EGU24-14986, updated on 20 May 2024
https://doi.org/10.5194/egusphere-egu24-14986
EGU General Assembly 2024

Assessing the Impact of Changing Warming Patterns on Transient Global Warming: A Multivariate Energy Budget Approach

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The pattern of surface warming plays a significant role in determining the Earth's response to radiative forcing. Indeed, the Earth's radiative response is intricately linked to the intensity of climate feedbacks, which, in turn, are influenced by the regional distribution of surface warming. 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 importance of evolving warming patterns on transient global warming.

Our approach involves developing a multivariate global energy budget, which provides a unified framework for interpreting the sensitivity of the radiative response of the Earth to the warming pattern. This framework explicitly separates the radiative response caused by the global mean temperature increase, from the additional response induced by changing temperature patterns.

Using this new energy balance model, we assess the relative contributions of the direct radiative forcing and changing temperature patterns to the global mean temperature change in linearly increasing forcing experiments (1pctCO2) from nine CMIP6 models. We show that the pattern effect consistently dampens global warming in the first 100 years of all simulations studied. Specifically, we quantify that the transient climate response, reached after 70 years of simulations, would be 0.4±0.2K higher (equivalent to a 20±15% increase) if the warming was uniformly distributed (i.e. in the absence of changing warming patterns).

Furthermore, our study demonstrates that distinct models exhibit significantly divergent transient global warming patterns solely due to variations in the pattern effect. Overall, our results highlight the importance of changing warming patterns, specifically through the pattern effect, in influencing decadal-scale transient warming. These findings notably support recent suggestions to incorporate warming pattern uncertainties in future climate projections.