Use of regional atmospheric modeling to address climate variability and change in Arizona

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University of Arizona

Invited seminar
Arizona State University
Tempe, Arizona

November 28, 2007

Presentation outline

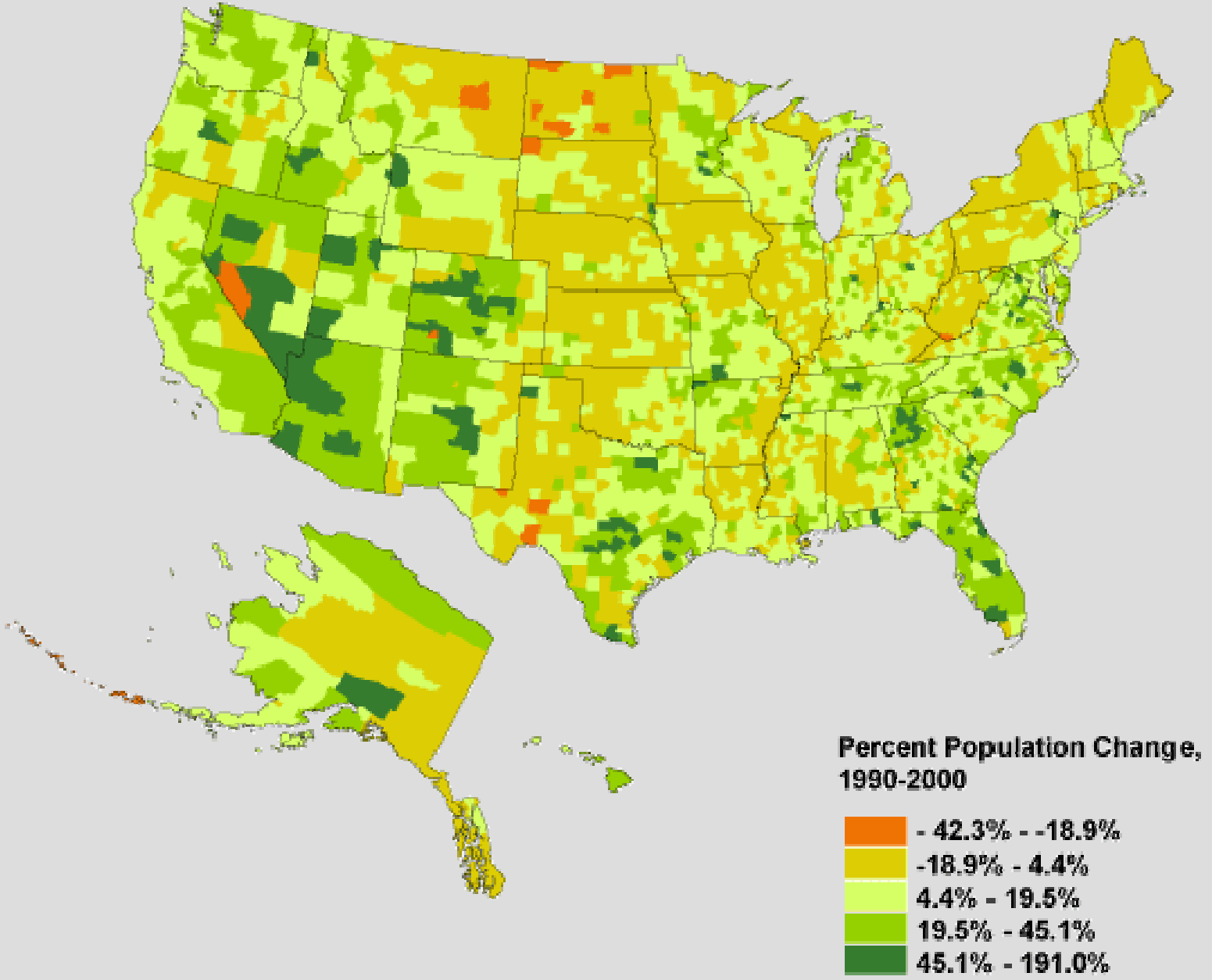
Motivation: Why climate REALLY matters in a place like Arizona.

GCM Projections of climate change…and their caveats

Use of regional models to represent recent summer climate

Towards long-range climate projection with a regional modeling approach

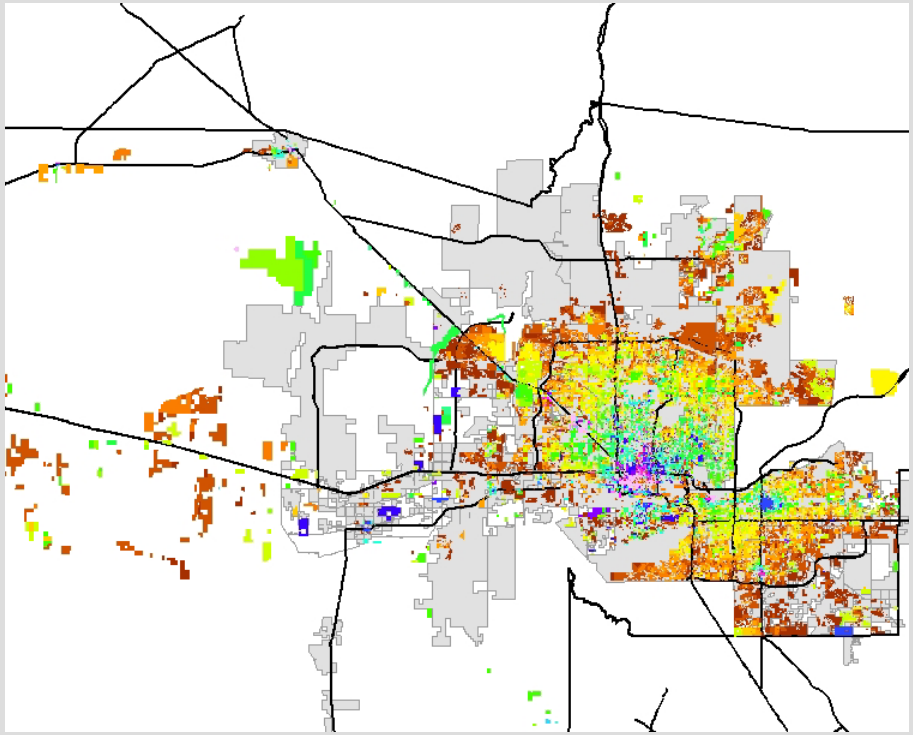
Summary points



(US Census Bureau)

Where has most of that growth in Arizona taken place?

Growth of Recorded Subdivisions in Maricopa County (1900-2007)



Source: http://www.maricopa.gov/assessor/

Georgescu (matt1@cep.rutgers.edu)
Assessing The Impact of LULCC on
The Greater Phoenix Area

Those “red” areas, representing the most recent development used to look like this…

Pinal county

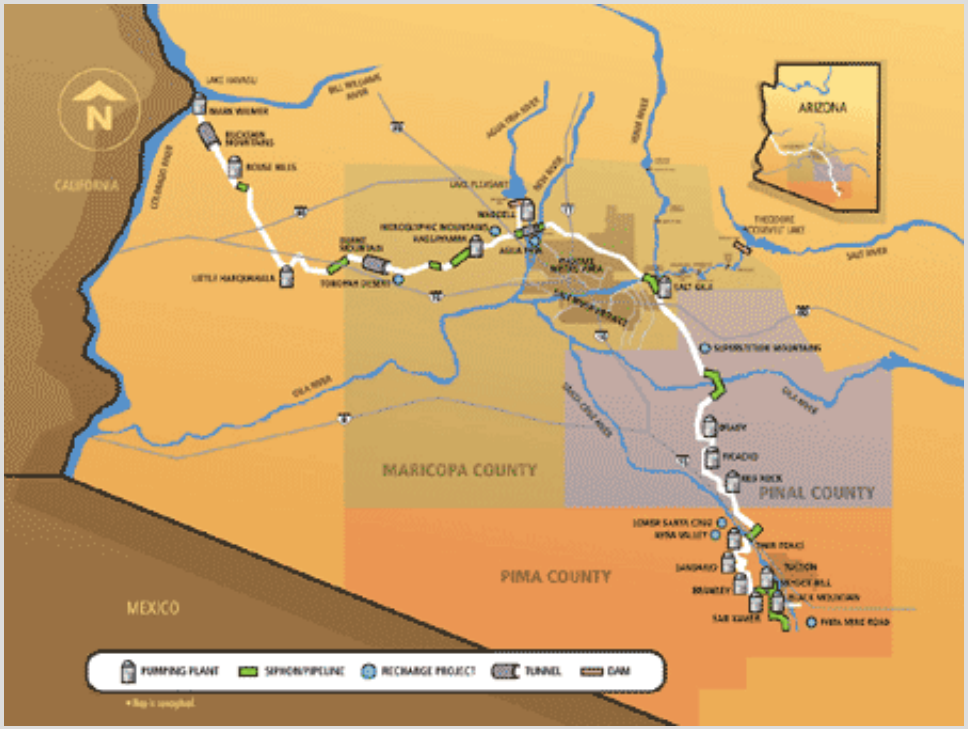
Before the city of Maricopa emerged in about 2001

Now it looks like this…

Rancho El Dorado Subdivision
Maricopa, Arizona

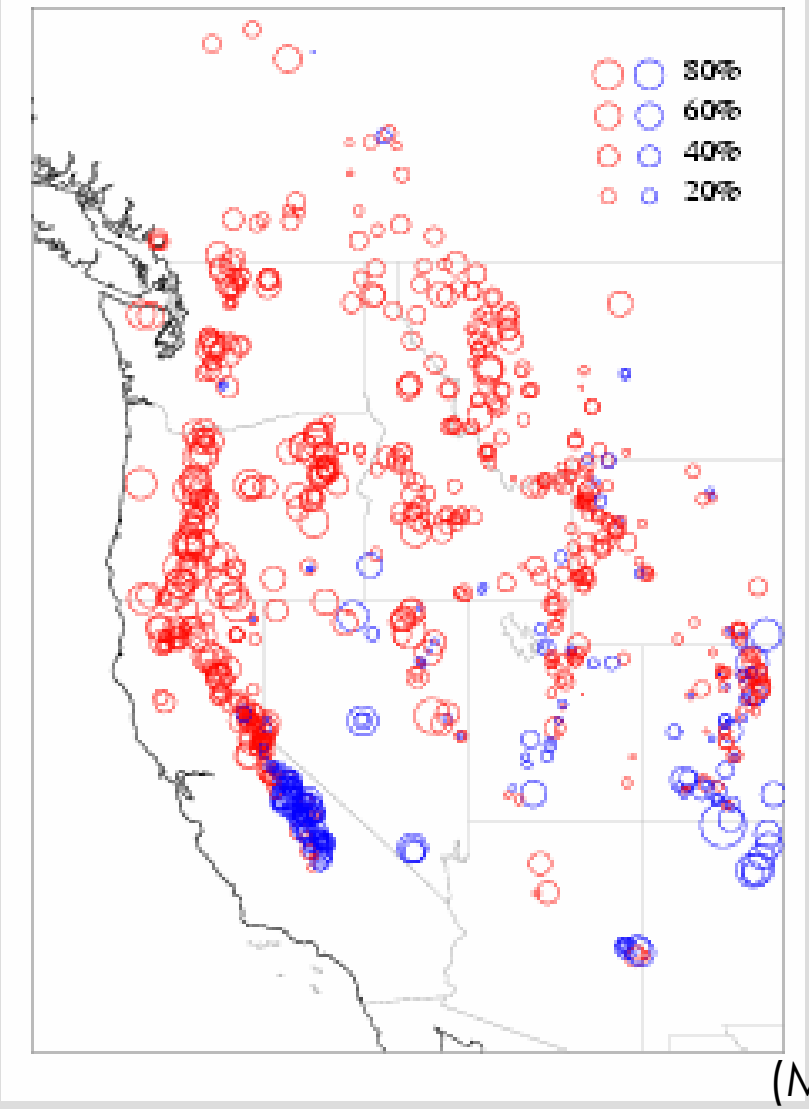
This basically happened in about three years, fueled mainly by real estate speculation and risky loans…and there are a lot of for sale signs here right now!

The Central Arizona Project
One of the main suppliers of water to Arizona



(www.cap-az.com)

Trends (1950-97) in April 1 snow-water content at western snow courses

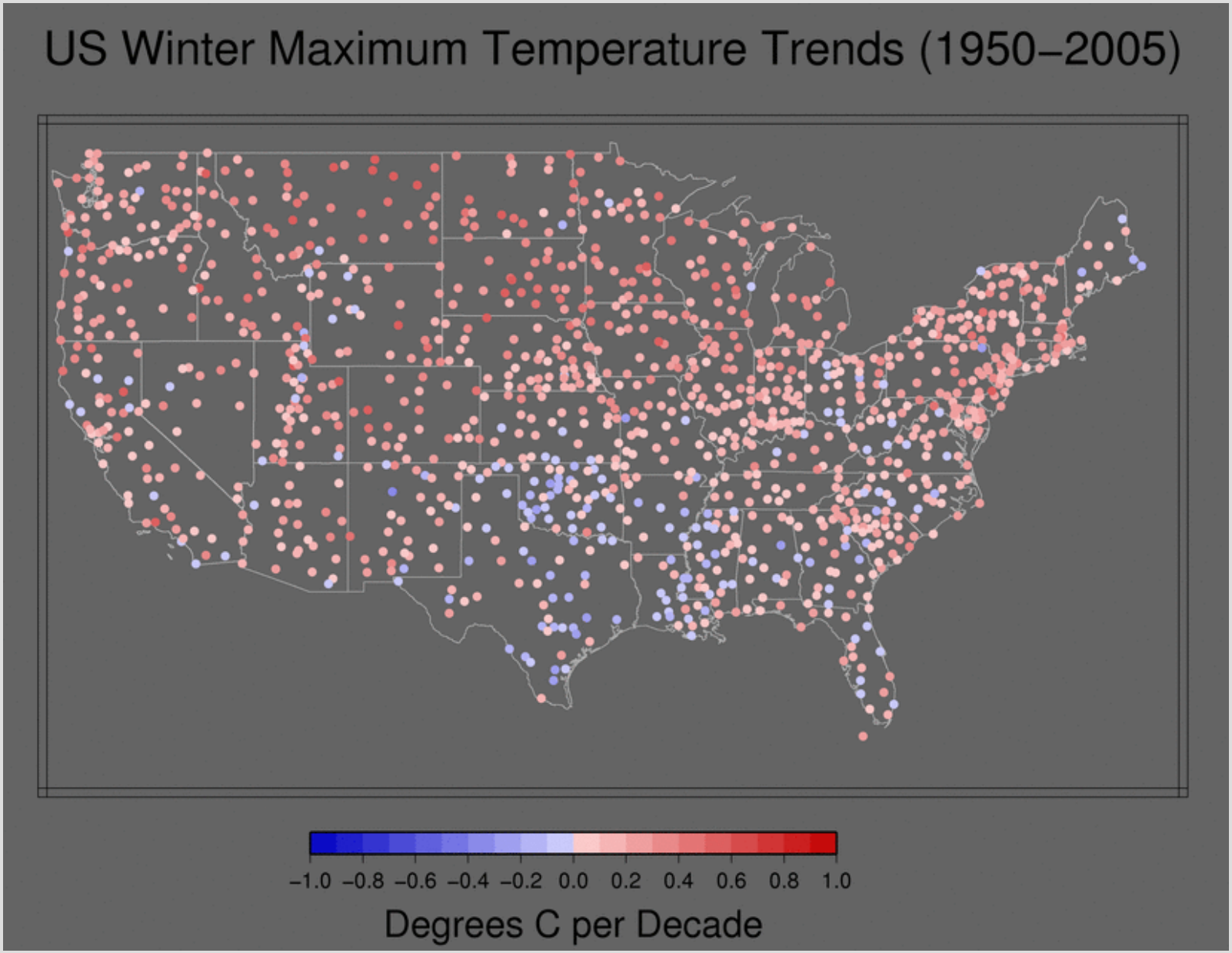


(Mote 2003)

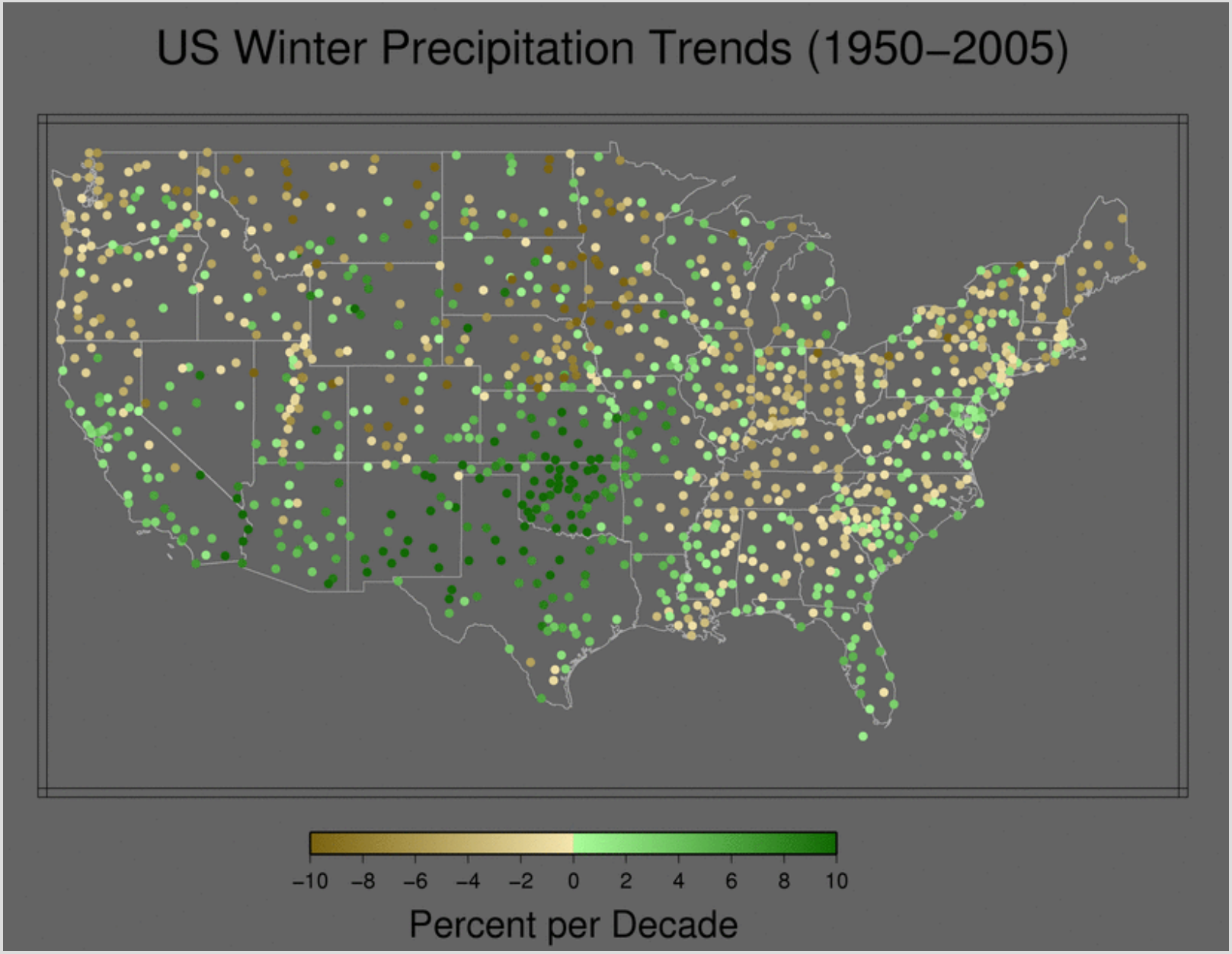
Big question:

Is this anthropogenic climate change?

IPCC report suggests yes, and I would agree.

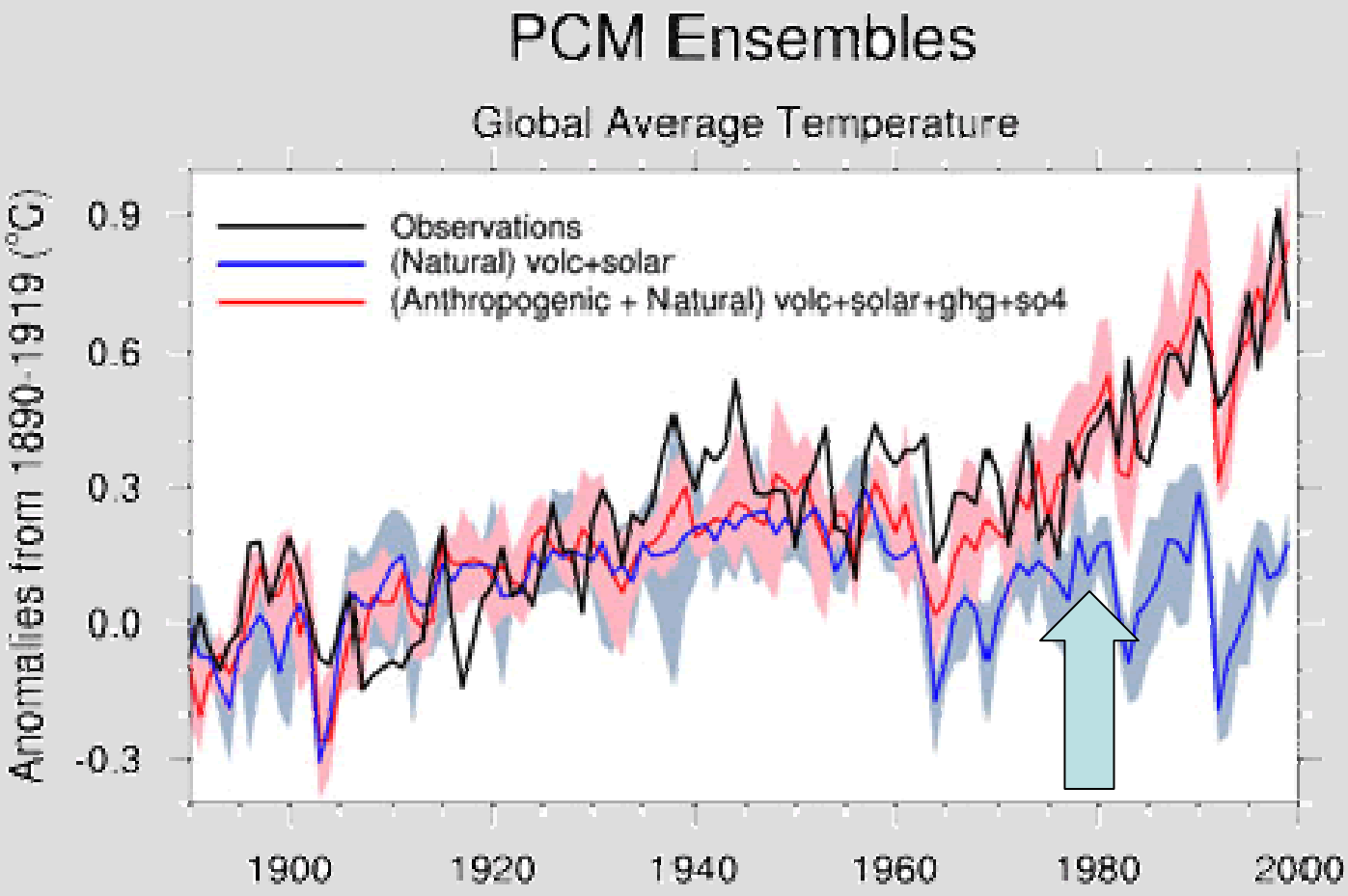


(NOAA National Climate Data Center)



(NOAA National Climate Data Center)

IPCC Attribution Experiments With General Circulation Models



(Meehl et al., National Center for Atmospheric Research)

So just how concerned is the state of Arizona about climate change?

Conference on Climate Change and Higher Education in Arizona

MEMORANDUM

TO: Campus Community
FROM: Robert N. Shelton, President
SUBJECT: Conference on Climate Change and Higher Education in Arizona
DATE: September 27, 2007

I am sending the following information on behalf of Kathy Jacobs, Executive Director of the Arizona Water Institute, and Marcus Ford, Pas President of the Arizona Faculty Council. This conference presents a unique opportunity for University of Arizona faculty to join their colleagu at Arizona State University and Northern Arizona University in a discuss about one of the most critical issues of our time.

On behalf of the Arizona Board of Regents, the three University Preside the Arizona Faculty Council, the Arizona Water Institute and the Global Institute of Sustainability, we would like to invite you to the first-ever statewide event to investigate the role of higher education in addressing issues associated with climate change.

The Climate Change and Higher Education Conference, "Preparing Our Students for a Changing World," will be held Monday, Nov. 26, 2007, fro... 9 a.m. to 1:30 p.m. (lunch included) on the Arizona State University's Tempe campus in the Carson Ballroom of Old Main.

We will feature presentations on the physical-science and social-science implications of climate change as well as perspectives from the three University presidents, members of the Board of Regents, the Governor's office, and students.

Conference speakers include:

- **Gov. Janet Napolitano** (invited)
- **Presidents Michael M. Crow, Robert N. Shelton and John D. Haeger**
- **Board of Regents members Ernest Calderon (confirmed) and Fred DuVal** (invited)
- **Featured Speakers Patricia Gober (ASU) and Jonathan Overpeck** (UA)

As public universities, we have a unique responsibility to educate our students about the far-reaching social and physical implications of climate change, and engage them in conversations about the adaptation and response options that may be available. In addition, Arizona's citizens need to explore what lies in store in the future and how we can best adjust to new realities. Arizona's universities have already engaged in research on climatic uncertainty; green building; sustainable materials and renewable technologies; alternative types of transportation; and curricular changes. The purpose of this conference is to reflect on whether or not our research and educational efforts will be adequate to face the challenges. We will ask:

- Is there more that we should be doing and, if so, what?
- Are system-wide changes needed?
- How can we mobilize our resources to address priority programs?

What is motivating the attention to the climate change issue?

1. **Attribution of recent climate change to anthropogenic activities**

2. **Climate change projections for the future—which look pretty scary**

A very recent study by Seager et al. (2007)

Sciencexpress Report

Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

Richard Seager,[1] Mingfang Ting,[1] Isaac Held,[2,3] Yochanan Kushnir,[1] Jian Lu,[4] Gabriel Vecchi,[2] Huei-Ping Huang,[1] Nili Harnik,[5] Ants Leetmaa,[2] Ngar-Cheung Lau,[2,3] Cuihua Li,[1] Jennifer Velez,[1] Naomi Naik[1]

[1]Lamont Doherty Earth Observatory of Columbia University, Palisades, NY, USA. [2]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA. [3]Program in Atmospheric and Oceanic Sciences, Department of Geosciences, Princeton University, Princeton, NJ, USA. [4]National Center for Atmospheric Research, Boulder, CO, USA. [5]Tel Aviv University, Tel Aviv, Israel.

Abstract of Seager et al. (2007)

How anthropogenic climate change will impact hydroclimate in the arid regions of Southwestern North America has implications for the allocation of water resources and the course of regional development. Here we show that there is a broad consensus amongst climate models that this region will dry significantly in the 21st century and that the transition to a more arid climate should already be underway. If these models are correct, the levels of aridity of the recent multiyear drought, or the Dust Bowl and 1950s droughts, will, within the coming years to decades, become the new climatology of the American Southwest.

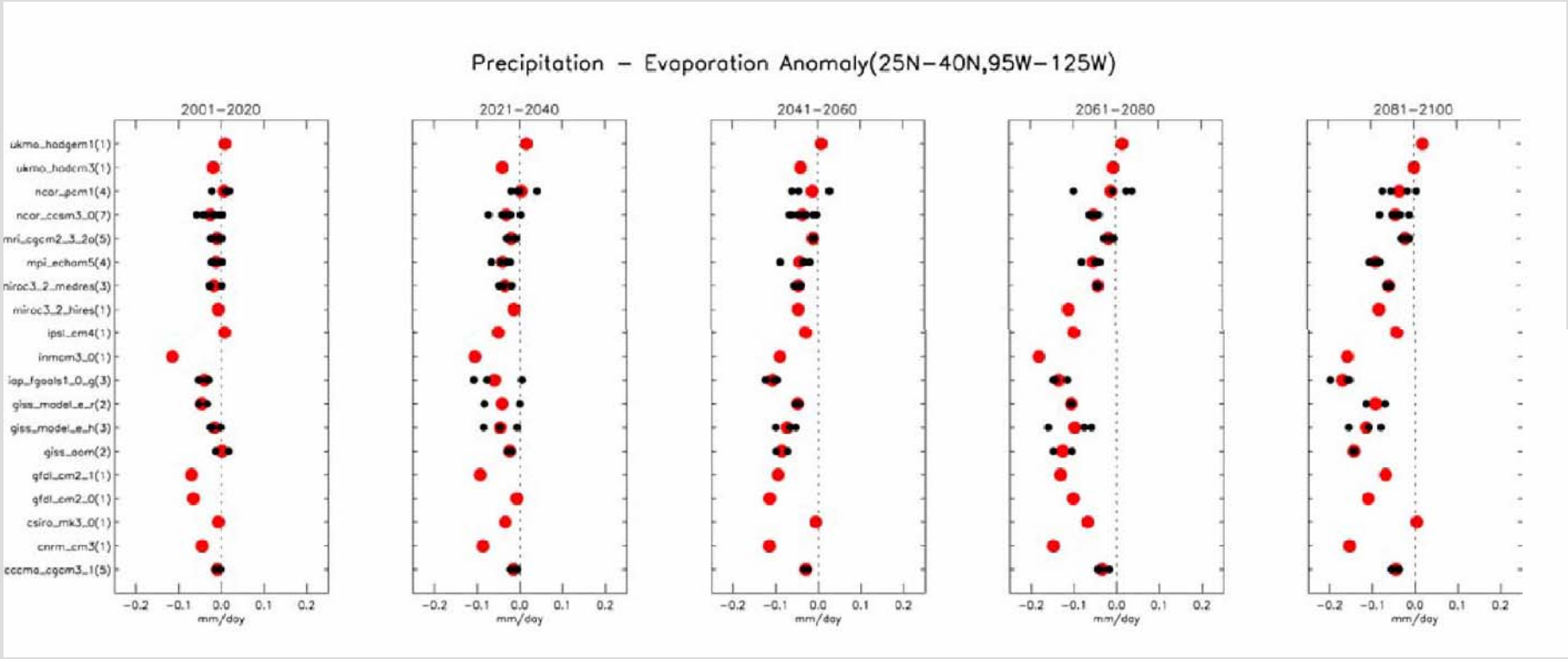
Scientists predict Southwest mega-drought

Climate models indicate region will be as dry as Dust Bowl for decades

David Mcnew / Getty Images

A bleached "bathtub ring," the result of a six-year drought that has dramatically dropped the level of the reservoir, shows on red Navajo sandstone formations near Last Chance Bay at Lake Powell near Page, Ariz. Lake Powell and the next biggest Colorado River reservoir, the nearly 100-year-old Lake Mead, are at the lowest levels ever recorded.

IPCC GCM P-E results for the SW (relative to model climatologies)



Seager et al. (2007)

But how far should we trust general circulation models for regional climate change projections like this?

There are some pretty big caveats there…if you dig a little bit.

In the multi-model ensemble mean there is a transition to a sustained drier climate that begins in the late 20th and early 21st centuries. In the ensemble mean both P and E decrease but the former by a larger amount. $P–E$ primarily reduces in winter when P reduces and E is unchanged or modestly increased while in summer both P and E decrease (not shown). The annual mean reduction in P for this region, calculated from rain gauge data within the Global Historical Climatology Network, was 0.09 mm/day between 1932 and 1939 (the Dust Bowl drought) and 0.13 mm/day between 1948 and 1957 (the 1950s Southwest drought). The ensemble median reduction in P that drives the reduction in $P–E$ reaches 0.1 mm/day in mid-century and one quarter of the models reach this in the early part of the current century.

(Seager et al. 2007)

Caveat #1: Is the ensemble mean really the best metric to gauge the impact of climate change?

Caveat #2: Do the IPCC GCMs have a good climatological representation of precipitation for the Southwest?

Caveat #3: If the global warming signal due to anthropogenic forcing starts to be realized in about 1980, do recent observed climate trends agree with the IPCC model results that precipitation decreases during the entire year?

The cool and warm seasons have very different weather and climate concerns in Arizona—so a yearly average precipitation value isn't probably the best metric.

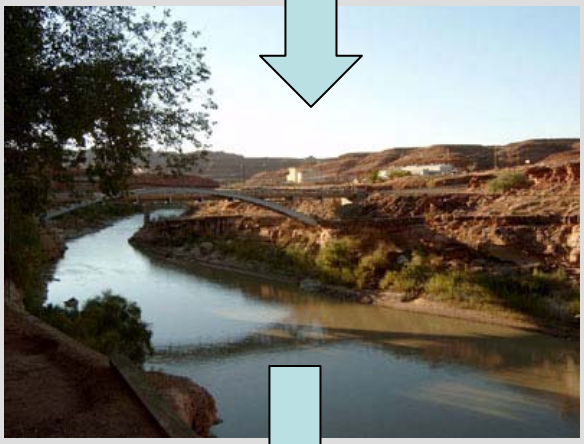
Cool season: Winter storms

Primarily the amount of winter snowpack for water supply

The major control on long-term drought in Arizona and the Southwest as a whole.

GCMs can do a somewhat reasonable job in representing winter precipitation because it is dependent on mid-latitude cyclones which the model can resolve—and the winters are, in general getting drier and warmer in the western U.S.

Snowpack in southern Rockies



Colorado River

CAP and Salt River Projects

Warm season: Monsoon

Though not as important for water supply and long-term drought in Arizona, there are a variety of other important considerations.

GCMs do a far worse job representing warm season precipitation because it occurs on a much smaller spatial scale.

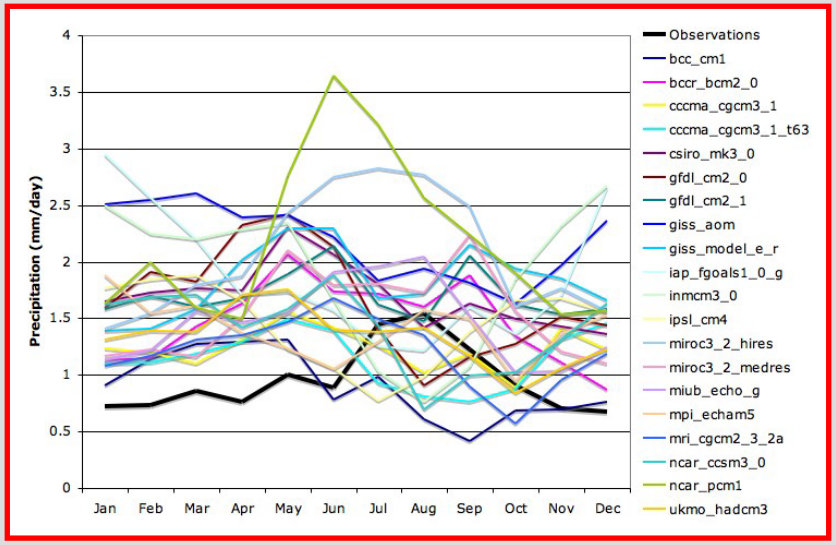
Severe weather

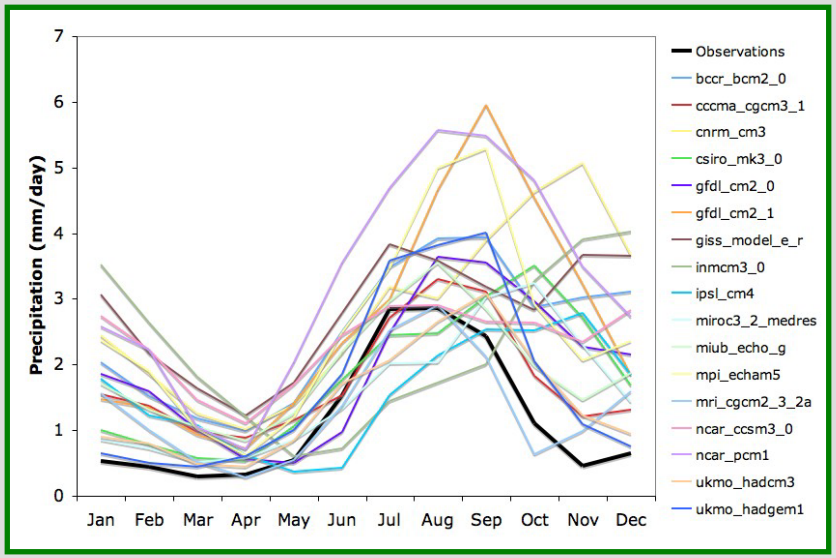
Wildfire

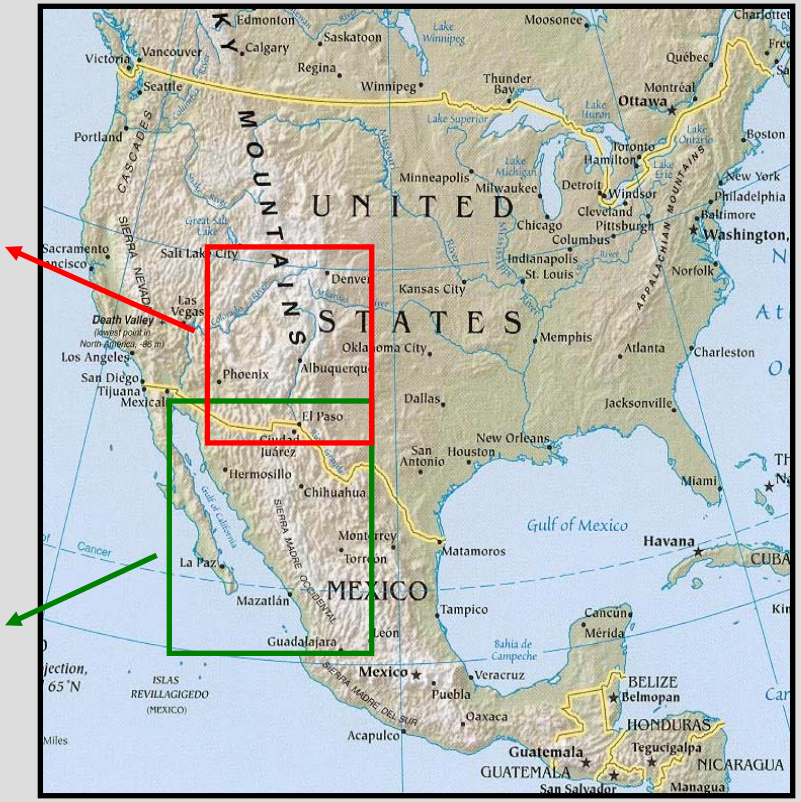
Water demand

Ranching and agriculture

GCM's still have problems capturing the seasonal cycle of precipitation, especially in the SW USA.



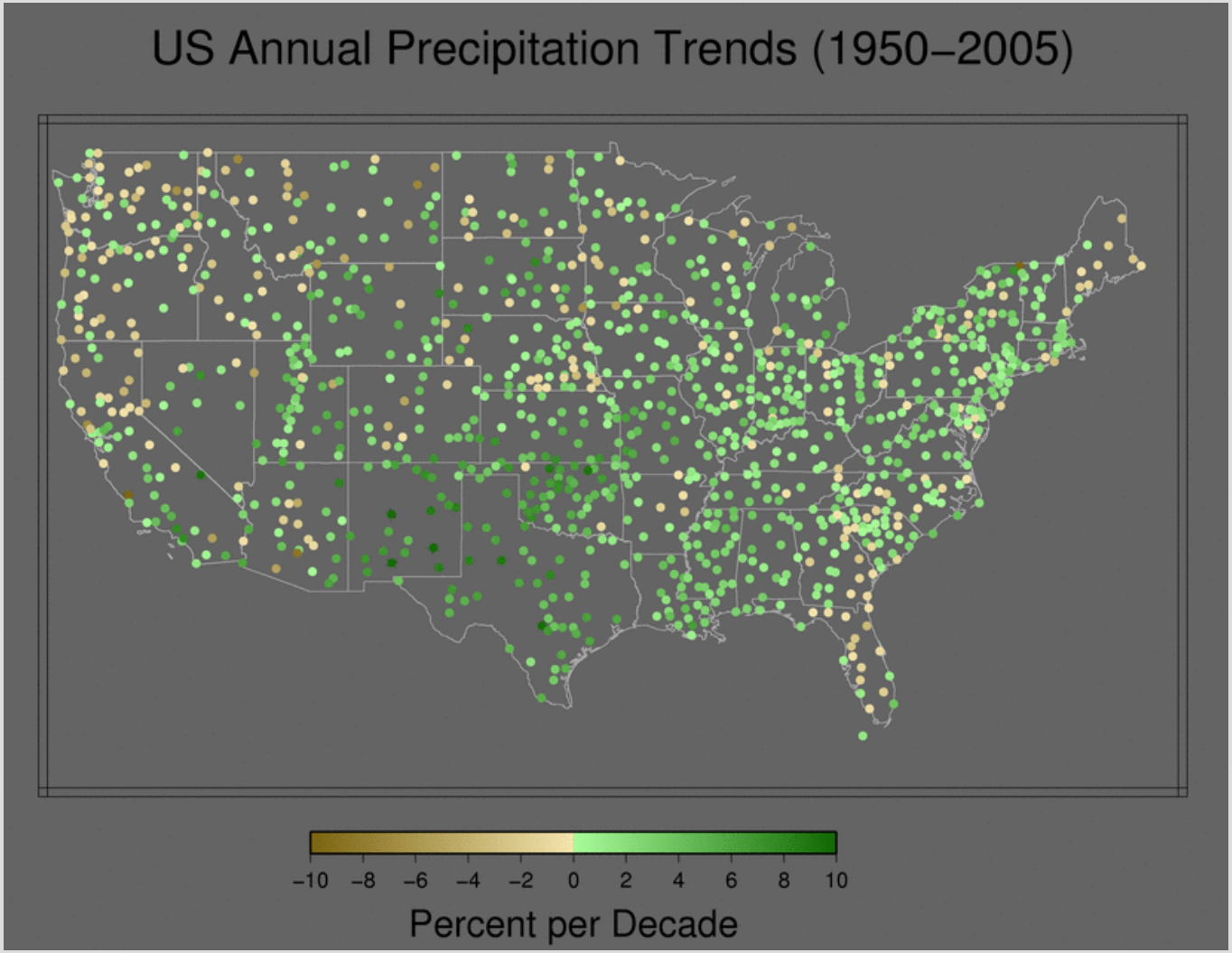




Average historical model runs (sres_20c3m) 1970-2000

(Courtesy Francina Dominguez)

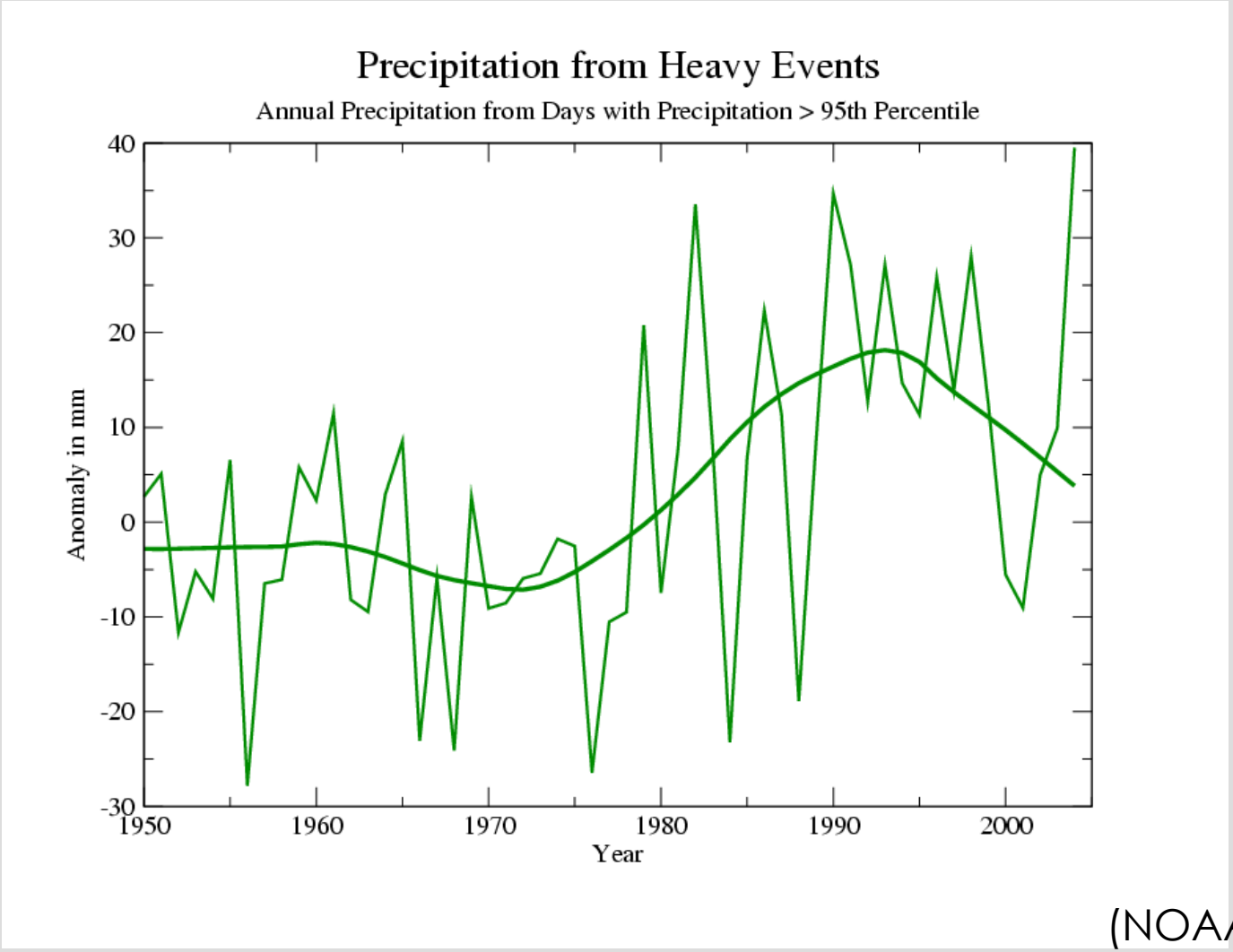
Precipitation in the U.S. has not been decreasing since 1980!



Much of this increase is occurring during the warmer parts of the year.

(NOAA National Climate Data Center)

The increased precipitation is due mainly to the extreme events…



(NOAA NCDC)

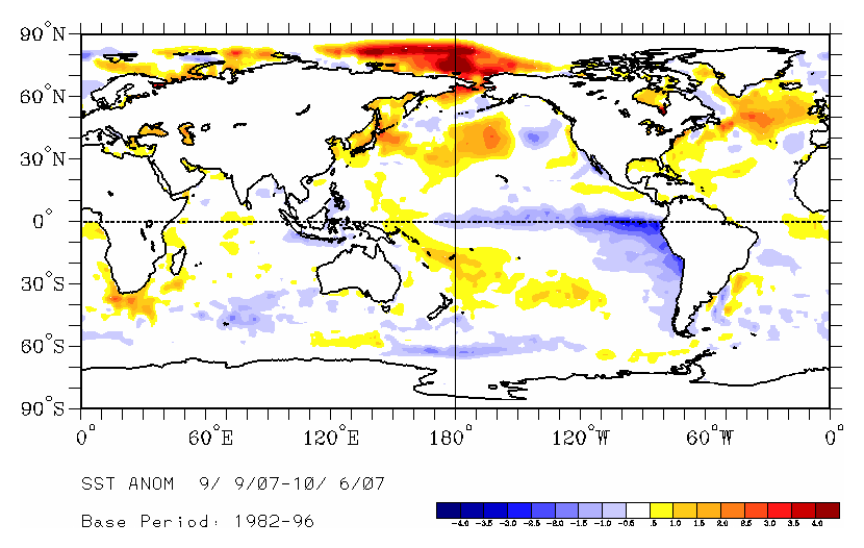
The six severe, multiyear, droughts that have struck western North America in the instrumental record have all been attributed, using climate models, to variations of sea surface temperatures (SSTs) in the tropics, particularly persistent La Niña-like SSTs in the tropical Pacific Ocean (*15–19*). The future climate of intensified aridity in the Southwest is caused by different processes since the models vary in their tropical SST response to anthropogenic forcing. Instead it is caused by rising humidity that causes increased moisture divergence and changes in atmospheric circulation cells that include a poleward expansion of the subtropical dry zones. The drying of subtropical land areas that, according to the models is imminent or already underway, is unlike any climate state we have seen in the instrumental record. It is also distinct from the multidecadal megadroughts that afflicted the American Southwest during Medieval times (*20-22*) which have also been attributed to changes in tropical SSTs (*18*, *23*). The most severe future droughts will still occur during persistent La Niña events but they will be worse than any since the Medieval period because the La Niña conditions will be perturbing a base state that is drier than any experienced recently (*25*).

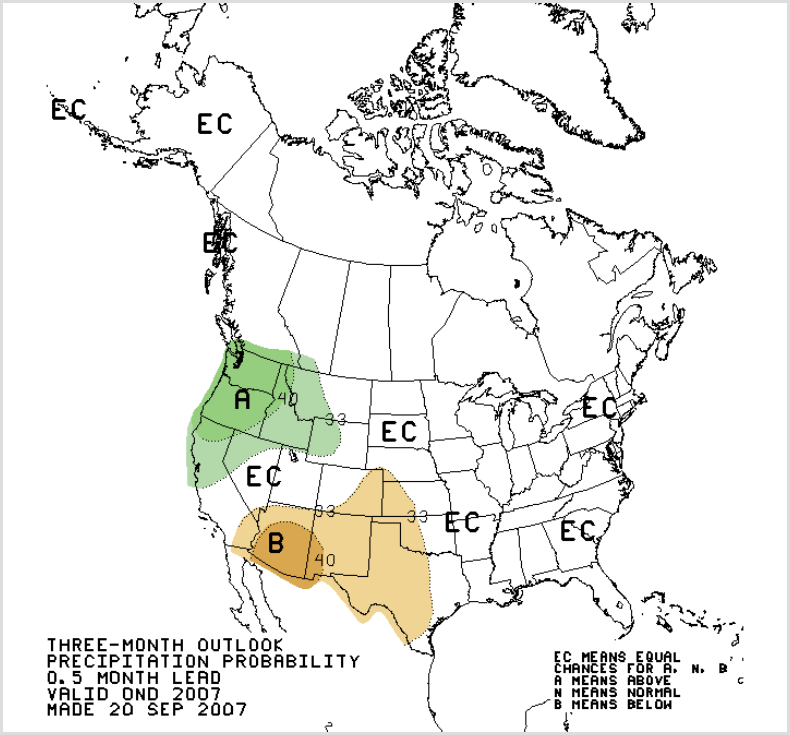
(Seager et al. 2007)

<u>Caveat #4</u>: Natural mechanisms of climate variability matter a lot to the climate in the Southwest, but some of the IPCC GCMs don't represent them well.

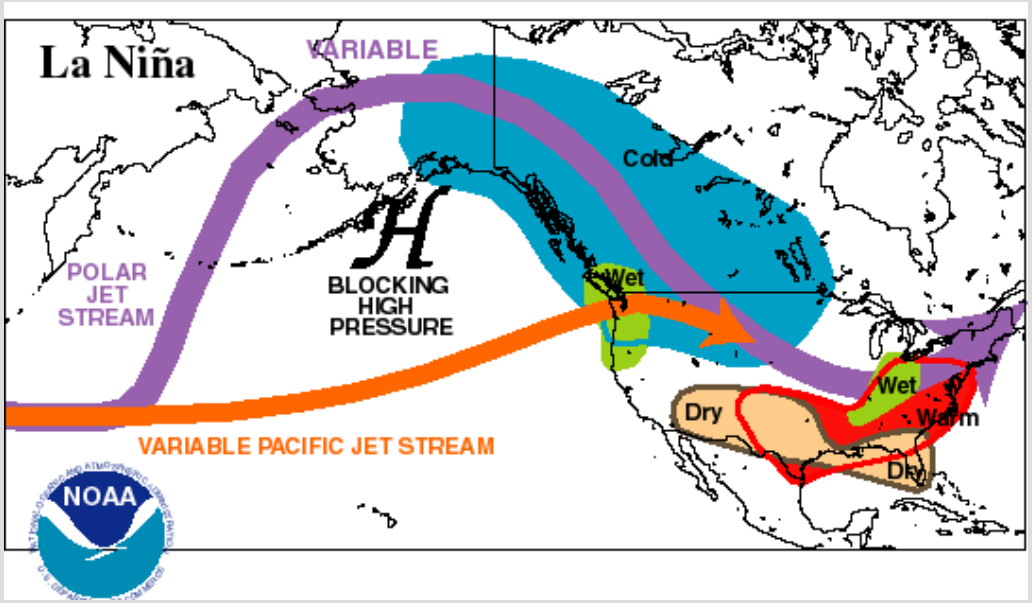
This affects how they are able to represent large-scale circulation patterns.

Current tropical Pacific SSTs and CPC long-range winter climate forecast



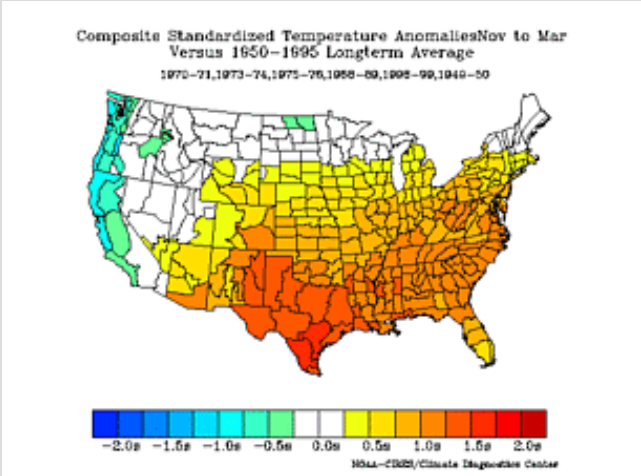


La Niña Impacts on United States: Winter

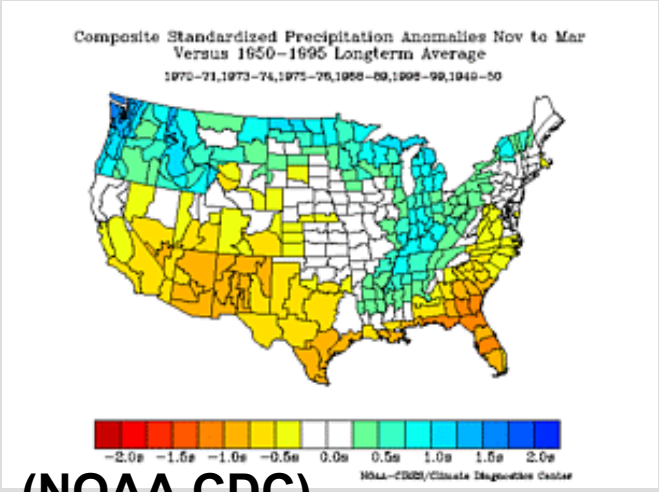


(NOAA CPC)

TEMPERATURE ANOMALY



RAINFALL ANOMALY



(NOAA CDC)

North American summer climate teleconnection to Pacific SST

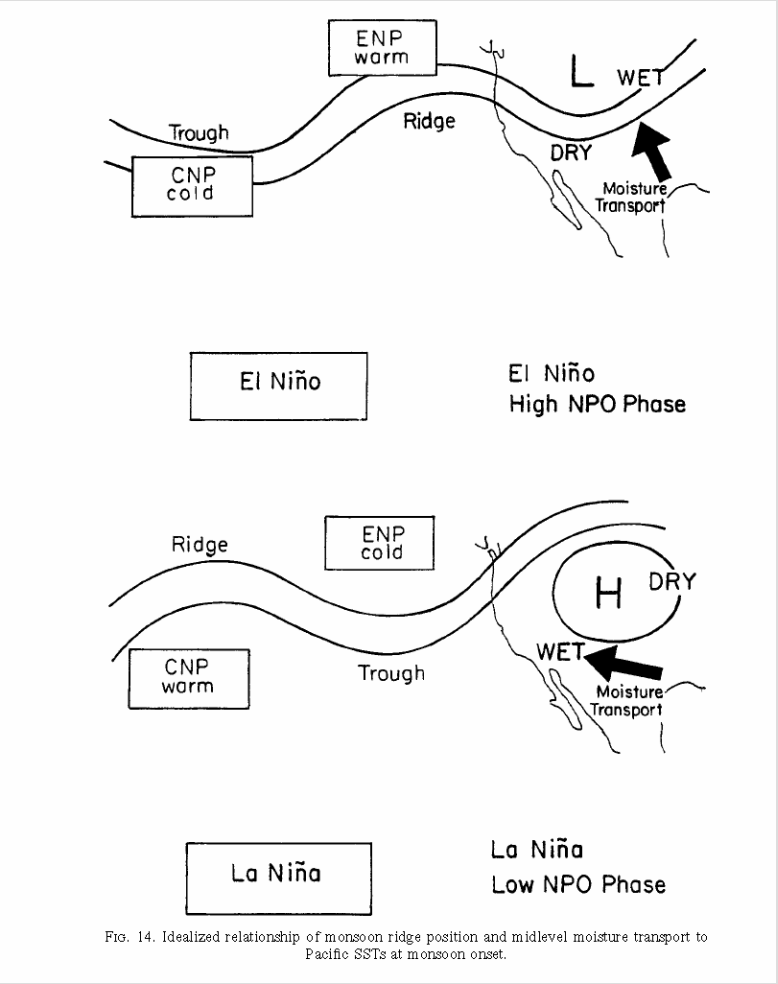


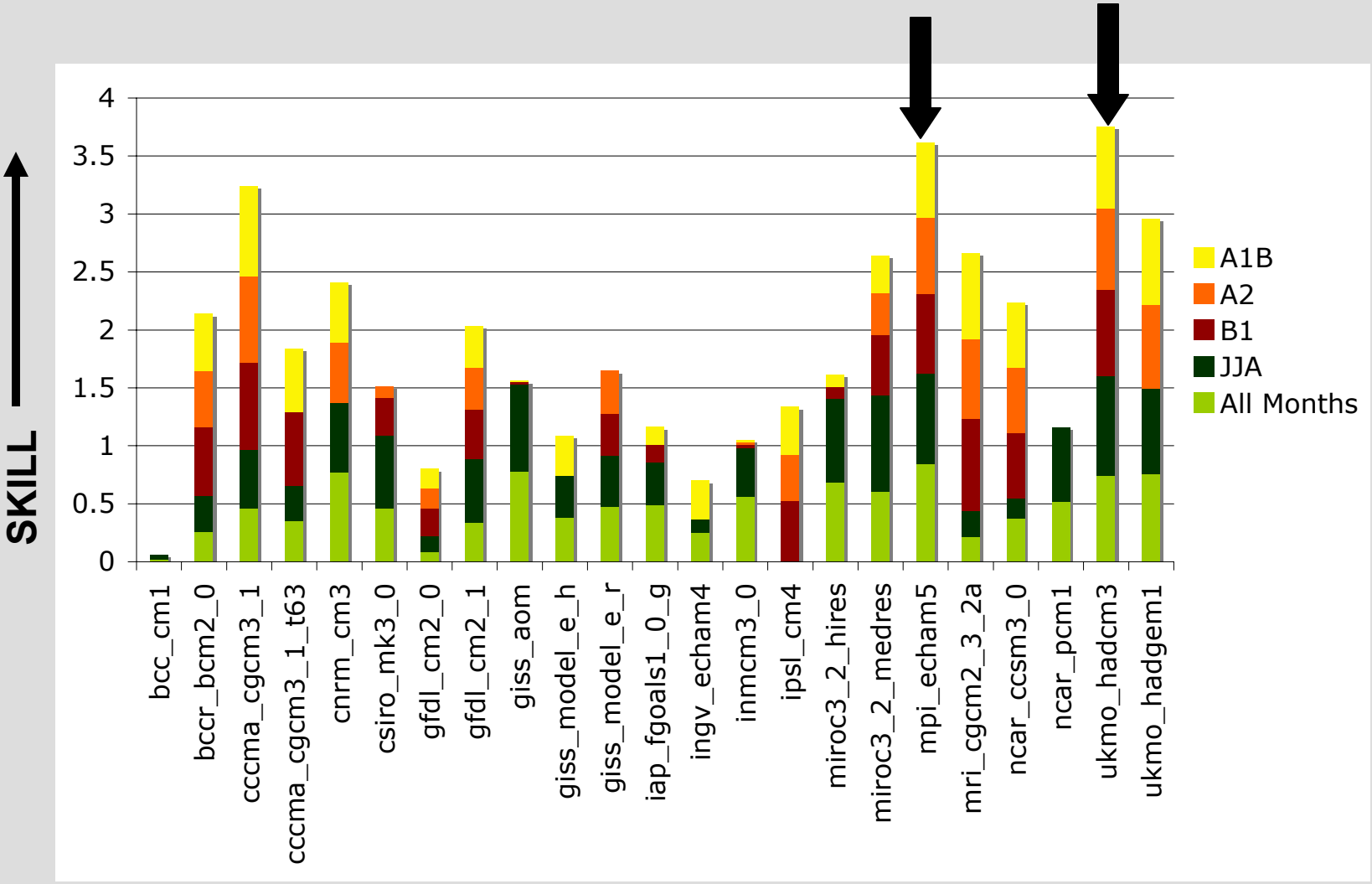
FIG. 14. Idealized relationship of monsoon ridge position and midlevel moisture transport to Pacific SSTs at monsoon onset.

(Castro et al. 2001)

What happens in the Pacific Ocean controls the position of the monsoon ridge in the early part of the summer.

AFFECTS THE ONSET OF THE MONSOON AND EARLY SUMMER RAINFALL IN ARIZONA—IN THE OPPOSITE WAY FROM THE WINTER!

Evaluation of 500-mb height in IPCC GCMs, based on similarity with historical data and convergence in the future.



(Courtesy Francina Dominguez)

"On The Importance Of Regional Climate Change Projection In The Southwest U.S. — And Its Caveats by Professor Christopher L. Castro" - "Though I am not a regular contributor to Dr. Pielke's blog, I would like to comment on some recent discussions regarding climate change projections in the southwest United States. To give some brief background on myself, I am a former student of Dr. Pielke's and currently an assistant professor at the Department of Atmospheric Sciences at the University of Arizona. My principal interests are regional climate and mesoscale modeling." (Climate Science)

JUNKSCIENCE.COM

"ALL THE JUNK THAT'S FIT TO DEBUNK"

Archives - June 2007

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"Meteorologist: 'Al Gore's Global Warming is the Biggest Myth of the Century'" - "I'm sure I'm speaking for millions of anthropogenic global warming skeptics when I say that virtually nothing brightens my day more than an article written by a climate expert exposing the Global Warmingist-in-Chief, soon-to-be-Dr. Al Gore, as nothing more than a snake oil selling charlatan." (Noel Sheppard, News Busters)

"Gore's assault on reason" - "The title of Al Gore's latest book, The Assault on Reason, says it all. Illogicalities, non sequiturs, false analogies, fallacies, ad hominem (or rather ad Exxoninem) arguments all tumble forth in profusion from its pages." (Peter Foster, Financial Post)

The way it could have been...

Buddies For Life

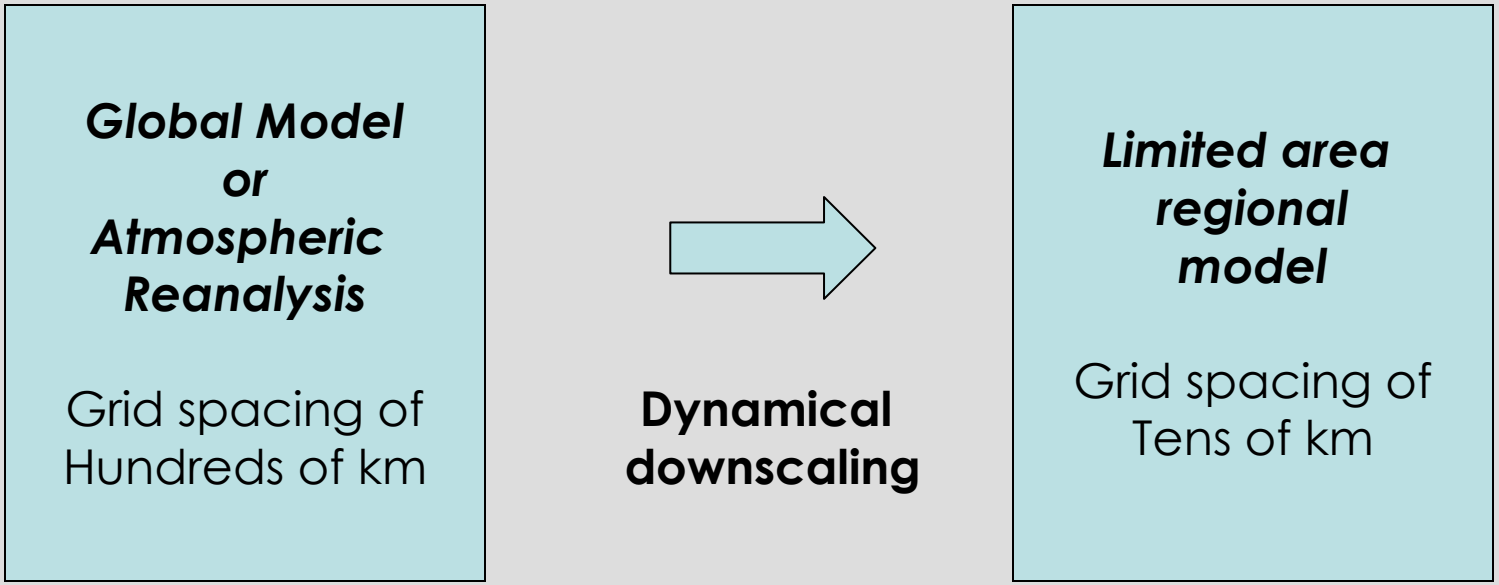
The way it is

AND THE IPCC MODELS WITHOUT A DOUBT TELL US THAT ALL OF THE SOUTHWEST U.S. WILL TURN INTO A GIANT, BURNING WASTELAND!!

EXECUSE ME, AL…THOSE GCMs AIN'T EVEN GOT A MONSOON IN THEM!!

Nemeses

Value added by a regional atmospheric model

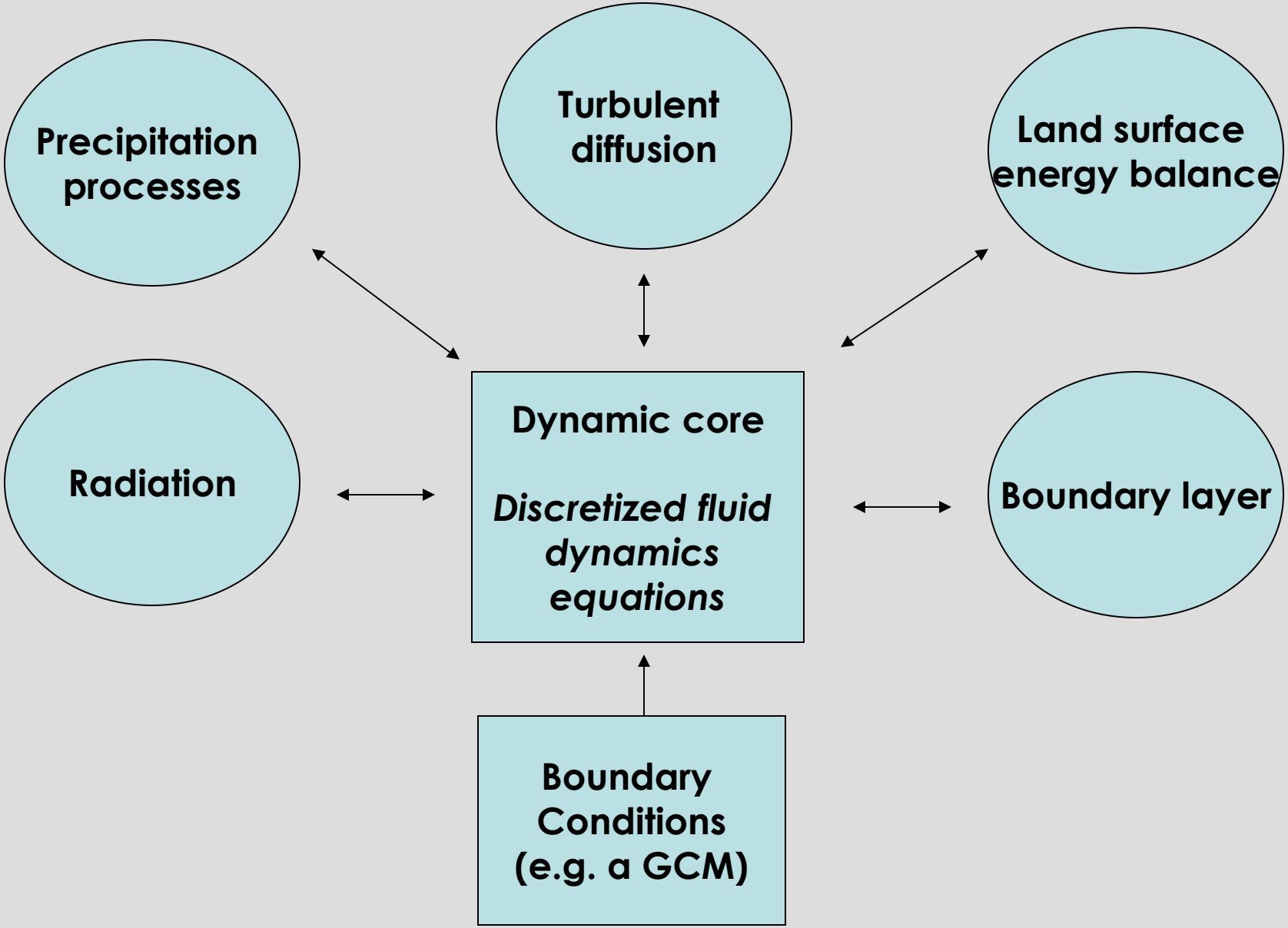


<u>Value added by this process</u>:

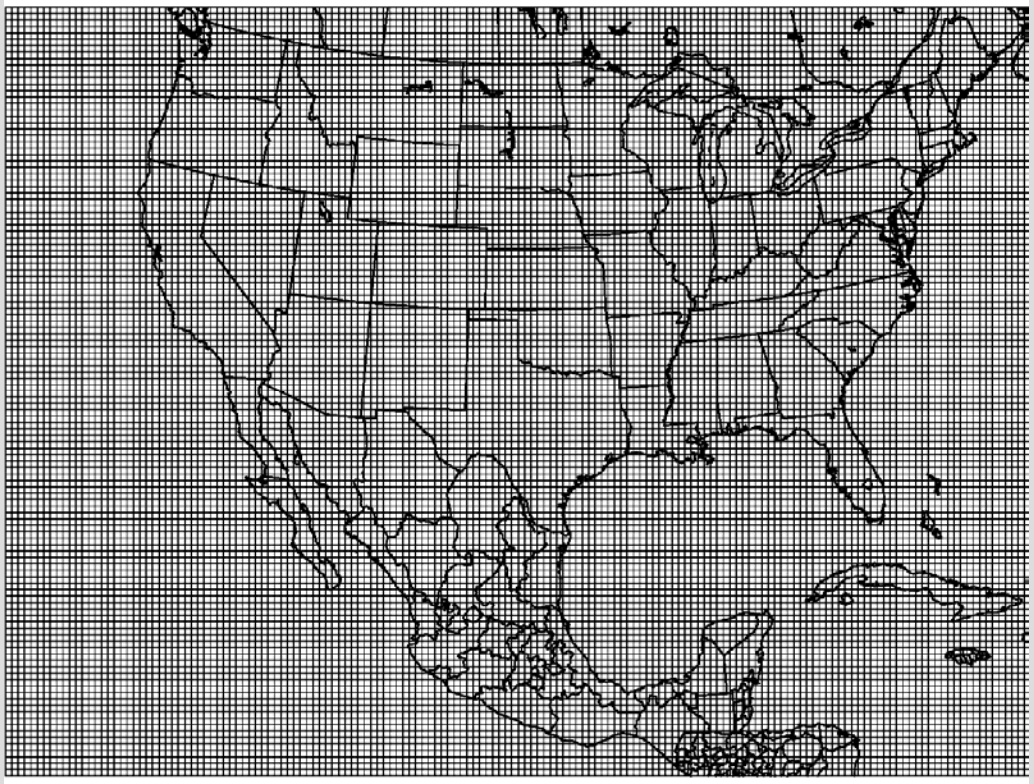
- **Better representation of the land surface and atmospheric circulation**

- **Improved representation of atmospheric processes, like convective rainfall**

What comprises an regional atmospheric model?



RAMS Setup for North American Study (Castro et al. 2007, *J. Climate*)



Grid spacing: 35 km

160 x 120 grid points horizontal

30 grid points vertical

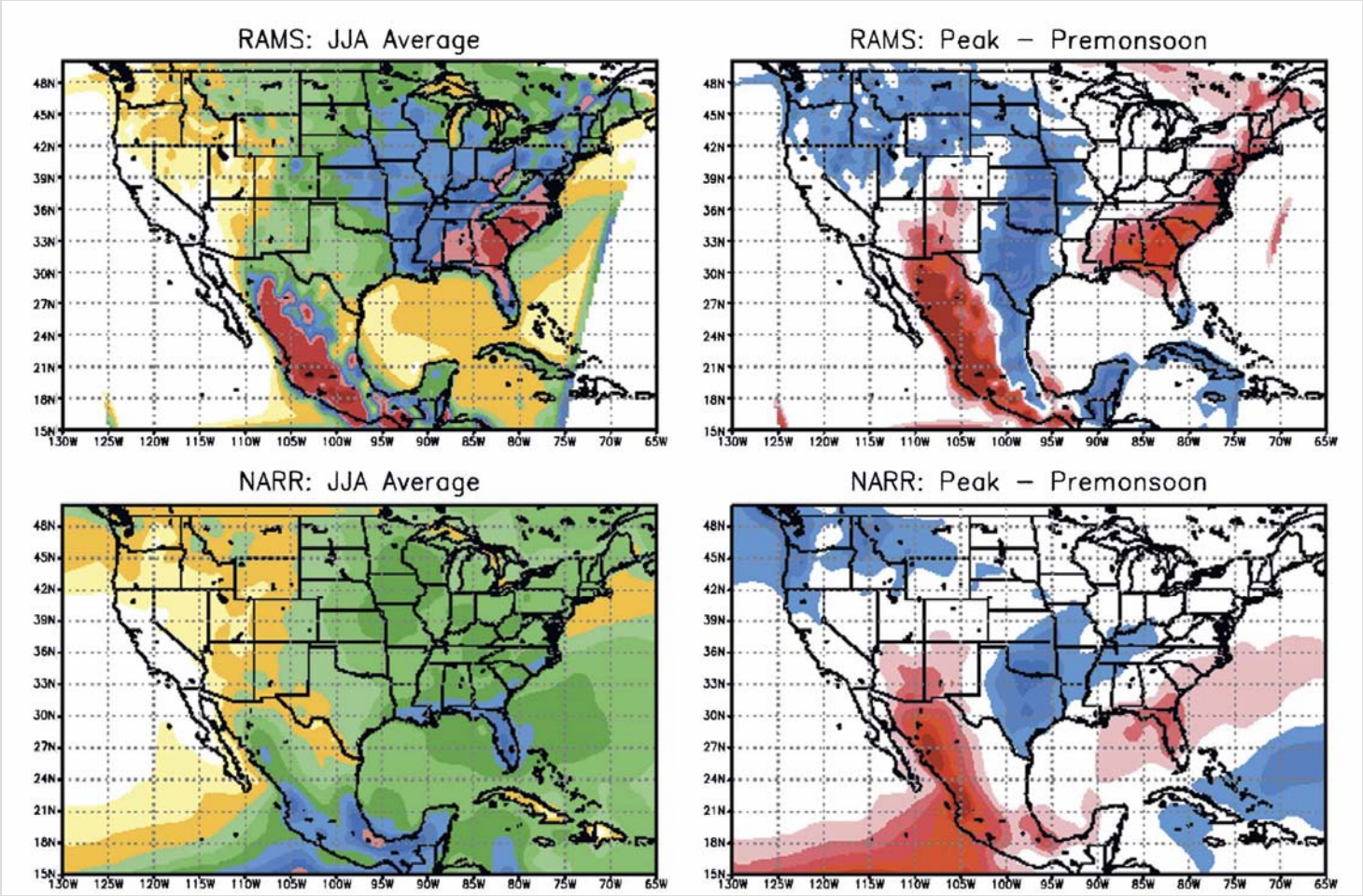
Simulation length:
15 May – 31 August

Years downscaled:
1950-2002
(using retrospective reanalysis)

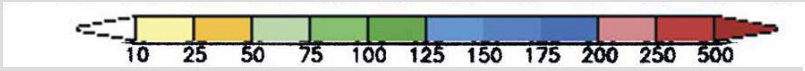
Model simulated precipitation corresponds to observations well—and gets a monsoon in AZ!

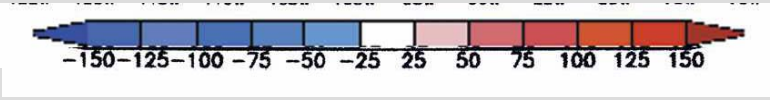
Regional model

Observed



Units: mm

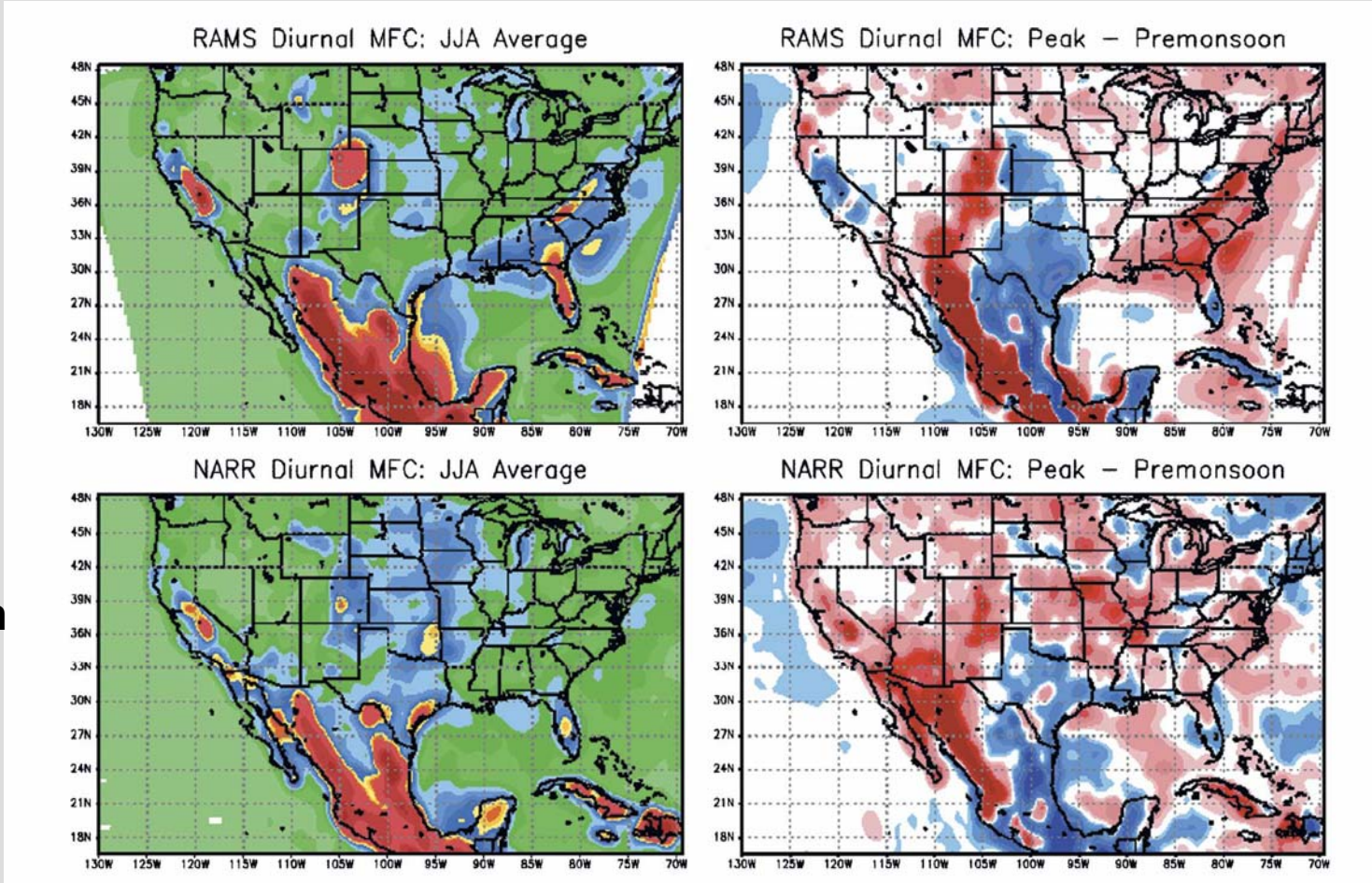




Weighted spectral power of diurnal moisture flux convergence—a proxy for convection

Regional model

North American Regional Reanalysis

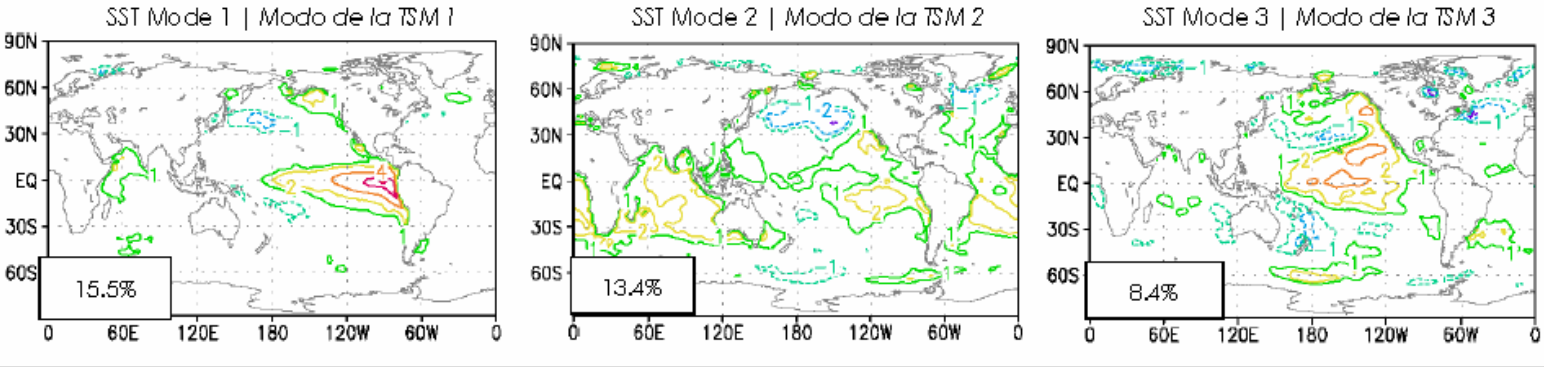


Units: $mm^2\ day^{-2}$

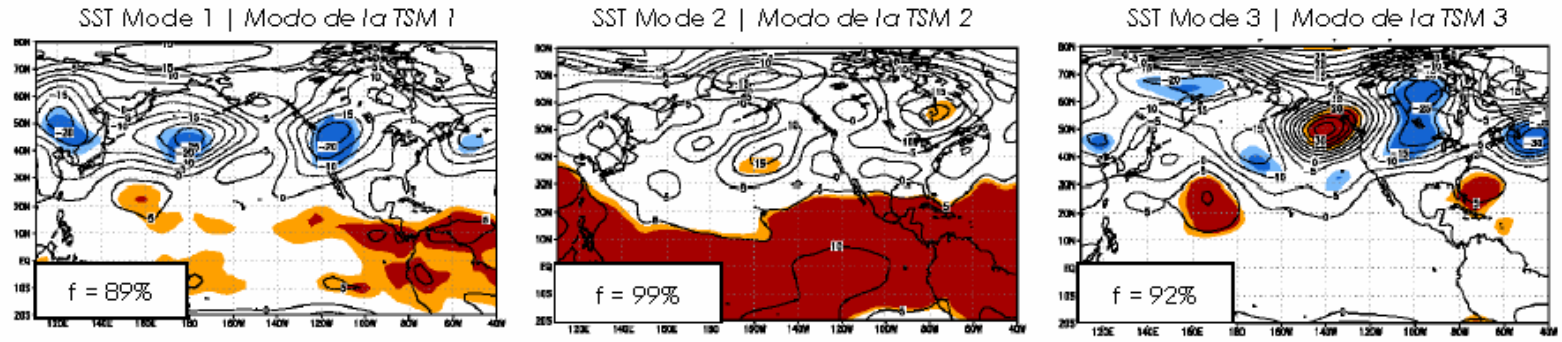
Large-Scale Forcing of North American Summer Climate Variability

Dominant modes of Pacific SSTs influence the summer climate of North America via remote forcing of the large-scale circulation. Teleconnections evolve in time and affect the onset of the North American monsoon.

Summer SST REOFs



500-mb Height Anomalies at monsoon onset

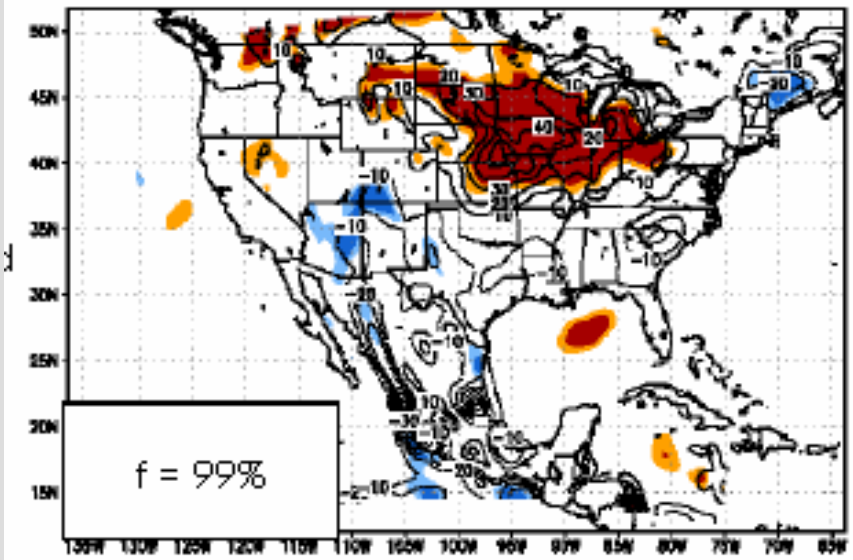


(Castro et al. 2007, *J. Climate*)

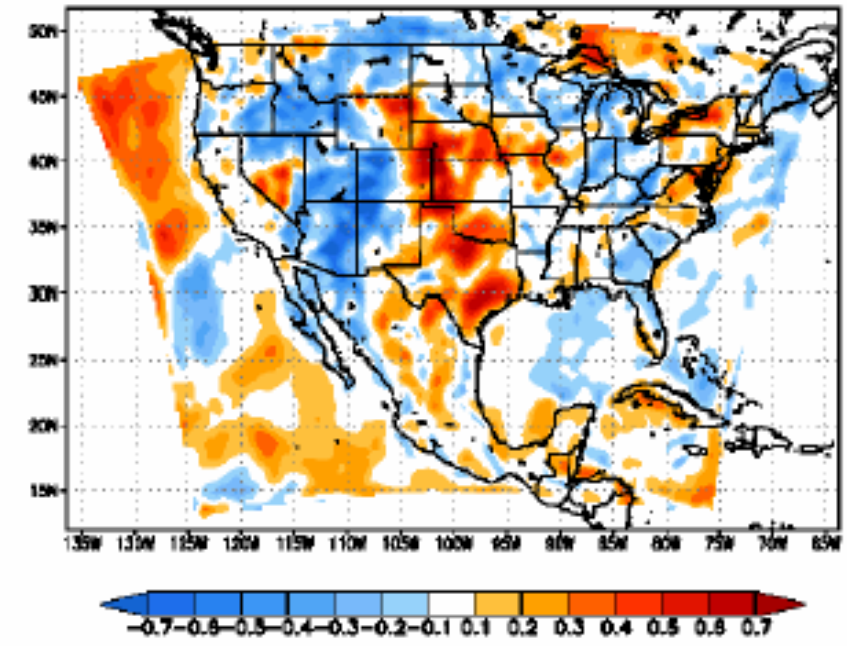
Changes in precipitation and diurnal convection due natural Pacific SST variability (at monsoon onset)

"Natural" equals:
ENSO
PDO

RCM Precip. Anomaly (mm)

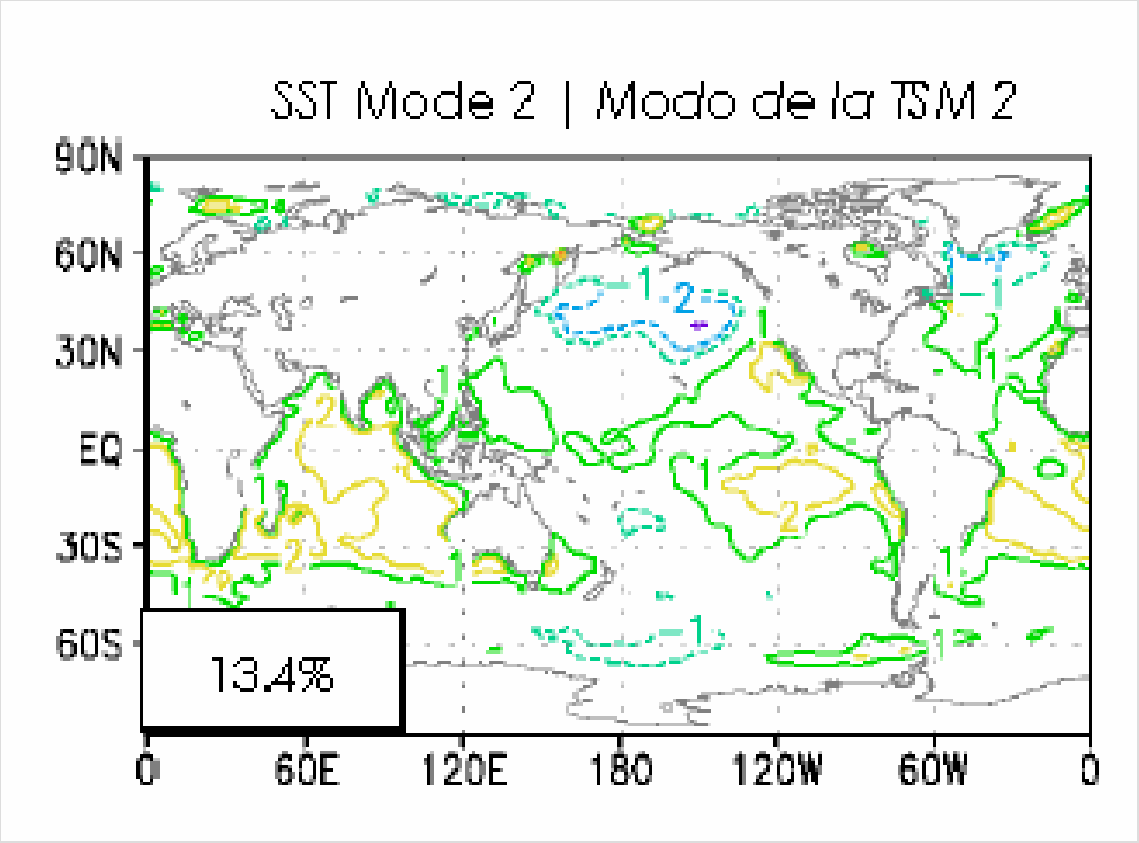


Change in diurnal moisture flux convergence

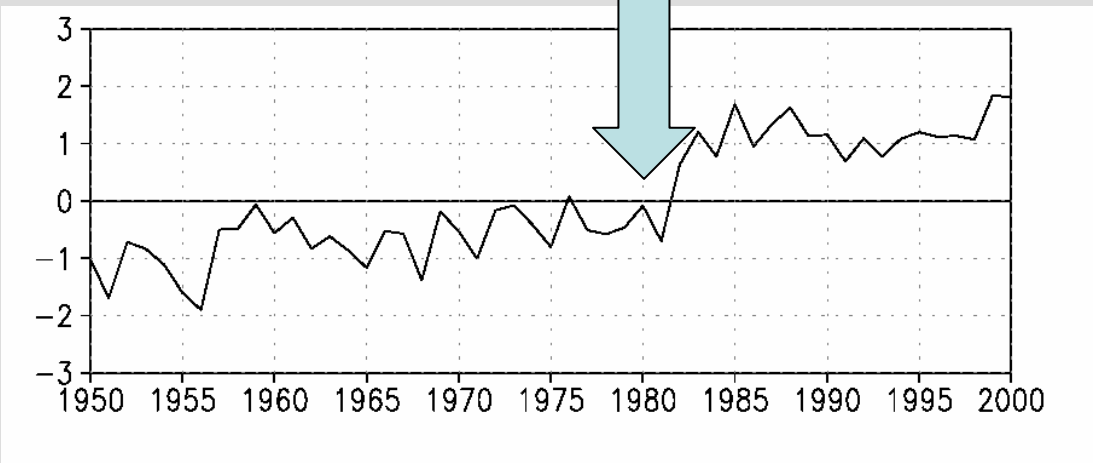


Since the model simulations encompass the past fifty years, what do they say about what has been happening since 1980, when IPCC attribution studies hint that the anthropogenic forcing starts to be realized in the climate system?

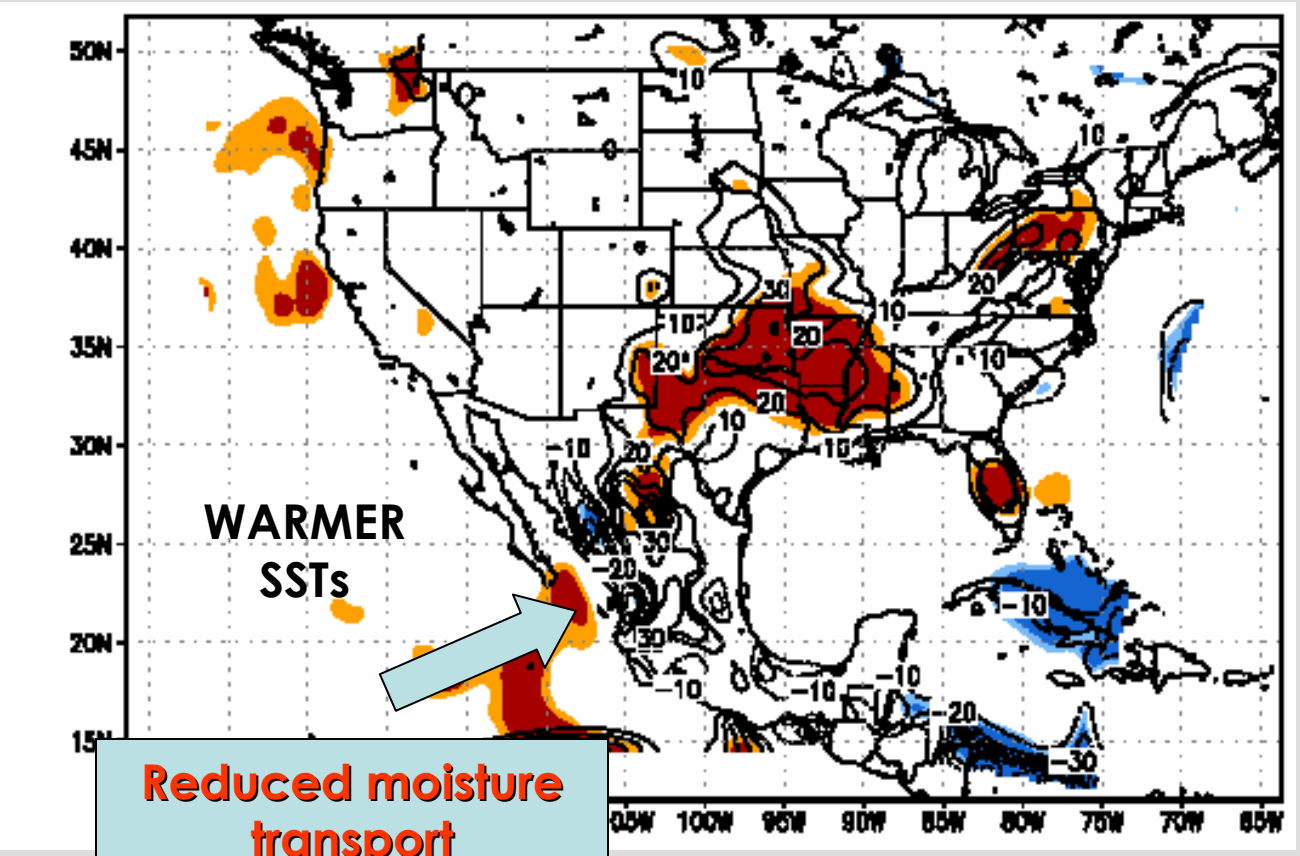
Tropical SST warming mode



Normalized principal component time series



RCM-simulated change in summer precipitation since about 1980…



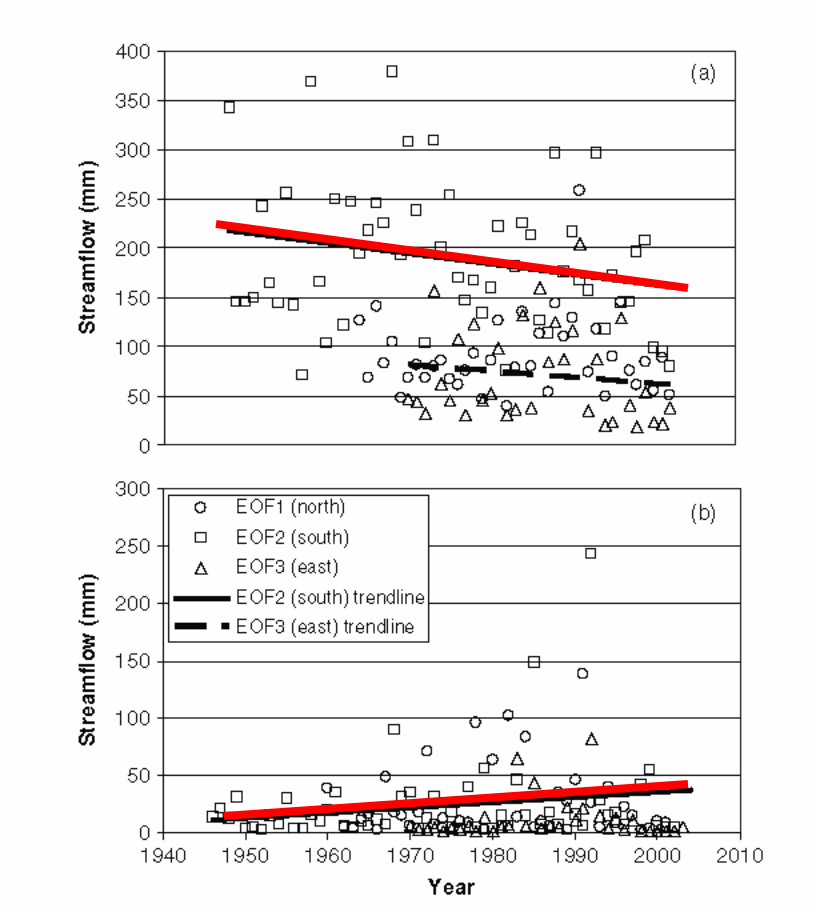
Precipitation in the U.S. generally increases, in agreement with observations.

Precipitation in western Mexico decreases due to a local change in sea surface temperature gradient in the eastern Pacific!

Tendencias en el flujo de agua en los ríos del sur de Sinaloa (las líneas rojas)

Verano

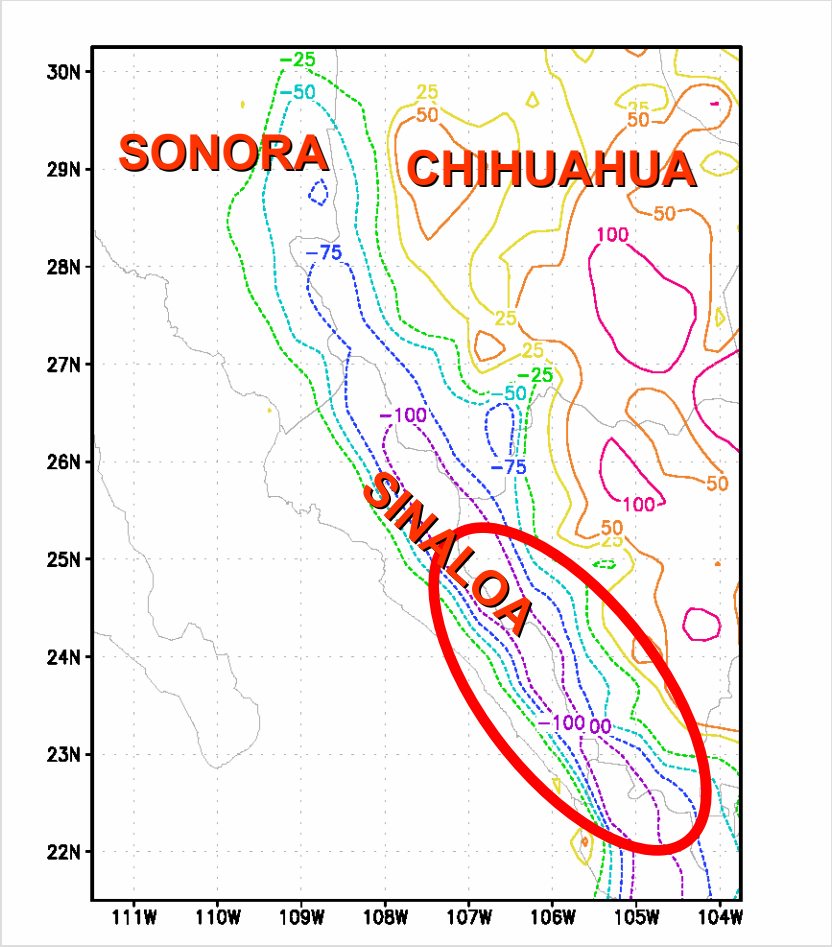
Invierno



Los datos de observación indican que el flujo de agua en los ríos del sur de Sinaloa disminuyó durante los últimos cincuenta años.

El porcentaje de la disminución en el flujo de agua es aproximadamente 30%

El cambio correspondiente de la precipitación del modelo regional durante el mes de julio asociado con el modo 2 de la TSM global

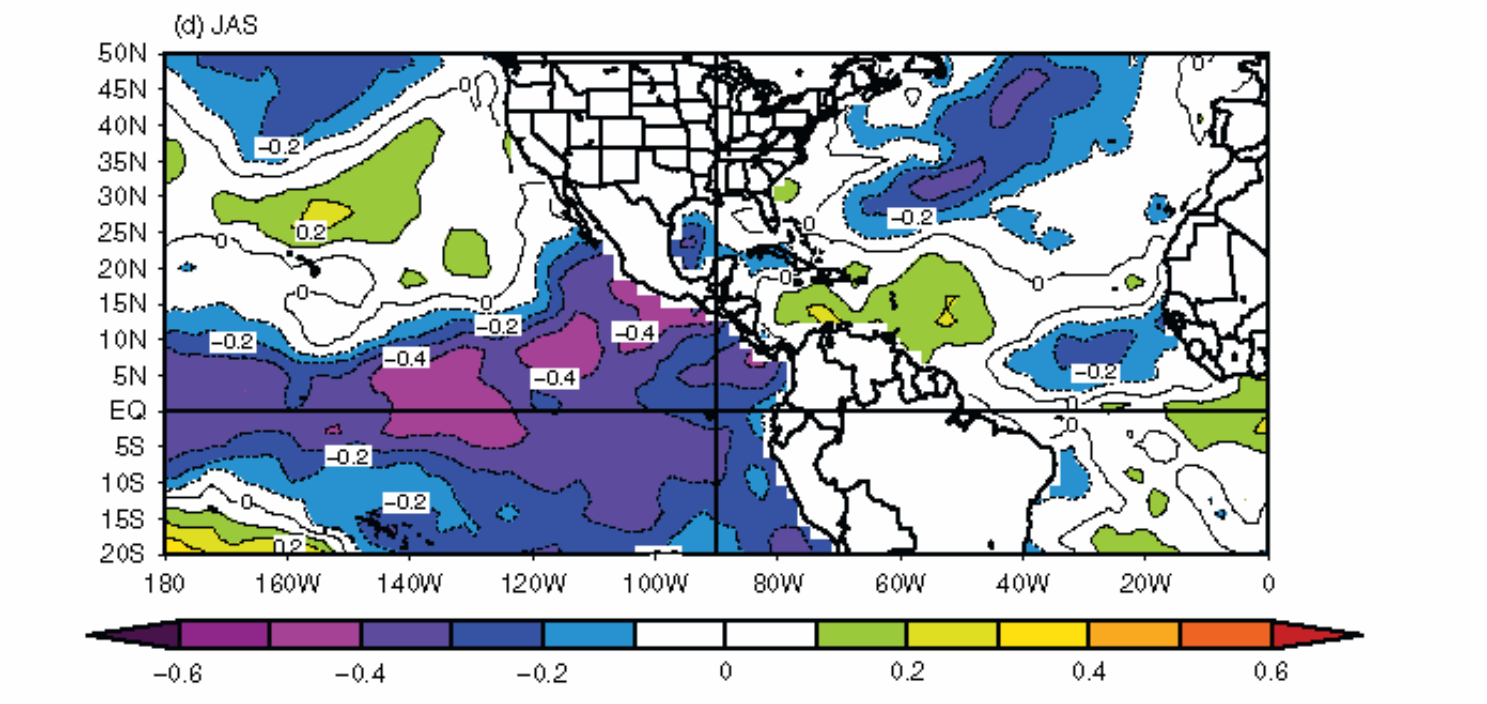


Las observaciones del flujo de agua en los ríos en el sur de Sinaloa generalmente están de acuerdo con los resultados del modelo regional.

El porcentaje de la disminución de la precipitación también es cerca de 30%.

Unidades: mm

Las anomalías de la TSM asociadas con las tendencias en el flujo de agua en los ríos en el sur de Sinaloa durante el verano



¡Es el mismo mensaje de las observaciones! Las aguas más calientes están asociadas con menos precipitación en el oeste de México.

The way forward: use of RCMs for climate projection

If the coarser scale general circulation model has a realistic climatology and adequately captures the natural modes of variability in the climate system (e.g. ENSO, PDO, etc.), dynamical downscaling with a regional model for the purposes of climate forecasting may be very worthwhile.

As our dynamical downscaling tool we propose to use the Weather Research and Forecasting Model (WRF).

Objective	GCM data to be downscaled
Short-range climate projection	Climate Forecast System Model (NCEP)
Long-range climate projection	Some "well performing" IPCC GCMs for A1B scenario

Summary points

Climate change is an important challenge facing Arizona and is probably already occurring. We need to make wise choices with respect to future growth and use of natural resources that acknowledge this reality. Are we currently doing that?

The most compelling evidence of climate change is the observational record. IPCC GCM projections of future climate may have utility for global and continental scales, but we should be wary of any regional projections, such as for the Southwest U.S.

Regional atmospheric models may add value to climate projection because they have a better representation of local scale processes, like convective rainfall during the warm season. This value added is realized if the driving GCM has a reasonable climatology and captures natural modes of climate variability.

Regional atmospheric models may yield very important and surprising insights about the impact of anthropogenic climate change. Possible changes in Mexican precipitation are a good example.