The role of efficient climate models in the projection of future climate feedback and surface warming

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Projecting the global climate feedback and surface warming responses to anthropogenic forcing scenarios remains a key priority for climate science. Here, we explore possible roles for efficient climate model ensembles in contributing to quantitative projections of future global mean surface warming and climate feedback within model hierarchies. By comparing complex and efficient (sometimes termed ‘simple’) model output to data we: (1) explore potential Bayesian approaches to model ensemble generation; (2) ask what properties an efficient climate model should have to contribute to the generation of future warming and climate feedback projections; (3) present new projections from efficient model ensembles.

Climate processes relevant to global surface warming and climate feedback act over at least 14 orders of magnitude in space and time; from cloud droplet collisions and photosynthesis up to the global mean temperature and carbon storage over the 21st century. Due to computational resources, even the most complex Earth system models only resolve around 3 orders of magnitude in horizontal space (from grid scale up to global scale) and 6 orders of magnitude in time (from a single timestep up to a century).

Complex Earth system models must therefore contain a great many parameterisations (including specified functional forms of equations and their coefficient values) representing sub grid-scale and sub time-scale processes. We know that these parameterisations affect the quantitative model projections, because different complex models produce a range of historic and future projections. However, complex Earth system models are too computationally expensive to fully sample the plausible combinations of their own parameterisations, typically being able to realise only several tens of simulations.

In contrast, efficient climate models are able to utilise computational resources to resolve their own plausible combinations of parameterisations, through the construction of very large model ensembles. However, this parameterisation resolution occurs at the expense of a much-reduced...
resolution of relevant climate processes. Since the relative simplicity of efficient model representations may not capture the required complexity of the climate system, the qualitative nature of their simulated projections may be too simplistic. For example, an efficient climate model may use a single climate feedback value for all time and for all sources of radiative forcing, when in complex models (and the real climate system) climate feedbacks may vary over time and may respond differently to, say, localised aerosol forcing than to well mixed greenhouse gases.

By far the dominant quantitative projections of global mean surface warming in the scientific literature, as used in the Intergovernmental Panel on Climate Change Assessment Reports, derive from relatively small ensembles of complex climate model output. However, computational resources impose an inherent trade-off between model resolution of relevant climate processes (affecting the qualitative nature of the model framework) and model ensemble resolution of plausible parameterisations (affecting the quantitative exploration of projections within that model framework). This computationally imposed trade-off suggests there may be a significant role for efficient model output, within a hierarchy of model complexities, when generating future warming projections.