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Effective and equilibrium climate sensitivity

Maria Rugenstein (1) and Jonah Bloch-Johnson (2)

(1) ETH Zürich, IAC, D-USYS, Zürich, Switzerland (maria.rugenstein@env.ethz.ch), (2) University of Chicago (jsbj@uchicago.edu)

Atmosphere-ocean general circulation models, as well as the real world, take thousands of years to equilibrate to CO_2 induced radiative perturbations. For decades scientists have used equilibrium climate sensitivity – the equilibrium surface warming associated with doubling the atmospheric CO_2 concentration – to project future climate change, to test our understanding of climate feedbacks and paleoproxies, and as a benchmark in model intercomparisons. Yet astonishingly little is known about how coupled climate models equilibrate to CO_2 perturbations, as computational costs lead to the widespread practice of extrapolating equilibrium conditions from transient simulations. We discuss a collection of atmosphere-ocean general circulation model simulations, each spanning one to six thousand years. We show that in all models and simulations the equilibrium warming is 5-40% higher than the most commonly used extrapolation method, which assumes feedbacks to be constant in time. We find that global and local feedbacks vary throughout the simulation time, with substantial spread in model behavior. The tropics govern the feedback on decadal to centennial time scales, while mid-latitudes in both hemispheres dominate the response on centennial to millennial time scales. As models approach equilibrium, feedbacks arising from internal variability become more difficult to separate from the forced response. Our findings imply limited predictive power of transient simulations for equilibrium, and raise questions about the adequacy of commonly used energy balance frameworks.

We also encourage others to use the dataset for questions other than feedback analyses, such as internal variability in equilibrated warmer states, ocean overturning responses on millennia time scales, or year-round, ice-free Arctic conditions and sea ice dynamics: www.longrunmip.org