How can Punjab adapt to a changing climate?
A systems approach to managing water, energy, agriculture and income

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**Outline**

- The climate context *(focus of this talk)*
  - The long view and predictability of the renewable water resource

- Some ideas for adaptation *(for discussion later)*
  - Regularizing supply
    - Firm water/energy contracts from Bhakhra based on forecasts
  - Demand Management: Incentives for Water/Energy conservation
    - Peak energy load management through efficiency and time shifting
    - Incentives for Water use reduction through sensors and other instruments
    - Crop/genome shifts based on climate and market forecasts
Paleoclimate reconstructions suggest that the period between 1350 and 1450 had a **megadrought** with average precipitation 2 standard deviations below the 20th century record.

Should we be prepared?

Fig. 7 MAMJ precipitation reconstruction (AD 1410–2005). The thick line represents the 50-year low pass filter.

Paleoclimate reconstructions suggest that there are several multi-year to multi-decadal **cycles** of wet/dry possible in the region?

Should we be prepared?

Fig. 10 Multi-Taper Power spectra for the reconstructed MAMJ precipitation (AD 1410–2005)
Rainfall clearly shows long term variation, and multi-year cycles.

Note the decline in the last 20 years. 1950-1990 was anomalously wet compared to the 1871-1950 period.

Part of the recent groundwater depletion could be due to the recent drying trend.

However, we may be entering a period similar to 1910 to 1940 which stayed drier than what we have recently experienced – consequences for Punjab?
Large scale trends in Punjab rain and N Mountains rain are similar, but JJAS drying in the recent period in N mountains is more pronounced => Upper catchment rain cannot mitigate Punjab shortfall

Evidence of shifts of rain across seasons in different epochs is also consistent across Punjab and N Mountains

Can such shifts be anticipated and used to plan agriculture and energy use of water?
Significant correlation of Jun-Sep Punjab Rain with Jun-Sep SST in Pacific Ocean – one of the highest in India.

Correlations with Pacific Pressure and temperature in May are also significant and provide a basis for predicting the Monsoon rain.

Potential for skilled Monsoon forecasts for Punjab is higher than for the rest of the country.
Significant correlation of Jun-Sep N. Mountain Rain with Jun-Sep SST in Pacific Ocean – one of the highest in India.

Correlations with Pacific and Indian Ocean temperatures in May are also significant and provide a basis for predicting potential for skilled Monsoon forecasts for N Mountains is higher than for the rest of the country.
Rank Correlation of El Nino conditions with rainfall and storage (irrigation) requirements to meet existing demands

During Monsoon Period

Using El Nino Formation 3 months prior to Monsoon Period = Same Predictability

Potential for skilled Monsoon forecasts for irrigation water requirements is higher than for total rainfall

Punjab ~0.8

Punjab ~0.5
Reconstruction of **Sutlej River inflow at Bhakhra** from Ed Cook @ Columbia Univ, using tree rings

Significant and persistent variability is noted

Recent drying trend replicated

El Nino/La Nina transitions (like this year) are predictive of Sutlej May-Sep flows
Seasonality of **Sutlej Flow** over the years

We are able to develop successful probabilistic forecasts of May-Sep Sutlej flows on March 1 of each year. They perform well under cross validation.
2014 CWC Forecast Issued for Punjab issued on May 20 2014

• The probability of below normal total rainfall is 64%.
Other Centers’ Forecasts at the same time

- IRI forecast (slide 13) shows that India will receive normal levels of precipitation (not dry)
- ECMWF forecast (slide 14) has a hint of a dry forecast over Punjab and normal for the country
- IMD (slide 15) has 56% probability of below normal rainfall for the country
ECMWF Seasonal Forecast
Prob(most likely category of precipitation)
Forecast start reference is 01/04/14
Ensemble size - 51, climate size - 450

System 4
JAS 2014
### IMD Long Range Forecast for the 2014 Southwest Monsoon Season Rainfall

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<th>Category</th>
<th>Rainfall Range (% of LPA)</th>
<th>Forecast Probability (%)</th>
<th>Climatological Probability (%)</th>
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<td>Excess</td>
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Firm Water/Energy Contracts and Flood Control for Bhakhra using Seasonal AND Year ahead forecasts

Similar to a model we applied in Brazil and the Phillipines

Concept:

- Probabilistic forecasts for monthly flow and flood volume are generated from a statistical model with climate predictors.
- Flood Control space is allocated every month to correspond to the forecast 100 year flood volume (based on a statistical forecast model)
- At specified dates we offer firm water and energy contracts for 2 durations, e.g., – 1 season, and 1 year
  - Specified contract terms: duration, amount, reliability and price
  - The contracts can be insured since their probability of failure is solved for

Forecasts are uncertain: System that allows robust decisions even under uncertainty
12 month Sutlej inflow forecast

- Current Reservoir Level
- Unit price 3 month energy contract
- Unit price 3 month water contract
- Unit price 12 month energy contract
- Unit price 12 month energy contract
- Contract reliability and penalty terms
- Minimum Values for Each contract

Optimization Model to determine and update contracts to Max Allocation Benefit

Forecasts and Contracts are updated every 4 months using this process

The unit prices (or priority weights) can be set by the government based on scarcity or other policies, or be determined in an auction, or through participatory negotiation.

The contracts can be tradable for their residual term with approval from the regulator.

The model preserves existing contracts for their term and solves for additional contracts.

We have already developed and numerically tested such a model with Bhakra data.
To adapt to a changing climate, Punjab needs to manage its total water and energy resource – Renewable River and groundwater.

Climate informed forecasts of near term rain and flow can inform many instruments for supply and demand management.

These can improve reliability for users and suppliers and if introduced carefully should be politically acceptable since they reduce risk through uncertainty reduction.

Price signals and incentives timed to the forecast can induce positive behavior and demand changes.

Models for groundwater and energy response to crop choices and climate forecasts for Central Punjab are also developed to support analyses and decision making on demand management options.