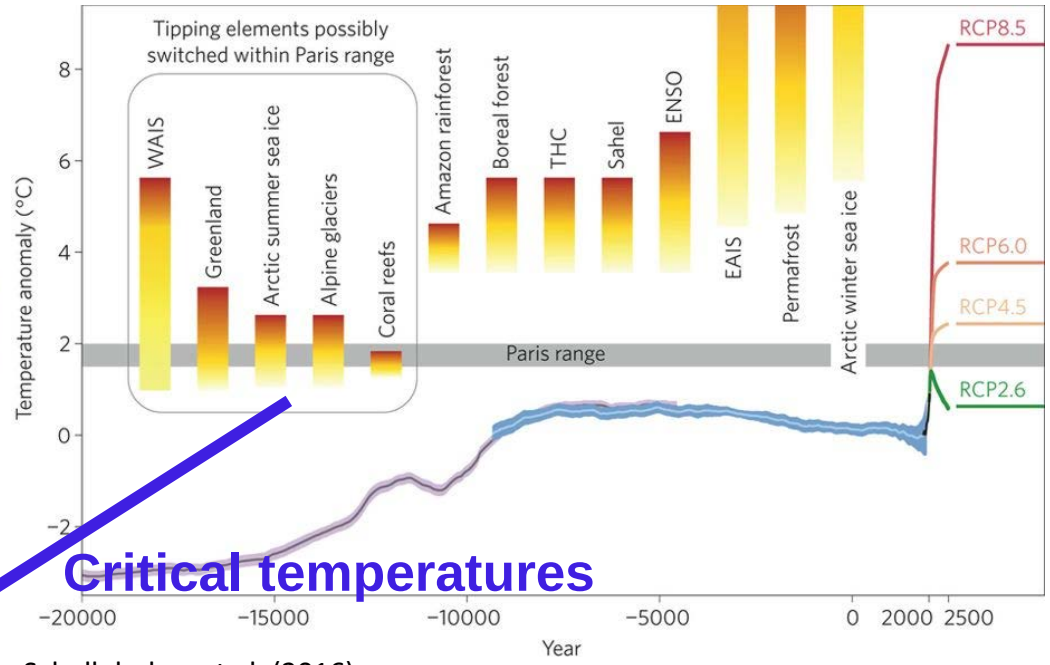
$$r_{crit} = 0.182$$



Risk of domino effects in the Climate system



Lenton & Williams (2013)



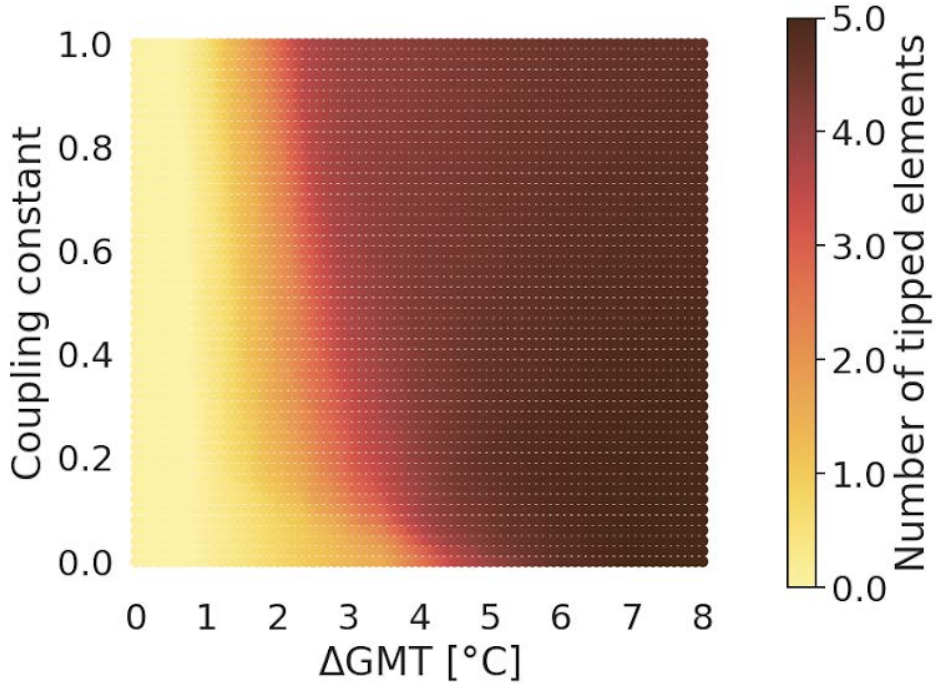
Schellnhuber et al. (2016)

Coupling

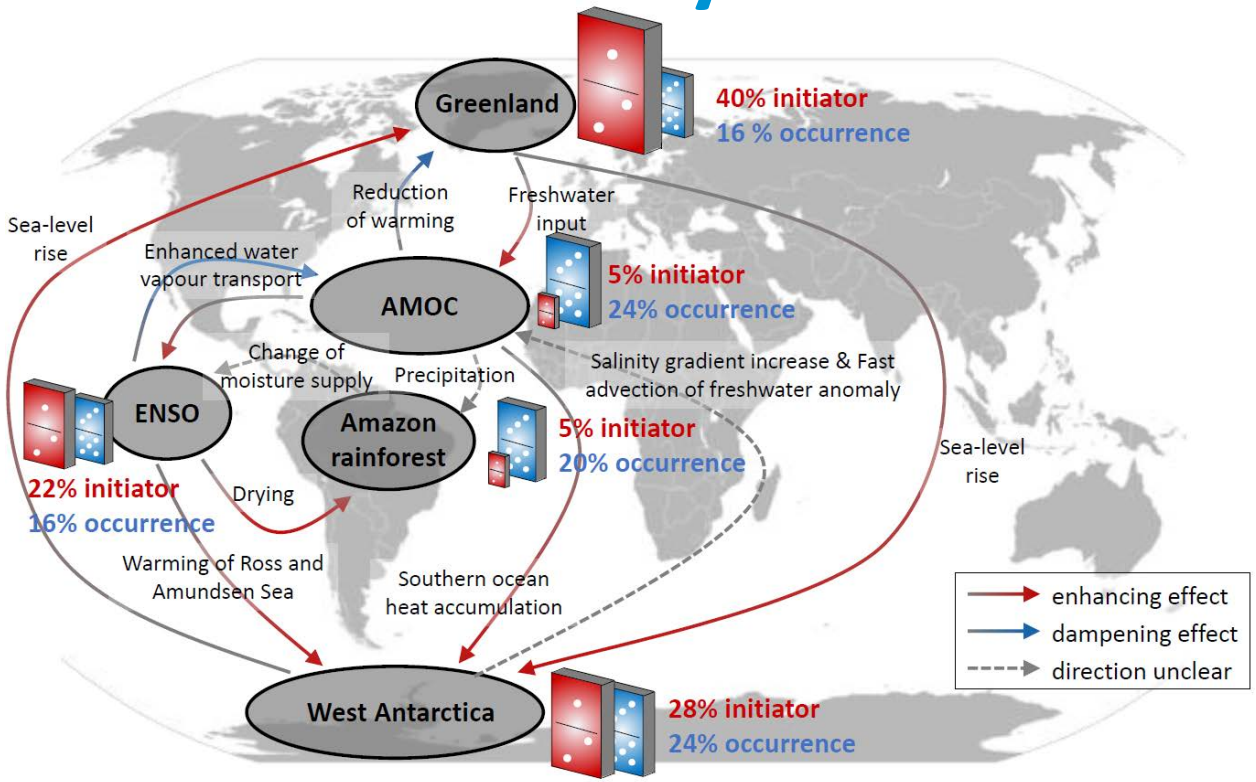
Critical temperatures

$$\frac{dx_i}{dt} = -a(x_i - x_0)^3 + b(x_i - x_0) + c_i + d \sum_{\substack{j \\ j \neq i}} a_{ij}(x_j - x_0)$$

Risk of domino effects in the Climate system



Donges, **Wunderling**, Kurths, Winkelmann (in prep.)



Wunderling, Donges, Kurths, Winkelmann (submitted)

1) Find **roles of tipping elements** within cascades
2) Determine **vulnerability** of climate tipping elements
3) **Risk analysis** approach with complex networks