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. CO_2)

Equilibrium Climate Sensitivity (ECS)

change in equilibrium temperature
due to (instantaneous) doubling of CO_2

Transient Climate Response (TCR)

change in temperature after 100 years
with 1% CO_2 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

Linear Response

$$\frac{dO}{dt} = \mathcal{L}\, O + g(t)$$

Evolution of temperature

$$\Delta T(t) = (G * g)(t) = \int_0^t G(s)\, g(t-s)\, ds$$

Green Function

forcing

Approximation of Green Function:

$$G(t) = \sum_{m=1}^{M} \beta_m\, e^{-t/\tau_m}$$

time scales

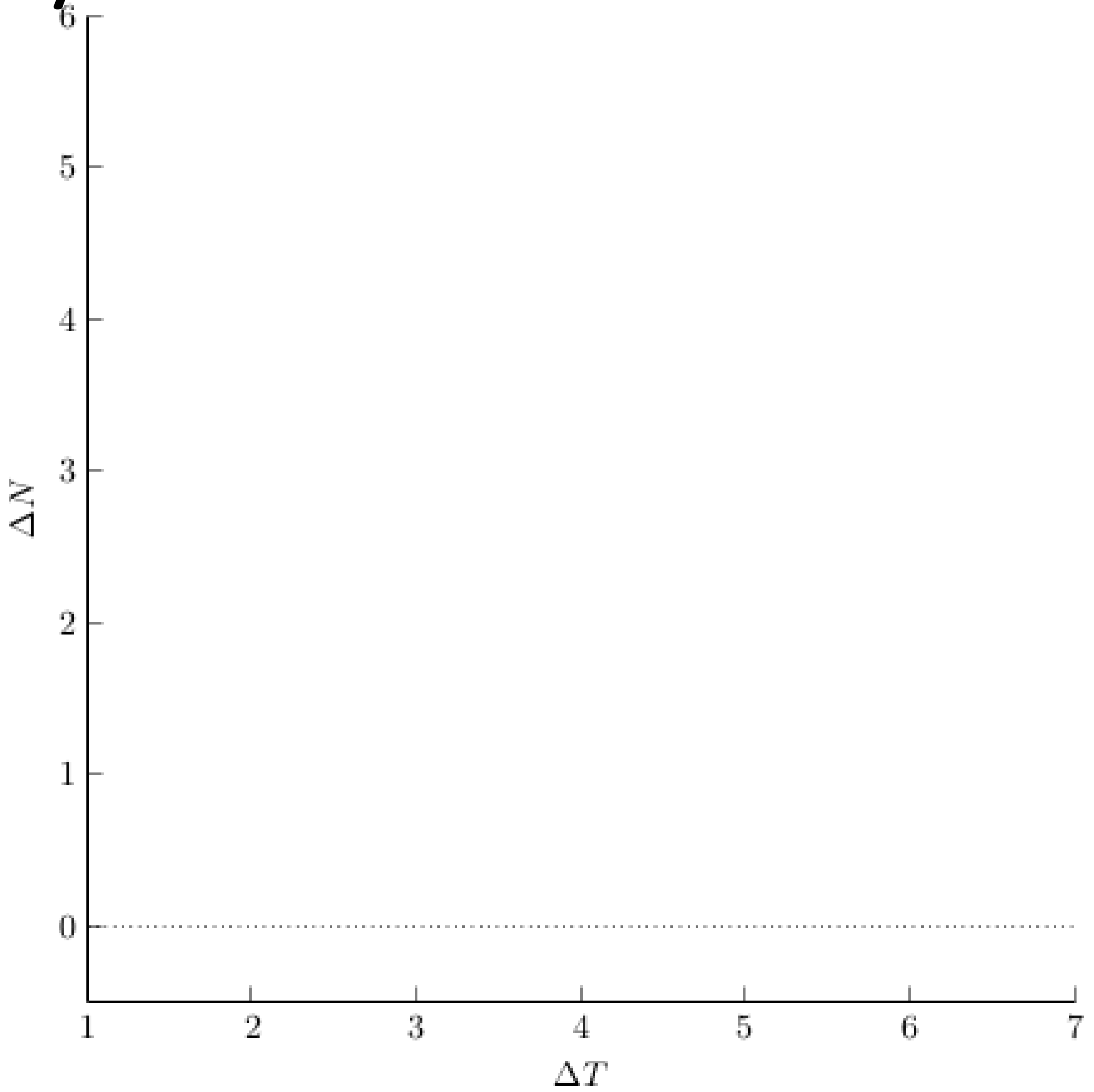
Gregory Method

Regress data to

$$\Delta N(t) = \boldsymbol{F} + \boldsymbol{\lambda}\, \Delta T(t)$$

Since $\Delta N_* = 0$ in equilibrium, ECS estimation is

$$\Delta T_*^{est} = -\,\boldsymbol{\lambda}^{-1}\, \boldsymbol{F}$$



[Gregory et al, 2014]

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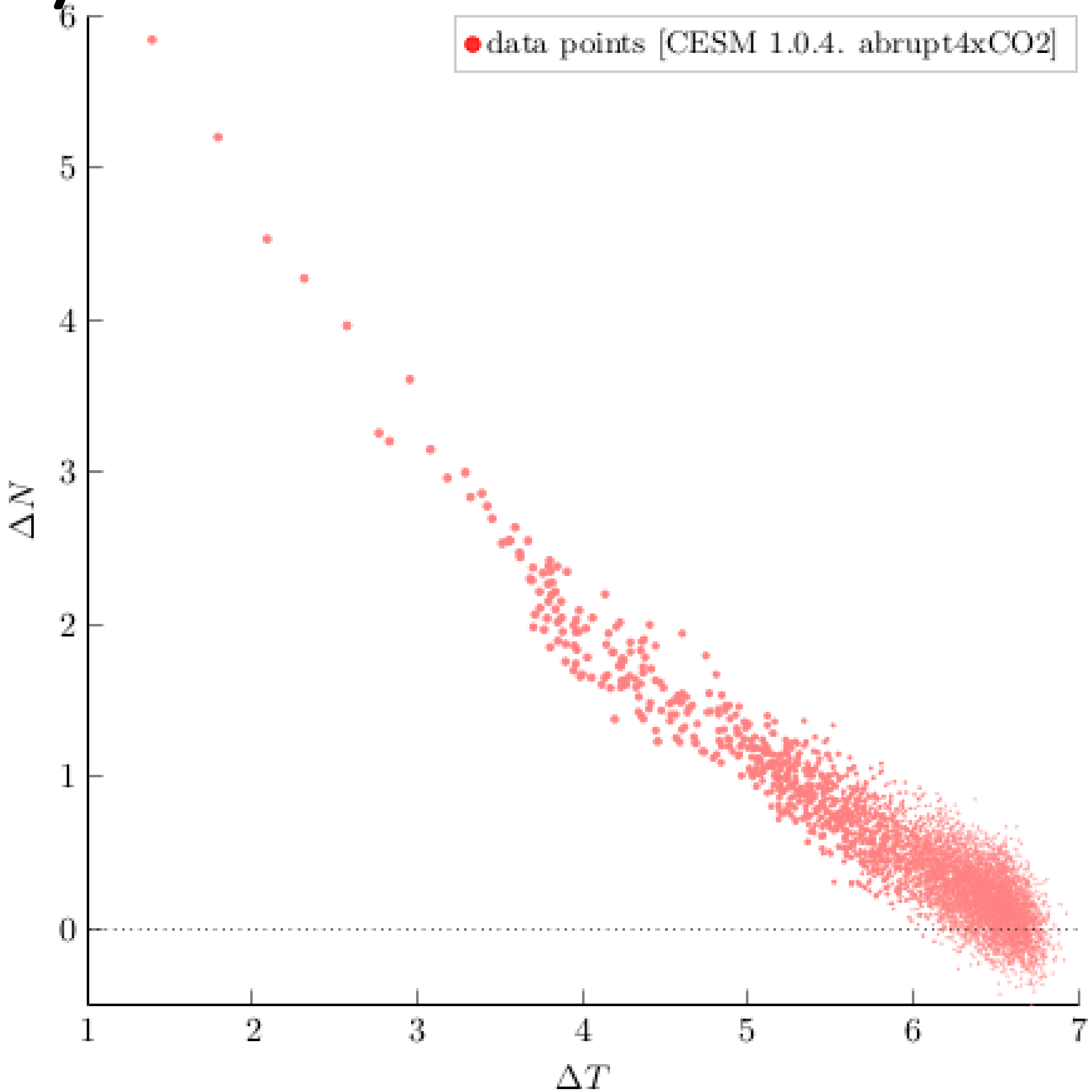

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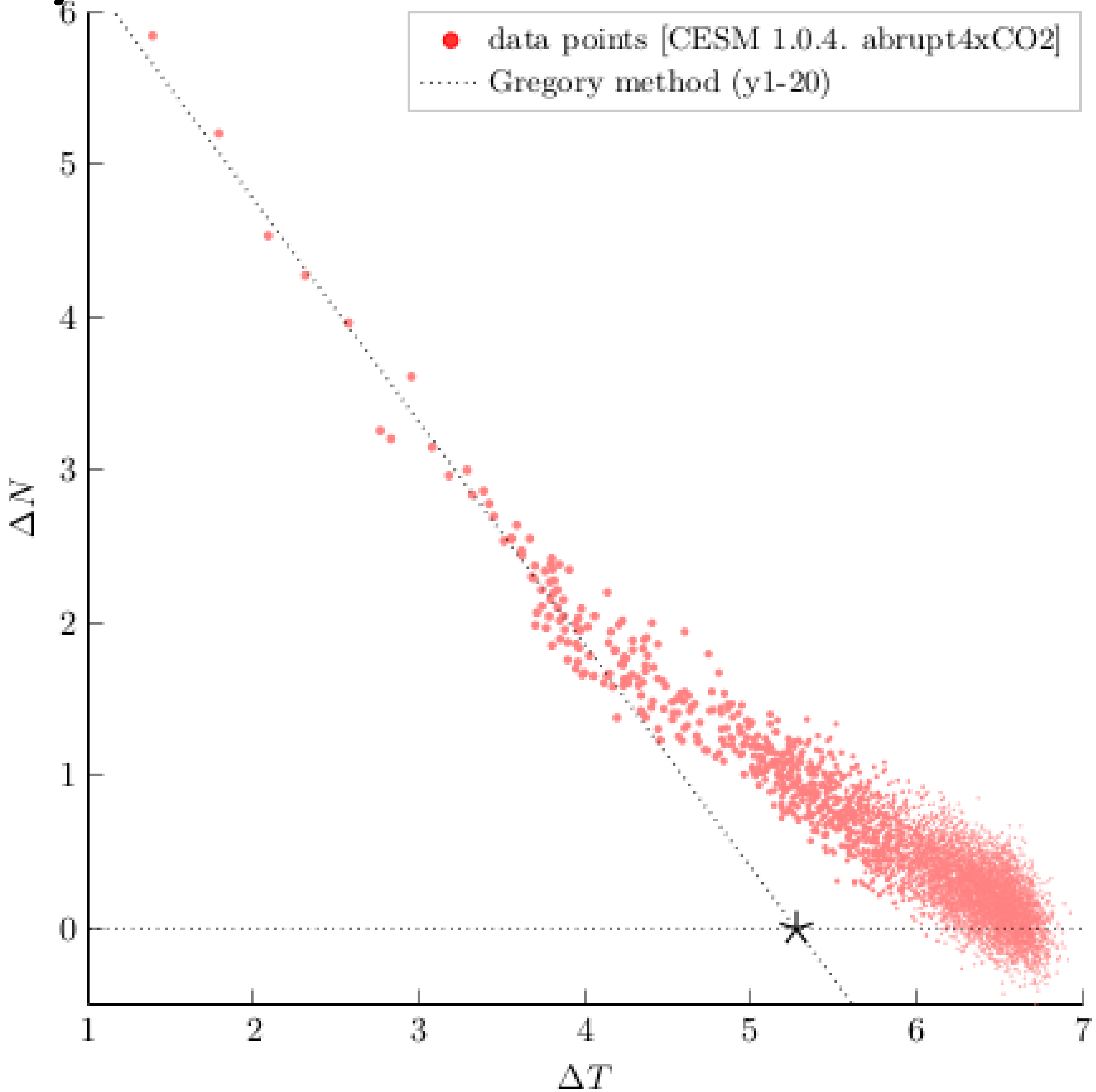

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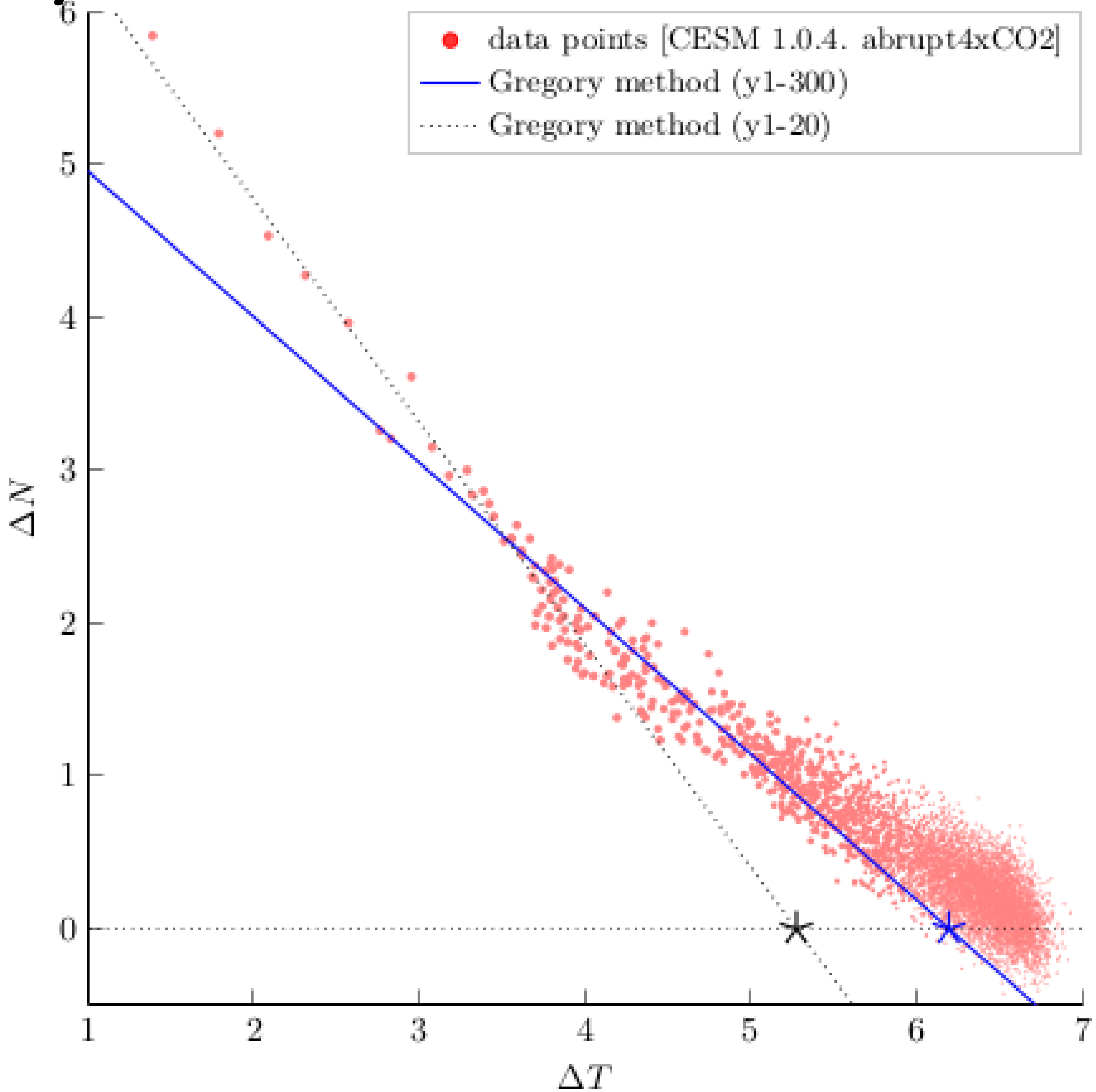

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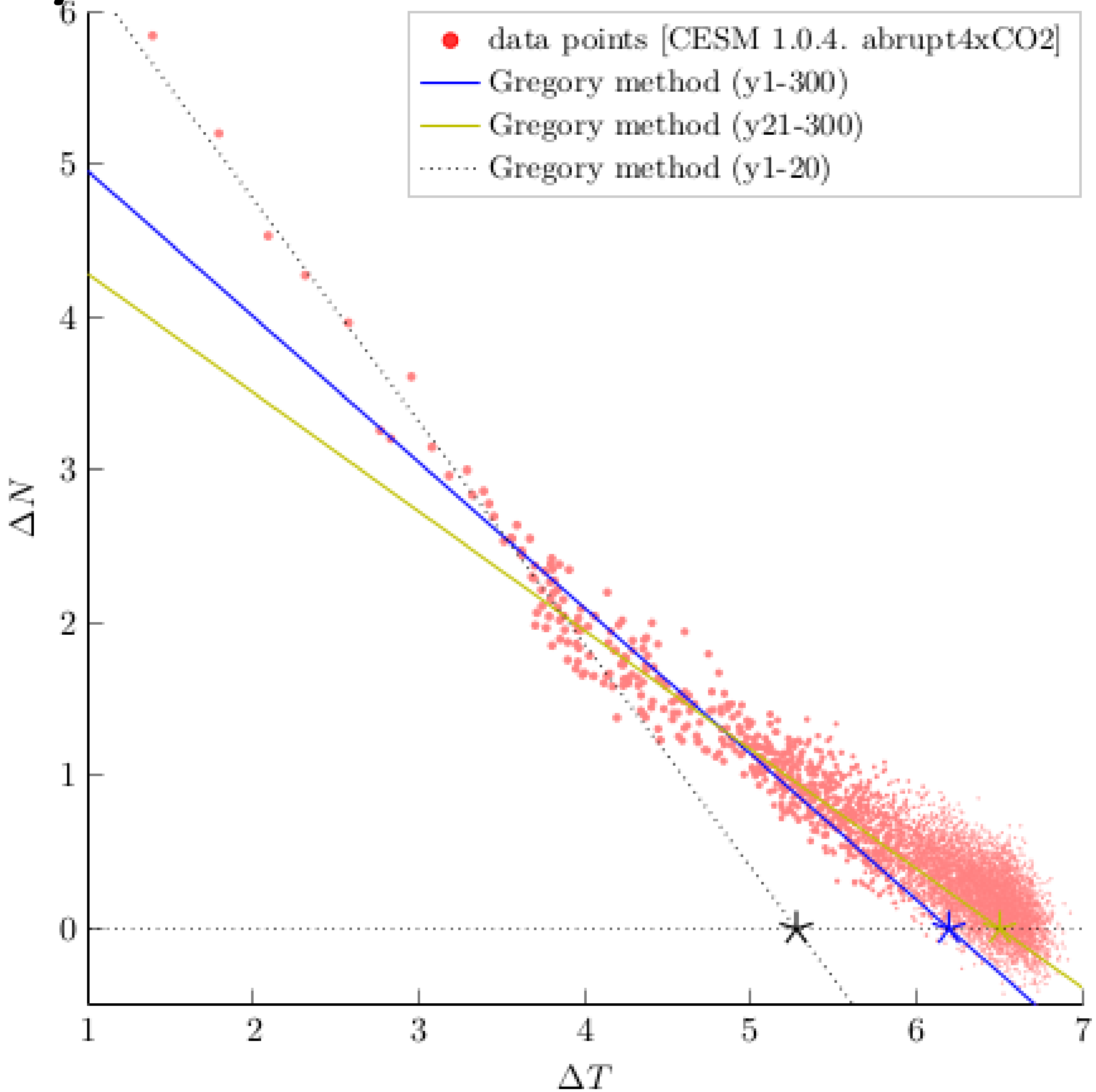

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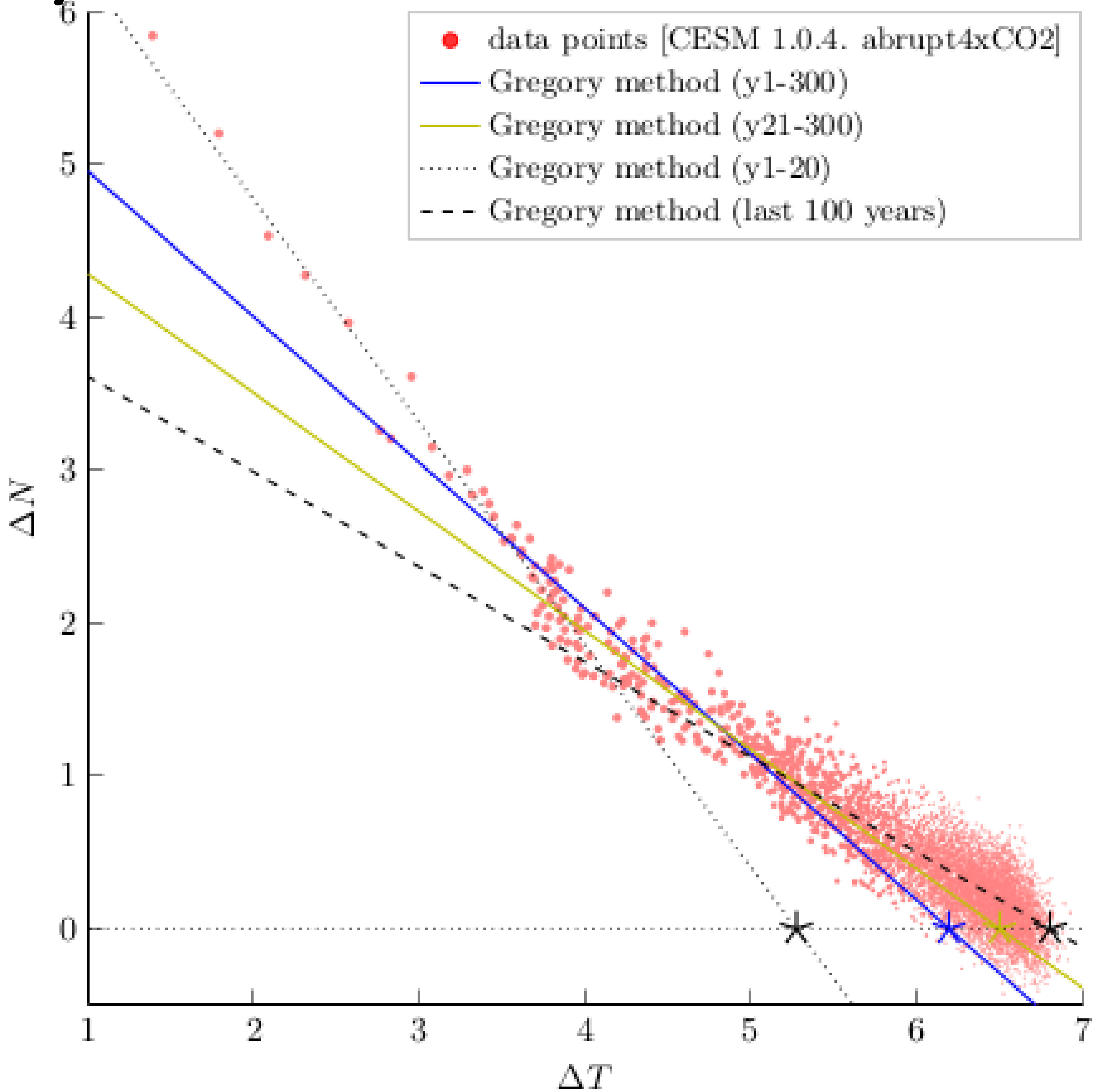

[Gregory et al, 2014]

New Multicomponent Linear Regression Method

Use additional observables!

Regress to:

$$\overrightarrow{\Delta Y} = \boldsymbol{A}\,\overrightarrow{\Delta X} + \vec{\boldsymbol{F}}$$

$\overrightarrow{\Delta Y}$: observables that **tend to 0** in equilibrium

$\overrightarrow{\Delta X}$: observables that **get estimated** in equilibrium

Multivariate ECS estimation is

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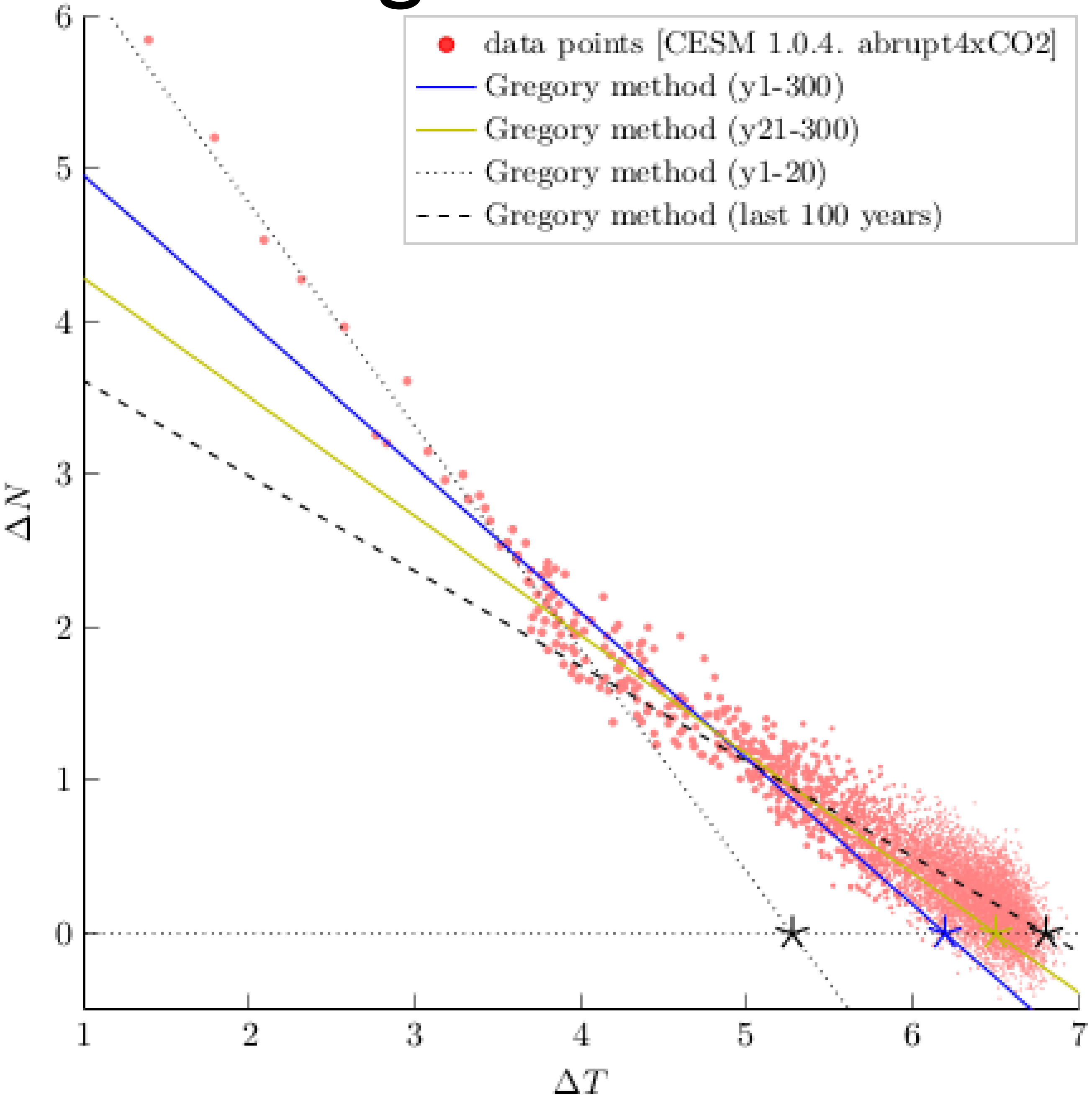

[Bastiaansen et al, 2021]

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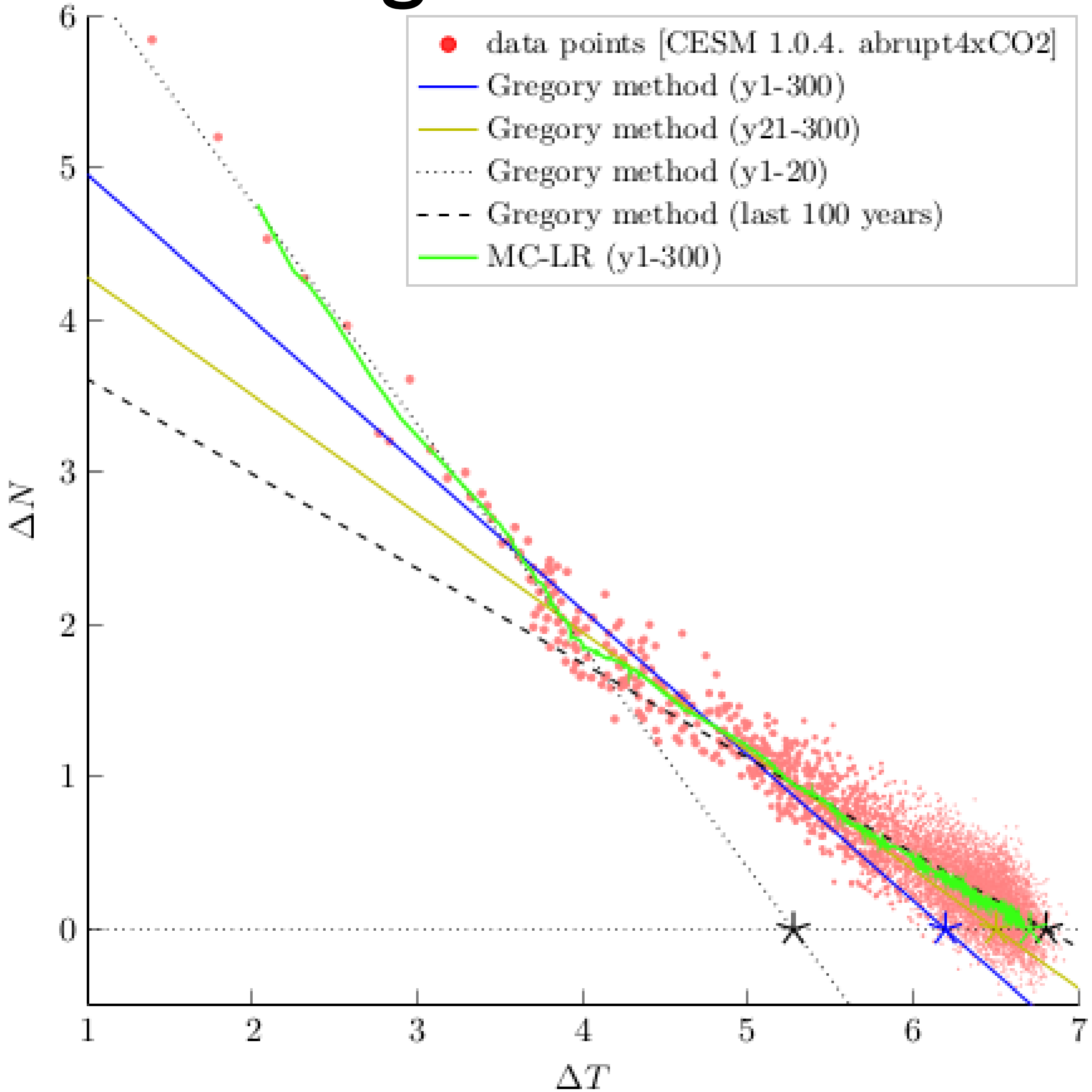
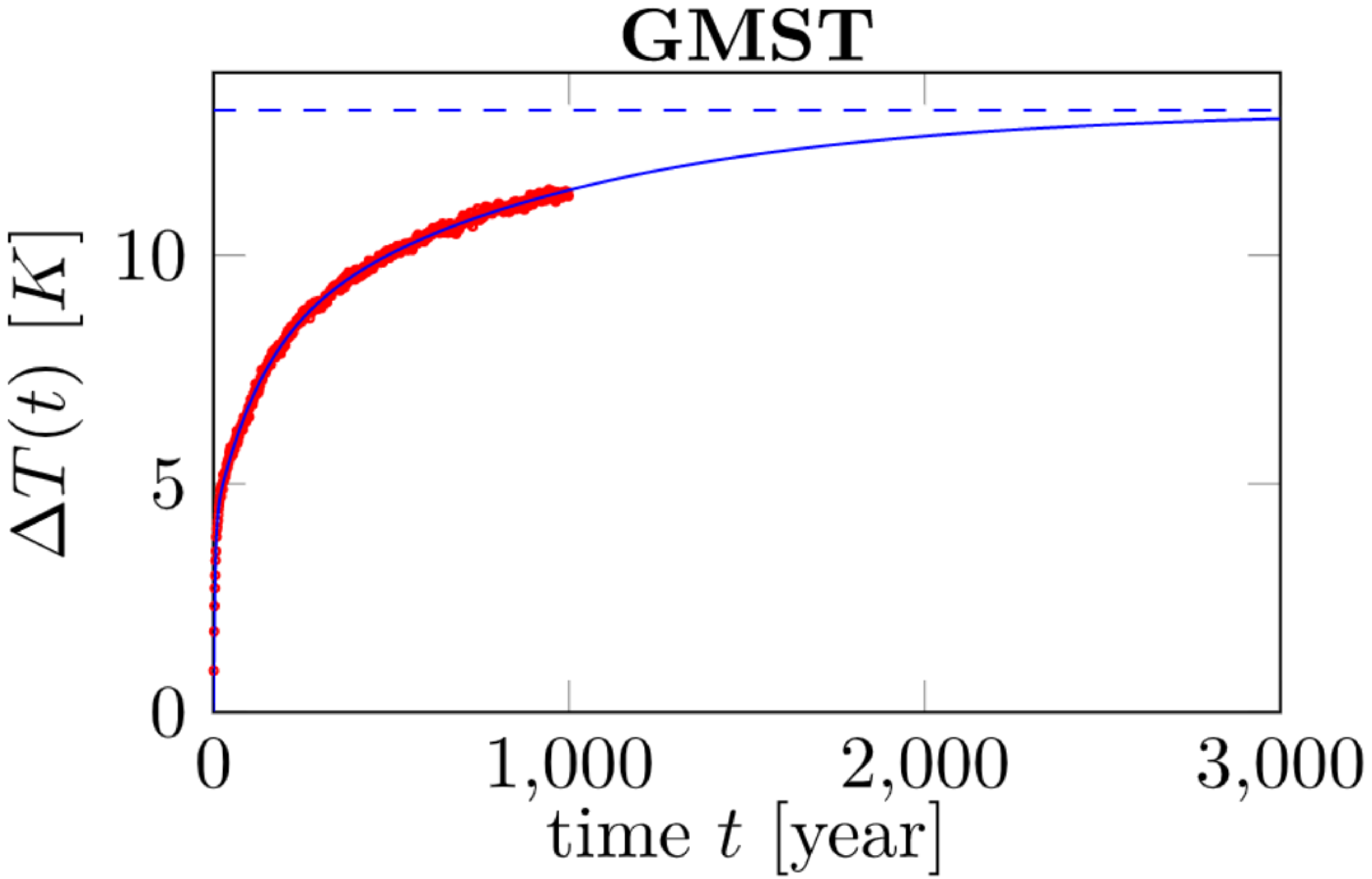


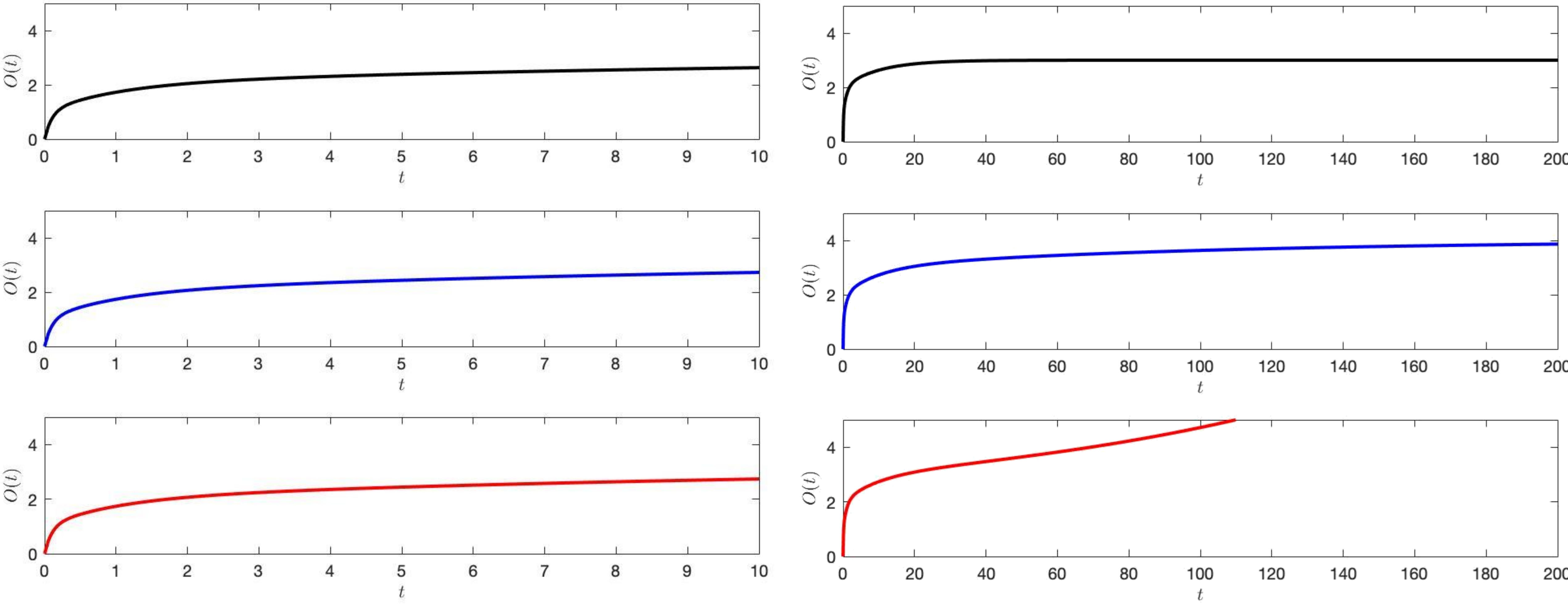
[Bastiaansen et al, 2021]

Projections of the Transient State-Dependency of Climate Feedbacks



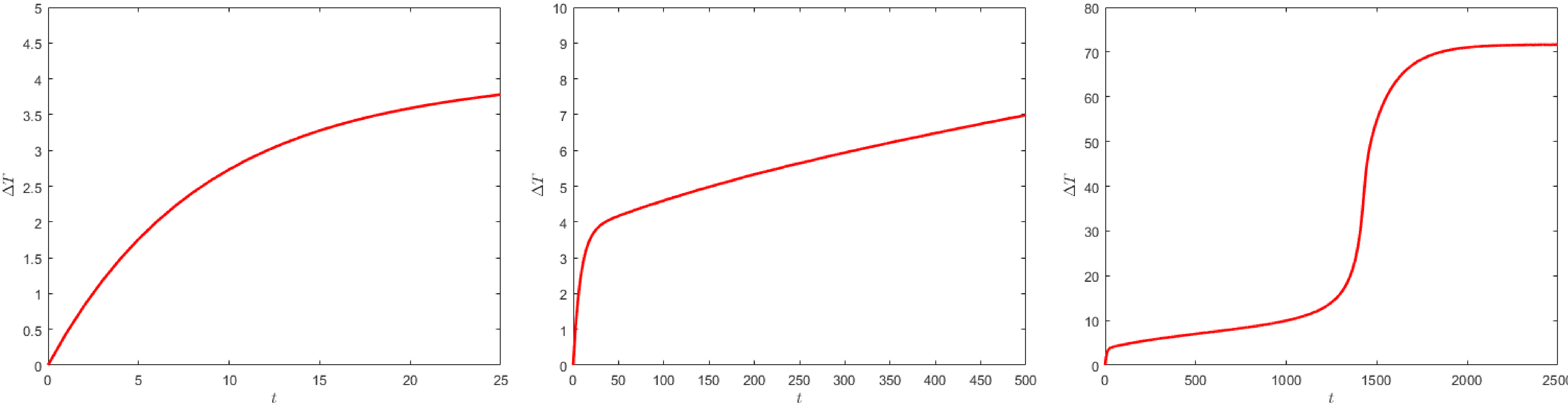
[Bastiaansen et al, 2021]

Pitfalls and problems



[Bastiaansen, Ashwin, Von der Heydt, 2023]

Nonlinear Response



[Bastiaansen, Ashwin, Von der Heydt, 2023]

Multiscale Global Energy Balance Model

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

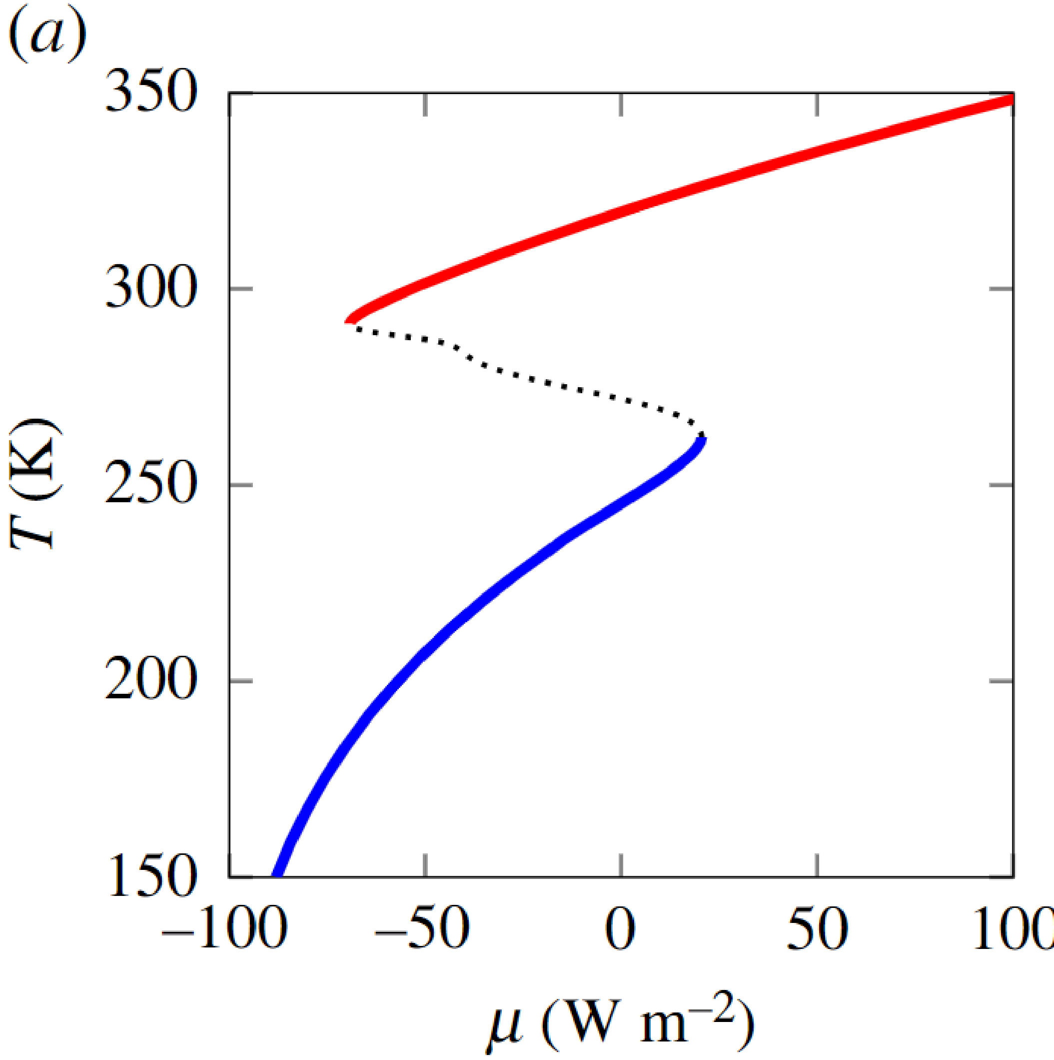
Short-Wave

Long-Wave

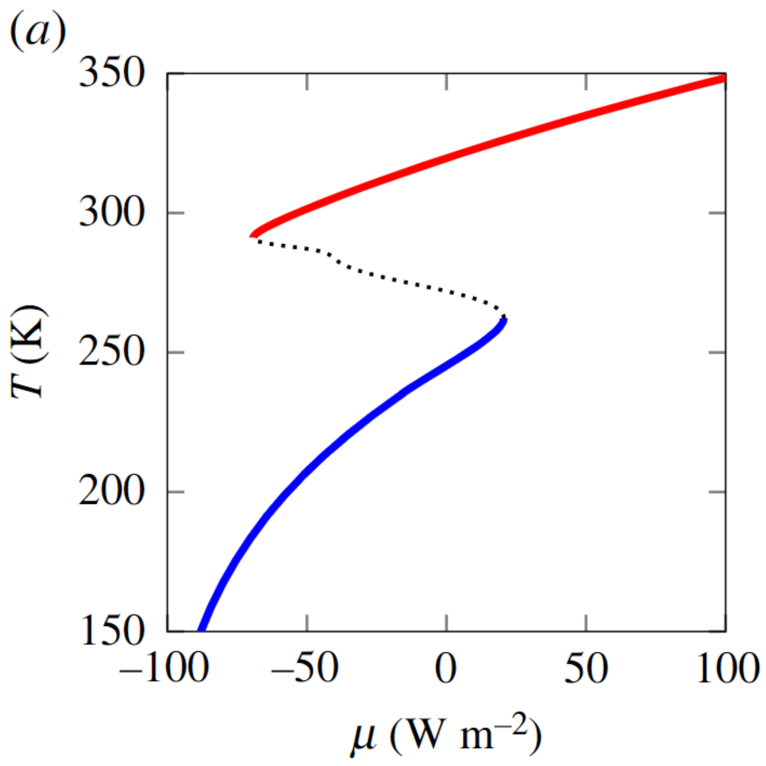
CO2

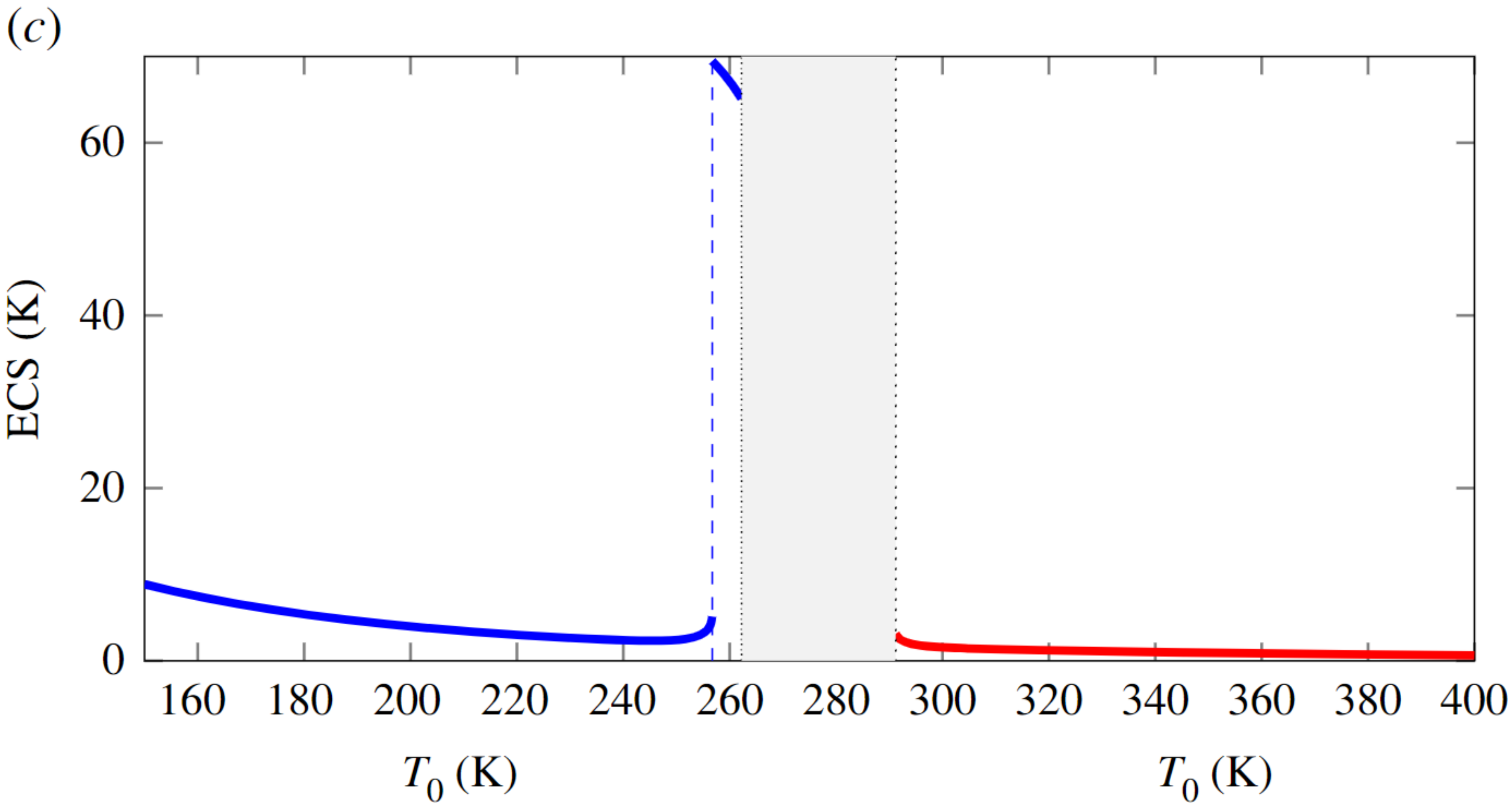
$$\tau_\alpha \frac{d\alpha}{dt} = \alpha_0(T) - \alpha$$

Dynamic albedo

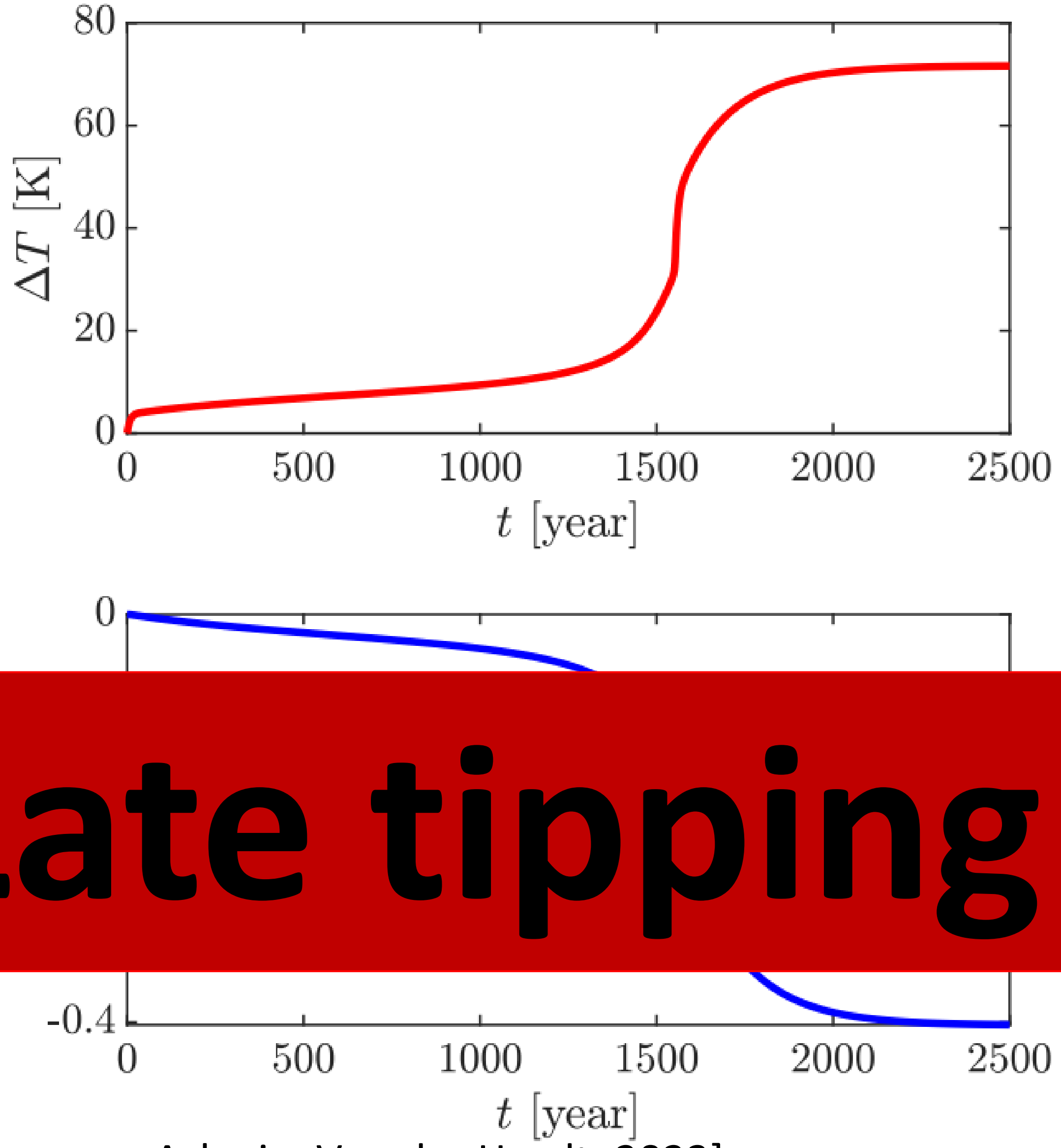


Background dependency

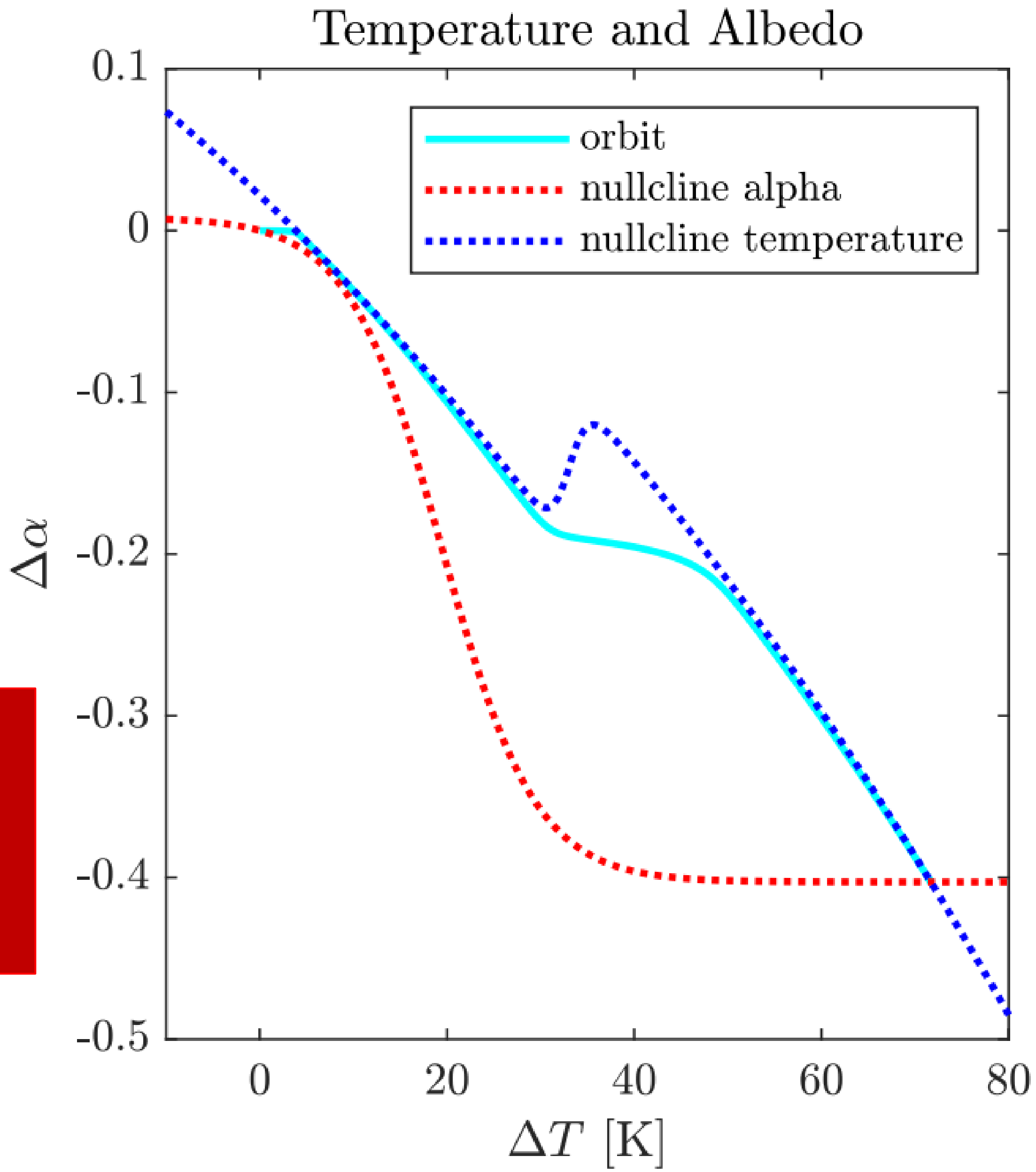




DYNAMICS: Nonlinear Response



Late tipping!



[Bastiaansen, Ashwin, Von der Heydt, 2023]

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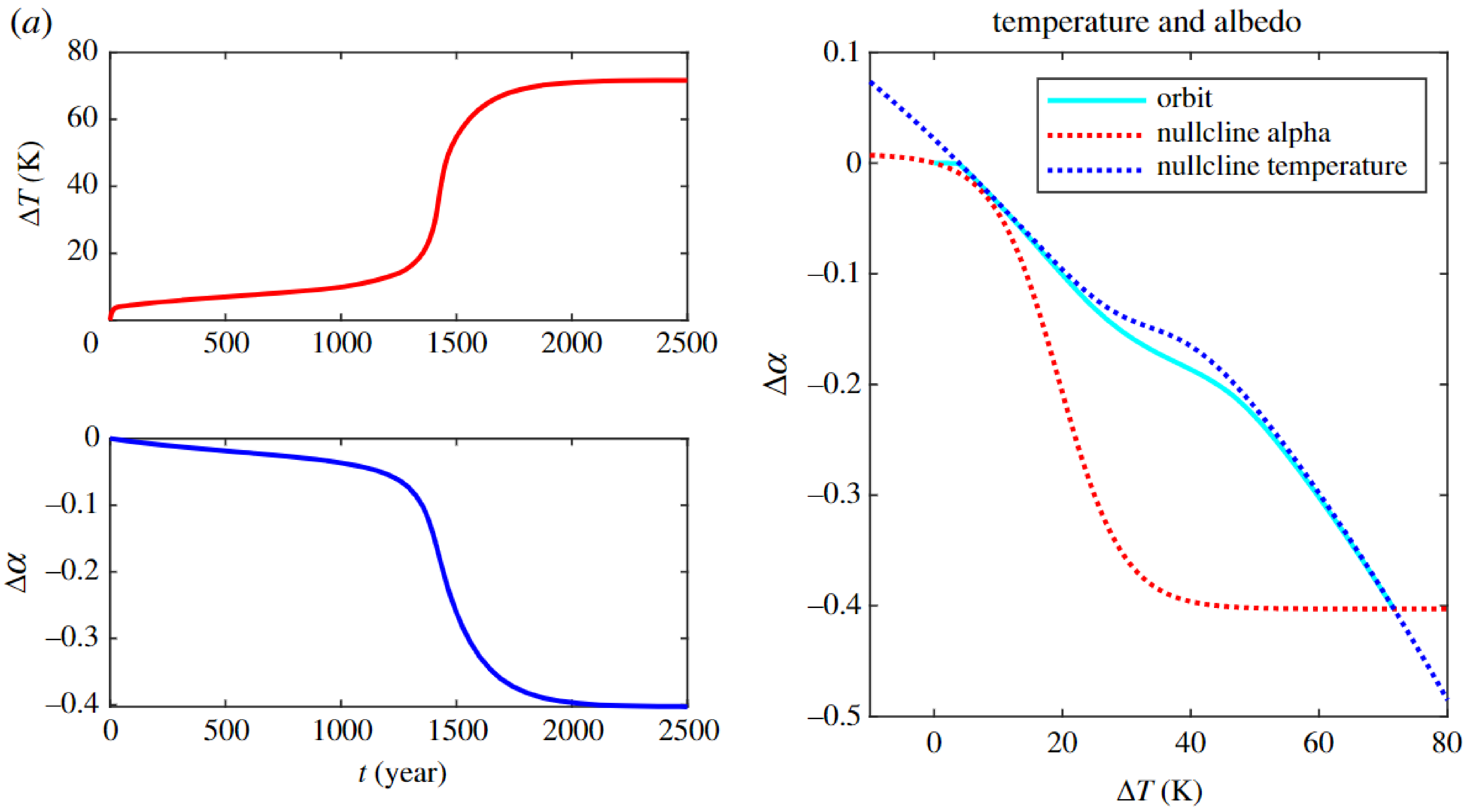
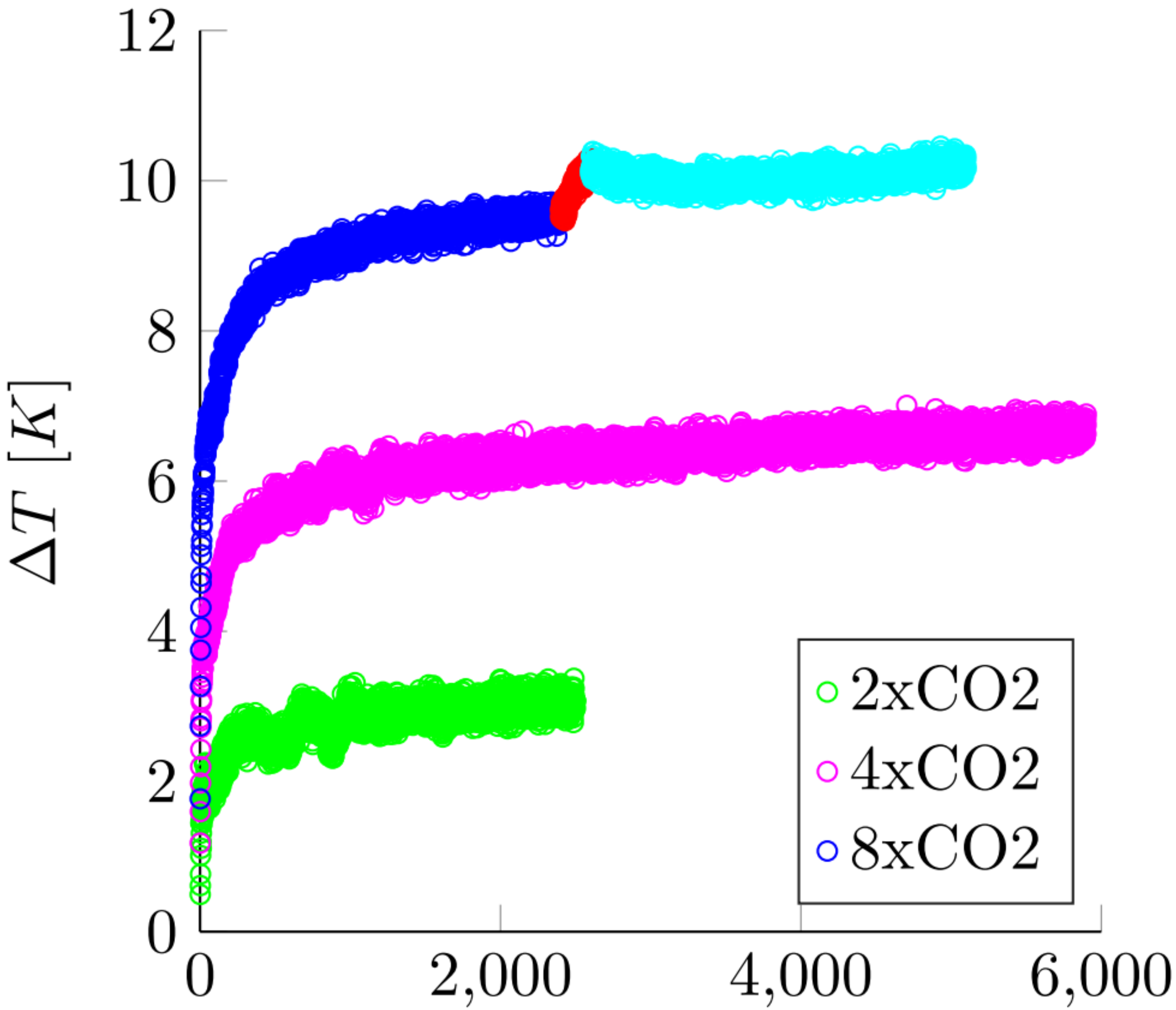


[Bastiaansen, Ashwin, Von der Heydt, 2023]

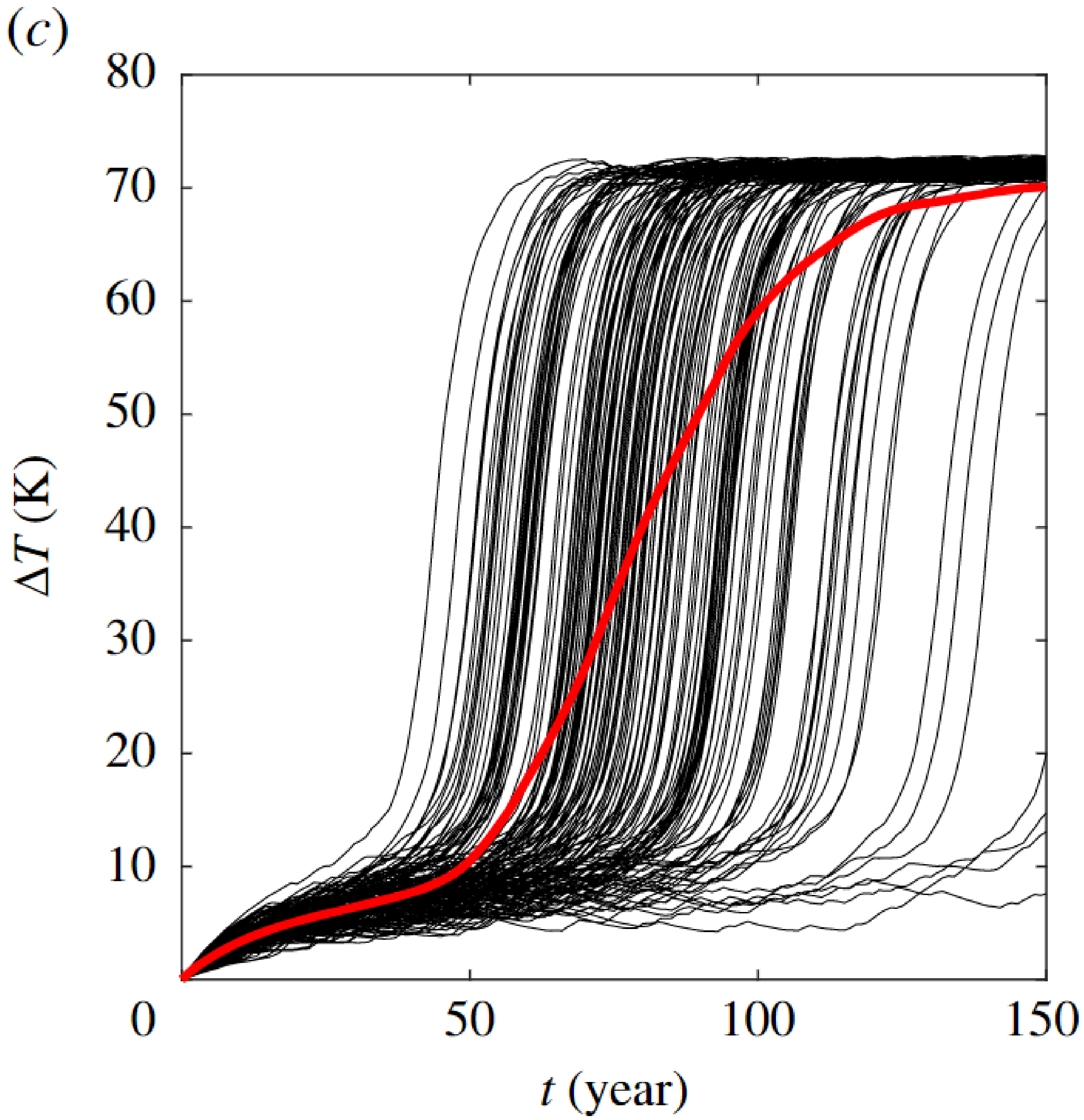
Nonlinear Response in GCM



[Bastiaansen, Ashwin, Von der Heydt, 2023]

(Data from CESM1.0.4 runs in LongRunMIP)

Chaotic Systems & Ensembles



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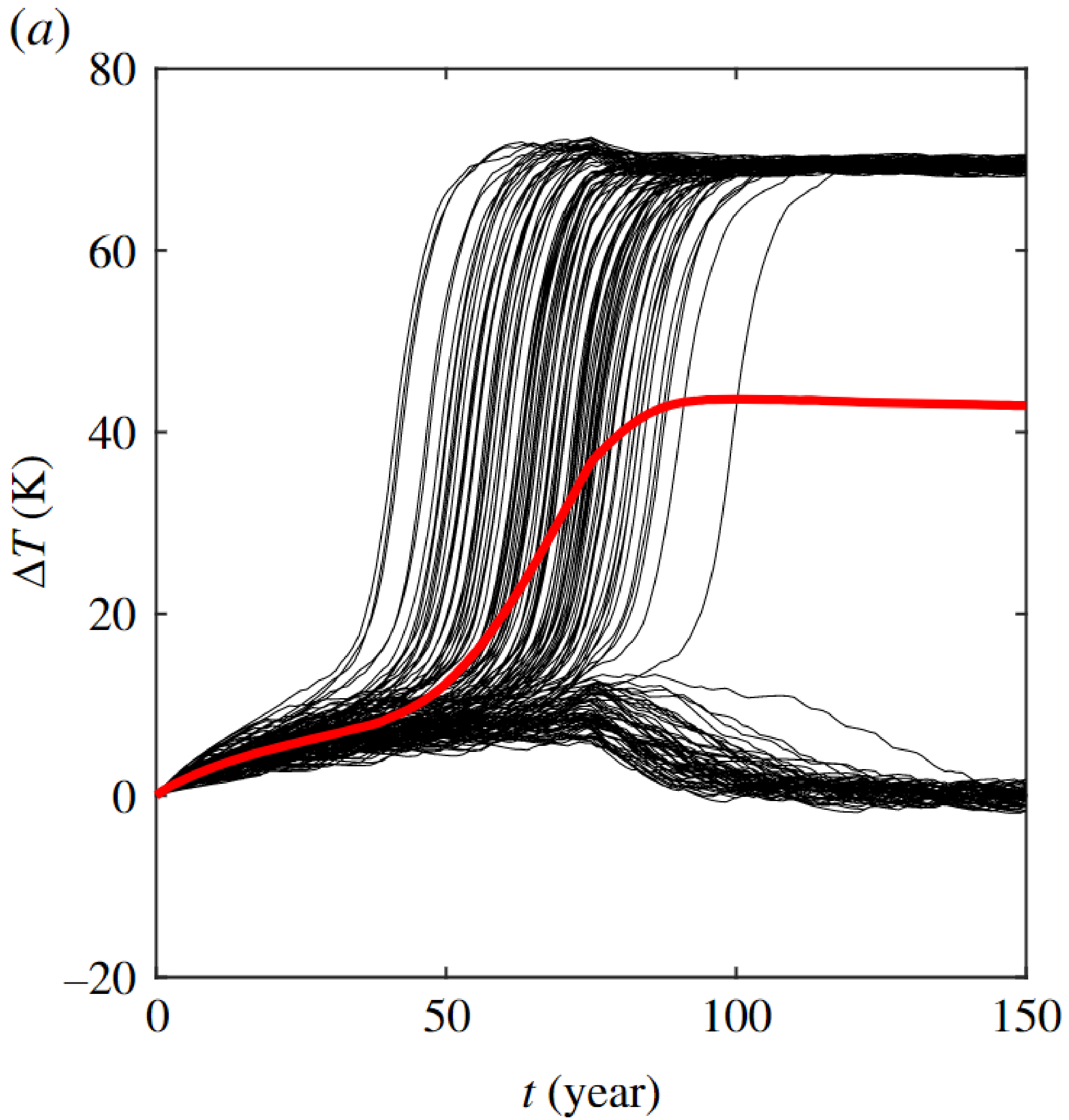


partial tipping

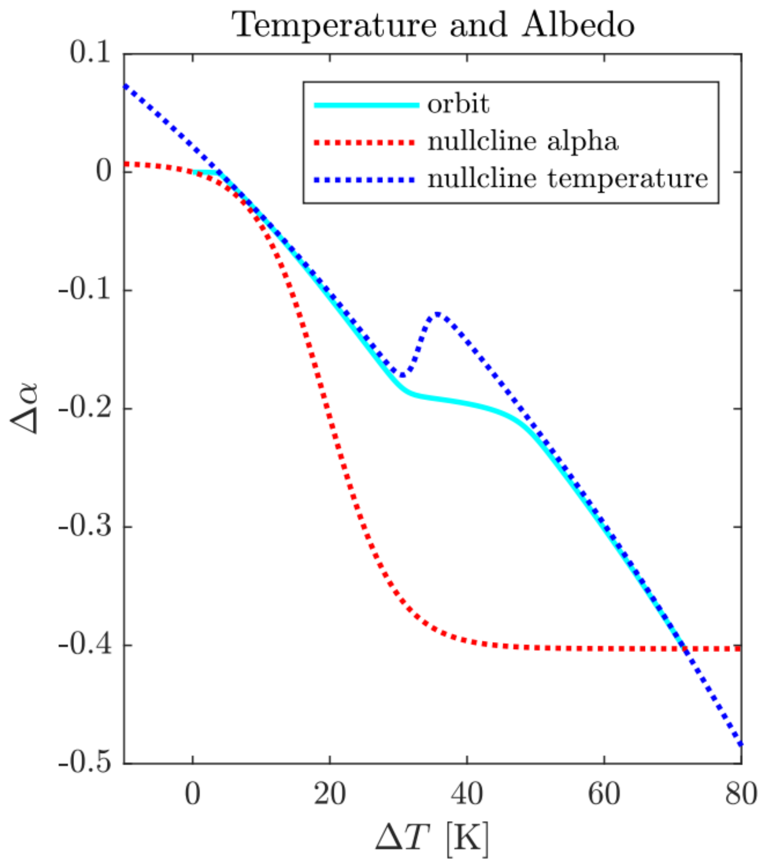
Alkhayuon, H. M., & Ashwin, P. (2018)

Conclusion

TIME SCALES !

- Models have time scale of validity
  - Extreme example: Late tipping points

- Climate response is sensitive to initial conditions
  - Extreme example: Partial tipping



After long period of SLOW change suddenly FAST change can happen!

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.