

Drought Under Global Warming

Aiguo Dai (戴爱国)

**National Center for Atmospheric Research (NCAR)
Boulder, Colorado, USA**

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Main reference:

Dai, A., 2010: Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, DOI: **10.1002/wcc.81**.

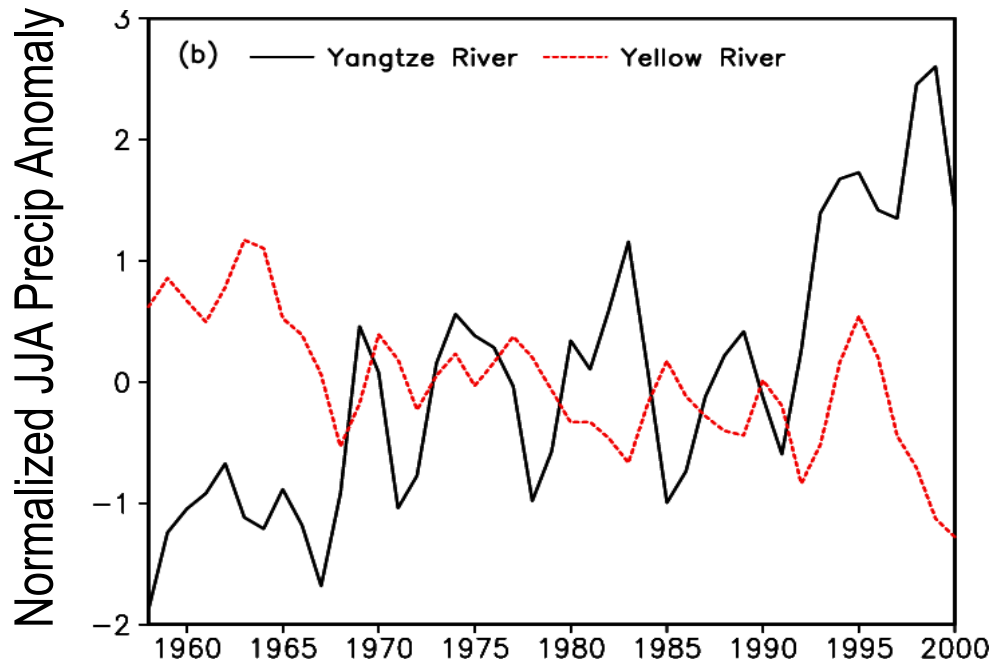
Lake Mead, 2002
Courtesy of Ken Dewey

Outline of the Talk

- A brief introduction on drought
- Regional analysis:
 - drought in China
 - drought in the U.S.
 - African drought
- Global analysis:
 - drought in the 20th century
 - drought in the 21st century

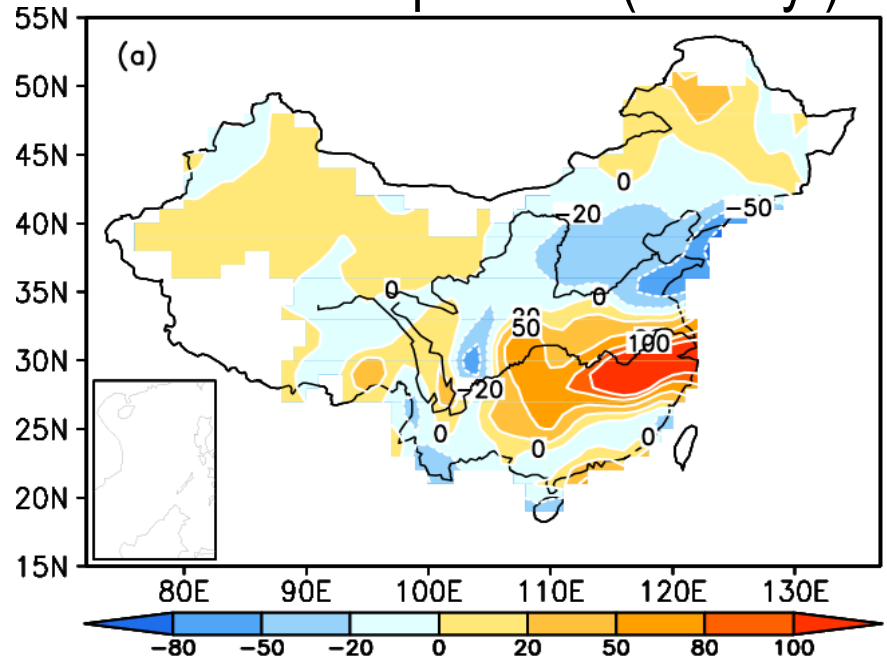
What is Drought?

- **Drought** is a recurring climate event over land characterized by a lack of precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid regions.
- **Three common types of drought:**
 - **Meteorological drought** is a period of months to years with below normal precipitation. It precedes and causes the other types of droughts.
 - **Agricultural drought** is a period of dry soils that result from a lack of precipitation and lead to reduced crop production and plant growth.
 - **Hydrological drought** develops when streamflow and water storages in aquifers, lakes or reservoirs fall below long-term mean levels.



Recent Drying in North China

JJA Precip. Trend (cm/50yr)

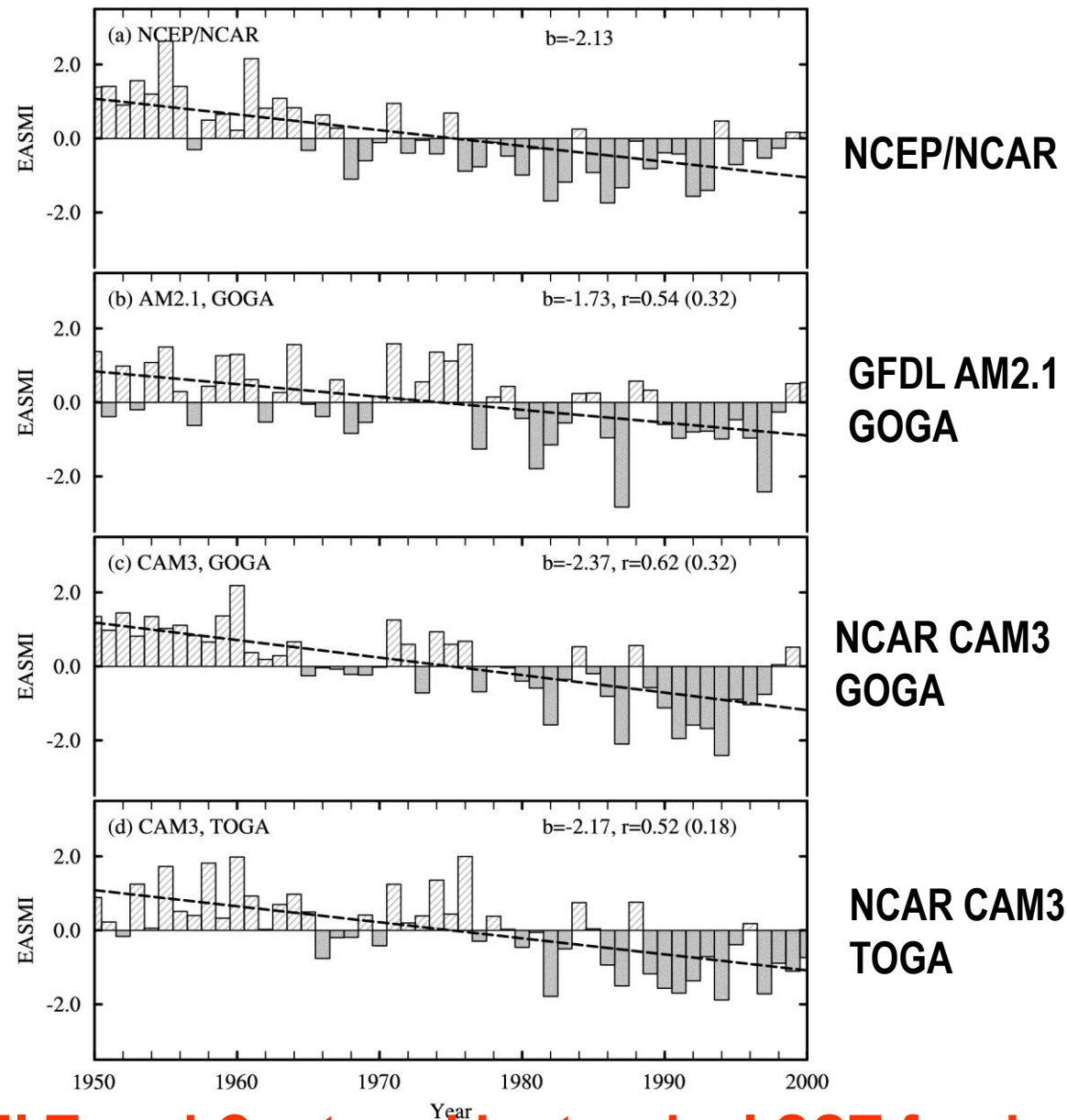


(From Zhou Tianjun)

East Asian Summer Monsoon Index: 1950-2000



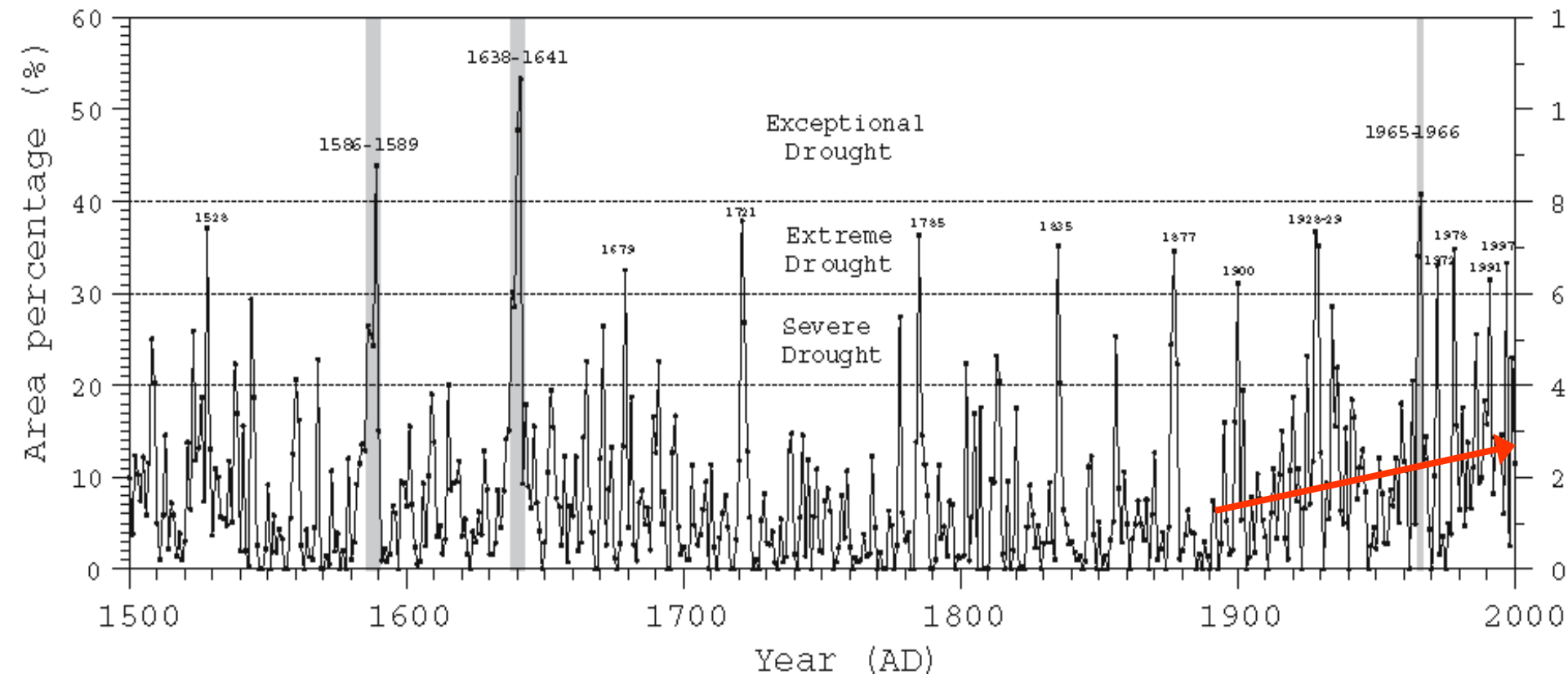
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Li et al. 2010

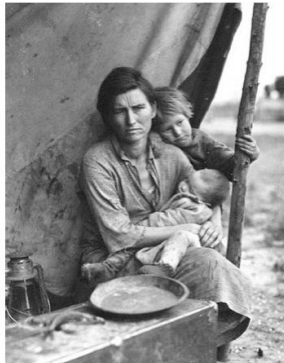
EASMI Trend Captured by tropical SST forcing.

Drought Area over East China: Year 1500-2000



Shen et al. 2007

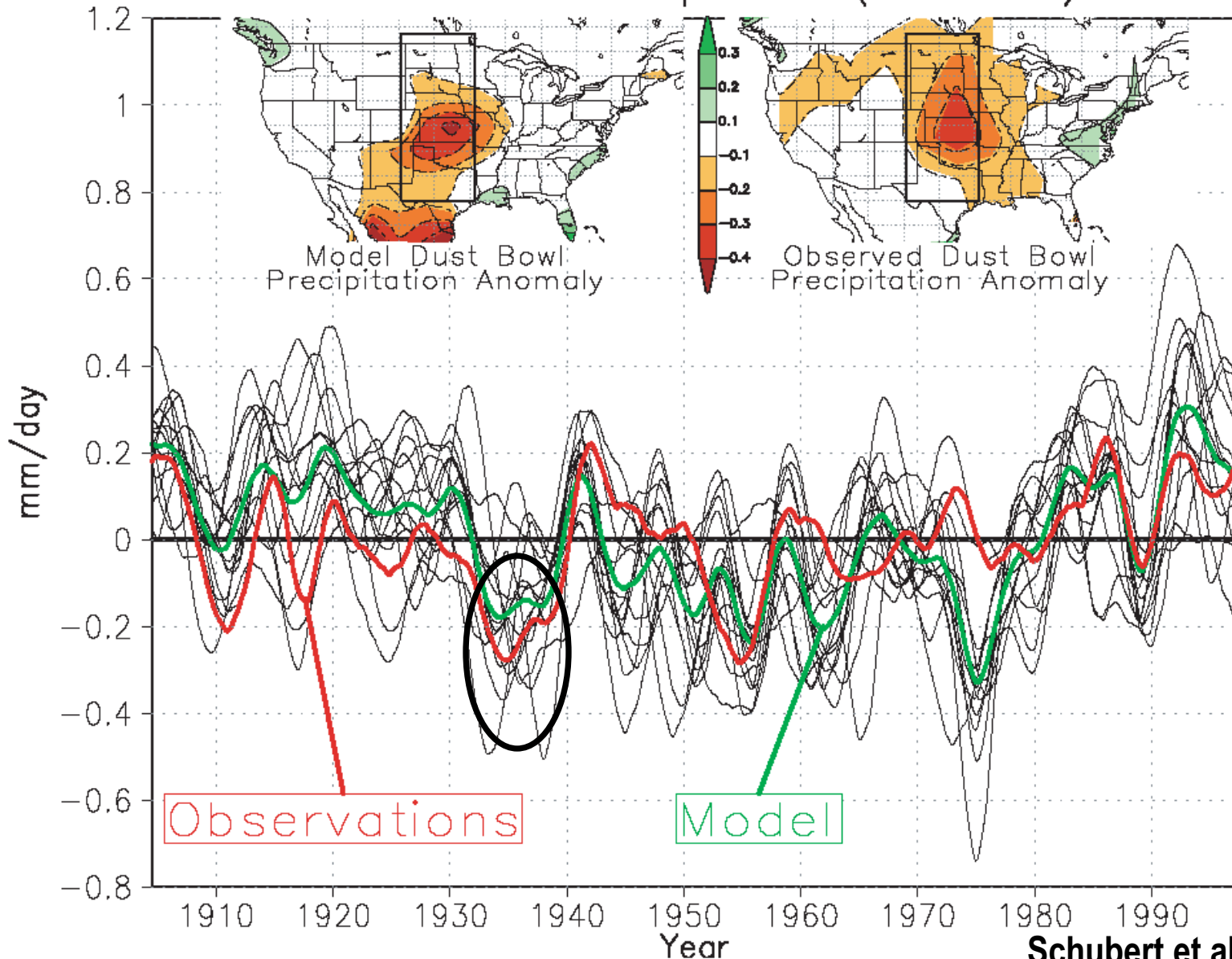
The Dust Bowl drought of the 1930s ... in the central U.S.



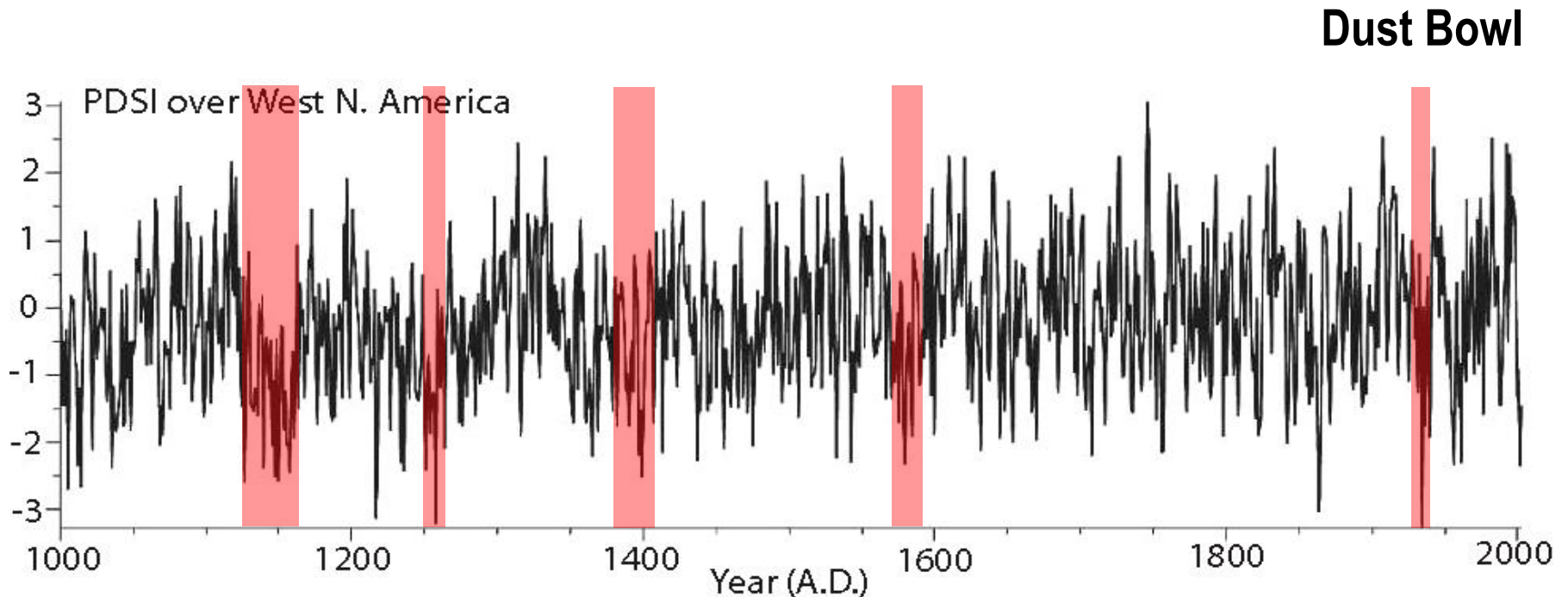
Model-Simulated U.S. Precipitation

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Great Plains Precipitation (Low Pass)



Historical Perspective for N. American Droughts

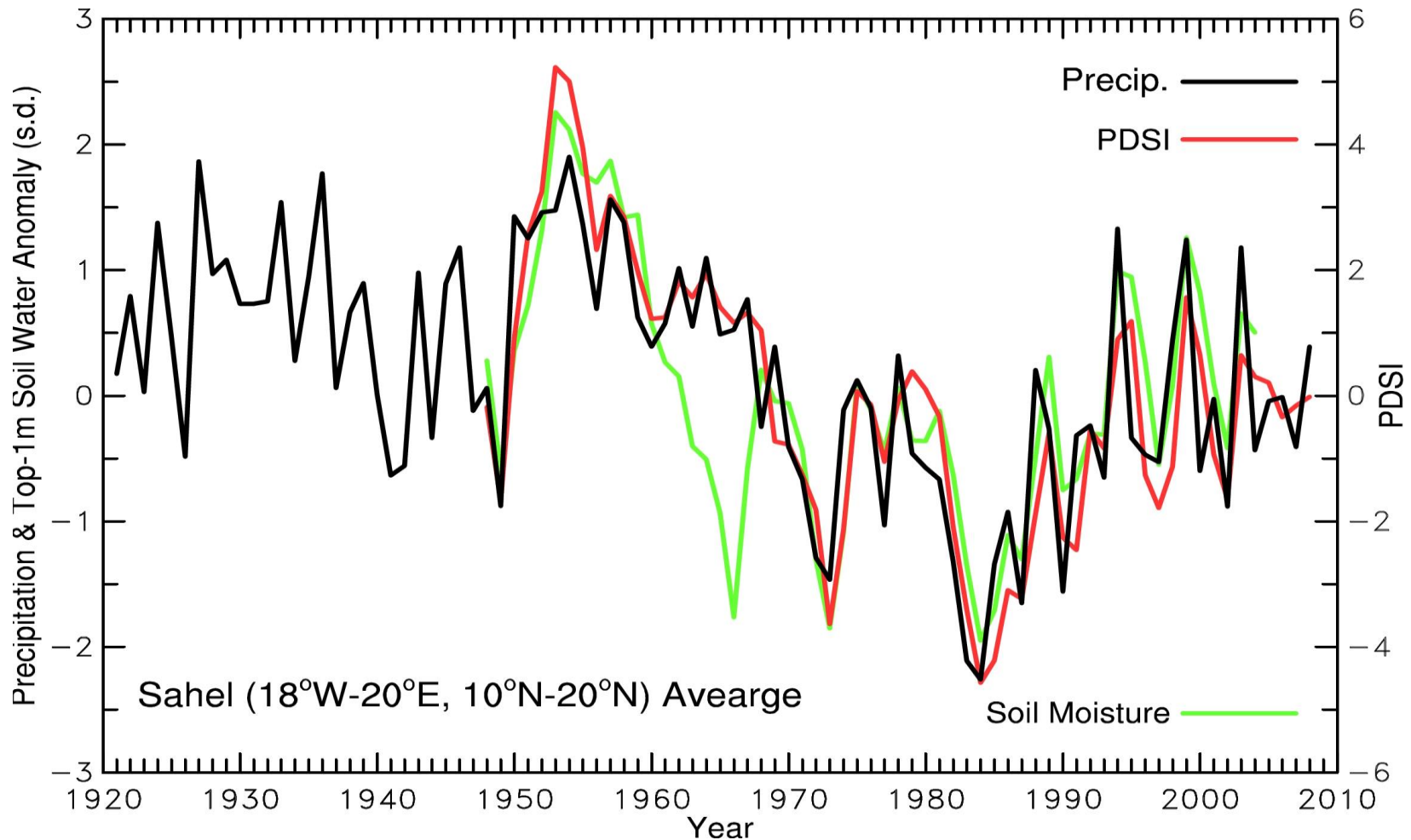


**Tree-ring re-constructed PDSI over West N. America (25-50°N, 95-125°W)
from 1000-2000 (from Herweijer et al. 2007, JC)**

African Drought



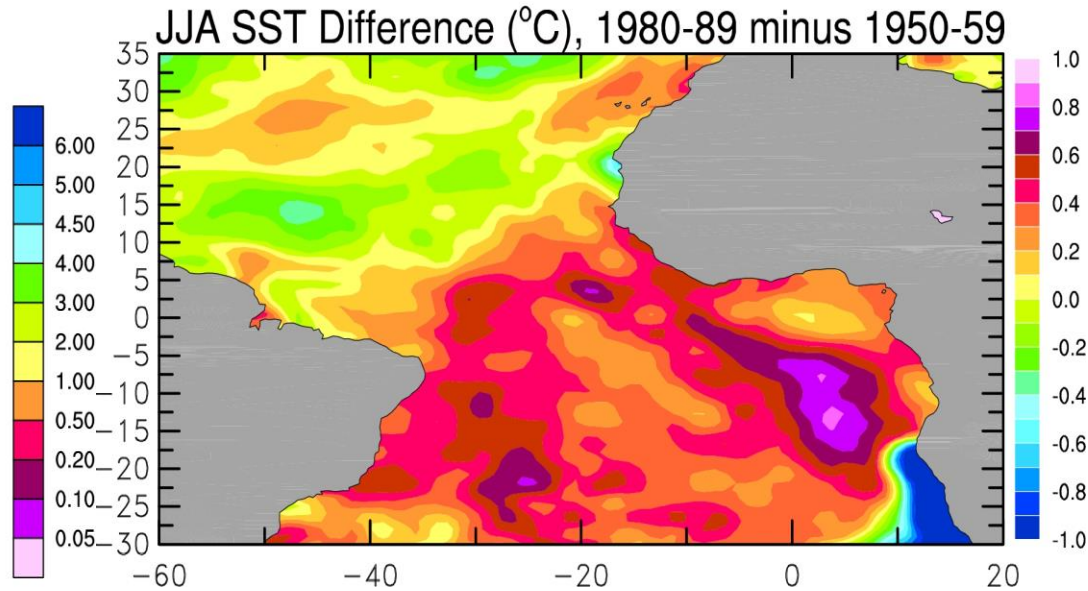
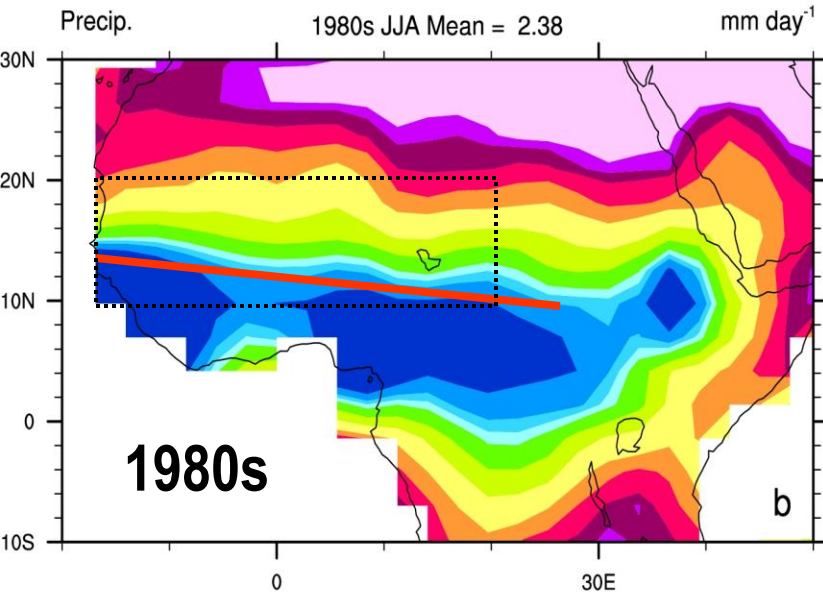
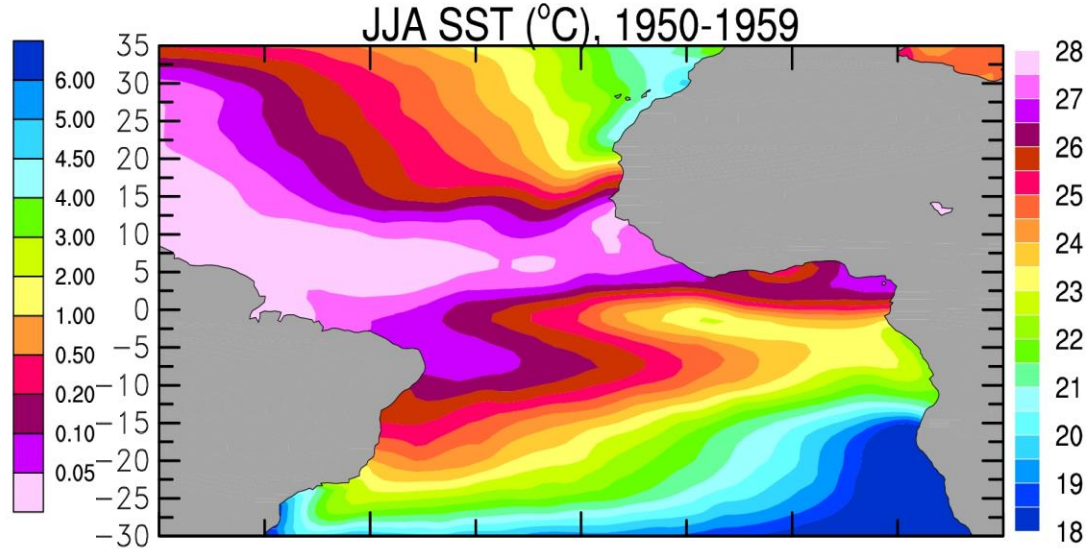
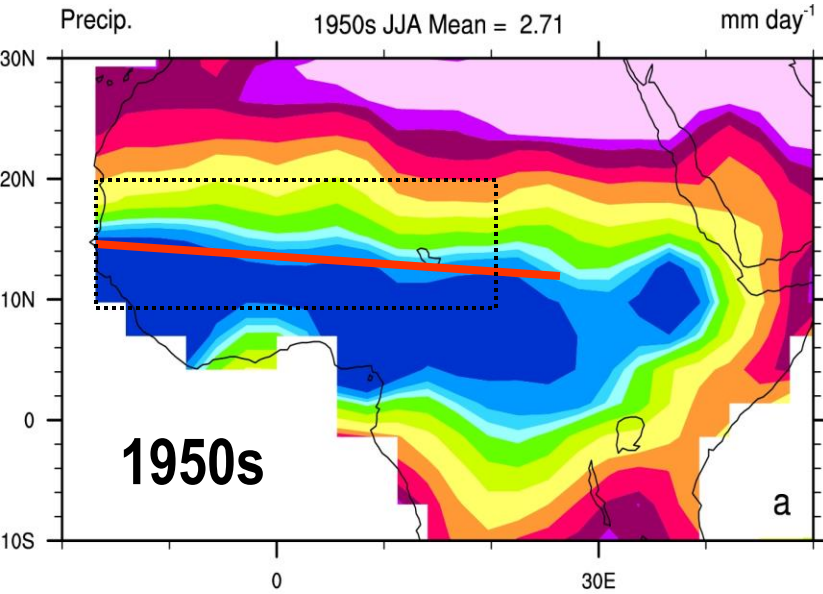
Sahel Annual Rainfall and PDSI: 1920-2008



Update to Dai et al. (2004)

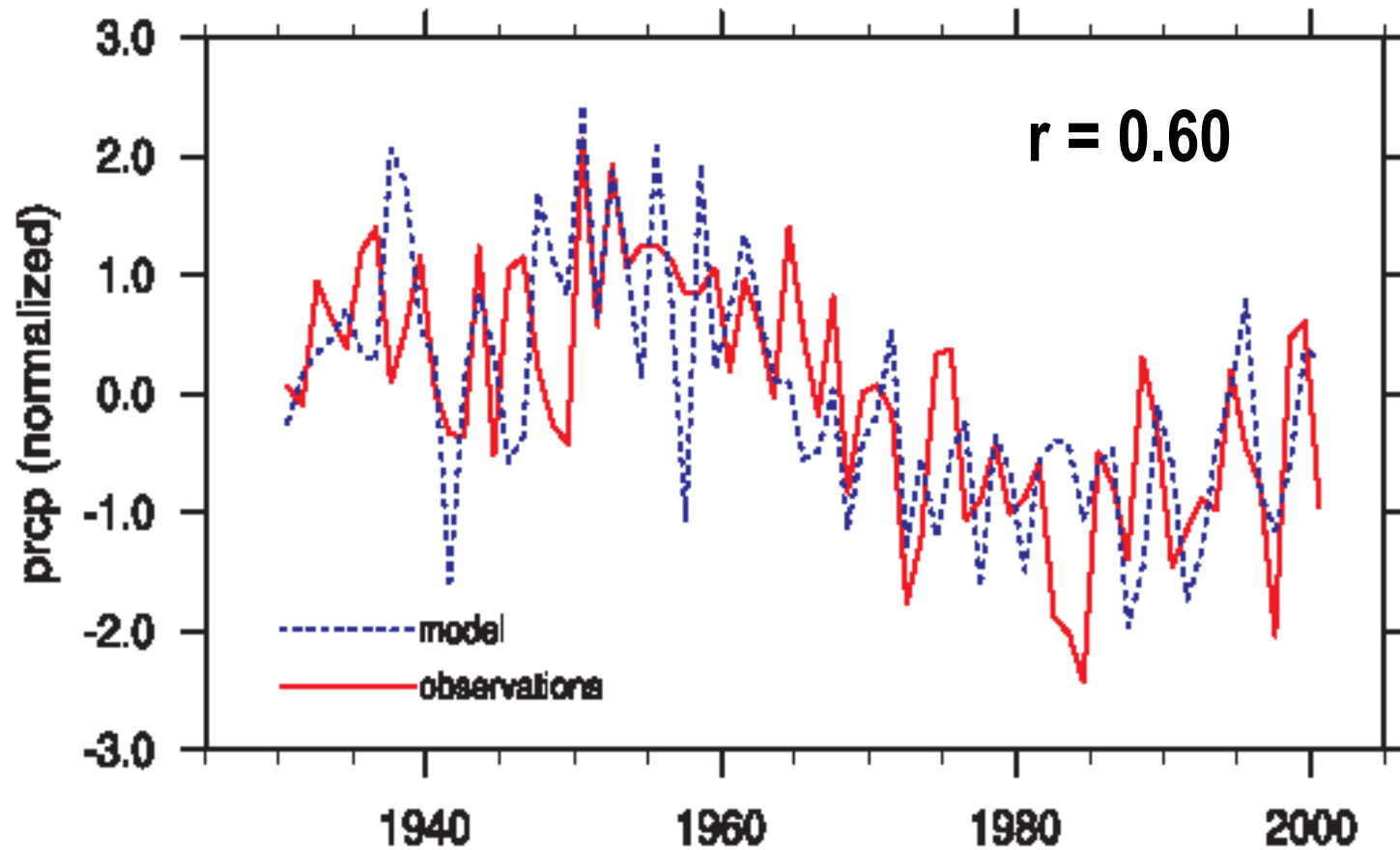
Sahel JJA Rainfall Pattern: 1950s vs. 1980s

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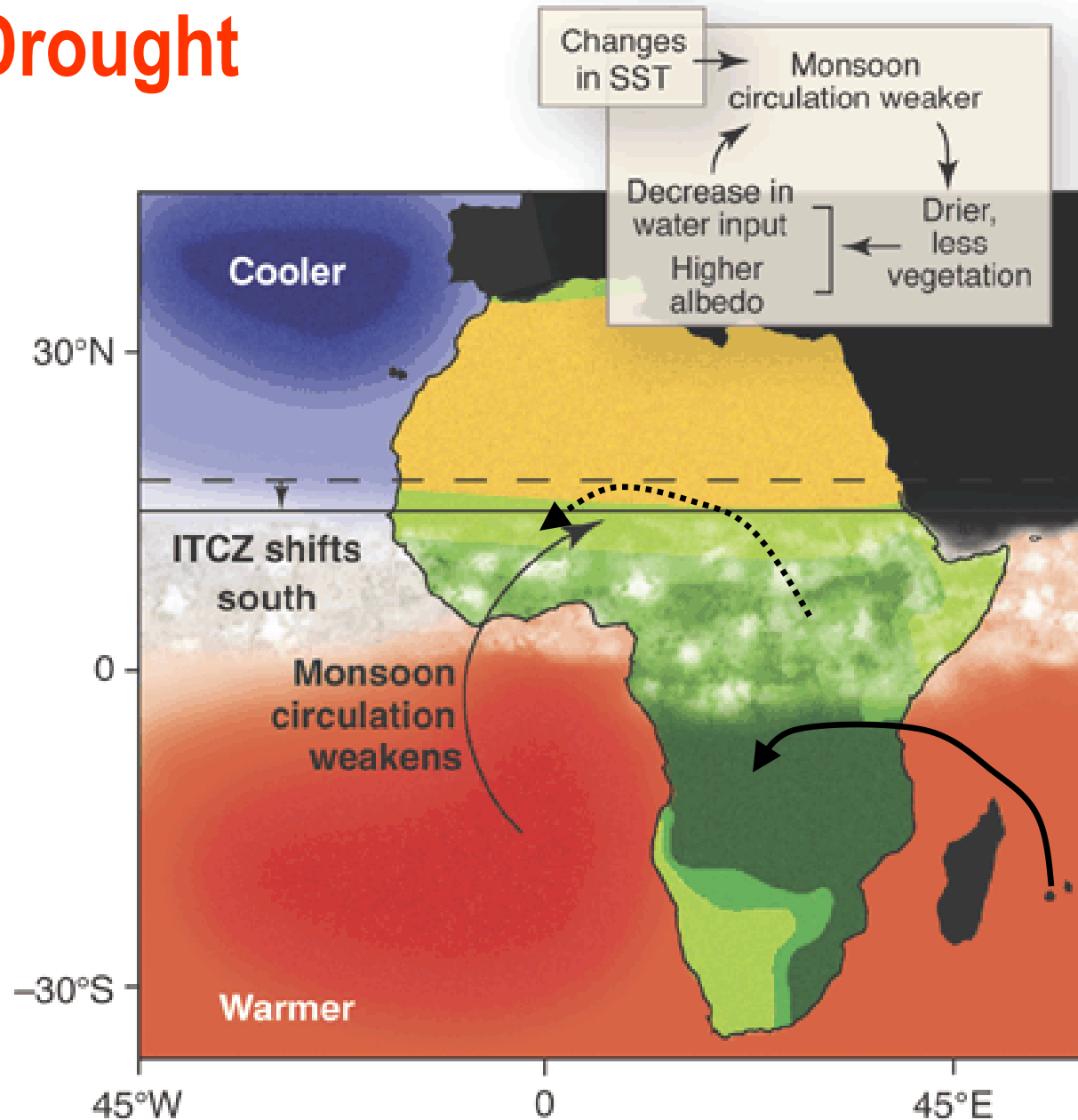
NASA AGCM Forced by Observed Global SST

Sahel precipitation - July-September 1930-2000



(Giannini et al. 2003)

Sahel Drought

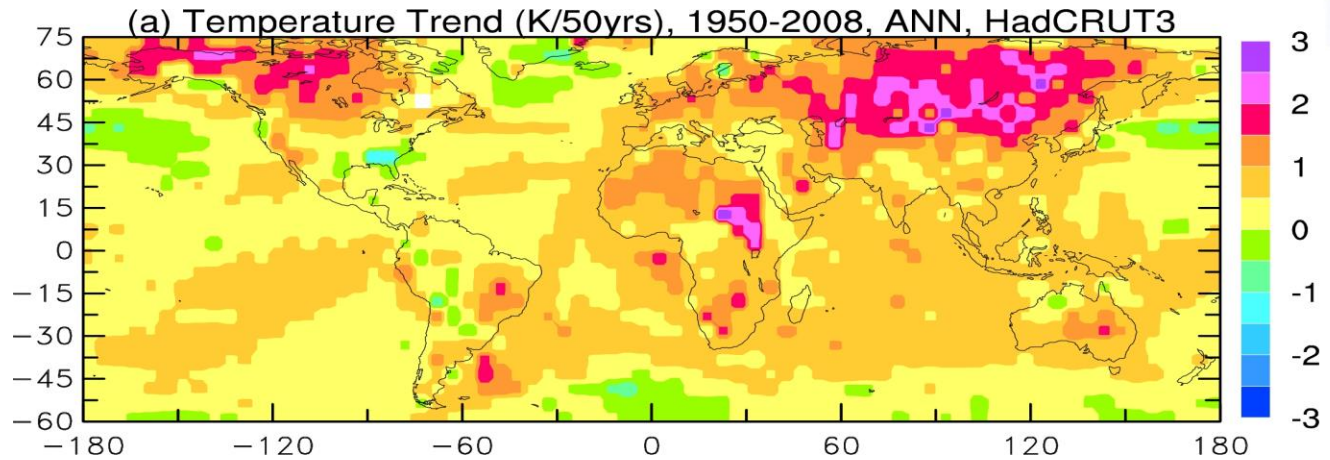


Modified from Zeng (2003)

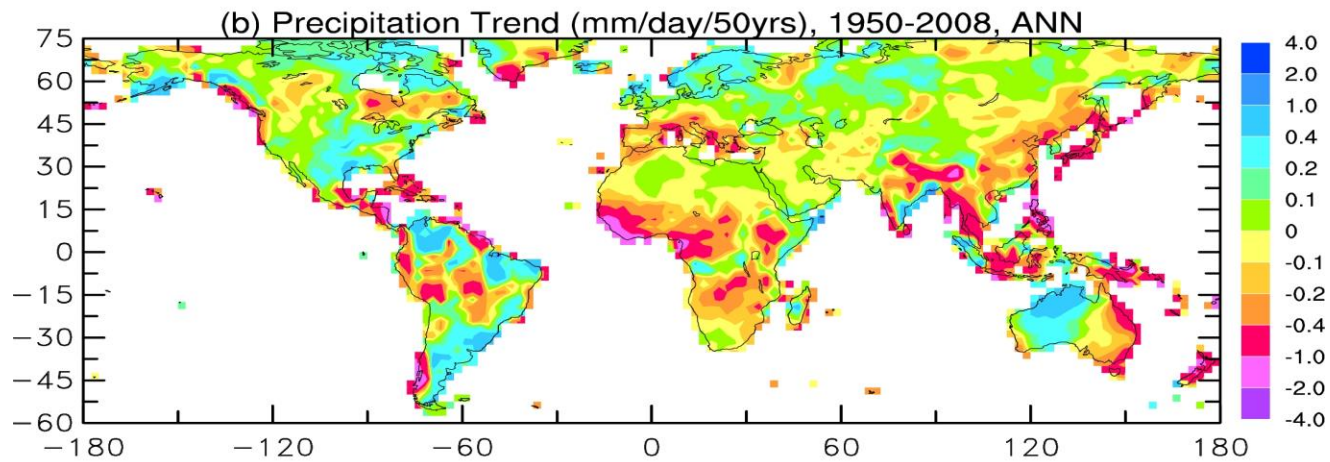
Processes May Lead to Increased Drying over Land under Global Warming

- Increased long-wave radiative heating provides additional energy for surface evaporation
- Higher air temperatures increase atmospheric demand for water vapor
- Reduced precipitation frequency can lead to dry soils
- Larger warming over land than over ocean leads to larger increases in potential evaporation over land than ocean, which may lead to increased water stress over land.

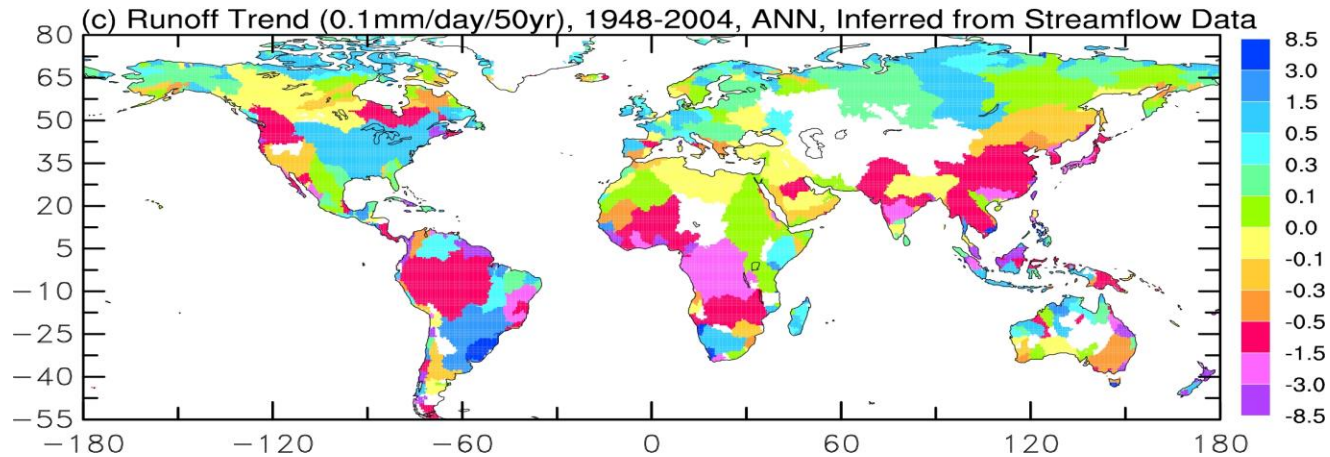
Temp.
Trend



Precip.
Trend



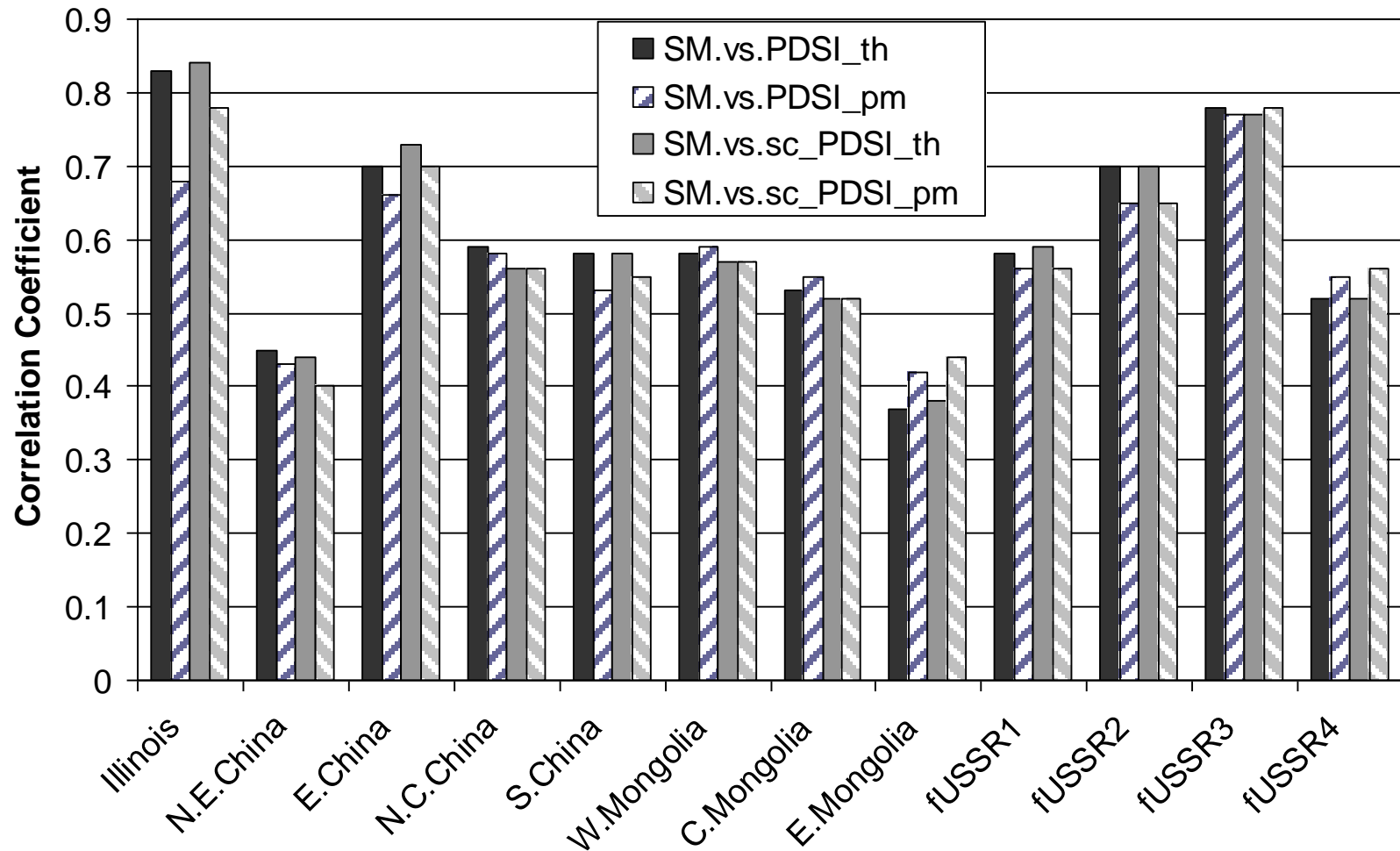
Runoff
Trend



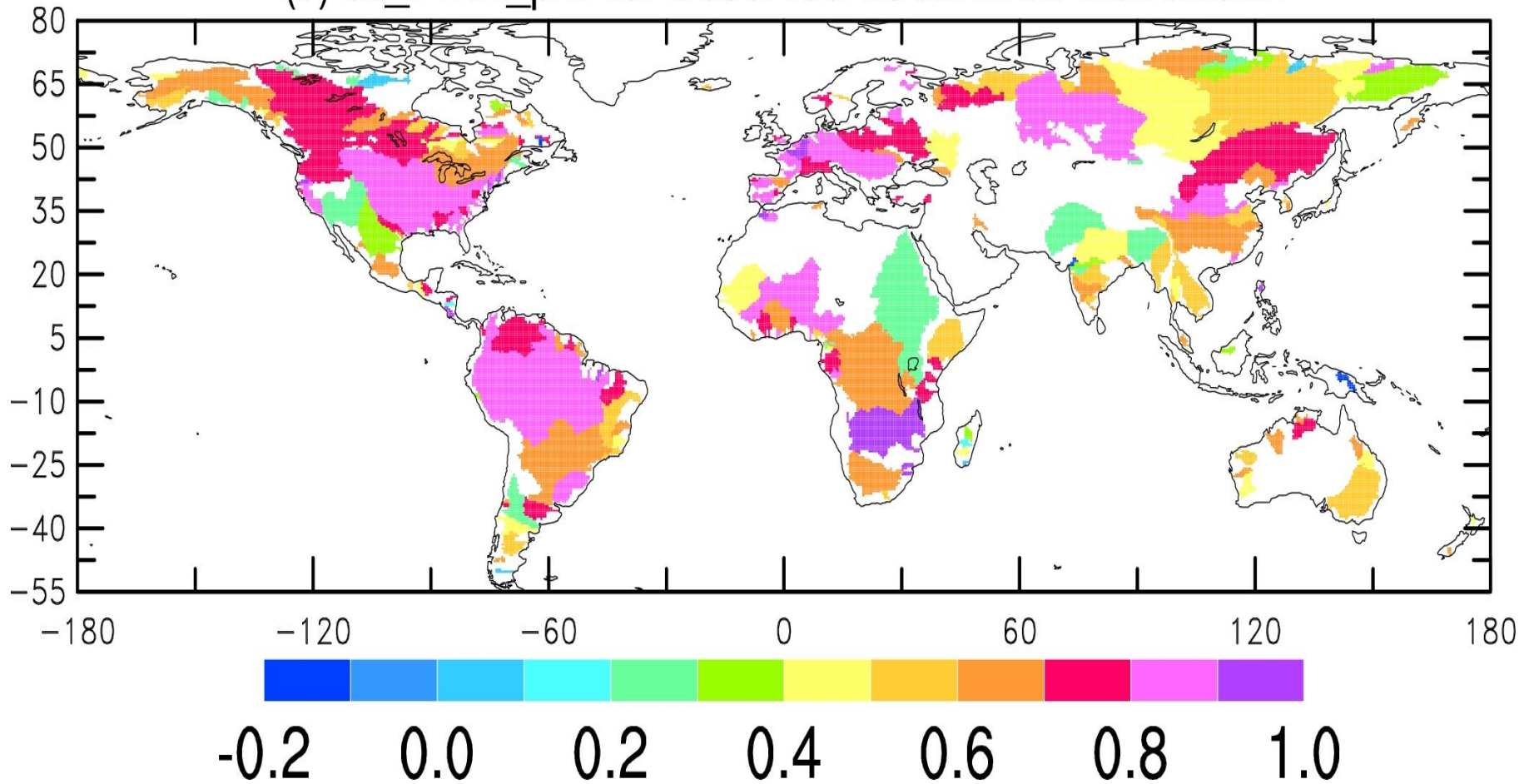
Palmer Drought Severity Index (PDSI)

- PDSI is a measure of **meteorological drought** widely used in the U.S.;
- PDSI is computed using a bucket-type land surface model using observed precipitation and surface air temperature;
- PDSI is correlated with observed soil moisture content and streamflow; and
- Improvements to PDSI: Penman-Monteith PE, SC-PDSI

PDSI vs. Observed Top-1m Soil Moisture Correlation

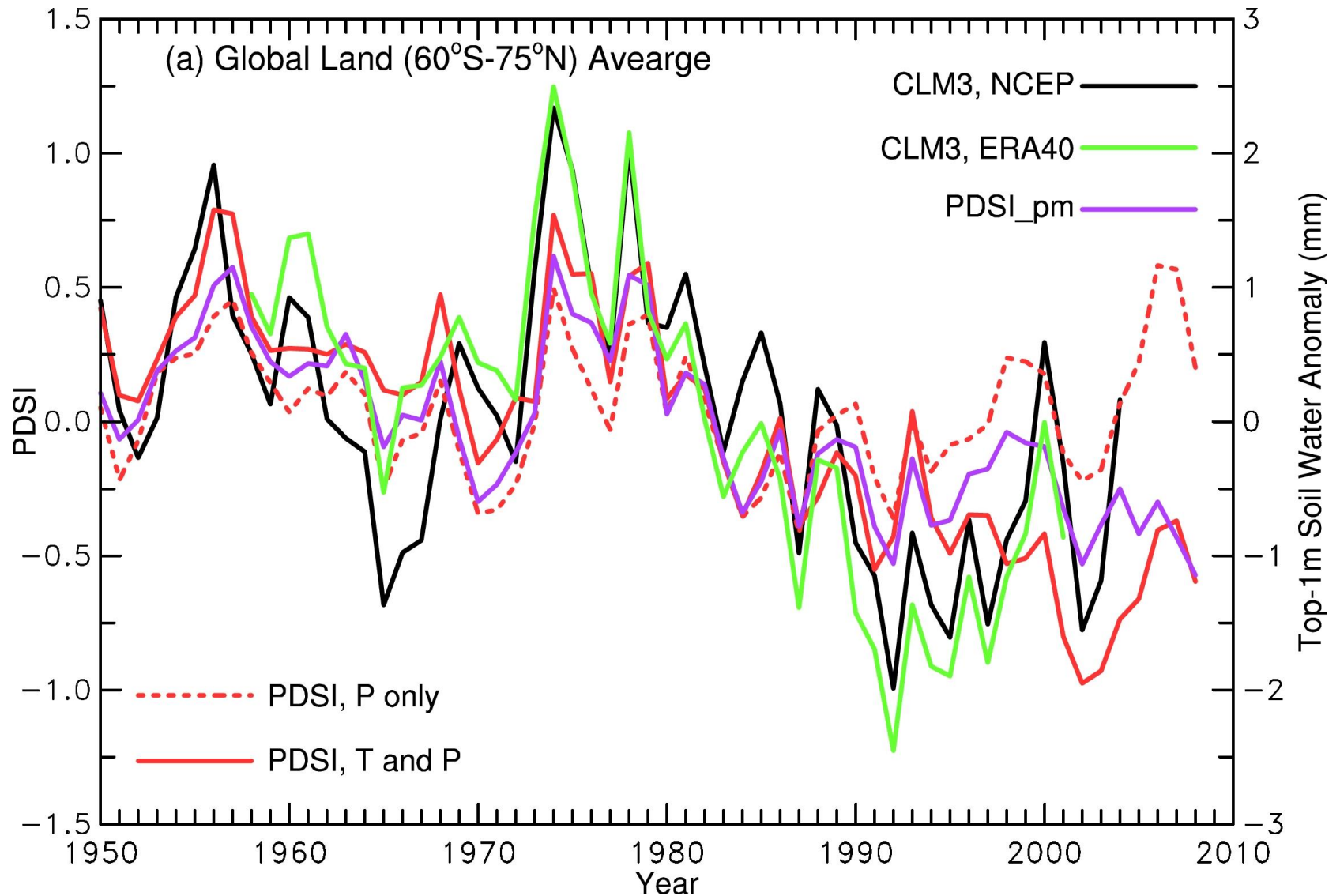


(c) sc_PDSI_pm vs. Observed Streamflow Correlation



Annual data, 1948-2006

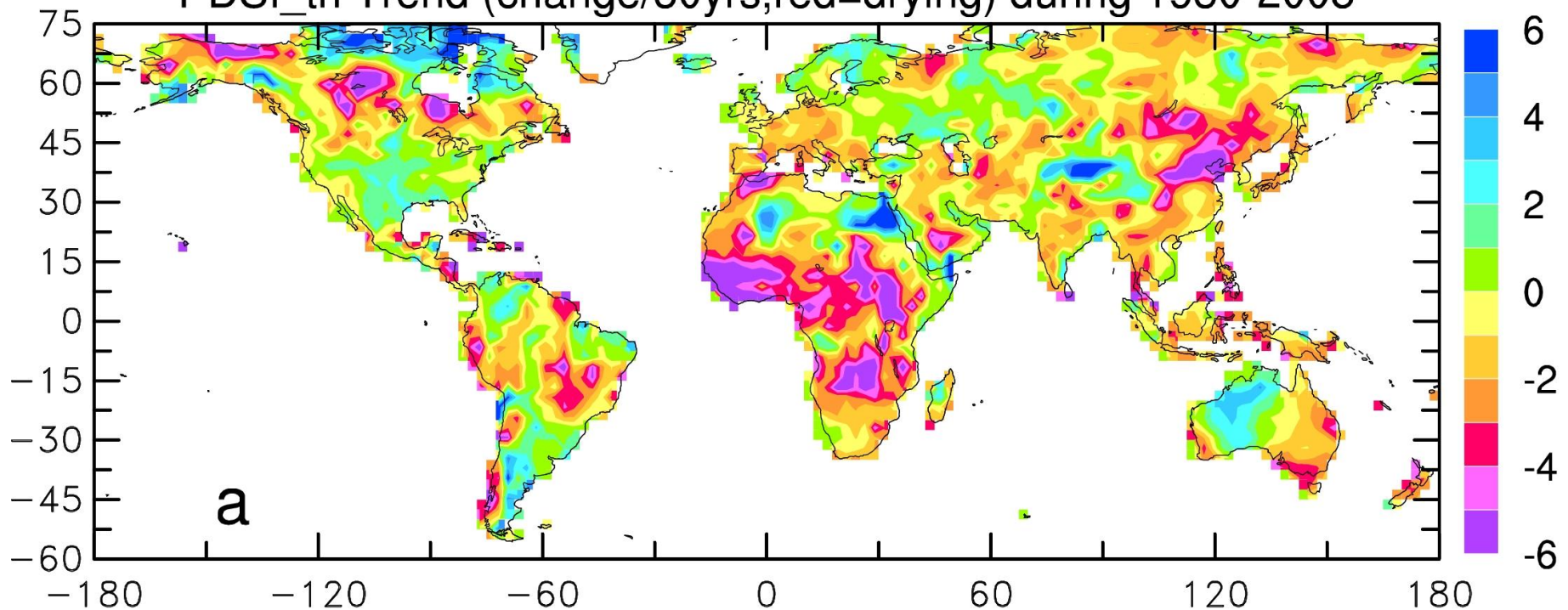
Global-mean PDSI and CLM Soil Water



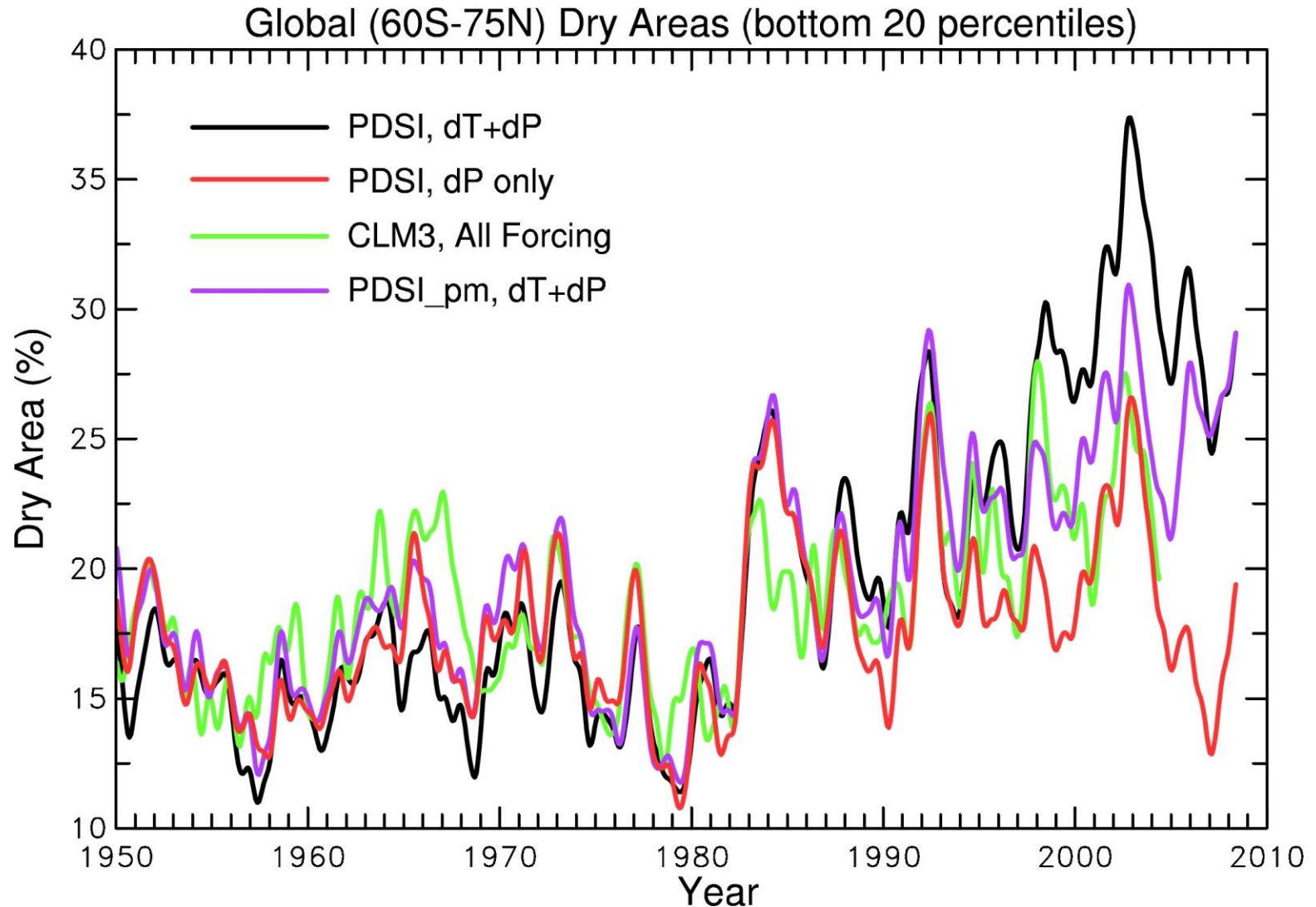
Trends in PDSI from 1950-2008

(red=drying)

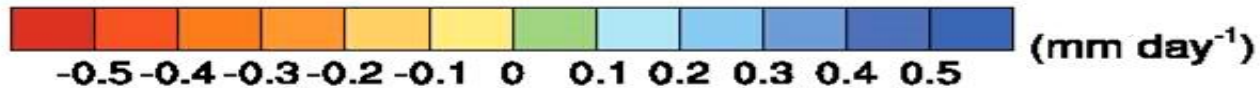
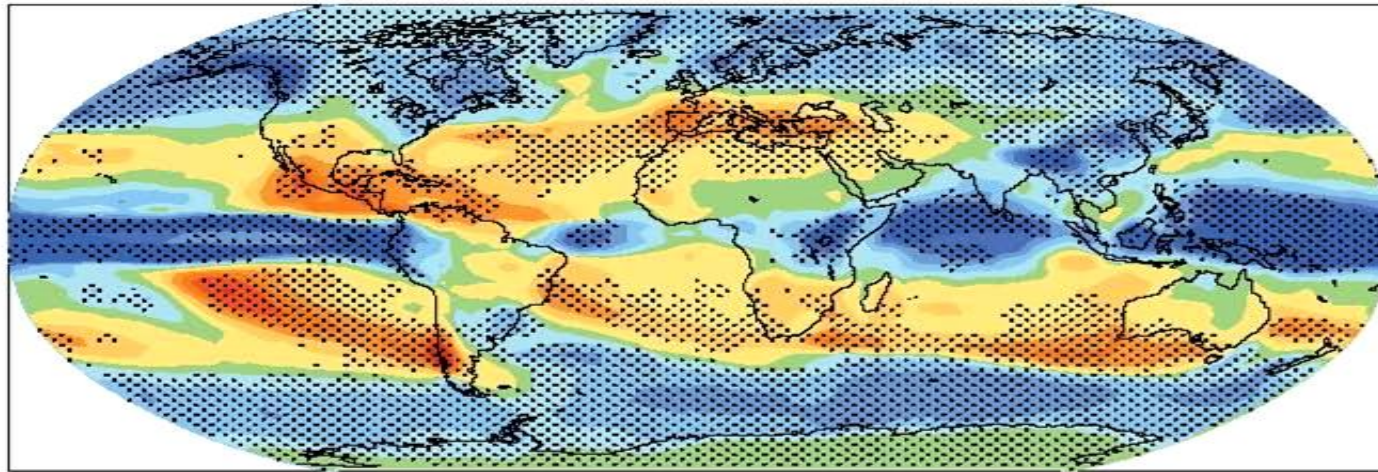
PDSI_th Trend (change/50yrs, red=drying) during 1950-2008



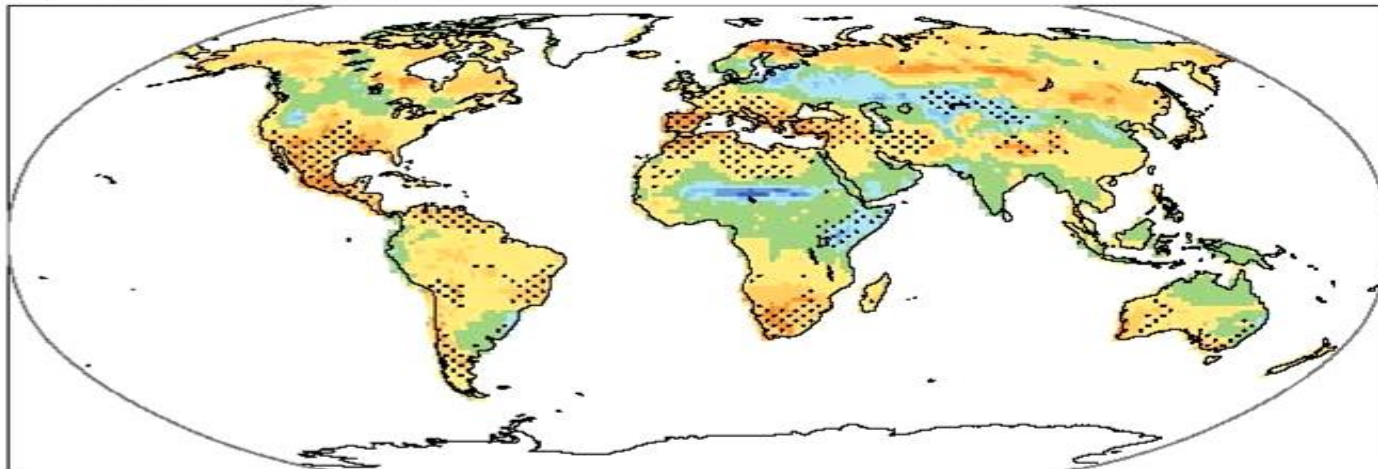
% Dry Area over Global (60S-75N) Land



(update to Dai et al. 2004)



b) Soil moisture

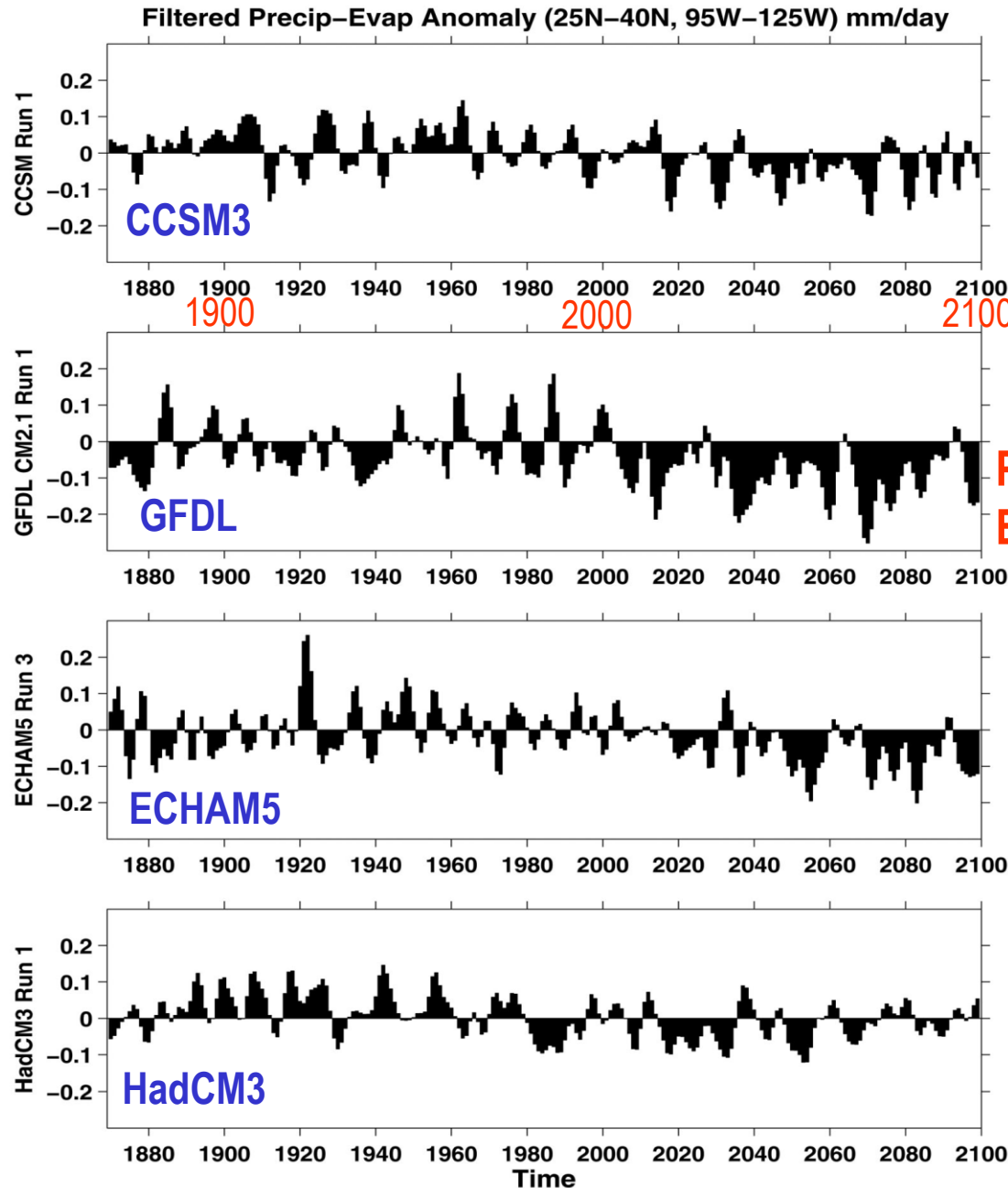


(IPCC 2007)

Model Simulated P - E Over the Southwest U.S.



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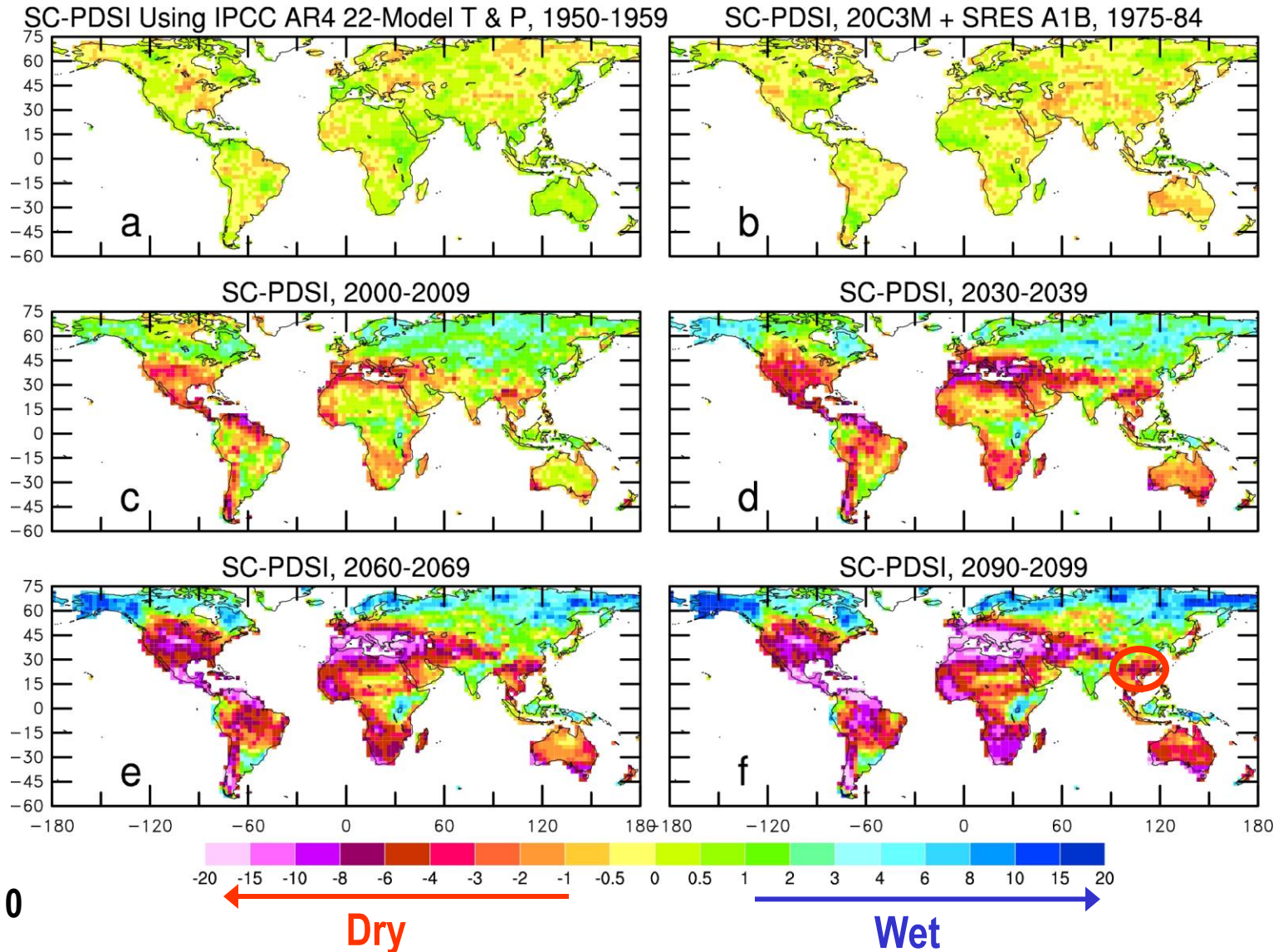


Partly due to poleward
Expansion of the Hadley Cell

Seager et al.'07, *Science*

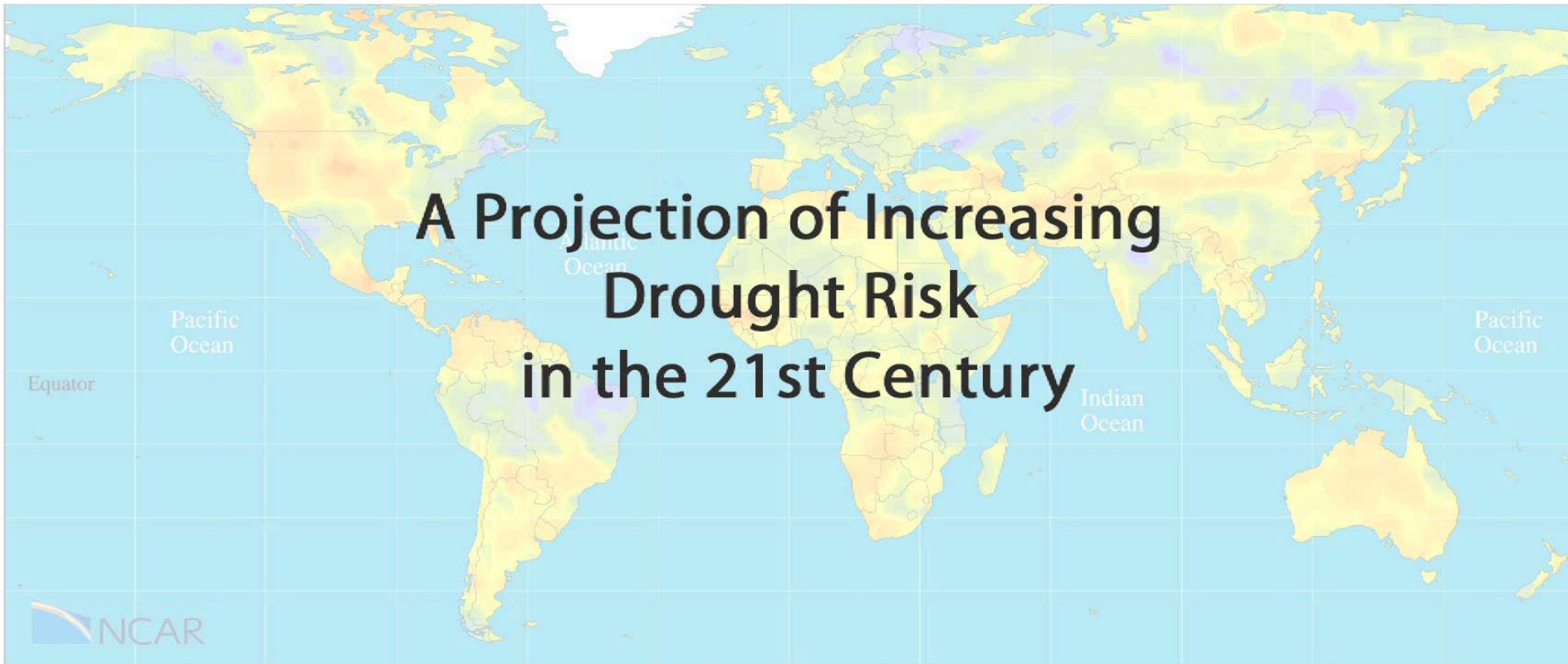
SC_PDSI_pm based on IPCC AR4 Model

Predicted Temp. and Precip under A1B Scenario





A Projection of Increasing Drought Risk in the 21st Century



Summary



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- Severe droughts similar to recent ones seen in China, N. America, and Africa occurred many times during the last 500-1000 years.
- Warming in tropical SST weakens EASM circulation that may lead to reduced precipitation in North China.
- Model studies suggest that tropical (La Niña-like) SST anomalies caused the “Dust Bowl” drought over the U.S. in the 1930s.
- The warming in the South Atlantic relative to the North Atlantic was a major cause for the Sahel drought, while the warming in the Indian Ocean contributed to the drought in southern Africa.
- Recent surface warming appears to have enhanced drying over high-latitude and subtropical land areas during the last 30 years.
- Both soil moisture and PDSI from model projections suggest severe drying over most land areas (except northern high-latitudes) in the 21st century.

Dai, A., K. E. Trenberth, and T. Qian, 2004: A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. *J. Hydrometeorology*, 5, 1117-1130. ([Paper](#)) ([PDSI data](#))

Dai, A., P. J. Lamb, K. E. Trenberth, M. Hulme, P. D. Jones, and P. Xie, 2004: The recent Sahel drought is real. *International Journal of Climatology*, 24, 1323-1333. ([Paper](#))

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Schubert, S. D., M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister, 2004: On the cause of the 1930s Dust Bowl. *Science*, 303, 1855-1859.

Seager, R., M. F. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa, N. C. Lau, C. H. Li, J. Velez, and N. Naik, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, 316, 1181-1184.

Zeng, N., 2003: Drought in the Sahel. *Science*, 302, 999-1000.