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How Uncertain Are Estimates of Key Climate Model Parameters? A Bayesian Inversion of an Earth System Model of Intermediate Complexity

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Current model-based climate projections are deeply uncertain. One important driver of this uncertainty is that climate model parameters are poorly constrained. Here we characterize the uncertainty of key parameters of a modified Earth System Model of Intermediate Complexity (EMIC), the University of Victoria Earth System Climate Model version 2.8 (UVic model). Our study advances on previous work by using a model with dynamic 3D ocean, thermodynamic sea ice, and dynamic vegetation components, which allows for better representation of relevant feedbacks. We add to the model forcings from non-CO2 greenhouse gases, volcanoes and anthropogenic sulfate aerosols. Then we sample parametric uncertainty using a large ensemble, and apply a simple emulator and a Markov Chain Monte Carlo method to assimilate observations of global mean surface temperatures and oceanic heat uptake.

Specifically, we run an ensemble of transient simulations spanning last two centuries. This ensemble samples parametric uncertainty about climate sensitivity, background vertical ocean diffusivity, and the sensitivity of radiative forcing to anthropogenic sulfate aerosol concentrations. We simulate different climate sensitivities by varying local outgoing longwave radiation feedbacks. We assimilate the observations using a statistically sound likelihood based approach. The inversion accounts for uncertainty in the statistical properties of the potentially correlated model-data residuals, and reduces biases due to sparse sampling of the parameter space using emulation. Our study results in dynamically consistent hindcasts and the joint nonparametric parameter probability density function (pdf) of the parameters.

The mode of climate sensitivity pdf is in broad agreement with previously published results. As in previous studies, our estimate of the climate sensitivity pdf hinges critically on divergent prior assumptions. The mode for vertical ocean diffusivity is within the range of previous results for the UVic model. The climate sensitivity and anthropogenic aerosol scaling factor pdfs are relatively well constrained by the considered observations, while the background ocean diffusivity pdf is more poorly constrained. We demonstrate how the relatively sparse sampling of the parameter space typical for EMIC studies can affect posterior parameter estimates, and how a simple emulator can reduce some of these artifacts. Finally, we evaluate the skill of the probabilistic UVic model hindcasts by comparing them with those from more complex atmosphere ocean general circulation models.