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Climate-informed stochastic hydrological modeling: Incorporating decadal-scale variability using paleo data

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A hierarchical framework for incorporating modes of climate variability into stochastic simulations of hydrological data is developed, termed the climate-informed multi-time scale stochastic (CIMSS) framework. To characterize long-term variability for the first level of the hierarchy, paleoclimate and instrumental data describing the Inter-decadal Pacific Oscillation (IPO) and the Pacific Decadal Oscillation (PDO) are analyzed. A new paleo IPO-PDO time series dating back 440 yr is produced, combining seven IPO-PDO paleo sources using an objective smoothing procedure to fit low-pass filters to individual records. The paleo data analysis indicates that wet/dry IPO-PDO states have a broad range of run lengths, with 90% between 3 and 33 yr and a mean of 15 yr. Model selection techniques were used to determine a suitable stochastic model to simulate these run lengths. The Markov chain model, previously used to simulate oscillating wet/dry climate states, was found to underestimate the probability of wet/dry periods >5 yr, and was rejected in favor of a gamma distribution. For the second level of the hierarchy, a seasonal rainfall model is conditioned on the simulated IPO-PDO state. Application to two high quality rainfall sites close to water supply reservoirs found that mean seasonal rainfall in the IPO-PDO dry state was 15%–28% lower than the wet state. The model was able to replicate observed statistics such as seasonal and multi-year accumulated rainfall distributions and interannual autocorrelations for the case study sites. In comparison, an annual lag-one autoregressive AR(1) model was unable to adequately capture the observed rainfall distribution within separate IPO-PDO states. Furthermore, analysis of the impact of the CIMSS framework on drought risk analysis found that short-term drought risks conditional on IPO/PDO state were far higher than the traditional AR(1) model.