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Calibrating Climate Models – what observations matter?

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Using the 20-year-old climate model, HadCM3, we show that it is possible to calibrate the model to multiple observations by algorithmically changing parameters in the atmospheric model. Fourteen atmospheric parameters were modified using a state-of-the-art derivative free optimization algorithm (DFOLS). The calibration reduces model-observational difference against hemispheric scale averages of multiple observations for the 2001-2005 period and used about 90 evaluations of the atmospheric model. The observations considered were outgoing longwave and shortwave radiation, land temperature and precipitation, sea level pressure, mid-tropospheric temperature and humidity, and global-average net flux into the Earth system. A 5-member ensemble was generated by starting the calibration from different initial parameter sets.

The calibrated model simulated large scale observations better than almost all CMIP5 and CMIP6 ensemble. Spatial patterns of variables from the calibrated ensemble except for outgoing SW, land precipitation and mid-tropospheric humidity are as well simulated as in the CMIP6 ensemble. For these variables, spatial patterns are as well simulated as the CMIP5 ensemble. In the calibrated ensemble, uncertainty in effective climate sensitivity (ECS; relative error of 10%) and the transient climate response (TCR; relative error of 5%) is small. This is the case for the response at doubling and quadrupling of CO2 concentrations. Uncertainties in regional climate change are also small.

A linear analysis which combines observational uncertainty with the Jacobian of observational sensitivity with respect to parameter change gives a parameter covariance matrix. This is in turn can be combined with the Jacobian of climate response with respect to parameter to give a linear estimate of uncertainty in climate response. The linear uncertainty is similar to the ensemble uncertainty. By increasing individual observational uncertainty in the linear analysis, it is possible to see which observations are providing the constraints in transient climate response at 4 times CO2. This analysis finds that almost all the constraint comes from land precipitation, outgoing SW radiation and the net flux, suggesting these are key observations to constrain climate model behaviour.