Final Technical Report for Award # US DOE/CHICAGO DE-SC0006694
UCLA portion

Title: Collaborative Research, Type 1: Decadal Prediction and Stochastic Simulation of Hydroclimate Over Monsoonal Asia

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Award Number: DOE-DE-SC0006694
Award period: (09/01/11 – 08/31/14)

This collaborative project brought together climate dynamicists (UCLA, IRI), dendroclimatologists (LDEO Tree Ring Laboratory), computer scientists (UCI), and hydrologists (Columbia Water Center, CWC), together with applied scientists in climate risk management (IRI) to create new scientific approaches to quantify and exploit the role of climate variability and change in the growing water crisis across southern and eastern Asia.

The UCLA team focused on novel methodological developments for data-driven stochastic modeling and prediction of the climate system, with an emphasis on hydroclimate applications. The final technical results of the project, from start to completion (09/01/11 – 08/31/14) are summarized below by sub-topic.

Data-based closure models via multilayered stochastic models

Kondrashov et al. (2014) undertook a rigorous mathematical analysis of empirical model reduction (EMR**:** Kondrashov et al. 2005; Kravtsov et al. 2005; Kravtsov et al. 2009) in their continuous-time limit; the authors called this limit multilayered stochastic models (MSMs). An MSM is a system of stochastic differential equations (SDEs) that models the dynamics of the macroscopic, observed variables along with their interactions with the microscopic, hidden variables.

The hidden variables are modeled through a "matrioshka" of layers, in which each additional layer contains an extra hidden variable that is less correlated with the observed variables than those in the previous layer, until some de-correlation criterion is reached. In practice, MSMs are learned in a polynomial basis by multilevel regression techniques that lead to an EMR model.

An MSM model can be written as a system of stochastic integro-differential equations that yields in practice a good approximation of the generalized Langevin equation of the Mori-Zwanzig formalism of statistical mechanics (Zwanzig, 2001). Furthermore, conditions were identified that guarantee the existence of a global random attractor for MSMs that generalize the EMR models used so far and allow for non-polynomial predictors. These generalized stochastic-dynamic, empirical models do not require energy-preserving nonlinearities — such as those present in fluid-dynamic models but not in ENSO or other climate models — while the global attractor still prevents numerical blow-up.

"Past-Noise Forecasting" (PNF) of Madden-Julian Osciilation

In the presence of both low-frequency variability (LFV) and noise, Chekroun et al. (2011) had shown that linear pathwise response of a nonlinear stochastic model to perturbations allows one to develop a novel Past-Noise Forecasting (PNF) method. The PNF method is based on the knowledge of "past noise" at times in the system's history that resemble in LFV phase the present from which one wishes to forecast. These authors successfully applied PNF to an EMR model for ENSO; they constructed an ensemble of forecasts that accounts for interactions between high-frequency variability ("noise"), estimated by EMR, and the LFV mode of ENSO, as captured by singular-spectrum analysis (SSA).

Following up on the development of PNF and its application to ENSO, Kondrashov et al. (2013) have shown that PNF improves the prediction of the Madden-Julian Oscillation (MJO), an important intraseasonal phenomenon that affects hydroclimate in Asia. Applying the EMR-PNF method to the two leading indices of the MJO, RMM1 and RMM2, yields a bivariate correlation skill that exceeds 0.4 at 30 days, a skill that is comparable to that of state-of-the art dynamical models. A key result is that — compared to an EMR ensemble driven by generic white noise — PNF is able to considerably improve prediction of the MJO's phase. When forecasts are initiated from weak MJO conditions, the useful skill is of up to 30 days. PNF also significantly improves MJO prediction skill for forecasts that start over the Indian Ocean.

Data-driven Stochastic Modeling and Prediction for Asian Hydroclimate

The UCLA team's multivariate EMR stochastic methodology has been applied to monthly gridded (2.5 x 2.5 degrees) Palmer Drought Severity Index (PDSI) for a 700-yr–long time interval (1300–2005). The data were based on the Monsoonal Asia Drought Atlas (MADA) and were projected onto the 8 leading PCs in the 10^0N–56^0N latitude band. The optimal EMR multi-level model was 2-level quadratic and energy conserving; it was compared with data in terms of spectral peaks identified by Multichannel Singular Spectrum Analysis (MSSA), in data as well as in EMR simulations. We did find, in fact, robust 5-yr and 8-yr low-frequency modes (LFMs) over the Indus river basin, in the actual dataset, as well as in the EMR simulations.

The tree-lab team at Lamont produced a 300-member ensemble of pseudo-reconstructions of Indus River discharge, based on maximum entropy bootstrapping of tree-ring proxy records. Our UCLA team analyzed this ensemble by MSSA and identified a robust 27-yr LFM. We assessed decadal predictability of hydrologic spatio-temporal modes by applying the SSA-MEM prediction methodology to the ensemble mean of the Indus River discharge reconstructions, and carried out retroactive forecasts with no look-ahead over the 1702–2005 time interval.

Validation shows some predictability of up to 15 yr, although this predictability appears to have been somewhat smaller in the 20th century, and it is largely due to the 27-yr LFM. We also generated a very long, 5000-yr stochastic simulation of a univariate EMR model of Indus streamflow reconstruction with realistic spectral features. This simulation will serve as a synthetic dataset for further analysis and testing of newly developed strategies for stochastic reservoir simulation and optimization.

Publications by the UCLA team acknowledging this grant

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