

Classic Estimations

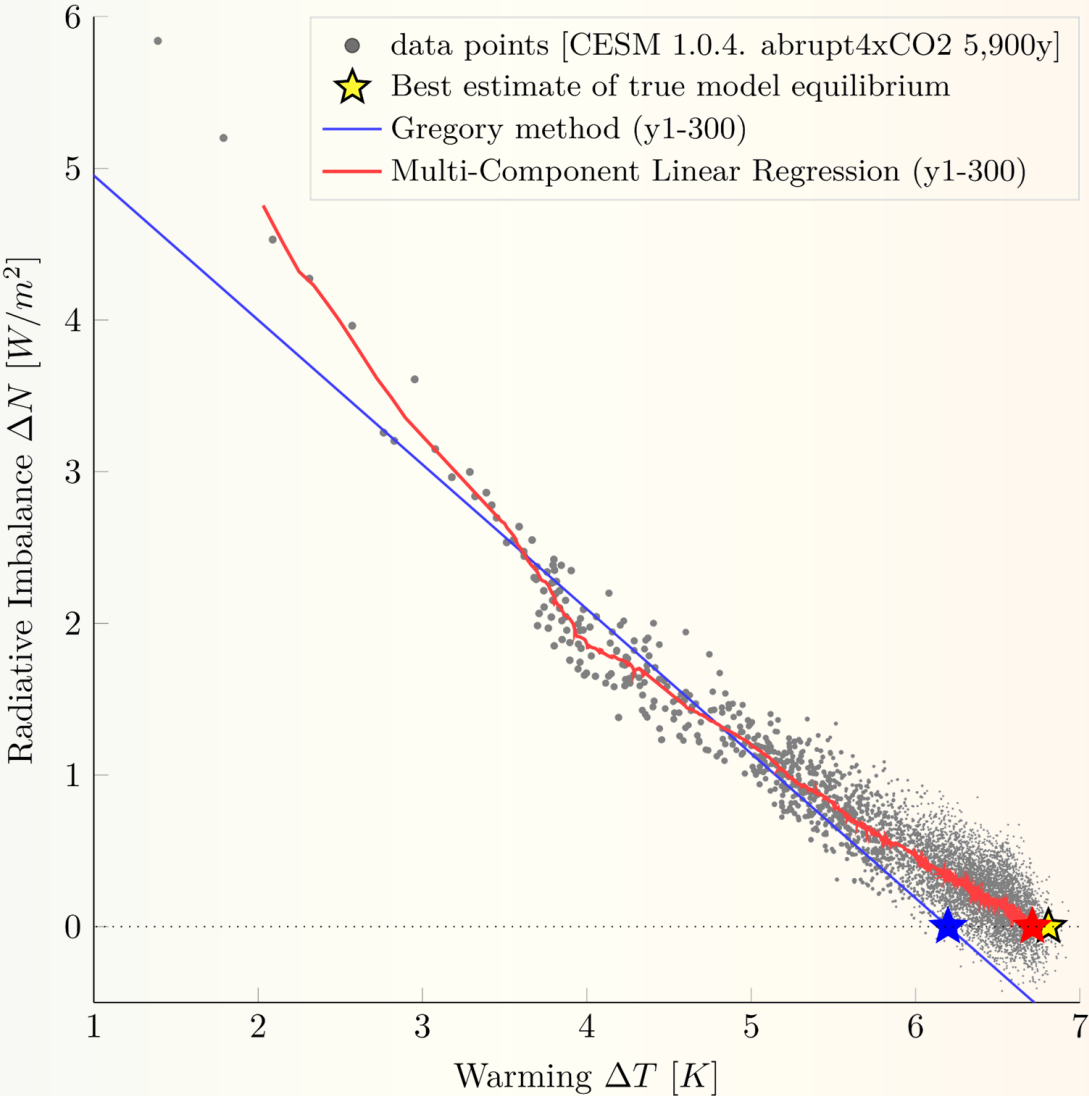
Univariate Regression

$$\Delta N(t) = a\Delta T(t) + f$$

Equilibrium Estimation:

$$\Delta T_*^{est} = -a^{-1} F$$

- ☹ only one time scale
- ☹ only temperature estimates



NEW

Multivariate Estimations

Multivariate Regression

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

↑↑
use of additional observables!

Equilibrium Estimation:

$$\overrightarrow{\Delta X_*^{est}} = -A^{-1} \overrightarrow{F}$$

- 😊 multiple time scales
- 😊 multivariate estimates
- 😊 more accurate estimates



Equilibrium Climate Sensitivity

If CO₂ doubles,

How much warmer will it get eventually?

- 🖥️ Computer models cannot be run for long
- 🖥️ Extrapolation & Estimation methods are needed

Problem:

Classic methods do *not* capture all long time scales

Solution:

Incorporate additional observables in new estimation methods

- 😊 Leads to more accurate estimates
- 😊 Leads to multivariate estimates

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- Background in (Applied) Mathematics
- 2015-2019:
PhD @ Leiden University on *desertification* and *pattern formation*
(with Arjen Doelman, Martina Chirilus-Bruckner & Max Rietkerk)
- Since JAN 2020:
PostDoc @ IMAU, Utrecht University on *Climate Sensitivity*
(with Anna von der Heydt & Henk Dijkstra)

Work within Horizon 2020 project TiPES: Tipping Points in the Earth System

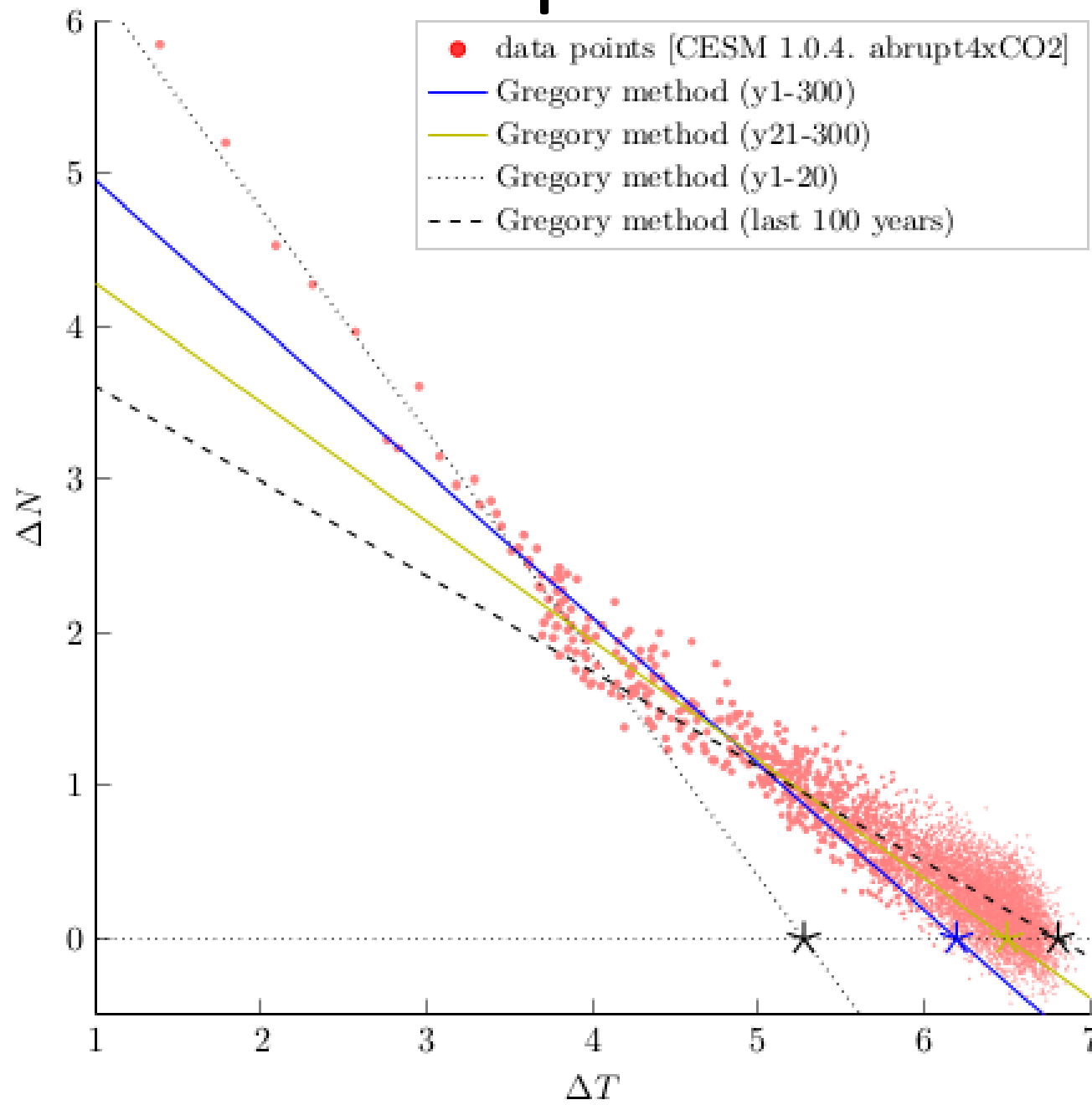
Classic estimation technique

Regress data to

$$\Delta N(t) = \mathbf{a} \Delta T(t) + \mathbf{f}$$

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

$$\Delta T_*^{est} = -\mathbf{a}^{-1} \mathbf{f}$$



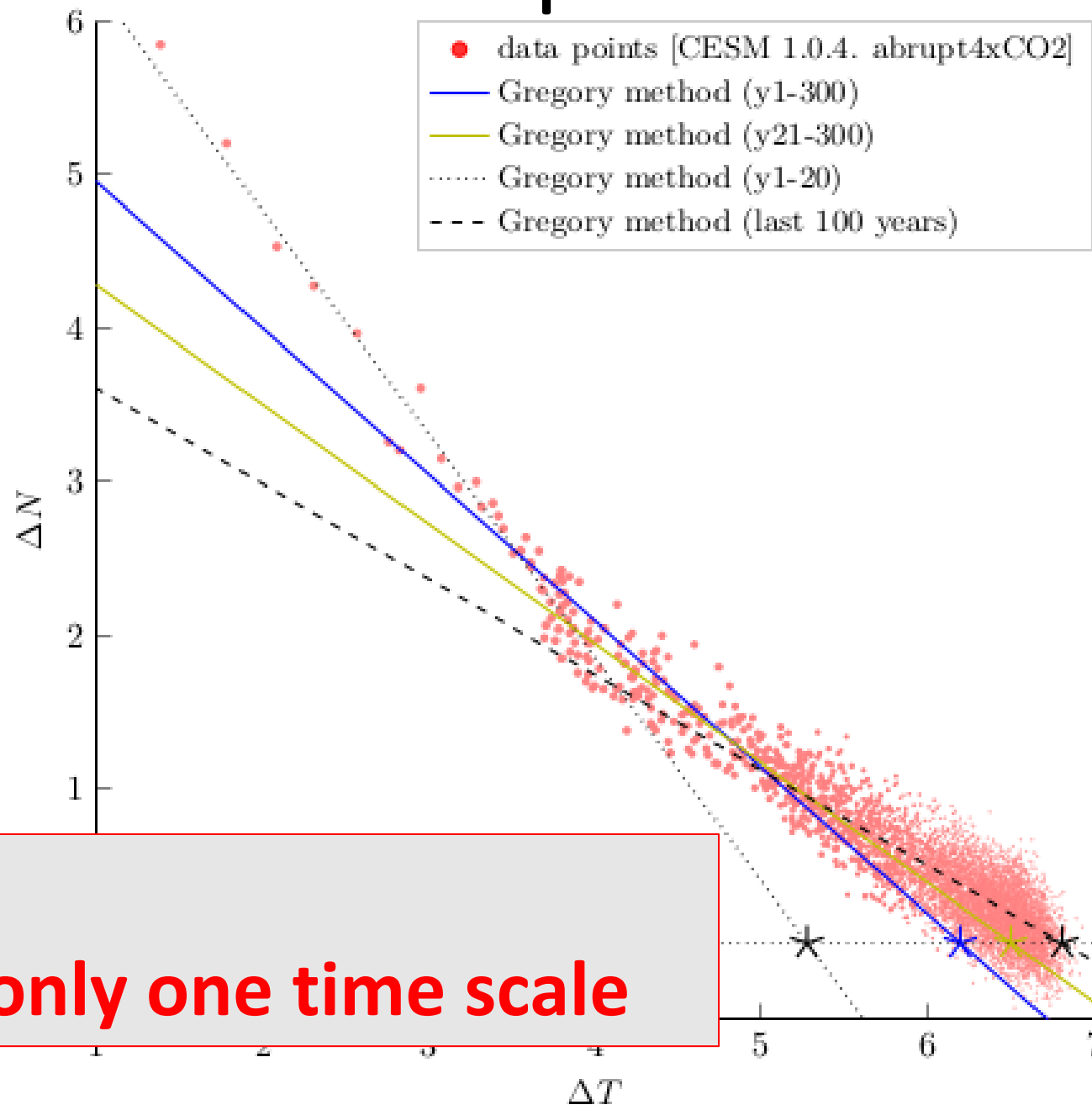
Classic estimation technique

Regress data to

$$\Delta N(t) = \alpha \Delta T(t) + f$$

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

$$\Delta T_*^{est} = -\alpha^{-1} f$$



SHORTCOMING:

Linear regression captures only one time scale

New Multicomponent Linear Regression Method

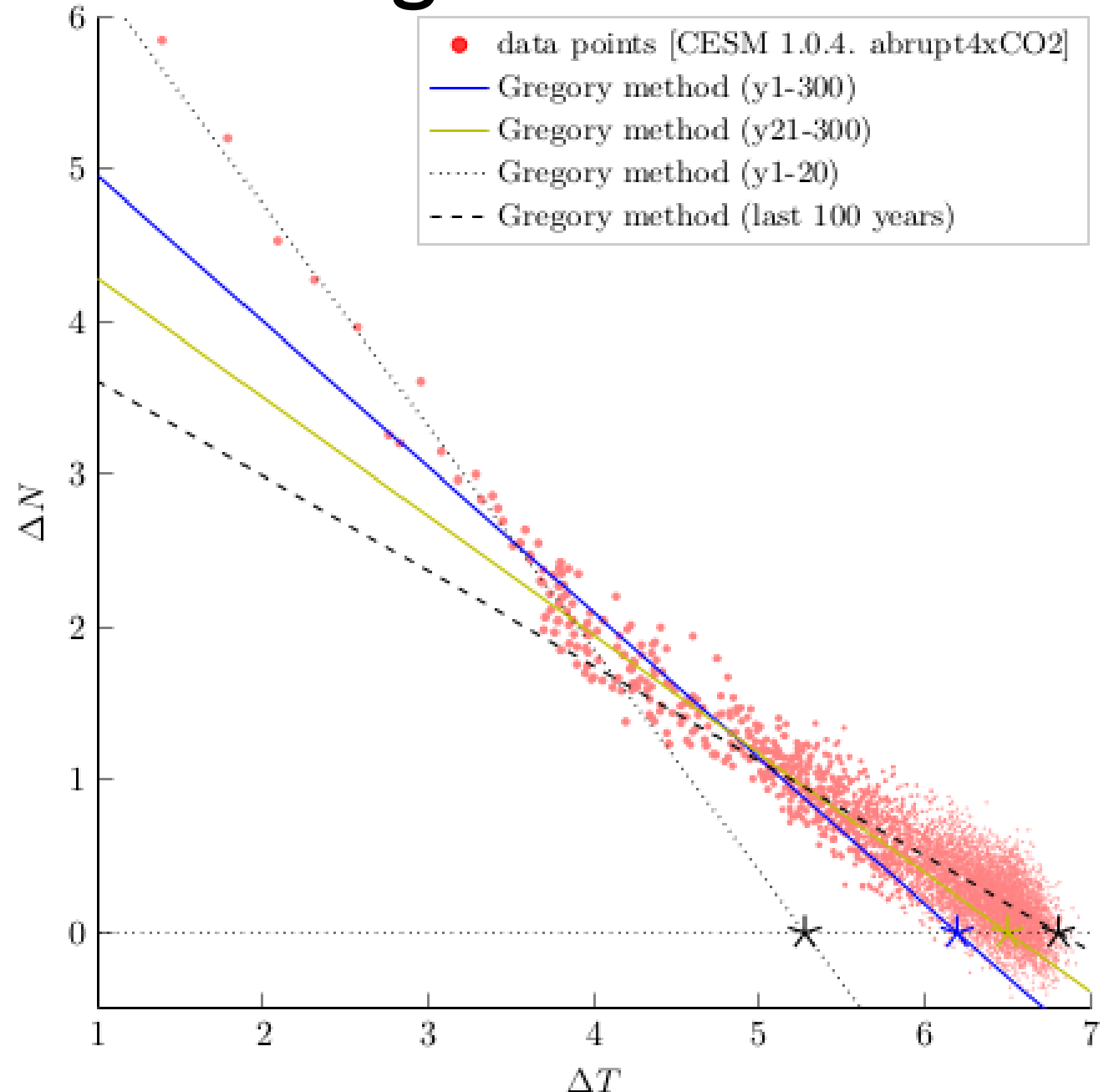
Use additional observables!

Regress to:

$$\begin{bmatrix} \Delta N(t) \\ \vdots \\ \vdots \end{bmatrix} = \mathbf{A} \begin{bmatrix} \Delta T(t) \\ \vdots \\ \vdots \end{bmatrix} + \vec{\mathbf{F}}$$

Examples of potential observables:

- Albedo
- Emissivity
- Ocean Heat Content
- ...



New Multicomponent Linear Regression Method

Use additional observables!

Regress to:

$$\overrightarrow{\Delta Y} = \mathbf{A} \overrightarrow{\Delta X} + \overrightarrow{\mathbf{F}}$$

$\overrightarrow{\Delta Y}$:

observables that
tend to 0
in equilibrium

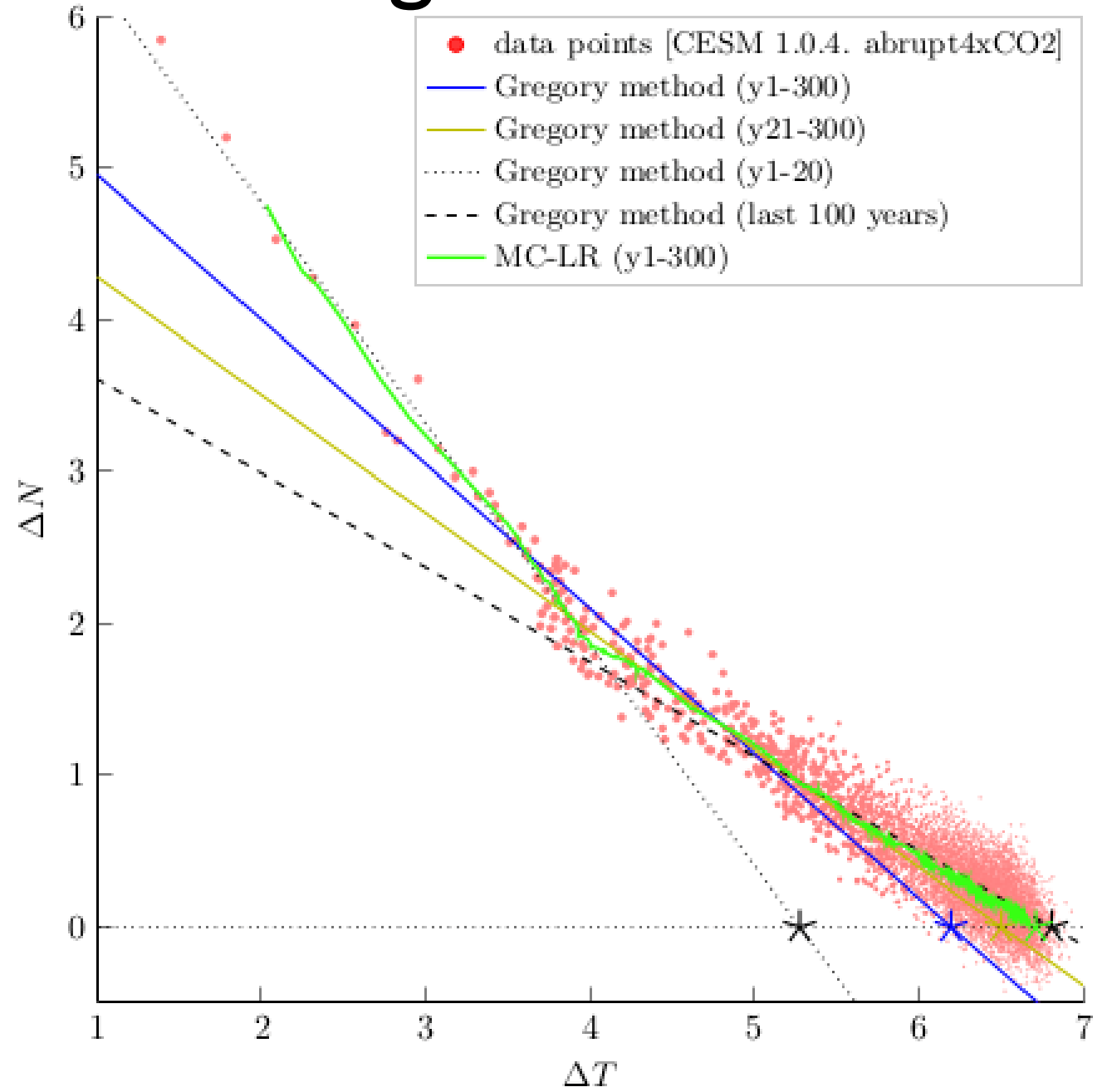
$\overrightarrow{\Delta X}$:

observables that
get estimated
in equilibrium

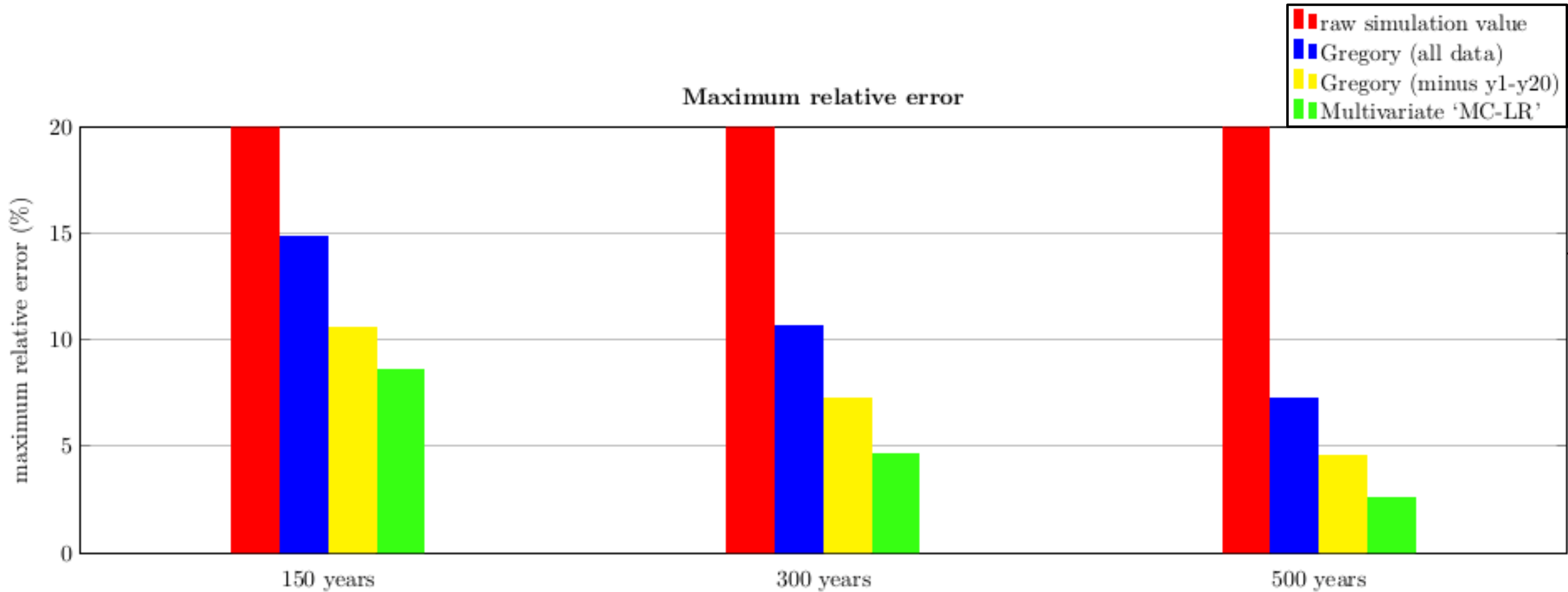
Multivariate ECS estimation is

$$\overrightarrow{\Delta X}_*^{est} = -\mathbf{A}^{-1} \overrightarrow{\mathbf{F}}$$

[Bastiaansen et al, 2021]



Other Global Climate Models



Computed as average of 11 millenia-long runs
from LongRunMIP [Rugenstein et al, 2019]

Discussion

SUMMARY

Multicomponent Linear Regression

$$\overrightarrow{\Delta Y} = \mathbf{A} \overrightarrow{\Delta X} + \overrightarrow{F}$$



Multivariate Estimate

$$\overrightarrow{\Delta X}_*^{est} = -\mathbf{A}^{-1} \overrightarrow{F}$$

- ☹ More accurate estimates from short transient warming simulations

CAVEAT:

- ☹ Finding observables is an art

OUTLOOK:

- ★ Method can help in design of model experiments
- ★ Multivariate estimate also provides insight in *how* climate changes