Probabilistic projections of climate change fields from a multivariate Bayesian analysis of climate model data

Reinhard Furrer1 (rfurrer@mines.edu), Reto Knutti2 (knutti@ucar.edu)

1 Colorado School of Mines, Golden, CO, USA; 2 National Center for Atmospheric Research, Boulder, CO, USA

Motivation and Overview

Impacts and adaptations are determined mostly by ‘local’ climate change and thus require a quantitative picture of the expected climate change and uncertainty on regional and seasonal scales. We present probabilistic projections for spatial patterns of future temperature change using a multivariate Bayesian analysis. The methodology is applied to the output from 21 global coupled climate models used for the IPCC Fourth Assessment Report. The statistical technique is based on the assumption that the simulated spatial patterns of climate change can be separated into a large scale signal related to the true forced climate change and a small scale signal from model bias and variability.

Method

Furrer et al. (2006) introduce a statistical methodology that can be seen as a direct extension of the assumptions of linear regression to the treatment of fields, rather than single scalar values. The fields, say future temperature change from different AOGCM, are represented upon basis functions, i.e. a series of fields that are chosen to explain the common large scale structure of the climate change signal. The coefficients of the regression are AOGCM specific, but on average assumed to be centered around the true (unknown) coefficients. The main statistical assumption of the method is that the large scale forced signal can be separated from small scale noise and that each AOGCM approximates the true common signal of climate change that we are trying to estimate. The residual of the unexplained by climate change due to model bias and internal unforced climate variability is again AOGCM specific in terms of small scale structure, but is assumed to be (spatially structured) noise with constant variance. The basis functions describing the large scale structure include spherical harmonics, indicators of continents and other geographic features, and the current observations. However, these observations do not attribute weights to the models and we do not have a bias and a convergence weighting as developed by e.g. Tebaldi et al. (2005). The R of the statistical model through a Markov Chain Monte Carlo algorithm gives (1) estimates of the true coefficients of the regression, (2) the uncertainty thereof and (3) estimates of the small scale structure. By recomposing the mean coefficient estimates with the basis functions an estimate of the true climate change field is derived. The uncertainty around this field can be determined, for example, by examining ensembles constructed from draws from the posterior distribution of the coefficient estimates. Since the model accounts for the spatial correlation of the large scale (through the basis functions) and of the small scales (through the error covariance), the probabilistic projections derived for the entire globe represent the joint probability of climate change for all locations.

The method currently does not account for the fact that some models perform better than others, and that the models are not entirely independent.

Global projections

On the largest scale, the Bayesian method produces probability density functions (PDFs) of global temperature change for various scenarios, decades and seasons. Results compare favourably with other studies based on very different techniques and models. Uncertainty in projections grows over time and projected warming is almost independent of the scenario for the next few decades.

Regional projections

Probability density functions of projected warming can be aggregated for arbitrary regions. However, the separation of the large scale forced patterns from small scale noise necessarily implies some smoothing of the fields (see opposite maps) such that PDFs cannot be interpreted on a grid point level but only on regional to continental scales. PDF widths change exceeded with any given probability, for both winter and summer, or alternatively as the probability for locally exceeding a given temperature threshold. Warming patterns are similar to the raw model spread and are wider than those derived by methods which weight models by bias and convergence criteria.

Conclusions

The statistical model presented has a simple structure, is based on very few statistical assumptions and provides a probabilistic interpretation of the projected climate change from a relatively small number of models while incorporating both the spatial nature of climate fields as well as structural uncertainty due to intermodel differences. The posterior fields can be analyzed as such or can be arbitrarily down-scaled or weighted with virtually no computational cost. Extensions of the model are possible, e.g. a joint model for temperature and precipitation.