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Dynamics of the global energy budget with a time dependent climate feedback parameter

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The representation of the Earth global energy budget with a linear radiative response is unsufficient to correctly reproduce the long term surface temperature response ΔTs of climate to a radiative forcing ΔF, notably because of the dependence of the climate feedback parameter λ on the geographical pattern of surface temperature increase. The introduction of a time-dependent climate feedback parameter λ(t) is an appropriate solution to this matter. However, there is no agreement in the community on how to define such a variable λ even though numerous definitions with different methods and time periods have been introduced in the past decade.

From Budyko's (1969) original linear relationship between the surface temperature and the outgoing longwave radiation, we apply the perturbation theory to provide a rigorous theoretical development of the Earth energy budget with a time dependant climate feedback parameter, along with a robust definition of the climate feedback parameter. We show that the 0-dimensional energy balance model with a variable λ: $N = \Delta F + \lambda(t)\Delta Ts$ (where N is the Earth energy imbalance) is incomplete and should include a supplementary term $\Delta\lambda(t)Ts(0)$, where Δλ(t) is the temporal evolution of the climate feedback parameter anomaly, and Ts(0) is the global mean surface temperature before the forcing is applied.

This new energy budget accurately reproduces the surface temperature response to abrupt increase of atmospheric CO_2 of 8 multimillenia long coupled climate models at all time scales.It also accurately reproduces the simulated radiative response of the Earth under different abrupt CO_2 increase scenarios. We confirm that the non linear radiative response of the Earth across abrupt increase CO_2 scenarios is essentially explained by a positive dependence of the climate feedback parameter on temperature (the dependence of the climate feedback parameter on the forcing being marginal as in Bloch-Johnson et al. -2021-)

Analysis of the asymptotic form of the radiative response yields a new expression of the climate sensitivity to a given radiative forcing which explicitely depends on the climate feedback parameter before the forcing is applied (λ0), and on the climate feedback parameter temporal change (Δλ). We evaluate the climate sensitivity in the LongRunMIP experiments and find that 97% of the spread in climate sensitivity is explained by the spread in Δλ/λ0 showing that both the temporal change in the climate feedback parameter

and its initial state are important to explain their climate sensitivity of climate models.