IMAGe Seminar

Institute for Mathematics Applied to Geosciences at NCAR

A Hidden Markov Model Perspective on Regimes and Metastability in Atmospheric Flows

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Abstract:

In this study we analyze data from three atmospheric models in order to investigate the existence of atmospheric flow regimes despite nearly Gaussian statistics of the planetary waves in these models. We use a hierarchy of models which describe the atmospheric circulation with increasing complexity. To systematically identify atmospheric regimes we search for the presence of metastable states in the data, and we do so by fitting so-called Hidden Markov Models (HMMs) to the timeseries.

A Hidden Markov Model is designed to describe the situation in which part of the information of the system is unknown or hidden and another part is observed. Within the context of this study, some representative variable of planetary scale flow (for example, mean zonal flow, or leading Principal Component) is known ("observed"), but its dynamics may depend crucially on the overall flow configuration, which is unknown. The behavior of this latter, "hidden" variable is described by a Markov chain. If the Markov chain possesses metastable (or quasi-persistent) states, we identify these as regimes. In this perspective, regimes can be present even though the observed data has a nearly Gaussian probability distribution.

We fit the parameters of the HMMs to the timeseries using a maximum- likelihood approach; well-established and robust numerical methods are available to do this. Possible metastability of the Markov chain is assessed by inspecting the eigenspectrum of the associated transition probability matrix.

We first apply the HMM procedure to data from a simplified model of barotropic flow over topography with a large scale mean flow. This model exhibits regime behavior of its large-scale mean flow for sufficiently high topography. In the case of high topography we find three regimes; two of those correspond to zonal flow and the third to blocking.

Next a three-layer quasi-geostrophic model is used as a prototype atmospheric General Circulation Model (GCM). Its first Empirical Orthogonal Function (EOF) is similar to the Arctic Oscillation (AO) and exhibits metastability. For this model we find two regime states: one corresponding to the positive phase of the AO with large amplitude and decreased variability of the streamfunction field, and another regime corresponding to the negative AO phase with small amplitude and increased variability. Finally, we investigate a comprehensive GCM. The leading 4 EOFs of this model show no signs of metastability.

The results of the barotropic flow over topography and of the quasi-geostrophic model suggests that the observed small skewness of planetary wave probability density functions (PDFs) is an imprint of blocked circulation states.

Mesa Lab- Chapman Room
Thursday, October 26, 2006
2:00pm

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