Climate response and sensitivity: time scales and late tipping points

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Climate Response

The change in observable due to climate forcing (e.g. CO2)

Equilibrium Climate Sensitivity (ECS)

change in equilibrium temperature
due to (instantaneous) doubling of CO2

Transient Climate Response (TCR)

change in temperature after 100 years
with 1% CO2 increase per year (until doubling)

Methodology

- DESIGN experimental protocol for GCM
- FIT resulting time series to simple model
- EXTRAPOLATION using simple model

TODAY: a few words of caution, and some recommendations

Multiscale Global Energy Balance Model

$$C\frac{dT}{dt} = Q_0(1 - \alpha) - \epsilon(T)\sigma T^4 + \mu + \mu_{NV}$$

Short-Wave

Long-Wave

CO2

Natural variability

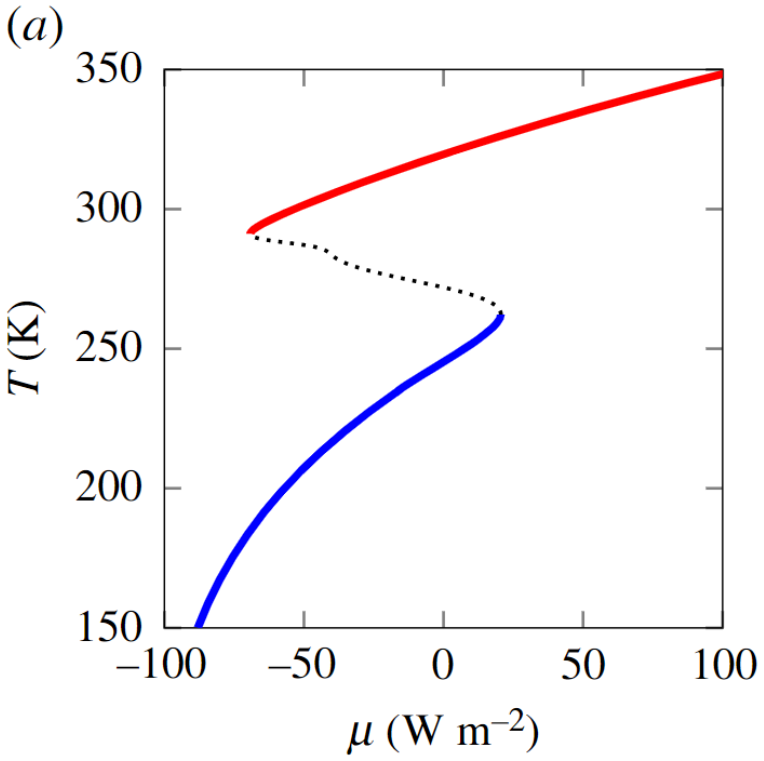
$$\mu_{NV} = \nu_{NV}\sin(\pi x/20)$$

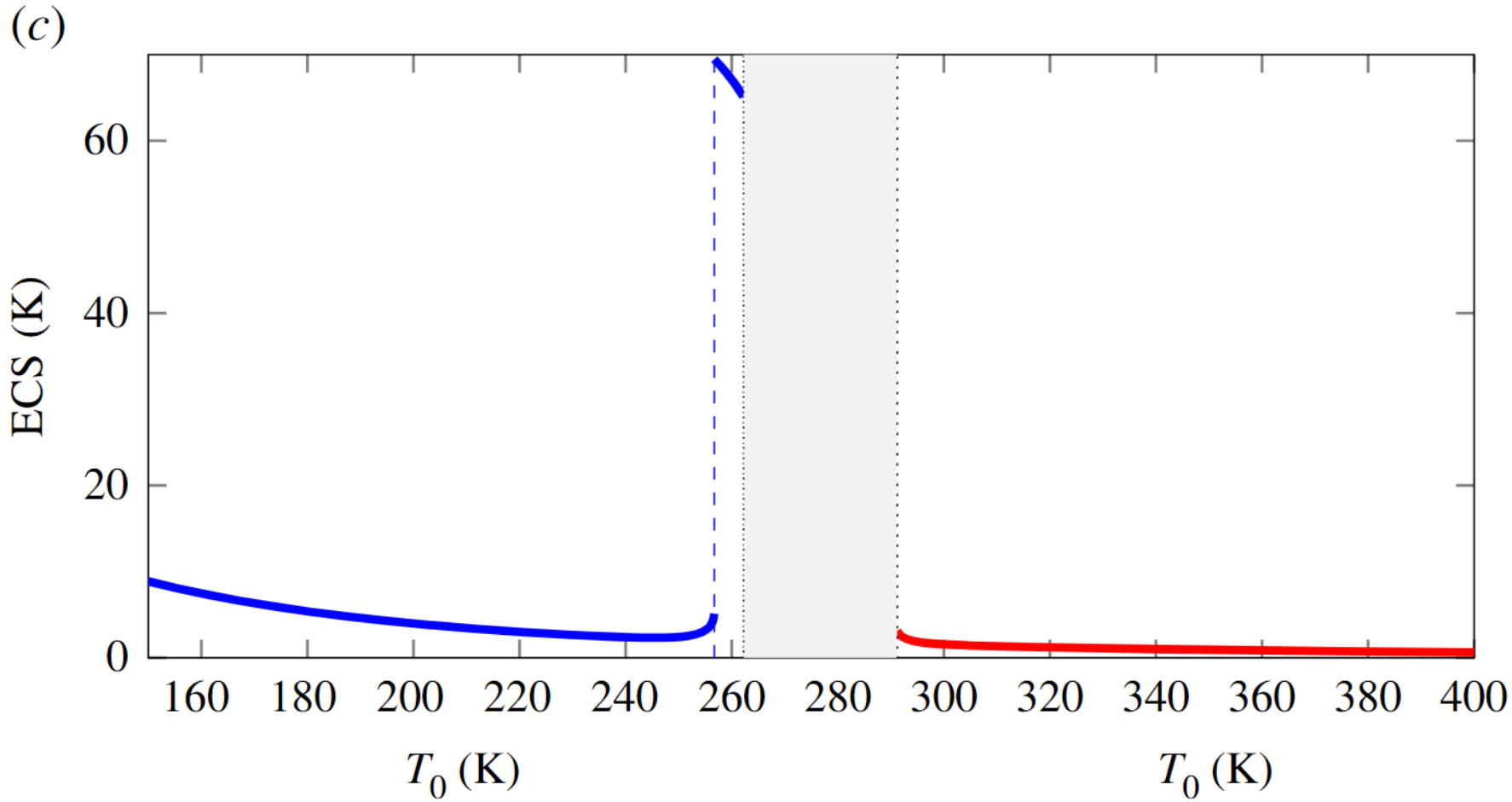
where x adheres to the Lorenz-63 model

$$\tau_\alpha \frac{d\alpha}{dt} = \alpha_0(T) - \alpha$$

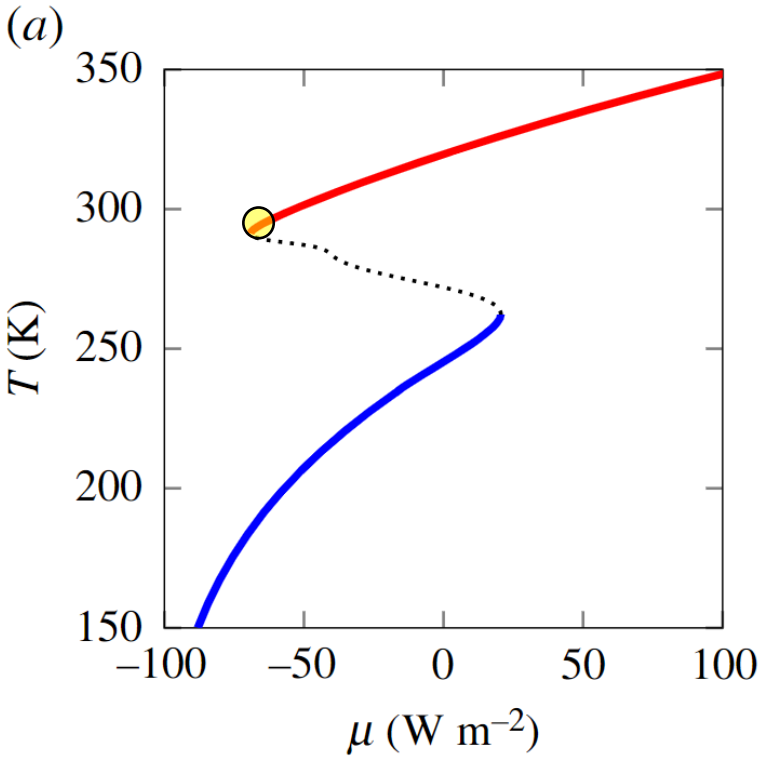
Dynamic albedo

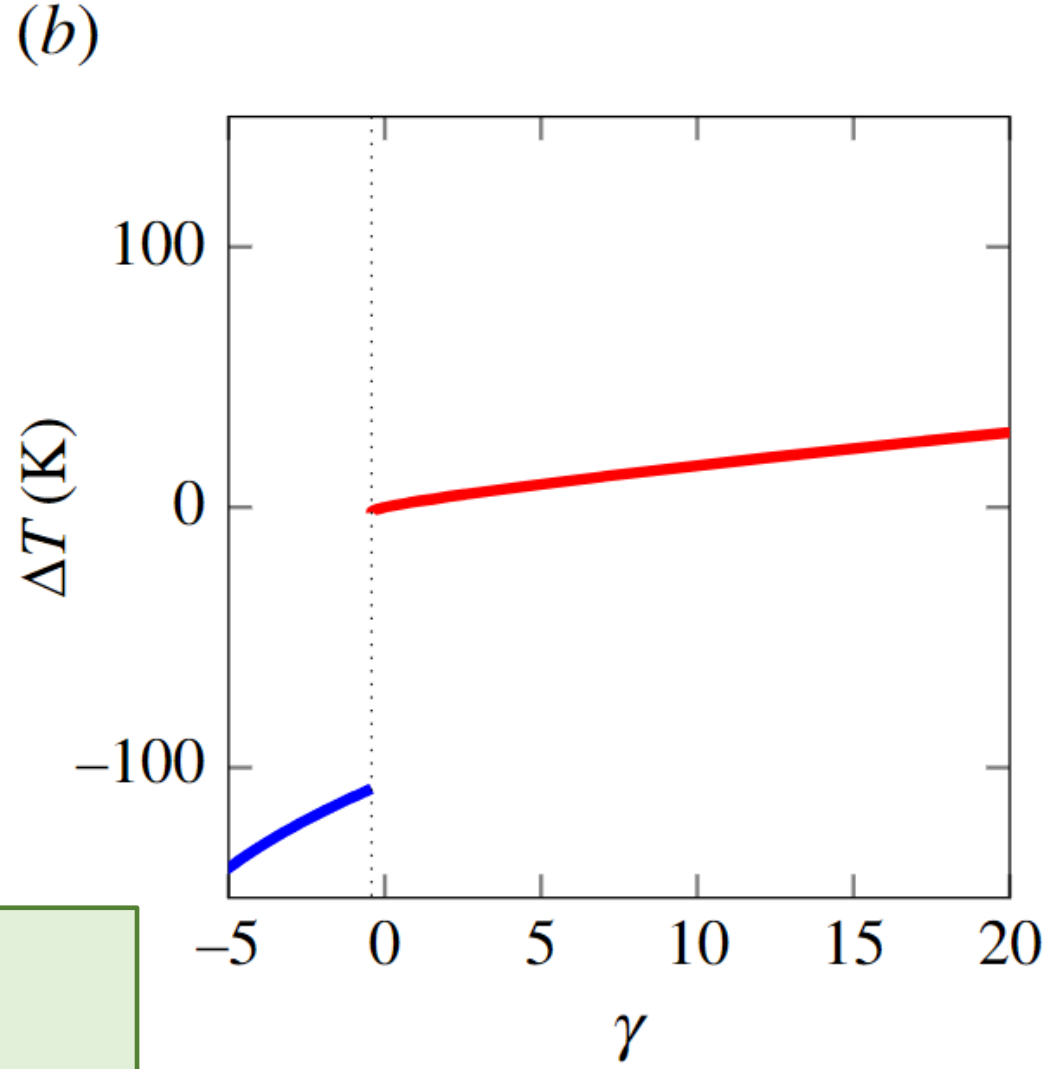
Equilibrium: Background dependency





Equilibrium: forcing dependency

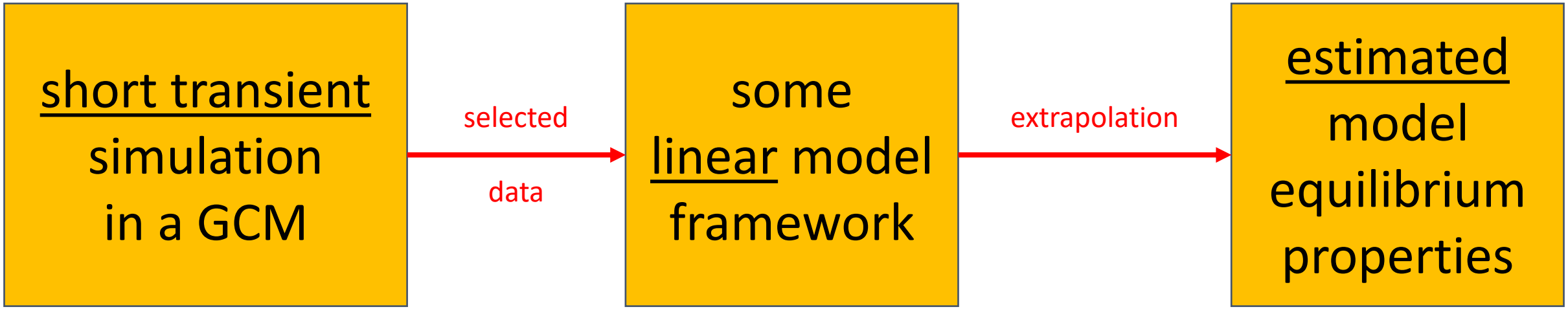




General belief on climate response:

$$Response(\ 2^{\gamma} \times CO_2) = \boldsymbol{\gamma}\ Response\ (2 \times CO_2)$$

Equilibrium inferred from dynamics

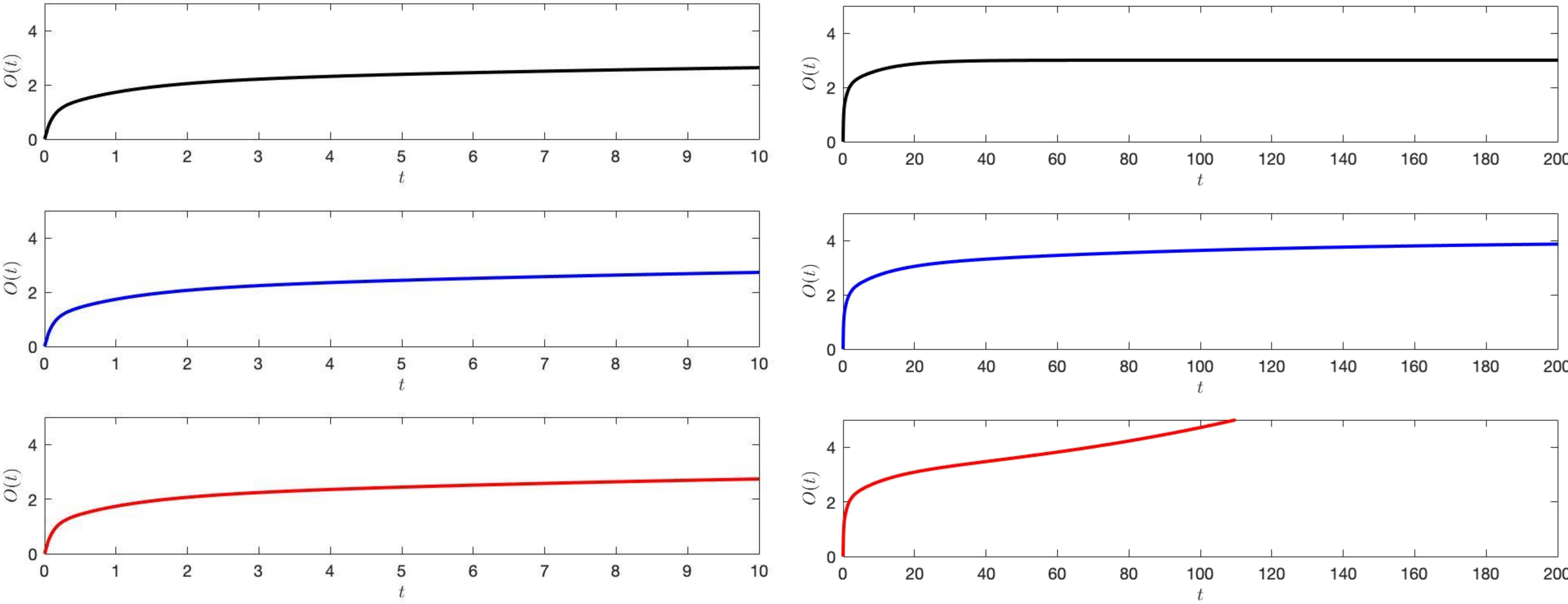


Examples:

Gregory method: $\Delta R(t) = \lambda\, \Delta T(t) + f$

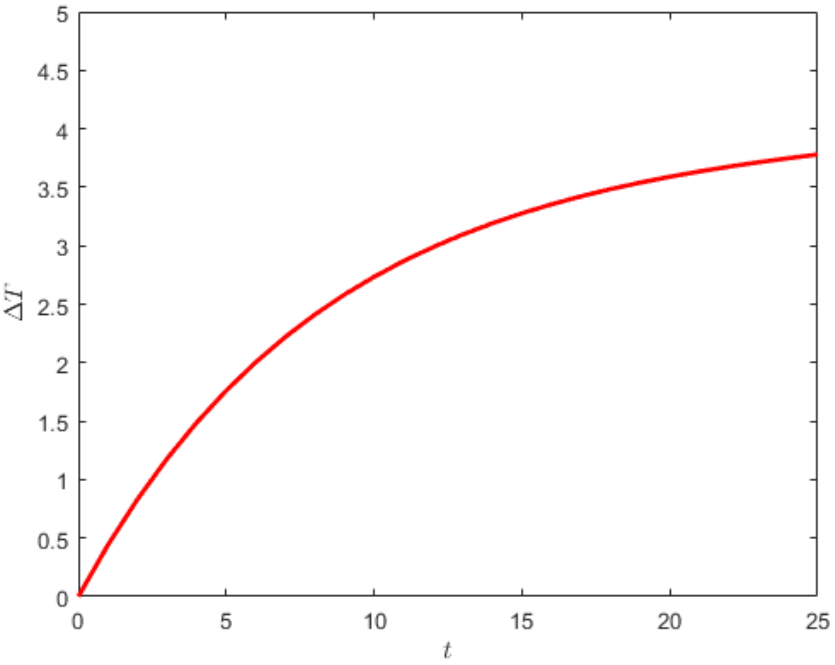
Linear Response Theory: $\Delta T(t) = (G \star g)\,(t)$

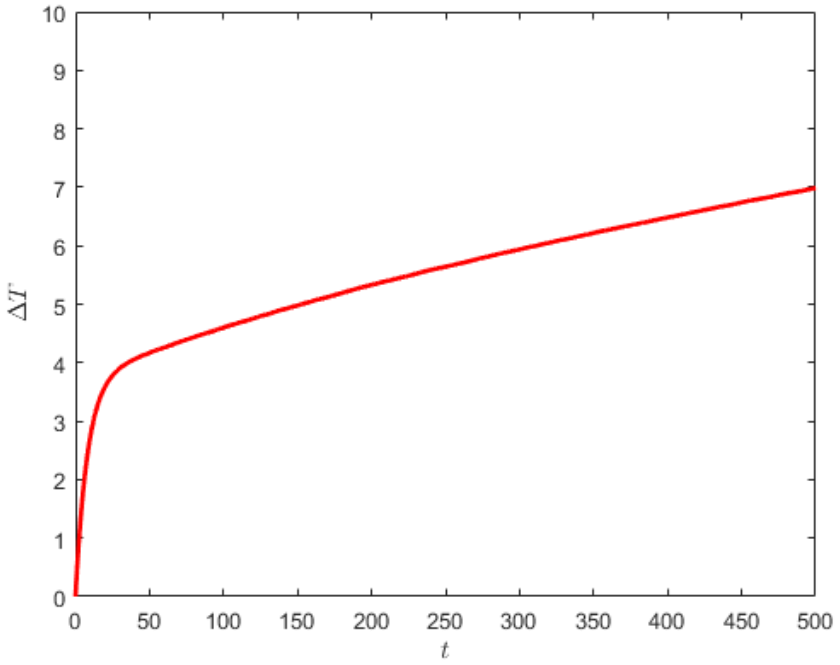
Dynamics: linear response – pitfalls of extrapolation

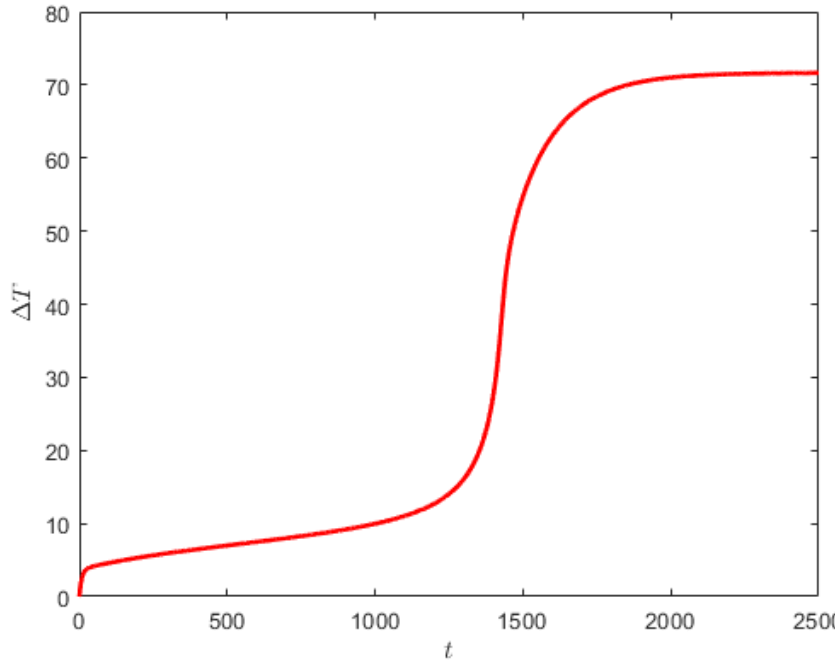


[Bastiaansen, Ashwin, Von der Heydt, 2023]

Dynamics: Nonlinear Response

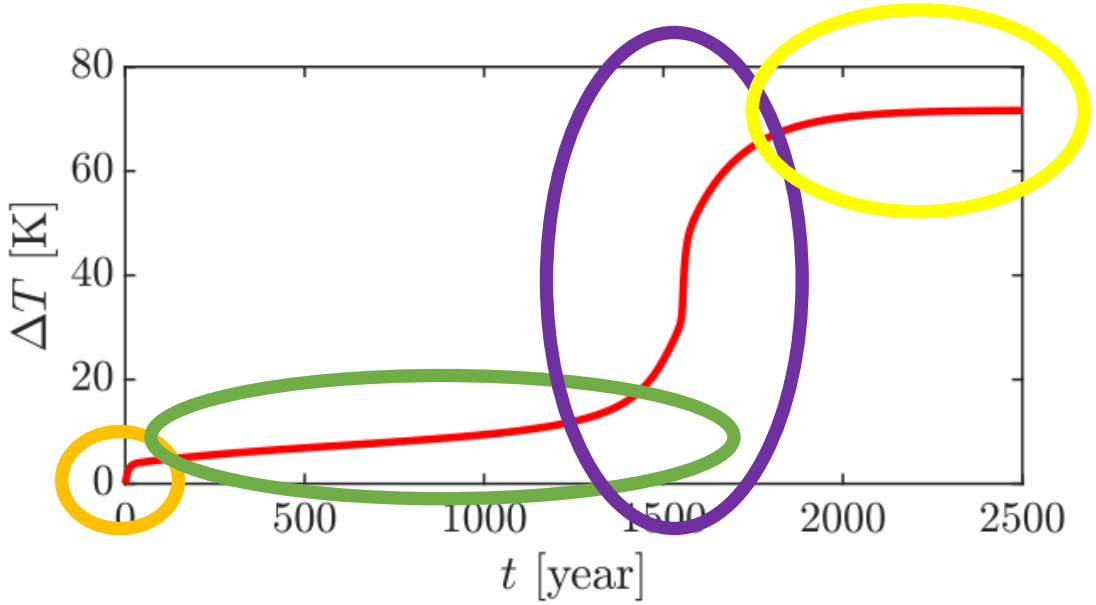


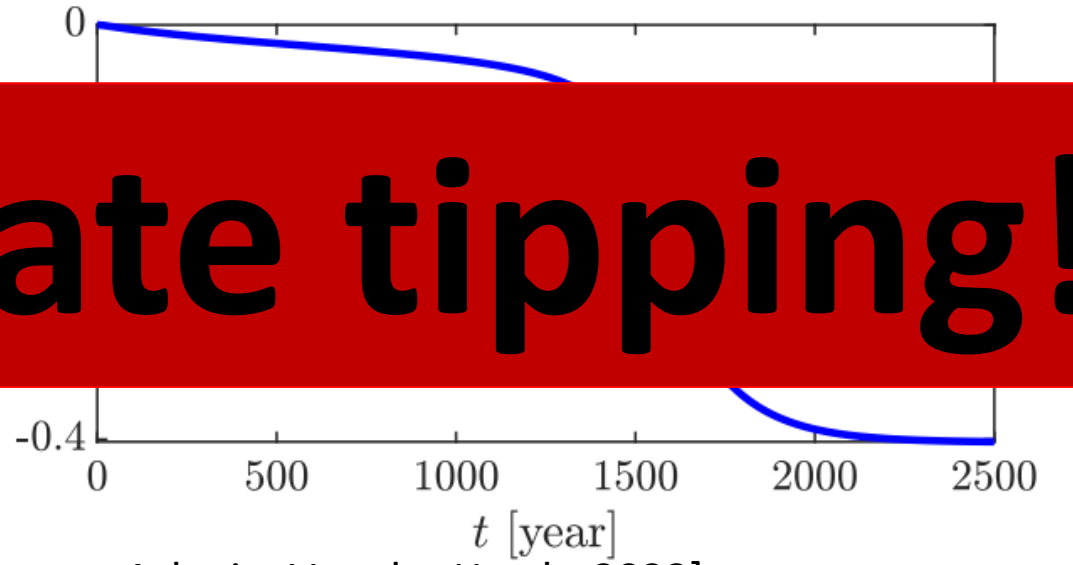




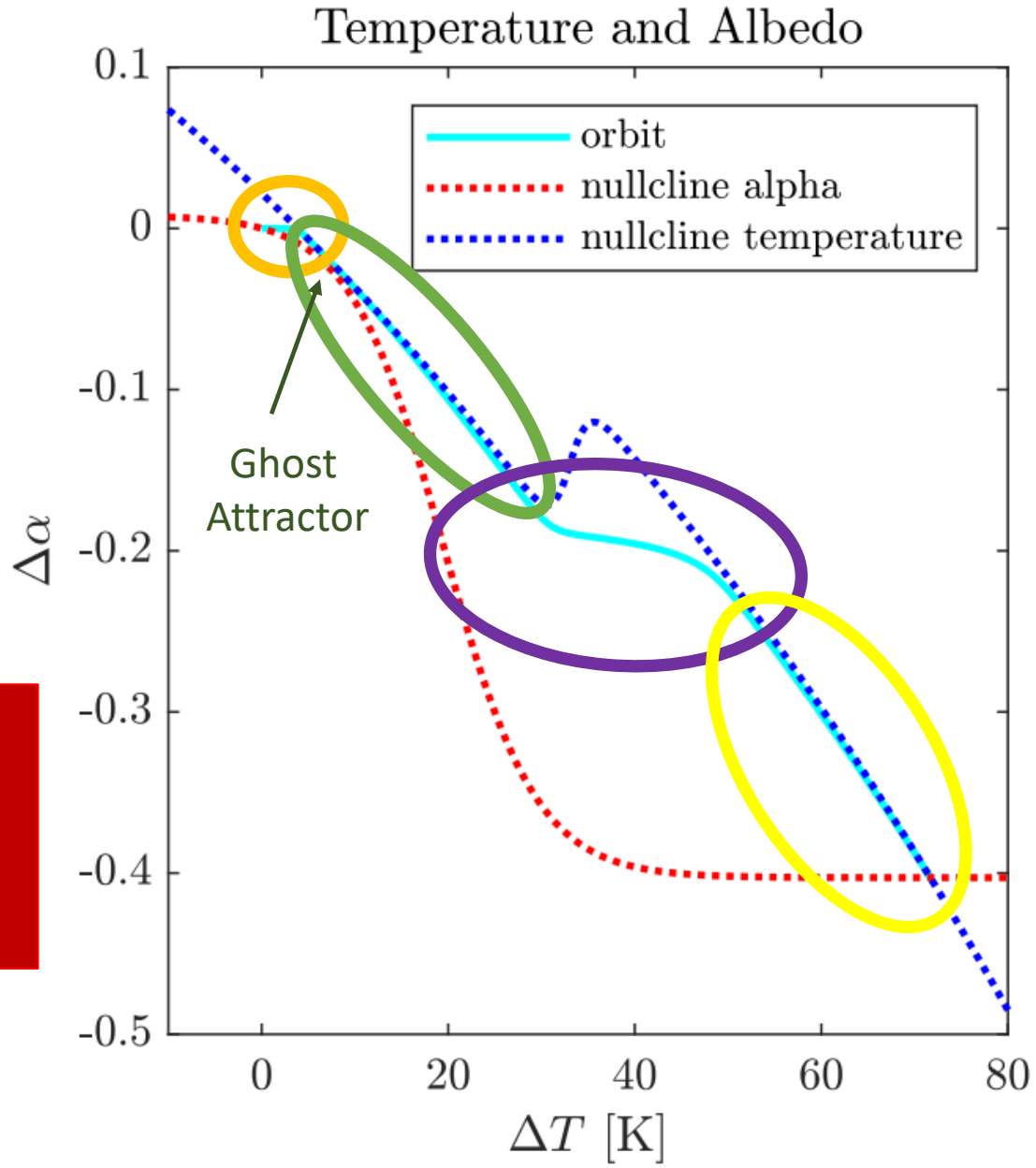
[Bastiaansen, Ashwin, Von der Heydt, 2023]

How does this work?



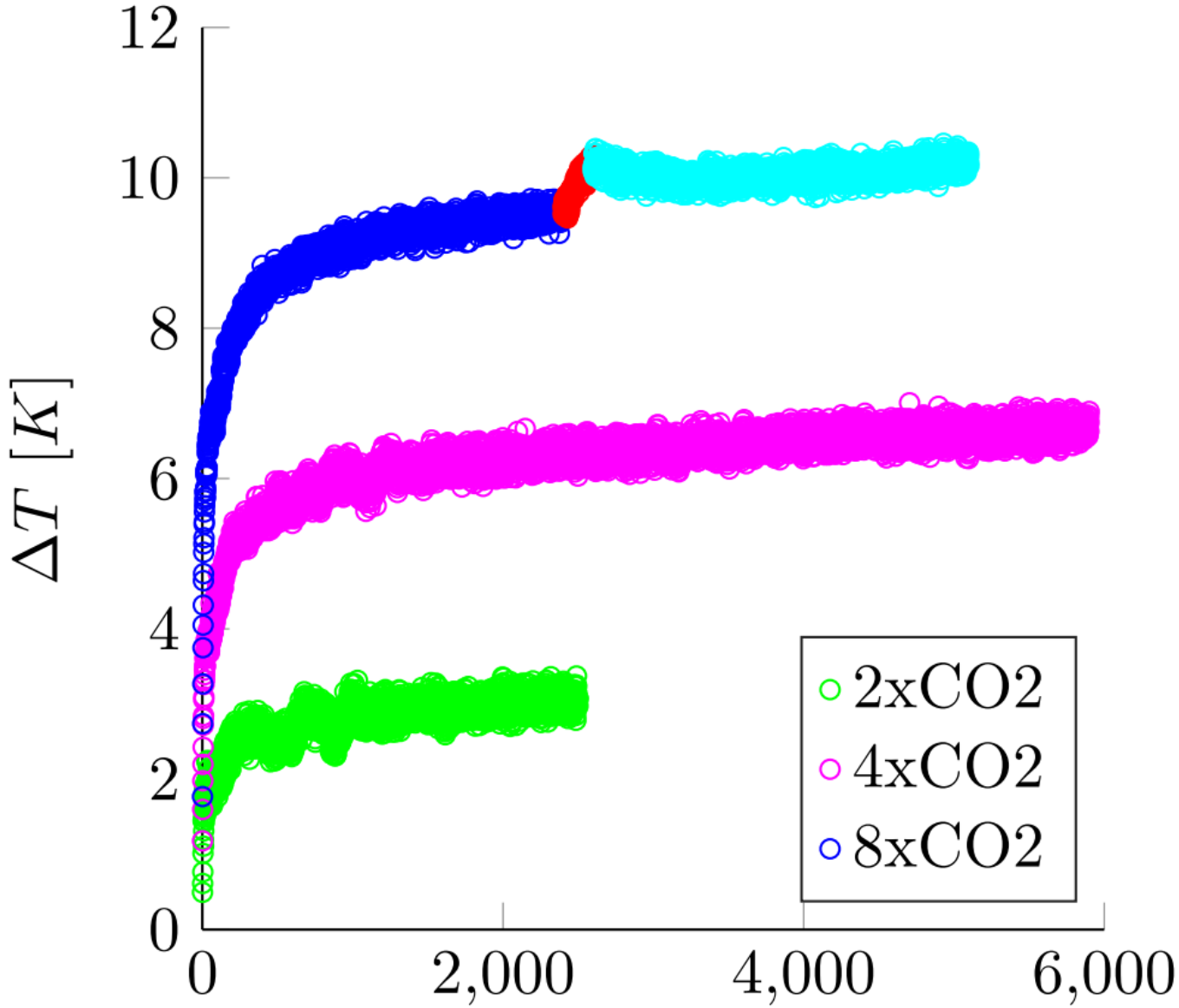


Late tipping!



[Bastiaansen, Ashwin, Von der Heydt, 2023]

Nonlinear Response in GCM

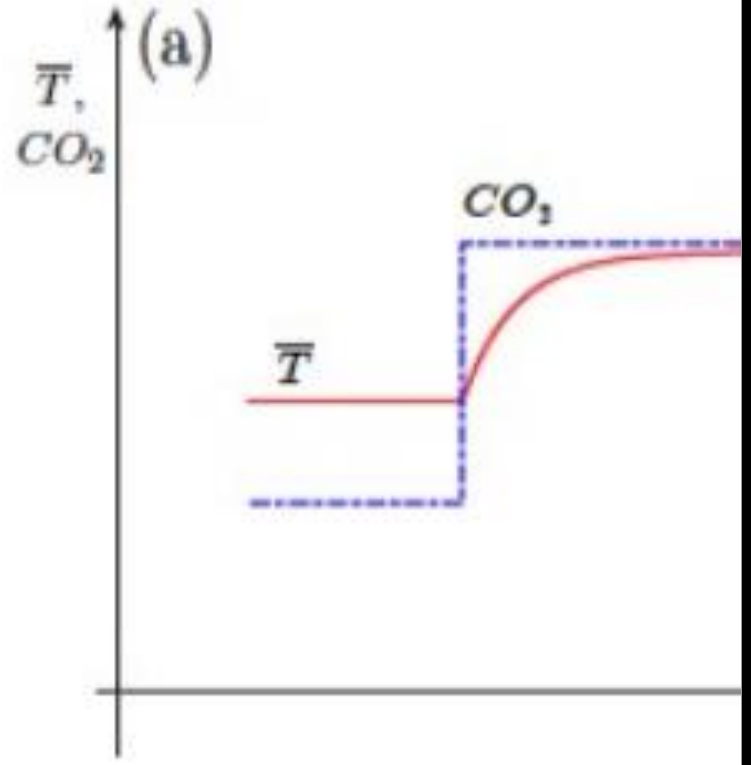


[Bastiaansen, Ashwin, Von der Heydt, 2023]

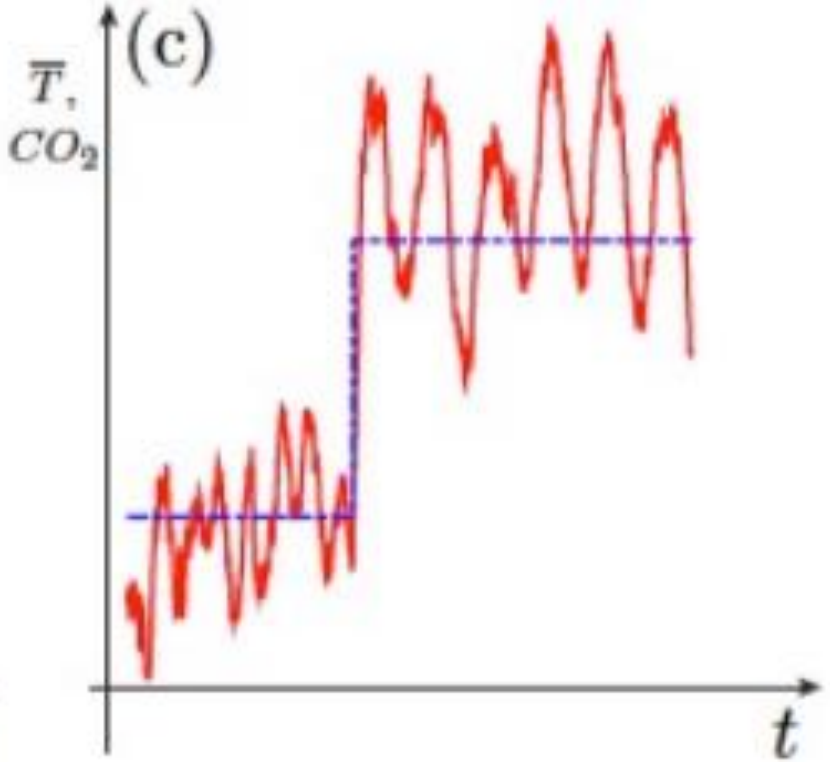
(Data from CESM1.0.4 runs in LongRunMIP)

Ensemble Variability

Variability due to precise location on initial attractor



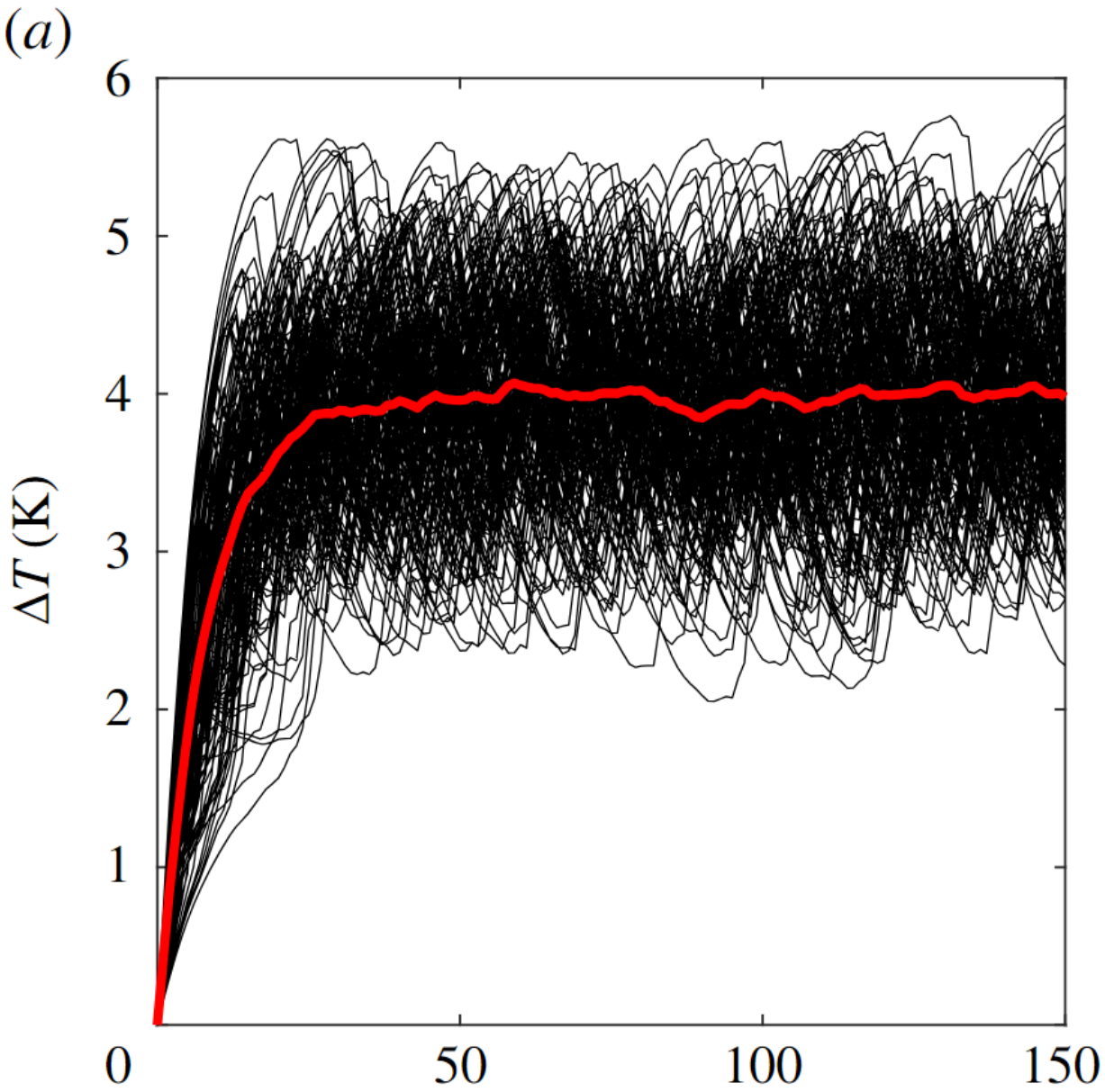
"equilibrium model"

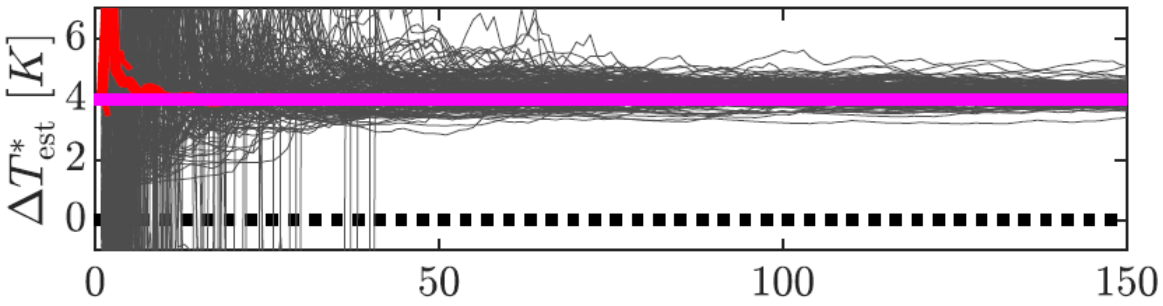


"chaotic model"

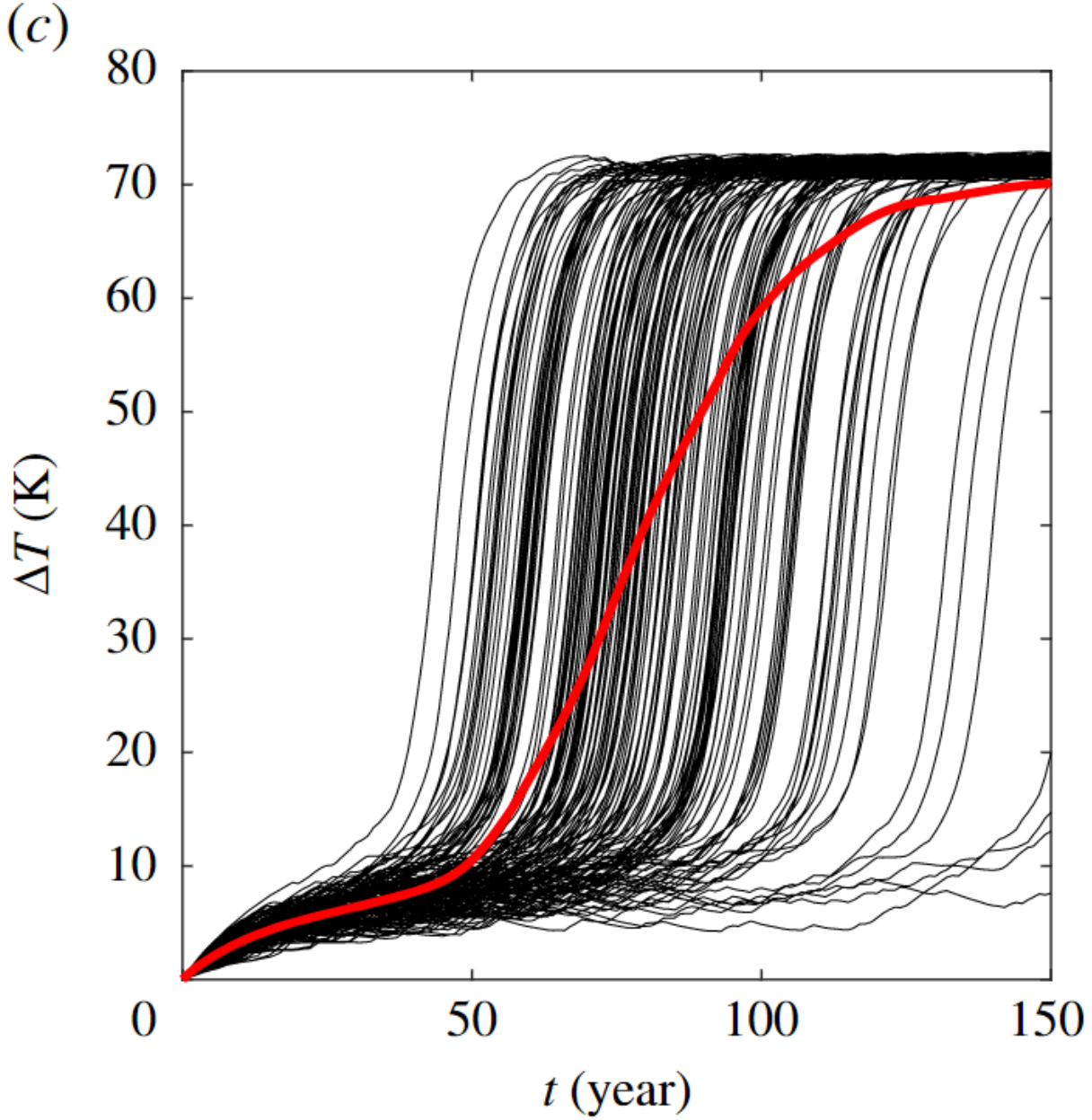
Image source: [Ghil & Lucarini, 2020] & [Ghil, 2017]

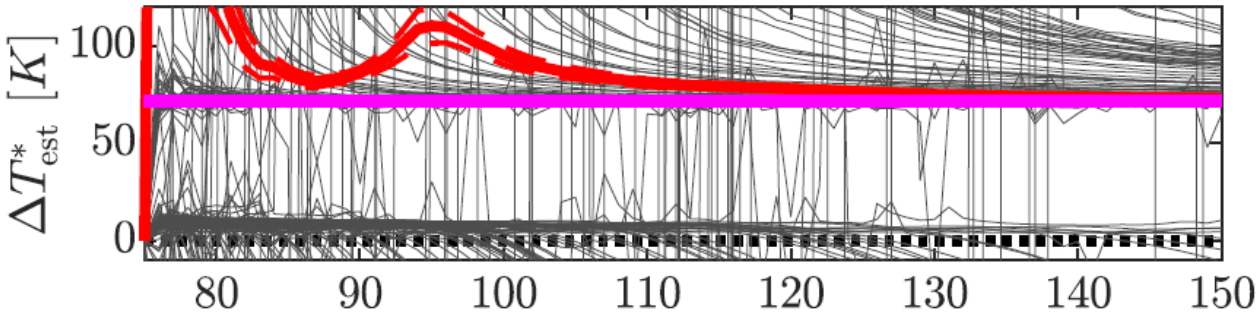
Ensemble Variability – NO tipping



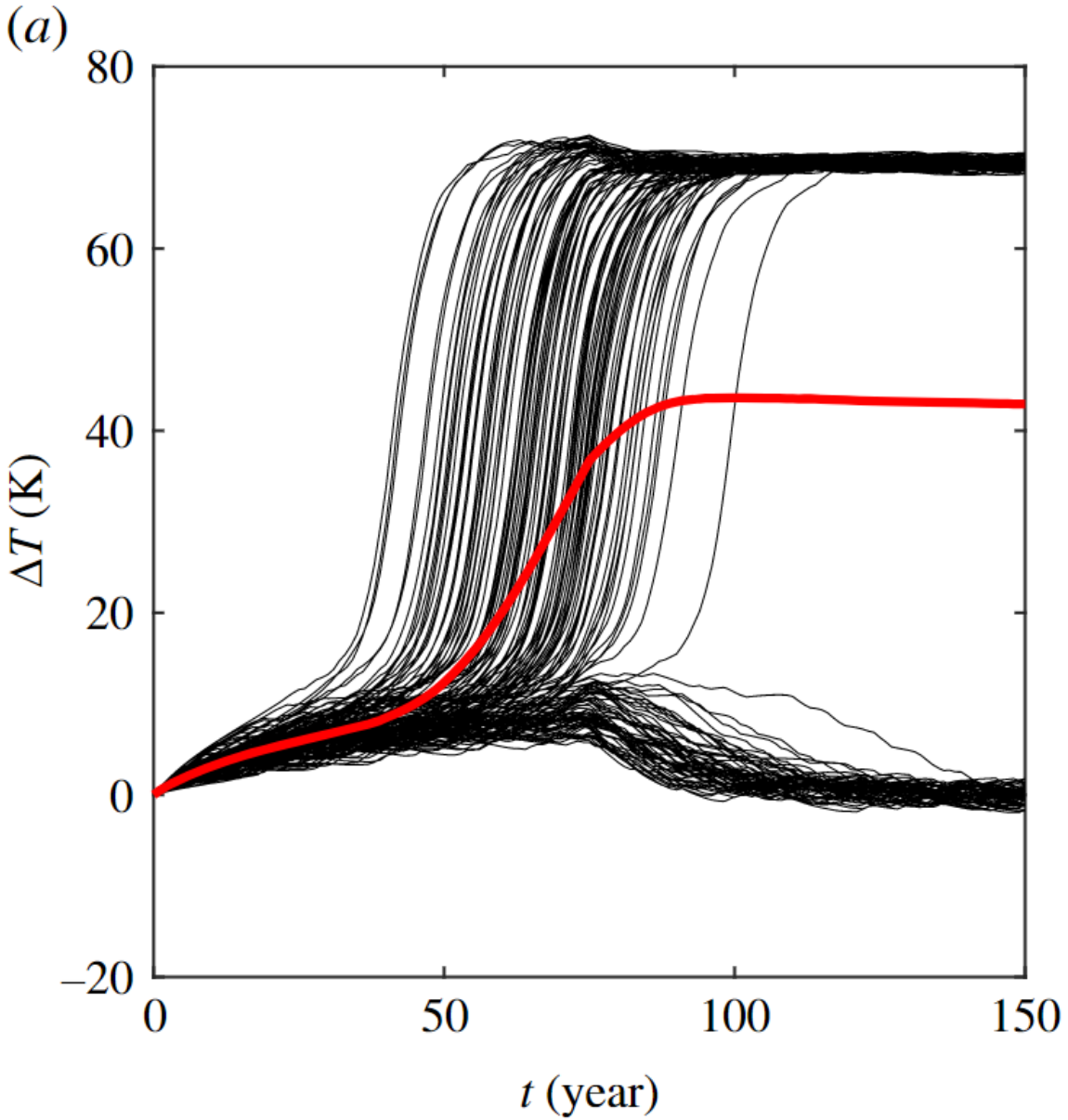


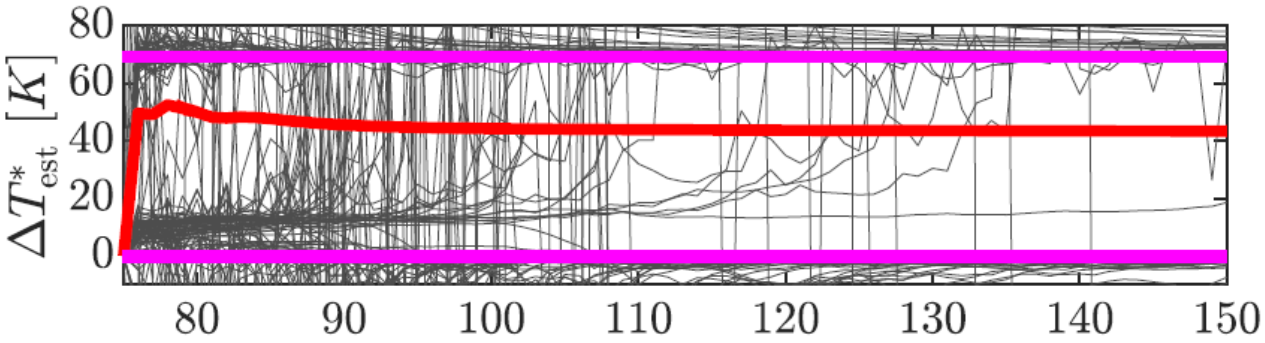
Ensemble Variability – WITH tipping





Partial Tipping



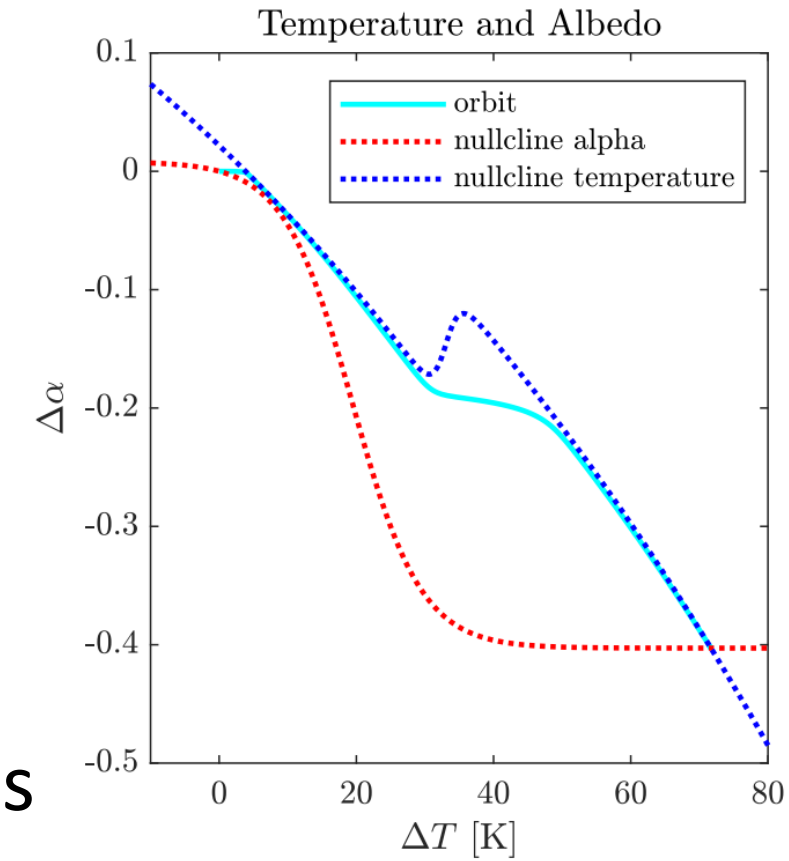


partial tipping

Alkhayuon, H. M., & Ashwin, P. (2018)

Summary

- Climate response is background dependent
- Response depends nonlinearly on forcing
- Models have time scale of validity
  - Extreme example: Late tipping points
- Climate response is sensitive to initial conditions
  - Extreme example: Partial tipping



Paper:
Bastiaansen, R., Ashwin, P., & von der Heydt, A. S. (2023). Climate response and sensitivity: time scales and late tipping points. Proceedings of the Royal Society A, 479(2269), 20220483.

Recommendations

1. Do response experiments with different background states
2. Investigate nonlinearities and tipping points
3. Give time scale of validity of models and extrapolations
4. Sample variation in response due to initial condition variation
5. Go beyond GMST (global mean surface temperature)

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