Fragmented tipping in a spatially heterogeneous world

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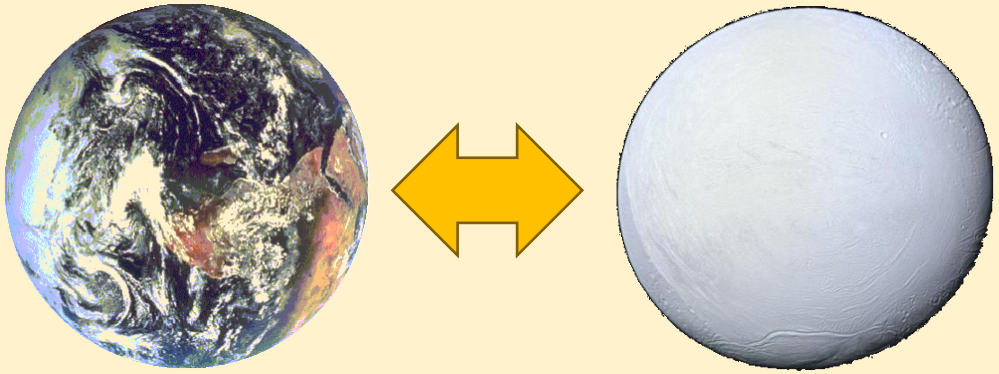
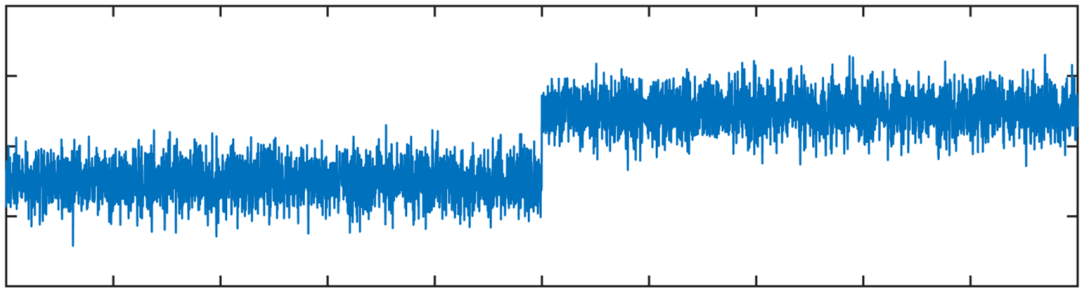
Robbin Bastiaansen (r.bastiaansen@uu.nl)

Tipping Points

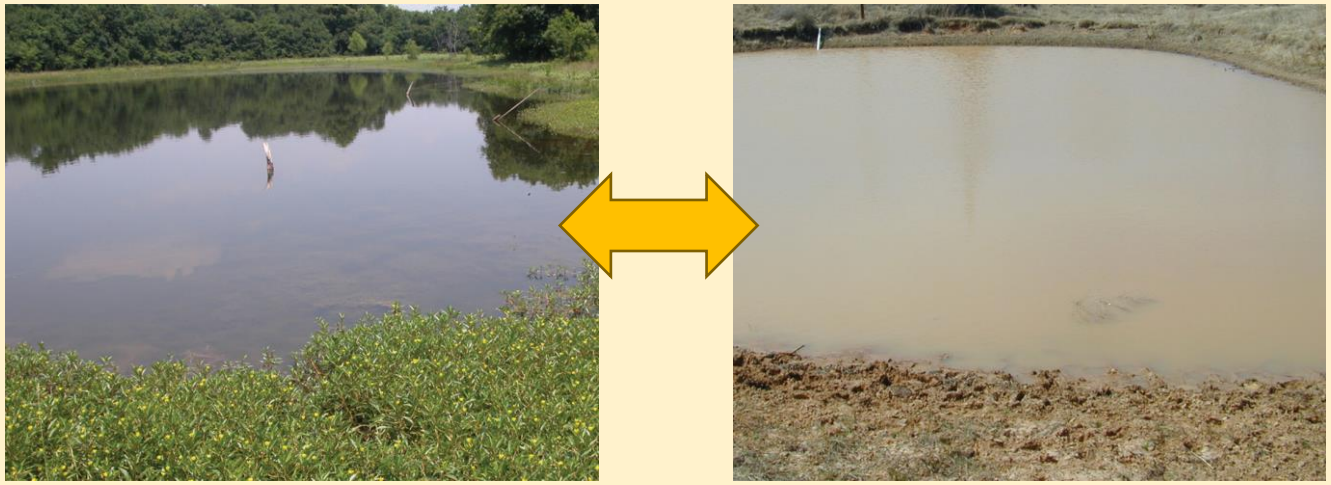
IPCC AR6 (2021) : “a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly”



Planetary transitions

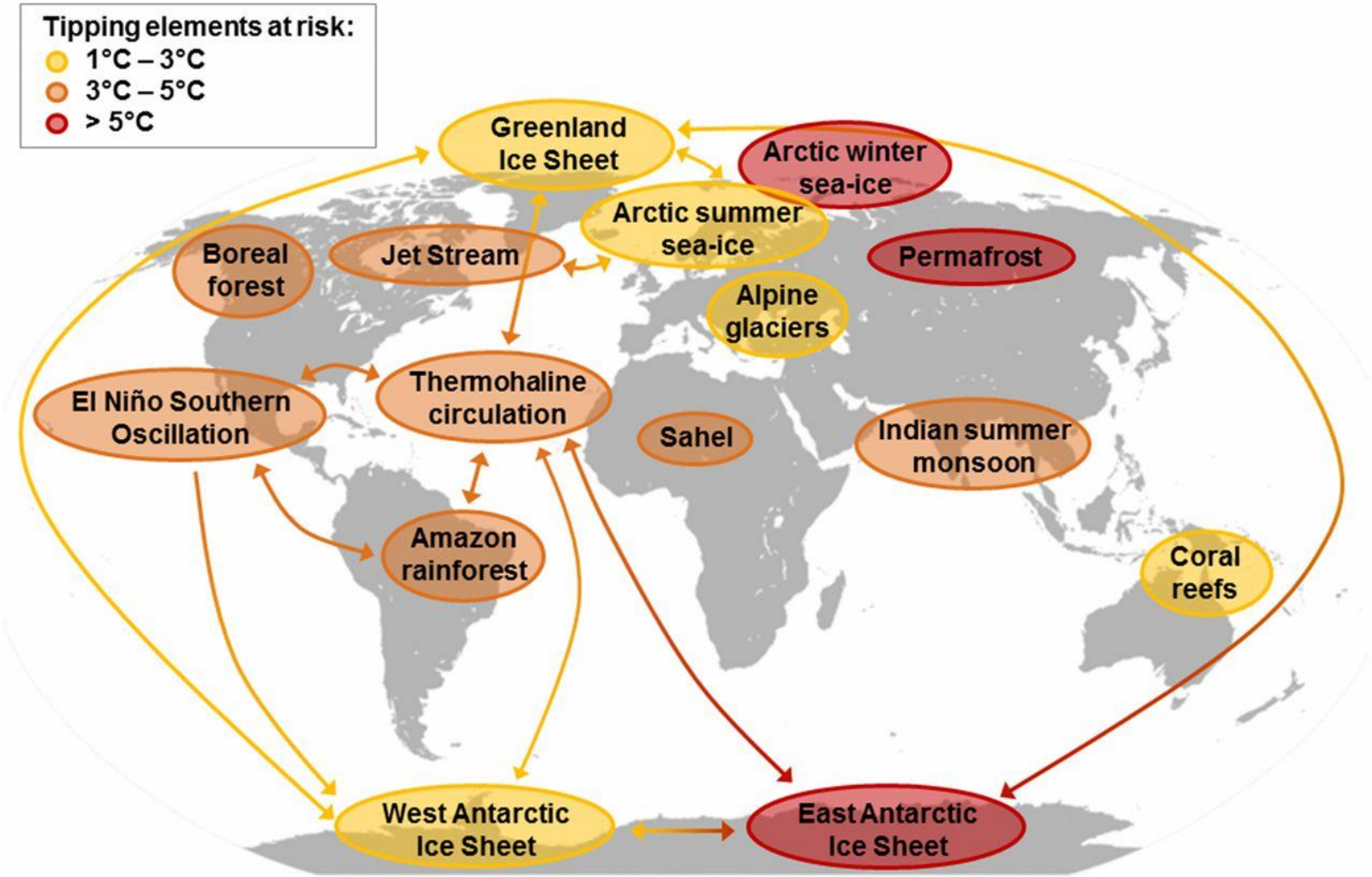


Ecosystem shifts



Tipping Points

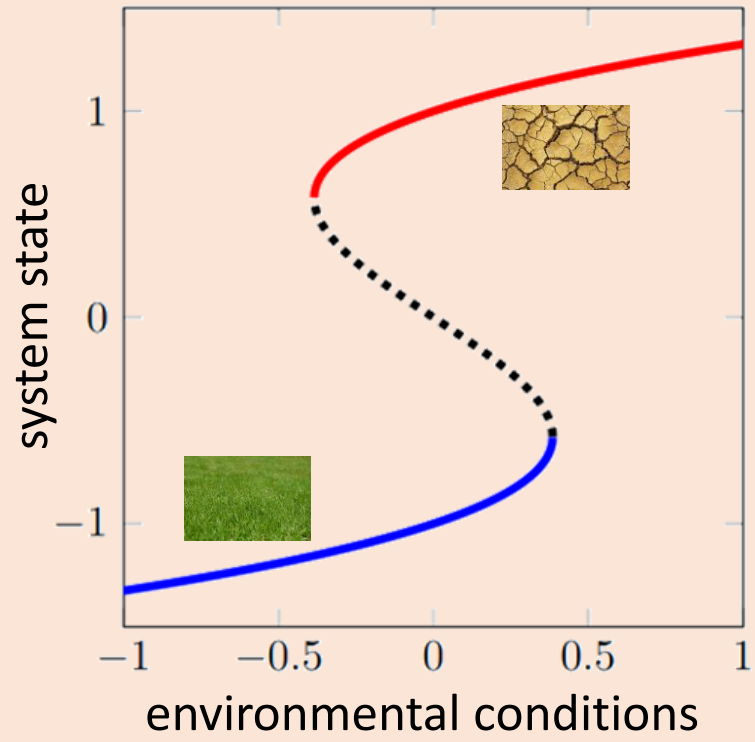
IPCC AR6 (2021) : "a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly"



source: Steffen et al, 2018

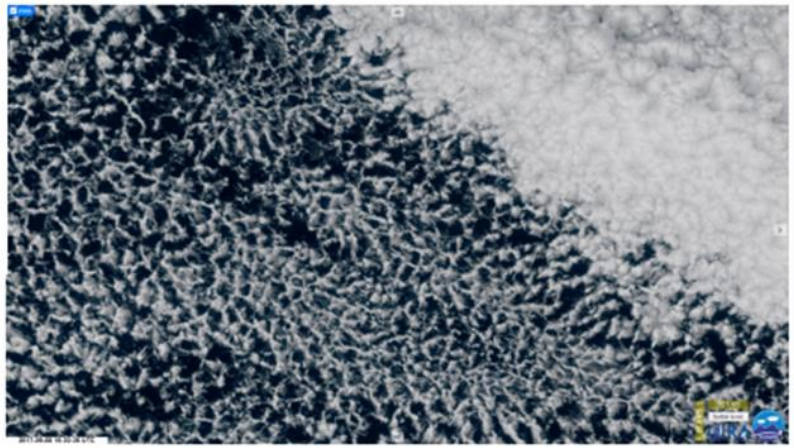
Tipping points ↔ Bifurcations

$$\frac{dy}{dt} = f(y, \mu)$$

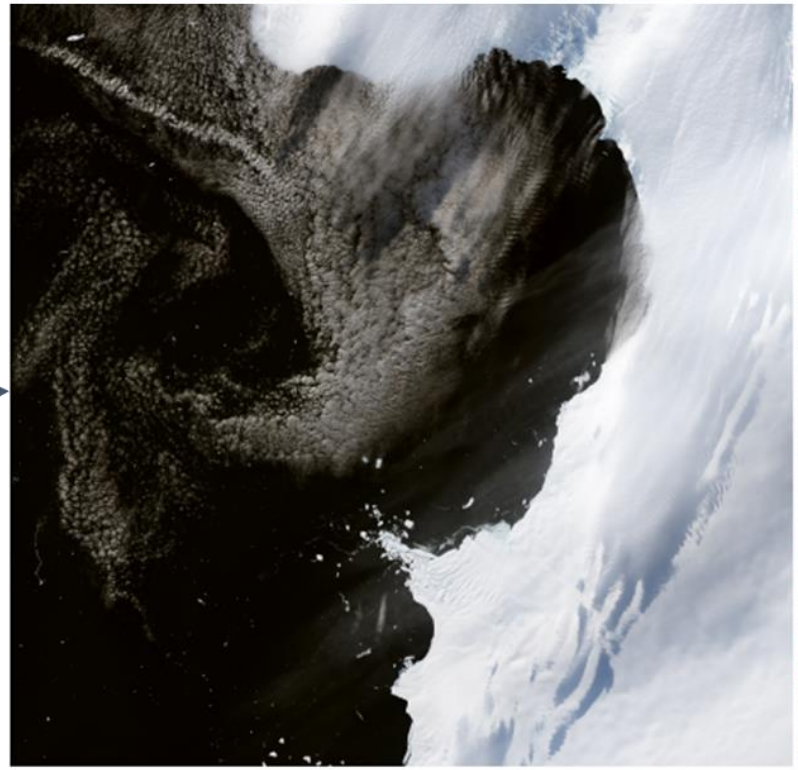


Reality is not always spatially-uniform!

tropical forest & savanna ecosystems
[Google Earth]



types of stratocumulus clouds
[RAMMB/CIRA SLIDER]



sea-ice & water at Eltanin Bay
[NASA's Earth observatory]

algae bloom in Lake St. Clair
[NASA's Earth observatory]

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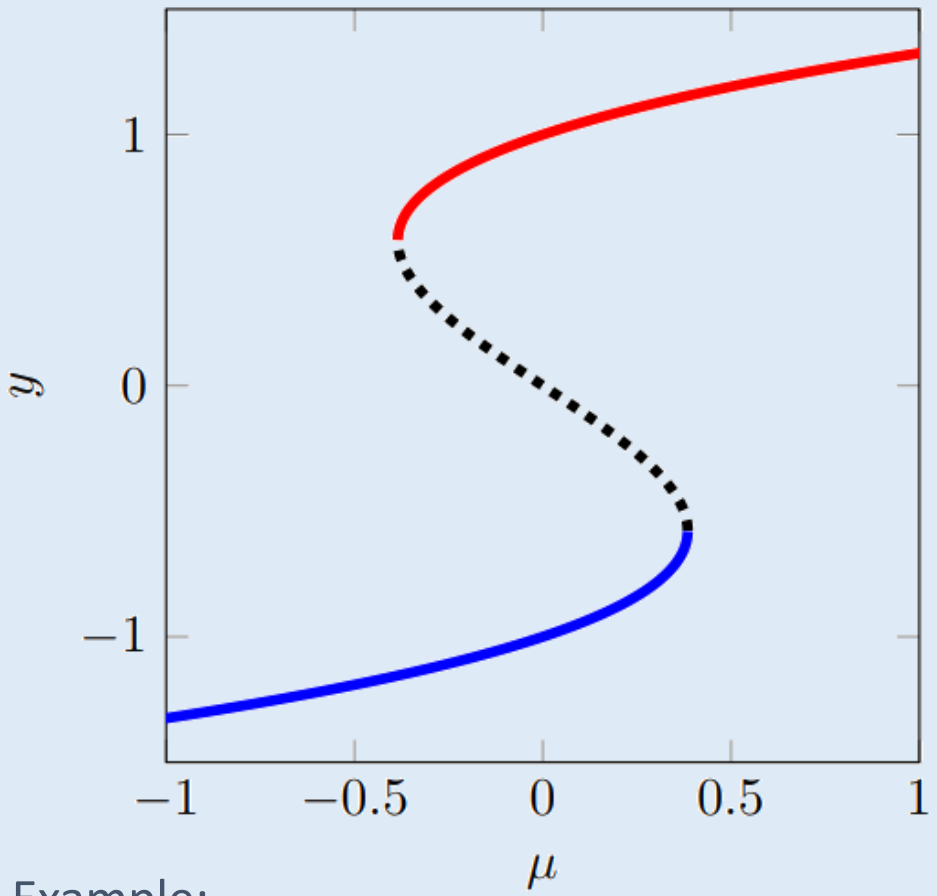
Co-financed by the Connecting Europe Facility of the European Union

Classic Tipping



Example:

$$\frac{dy}{dt} = y(1-y^2) + \mu$$

Tipping in Spatially Heterogeneous Systems

Spatial Transport

Spatial Variation in Environmental Conditions

Example:

$$\frac{\partial y}{\partial t} = \boldsymbol{D}\frac{\boldsymbol{\partial^2 y}}{\boldsymbol{\partial x^2}} + y(1-y^2) + \mu + \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\cos(\pi x)}$$

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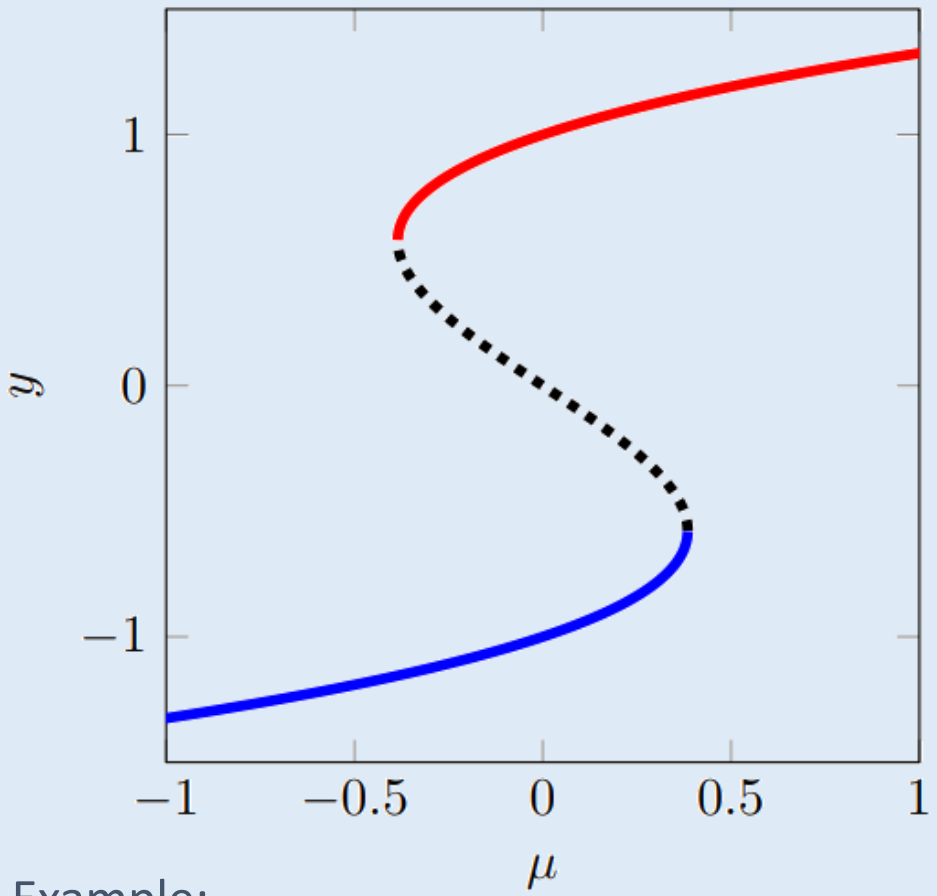
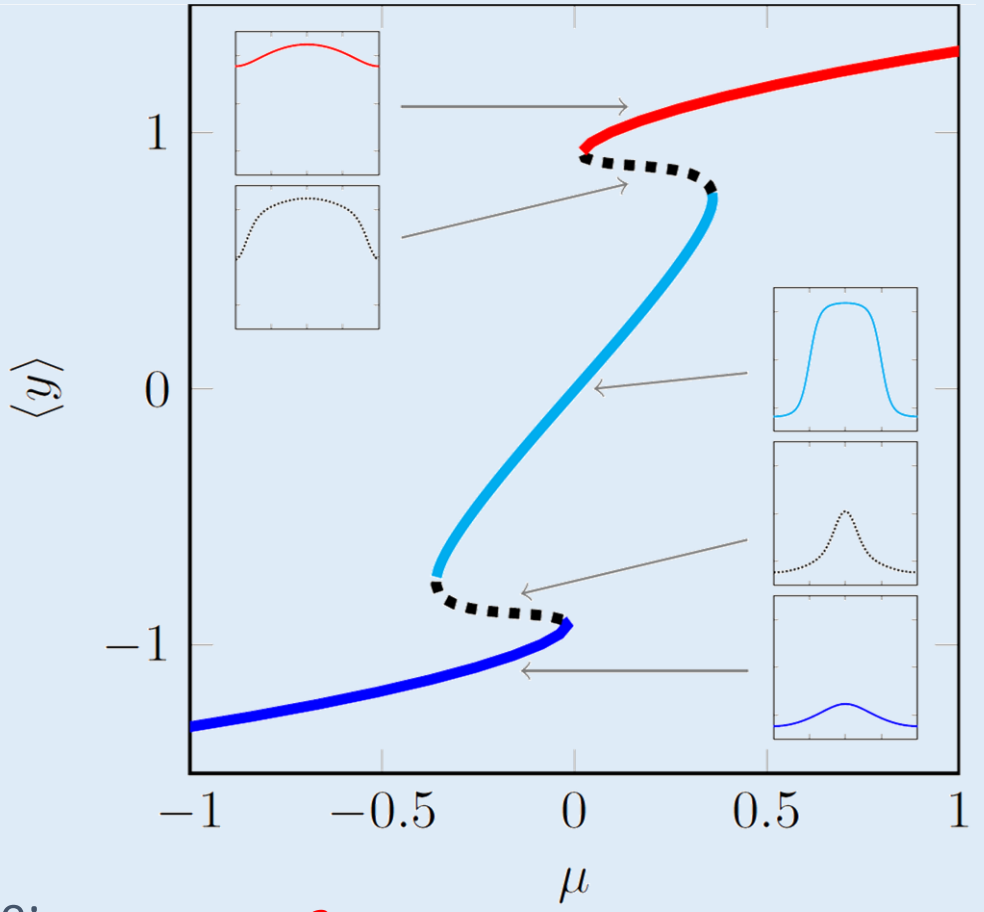
Classic Tipping



Example:

$$\frac{dy}{dt} = y(1-y^2) + \mu$$

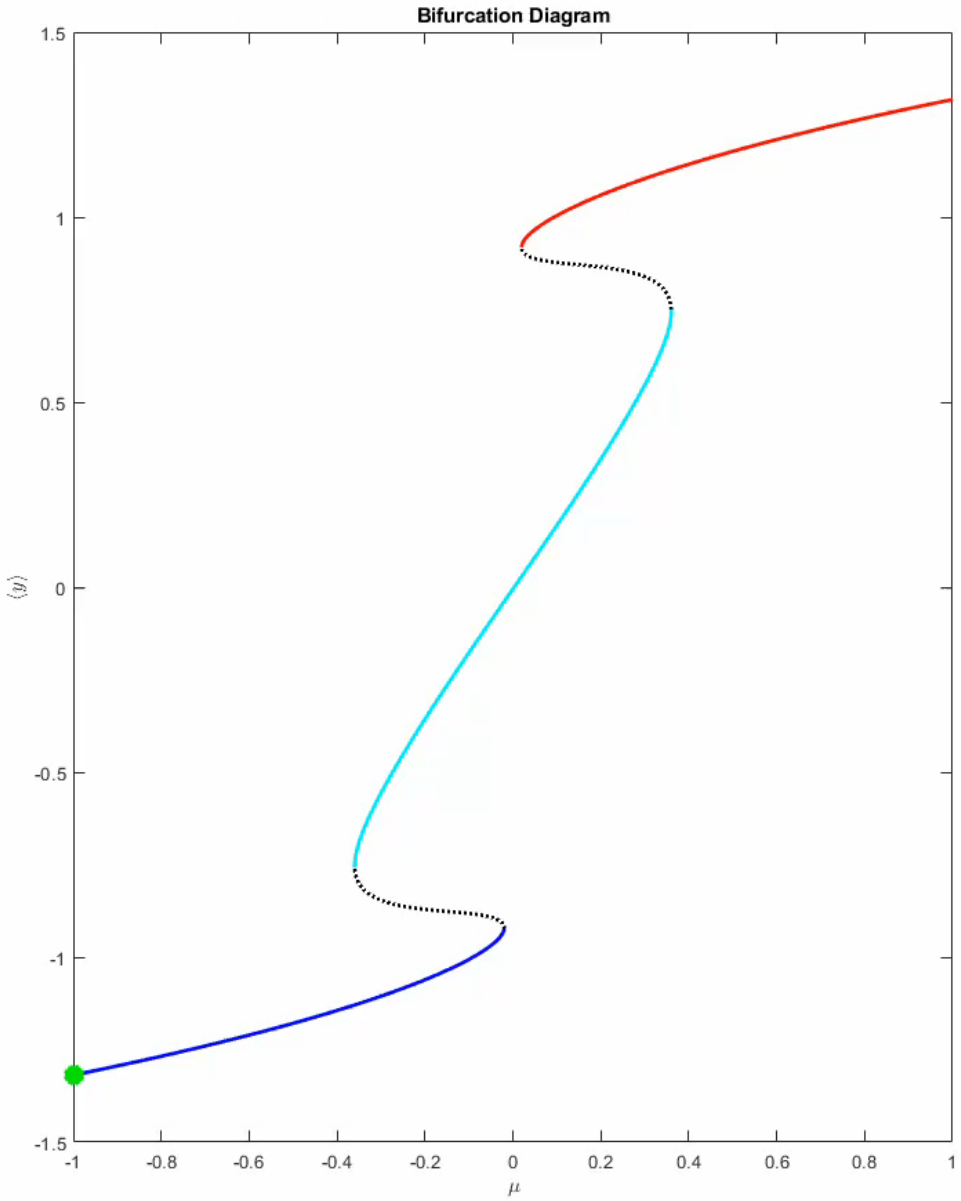
Tipping in Spatially Heterogeneous Systems

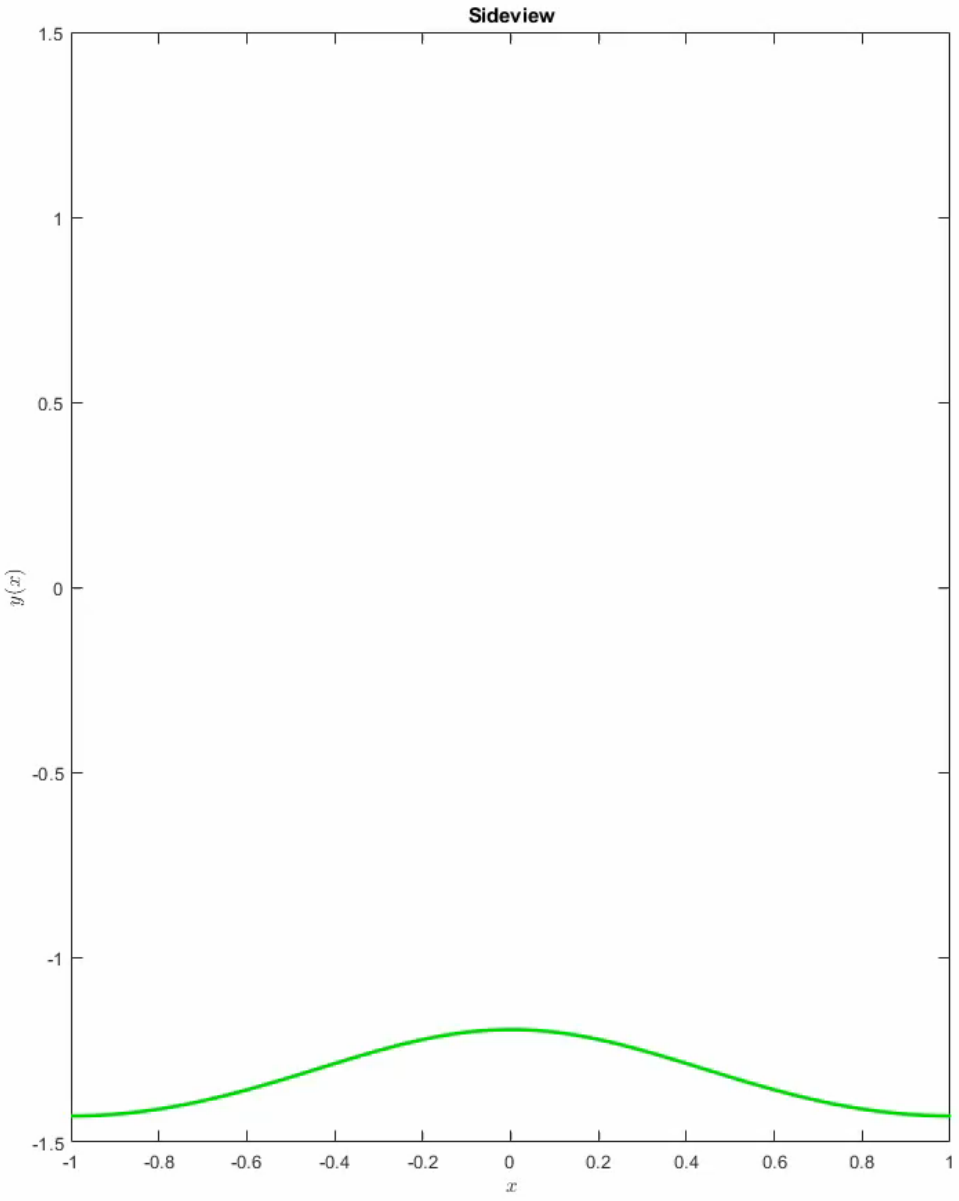


Example:

$$\frac{\partial y}{\partial t} = D\frac{\partial^2 y}{\partial x^2} + y(1-y^2) + \mu + \frac{1}{2}\cos(\pi x)$$

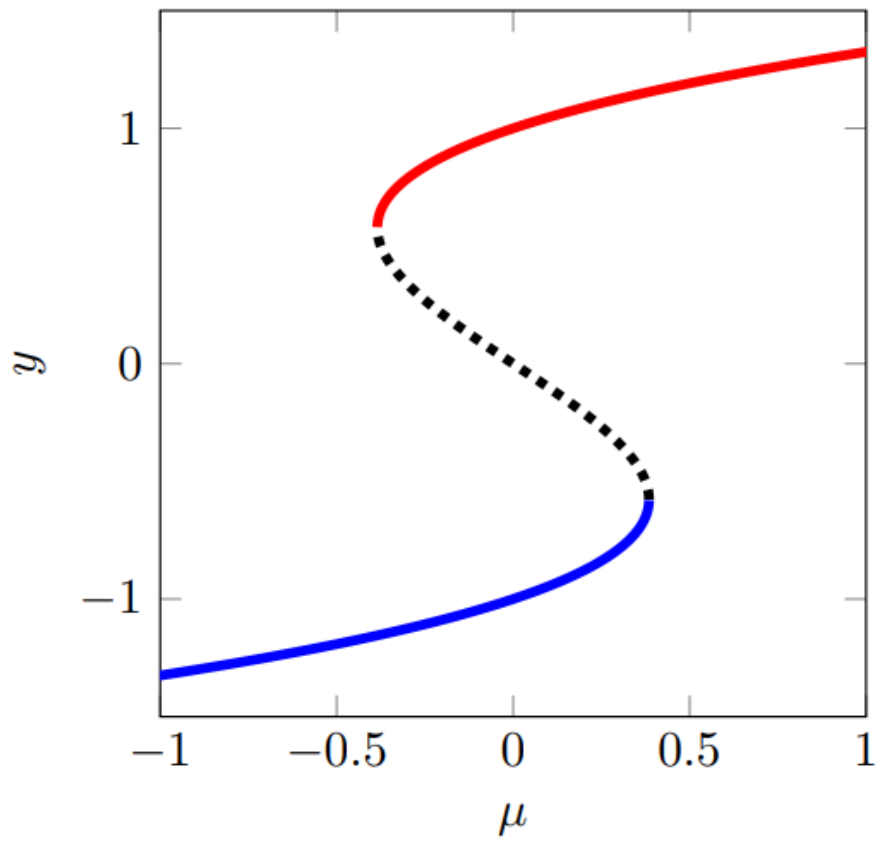
Fragmented Tipping





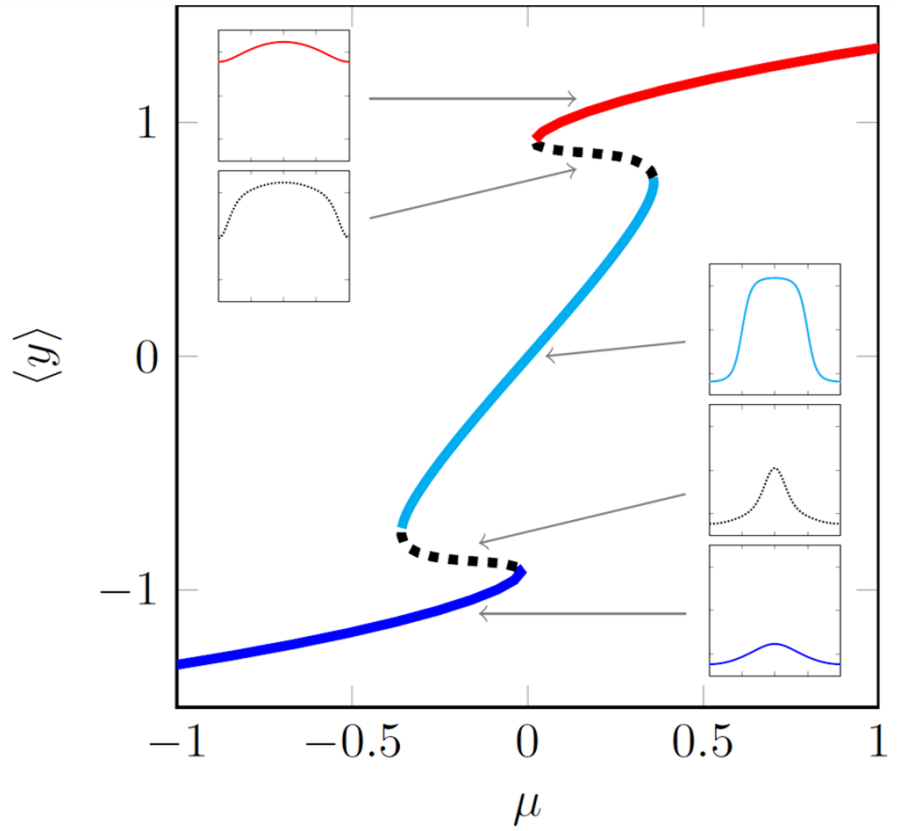
Fragmented Tipping

Classic picture



Tipping leads to full reorganisation

New picture



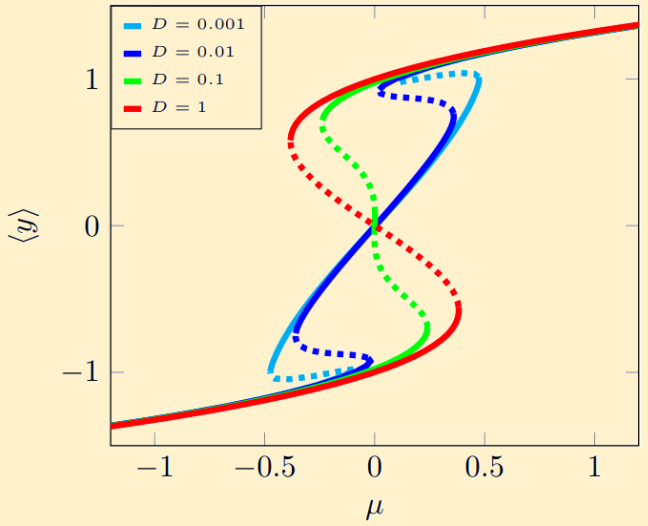
Fragmented tipping possible:
Only part of the domain reorganises

Do systems always behave like this? (a.k.a. the small print)

No.

Well-mixed systems

Spatially confined systems



→ Such systems (again) just have one global tipping point ←

But even in other systems terms & conditions apply:
System-specific knowledge is required!

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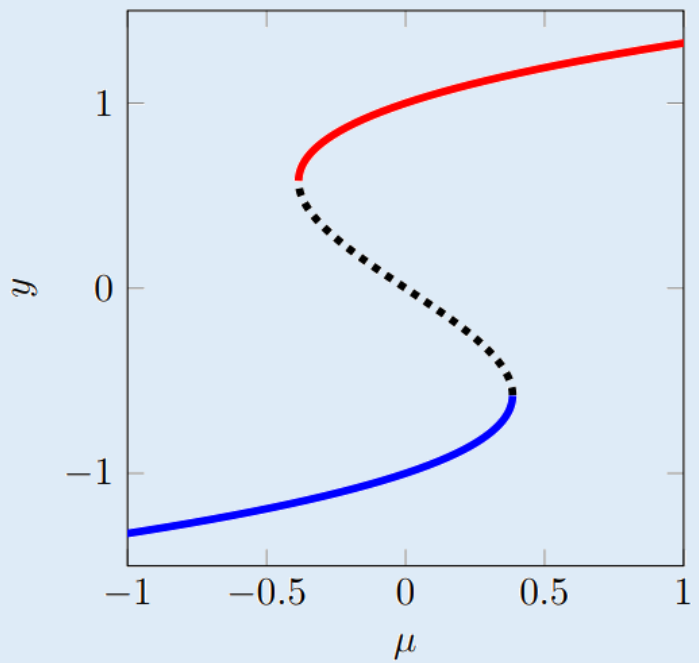
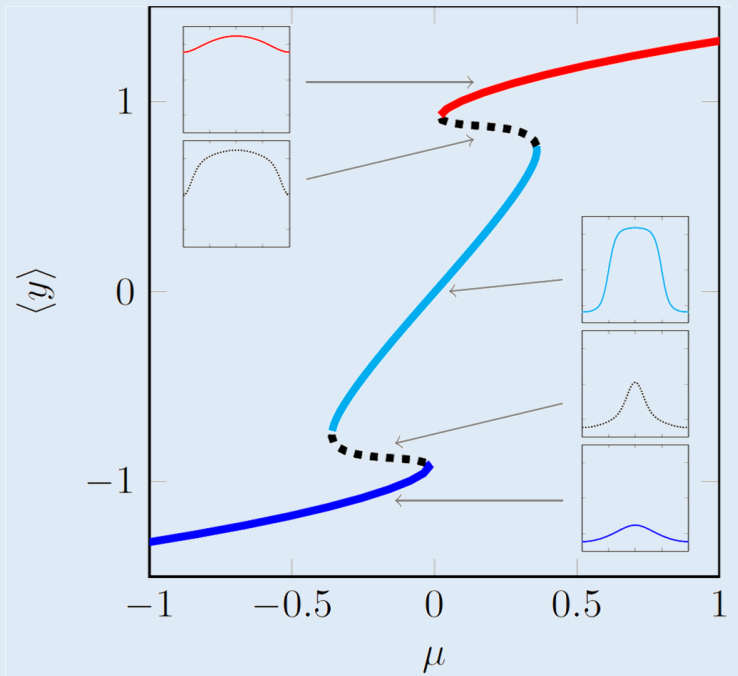
Classic Tipping Picture



Fragmented tipping in spatially heterogeneous systems



Bastiaansen, R., Dijkstra, H. A., & von der Heydt, A. S. (2022). Fragmented tipping in a spatially heterogeneous world. *Environmental Research Letters, 17, 045006*