Simulated Impacts of Three Decadal Climate Variability Phenomena on Water Yields and Urban Water Security in the Missouri River Basin, U.S.A.

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- What is decadal climate variability (DCV)?
- Importance of the Missouri River Basin (MRB)
- Impacts of DCV phenomena on hydro-meteorology and water yield
- Impacts of DCV Phenomena on urban water security
- Summary

Acknowledgements

NOAA - Climate Program Office - Sectoral Applications Research Program
Grants NA06OAR43100681 and NA11OAR4310147

Towards Societally-relevant Climate Prediction

Prediction of Climate Impacts on

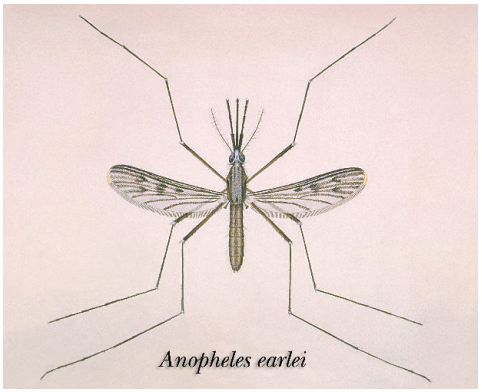
Water

Food

Energy

Transportation

Public health



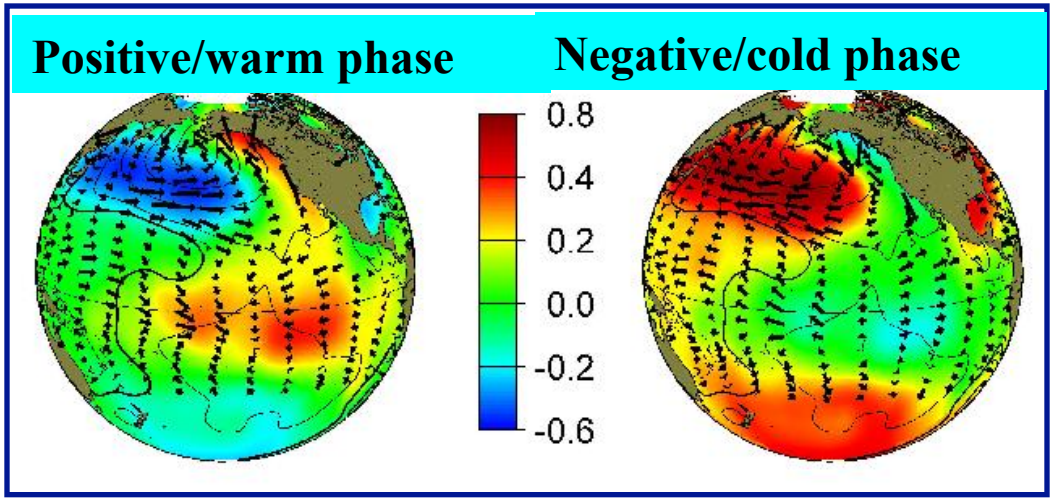
Economy

What is decadal climate variability (DCV)?

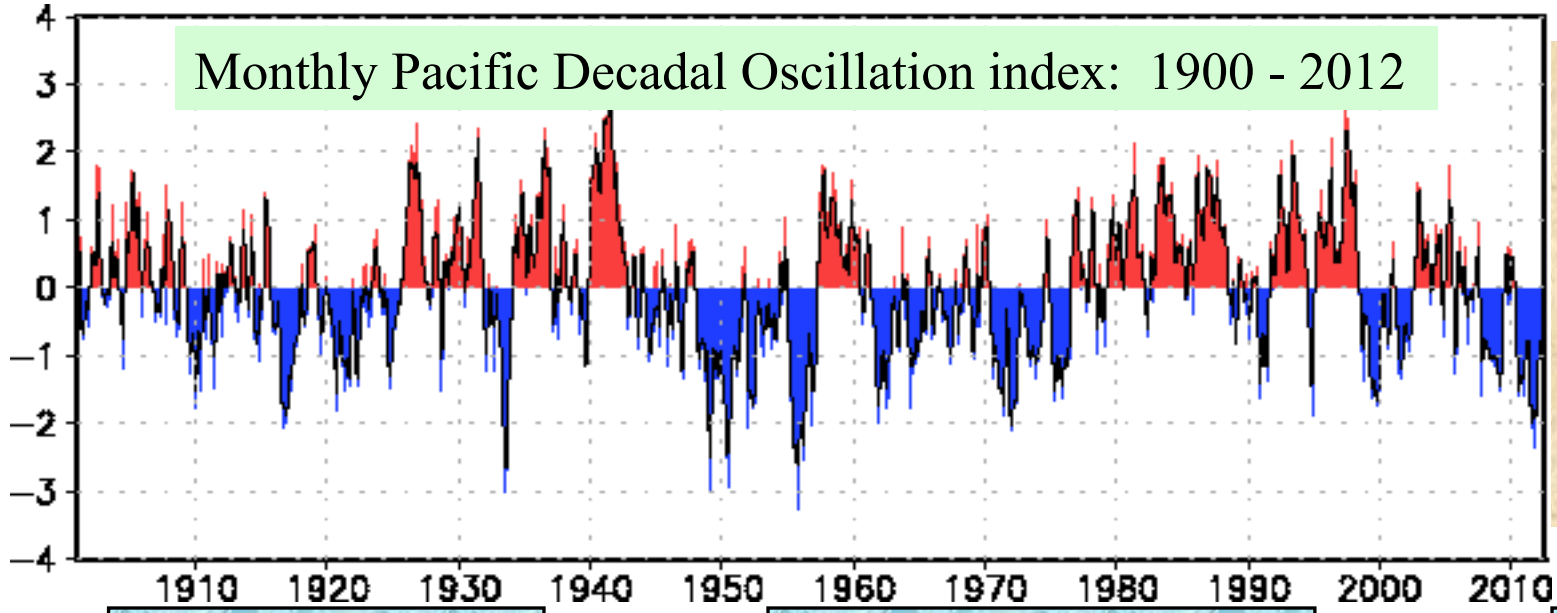
Observed Pacific Decadal Oscillation Sea-surface Temperature Pattern: 1900 – 2012

Courtesy: Nathan Mantua, Stephen Hare
Univ. of Washington

Warm/cold surface water in much of the Pacific Ocean



Anomalous SST patterns



Warm/cold phases persist for a few years to a few decades

How does SST variability influence climate on continents?

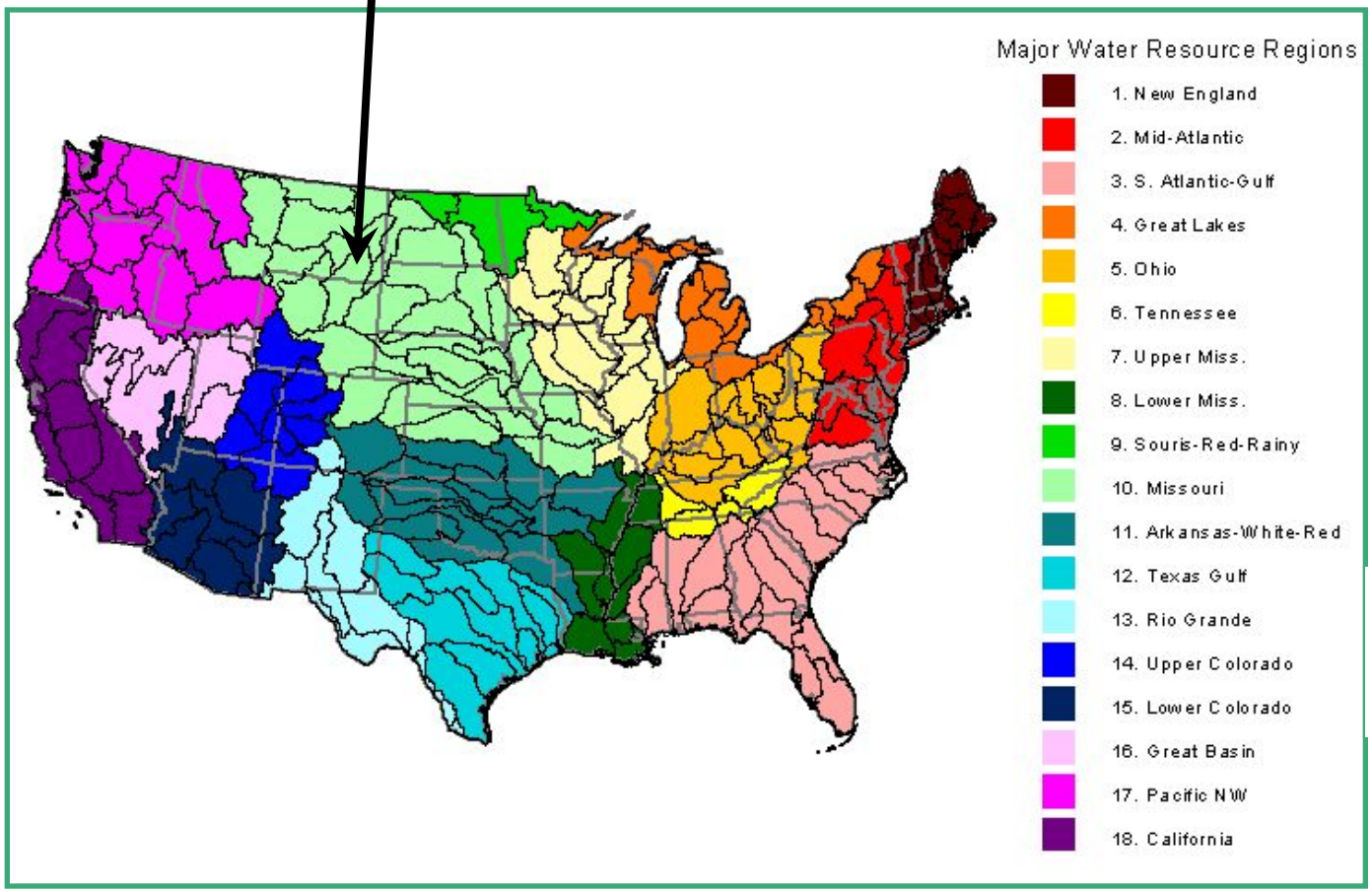
- SST variability modulates transfers of heat and water vapor between ocean and atmosphere…
- …modulating cloud formation, rainfall, and large-scale atmospheric motions…
- …influencing water vapor and heat transport *to* and pressure, temperature and winds *over* continents…
- …resulting in precipitation and temperature variability on continents.

Importance of the Missouri River Basin

The Missouri River Basin

Missouri River Basin

Produces 46% of wheat, 22% of grain corn, 34% of cattle in the United States



Largest river basin in the US

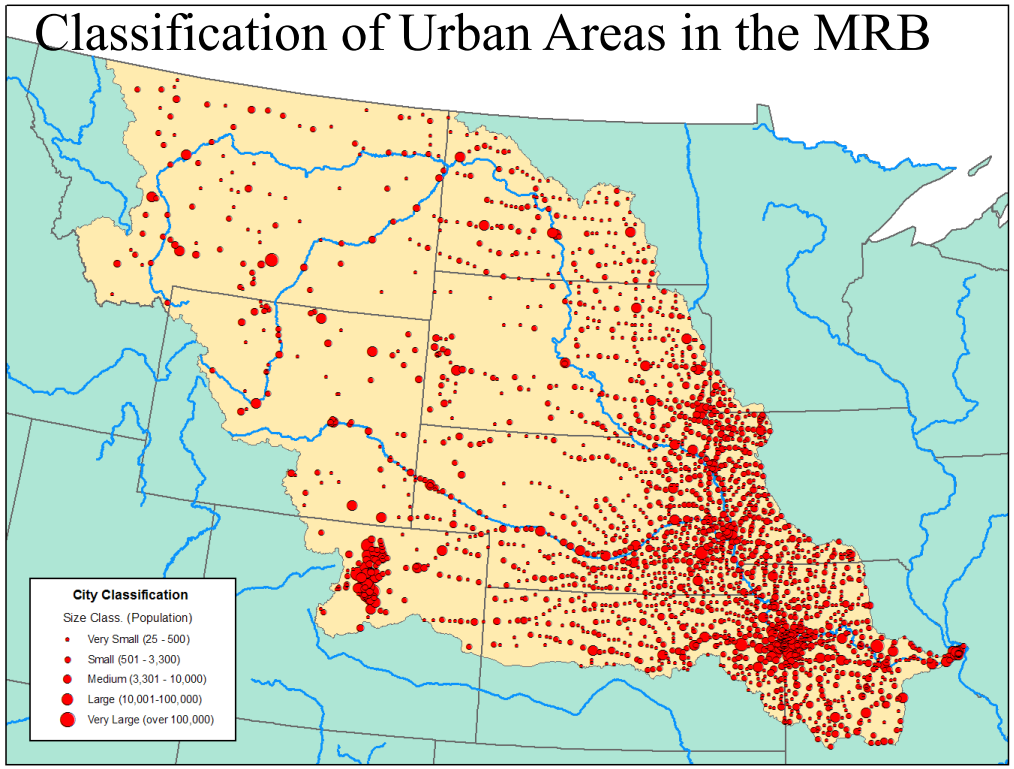
Covers 500,000 sq. miles, 10 States, many Native American reservations, parts of Alberta and Saskatchewan

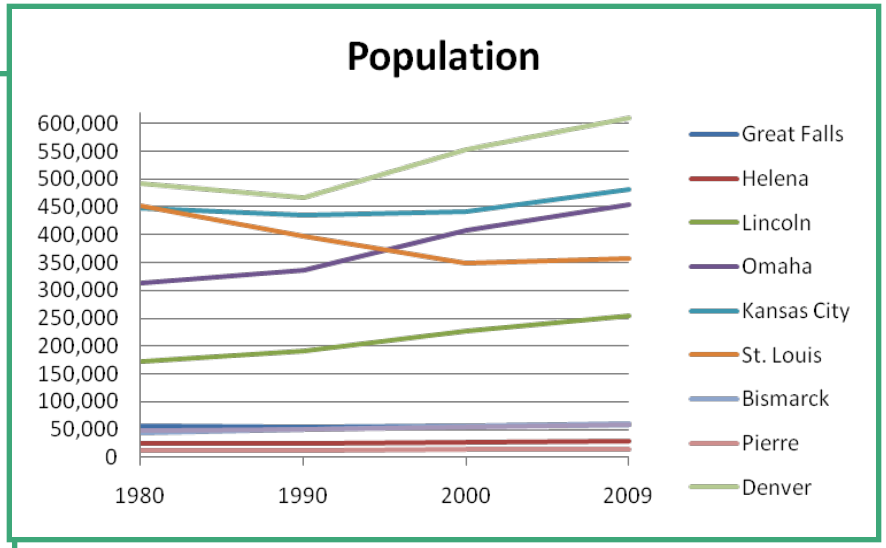
Value of crops and livestock over $100 billion in 2008

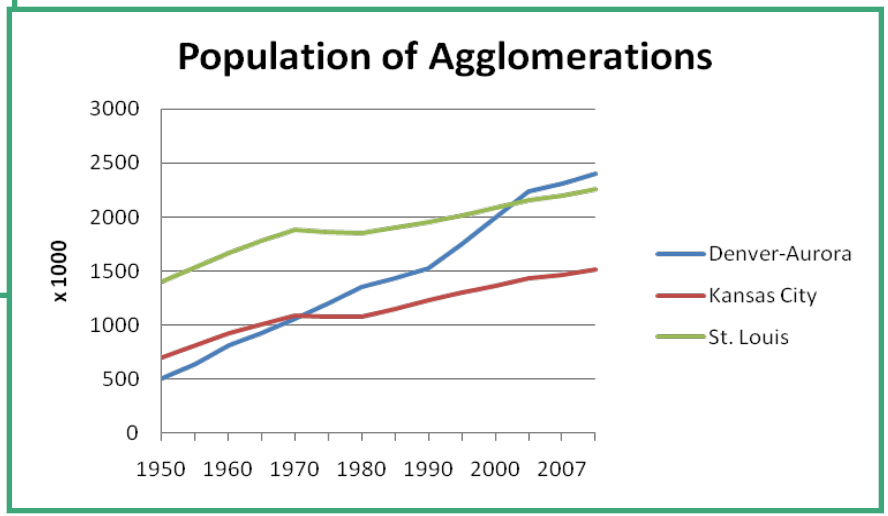
117 million acres cropland, only 12 million acres irrigated

Dependence on the Missouri River for drinking water, irrigation and industrial needs, hydro-electricity, recreation, navigation, and fish and wildlife habitat

Increasing Urbanization in the Missouri River Basin

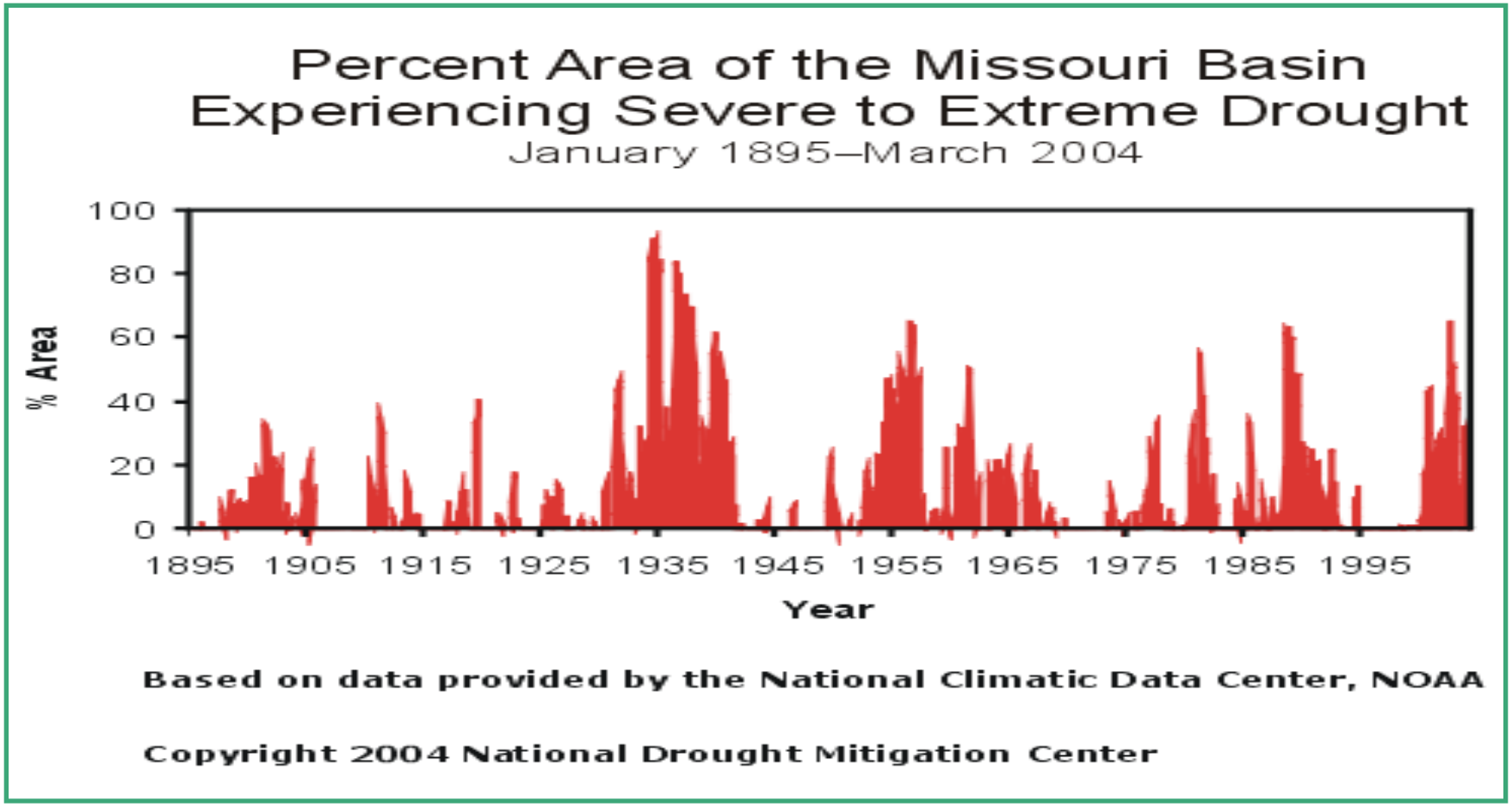






Over 1000 urban areas in the Basin;
Population increase in most urban areas.

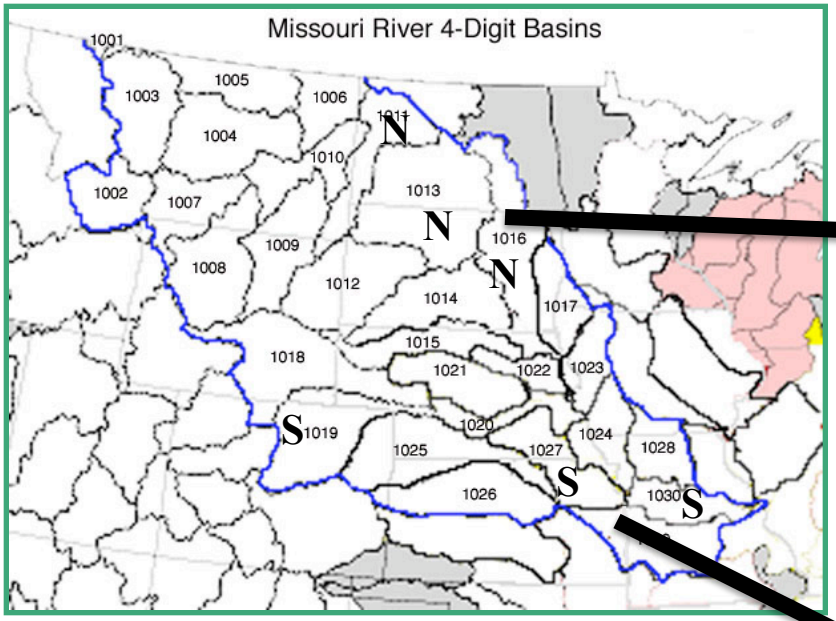
Droughts in the Missouri River Basin

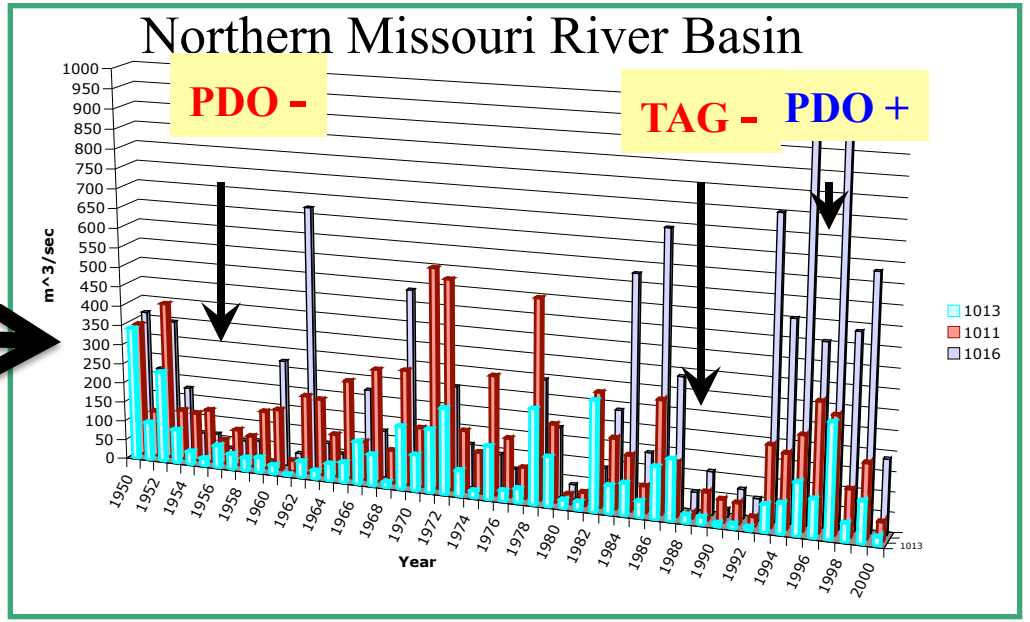


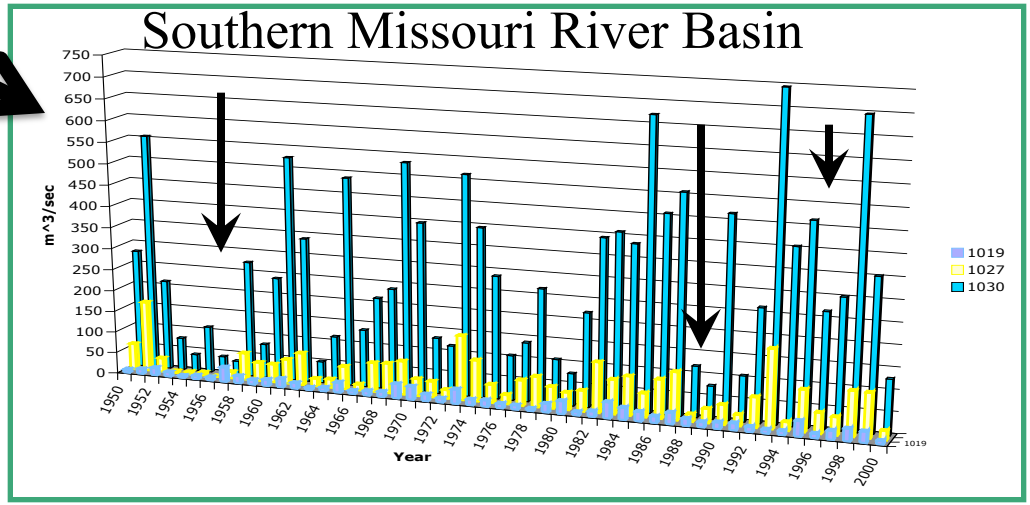
The Basin experiences severe to extreme decadal droughts.

Impacts of DCV phenomena on hydro-meteorology and water yield in the MRB

MRB USGS Gauged Streamflow (1950-2000)







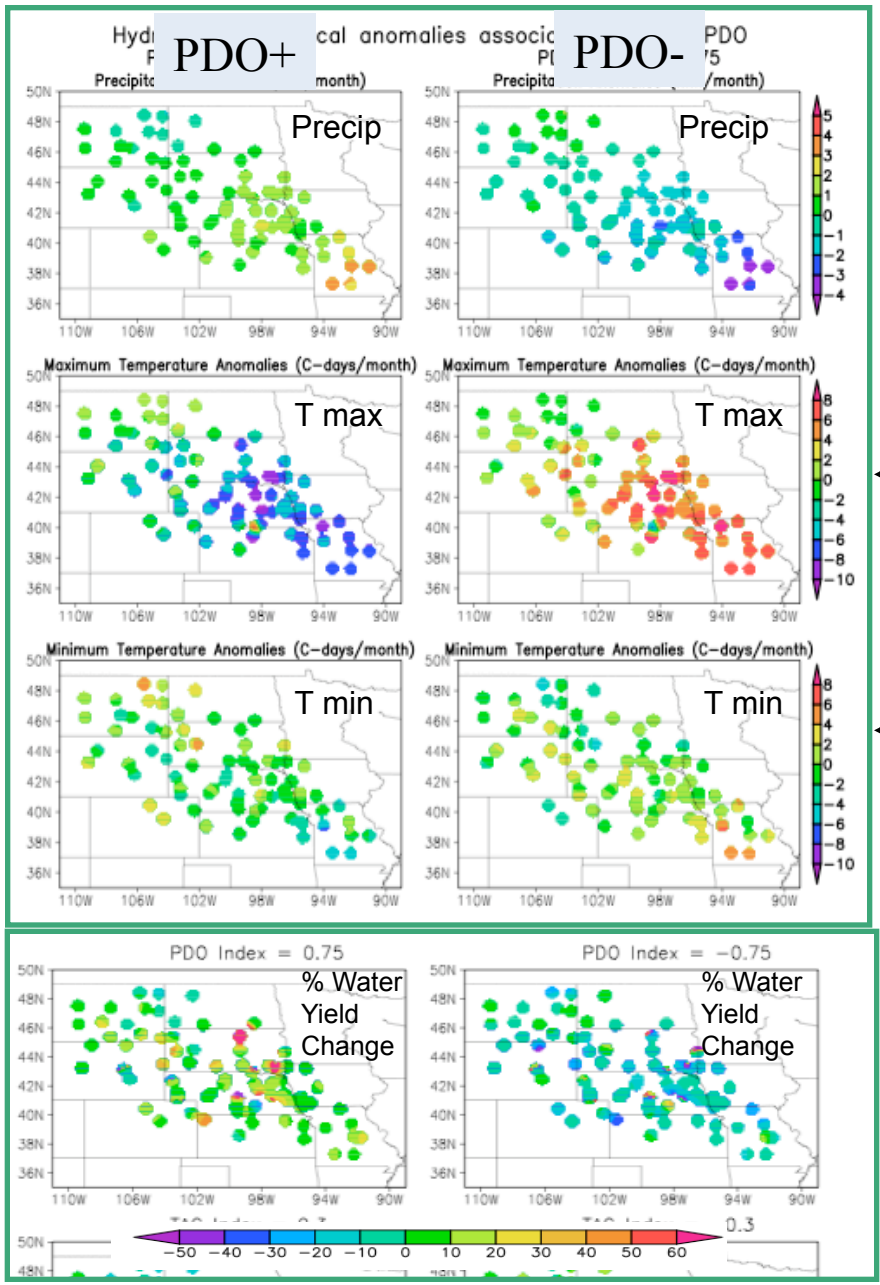
PDO: Pacific Decadal Oscillation
TAG: Tropical Atlantic Gradient
N: Northern Missouri River Basin
S: Southern Missouri River Basin

Impacts of extrema of PDO,TAG, and WP combine to create droughts (floods?) in the MRB.

SWAT Water Yield Changes in PDO Phases

Positive phase of PDO: More precip., cooler temperatures, and higher water yields

Negative phase of PDO: Less precip., warmer temperatures, and lower water yields



(Mehta et al., *JAWRA.*, 2011)

← mm/month ~inches/month

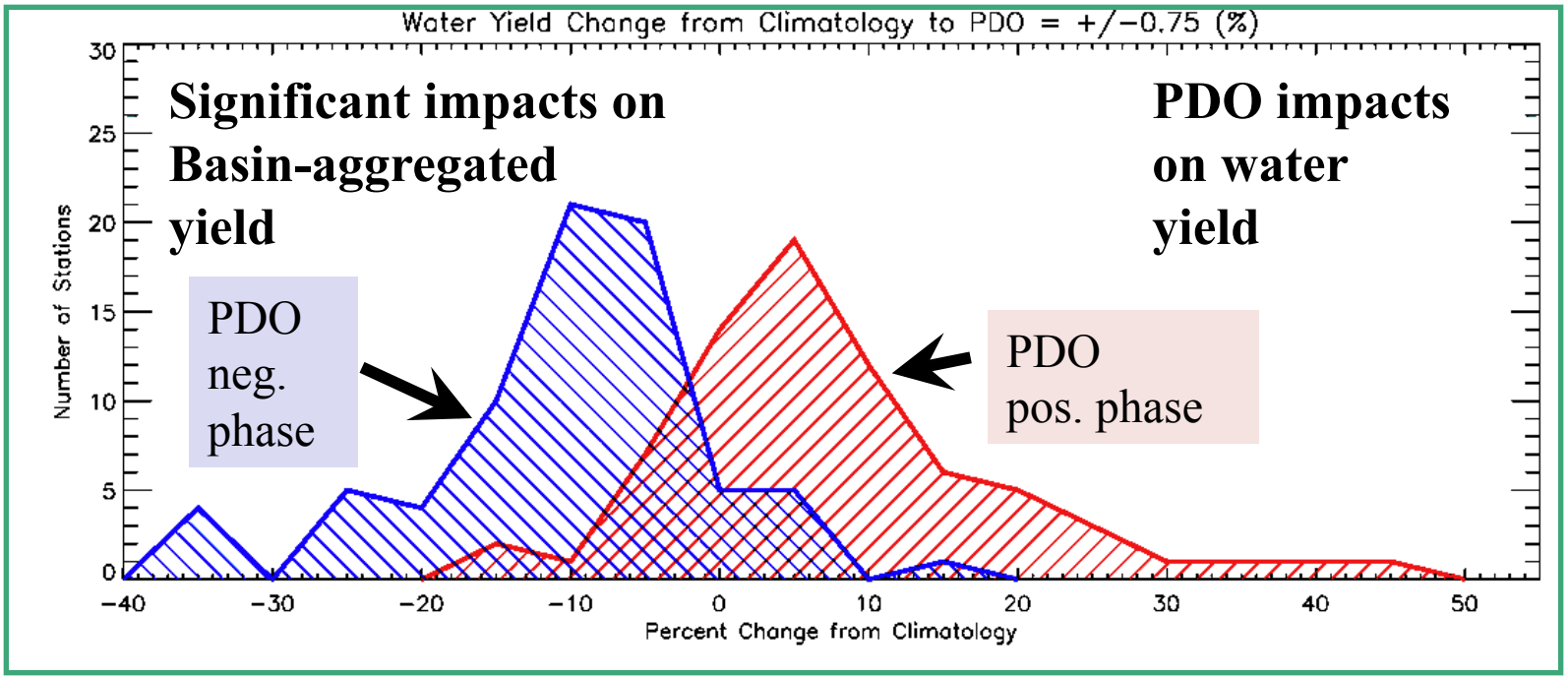
← °C-days/month

← °C-days/month

← % water yield change

Simulation of DCV Impacts on Missouri River Basin Water Yield with SWAT

(From: Mehta et al., *J. Amer. Water Res. Assoc.*, 2011)



50-60% change in individual locations; substantial impacts of tropical Atlantic and west Pacific Warm Pool variabilities also

Impacts of DCV phenomena on urban water security in the MRB

Case study of climate variability impacts on water security in three urban areas: Great Falls, Montana (small); Lincoln, Nebraska (medium); and Kansas City, Missouri and Kansas (large)

Data analysis and simulation of impacts with SWAT

The Great Falls Water System

Aerial view of Great Falls and the Missouri River

Number of people Served: 64,000

Number of water Connections: ~21,000

Daily maximum delivery Capacity: 56 million gallons

Great Falls Water Supply, Precipitation, and Temperatures: 1965 - 2010

June-July-August

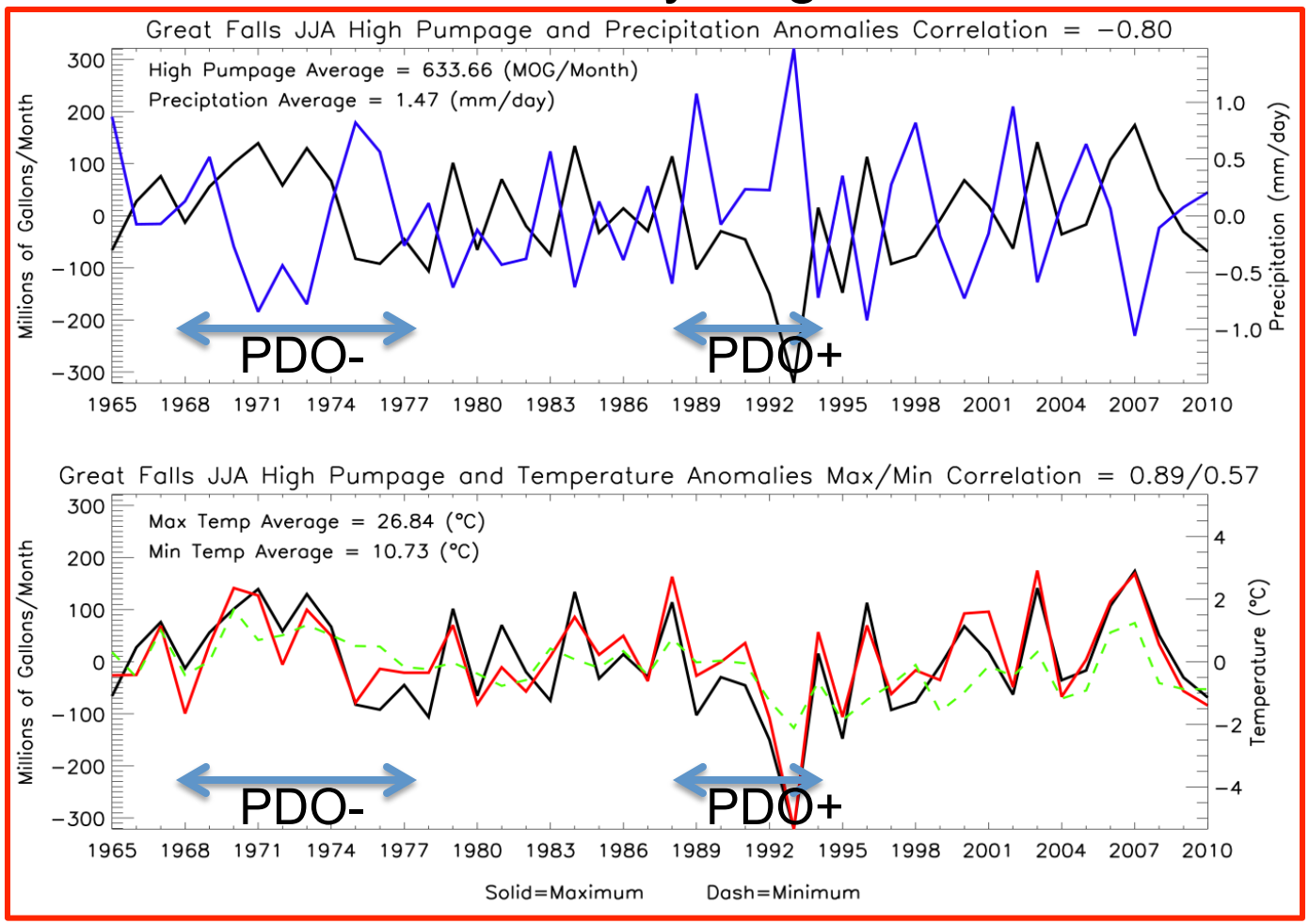
Precip. blue

Supply black

Max. T solid

Min. T dashed

Supply black



Corr. coeff. **-0.8**

Corr. coeff.
Tmax **0.89**
Tmin **0.57**

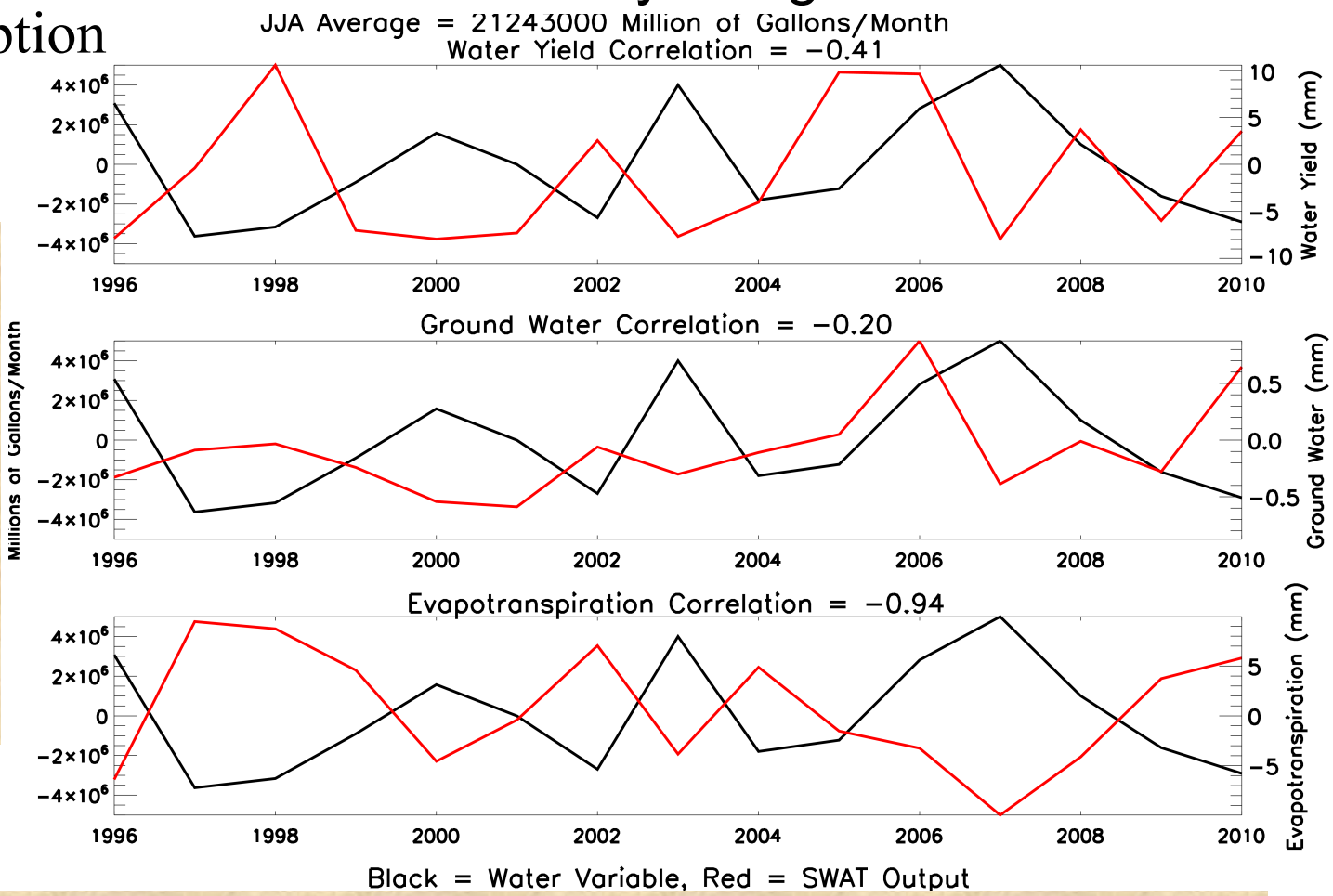
Very high correlations of water supply variability with precipitation and temperature variability; decadal variations in 1968-77, 1988-94

Great Falls Water Consumption; and SWAT-simulated Water Yield, Ground Water, and Evapotranspiration: 1996 - 2010

June – July - August

Black – Consumption

Red - SWAT



Less surface and ground water available, less ET, more demand on the urban water system

Good agreement between interannual variability of observed water consumption and SWAT-simulated water variables

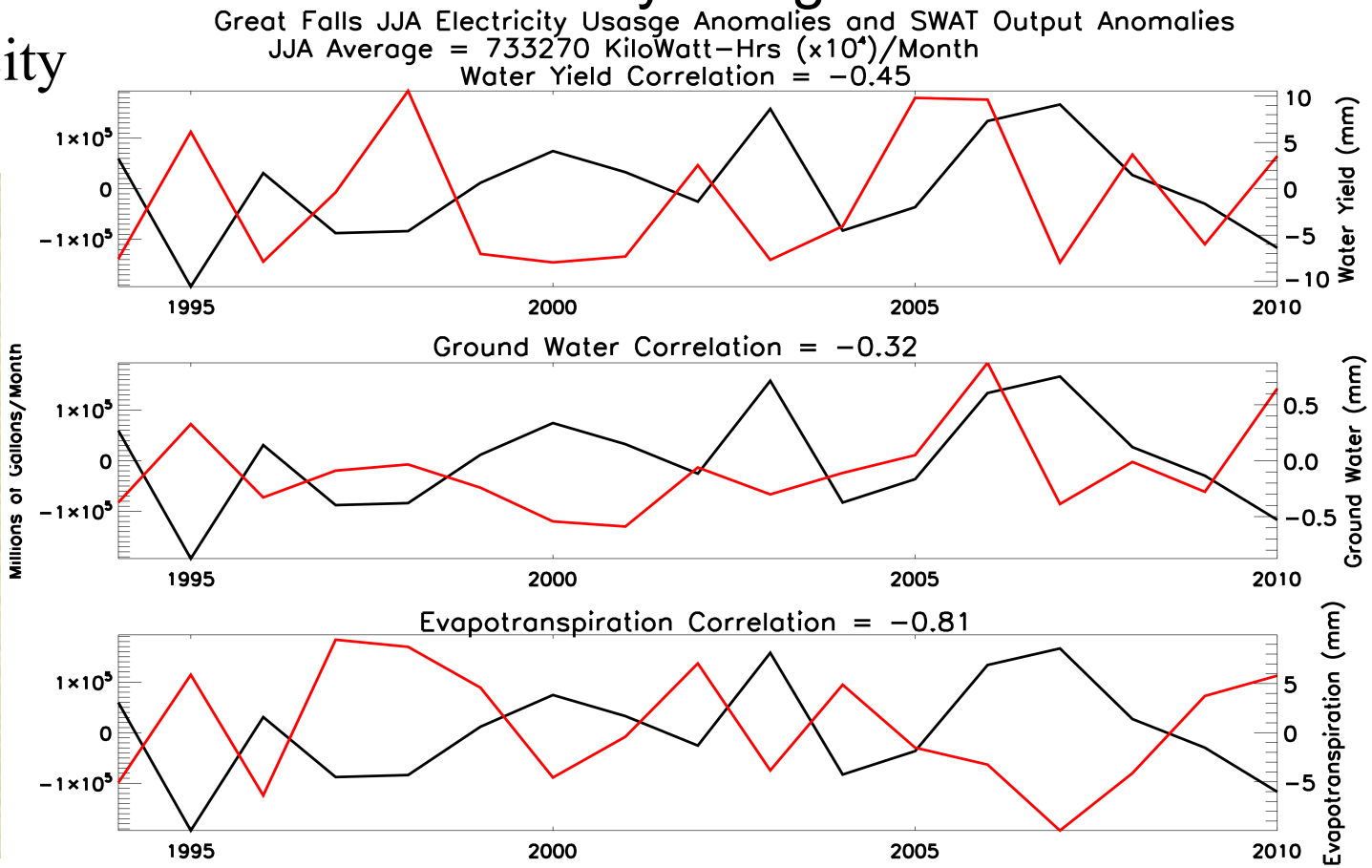
Great Falls Water System Electricity Usage; and SWAT-simulated Water Yield, Ground Water, and Evapotranspiration: 1996 - 2010

June – July - August

Black – Electricity

Red - SWAT

Less surface and ground water available, more electricity consumption to pump water



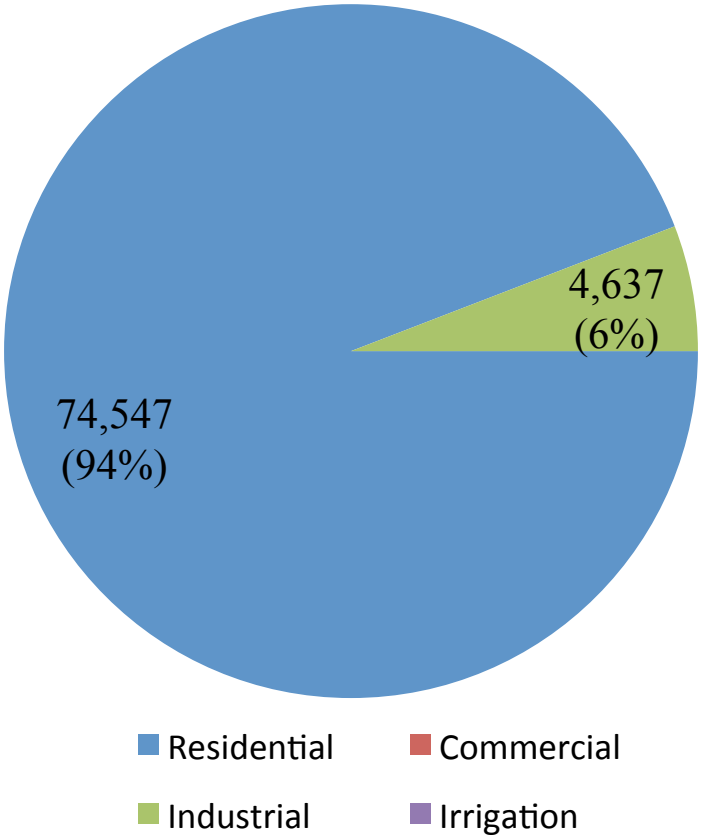
Good agreement between observed electricity consumption and SWAT-simulated water variables

The Lincoln Water System

Number of people served: 263,000
Number of water connections: 79,187
Daily maximum delivery capacity: 100 million gallons

Aerial view of Lincoln

Number of customers



Lincoln Annual Water Supply and Demand, and SWAT-simulated Surface and Ground Water and Evapotranspiration: 1973 - 1999

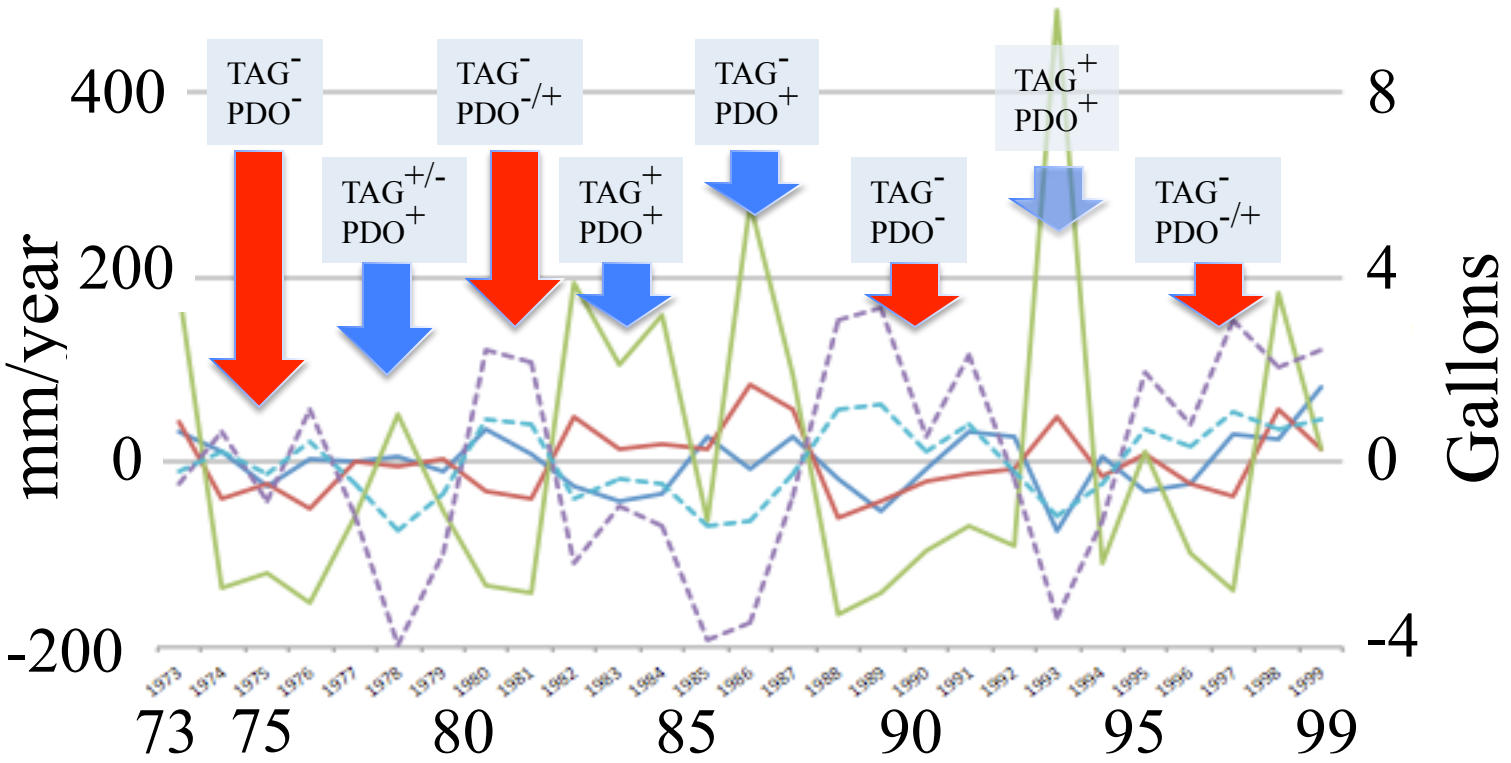
ET
Ave. 572 mm/year

Surf. water
Ave. 166 mm/year

Ground water
Ave. 60 mm/year

Supply BG/ year
Ave. 12

Ave. daily demand MG/day
Ave. 33



Moderate negative correlation among simulated surface and ground water, and measured water supply and demand

Association among PDO^{+}/TAG^{+}, above-average surface and ground water, and below-average water supply and demand

Association among PDO^{-}/TAG^{-}, below-average surface and ground water, and above-average water supply and demand

Summary

- Several major patterns of decadal climate variability (DCV).
- Substantial associations between hydro-meteorological anomalies in the Missouri River Basin (MRB) and DCV patterns.
- Hydro-met. anomalies associated with realistic values of the DCV indices applied to SWAT show substantial sensitivity of water yields in the MRB to DCV phenomena.
- Good agreement between observed water consumption and other associated variables measured by Great Falls and Lincoln urban water systems, and SWAT-simulated water variables.
- SWAT can be used to predict climate variability impacts on urban water security given skillful climate prediction.

Thank you!!

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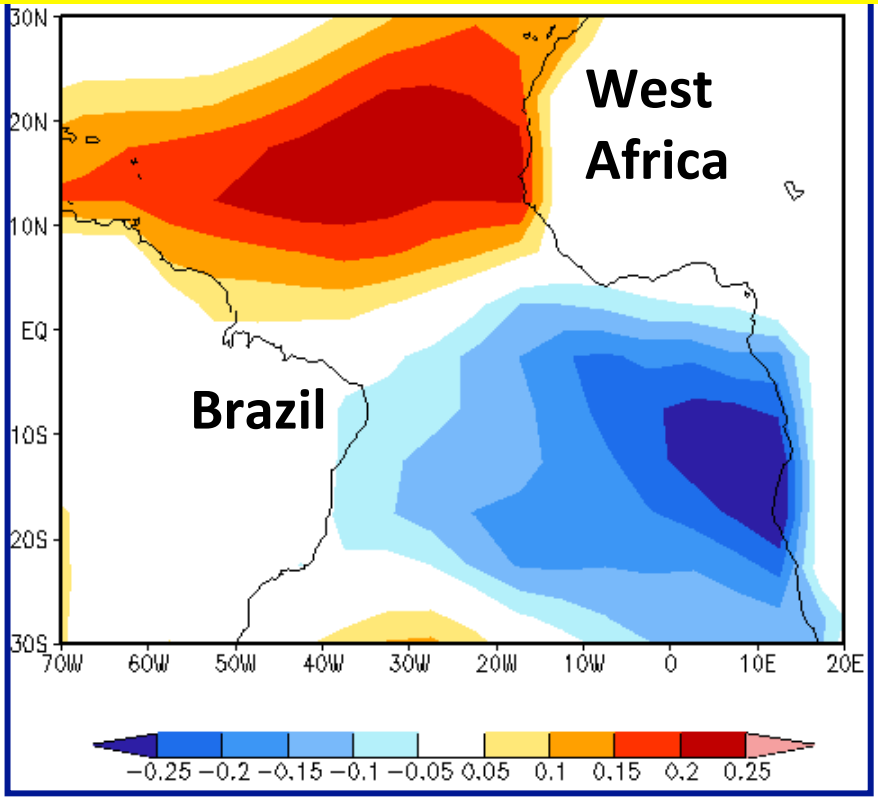
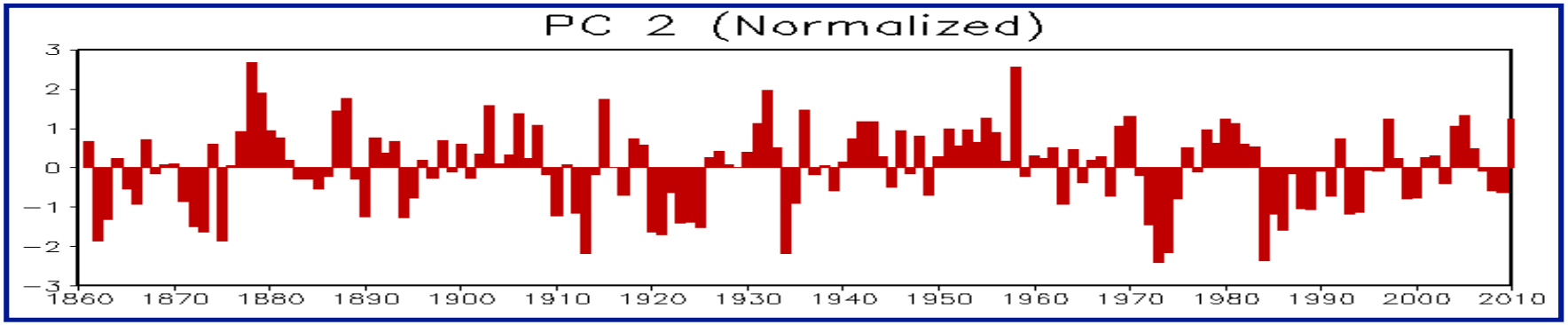
Observed Tropical Atlantic SST Gradient Variability Pattern: 1861 – 2010

Cross-equatorial SST gradient points south-to-north or north-to-south for a few years to a decade



Substantial SST anomalies (°C) associated with one standard deviation in the time series below

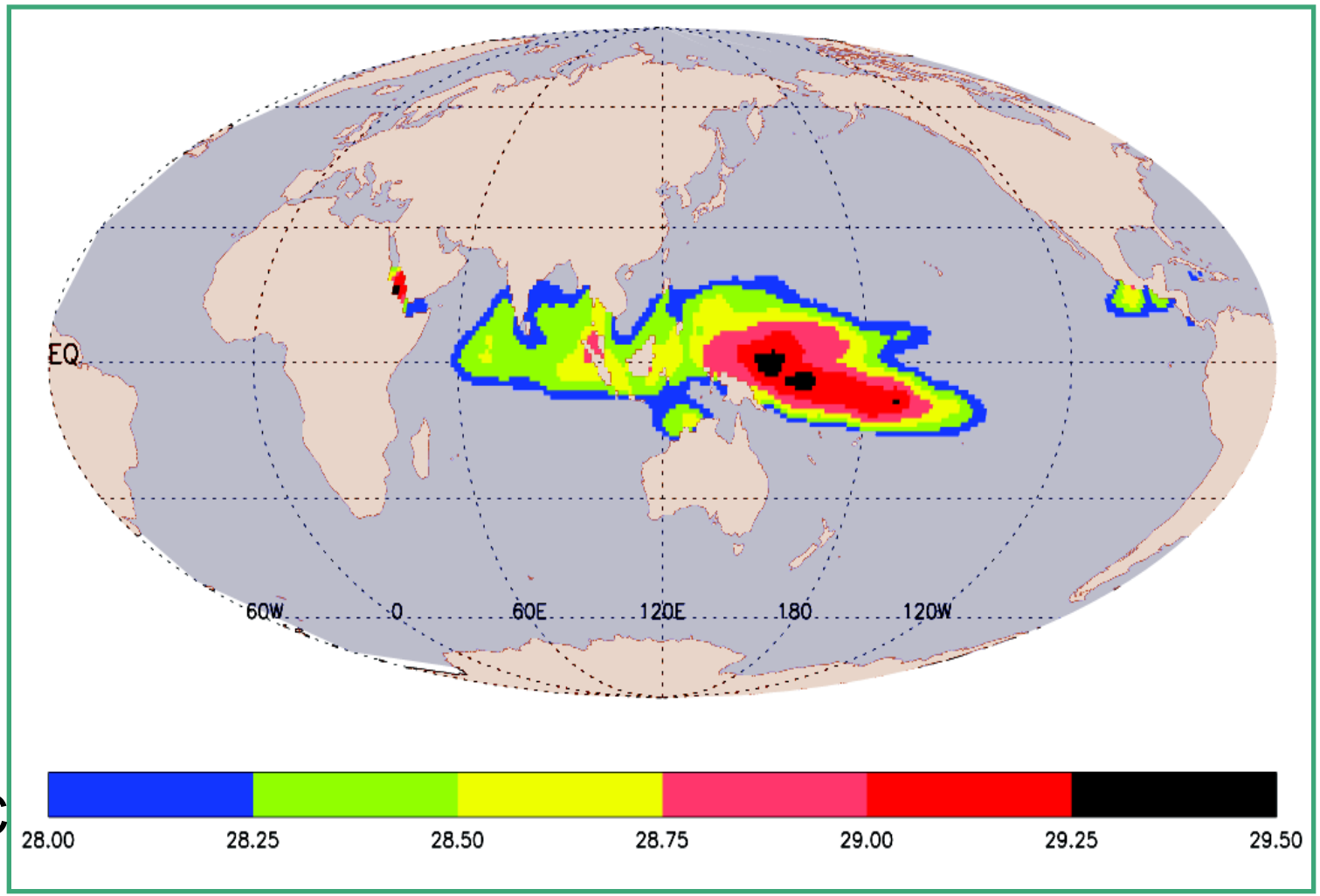


Observed West Pacific Warm Pool Average SST Pattern

Average Warm Pool SSTs (°C)

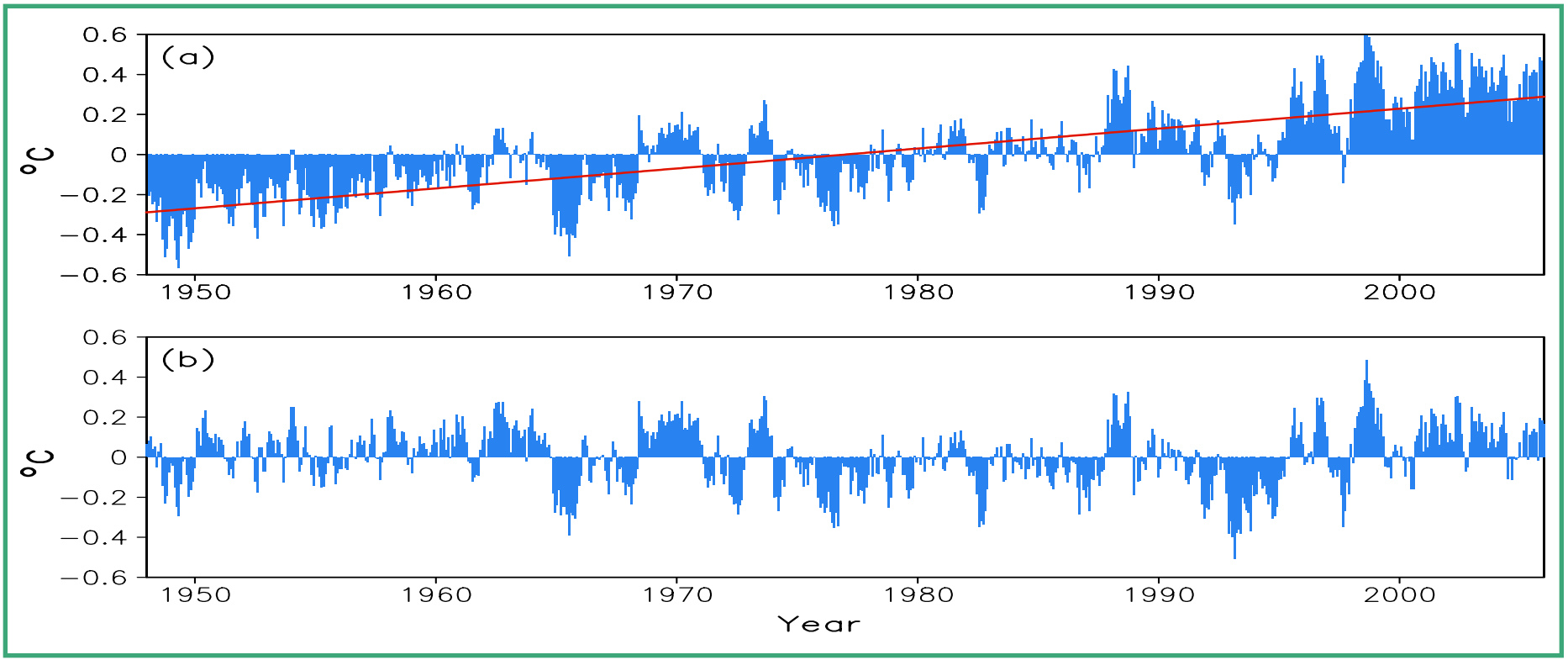
Tropical Warm Pool definition: SST above 28.5°C

Substantial increase in atmospheric convection and clouds when SST above 28.5°C



Observed West Pacific Warm Pool SST Anomaly Time Series

Original and detrended time series



Indo-Pacific Warm Pool becoming warmer over the last 50 years; also, multi-year to decadal variability

Great Falls Water Consumption; and SWAT-simulated Water Yield, Ground Water, and Evapotranspiration: 1996 - 2010