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Crossbreeding Earth System Models with an Emulator for Regionally-optimized Land Temperature Projections

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Earth System Models (ESMs) are invaluable tools to study the climate system's response to a specific greenhouse gas emission scenario, but their projections are associated with internal climate variability and model uncertainty. To account for these uncertainties, large single-model initial-condition ensembles and multi-model ensembles are created and observations are used to constrain their projections. However, ensemble size is usually limited since ESM simulations are computationally costly. Climate change impact and integrated assessment models, on the other hand, could profit from more realizations which are consistent with observations and the associated improved sampling of the constrained phase space.

Here, we employ MESMER, a Modular Earth System Model Emulator with spatially Resolved output, to generate stochastic realizations of land temperature field time series at a yearly resolution at a negligible computational cost (Beusch et al., 2019). MESMER successfully approximates large multi-model initial-condition ensembles on grid-point to regional scales if it is trained with runs from each contained ESM. Here, we create 1000 emulations per ESM for models of the 6th phase of the Coupled Model Intercomparison Project (CMIP6) covering the historical time period and the high-end emission scenario SSP585 (1870 – 2100) (Beusch et al., submitted). The resulting ensemble is referred to as a "superensemble".

The modular framework of MESMER opens new avenues for validating and constraining ESM ensembles (Beusch et al., submitted). Within the emulator, the local warming signal is expressed as a combination of the global mean temperature trend and the local response to this global trend. These two features can be validated separately by comparison to observations. It is found that ESMs which perform well in terms of global mean temperature trend do not necessarily perform well in terms of local response and vice versa. Additionally, different ESMs perform well in different regions. The most naive approach would be to base temperature projections solely on ESMs which perform well on both global and regional scales. However, this would result in discarding valuable information from many ESMs which perform well at only one of the scales. To circumvent this issue, we therefore propose to use MESMER to combine all global mean temperature trends with all local modules that are consistent with observations. Thereby, we obtain a regionally-optimized "crossbred" superensemble which constitutes a large recombined multi-model initial-condition ensemble and makes full use of all ESM features which are consistent with observations. The regionally diverse behavior of the crossbred superensemble highlights the importance of considering spatially resolved temperature projections.

L. Beusch, L. Gudmundsson, and S. I. Seneviratne: Emulating Earth System Model Temperatures: from Global Mean Temperature Trajectories to Grid-point Level Realizations on Land, doi: 10.5194/esd-2019-34, 2019 (accepted for ESD).

L. Beusch, L. Gudmundsson, and S. I. Seneviratne: Crossbreeding CMIP6 Earth System Models with an Emulator for Regionally-optimized Land Temperature Projections, submitted.