High-resolution Simulations of Decadal Climate Variability Impacts on Water and Crop Yields in the Missouri River Basin with the Soil and Water Assessment Tool (SWAT)

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- Introduction
- Importance of the Missouri River Basin (MRB)
- Decadal Climate Variability (DCV), Water, and Agriculture
- Simulation of DCV Impacts on Water and Crop Yields in the MRB
- Summary

The Project Team

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Water – Food – Energy – Public Health Securities

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Water is the determinant of societal wealth and health.

Why is decadal hydrologic variability important?

- Crop Production; Pasture and Range Conditions
- Rural and Urban Water Systems
- Livestock Production and Health
- Hydro-, Thermal-, and Nuclear-Electricity Generation; River Navigation; Aquatic Recreation
- Infrastructure
- Natural and Managed Eco-systems
- Local, Regional, and National Economies

Why is decadal hydrologic variability important?

⊙ Dramatic effects of multiyear to decadal droughts, resulting in billions of dollars in crop losses around the world annually.

⊙ Stresses due to drought contribute to social and political strife, civil wars, and international conflicts.

⊙ Planning for water, food, and energy would benefit greatly from reliable information on prospects for wet and dry periods two or more decades into the future.

Overarching Objective

To develop an 'end-to-end', decadal climate and impacts prediction system, and adaptive water and agriculture management system, using the Missouri River Basin as a case study

Summary of this project

Climate Prediction

↓

Climate Data Localizing and Scenario Development

↓

Water and Crop Yields Simulation and Prediction

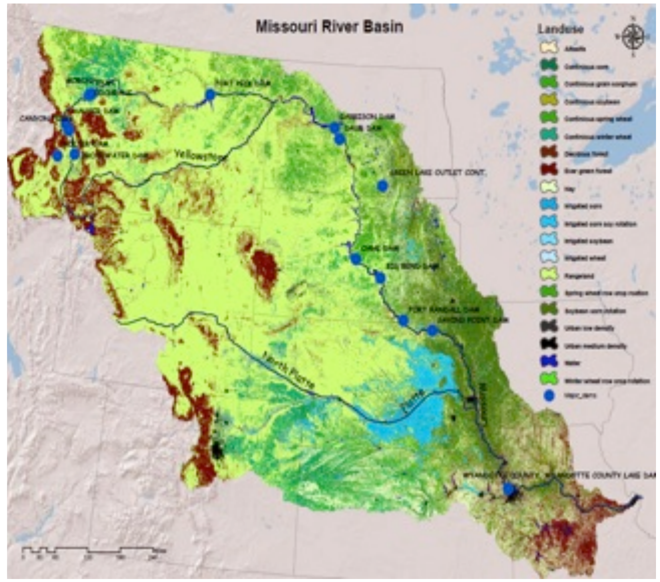
↓

Impacts on Agricultural Economy

↓

Use of Climate Information in Water and Agriculture Management

Decadal Climate and Impacts Information for Decision Support in the Missouri River Basin



A system also adaptable to other river basins

DCV phenomena
↓
Influences on Basin hydro-meteorology
↓
Influences on Agriculture Urban water Industries Navigation Recreation Others
→
Rural and urban economies; Local, regional, national, international economies
→
Adaptation strategies via understanding, prediction, and scenario development
→
Data, information, and decision-support systems
→
Active involvement of stakeholders and policymakers
↑
Applications In various sectors

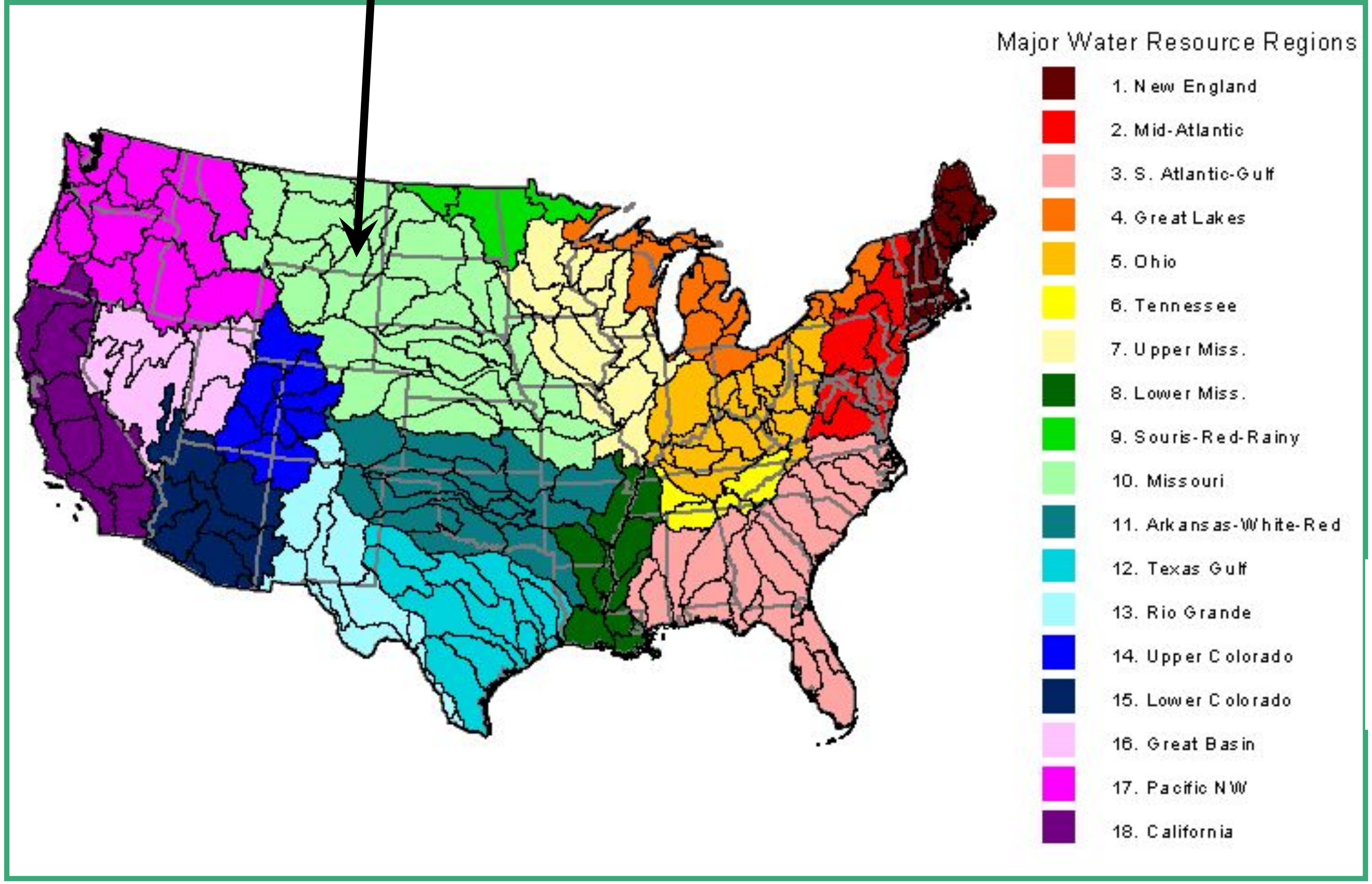
Importance of the Missouri River Basin

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, many Native American reservations, parts of Alberta and Saskatchewan



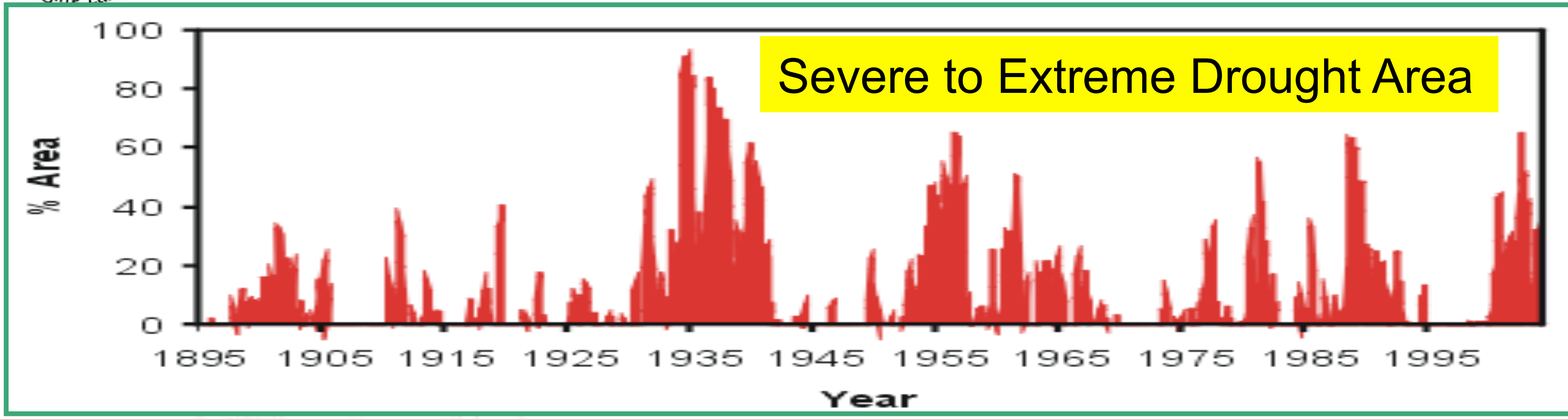
Value of crops and livestock over $100 billion per year

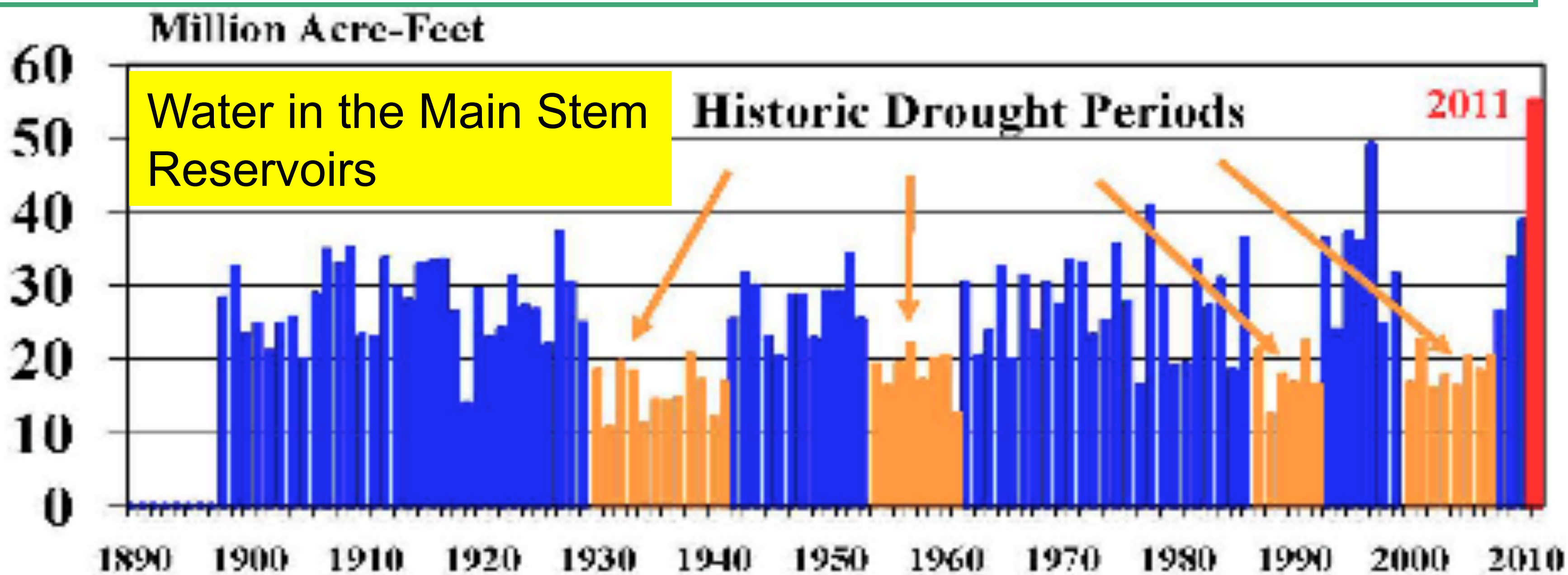
117 million acres cropland, only 12 million acres irrigated

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

Droughts and Water in the Main Stem Reservoirs

(Lower figure: courtesy Kevin Grody, USACE)





Decadal Climate Variability (DCV)

What is DCV?

- Climate "cycles"with ~8-20 years periods
- Seen in long-term ocean, land,and atmosphere observations
- Main causes: Ocean-atmosphere interactions, land-atmosphere interactions, solar variability

Major DCV Phenomena

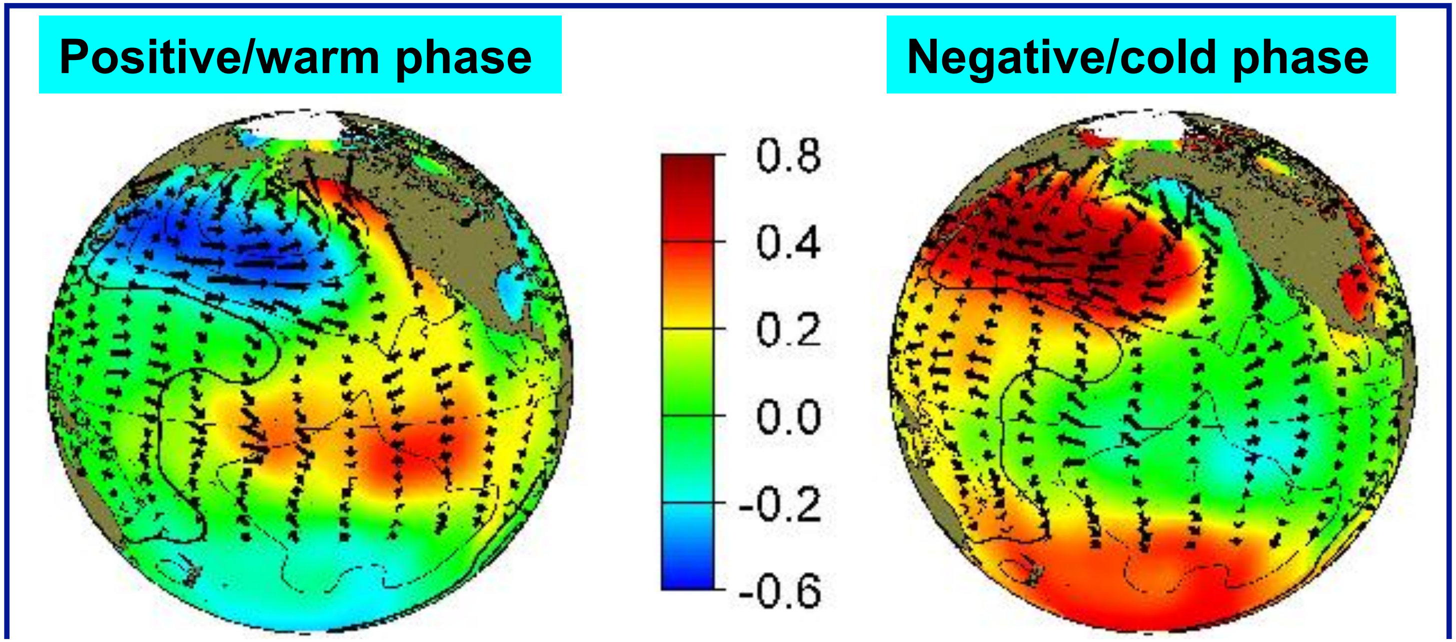
- Pacific Decadal Oscillation (PDO)
- Trop. Atlantic sea-surface temperature (SST) gradient oscillation (TAG)
- West Pacific Warm Pool oscillation (WPWP)
- Decadal variability of ENSO

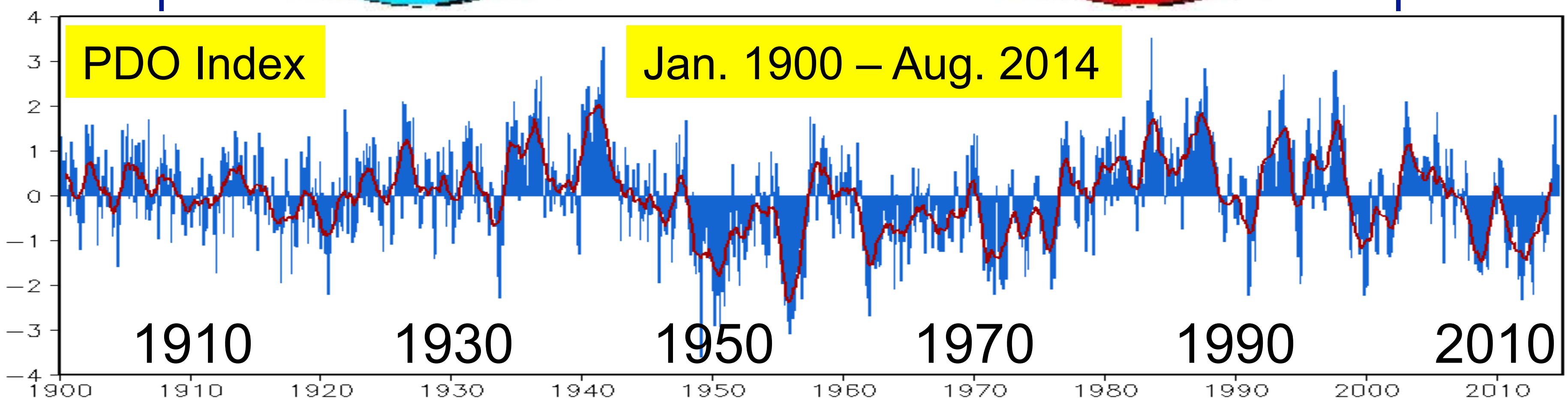
Sources of potential multiyear to decadal climate predictability

Pacific Decadal Oscillation

From: Nathan Mantua, Stephen Hare
Univ. of Washington

Anomalous sea-surface temperature patterns





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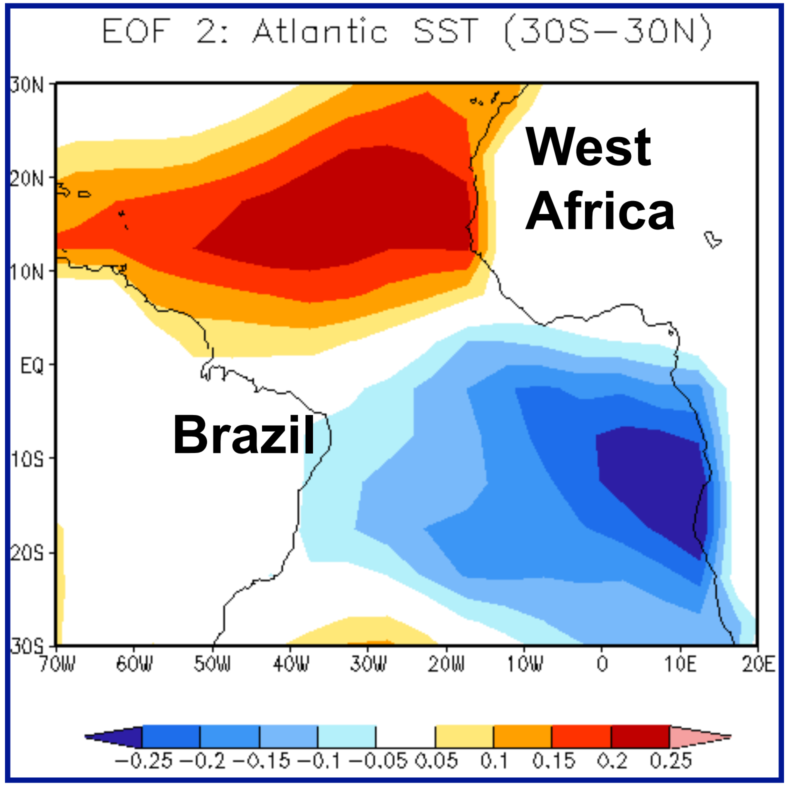
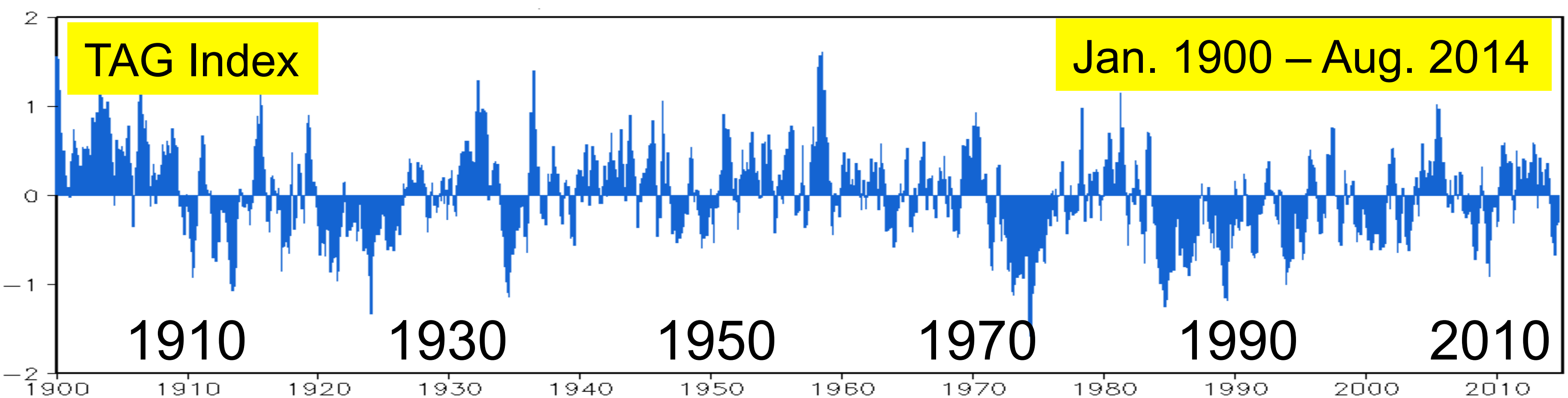
Tropical Atlantic sea-surface temperature gradient (TAG) variability

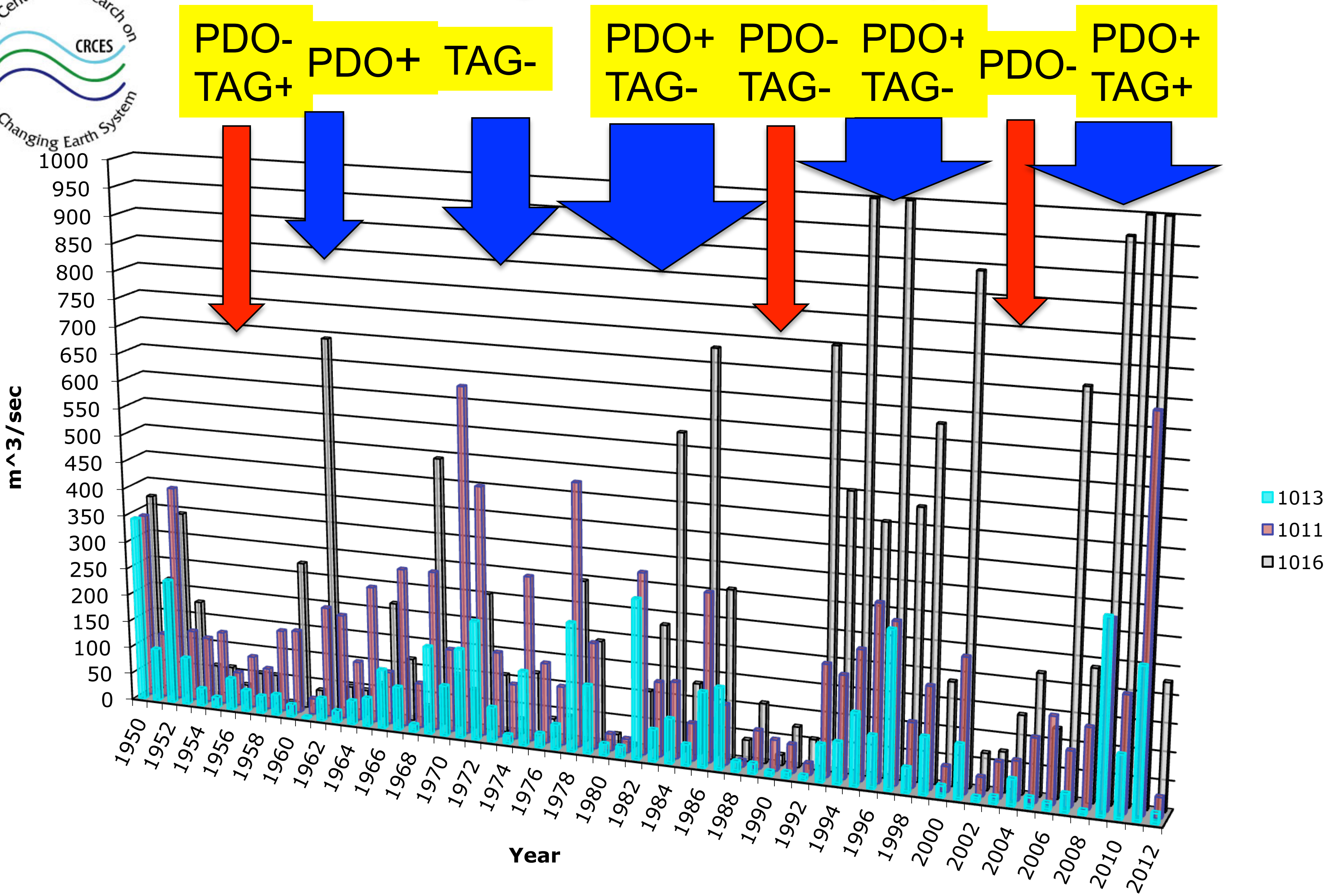
TAG Index: SSTA difference between (60°W–30°W, 5°N–20°N) and (30°W–10°E, 20°S–Equator)



TAG positive state



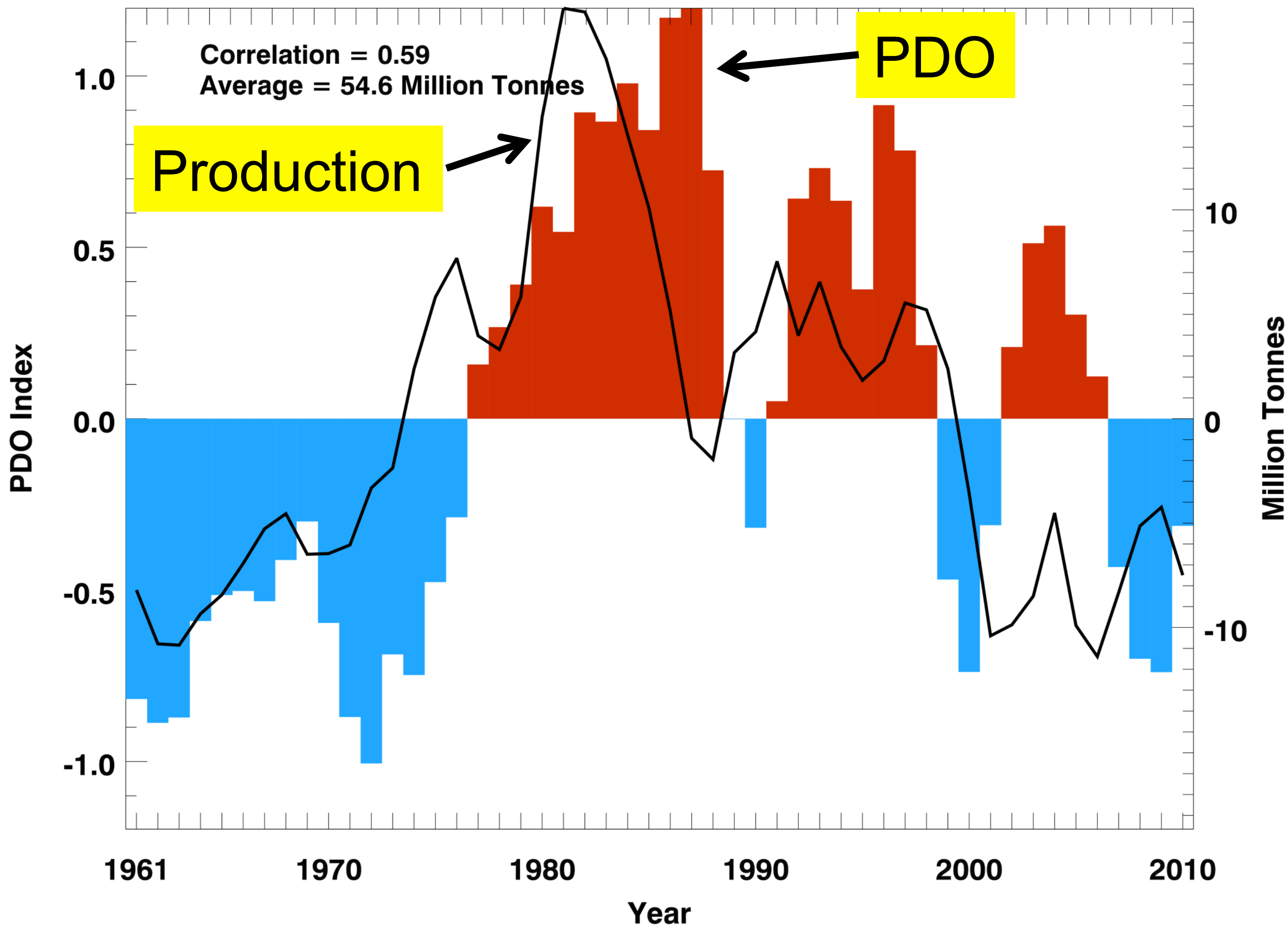
MRB USGS Gauged Streamflow (1950-2012)



The Pacific Decadal Oscillation and U.S. Wheat Production

Annual production data from the FAO

Wheat production decreases significantly during multiyear droughts associated with negative PDO phase



Simulations and predictability of water and crop yields with high-resolution version of the Soil and Water Assessment Tool (SWAT)

SWAT attributes

- Watershed characterization
- Sub-watersheds and streams
- Land use – land cover at 30 m resolution, crop rotation and irrigation
- Irrigated land and soil data
- Precipitation, temperature, winds, solar radiation data at 12 km x 12 km

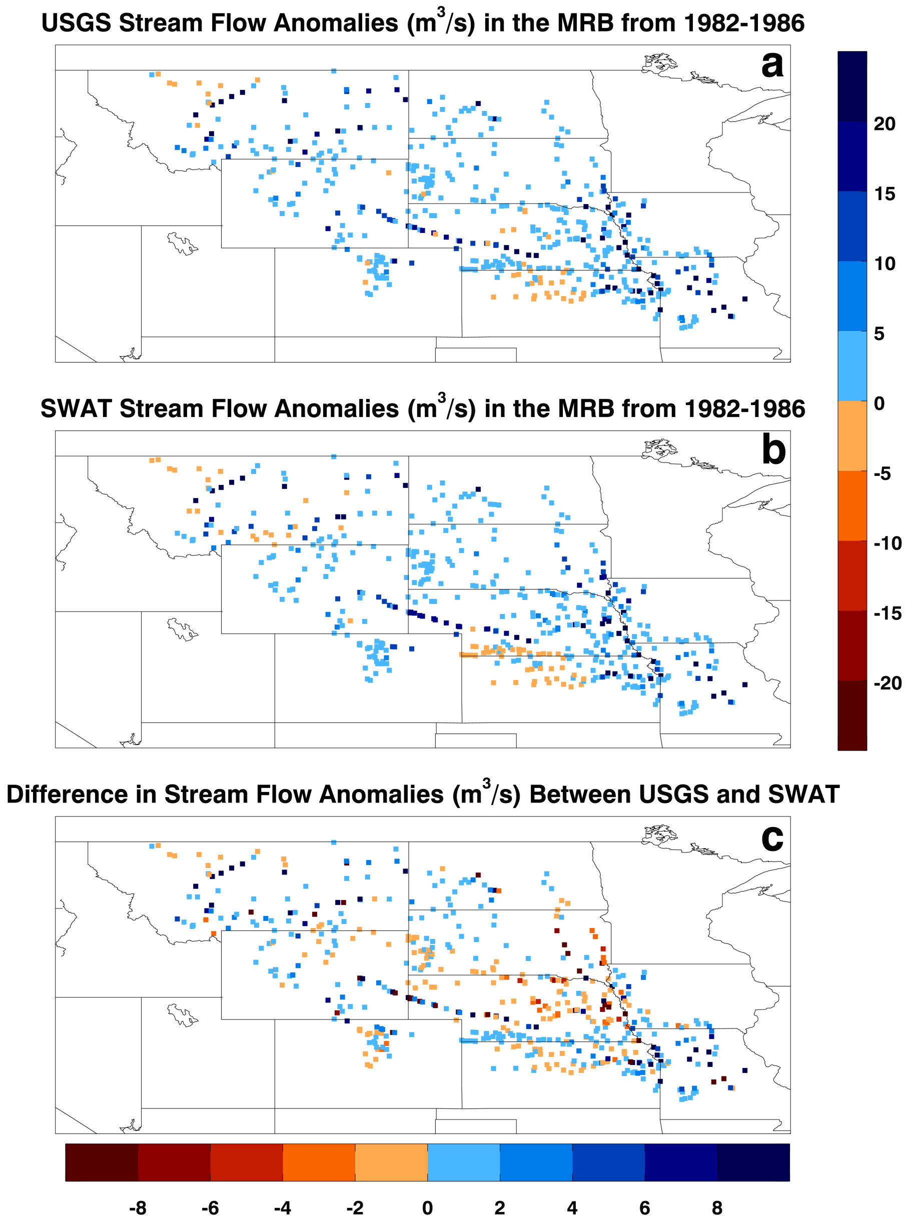
- Crop yield calibration
  - Crops evaluated: Winter and spring wheat, corn (dryland and irrigated), soybean (dryland and irrigated)
  - Observed and SWAT simulated crop yields agree well
- Water yield (total surface and base flow) calibration

Annual-average daily streamflow anomalies (m^3/s) in the Missouri River Basin from 1982 to 1986 (wet)

Observed USGS estimate

Simulated SWAT estimate

Difference



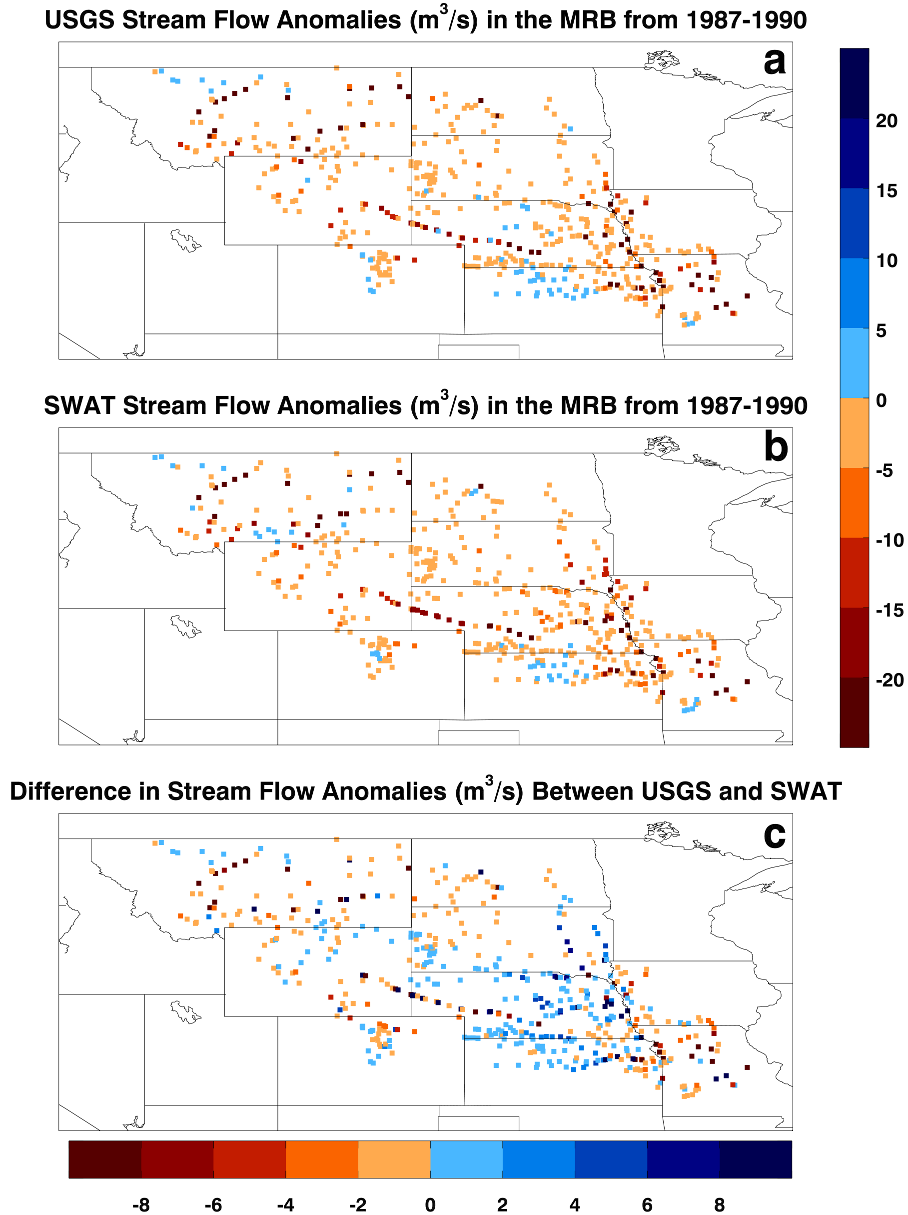
- SWAT driven by daily observed precip., max. and min. temperatures, winds and humidity
- Reasonably accurate simulation of multi-year wet period

Annual-average daily streamflow anomalies (m^3/s) in the Missouri River Basin from 1987 to 1990 (dry)

Observed USGS estimate

Simulated SWAT estimate

Difference

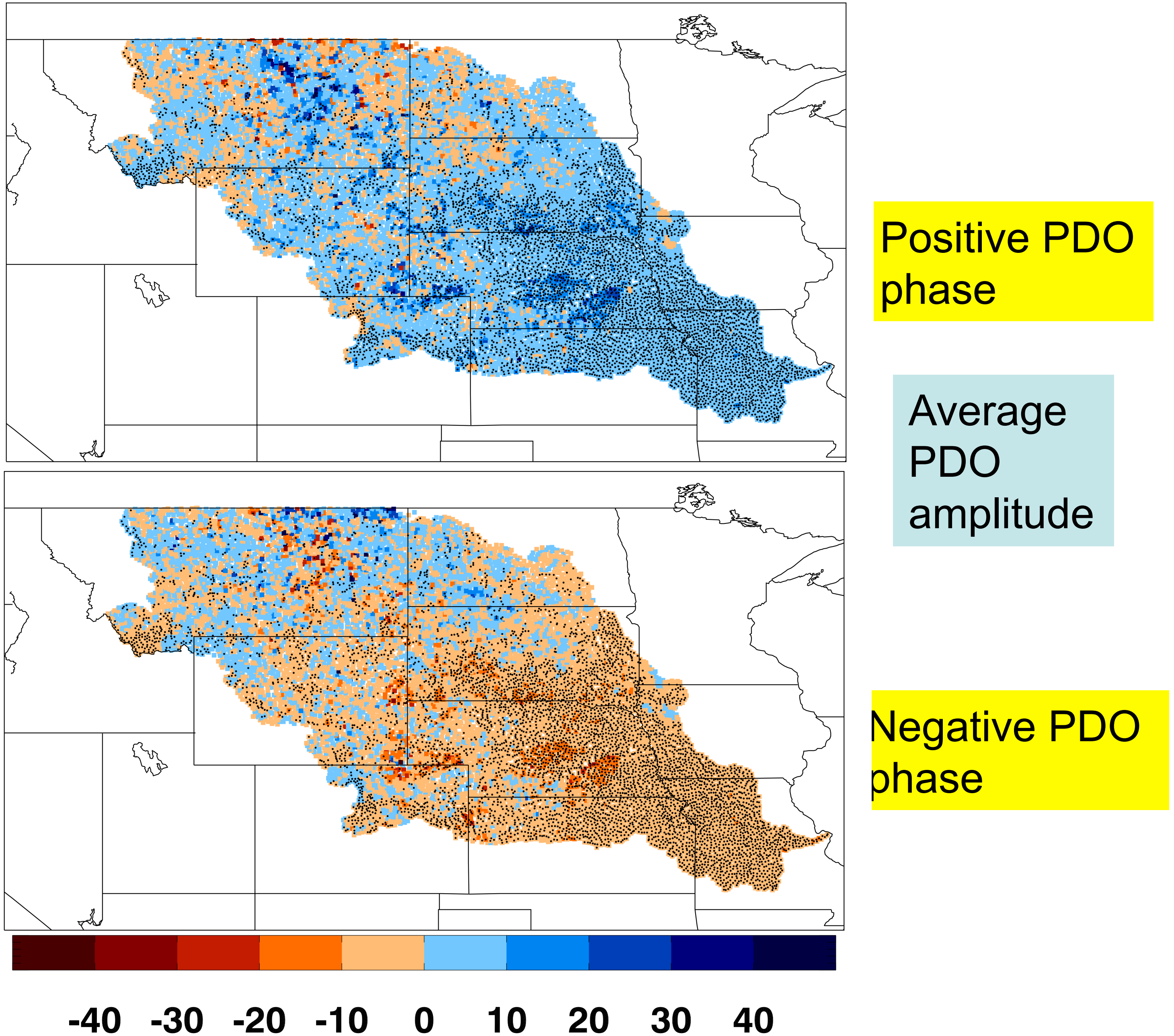


- SWAT driven by daily observed precip., max. and min. temperatures, winds and humidity
- Reasonably accurate simulation of multi-year dry period

SWAT Simulation of PDO Impacts on Water Yield

Idealized scenarios based on observed precip., and max. and min. temp. data

12 km x 12 km resolution



% change from climatology

Sub-basin Aggregated Histograms of Water Yield Changes

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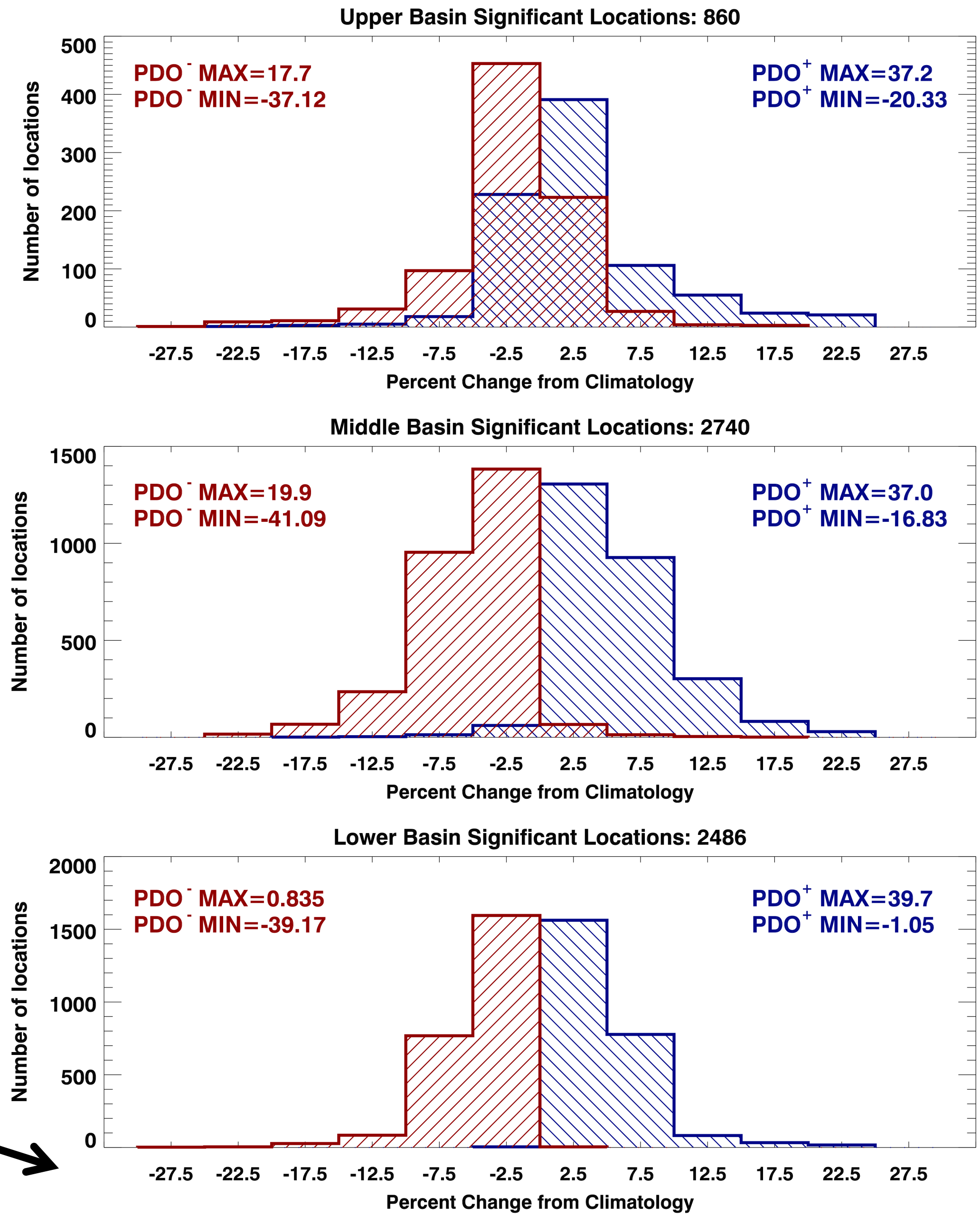
- 10-15% changes in sub-basin aggregated water yield from one phase to the other

- Clean separation between phases in middle and lower sub-basins



Upper Sub-basin

Middle Sub-basin

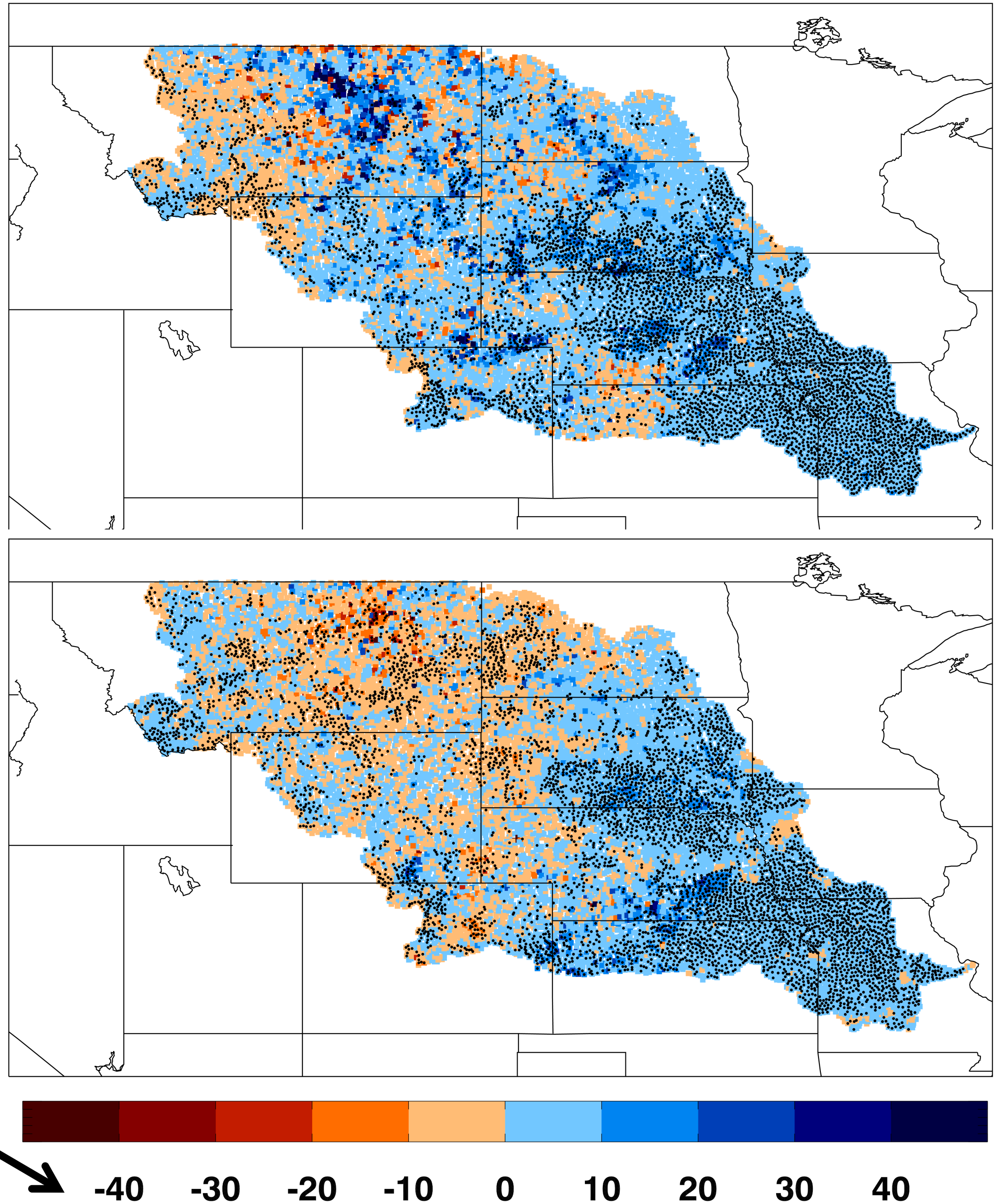
Lower Sub-basin

% change from climatology

SWAT Simulation of PDO and TAG Impacts on Water Yield

Constructive superposition increases water yields

Destructive superposition decreases water yields



Positive PDO and Negative TAG phases

Average PDO and TAG amplitudes

Positive PDO and Positive TAG phases

% change from climatology

SWAT Simulation of DCV Impacts on Spring Wheat Yields

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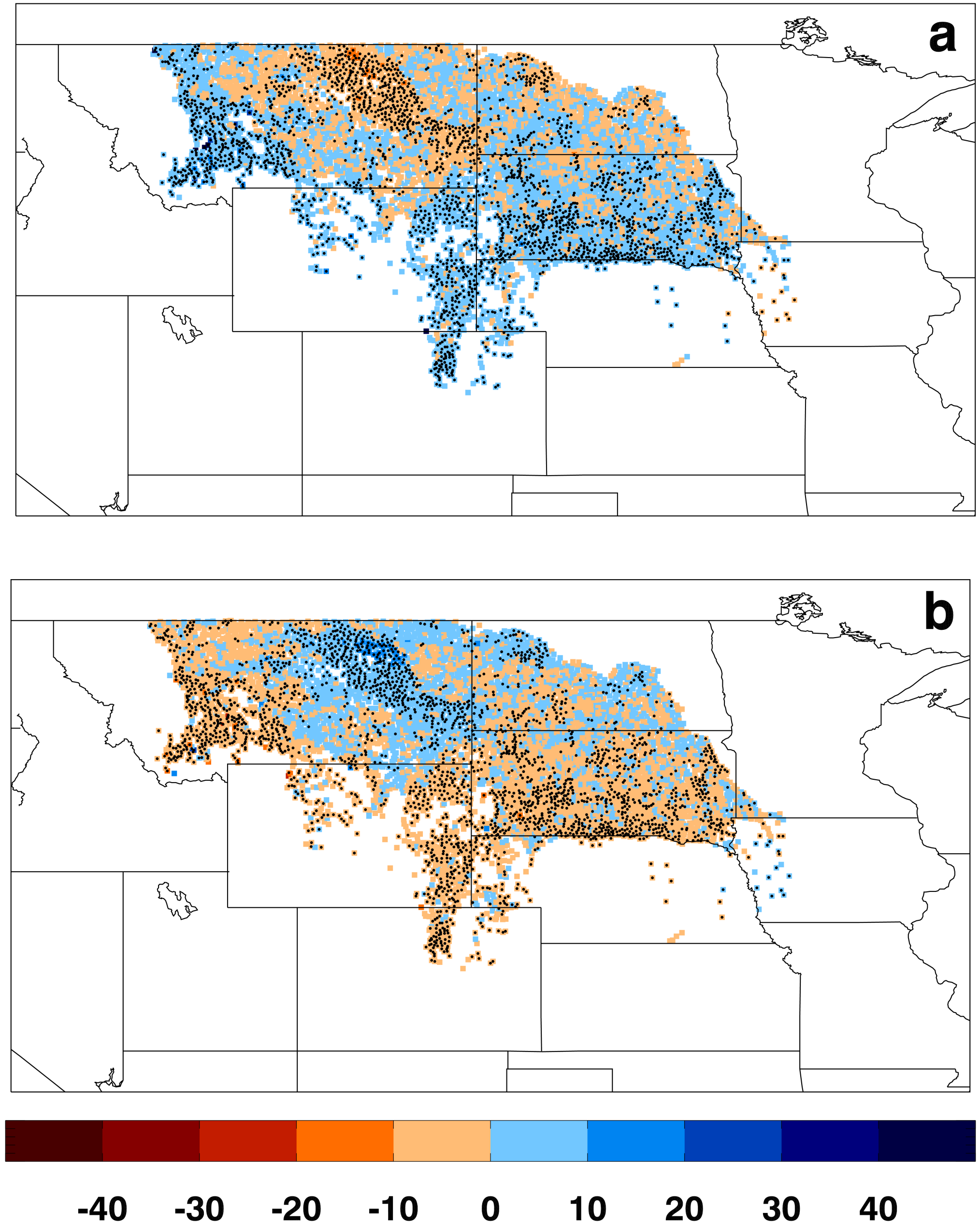
Idealized scenarios based on observed precip., and max. and min. temp. data

12 km x 12 km resolution



Positive PDO phase

Average PDO amplitude

Negative PDO phase

% change from climatology

SWAT Simulation of DCV Impacts on Winter Wheat Yields

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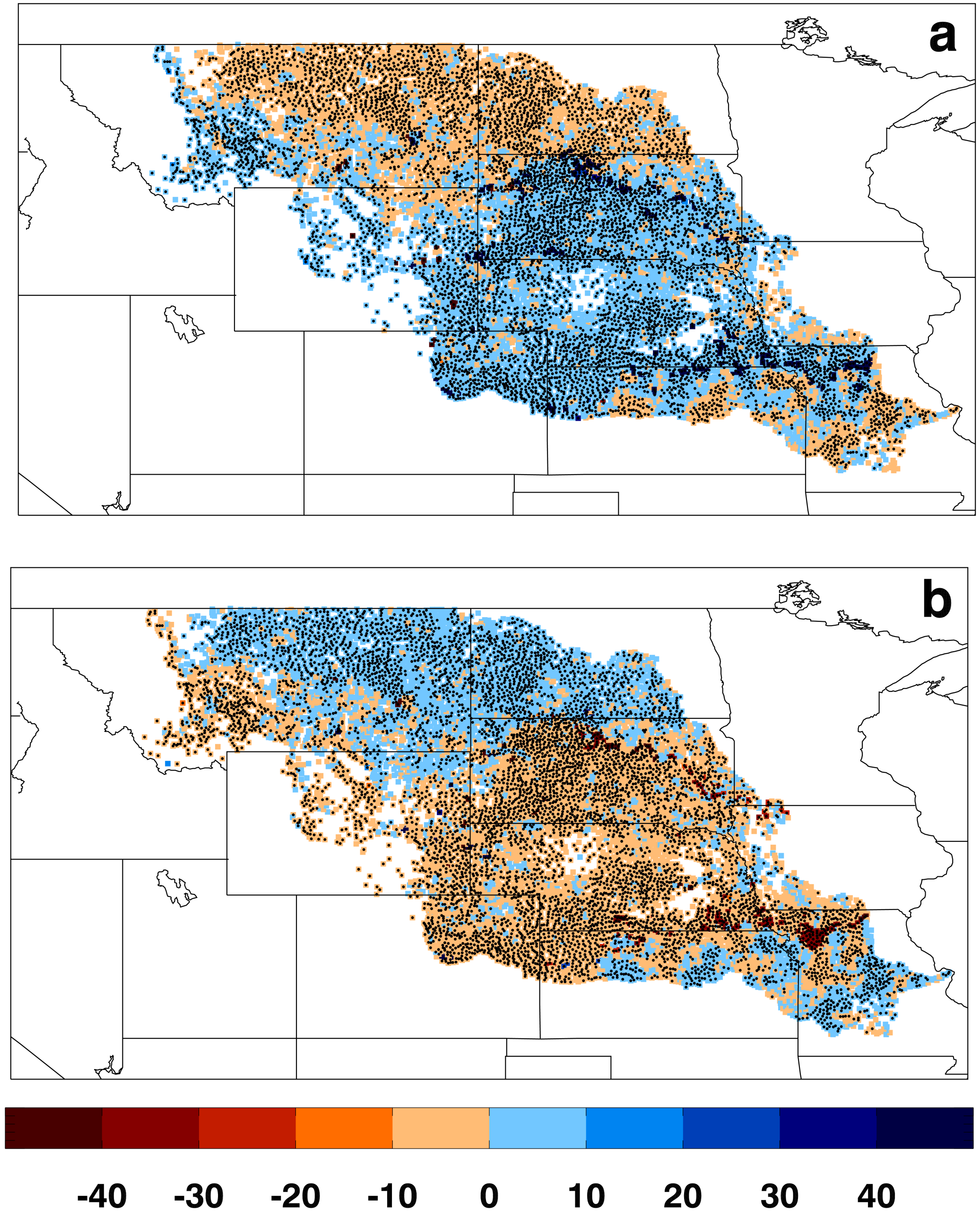
Idealized scenarios based on observed precip., and max. and min. temp. data

12 km x 12 km resolution



Positive PDO phase

Average PDO amplitude

Negative PDO phase

% change from climatology

Correlation coefficients between PDSI-SC and Decadal Climate Variability Indices

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Dry/wet when index positive

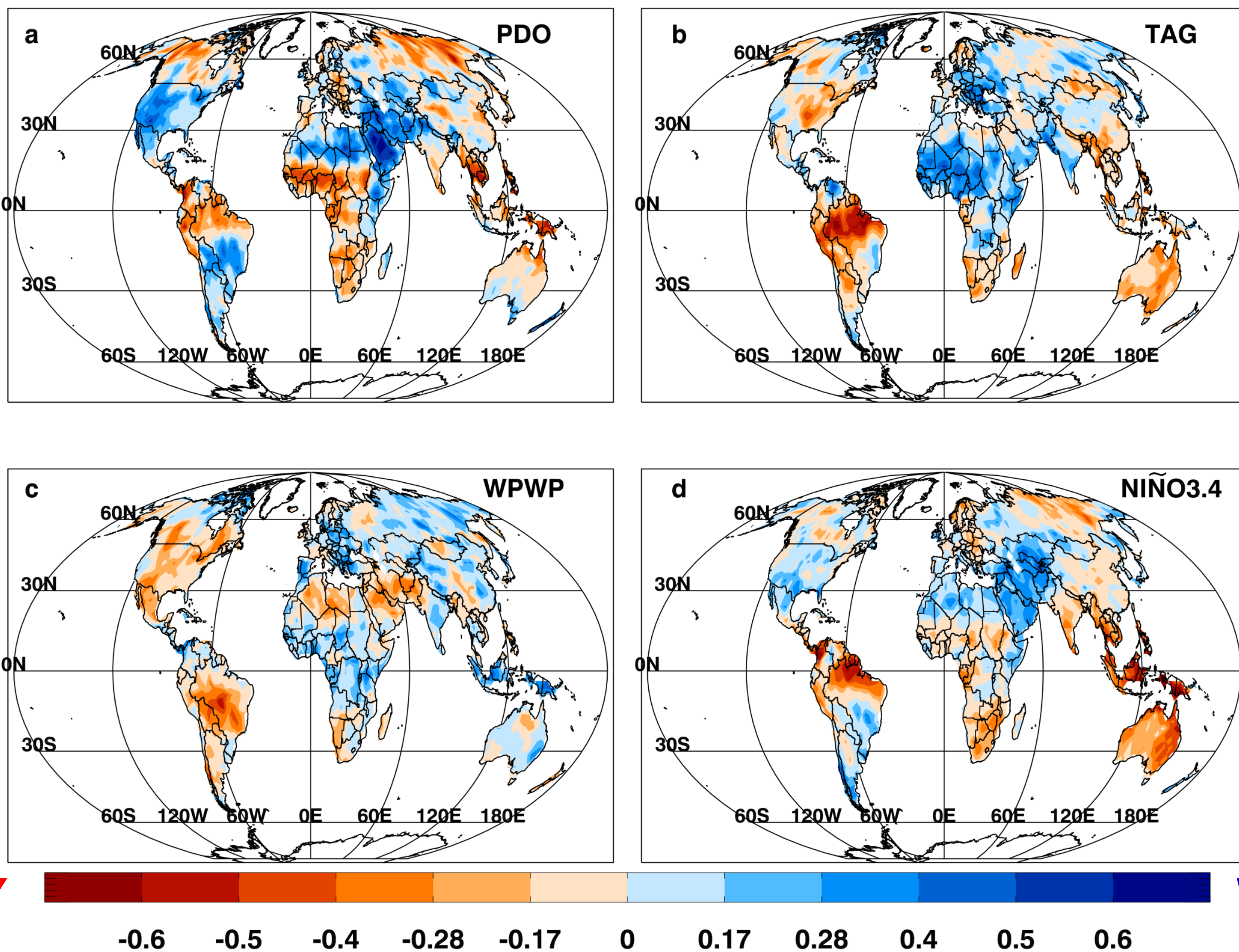
Correlation of Detrended Annual PDSI_sc and ERSST Indices from 1961-2010 Values of +/- 0.28 are 95% Significant

Pacific Decadal Oscill.

Tropical Atlantic SST Variabil.

West Pacific Warm Pool SST Variabil.

El Niño-La Niña SST Variabil.



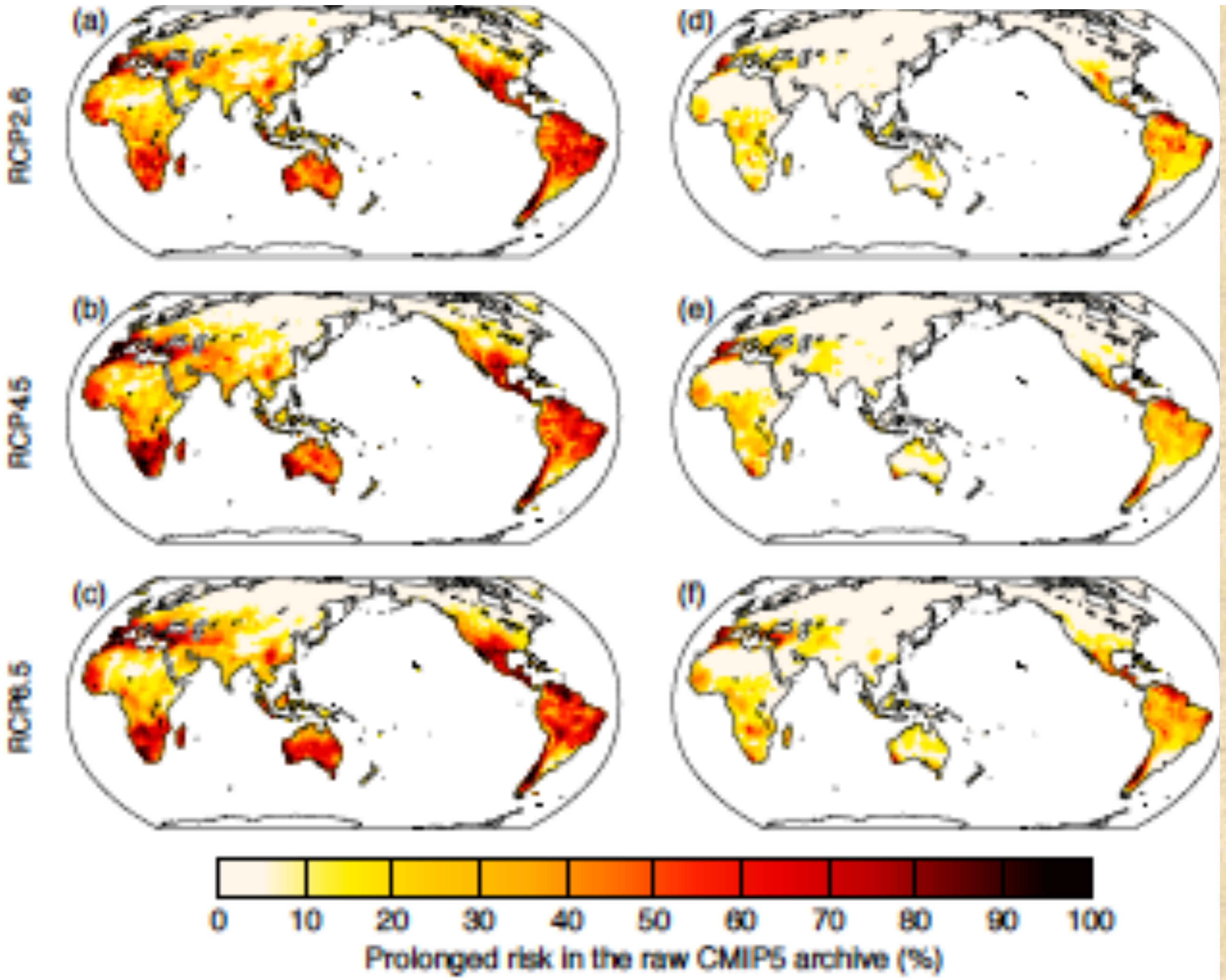
DRY

WET

Risks of Decadal and Multidecadal Droughts in the 21st Century Based on CMIP5 Climate Model Scenarios (From: Ault et al., 2014)

Decadal drought | Multidecadal megadrought

Medium to high-risk areas: Southern and Western Africa, Australia, Southern Asia, South America, Southern North America, Western and Central Europe



Low to medium-risk areas: Southern and Western Africa, Australia, Southern Asia, South America, Southern North America, Western and Central Europe

Summary

- Substantial impacts of DCV phenomena on stream flow, and water and crop yields in the Missouri River Basin
- Stakeholders and policymakers identify DCV impacts from their experience and very interested in getting DCV and impacts information tailored to various sectors
- Fine scale SWAT calibrated and validated; water and crop yield simulation and prediction experiments indicate significant DCV impacts
- Encouraging initial results of end-to-end DCV and impacts predictability studies

Thank you!!

Publications

Mehta, V.M., H. Wang, K. Mendoza, and N.J. Rosenberg, 2014: Predictability and Prediction of Decadal Hydrologic Cycles: A Case Study in Southern Africa. *Weather and Climate Extremes*, **3**, 47-53.

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