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Stochastic Parametrisations and Regime Behaviour of Atmospheric Models

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The presence of regimes is a characteristic of non-linear, chaotic systems (Lorenz, 2006). In the atmosphere, regimes emerge as familiar circulation patterns such as the El-Nino Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and Scandinavian Blocking events. In recent years there has been much interest in the problem of identifying and studying atmospheric regimes (Solomon et al, 2007). In particular, how do these regimes respond to an external forcing such as anthropogenic greenhouse gas emissions? The importance of regimes in observed trends over the past 50-100 years indicates that in order to predict anthropogenic climate change, our climate models must be able to represent accurately natural circulation regimes, their statistics and variability.

It is well established that representing model uncertainty as well as initial condition uncertainty is important for reliable weather forecasts (Palmer, 2001). In particular, stochastic parametrisation schemes have been shown to improve the skill of weather forecast models (e.g. Berner et al., 2009; Frenkel et al., 2012; Palmer et al., 2009). It is possible that including stochastic physics as a representation of model uncertainty could also be beneficial in climate modelling, enabling the simulator to explore larger regions of the climate attractor including other flow regimes. An alternative representation of model uncertainty is a perturbed parameter scheme, whereby physical parameters in subgrid parametrisation schemes are perturbed about their optimal value. Perturbing parameters gives a greater control over the ensemble than multi-model or multiparametrisation ensembles, and has been used as a representation of model uncertainty in climate prediction (Stainforth et al., 2005; Rougier et al., 2009).

We investigate the effect of including representations of model uncertainty on the regime behaviour of a simulator. A simple chaotic model of the atmosphere, the Lorenz '96 system, is used to study the predictability of regime changes (Lorenz 1996, 2006). Three types of models are considered: a deterministic parametrisation scheme, stochastic parametrisation schemes with additive or multiplicative noise, and a perturbed parameter ensemble.

Each forecasting scheme was tested on its ability to reproduce the attractor of the full system, defined in a reduced space based on EOF decomposition. None of the forecast models accurately capture the less common regime, though a significant improvement is observed over the deterministic parametrisation when a temporally correlated stochastic parametrisation is used. The attractor for the perturbed parameter ensemble improves on that forecast by the deterministic or white additive schemes, showing a distinct peak in the attractor corresponding to the less common regime. However, the 40 constituent members of the perturbed parameter ensemble each differ greatly from the true attractor, with many only showing one dominant regime with very rare transitions. These results indicate that perturbed parameter ensembles must be carefully analysed as individual members may have very different characteristics to the ensemble mean and to the true system being modelled. On the other hand, the stochastic parametrisation schemes tested performed well, improving the simulated climate, and motivating the development of a stochastic earth-system simulator for use in climate prediction.

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