Decadal Climate Variability and Global Food Security

A Case Study of Impacts of Decadal Climate Variability on Crop Yields in the Missouri River Basin

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M.V.K. Sivakumar, Agricultural Meteorology Program, WMO

Outline

- Decadal Droughts and Floods
- Major Decadal Climate Variability (DCV) Phenomena
- Global Food (In)security Requires Assessment, Prediction and Adaptation to DCV
- A Case Study: DCV and Agriculture in the Missouri River Basin (MRB)
  - Tropical-Subtropical DCV Patterns' Association with Droughts and Floods
  - Impacts of the DCV Patterns on the MRB Agriculture
- Summary

Summary

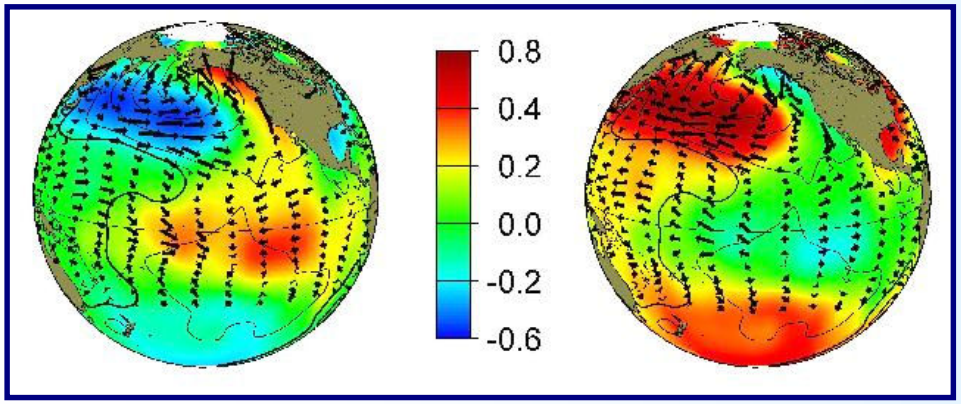
- Global food security precarious
- History of multiyear to decadal droughts and floods in food-producing and -consuming regions
- Potentially devastating impacts of simultaneous, DCV-related droughts/floods in major food-producing and -consuming regions
- Urgent to assess impacts of DCV on global food security; and develop models-methodologies to predict possible DCV impacts
- Significant impacts of DCV on MRB hydro-meteorology
- Possible to simulate impacts of DCV phenomena on crop yields in the MRB; Prediction of DCV impacts on crop yields may be possible if evolution of these phenomena predictable
- By integrating water resource availability with crop water demand, regions and crops that are most sensitive to DCV can be identified; help to target adaptation efforts to the most vulnerable regions and crops
- Climate science helpful in ensuring water and food securities for society in response to the evolving climate; much more research required on understanding, prediction and impacts assessment

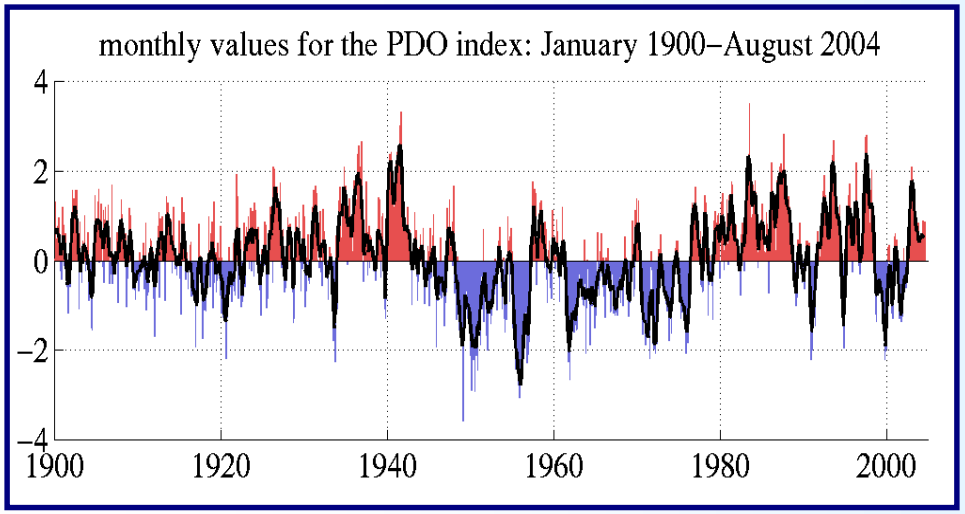
Decadal climate variability in recent times

- History of decade-long droughts and floods in Europe, Asia, North America
- Decade-long droughts in the North American Great Plains in 1890s, 1930s, 1950s, 1980s, and since 2000-01
- Societal problems in Brazil due to decade-long droughts
- The Sahel droughts in 1970s-1980s-1990s and consequent societal impacts
- Decadal droughts in India in early 1900s, mid-1960s to early-1970s, 1980s, late 1990s to early 2000s
- Decadal droughts in Pakistan and Afghanistan in 1980s and 1990s and consequent socio-economic-political upheavals, with geopolitical consequences
- Decadal-multidecadal variability in numbers of hurricanes and other tropical cyclones

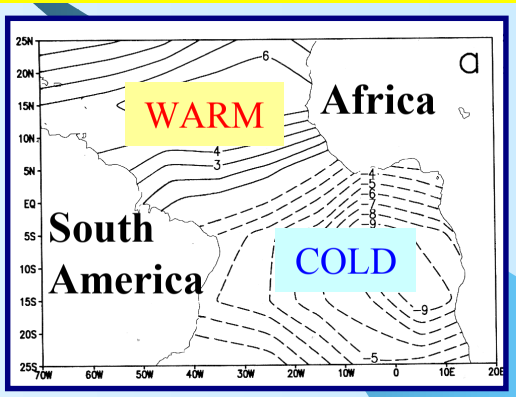
Examples of Decadal Climate Cycles

The Pacific Decadal Oscillation at 10 Years and Longer Periods



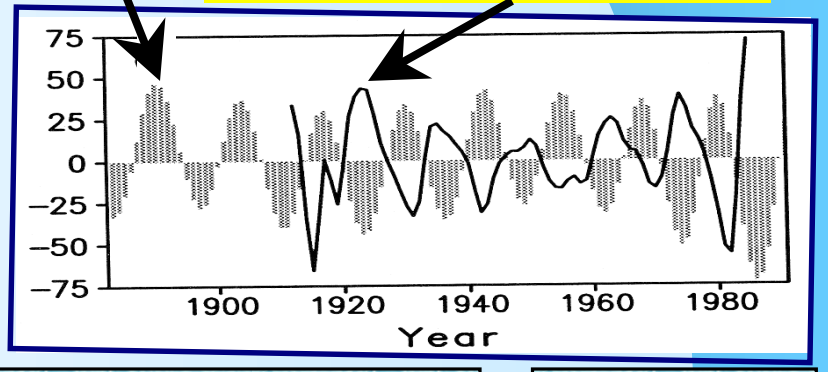


The Tropical Atlantic Sea-surface Temperature Gradient Oscillation at 12 Years Period



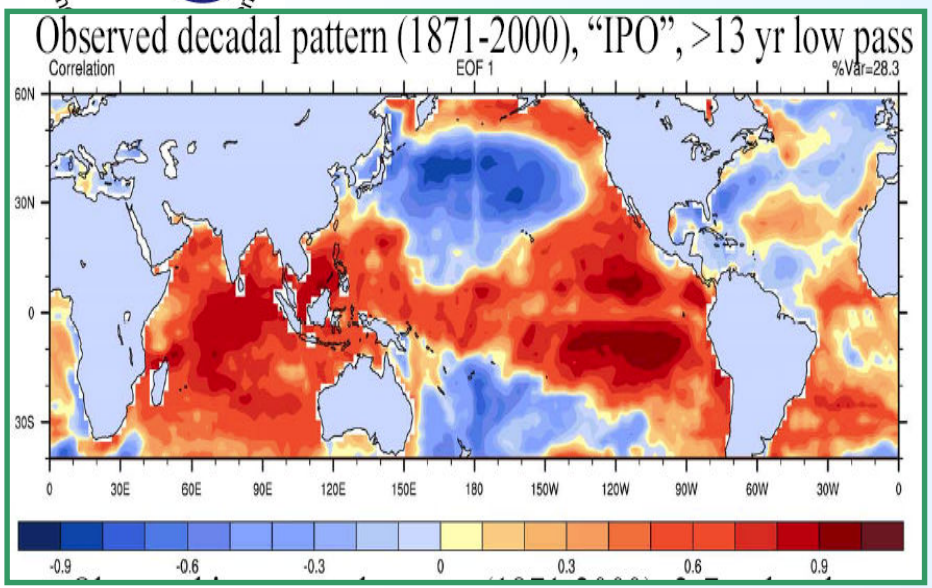
Temperature gradient oscillation

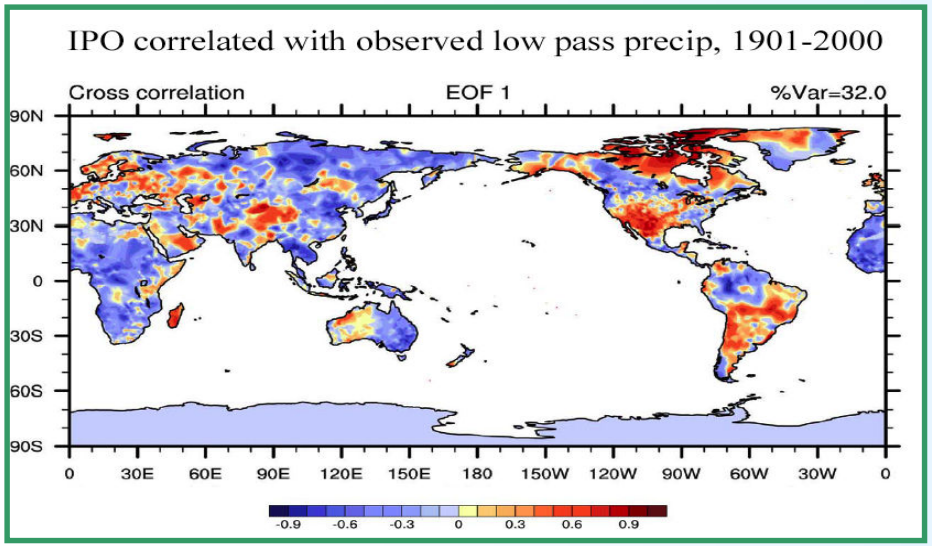
Northeast Brazil rainfall oscillation



Mega-droughts in Related to Inter-decadal Pacific Oscillation

(Meehl and Hu, 2005; *J. Climate*)



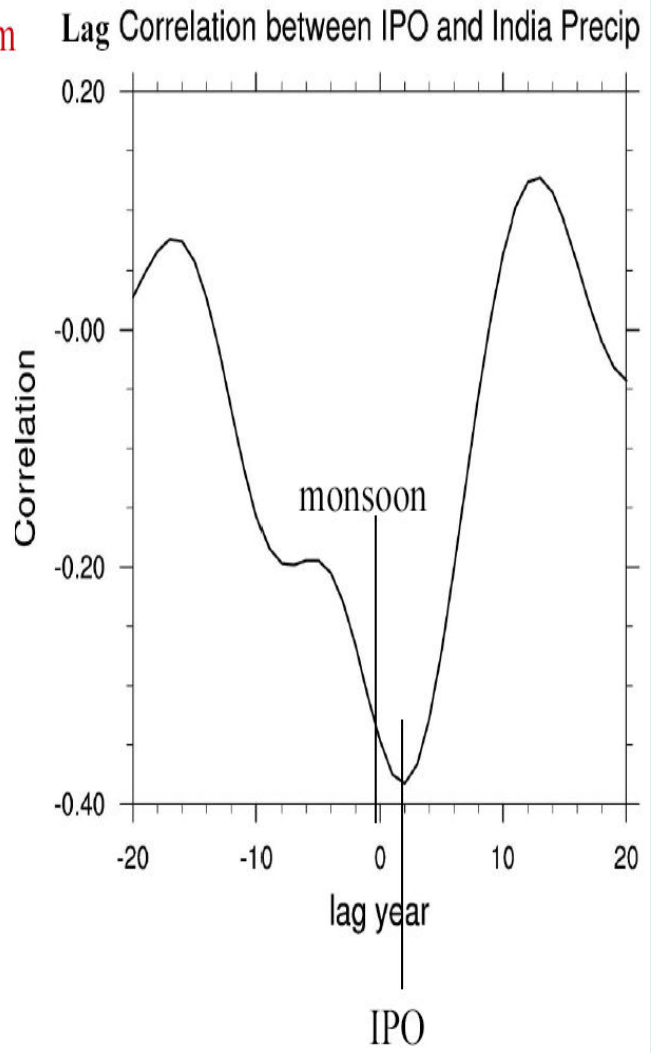


Weak Indian monsoon leads warm IPO by two years

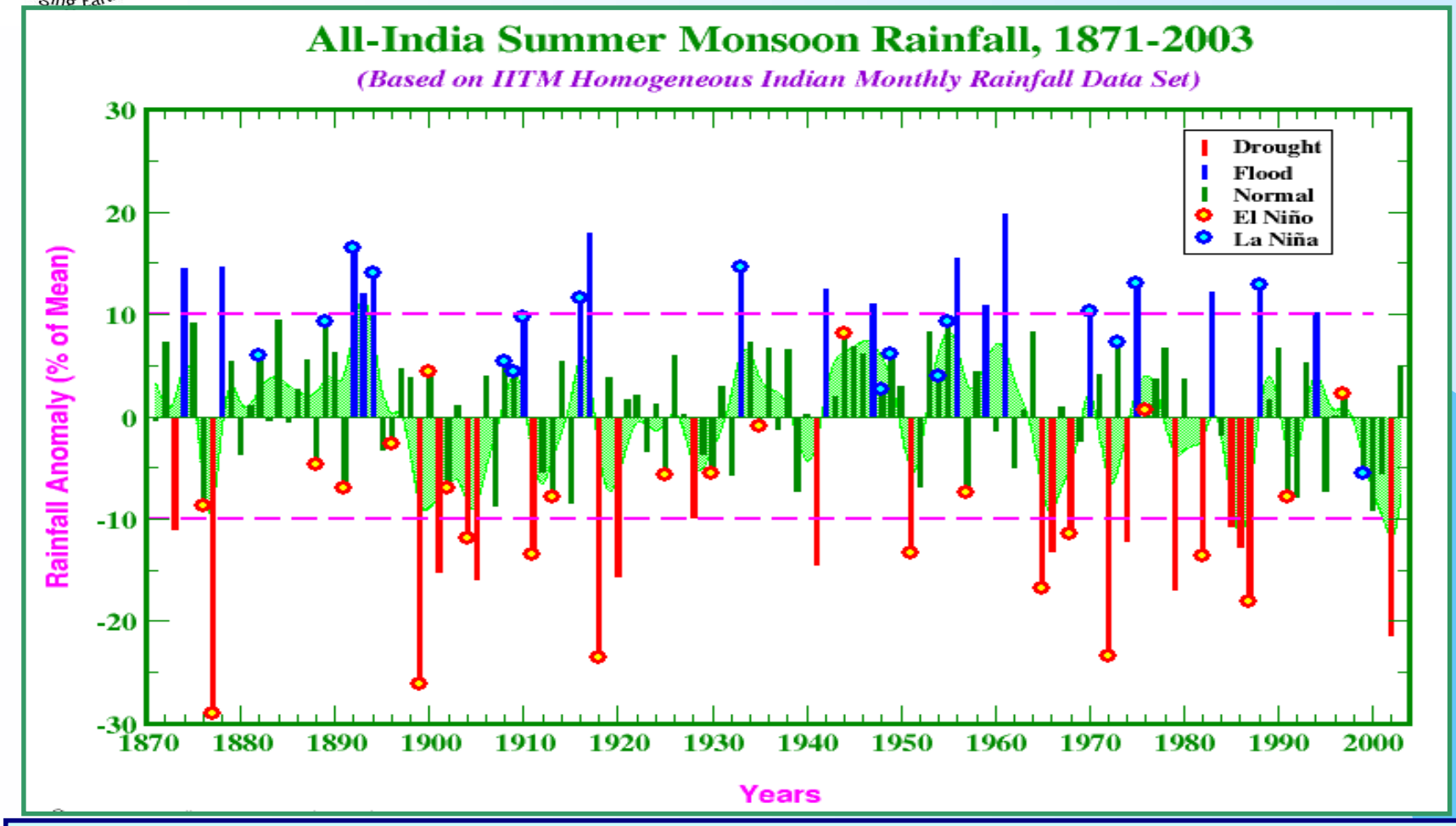
Lag correlations:

Cool Indian SSTs; 1 yr later monsoon drought maximum; 1 yr later Pacific trades weakest, Pacific SSTs warmest, and STCs weakest; one year later IPO warmest;

Monsoon leads Pacific decadal changes



All-India summer monsoon rainfall



Large, year-to-year and longer term variability in all-India rainfall

Increasing global food demand…

Increase in demand for cereals by 39% between 1995 and 2020; production will not keep pace with demand, but cereal imports expected to double

Increase in demand for meat by 58%

Increase in demand for roots and tubers by 37%

Food production in the developing world expected to increase much faster (51%) than the developed world (24%)

Irrigated area projected to grow at an average annual rate of 0.6%/year during 1995-2020, less than half the annual growth rate of 1.5%/year during 1982-93.

Soil degradation, especially in the developing countries, is a growing problem. Worldwide 38% of all agricultural land have become degraded.

…and stagnant/declining food production are combining to produce…

"World wheat production in 2007 is forecast to rise by over 5 percent to 630 million tonnes. Total wheat utilization is expected to reach 632 million tonnes, up 1 percent from 2006/07, mostly on faster demand for feed. World wheat inventories are forecast to decline for the second consecutive season, to 148 million tonnes, resulting in **the world stocks-to-use ratio reaching 23 percent, down from the previous season and the lowest level since 1980.**" **- UN FAO**


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Global food crisis looms as climate change and population growth strip fertile land

. 'Ignorance, need and greed' depleting soil
. Experts warn competition will lead to conflict

"International trade in coarse grains is anticipated to decline by 2 million tonnes to 108 million tonnes in 2007/08, mostly on smaller maize imports by several countries in Asia. **In spite of larger exportable supplies this season, world prices are likely to remain high and volatile, supported by rapid increases in demand from the ethanol industry and uncertainties in the global petroleum sector.**" **- UN FAO**

…Global Food Insecurity

"While the prospect of a strong recovery in global cereal production in 2007 is a positive development for the 2007/08 marketing season, **total supplies in the new season would still be barely adequate to meet an anticipated rising demand, not only from the traditional food and feed sectors but in particular from the fast-growing biofuels industry. As a result, international prices for most cereals are likely to remain high and volatile again in 2007/08.**" - **UN FAO**

Why Study DCV Impacts on Global Food Security?

The precarious global food situation can be worsened into a global food catastrophe by simultaneous, multiyear to decadal droughts in several major food-producing and -consuming countries.

Therefore, it is very important and urgent to assess impacts of decadal climate variability phenomena on global food supply and demand (food security); and develop models and methodologies for multiyear to decadal prediction of possible climate impacts on global food production.

A Case Study: Decadal Climate Variability Impacts on Agriculture in the Missouri River Basin

Objectives

- To identify impacts of global-scale decadal climate variability on the hydro-meteorology of the MRB
- To identify hydrologic responses
- To identify impacts on dryland and irrigated crop yields
- To evaluate impacts on demand for and supply of water for irrigation
- To calculate the first-order economic effects and identify further societal impacts

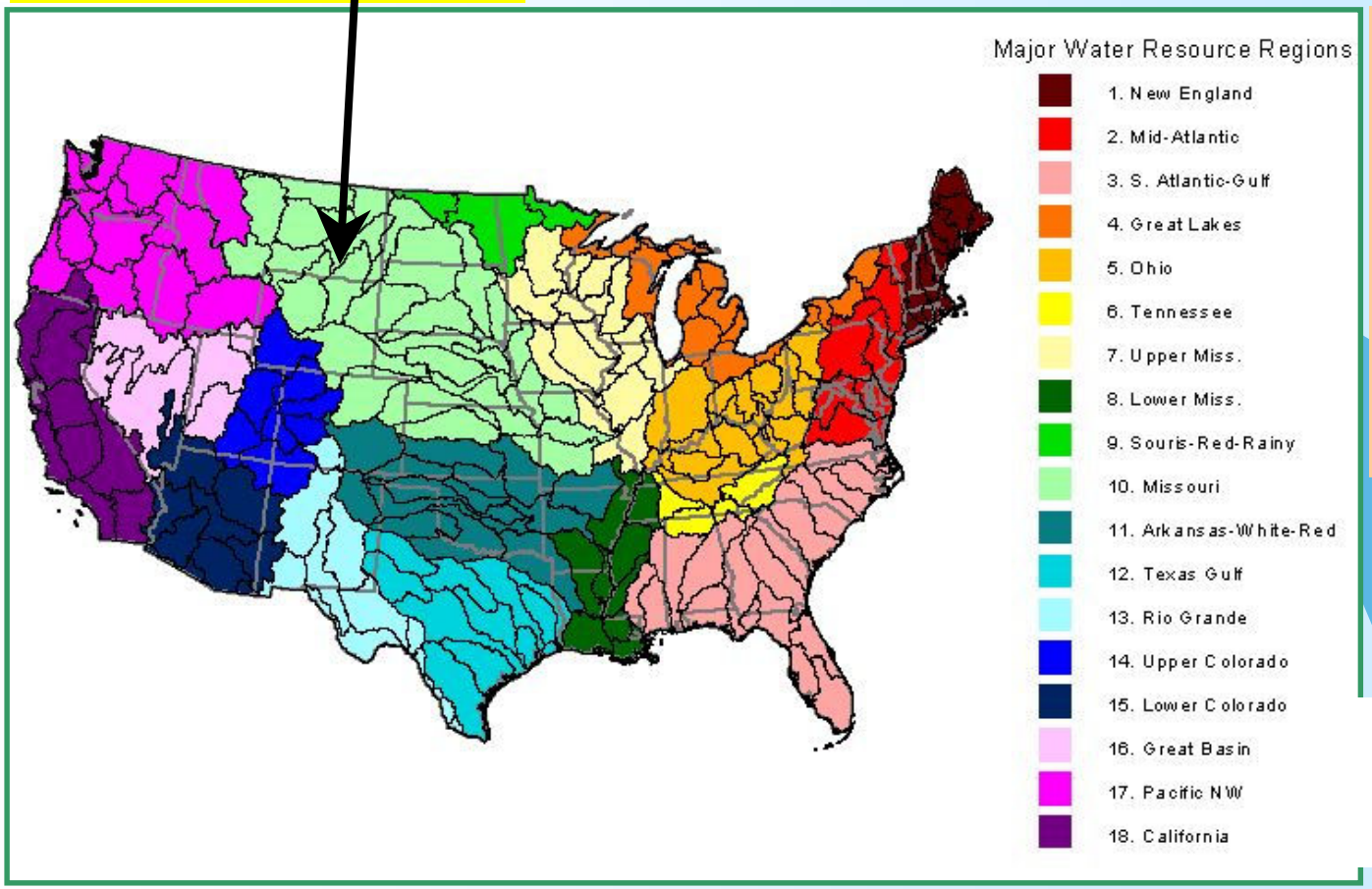
Importance of the Missouri River Basin

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, numerous Native American reservations, parts of Canadian Provinces of Alberta and Saskatchewan



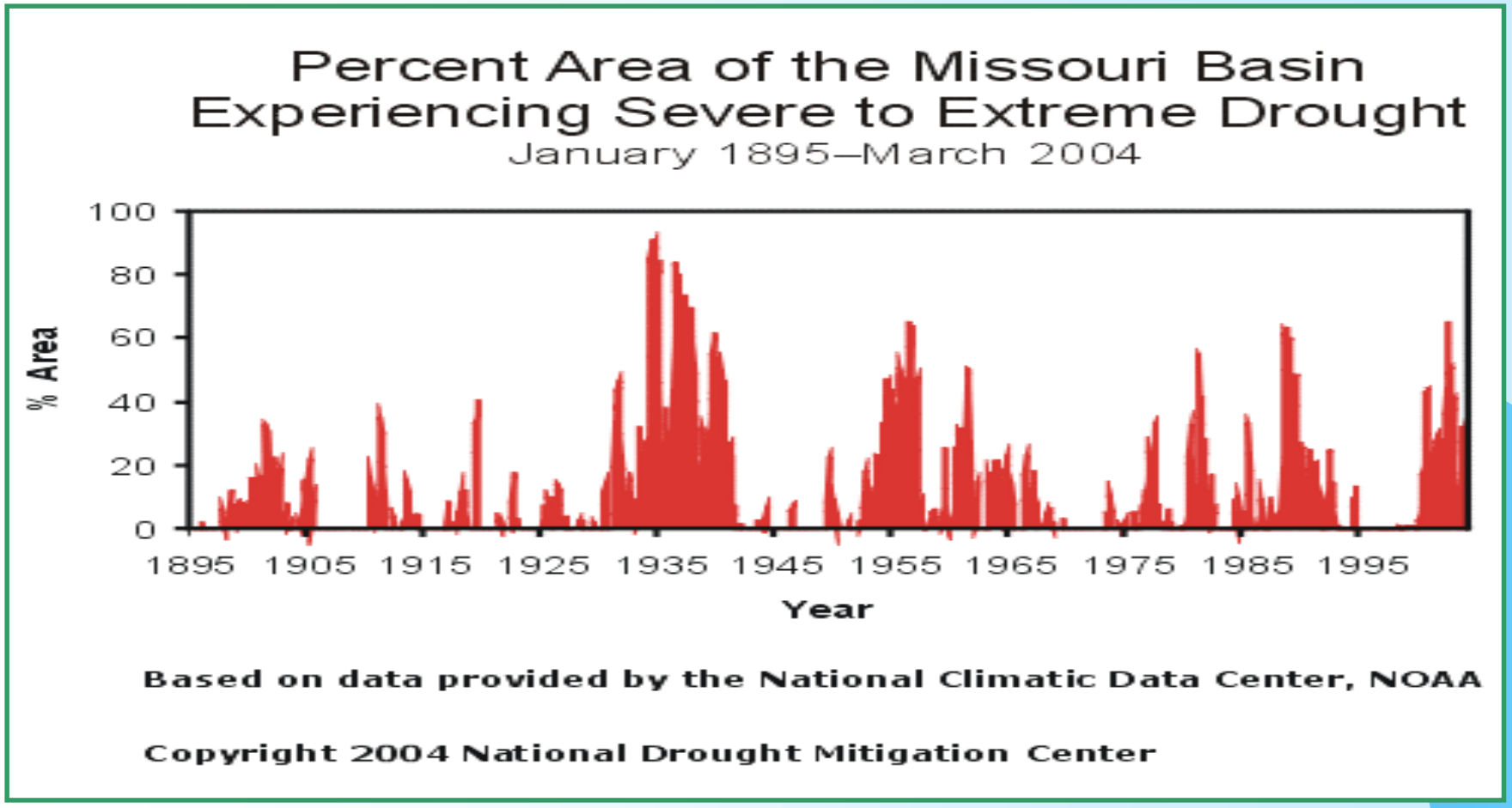
Dependence on the Missouri River for drinking water, irrigation and industrial needs, hydro-electricity, recreation, navigation, and fish and wildlife habitat

Value of crops and livestock $27 billion in 2002

117 million acres cropland, only 12 million acres irrigated

MRB water resources vulnerable to climate change on four indicators; *Demand*, *Dependence on hydroelectricity*, *Groundwater vulnerability*, and *Streamflow variability*, only *Storage capacity adequate*

Droughts in the Missouri River Basin



There are decadal droughts in the MRB.

Hydro-meteorological and Climate Data

- **Hydro-meteorological variables from Maurer et al. (2002)**
  Precipitation, surface air temperature, surface air humidity, surface wind speed; 1/8 degree longitude – 1/8 degree latitude grid spacing over North America; 3-hourly, daily, and monthly time resolution; January 1950 to December 2000

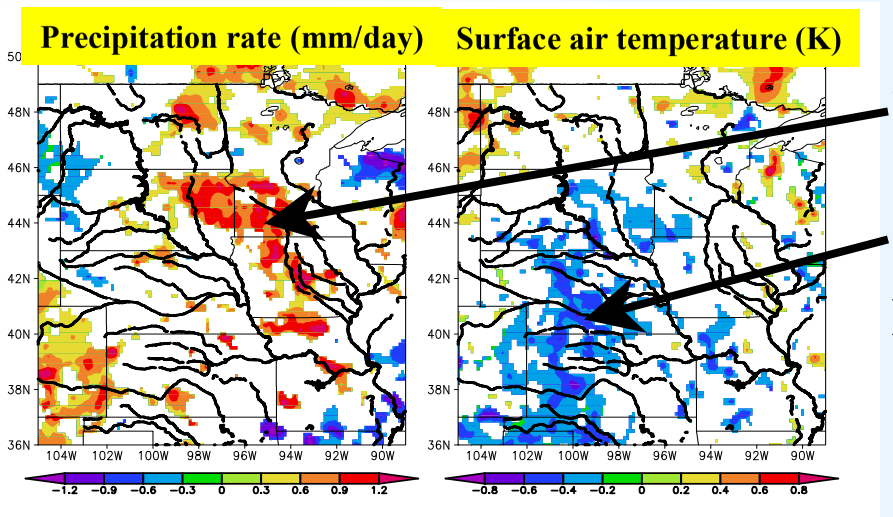
- **Stream flow estimates from US Geological Survey gauges**

- **Climate Pattern Indices**
  Pacific Decadal Oscillation index from Mantua et al. (1997); January 1900 to December 2003

  Warm Pool and tropical Atlantic indices formed by area-averaging the Smith et al. (1996) SST anomalies for each month from January 1948 to December 2005

Association between the Pacific Decadal Oscillation and the Missouri River Basin Hydro-meteorological Anomalies in Summer (1950-2000)

Warm Pacific Decadal Oscillation



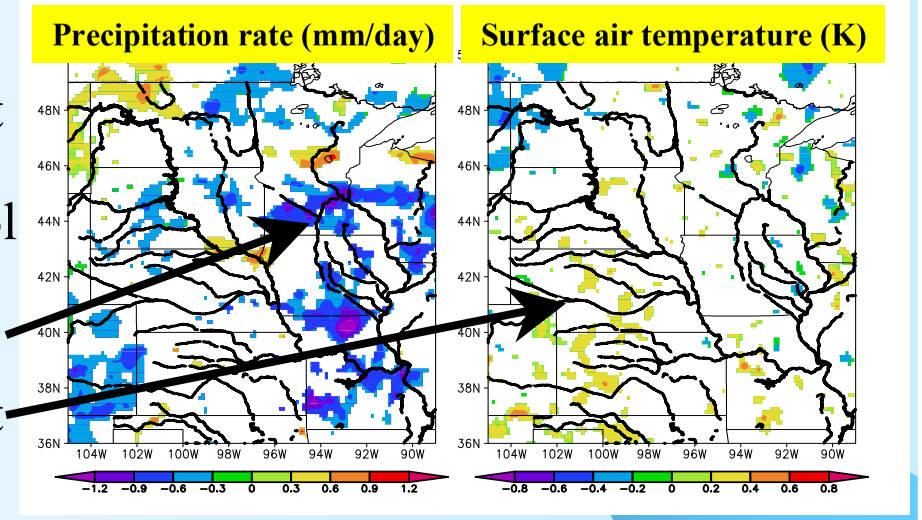
Wet

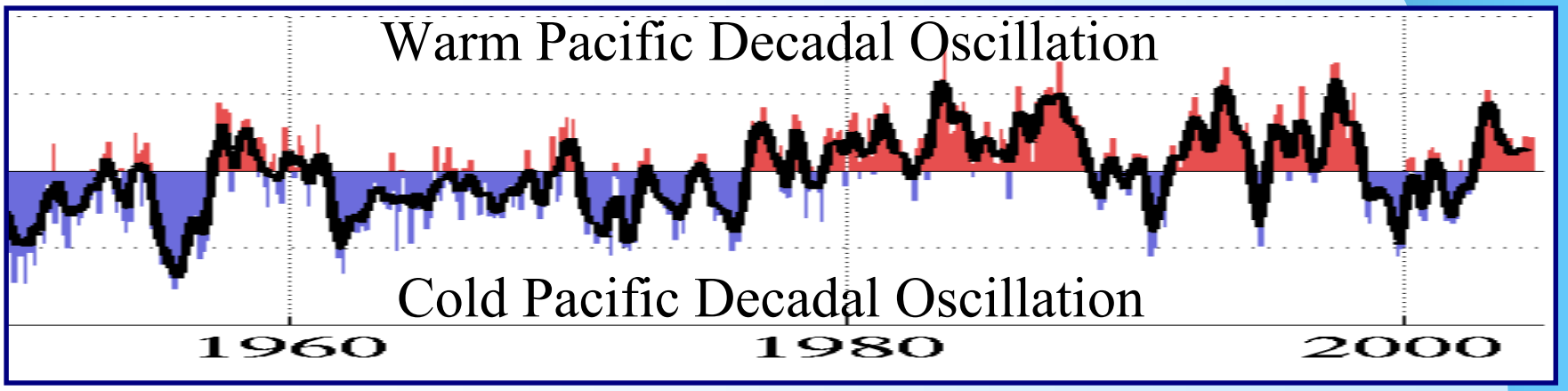
Cool

Dry

Hot

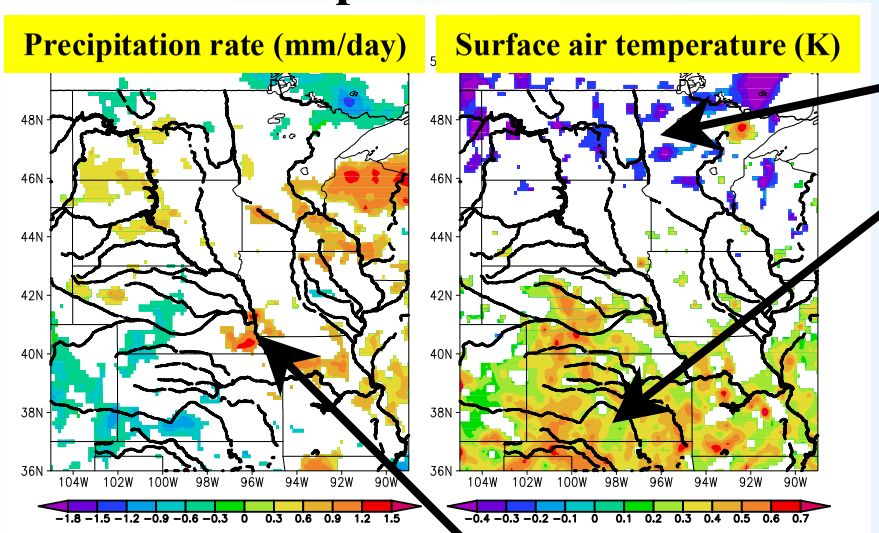
Cool Pacific Decadal Oscillation





Association between Decadal Variability of Tropical Atlantic Temperature Gradient and the Missouri River Basin Hydro-meteorological Anomalies in Summer (1950-2000)

Warm Tropical South Atlantic



Cool

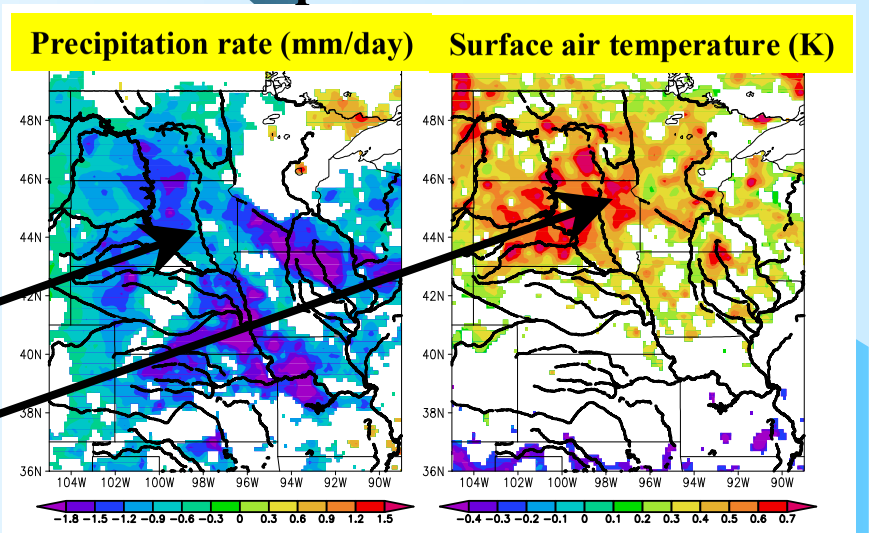
Hot

Dry

Hot

Wet

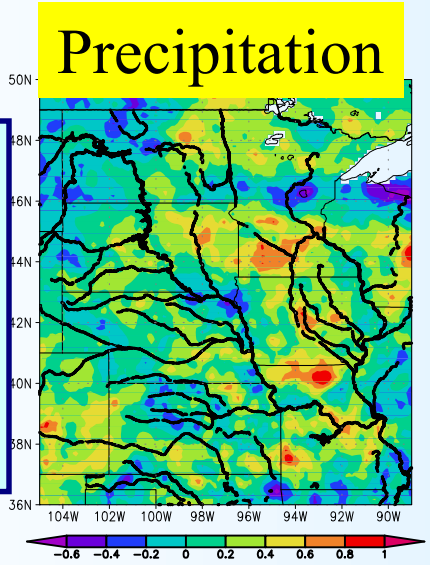
Cool Tropical South Atlantic

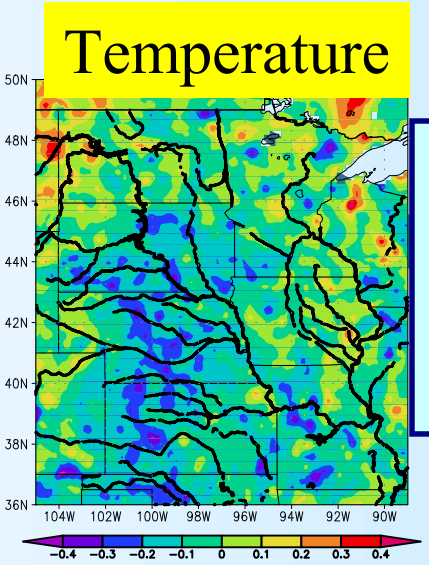


Major impacts of the Pacific Decadal Oscillation and the tropical Atlantic temperature gradient oscillation on precipitation and temperature

Contributions of Tropical Atlantic Temperature Gradient and Pacific Decadal Oscillation to the Missouri River Basin Droughts in 1987-89

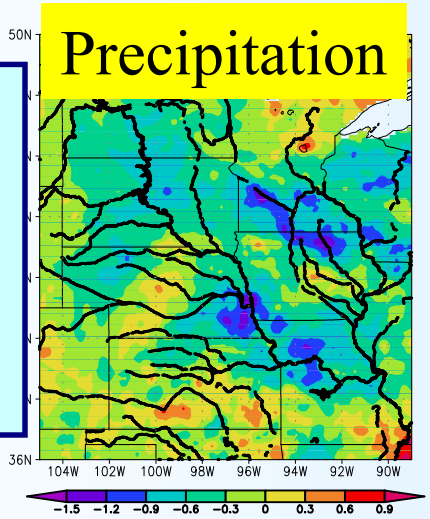
Pacific Decadal Oscillation causes small increase in precipitation in central MRB and small decrease in north and south MRB.

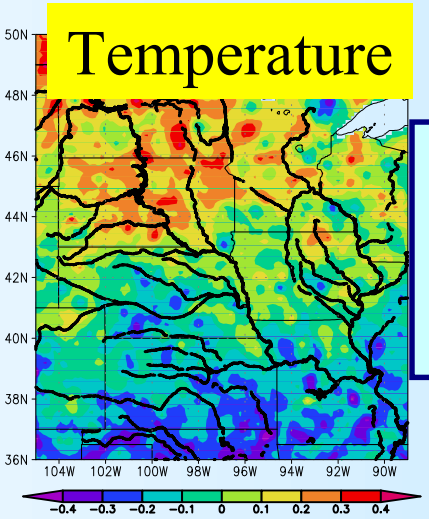




Pacific Decadal Oscillation causes cooling in central MRB and warming in north and south MRB.

Tropical Atlantic Gradient causes large decrease in precipitation in central MRB and small increase in north and south MRB.

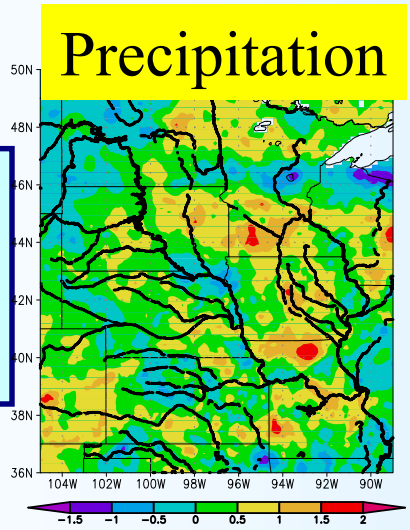


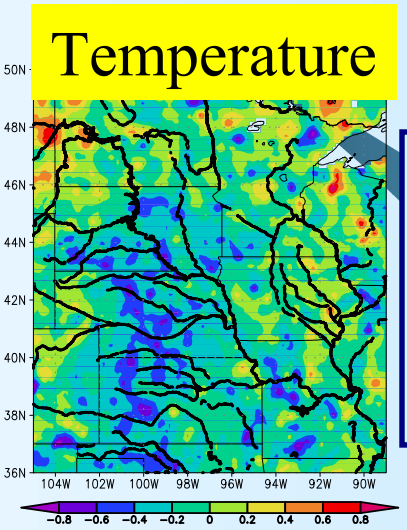


Tropical Atlantic Gradient causes warming in north MRB and cooling in south MRB.

Contributions of Tropical Atlantic Temperature Gradient and Pacific Decadal Oscillation to the Missouri River Basin Floods in the mid-1990s

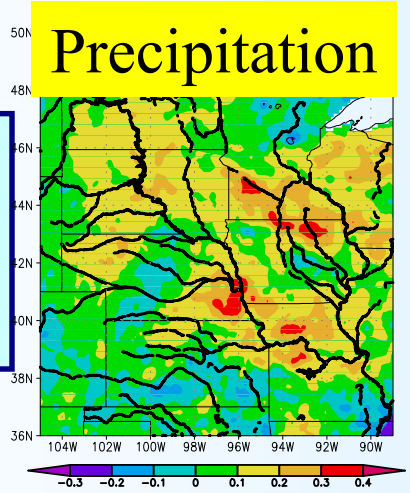
Pacific Decadal Oscillation causes large increase in precipitation in MRB.

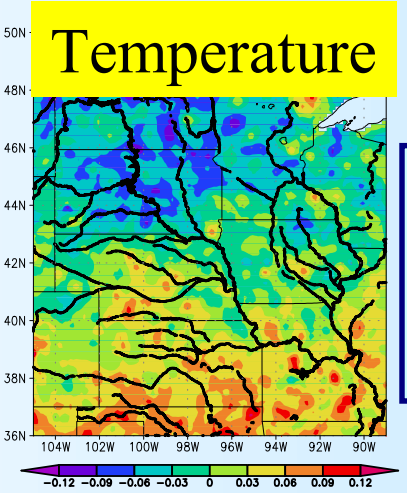




Pacific Decadal Oscillation causes cooling in central MRB and warming in north and south MRB.

Tropical Atlantic Gradient causes small increase in precipitation in MRB.





Tropical Atlantic Gradient causes cooling in north MRB and warming in south MRB.

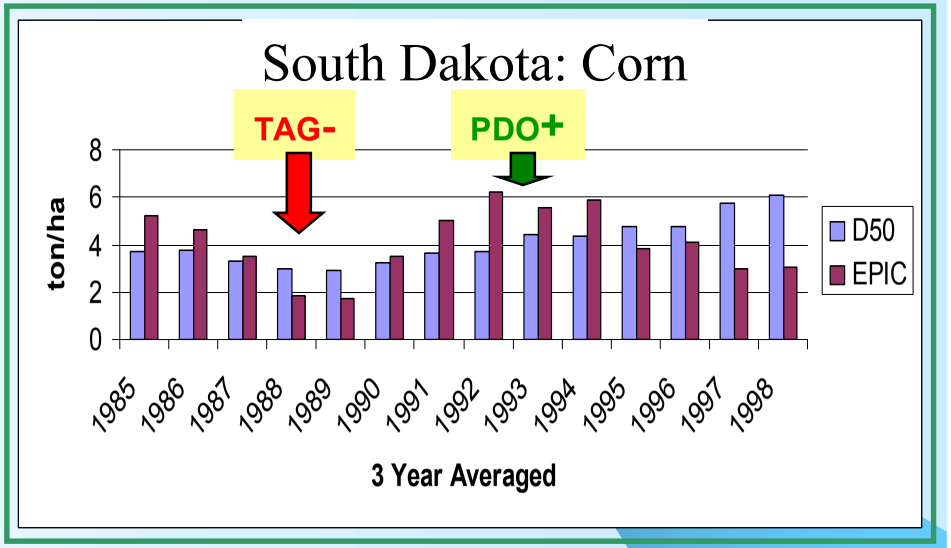
Environmental Policy Integrated Climate (EPIC)

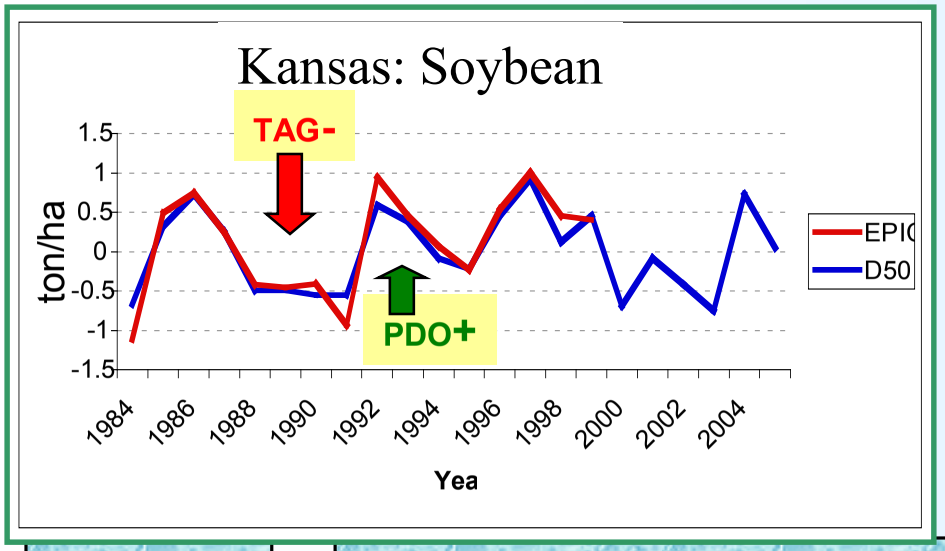
(Erosion Productivity-Impacts Calculator)
(Williams et al., 1983)

- A field-scale crop model developed to assess the effects of soil erosion, economic factors, hydrologic patterns, weather/climate effects, plant growth dynamics, crop management, and nutrients on agricultural productivity and water quality.
- Used widely for the study of impacts of global climate change on water and agriculture.
- Major components include weather generation, hydrology, erosion-sedimentation, nutrient cycling, pesticide impact, plant growth, soil temperature, tillage, economics, and plant environment control.
- Predicts plant biomass by simulating carbon fixation by photosynthesis, maintenance respiration, and growth respiration.
- Uses the concept of light-use efficiency as a function of photosynthetically active radiation (PAR) to predict biomass.
- Crop management explicitly incorporated into the model.

Examples of Actual and Simulated Crop Yield Deviations

Three-year running-average of actual (NASS) and simulated crop yields agree reasonably well and show that yield difference between DCV extrema can be as much as 40-50% of average yield.





There is no single DCV "smoking gun" responsible for decadal crop yield variations in the MRB. TAG, PDO, and IPWP variability are all responsible.

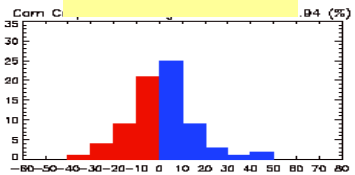
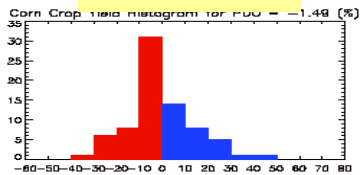
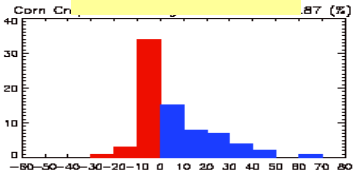
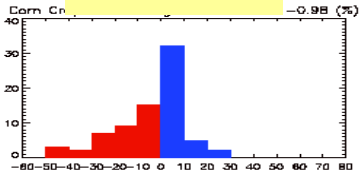
Impacts of DCV Phenomena on Missouri River Basin Hydro-meteorology and Corn Yields

PDO Impact on Corn Yield

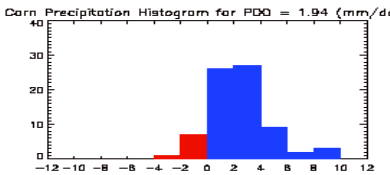
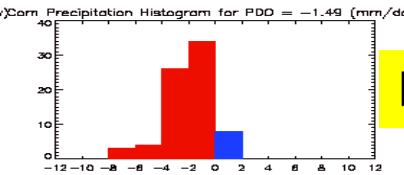
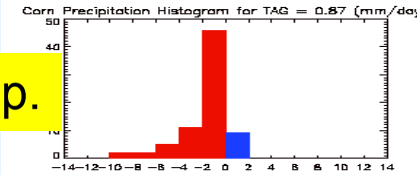
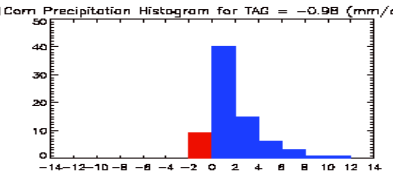
TAG Impact on Corn Yield

PDO +ve | PDO -ve | TAG +ve | TAG -ve

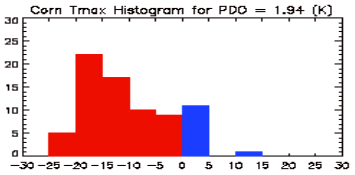
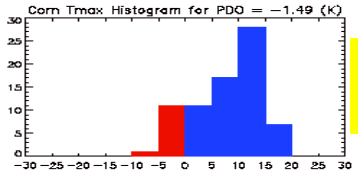
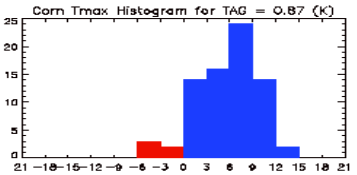
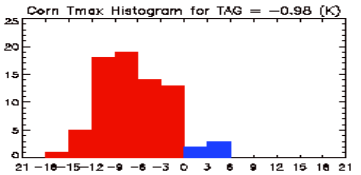
Yield

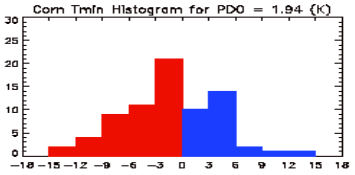
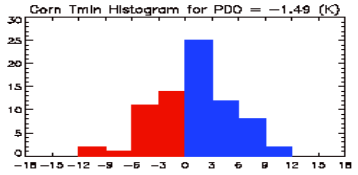
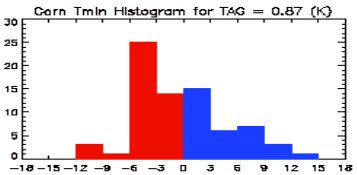
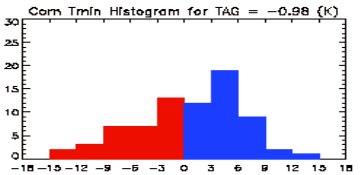
Precip.

T_{max}

T_{min}

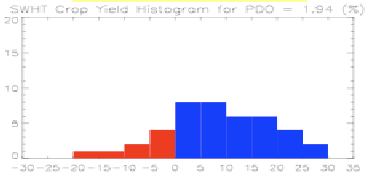
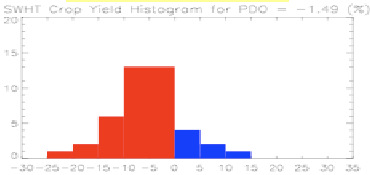
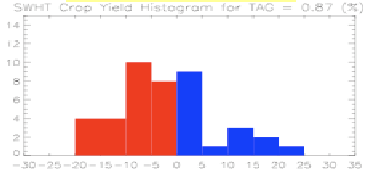
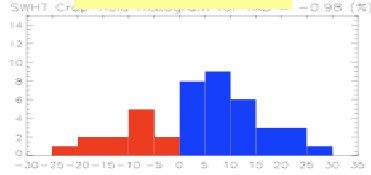
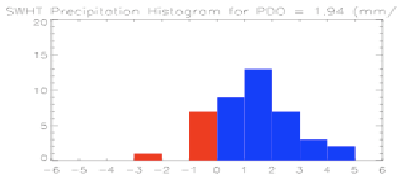
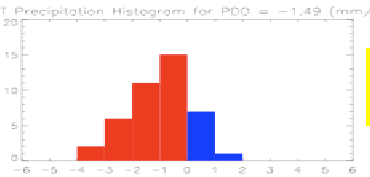
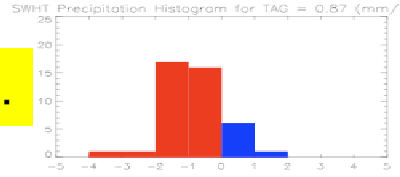
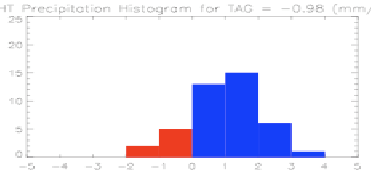
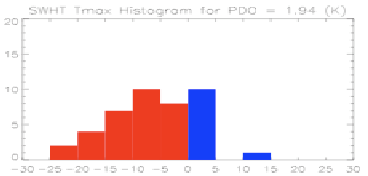
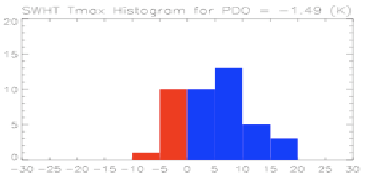
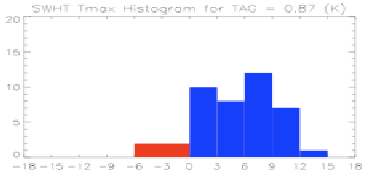
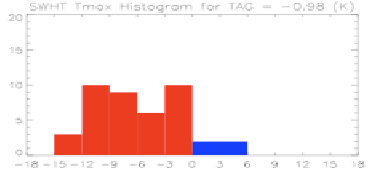
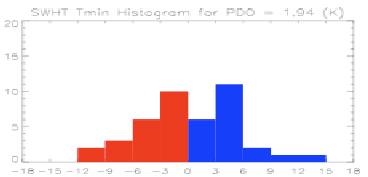
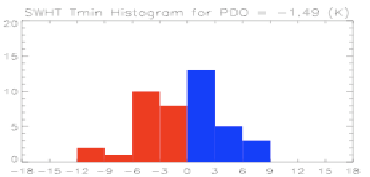
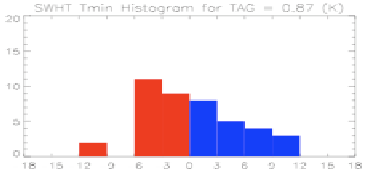
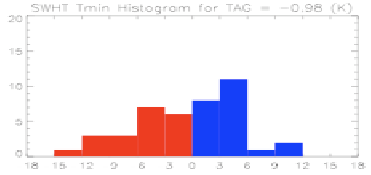





Substantial impacts of 50-year maximum and minimum PDO and TAG indices on MRB hydro-meteorology and corn yields

Impacts of DCV Phenomena on Missouri River Basin Hydro-meteorology and Spring Wheat Yields

PDO Impact on Wheat Yield

TAG Impact on Wheat Yield

PDO +ve	PDO -ve		TAG +ve	TAG -ve
		Yield		
		Precip.		
		T_{max}		
		T_{min}		

Substantial impacts of 50-year maximum and minimum PDO and TAG indices on MRB hydro-meteorology and wheat yields

Summary

- Global food security precarious due to increasing population, increasing food consumption, stagnant or falling production, and low buffer stocks
- History of multiyear to decadal droughts and floods in many food-producing and -consuming regions of the world
- Potentially devastating impacts of simultaneous, decadal climate variability-related droughts/floods in major food-producing and -consuming regions
- Very important and urgent to assess impacts of decadal climate variability on global food security; and develop models and methodologies for multiyear to decadal prediction of possible climate impacts on global food security

Summary

- Instrument-based records in the last 100 years (and tree-ring records in the last ~1000 years) show decadal variability of area covered by droughts in the Missouri River Basin (MRB).
- Significant impacts of decadal climate variability (DCV) phenomena on MRB hydro-meteorology, especially on summer precipitation, surface air temperature, and stream flow.
- Possible to simulate impacts of DCV phenomena on crop yields in the MRB; Prediction of DCV impacts on crop yields may be possible if evolution of these phenomena can be predicted.

Summary

- Can climate science help in ensuring water and food securities for society in response to the evolving climate? Yes, but much more research required on understanding, prediction and impacts assessment.
- By integrating water resource availability with crop water demand, regions and crops that are most sensitive to DCV can be identified; Help to target adaptation efforts to the most vulnerable regions and sectors.
- Stake-holders and policy-makers must be involved in assessment of DCV impacts, and must be trained to interpret climate outlooks and predictions.
- Investment of necessary resources needed in this effort. Because of rapidly declining government research budgets, funding by private sector, Foundations, and philanthropic individuals needed to realize potential of predicting DCV impacts on water and agriculture. **Compared to likely returns, this investment is trivial.**

Thank you!!

India needs food, feed, and fiber,…

- 16% of the world's population in India on 2.4% of the world's land
- Agriculture contributes 24% of GDP
- Agriculture supports at least 2/3 of the population
- Nearly 80% of total cultivated area dependent on rainfall
- Irrigation from reservoirs and rivers dependent on rainfall
- Significant decrease in summer monsoon rain decreases kharif production
- 49% decrease in July 2003 rainfall, kharif production fell by 19% and agricultural GDP by 3.1%

…but the situation is worsening…

- Agricultural production stagnating, population increasing, food consumption patterns changing
- Necessary to import food grains and pulses to maintain buffer stocks
- Food insecurity a major limiting factor on economic growth and potentially a major cause of socio-economic and political instability unless agricultural production increases to keep pace with demand

..and is a high-priority area in the 11th Plan;…

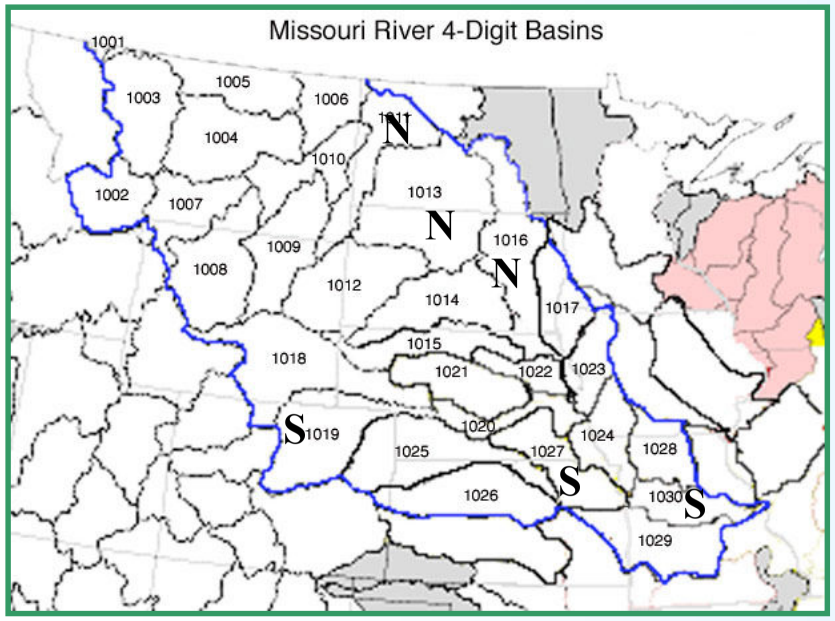
- The Central Government's approach to the 11th Plan for the 2007-2012 period identifies tackling agricultural crisis as a major challenge facing India
- Decelerating growth in agriculture identified as the root cause of rural distress
- Increasing uncertainty about weather and climate among causes of growth deceleration

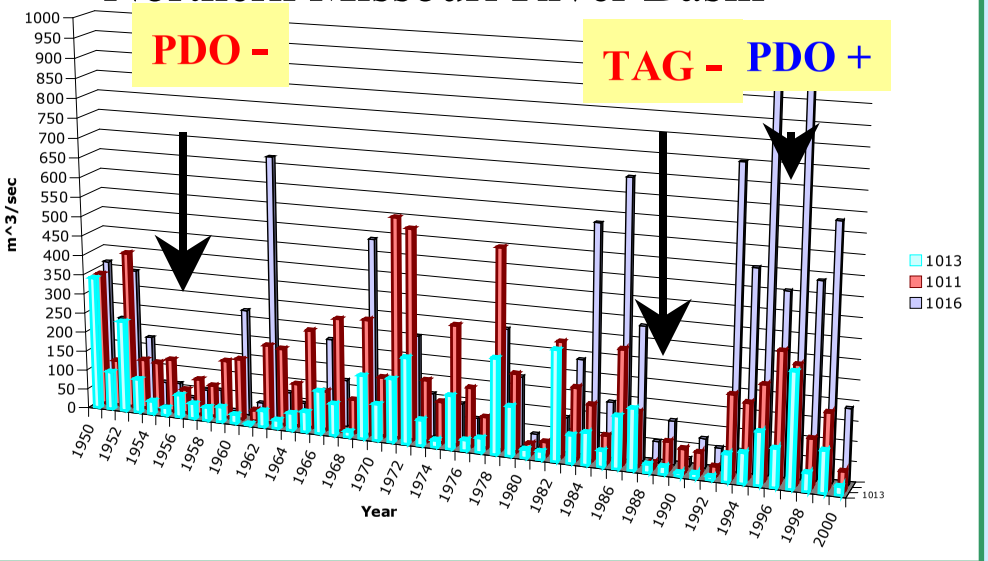
Increasing Human Population…

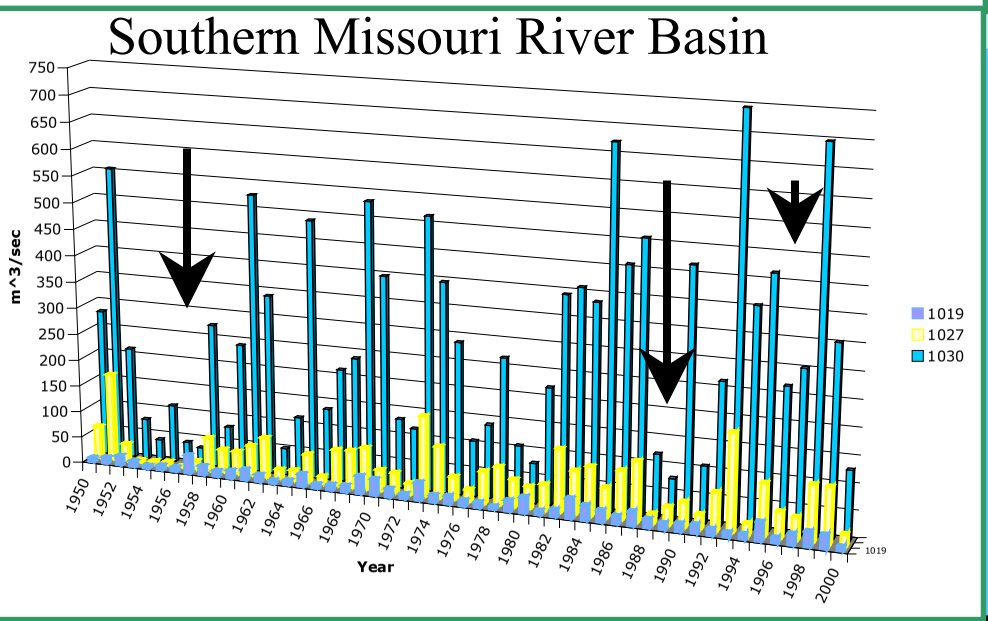
12000 years ago:	10 million
From the beginning of the Christian era to the eighteenth century:	First billion
Next 100 years:	Second billion
Next 30 years (1961-63 to 1990-92):	2.1 to 4.1 billions
Middle of 21st century:	11 billions
Future world population growth:	73 million/year, 7.5 billion in 2020

Association between Decadal Climate Cycles and the Missouri River Basin USGS Gauged Streamflow (1950-2000)

Impacts of extrema of PDO and TAG combine to create multiyear to decadal droughts and floods in the MRB.







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