Diagnostics of interannual-to-interdecadal climate and streamflow variability: Applications to reservoir management over NW India

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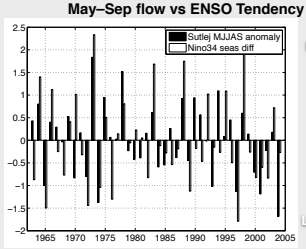
Abstract

Multi-year storage reservoirs must be managed in the face of weather and climate variability across time scales ranging from daily weather to interannual climate. While seasonal climate may contain a predictable component associated with the El Nino-Southern Oscillation (ENSO), longer time scales are not yet usefully predictable, nor is the interannual-to-interdecadal power spectrum well estimated from observed data. In addition, climate simulations from general circulation models (GCMs) are often lacking in their ability to generate realistic hydroclimate variability across time scales, especially at small spatial scales. These issues are critical for climate change adaptation planning in water management, where realistic estimates of climate and stream flow variability are required.

For the Bhakra reservoir in northern India, we develop estimates of climate and stream flow variability, including the interannual-to-interdecadal power spectrum, based on (1) instrumental stream flow records of the Sutlej river, 1963–2010; (2) tree ring reconstructions of the Sutlej flow back to 1321; and (3) multi-century control simulations of precipitation-minus-evaporation made with several coupled ocean-atmosphere GCMs archived in the IPCC CMIP5 database. By comparing these observed, paleo-proxy, and GCM-based estimates, we shed light on the ability of GCMs to simulate realistic hydroclimate variability over the Indus basin, as well as on the nature of tree-ring based streamflow reconstructions. In addition to these estimates of the variability spectrum, we explore the use of a nonlinear, multi-level stochastic polynomial inverse model to bridge between these different datasets.

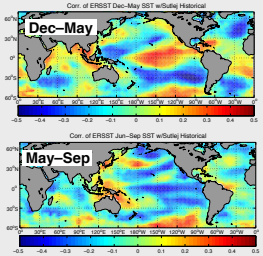
Sutlej River vs ENSO Transitions

May–Sep flow vs ENSO Tendency



• Large May–Sep flows tend to be associated with El Niño-to-La Niña transitions

Correlations of May–Sep flow vs Sea Surface Temp.

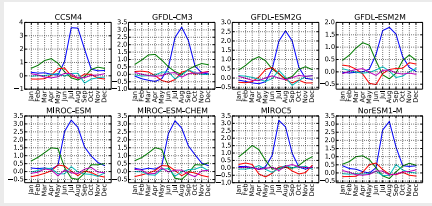


• El Niño SST pattern in the preceding winter

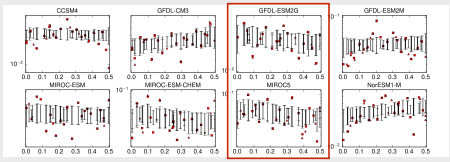
• weak La Niña in summer

CMIP5 GCM Precip. Simulations

Seasonal cycle Precip. EOFs for Upper-Indus Region

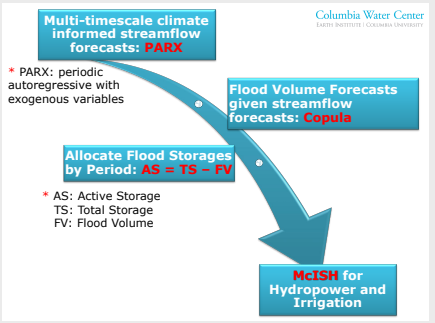


SSA Spectra of Long Control Runs (Dec–Mar)

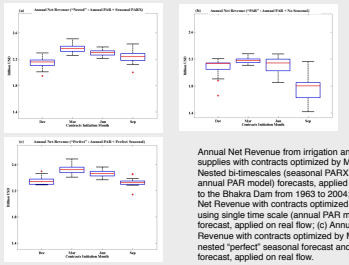


• Of all the 31 CMIP5 models with multi-century pre-industrial control runs, only two emerge with (a) realistic regional precip. seasonal cycles, and (b) for ENSO and low-freq. spectral peaks

Reservoir Management Model



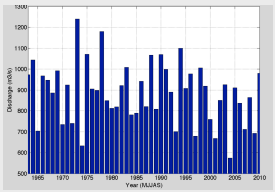
Optimized Contracts' Performance vs Start Month



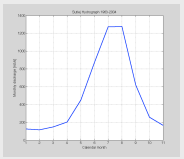
Annual Net Revenue from irrigation and hydropower supplies with contracts optimized by McISH using Nested bi-timescales (seasonal PARX model and annual PAR model) forecasts, applied on real inflow to the Bhakra Dam from 1963 to 2004; (b) Annual Net Revenue with contracts optimized by McISH using single time scale (annual PAR model) forecast, applied on real flow; (c) Annual Net Revenue with contracts optimized by McISH using nested "perfect" seasonal forecast and annual forecast, applied on real flow.

Sutlej River Flows 1963–2010

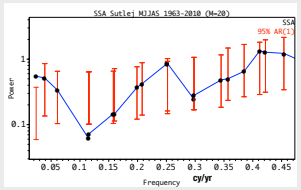
May–Sept Flows



Hydrograph



SSA Power Spectrum



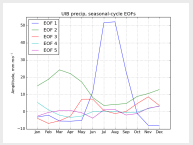
Spectrum - blue, error bars - red

• Peaks near 4 and 2 years; statistical significance not very high

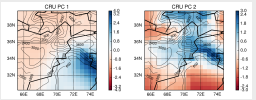
• Variability dominated by interannual time scales

Precipitation Variability

Seasonal cycle Precip. EOFs for Upper-Indus Region

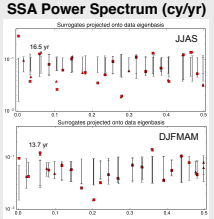


[65E–75E, 30N–40N]



• Winter precip. from "western disturbances" + Summer monsoon

SSA Power Spectrum (cy/yr)

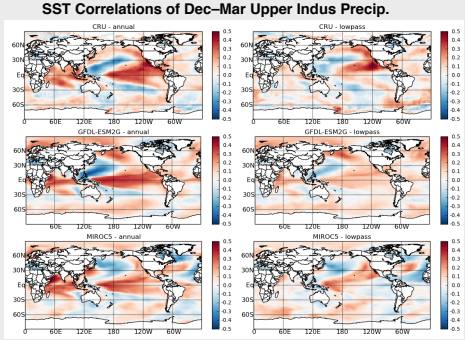


• Power spectr of seasonal-average precip. + 25% conf. limits

• ENSO and low-freq. peaks, marginally significant

GCM Teleconnections with SST

SST Correlations of Dec–Mar Upper Indus Precip.



- ENSO patterns, with excessive westward extension in equatorial W. Pacific
- Strong Indian Ocean loadings
- PDO-like Low freq. patterns
- GCMs show ocean-gyre patterns
- MIROC5 North Atlantic signal

Conclusions

- Sutlej river is fed by both winter precip., snowmelt and the summer monsoon
- Sutlej river integrates signal of ENSO transitions (EN➔LN gives high flows), amplifying ENSO impact
- Historical flow record shows ENSO peaks though not significant
- Most CMIP5 GCMs do not capture the precip. seasonality. Of the 8 of 31 that do, only two GCMs reproduce the spectrum of ENSO + decadal climate influences
- The GFDL-ESM2G and MIROC5 exhibit different flavors of decadal SST teleconnection
- A dual-timescale reservoir optimization model was developed to use seasonal and longer-lead forecast information, maximizing the expected value of releases, conditioned on the forecasts
- A "PARX" periodic autoregressive flow-prediction model with exogenous inputs provides a framework for incorporating climate predictors
- Contracts initiated in March yield the highest annual net revenue

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