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Emulating Global Circulation Model Temperatures: From Global Mean Temperature Trajectories to Grid Point Level Realizations

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Global circulation models (GCMs) are valuable instruments to study the Earth System's response to a given greenhouse gas emission scenario. This information is needed for impact and integrated assessment modelling and is useful to gain a deeper understanding of the climate system. Such GCM projections are associated with uncertainties arising from internal climate variability as well as model uncertainty. The first source of uncertainty is usually accounted for by perturbing the initial conditions of a given GCM while applying the same external forcing and hence, sampling climate variability. Model uncertainty, on the other hand, can be taken into account by evaluating multi-model GCM ensembles. However, the complexity of GCMs makes them computationally expensive and limits the number of runs which are feasible to be generated. Here, we investigate the question whether (i) initial condition and / or (ii) multi-model ensembles can be approximated by computationally inexpensive stochastic emulators. For this purpose, we propose a novel modular framework to emulate climate model land temperatures at the grid point level (Beusch et al., in prep.). In our framework, we separate the emulation problem into three parts: (i) the stochastic generation of global mean temperature trajectories, (ii) the estimation of an associated grid point level mean response, and (iii) the modelling of residual climate variability around this mean response. We train the emulator on a single climate model run spanning 1870 – 2100 with a yearly temporal resolution. Global mean temperature trajectories are built as a combination of a smooth trend representing global warming and an AR process accounting for temporally correlated natural variability. The grid point level response model and the residual variability model are chosen by cross-validation. While the grid point level mean response is deterministically linked to global mean temperature, the residual climate variability is stochastically generated by means of grid point specific AR processes with spatially correlated innovations. The resulting emulator can be used to produce large ensembles of global land temperature fields upholding the GCM's spatio-temporal correlations at a negligible computational cost. We apply our framework to a set of GCMs stemming from the CMIP5 archive and show that we are able to emulate a single-model initial condition ensemble for a given greenhouse gas emission scenario. However, the considered GCMs exhibit distinct structural differences which cannot be captured by an emulator trained on a single model. Hence, to successfully emulate multi-model ensembles, such as CMIP5, it is necessary to train different emulators on single realizations of the contained models.