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Using an information theory-based method for statistical detection of high-frequency climate signals in northern-hemisphere water supply variations

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Water scarcity is an acute global concern under population and economic growth, and understanding hydroclimatic variation is becoming commensurately more important for resource management. Climatic drivers of water availability vary complexly on many time- and space-scales, but serendipitously, the climate system tends to self-organize into coherent dynamical modes. Two of these are El Niño-Southern Oscillation (ENSO) and the Arctic Oscillation (AO), which have hemisphere- to planet-wide impacts on regional climate through intricate relationships called teleconnections. Traditionally, statistical studies assume such teleconnections are linear, or at least monotonic. Recent work instead suggests ENSO and AO impacts can be strongly nonlinear – specifically, parabolic. However, these phenomena remain incompletely understood, and river flows spatiotemporally integrate upstream climatic influences in complicated ways, sensitive to local terrestrial hydrologic characteristics. We therefore directly examine annual flow volume time series from 42 of the northern hemisphere's largest ocean-reaching rivers for highly nonlinear teleconnections. We apply a novel approach based on optimal polynomial selection using the Akaike information criterion, which combines the Kullback-Leibler information, quantifying how much information content is lost when approximating truth using a model, with maximum likelihood concepts. Unlike conventional null-hypothesis significance testing, the method provides a rigorously optimal balance between model performance and parsimony; explicitly accommodates no-effect, linear-effect, and strongly nonlinear-effect models; and estimates the probability that a model is true given the data. While we discover a rich diversity of responses, parabolic relationships are formally consistent with the data for almost half the rivers and are optimal for eight. Highly nonlinear teleconnections could radically alter the standard conceptual model of how water resources respond to climate variability. For example, the Sacramento River in drought-ridden California exhibits no significant linear ENSO teleconnection but a 92% probability of a quadratic relationship, improving simple mean predictive error by up to 65% and implying greater opportunity for climate-informed early-season water supply forecasting than previously appreciated.

Primary author: Dr FLEMING, Sean W. (Environment Canada, MSC Science Division)

Co-author: Dr DAHLKE, Helen E. (University of California, Davis)

Presenter: Dr FLEMING, Sean W. (Environment Canada, MSC Science Division)

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