An Imminent Transition to Drier Conditions in the United States?

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Invited Talk at *Water Forum II: Texas Drought and Beyond*
Austin, Texas, 22-23 October, 2012

Questions to: adai@albany.edu

Related Papers:

Dai, A., 2012: Increasing drought under global warming in observations and models. *Nature Climate Change*, published online on Aug. 5, 2012 (available here).

Dai, A., 2011: Characteristics and trends in various forms of the Palmer Drought Severity Index (PDSI) during 1900-2008. *J. Geophys. Res.*, 116, D12115, doi:10.1029/2010JD015541. (PDSI Data)

Dai, A., 2011: Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, **2,** 45-65.

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Outline

- Introduction:
  - Drought Indices, PDSI
  - Global warming & its potential impact on drought
- Observed global changes of drought
- Model Predictions
- U.S. precipitation & drought changes
- Conclusions

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Texas

JJA 2011 Hottest on record

Some towns in western Texas went more than 60 straight days over 100F

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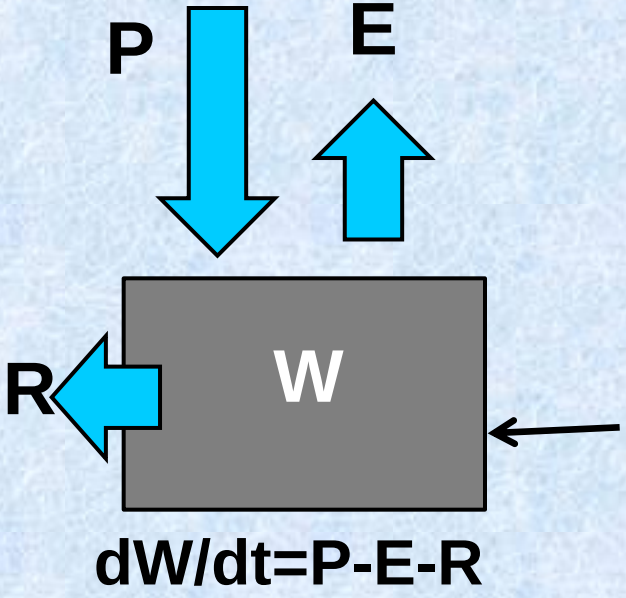
How do we quantify drought?

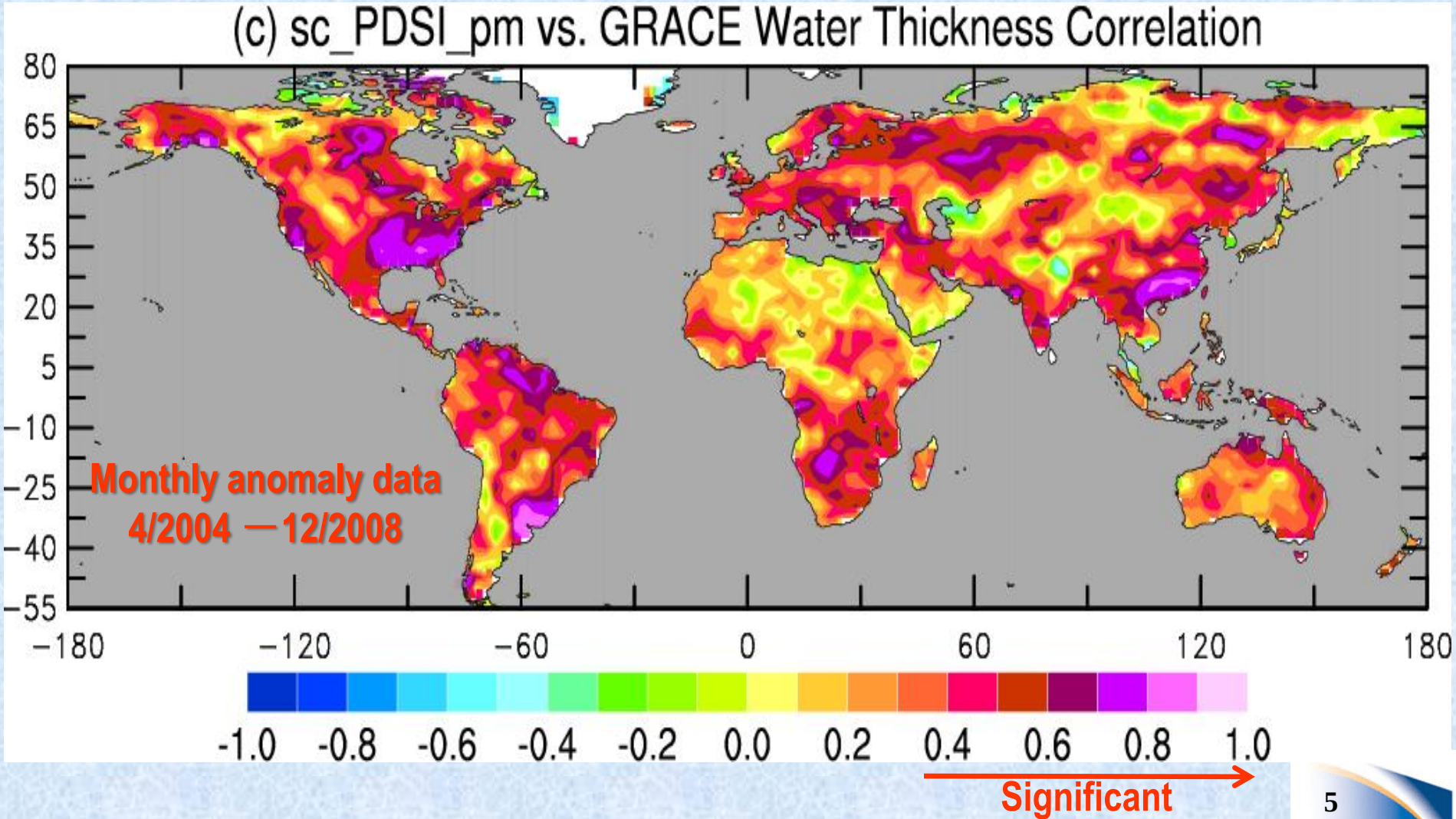
- **Drought Indices** are used to monitor and quantify the areal extent and severity of drought
- Many drought indices are based on precipitation alone
- Some are based on P minus Potential Evaporation (PE)
- A few are based on a surface water balance model, such as the Palmer Drought Severity Index (PDSI).



- Temperature affects PDSI through E
- Negative PDSI = dry conditions;
- PDSI< -3 : Severe drought
- Self-calibrated PDSI with Penman-Monteith PE (sc_PDSI_pm)

Two soil layers in the PDSI model

PDSI correlates with observed soil moisture, streamflow, and water storage over land (Dai 2011)



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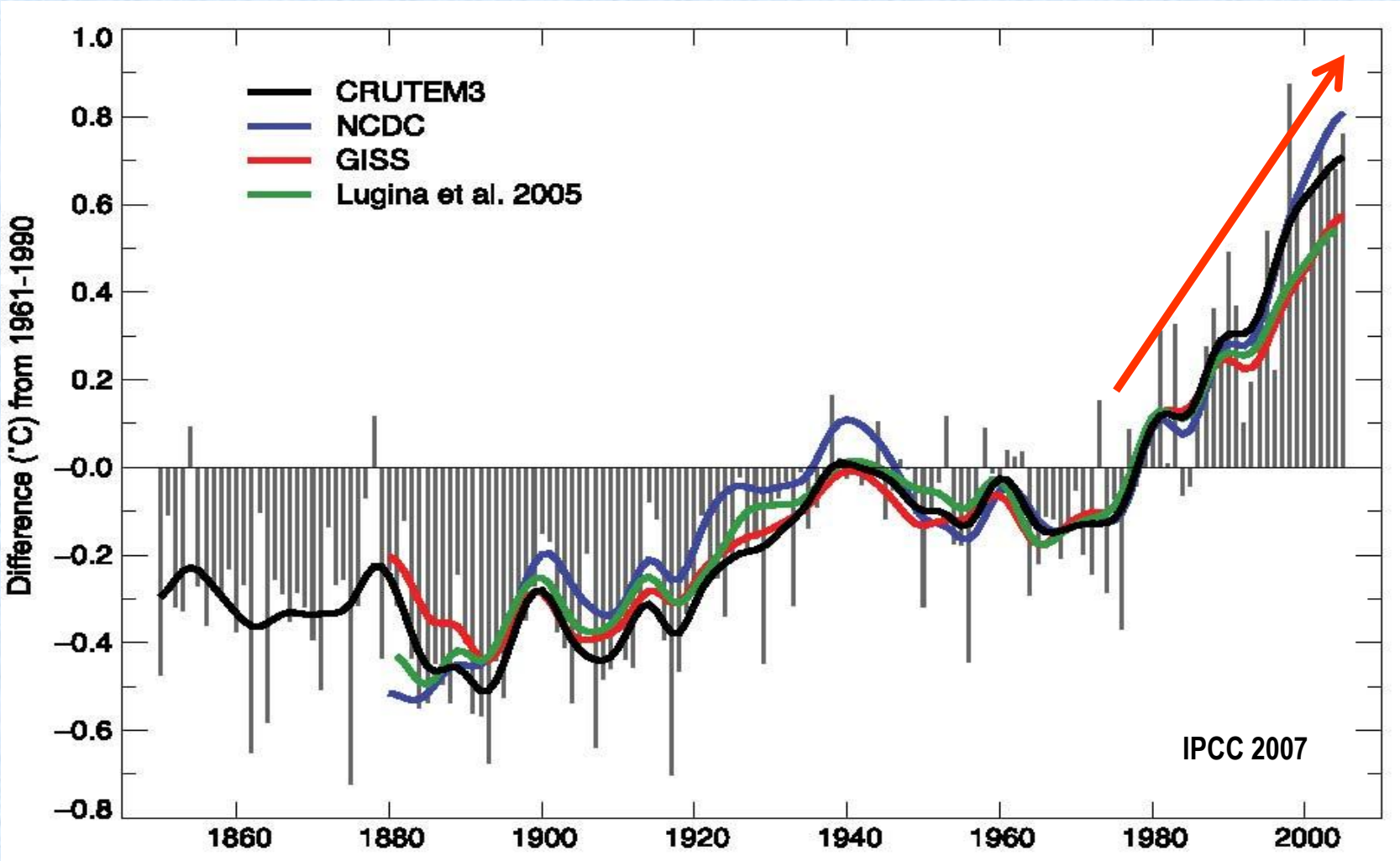
Observed Global Temperature Series 1850–2006



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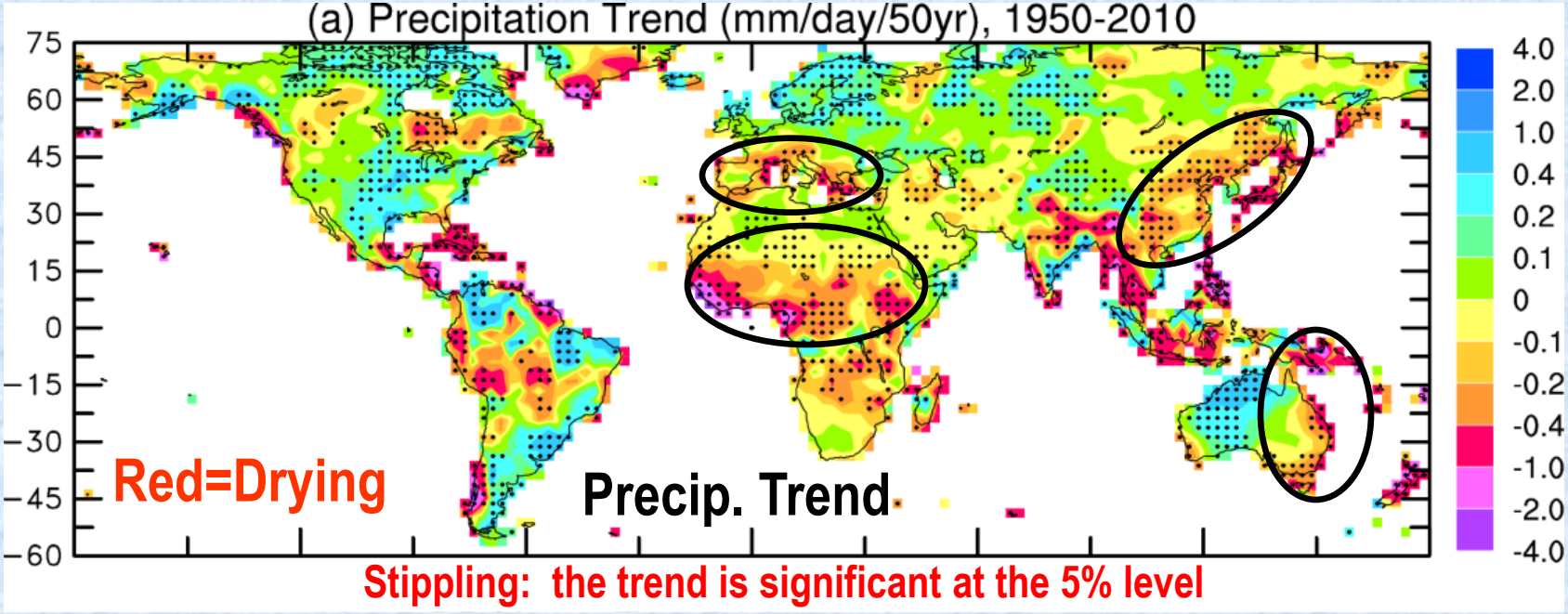
Drying Processes under Global Warming

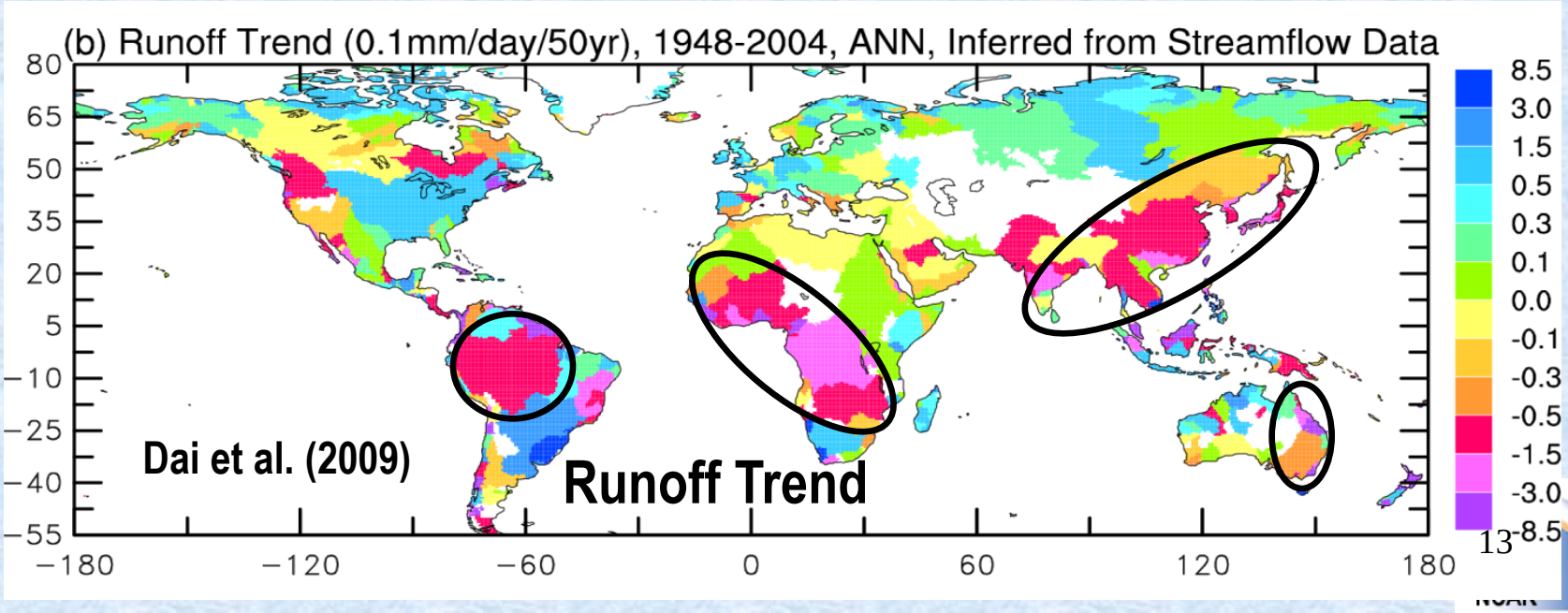
- Increased surface radiation provides new energy for evaporation
- Higher temperatures increase atmospheric demand for water vapor
- Reduced precipitation frequency means more dry spells
- Larger warming over land than over ocean leads to
  - larger PE increases over land than over ocean
  - increases in water vapor transport from oceans can not match atmospheric demand over land → drier conditions over land.

Has drought increased during the recent warming?

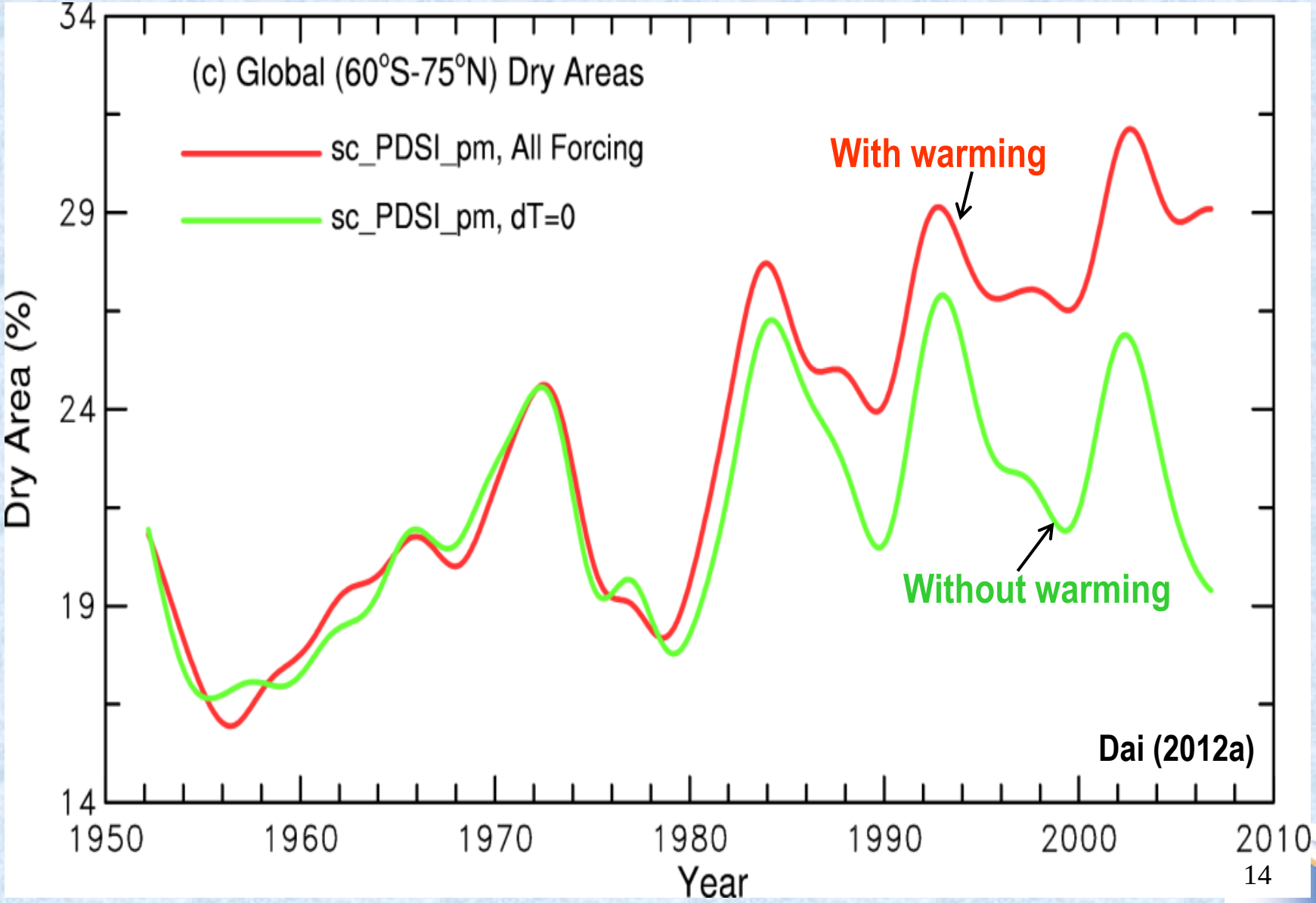
Precipitation and PDSI Trends: 1950-2010



Other Observational Evidence of Drying



Effect of Surface Warming on Drought Area



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Do models predict increasing drought under GHG-induced global warming?

Climate models are imperfect, but useful for studying what MIGHT happen in the future.

We use CMIP5 multi-model ensemble mean to represent the GHG-induced change, as natural variations are small in the ensemble mean.

GHG = greenhouse gas

CMIP5 = the Fifth Coupled Model Inter-comparison Project, used for IPCC AR5

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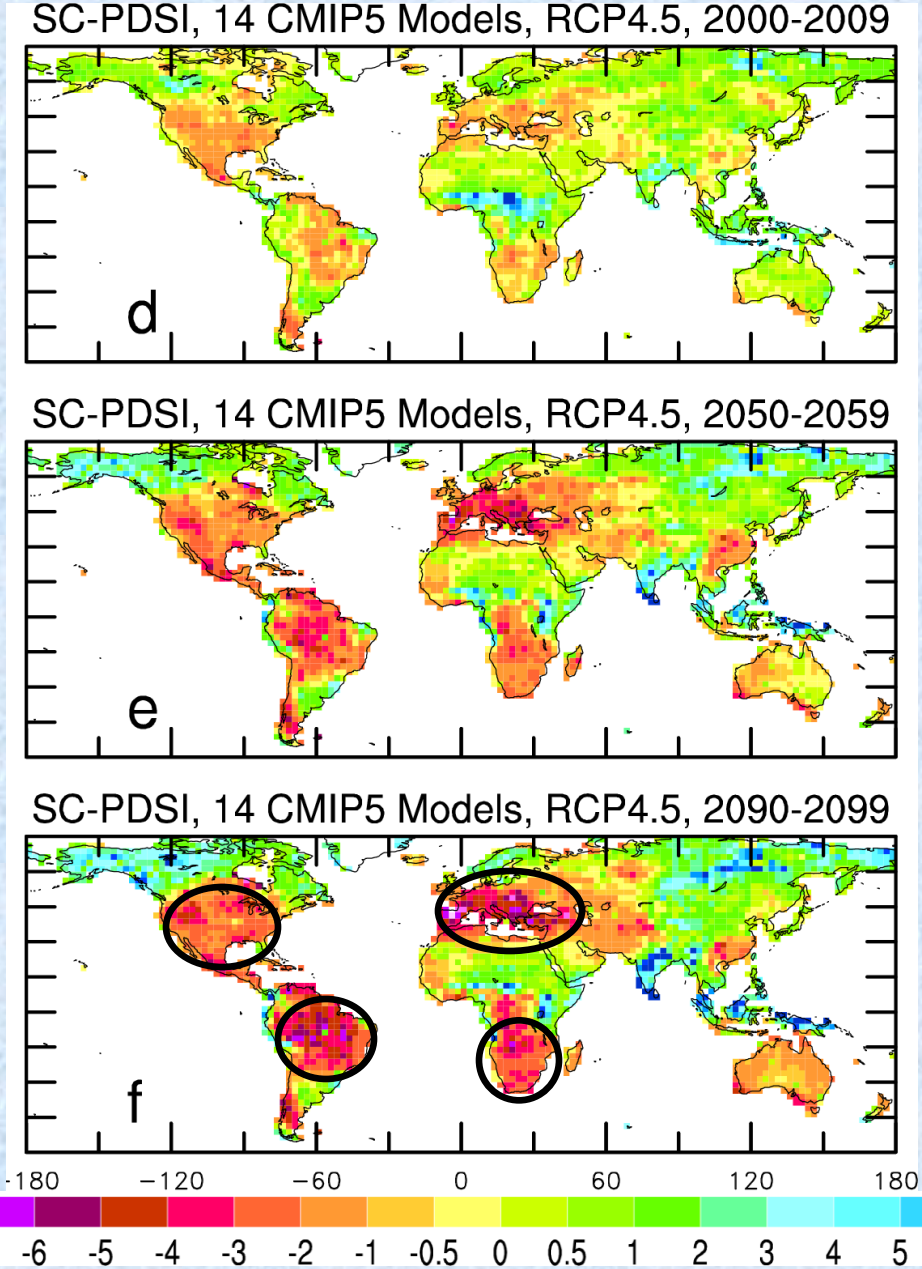
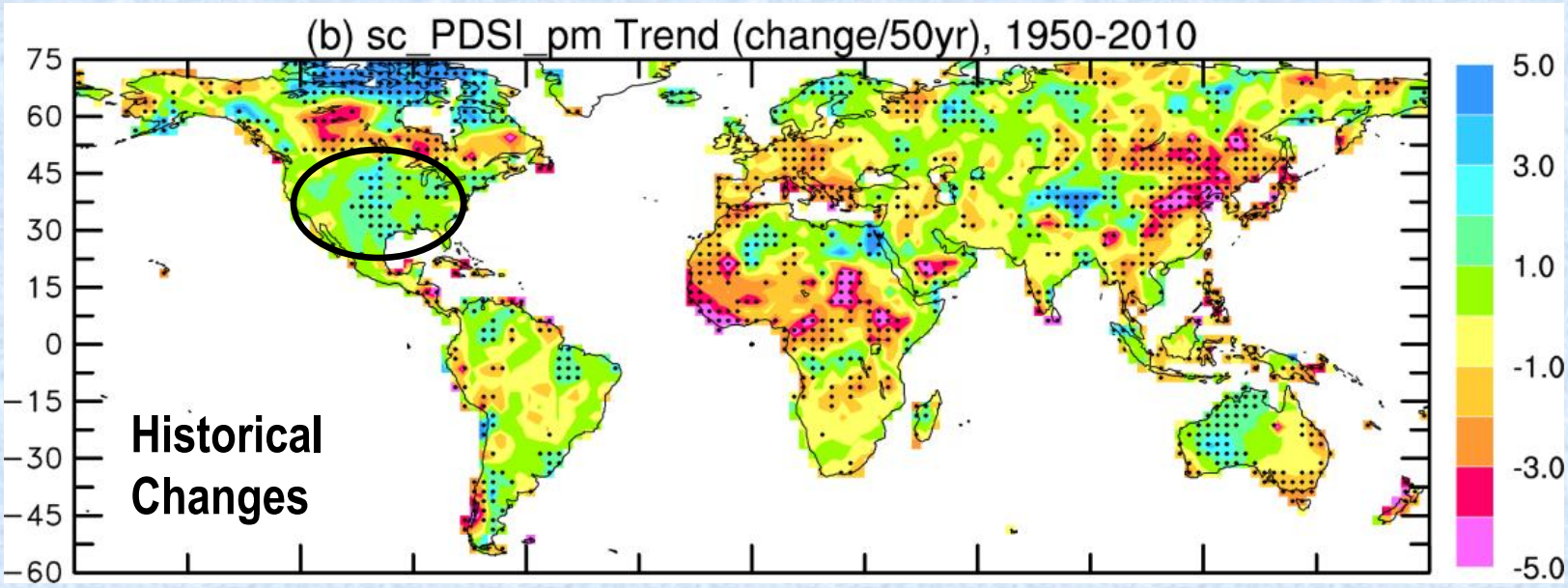
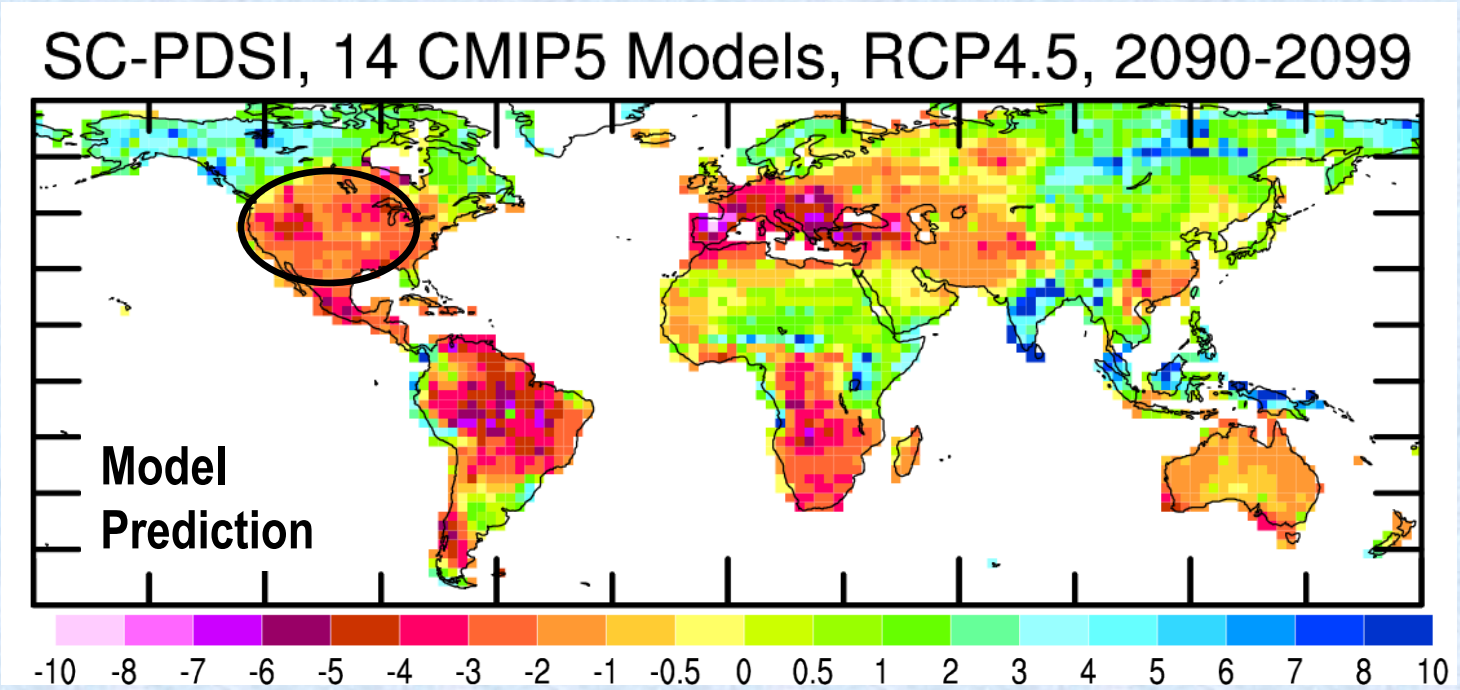
PDSI in 21st Century: PDSI<−3 = Severe Drought



Different PDSI Trends over the U.S.: Obs. vs. Model





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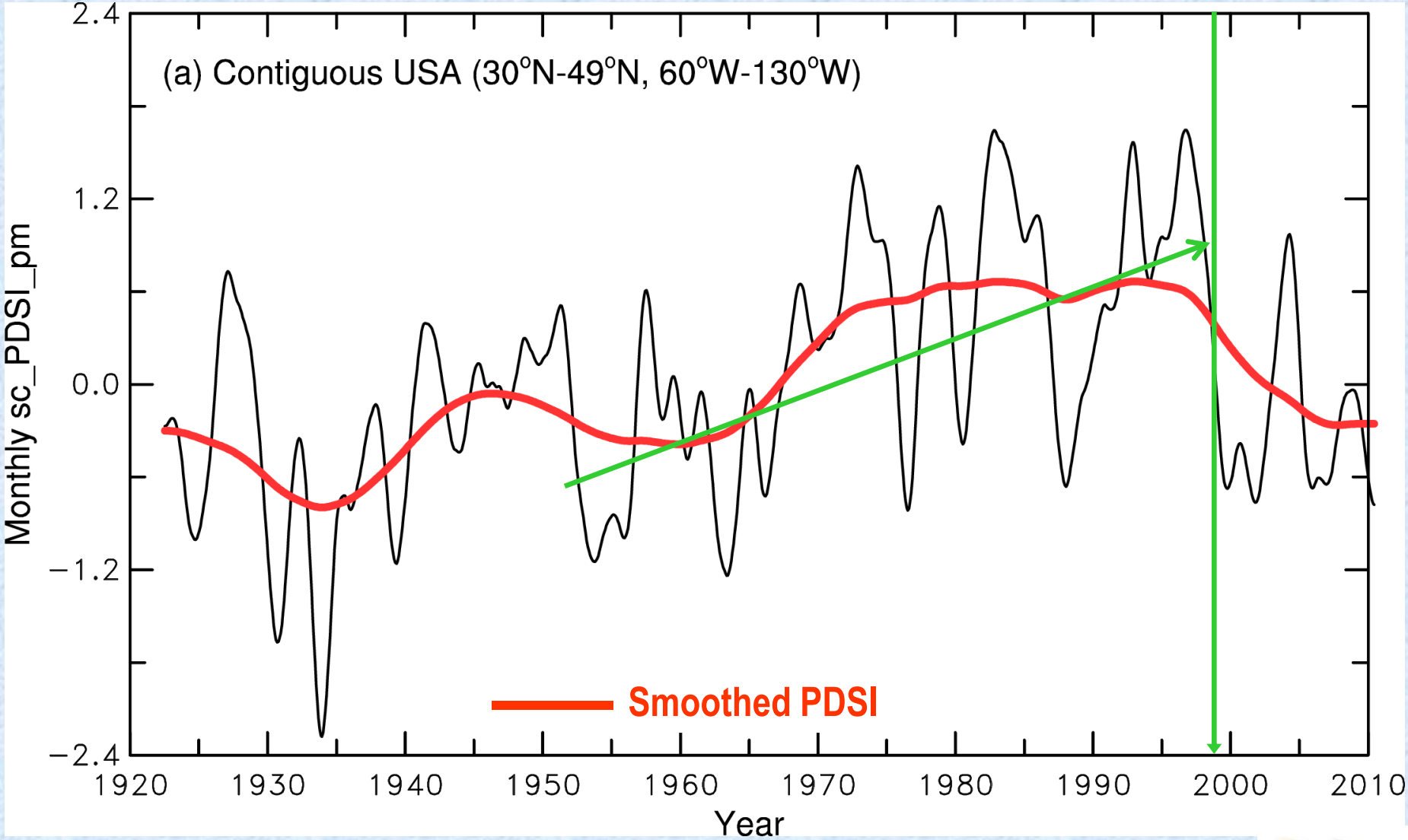
What Caused the Historical Wetting Trend in the U.S.?

U.S. PDSI Time Series: 1923-2010



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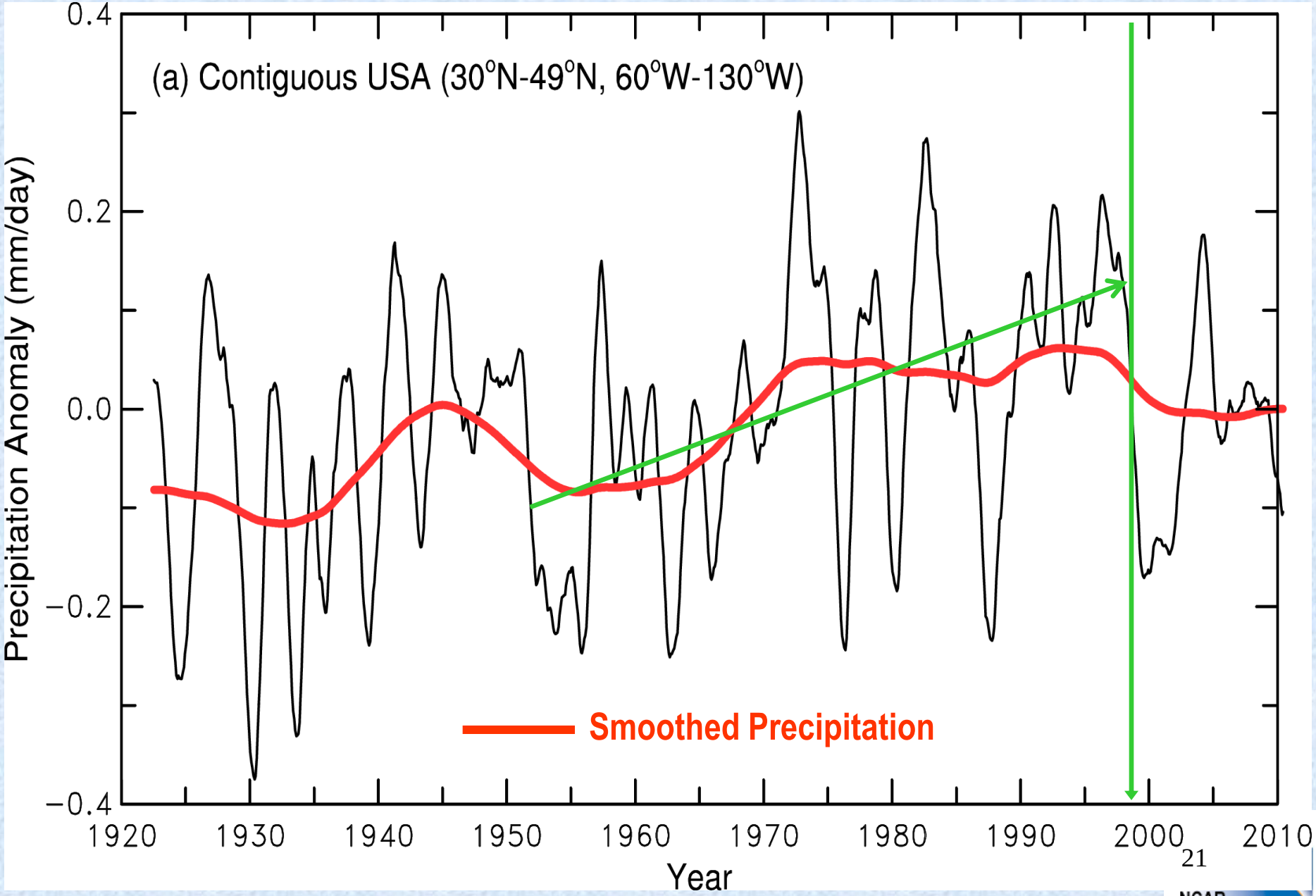
U.S. Precipitation Time Series: 1923-2010



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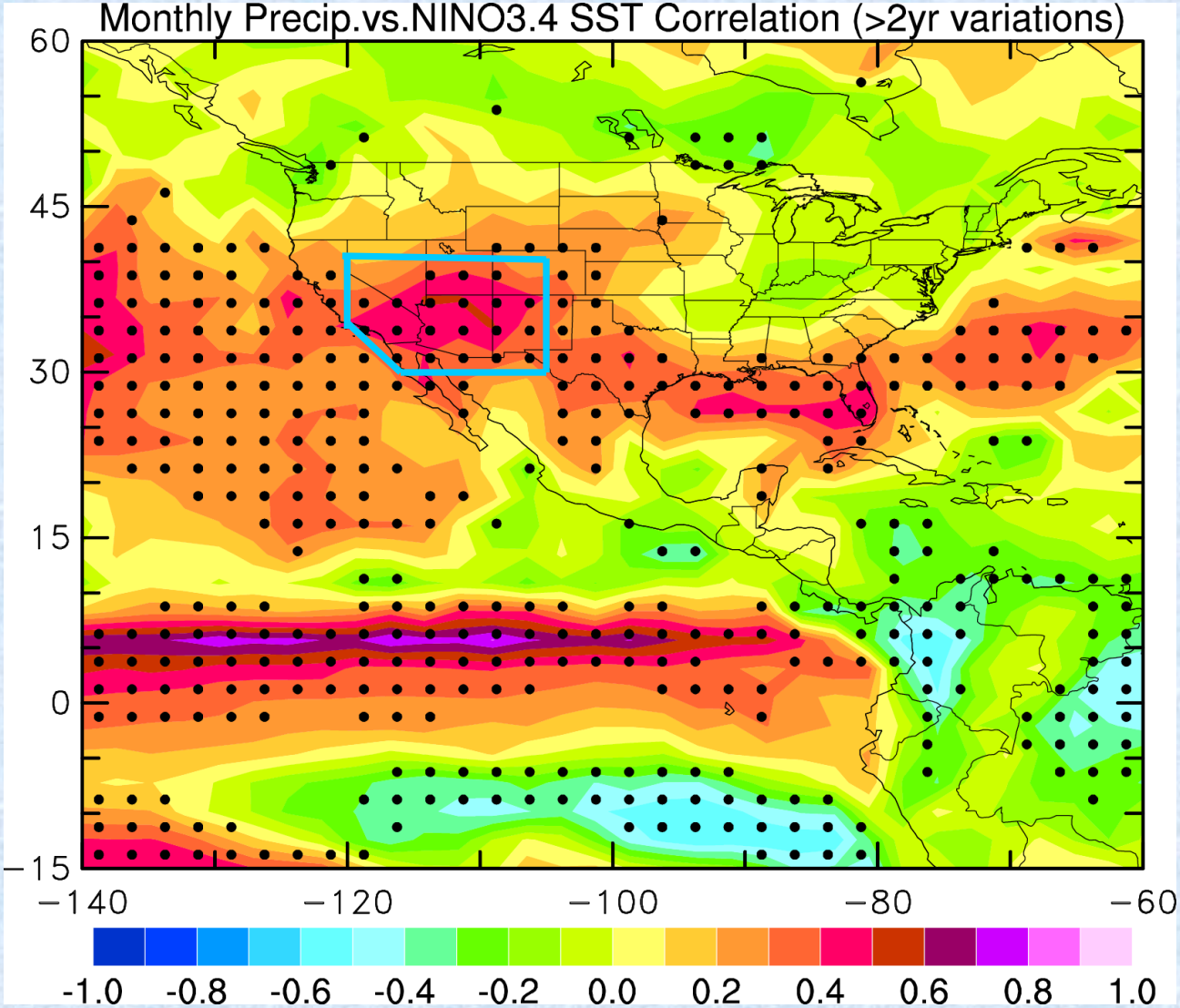
Observed Monthly Precipitation vs. Nino3.4 SST Correlation

Data Period: 1920-2010 (land) and 1979-2010 (ocean)



Nino3.4 = 5°S-5°N, 120°W-170°W

Dotted area: significant at 5% level

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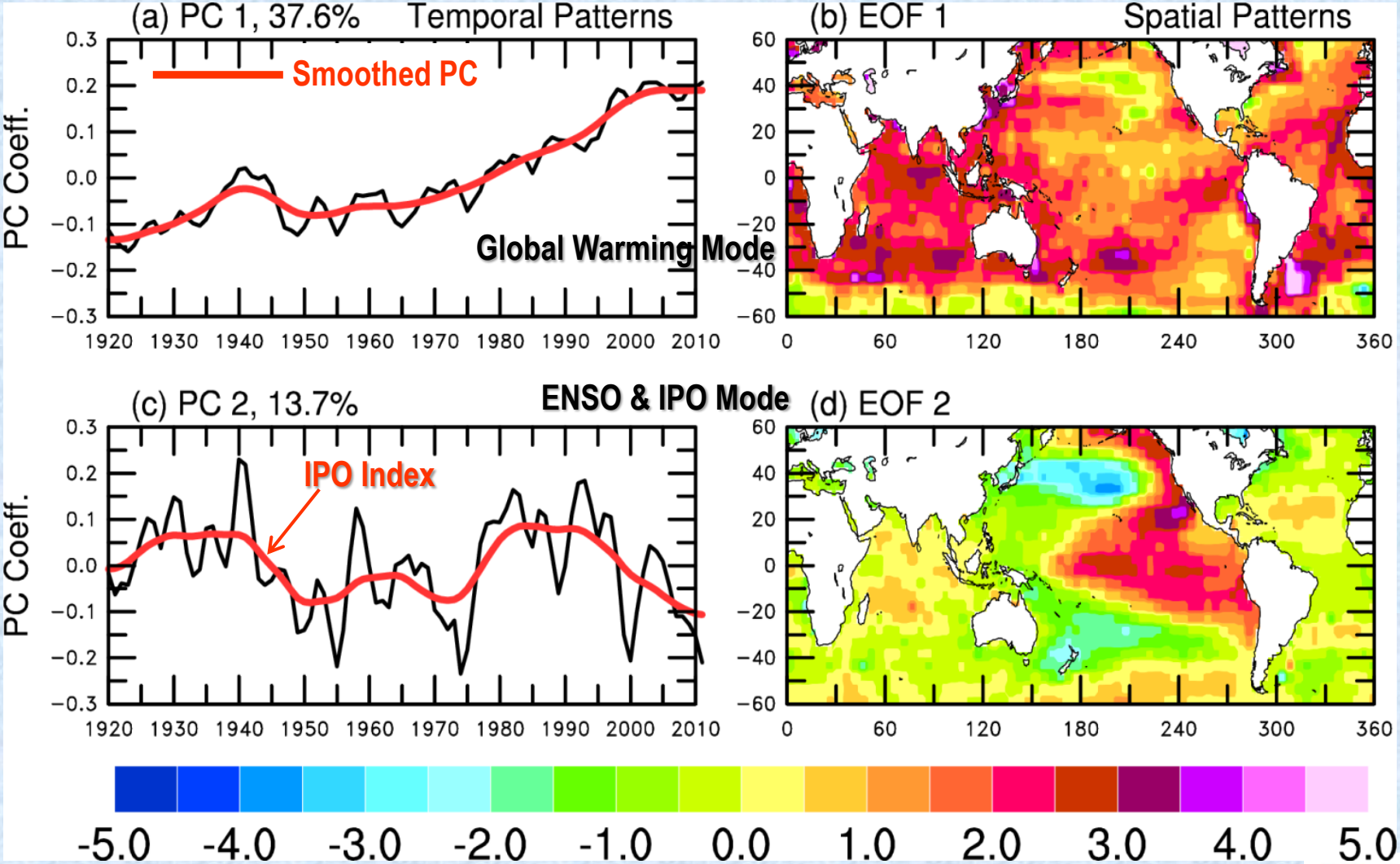
Leading Modes of Global SST Variability: 1920-2011

Defining the Inter-decadal Pacific Oscillation (IPO) Index



EOF = Empirical Orthogonal Function

SST data source: HadISST data set from U.K. Met Office Hadley Centre

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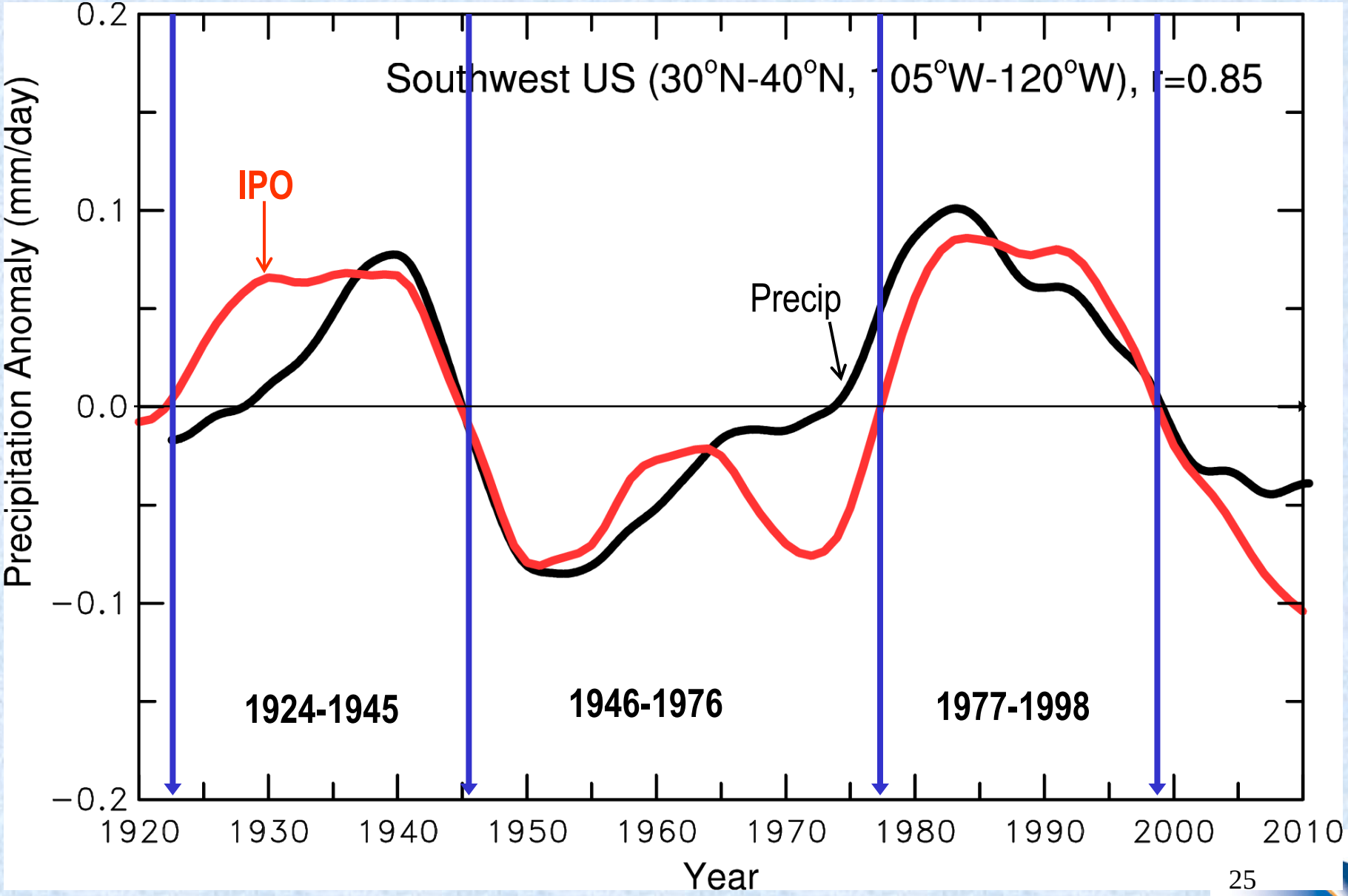
IPO vs. Southwest U.S. Precip Correlation



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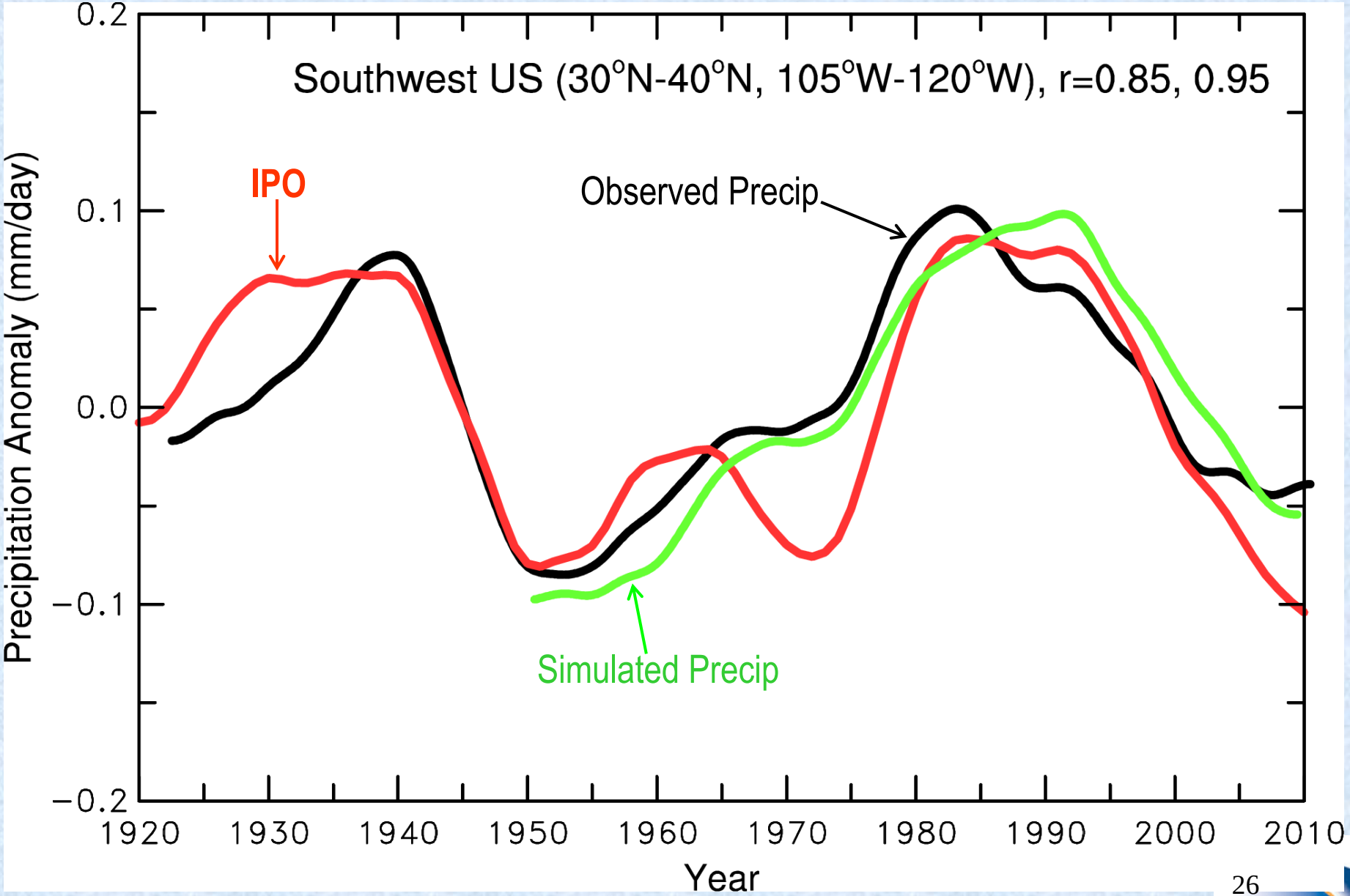
IPO vs. Southwest U.S. Precip Correlation



CanAM4 - Canadian Atmospheric Model version 4 (dx~2.8°) forced with observed SST from 1950-2009

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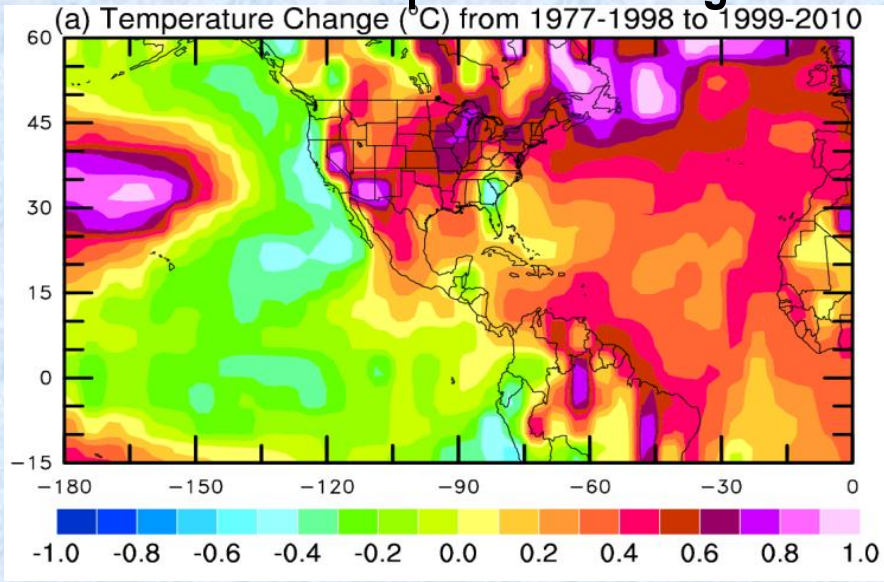
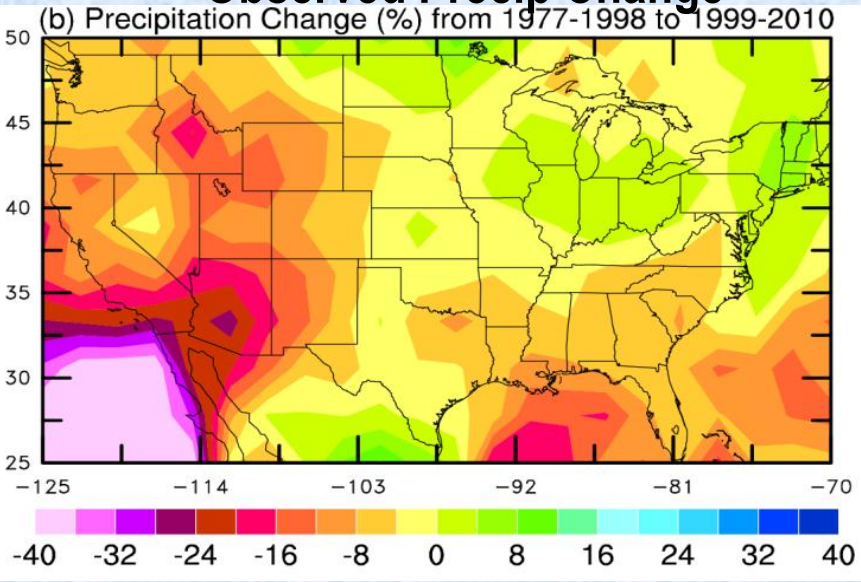
Change Patterns: 1999-2010 minus 1977-1998

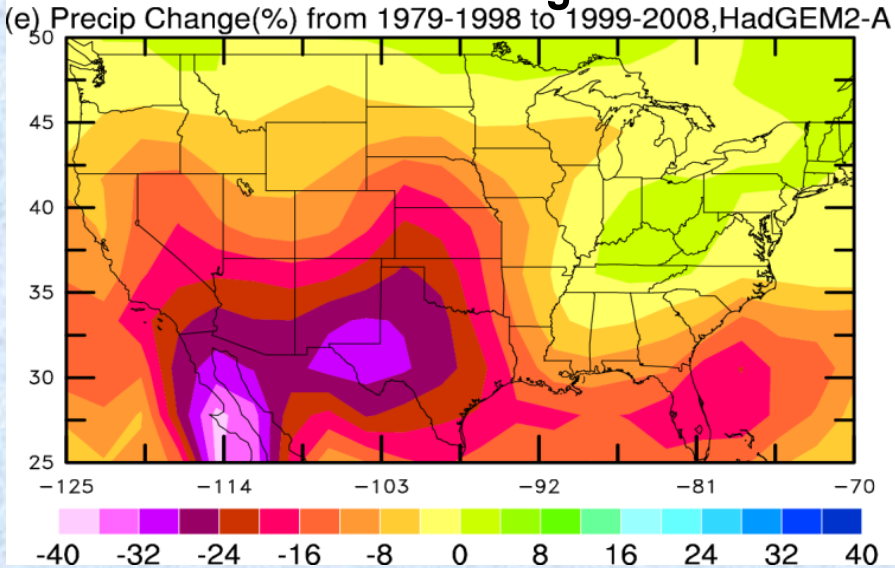
Observed Temperature Change



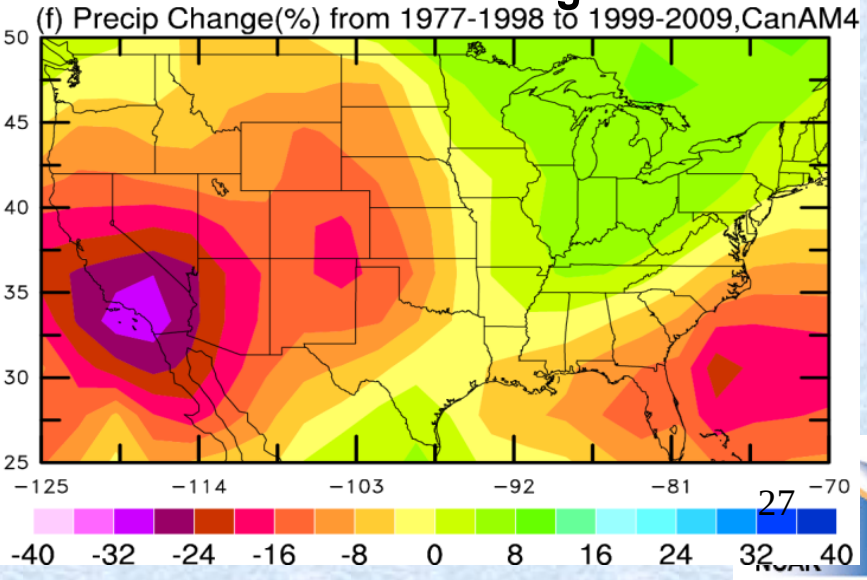
Observed Precip Change



Model Simulated P Change: HadGEM2-A



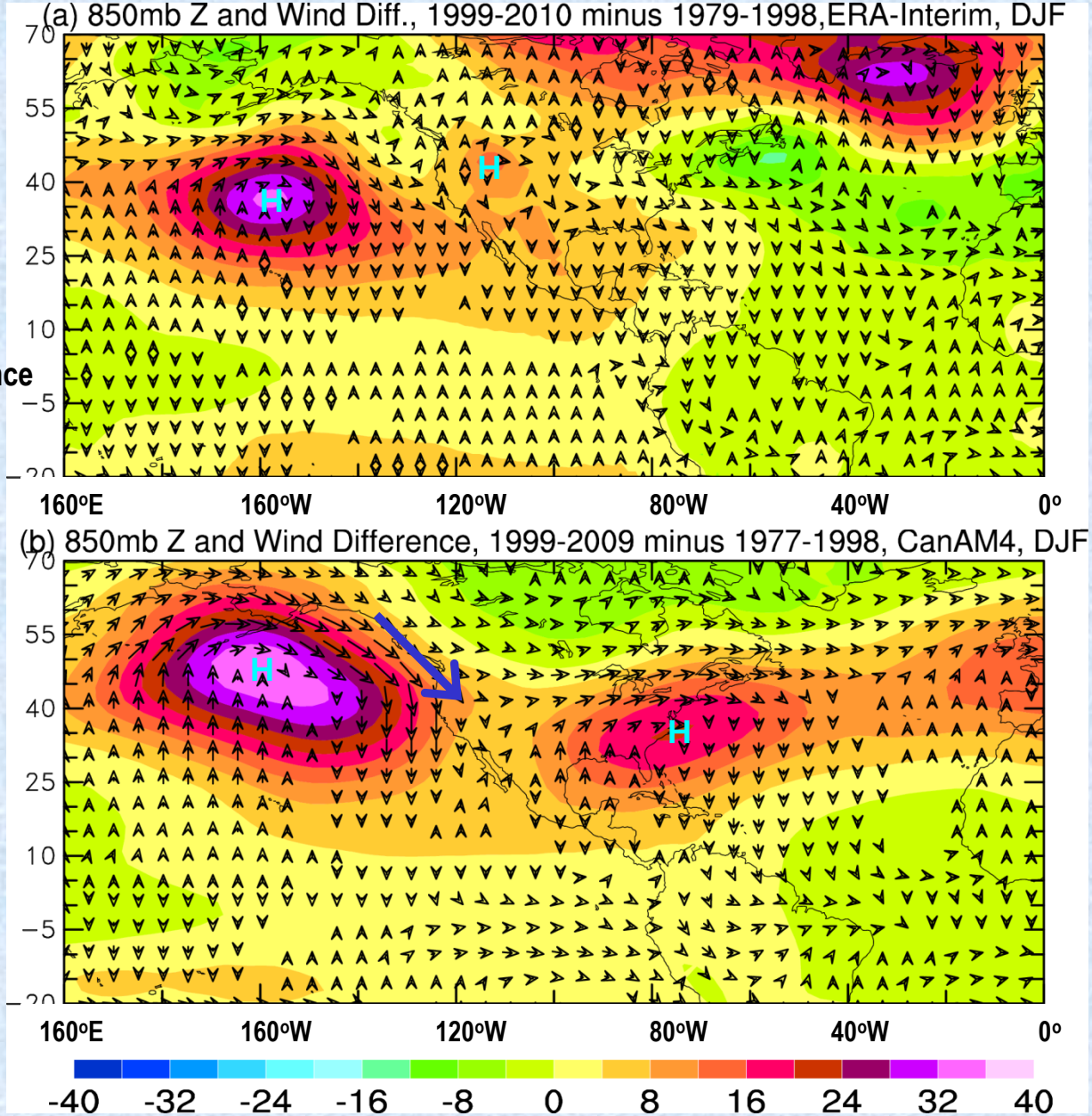
Model Simulated P Change: CanAM4



Change Patterns: 1999-2010 minus 1977-1998

Colors:
850mb geopotential height difference

Arrows:
850mb wind difference



Atmos. Reanalysis
ERA-Interim

Model Simulation
CanAM4

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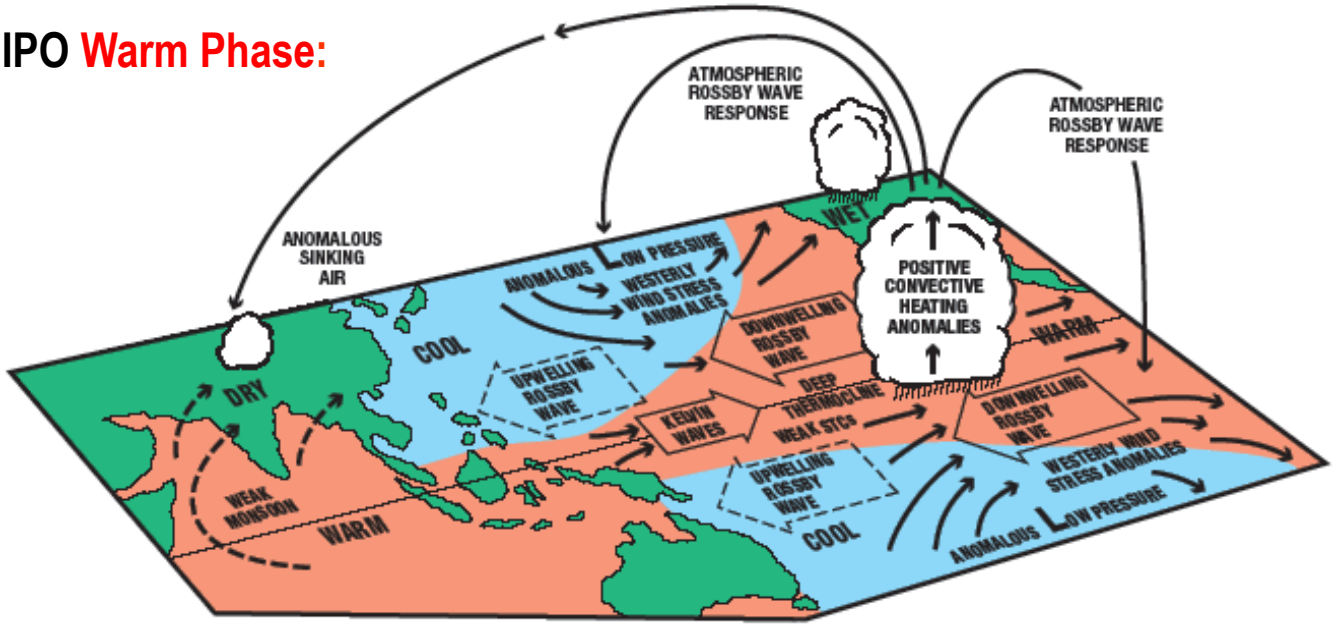
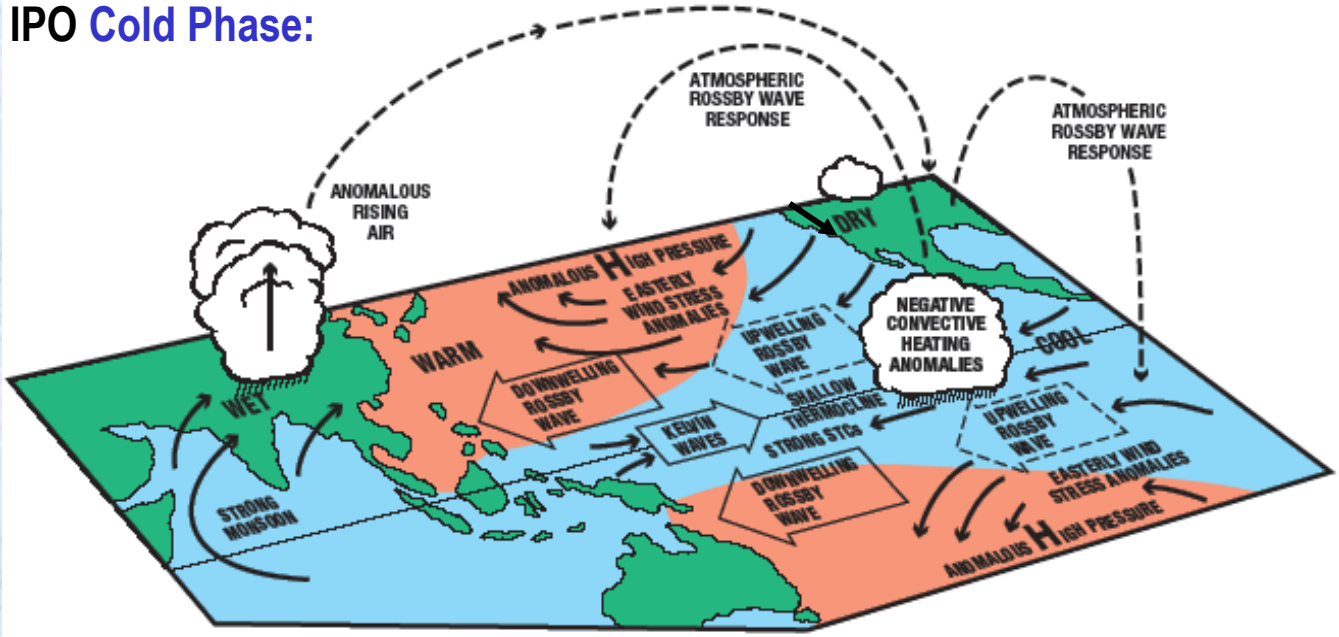
IPO Warm Phase:



IPO Cold Phase:



Meehl & Hu (2006)

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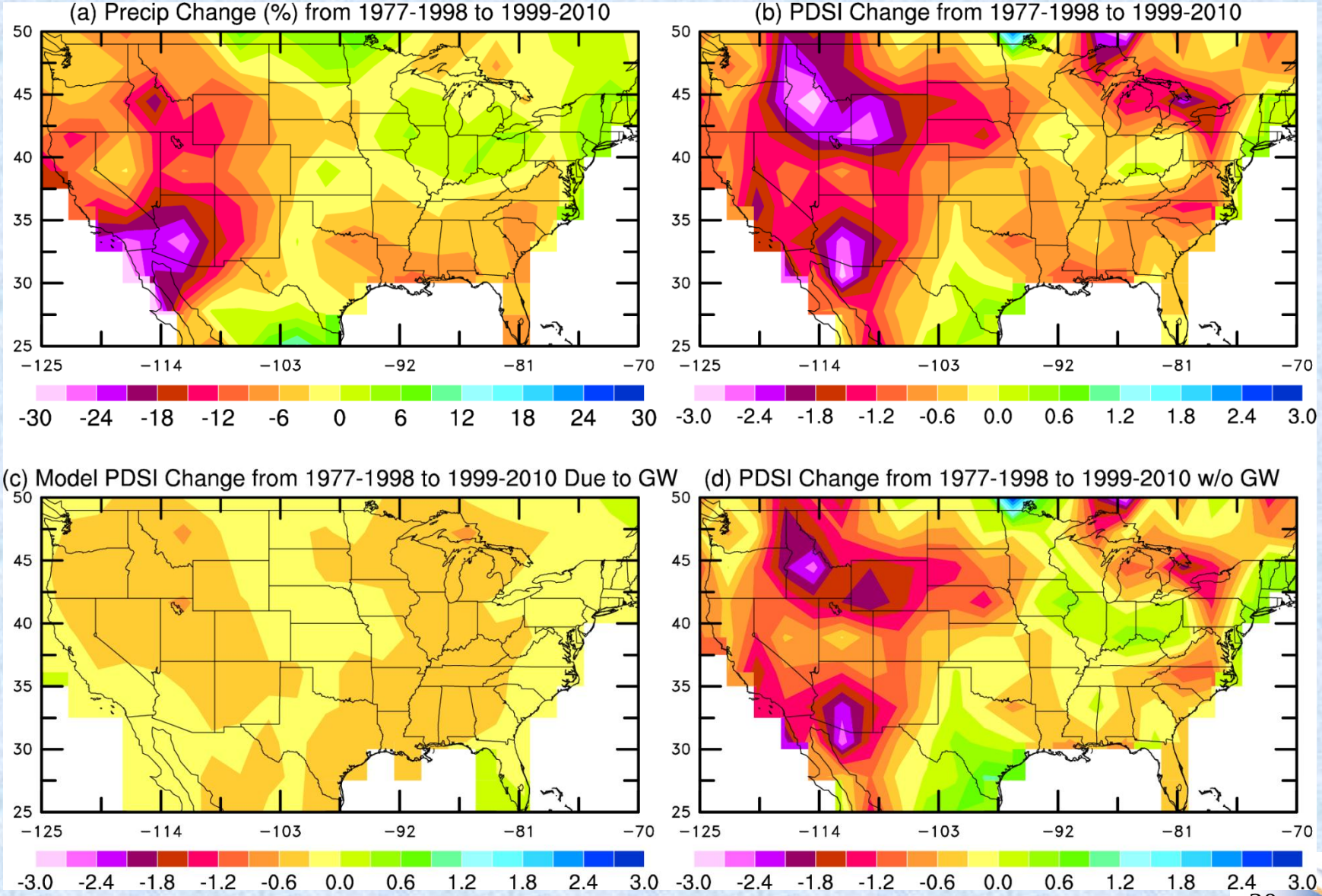
Decadal Difference: 1999-2010 minus 1977-1998



Drying from 1977-1998 to 1999-2010 resulted mainly from IPO and other natural variations.

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What is the outlook for the near future?

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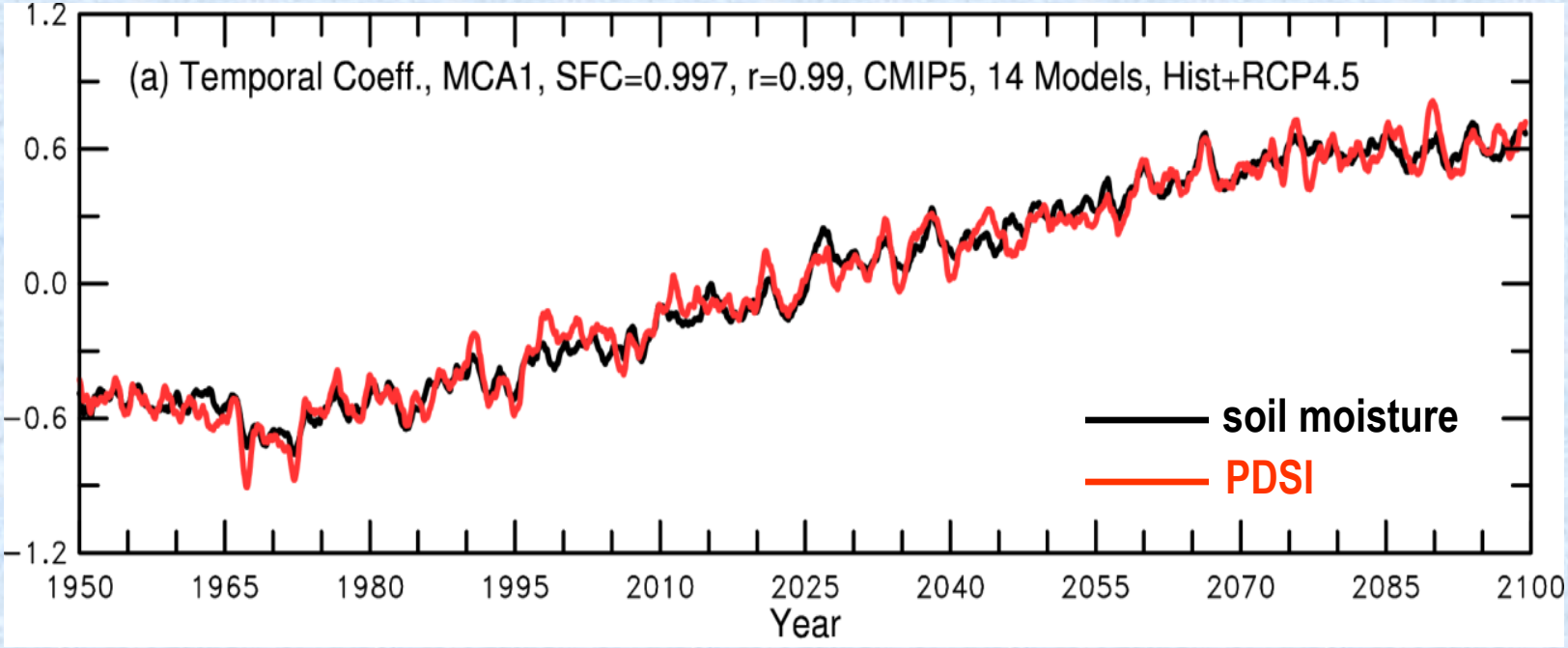
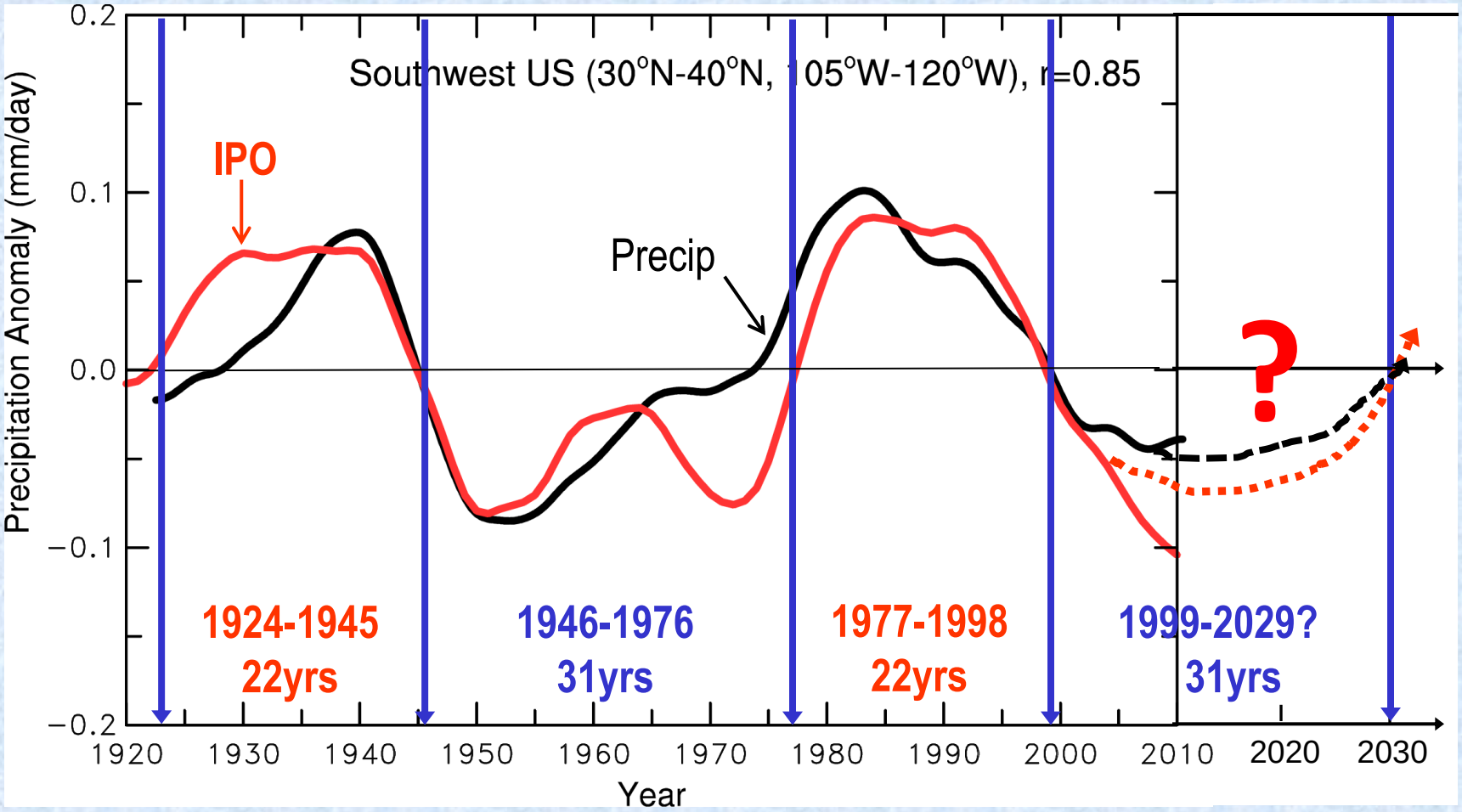
Future Trends in Soil Moisture and PDSI due to Global Warming Only



Prediction of the IPO



- What controls the IPO phase change is not well understood
- Models still have difficulties in predicting the IPO
- If it follows previous cycles → Cold phase 1999-2029, Warm phase 2030-2051

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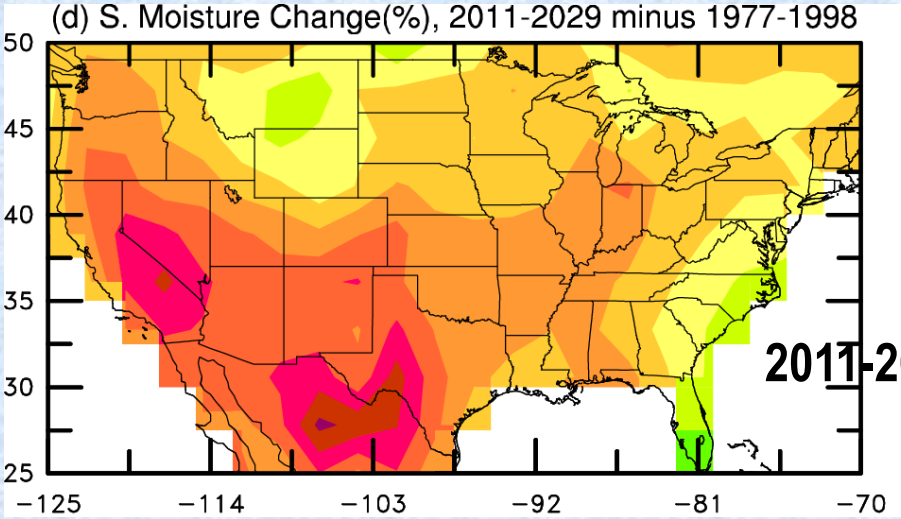
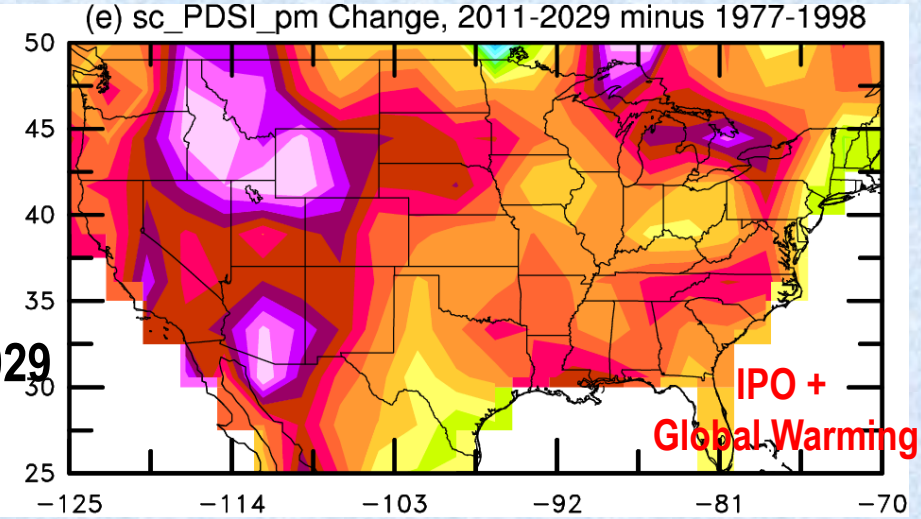
Future Changes Relative to 1977-1998

Model-simulated Soil Moisture Changes
Global Warming Effect Only



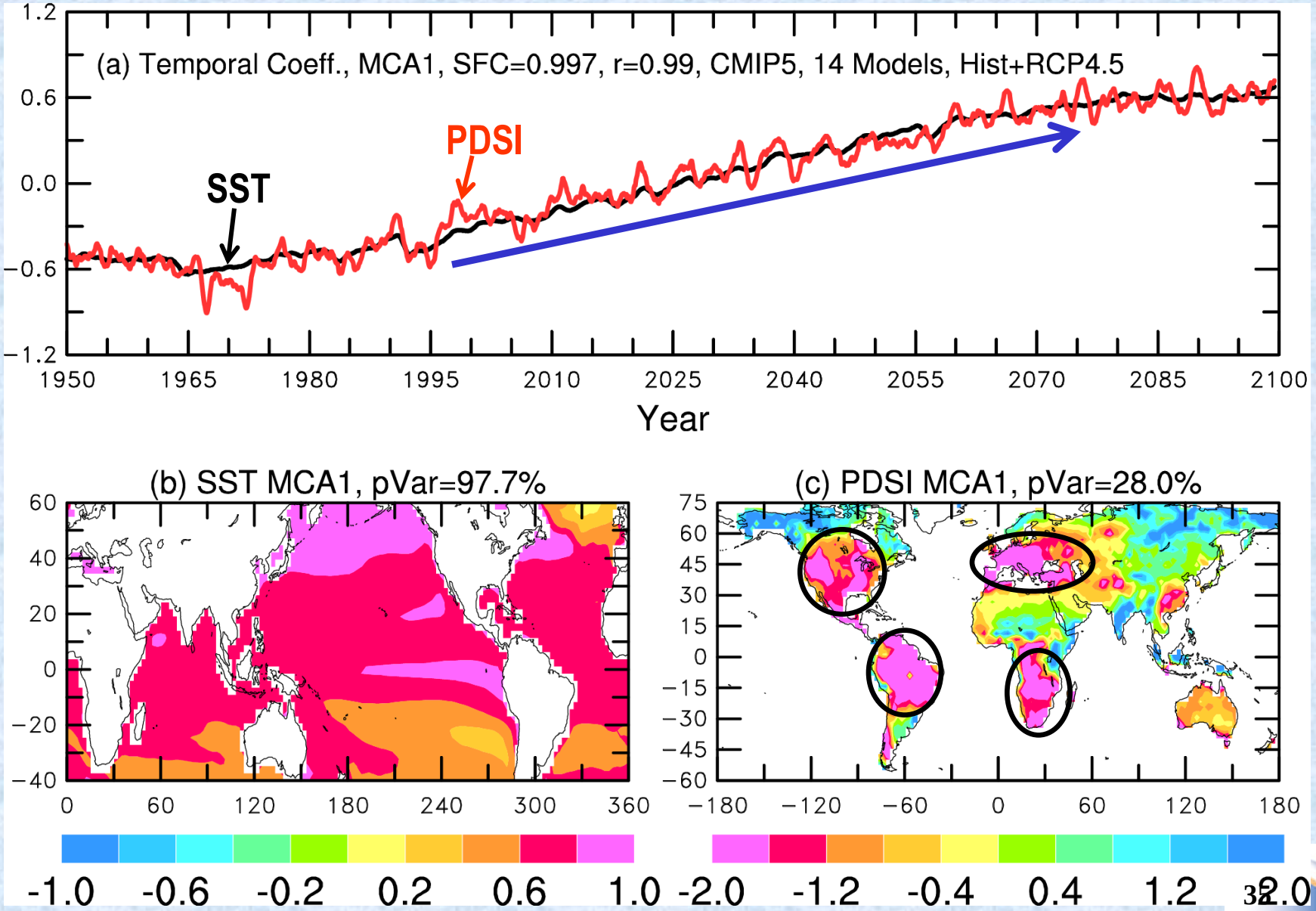
2011-2029

Future PDSI Changes
With/wihtout IPO Effect



IPO +
Global Warming

Global Warming Mode: 1950—2099



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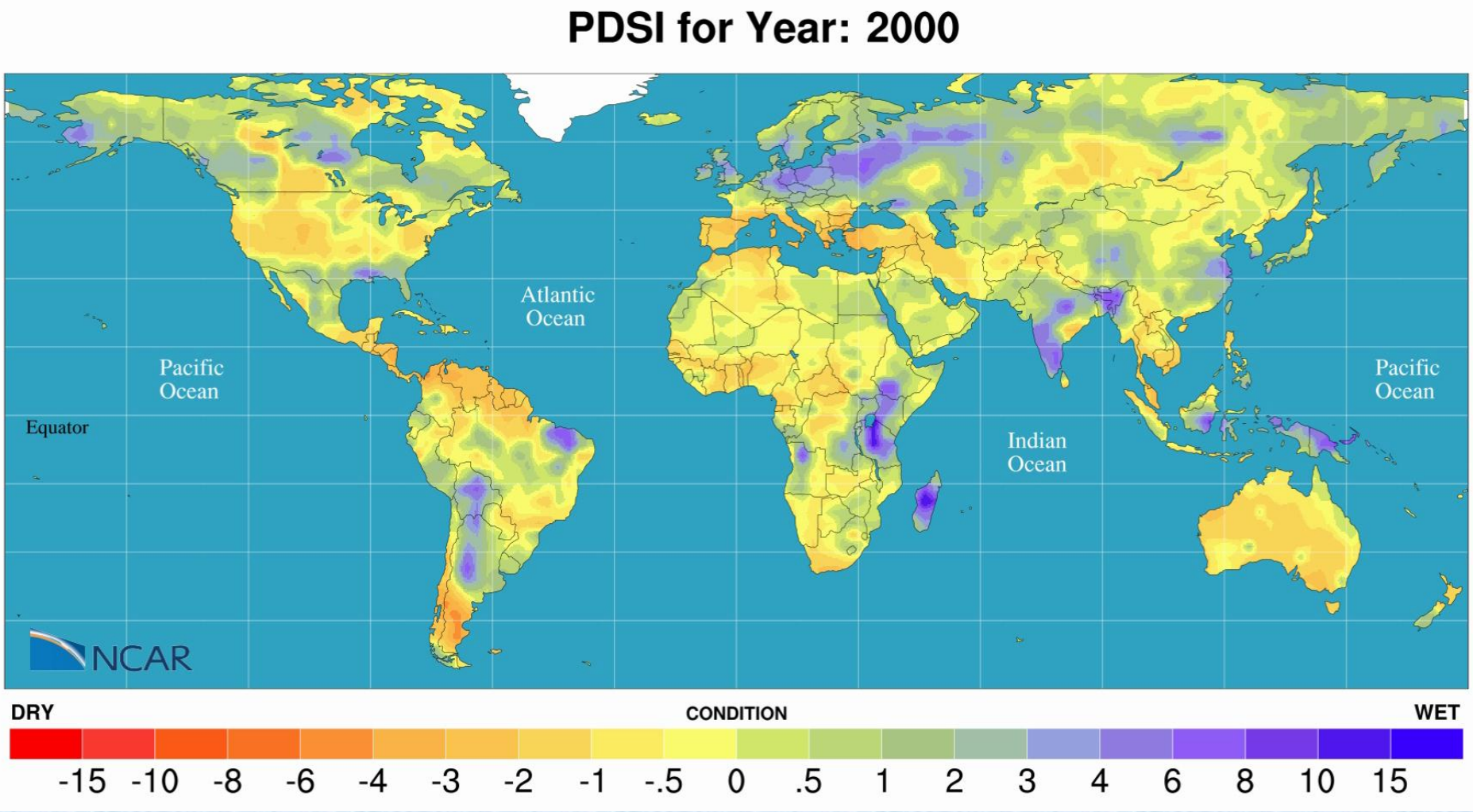
PDSI Due to GHG-induced Global Warming Only



Available on YouTube: www.youtube.com/NcarUcar

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Is this our future?

Worst wild fire in Texas history!

Bastrop State Park: 14,000 acres, Nearly 600 homes destroyed. 5 Sept 2011

Sixty separate wildfires, whipped by strong winds, were burning across Texas on Monday, destroying hundreds of homes and killing at least two people: TIME

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Summary

- Precipitation and streamflow data, together with PDSI, show a drying trend over most Africa, South and East Asia, southern Europe, eastern Australia and other regions since 1950;
- Recent warming appears to have enhanced drying over many land areas during the last 30 years;
- Model projections suggest severe drying in the 21st century over most land areas (including the U.S.), except northern high-latitudes and most Asia;
- Warm tropical Pacific SSTs led to the wet period from 1977-1998 over the U.S.;
- The switch to cold tropical Pacific SSTs since 1999 caused drier conditions over the U.S. during 1999-2011;
- The current dry conditions may last and worsen during the next 20 yrs as the IPO cold phase persists and global warming continues; and
- Even if the IPO switches back to a warm phase after 2030, the U.S. may still face dry conditions as the drying from global warming becomes large.

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