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Emulation and probabilistic climate predictions

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We present two applications of emulation which we apply to the quantification of uncertainty in climate predictions. Emulators are computationally cheap surrogates for simulators, here derived from the Intermediate Complexity earth system models GENIE-1 (2D atmosphere, 3D ocean) and GENIE-2 (3D atmosphere, 3D ocean).

The first technique (Holden et al, 2010) addresses the design and evaluation of ensembles of climate change. In order to better quantify model uncertainty, we precalibrate (Edwards et al, in press) GENIE-1, allowing 25 model parameters to each vary over the entire range of plausible input values. We require that the resulting model states reproduce the main features of climate (but not precise observations) and demonstrate that this approach leads to a wide range of large-scale feedback strengths (generally encompassing the range of GCM behaviour). However, in the design of such an ensemble it is not feasible to explore the entire input space with a naive Monte-Carlo approach; only 10 from 1,000 Maximin Latin Hypercube ensemble members result in “plausible” climates. We thus build emulators of GENIE-1 and perform a rejection sampling to derive a collection of 1,000 parameter sets which the emulators predict will be modern plausible; 894 of these are indeed found to provide plausible climates in the simulator. We then perform an LGM-constrained Bayesian calibration (Rougier, 2007) of the simulated output of this ensemble, including climate sensitivity and carbon storage under doubled CO_2, incorporating data-driven priors and accounting for structural error. The emulators additionally allow us to investigate the statistical relationship between model inputs and outputs; we use them to derive “total effects” for each parameter, thereby quantifying each parameter’s contribution to the variance of specific model outputs.

The second technique (Holden and Edwards, 2010) applies dimensional reduction to build emulators of GENIE-2 2D-output fields. The approach is developed as an alternative to pattern scaling that allows for non-linear spatio-temporal behaviour. Such fast calculations of climate change are required for the evaluation of uncertainty in many computationally demanding applications, notably in the fields of climate change impacts and integrated assessment. We apply principal component analysis to project 2D model output onto 1D space and then emulate the map from input space (19 model parameters and 3 forcing inputs) to the 1D output space. An emulated 122-member ensemble takes $\sim$0.06 s, in stark contrast to the $\sim$1,000 hours required by this simulator. This efficiency paves the way for incorporating improved calculations of climate change into integrated assessment, including location-dependent estimates of uncertainty.

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