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Uncertainties in climate projections: The case for a process-oriented evaluation of Earth System Models

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The ability to understand and project future climate is fundamental to society. Currently, large uncertainties in climate projections exist due to uncertainties in physical climate feedbacks simulated by coupled Atmosphere-Ocean General Circulation Models (AOGCMs) and additional feedbacks that arise from complex interactions between climate and other components of the Earth System as simulated by Earth System Models (ESMs). Here we review important climate feedbacks and argue for a process-oriented evaluation in addition to the evaluation of Essential Climate Variables (ECVs). A set of core processes that are related to important feedbacks in the climate system is structured around three major topics (physical climate, global carbon cycle, and atmospheric composition). Each process is associated with one or more model diagnostics and with relevant observational datasets that can be used for the evaluation. Following this approach, outputs from individual component models and from coupled ESMs can be confronted with observations in a consistent and quantitative way. The review suggests that continued investment in systematic and consistent model evaluation will allow a rigorous assessment of the strengths and weaknesses of ESMs and should lead, on the long-term, to a more quantitative estimate of uncertainties in climate projections and to improved ESMs with demonstrably enhanced projection skills. This approach will also fully exploit the combined use of models and observations to better understand the climate system.