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Is the linear global radiative forcing-feedback framework still useful?

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The energy balance equation with a single constant feedback parameter is often used for simple climate models or to estimate the effective climate sensitivity from transient simulations. However, several limitations in this forcing-feedback framework are becoming obvious, including the definition of the forcing, the dependence of feedbacks over different timescales, and the changing character of ocean heat uptake over time.

We force a 130-member ensemble of the coupled climate model CESM with abrupt 4xCO_2 increase and study various equilibration time scales. Our focus is on (1) alternative definitions of the forcing term, (2) the spatial patterns of the radiative imbalance, or equivalently ocean heat uptake term, and (3) common methods of linearly regressing the radiative imbalance against the surface temperature.

On timescales of years or shorter, the cloud radiative effect, surface fluxes, meridional ocean heat transport, and the spatial patterns of surface temperature modify the instantaneous forcing. The climate feedback parameter over the adjustment time is twice as high on decadal timescales and more than three times as high on centennial time scales. Fixed-SST simulations give a spatial pattern of surface fluxes and cloud radiative effect not representative of the adjustment phase and thus, give a different forcing than obtained with the regression method.

On time scales of decades to centuries, the introduction of the ocean heat uptake efficacy (or equivalently an adjusted radiative forcing) does not explain the non-linearity for decadal but possibly longer time scales. Enhanced high latitude surface heat fluxes impact the ocean circulation and heat uptake rate as well as the strength of atmospheric feedbacks. Previous studies have typically used simulations of 150 year or less, often with a slab ocean; however, with our 1500 year long simulation we show that the non-linearity can be strong, e.g., between year 100 and 400 when the Atlantic Meridional Overturning Circulation returns to its control strength.

Implications of the non-linearity on all timescales are that an estimation of the equilibrium climate sensitivity from observations by simple regression of radiative imbalance to temperature is impossible and model inter comparison is challenging since the non-linearities appear to be model dependent.

We show that the linearity is still a defensible approximation for certain time scales if the forcing term is strongly adjusted and reduced several W/m2 from the current definition. Alternatively, the climate feedback parameter has to be described spatially and temperature dependent in each model and the linear forcing-feedback framework would have to be abandoned.