Regional Climate-Change Projections Through Next-Generation Empirical and Dynamical Models

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Introduction

Our DOE-funded work has developed a twin approach of non-homogeneous hidden Markov models (NHMMs) and coupled ocean-atmosphere (O-A), intermediate-complexity models (ICMs) to identify the potentially predictable modes of climate variability and to investigate their impacts on the regional-scale. We have developed a family of latent-variable NHMMs to simulate historical records of daily rainfall, and used them to downscale seasonal predictions. We have also developed empirical mode reduction (EMR) models for gaining insight into the underlying dynamics in observational data and general circulation model (GCM) simulations. Using coupled O-A ICMs, we have identified a new mechanism of interdecadal climate variability, involving the midlatitude oceans' mesoscale eddy field and nonlinear, persistent atmospheric response to the oceanic anomalies. A related decadal mode is also identified, associated with the oceans' thermohaline circulation.

Goal

The goal of the continuation is to build on these ICM results and NHMM/EMR model developments and software to strengthen two key pillars of support for the development and application of climate models for climate change projections on time scales of decades to centuries, namely: (a) dynamical and theoretical understanding of decadal-to-interdecadal oscillations and their predictability; and (b) an interface from climate models to applications, in order to inform societal adaptation strategies to climate change at the regional scale, including model calibration, correction, downscaling and, most importantly, assessment and interpretation of spread and uncertainties in multi-model ensembles.

Objectives

- to assess the uncertainties in atmosphere-ocean GCM climate-change projections at the scale of local rainfall statistics
- to assess candidate schemes with respect to potential predictability and prediction skill at decadal time scales, using empirical and intermediate dynamical models
- to estimate potential biases in current global climate projections due to lack of active eddy dynamics in state-of-the-art AOGCMs
- to develop parallel, scalable Bayesian estimation software for a family of NHMM and EMR models

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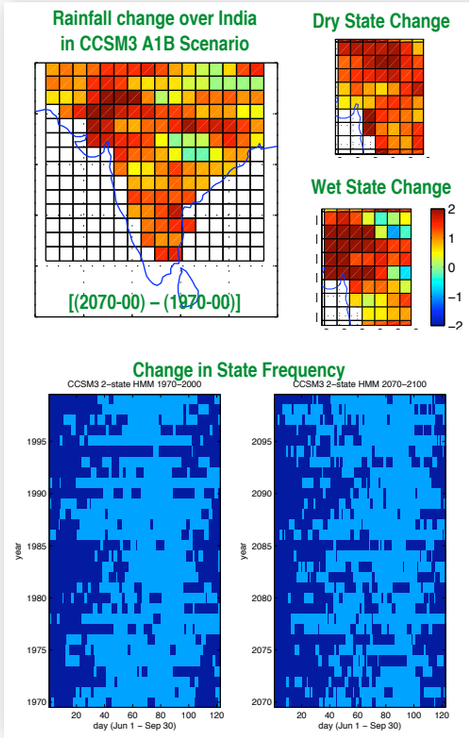
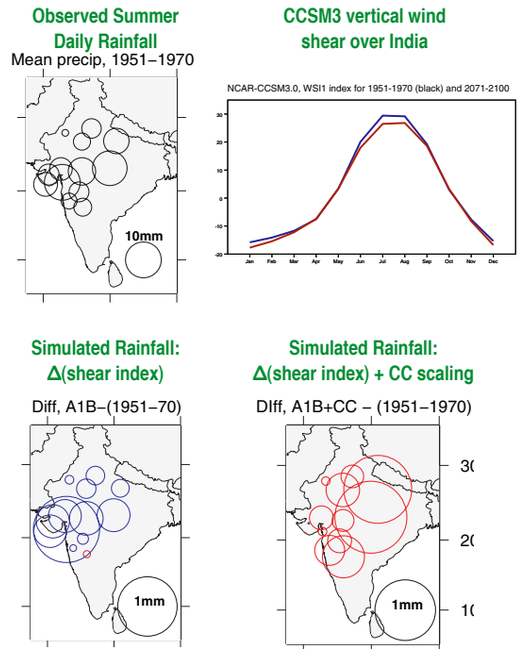
Empirical Models

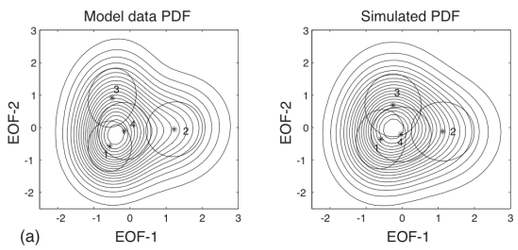
Hidden Markov Models applied to interpret and "downscale" GCM climate-change projections at regional scale.
Empirical Mode Reduction used to link ICM and GCM results.



Hidden Markov Model (HMM) applied to CCSM3 simulated summer rainfall changes over NW India.



Non-homogeneous Hidden Markov Model (NHMM) applied to observed rainfall over India. Projections made with (i) CCSM3 shear index change; (ii) shear index change + Clausius-Clapeyron scaling.



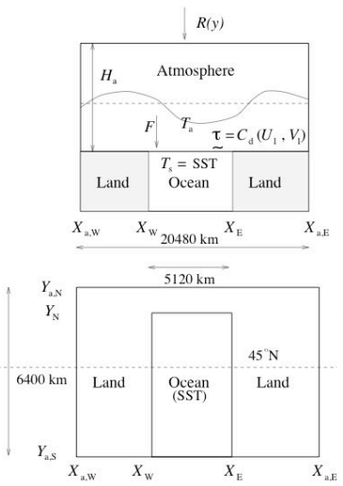
$$
\begin{aligned}
dx_i &= \tau_{ijkl}\, x_j x_k x_l + \alpha_{ijk}\, x_j x_k + \beta_{ij}^{(0)}\, x_j + \gamma_i + r_i^{(0)} \\
dr_i^{(0)} &= \beta_{ij}^{(1)}\, [x;\ r^{(0)}]_j + r_i^{(1)} \qquad (1) \\
dr_i^{(1)} &= \beta_{ij}^{(2)}\, [x;\ r^{(0)};\ r^{(1)}]_j + dw_i
\end{aligned}
$$

Reduced model in phase space x of EOFs with two hidden levels (r_1 & r_2) driven by spatially-correlated white noise. Estimated via least-squares fit.

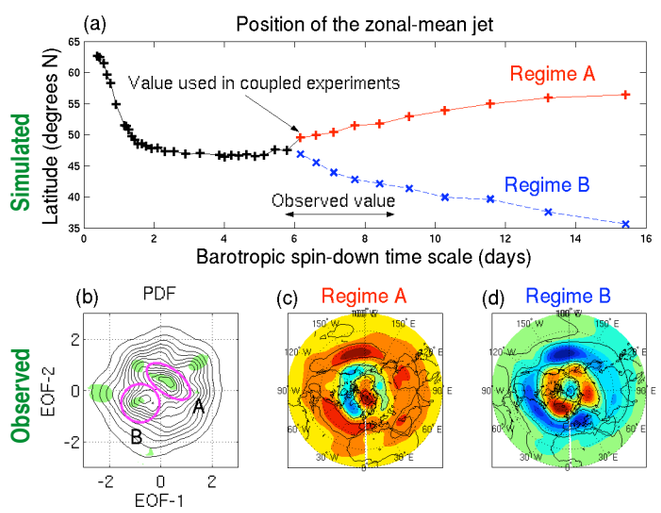
Empirical Mode Reduction applied to mid-latitude atmospheric variability simulated by a 3-layer quasi-geostrophic model.

Intermediate Coupled Models

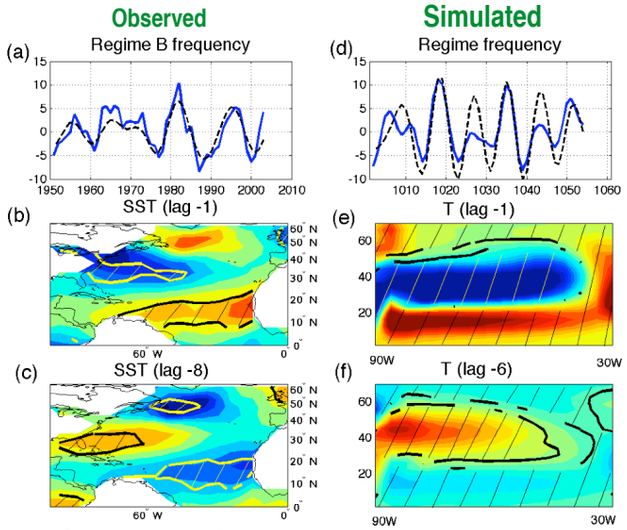
Bimodal regimes of atmospheric mid-laititude jets coupled to oscillations in the ocean's wind-driven and thermohaline circulations.



Coupled QG channel atmosphere and QG or PE sector ocean.



Atmospheric bimodality in models and observations.



Observed and simulated 10–15 year oscillation.