Assessing the impact of changing warming patterns on transient global warming

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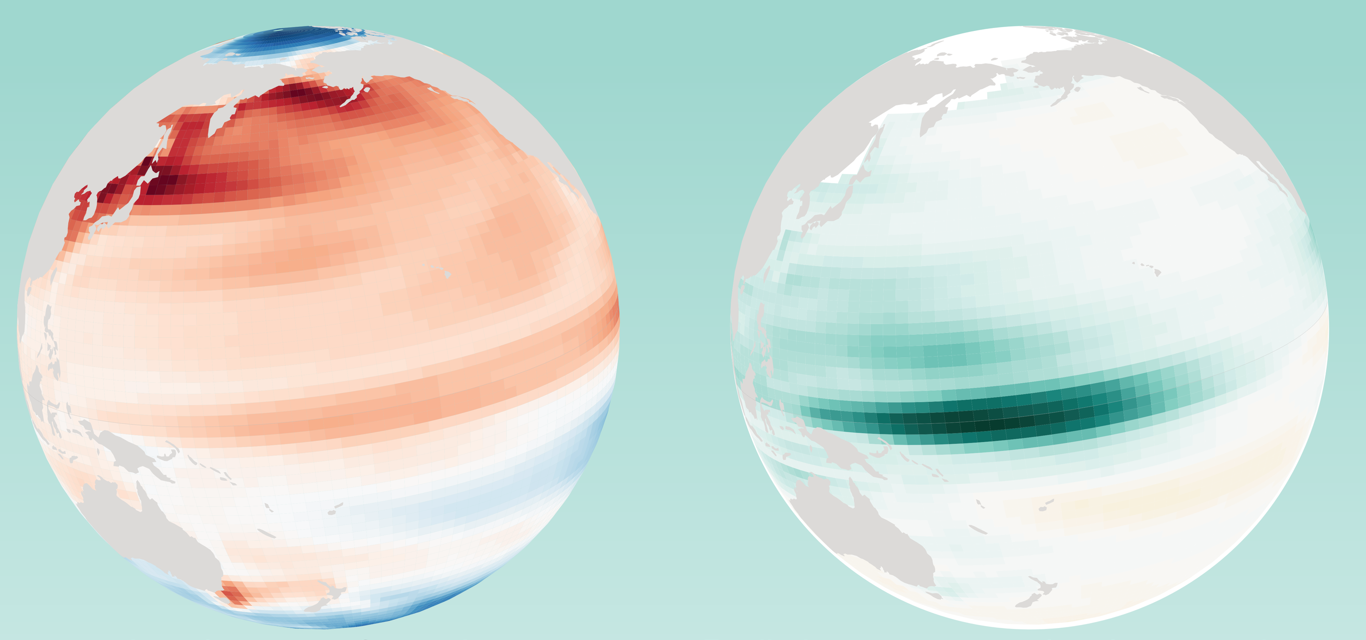


Local pattern of warming

Radiative response to local pattern change

Context:

The pattern of surface warming plays a significant role in determining the Earth's response to radiative forcing as it influences the intensity of climate feedbacks. Distinct patterns of surface warming lead to divergent equilibrium and transient responses to identical forcing, emphasizing the need to analyse this **pattern effect** to understand the climate responses to external forcing.

While existing studies have primarily focused on assessing the influence of warming patterns on **long-term warming**, such as equilibrium climate sensitivity or committed warming, the role of warming patterns in shaping the transient trajectory of global warming remains poorly understood. In this study, we introduce **a novel analytical method** to quantify the significance of evolving warming patterns on **transient global warming**.

Key results

1. For an identical response to forcing, different warming patterns lead to different global warming trajectories
2. The pattern effect generally attenuates global surface warming in idealized 1pctCO2 simulations
3. The TCR in particular is reduced by 11% on average
4. The spread in cooling induced by the pattern effect comes from small key regions, notably the western tropical Pacific

Separating the radiative response to global warming and to zero-mean SST pattern change

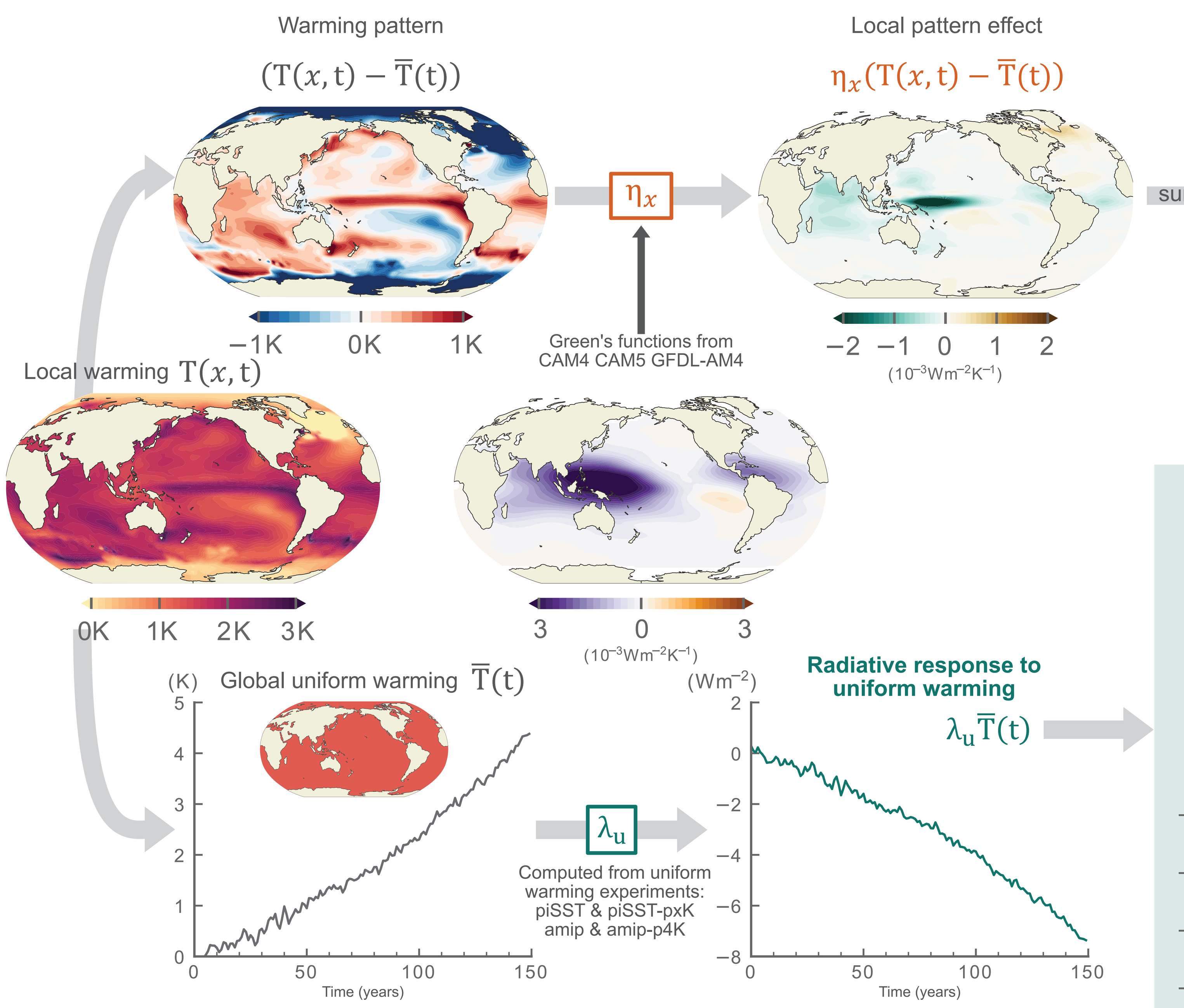
Method

The radiative response is computed separately on global warming and on local warming patterns using Green's functions coefficients.

$$dR(t) = \frac{\partial R}{\partial \overline{T}}\overline{T}(t) + \sum_x \frac{\partial R}{\partial (T(x) - \overline{T})}(T(x) - \overline{T})$$

Response to global warming: $\lambda_u \overline{T}(t)$

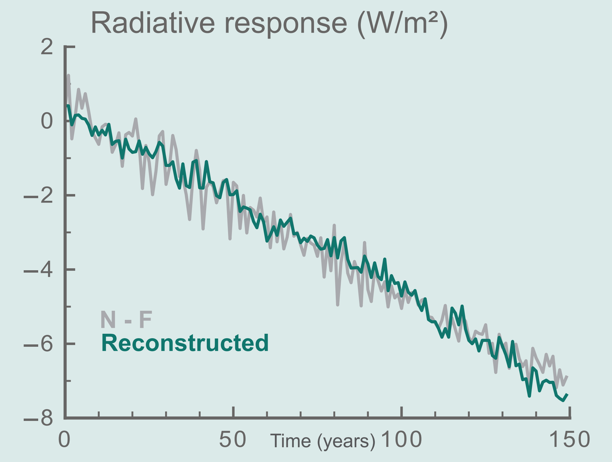
Response to local SST pattern change: $\eta_x (T(x) - \overline{T})$



Example with CESM2
Maps show years 60-80 mean values

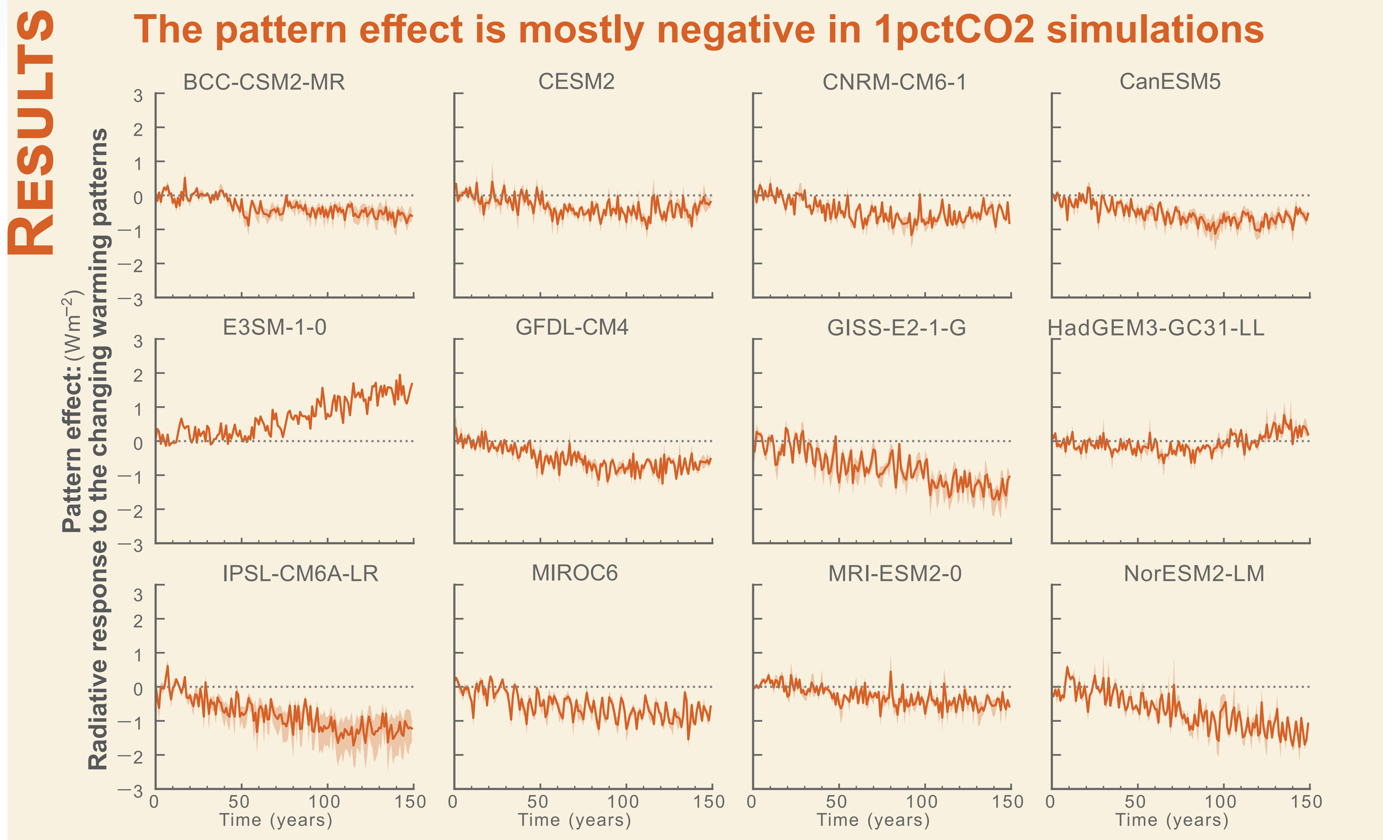
Validation

With independant estimates of the parameters for the radiative response and of the radiative forcing, we verify that the radiative response is reproduced



Results

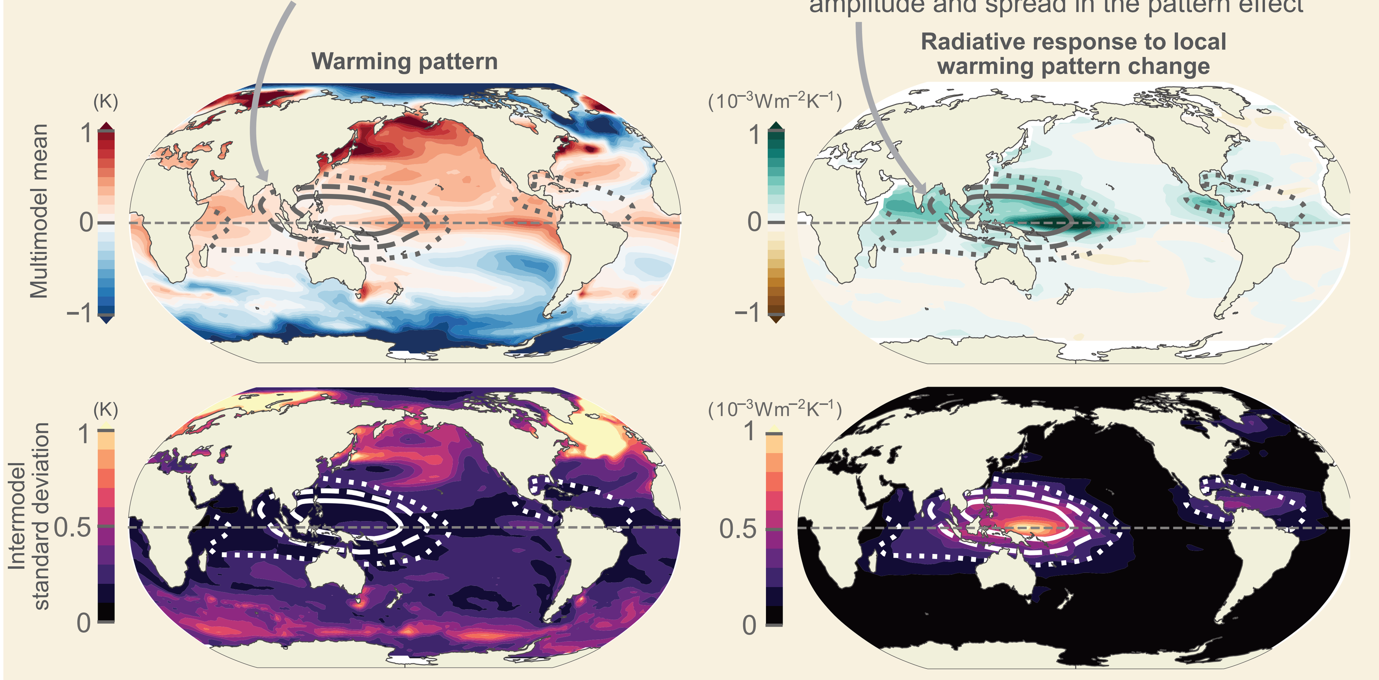
The pattern effect is mostly negative in 1pctCO2 simulations



Small pattern changes in key tropical regions are responsible for the amplitude and the model spread in the pattern effect

Green's functions contours highlight the tropical regions where pattern variability is very small

Despite the small SST variability in these tropical regions, they explain most of the amplitude and spread in the pattern effect



Integrating the global energy budget to quantify global warming induced by the pattern effect

Method

We incorporate the multilinear radiative response in a two-layer energy balance model that we integrate numerically to obtain quantitative results.

Two-layer global energy balance model:

Surface + mixed layer ocean: $C\frac{d\overline{T}}{dt}(t) - \lambda_u \overline{T}(t) - \gamma(\overline{T}(t) - \overline{T}_0(t)) = F(t) + P(t)$

Deep ocean: $C_0\frac{d\overline{T}_0}{dt}(t) - \gamma(\overline{T}(t) - \overline{T}_0(t)) = 0$

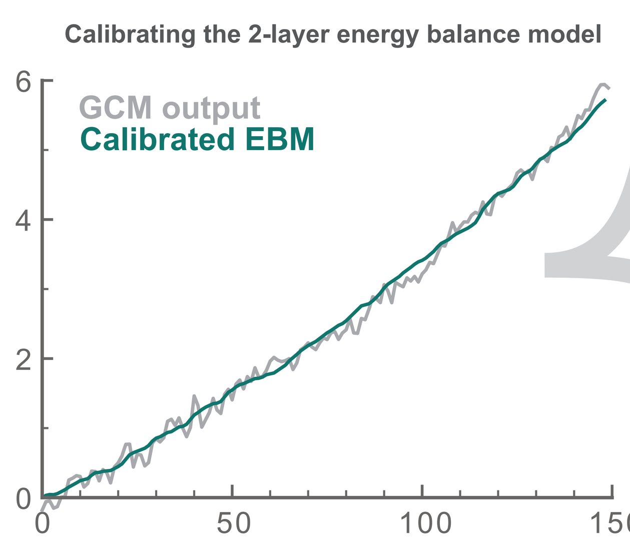
Heat storage — Climate feedbacks — Heat exchange — Forcing terms

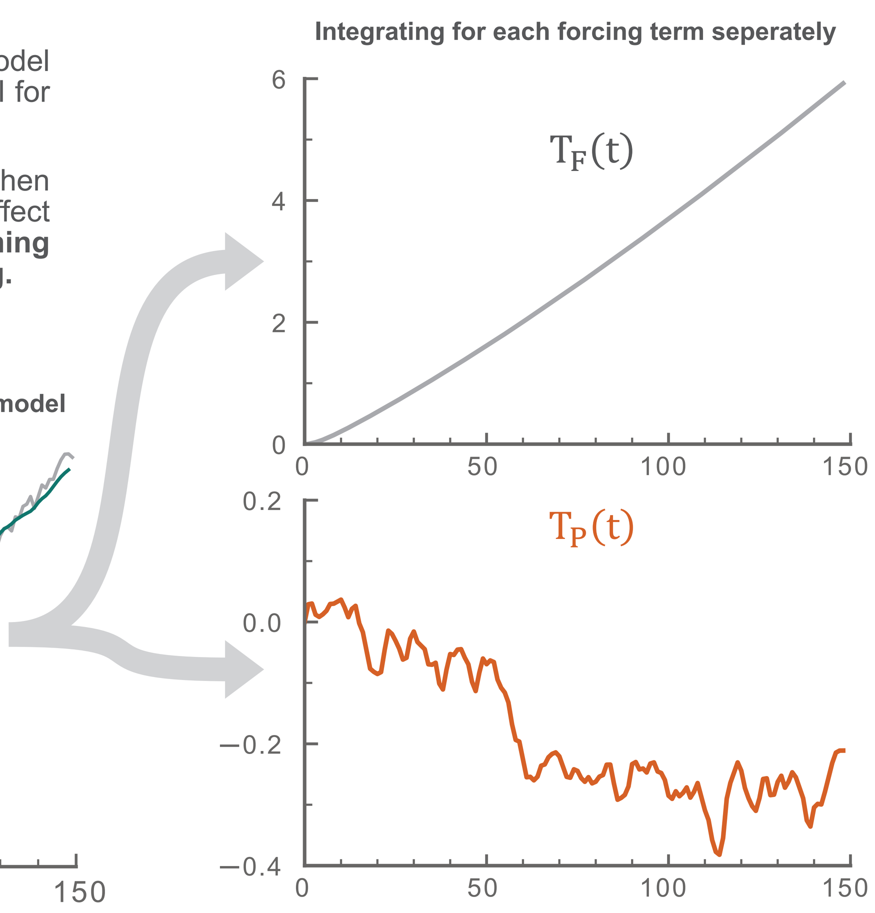
Consequences: $T(t) = T_F(t) + T_P(t)$

Global warming caused by the radiative forcing (T_F) — Global warming caused by changing warming patterns (T_P)

After calibrating the energy balance model we integrate the energy balance model for each forcing term separately.

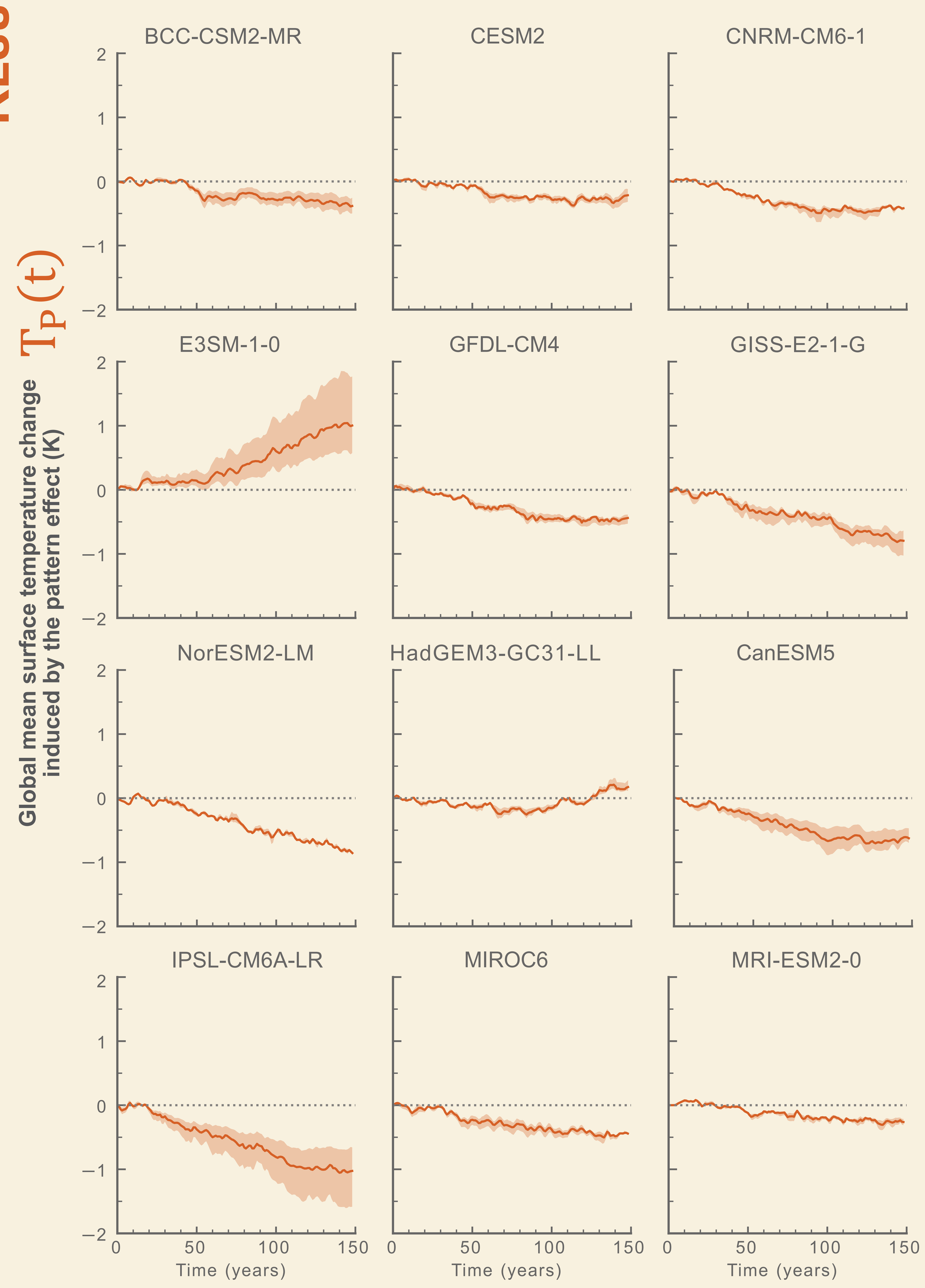
The global warming obtained when integrating with the pattern effect **quantifies how changing warming patterns influence transient warming.**



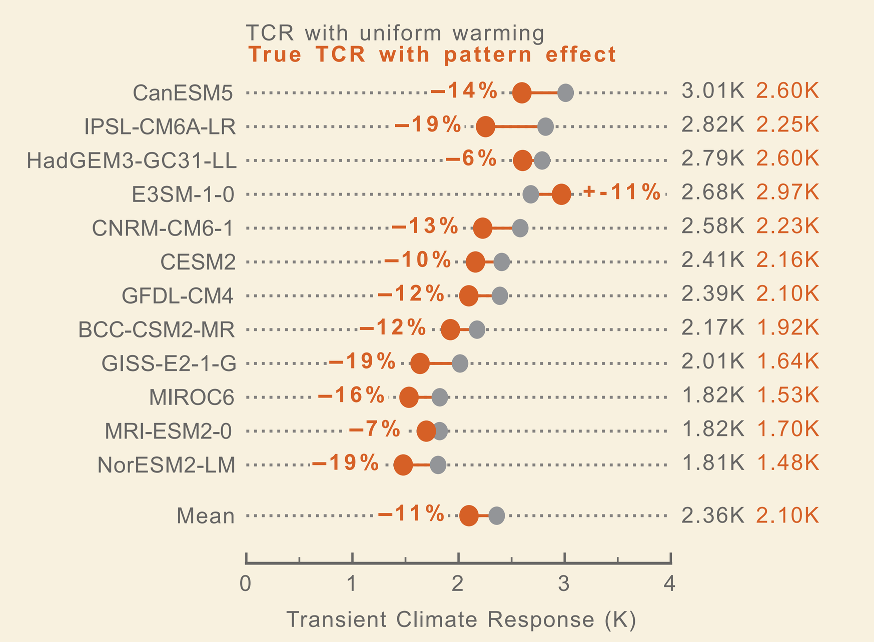


Results

The pattern effect generally limits global warming in 1pctCO2 simulations



The Transient Climate Response is damped by 11% on average by the pattern effect



These idealized results are relevant for historical warming