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Robustness in quantification of uncertainty in climate change projections

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Bayesian statistics provides a framework for quantifying uncertainty in climate modelling. However, every statistical analysis is based on specific assumptions that can only partly be corroborated by empirical data. It is thus important to gain an understanding of the robustness of the derived uncertainty estimates with respect to these assumptions. Robust Bayesian statistics is an attempt to assess, and formally account for, the sensitivity of the results of a Bayesian statistical analysis to the adopted assumptions. Instead of single prior distributions and likelihood functions, classes of prior distributions and likelihood functions are considered, and upper and lower expectations of quantities of interest are calculated.

We present results of the application of robust Bayesian analysis to the quantification of uncertainty in the context of climate change projections using the Bern 2.5D climate model, an earth system model of intermediate complexity. In particular, we discuss the density ratio class of priors and the sensitivity of the uncertainty analysis to the choice of the likelihood function. As with most studies dealing with the quantification of uncertainty in climate change projections, a model of reduced complexity was used since full atmosphere-ocean general circulation models are computationally too expensive for this purpose.

In the course of working with this model of reduced complexity, we found that the basic statistical assumptions that underlie typical uncertainty analyses are not fulfilled.

As with other models, even GCMs, the results show systematic deviations from the data due to omitted or poorly parameterized processes.This raises the question of how to satisfy the assumptions of a statistical uncertainty estimation without corrupting and biasing the analysis. We propose an approach that employs the concept of general state-space modelling. Key uncertain parameters that on physical grounds are considered to be time-varying are modelled using a stochastic process. The hyperparameters of this stochastic process are estimated by means of the data time series. Since the uncertain model parameters are considered to be random variables, this method does not introduce “artificial skill”, but rather leads to the result that the basic statistical assumptions of uncertainty analysis are fulfilled. The procedure has the additional advantage that, in the course of the analysis, specific model deficiencies may be identified and potentially attributed to specific physical phenomenon. This may result in an explicit modelling (stochastic or not) of certain important physical processes that have previously been omitted from the model. We use a simple zero-dimensional energy balance model to demonstrate the general state-space approach to uncertainty analysis in this context. A comparison to a procedure where model deficiencies are taken into account by appropriate statistical error models is presented.