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DEFINING AND QUANTIFYING FEEDBACKS IN EARTH'S CLIMATE SYSTEM

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ABSTRACT

Feedbacks in Earth's climate system are increasingly being examined to identify processes controlling Earth's climate sensitivity, to quantify the effects of these processes, and to assess the ability of climate models to accurately represent the actual climate system and changes due to increases in greenhouse gases and other forcings. At present differing explicit or implicit choices of the measure of climate change, of definitions of feedbacks, and of the underlying non-feedback climate to which feedbacks must be referred have resulted in differing measures of feedbacks. The single variable that is most commonly taken as a measure of climate response to radiative perturbation is global (and annual) mean (near) surface (air) temperature GMST; climate models indicate that many other changes in Earth's climate scale with change in GMST. The choice of GMST as the index of climate change together with recognition that Earth's energy content H is controlled by shortwave absorption and by longwave emission at the top of the atmosphere as $dH/dt = \gamma J_S/4 - \varepsilon\sigma T_s^4$, where T_s is GMST, γ is the planetary coalbedo (complement of the Bond albedo, ~0.70), J_S is the solar constant (~1368 W m^{-2}), *s* is the Stefan-Boltzmann constant, and ε defines an effective emissivity (~0.62) as the ratio of the longwave flux emitted at the top of the atmosphere to that emitted by a black body radiator at the global mean surface temperature, leads to the choice of reference no-feedback or "open loop" climate sensitivity S_0 as the equilibrium change in GMST that would result from a small change the planetary energy budget, forcing ΔF, normalized to that forcing, for γ and ε held constant. This definition yields to first order a climate sensitivity in the absence of feedbacks $S_0 \equiv \left(dT_s/dF\right)_0 = T_s/\gamma_0 J_S$, where the subscript 0 denotes absence of feedback. For T_s = 288 K, S_0 = 0.30 K/ (W m^{-2}); for forcing from doubled CO_2 taken as $\Delta F_{2\times}$ = 3.7 W m^{-2}, the corresponding CO2 doubling temperature change (interpreted as a derivative quantity) $\Delta T_{2\times 0}$ = 1.1 K. This no-feedback sensitivity serves as the basis for considerations of feedbacks which would increase or diminish Earth's climate sensitivity from this no-feedback value. Formally this sensitivity is $S = fS_0 = S_0/(1-\Phi)$ where f is the feedback factor and where the total feedback strength is $\Phi = (d\ln\gamma/d\ln T_s)_0/4 - (d\ln\varepsilon/d\ln T_s)_0/4$; a positive value of Φ denotes positive feedback, increasing the sensitivity over the no-feedback value. The two contributions to feedback strength denote changes in planetary coalbedo and effective emissivity with change in GMST. A decrease in cloudiness (increase in coalbedo) with increasing GMST would result in positive shortwave feedback (positive contribution to Φ) similarly an increase in atmospheric water vapor content and associated longwave absorption with increasing GMST (decrease in emissivity) would result in positive longwave feedback. For climate sensitivity $\Delta T_{2\times}$ = 3 K (IPCC, 2007) the feedback factor 2.7 corresponds to feedback strength Φ = 0.63. Determining the contributions of individual climate processes to the feedback strength and the sensitivity of feedback to representations of these processes is a major challenge facing the climate modeling community.