Systematic reduced stochastic climate models of atmospheric low-frequency variability

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Abstract

This study applies a new systematic, mathematical strategy for stochastic climate modeling of atmospheric low-frequency variability. The systematic strategy, developed by Majda et al. (1999, 2001, 2002, 2003) and Franzke et al. (2005) consists first of the identification of slowly evolving climate modes and faster evolving non-climate modes by use of an empirical orthogonal function decomposition and by minimal regression fitting of the unresolved modes. The stochastic climate model predicts the evolution of these climate modes only. Since the climate system is governed by nonlinear equations the interactions of the resolved climate modes with the unresolved non-climate modes have to be taken into account. The presented stochastic mode elimination strategy takes properly account of these neglected interactions with the unresolved modes through a systematic, mathematical way. The stochastic mode elimination strategy predicts all additional interaction terms which account for the neglected interactions with the unresolved modes. The stochastic mode elimination procedure is rigorously valid in the limit that the ratio of the time scales of the fast unresolved modes to the slow resolved modes goes to zero.

This strategy is motivated by the fact that atmospheric low frequency variability can be efficiently described by only a few dominant teleconnection patterns or basis functions. The stochastic modeling strategy is applied to a set of global circulation models with increasing complexity which simulate the observed winter circulation well. In

particular, results from a global barotropic model and a global 3 layer quasi-geostrophic model will be presented.

The low-order stochastic climate model predicts the evolution of these climate modes a priori without any regression fitting of the resolved modes. The systematic stochastic mode reduction strategy determines all correction terms and noises with minimal regression fitting of the variances and correlation times of the unresolved modes. These correction terms and noises account for the neglected interactions between the resolved climate modes and the unresolved non-climate modes. No ad hoc damping is necessary as in previous studies. All additional interaction terms are predicted which include constant forcing terms, linear terms, quadratic and cubic nonlinear terms, as well as additive and multiplicative (state dependent) noises. These additional interaction terms describe the interaction of the resolved with the unresolved modes in a rigorous systematic way.

The stochastic models reproduce the geographical distributions of the variances and transient eddy forcing well. Also the decay of the autocorrelation functions and the PDFs are captured reasonably well. These results provide evidence of effective stochastic dynamics in climate. Furthermore, the stochastic mode reduction strategy reveals fundamental differences between the barotropic and the baroclinic models. While the reduced stochastic model of the barotropic model is essentially linear with additive noise, the reduced stochastic model of the 3 layer quasi-geostrophic model is dominated by both linear and nonlinear dynamics and by both additive and multiplicative noises. The dynamical implications of these differences as well as different optimal basis function strategies will be discussed.