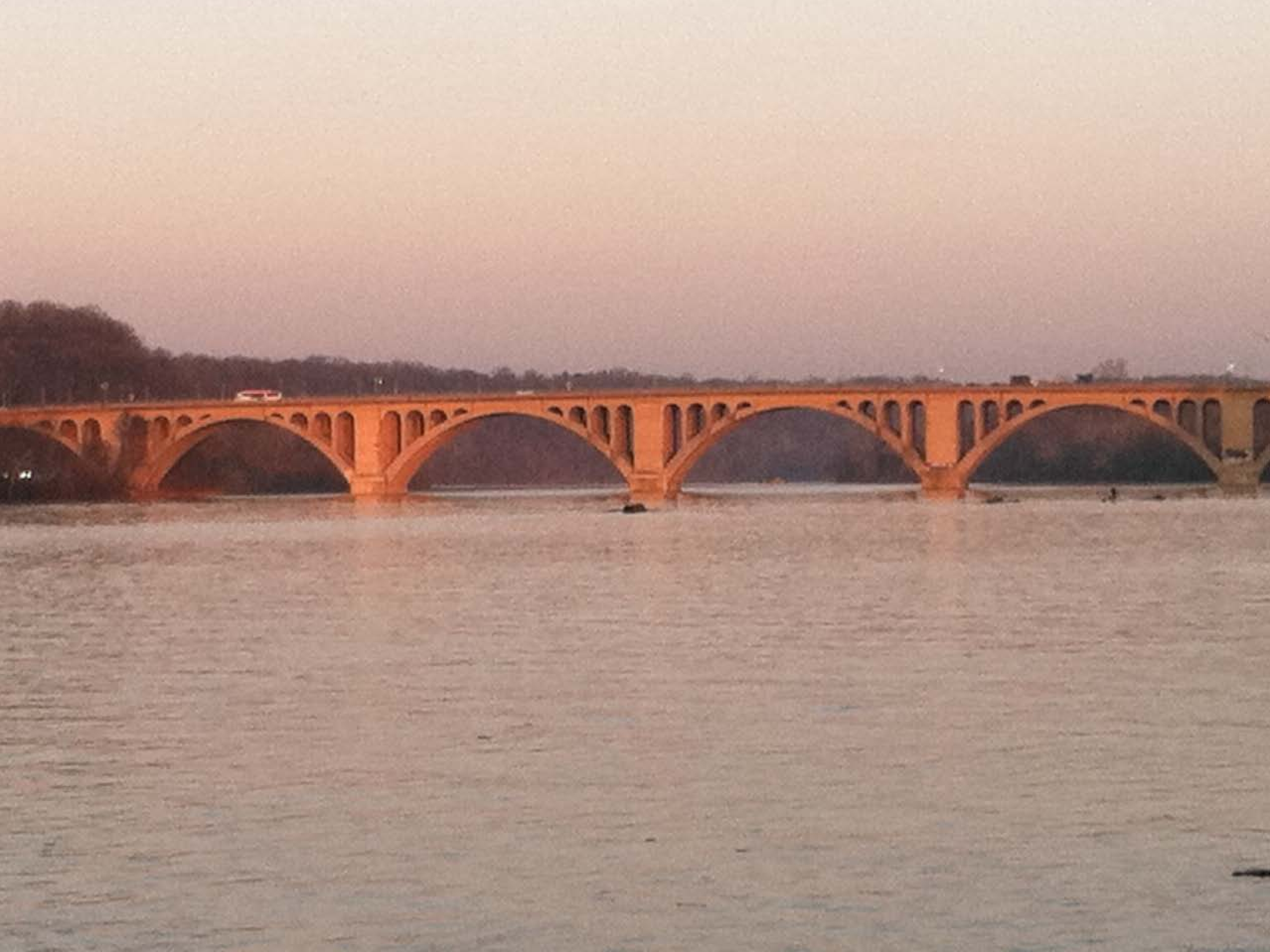
Streamflow, floods and climate change *or* *"Stationarity is dead" whither water science and management?*

Robert M. Hirsch,
Research Hydrologist, USGS
November 17, 2011

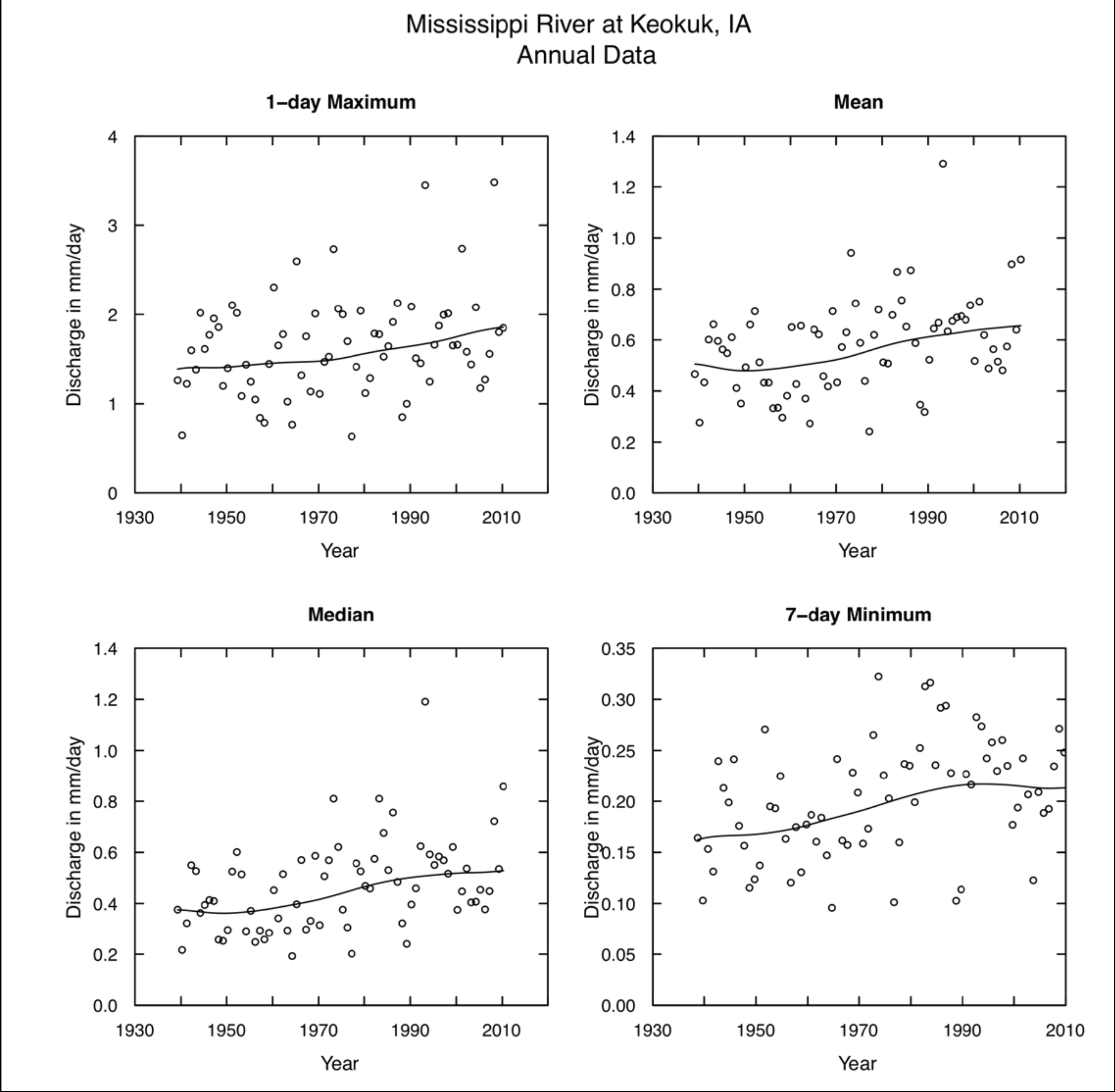


Short record

1-day max
+ 39%

Mean
+ 45%

7-day min
+ 22%



Full Record

1-day max
- 21% then
+ 39%

Mean
- 28% then
+ 45%

7-day min
- 28% then
+ 65%

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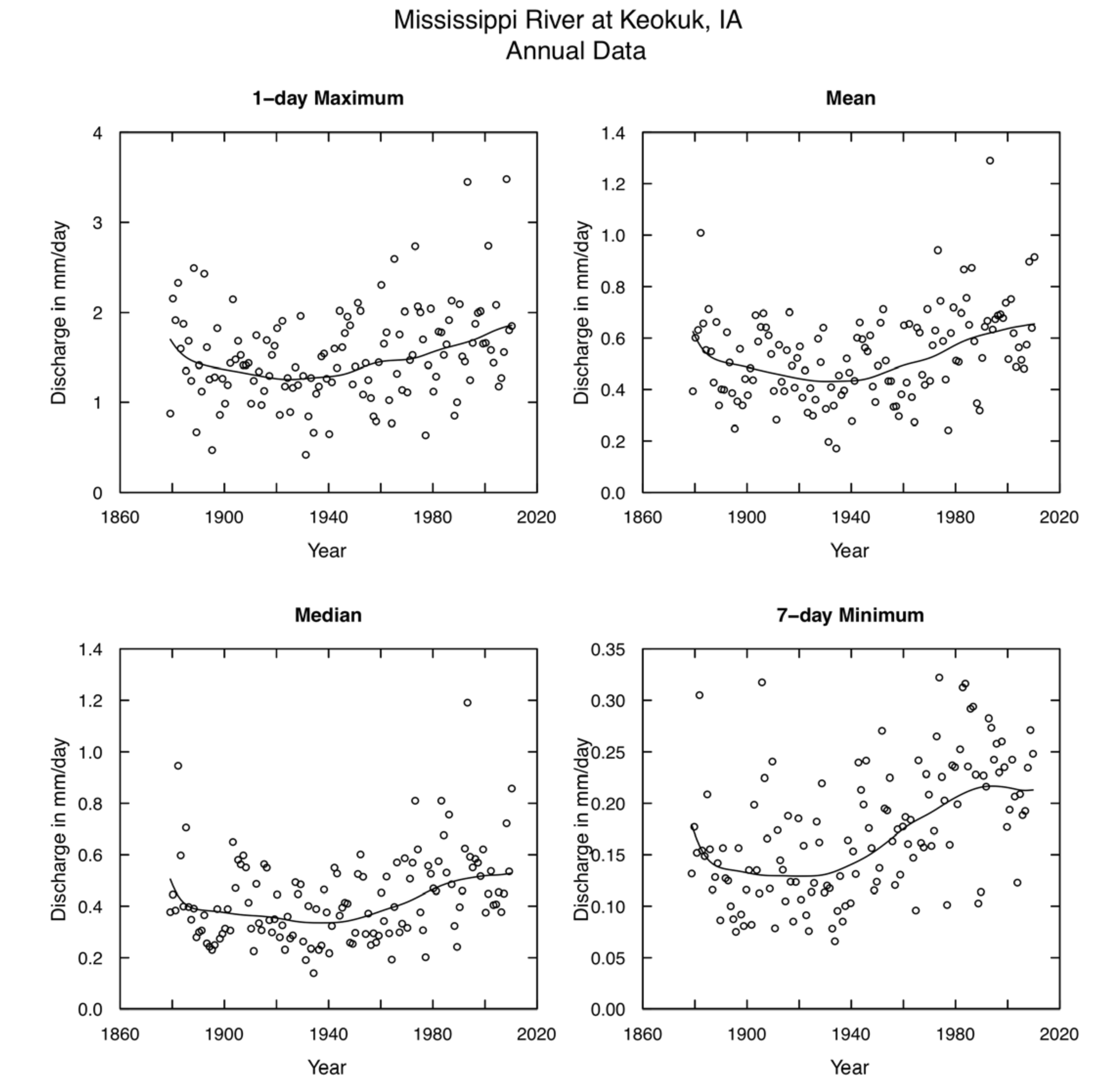
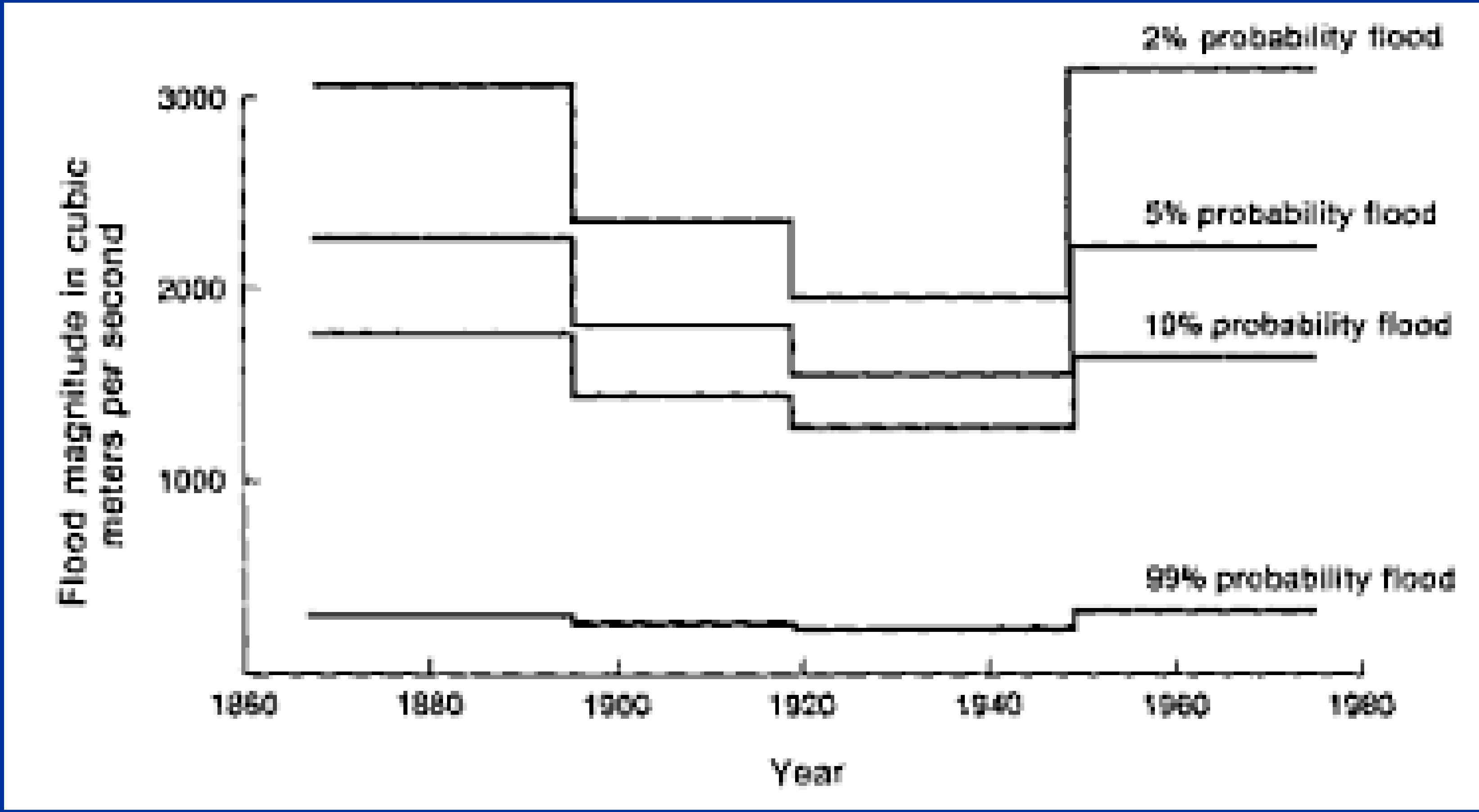
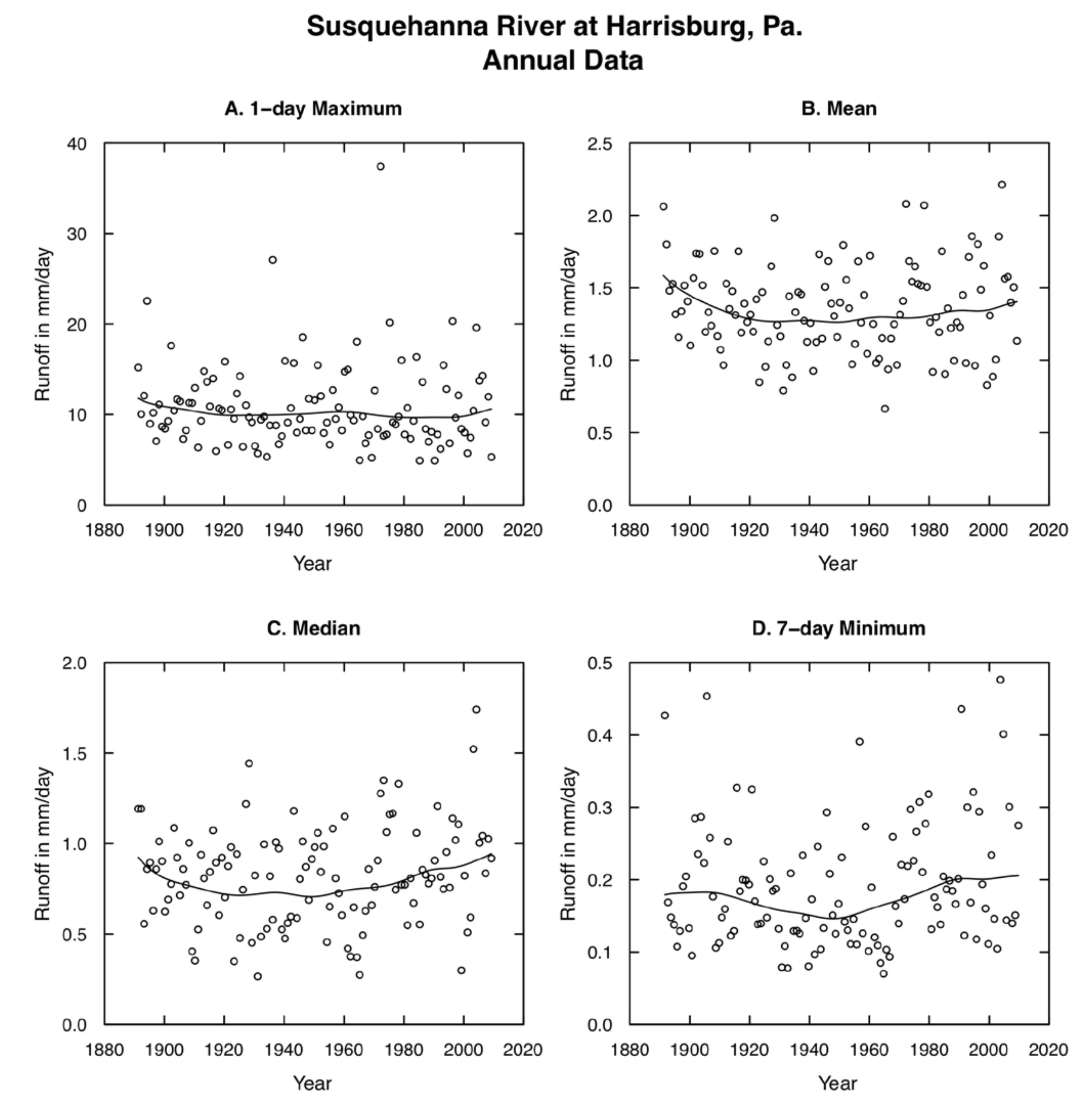


Paleo reconstruction of flood frequency, Mississippi River at St. Paul: Knox, 1983



Increase in the mean flow since the 1940's is 12%, but…

The increase in the 7-day minimum is 36%



For the autumn only

The mean is up 48% and

the 7-day low flow is up 72%

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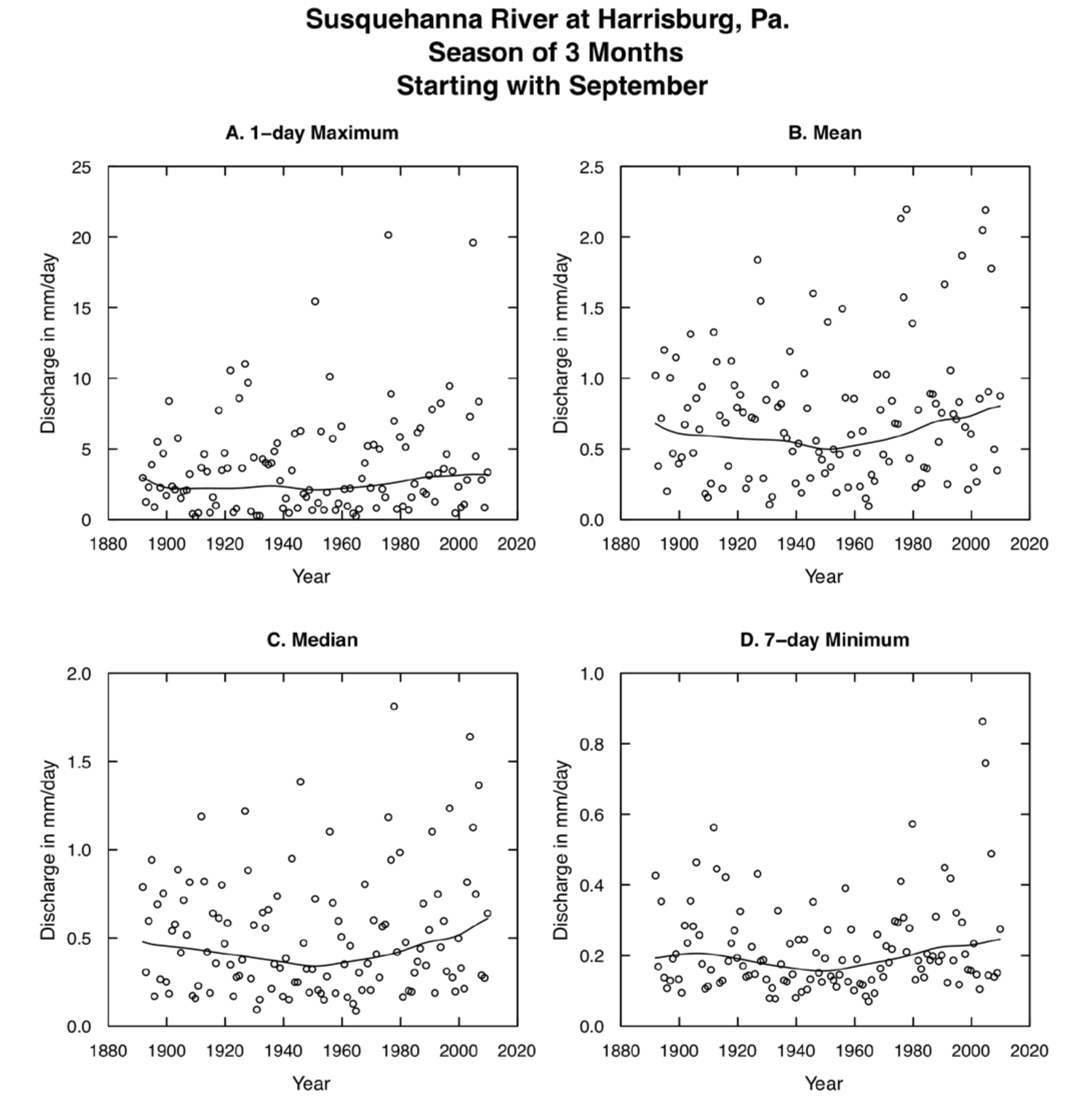
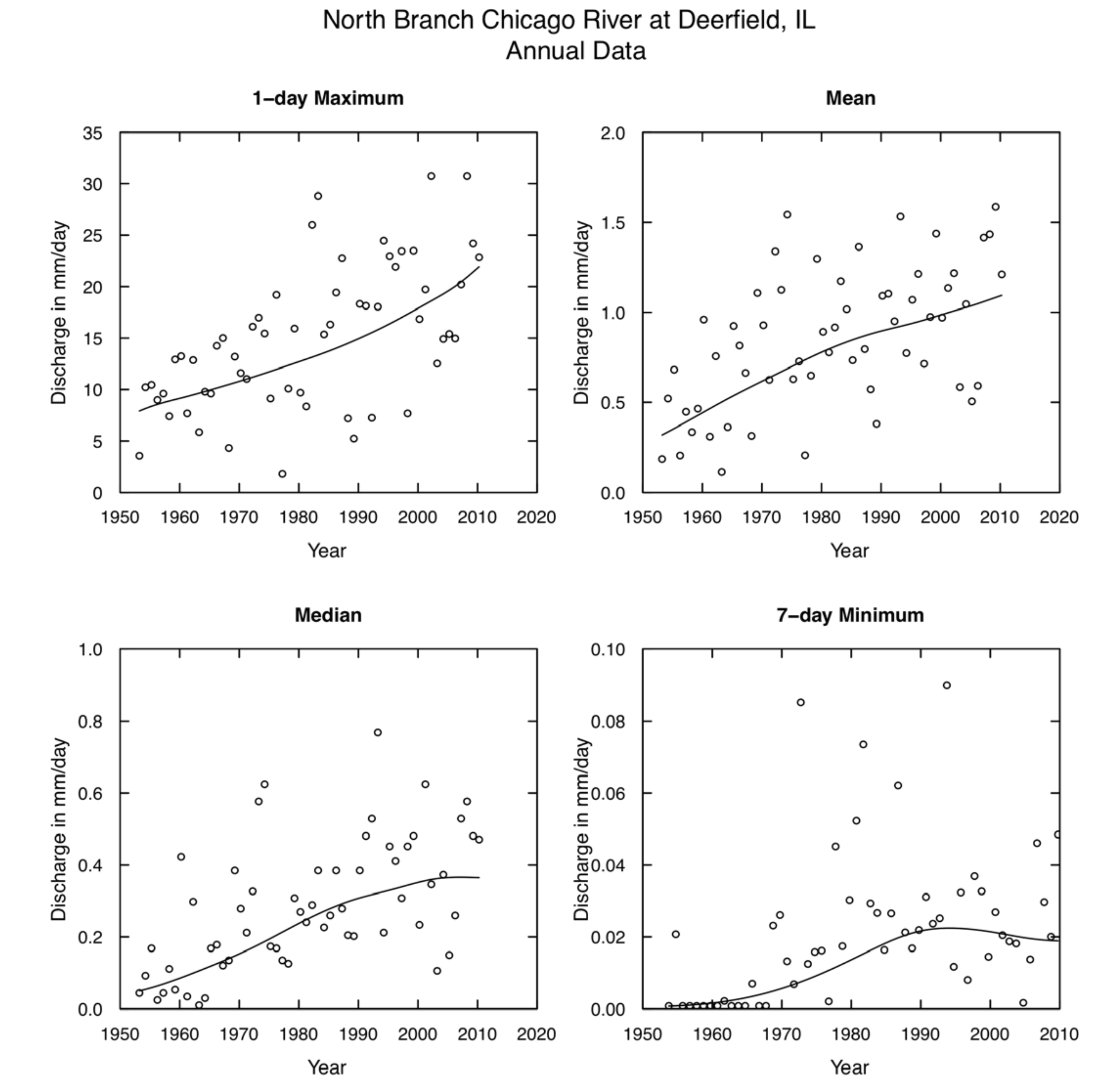


1-day max
+ 177%

Mean
+ 243%

Median
+ 627%



Learning from the unplanned global greenhouse gas experiment

- CO_2 has increased 32% since 1885
- Expected increase: 30% - 40% by 2050
- Use watersheds as experimental subjects
- Use very long records to partially overcome the "trend-like" effect of quasi-periodic oscillations
- Simple question: what's the relationship between log(annual flood) and global CO2?

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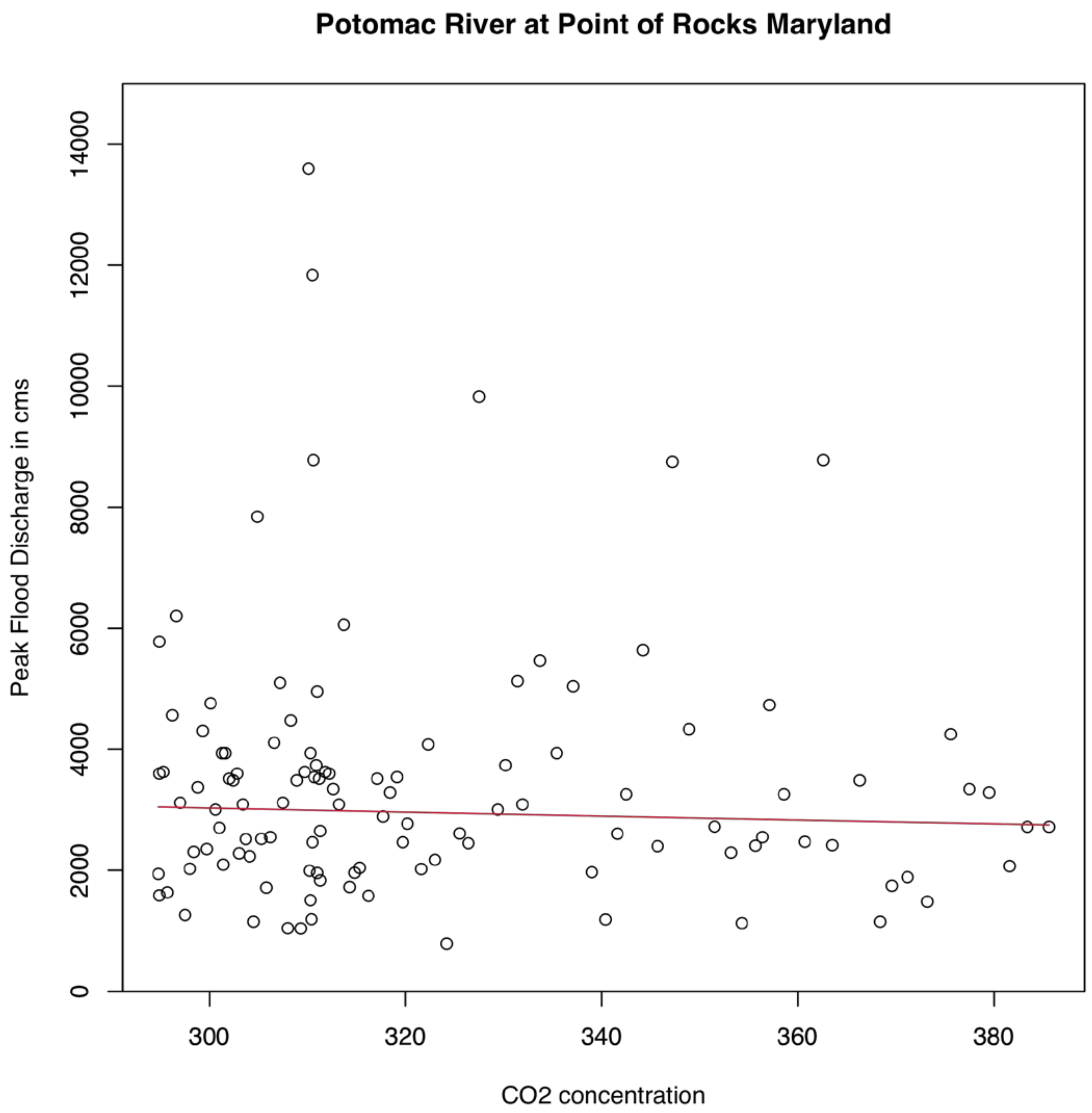
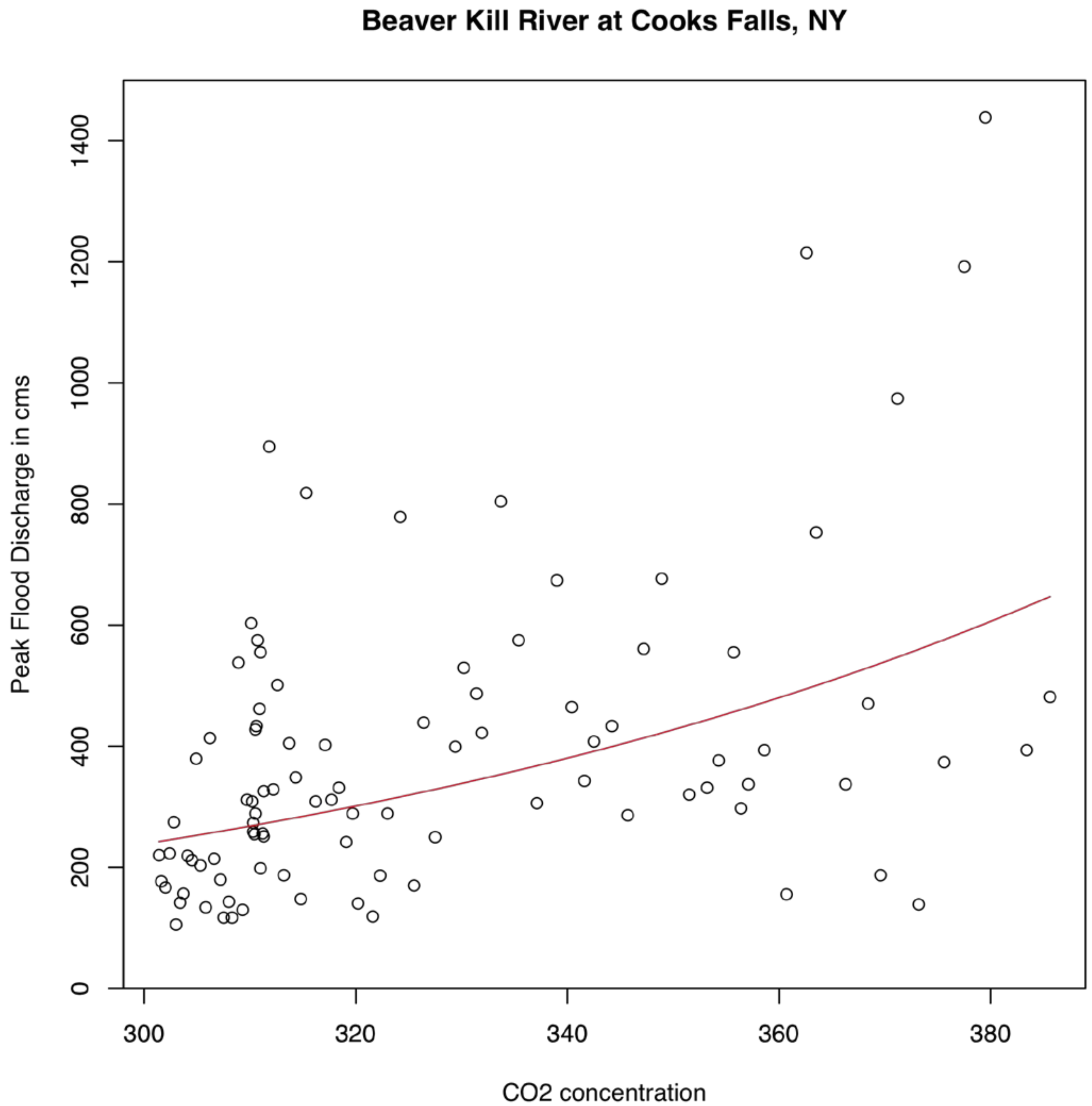
Slope= -1.4 % per 10 ppm CO_2

p=0.5



Slope= +12.4 % per 10 ppm CO_2

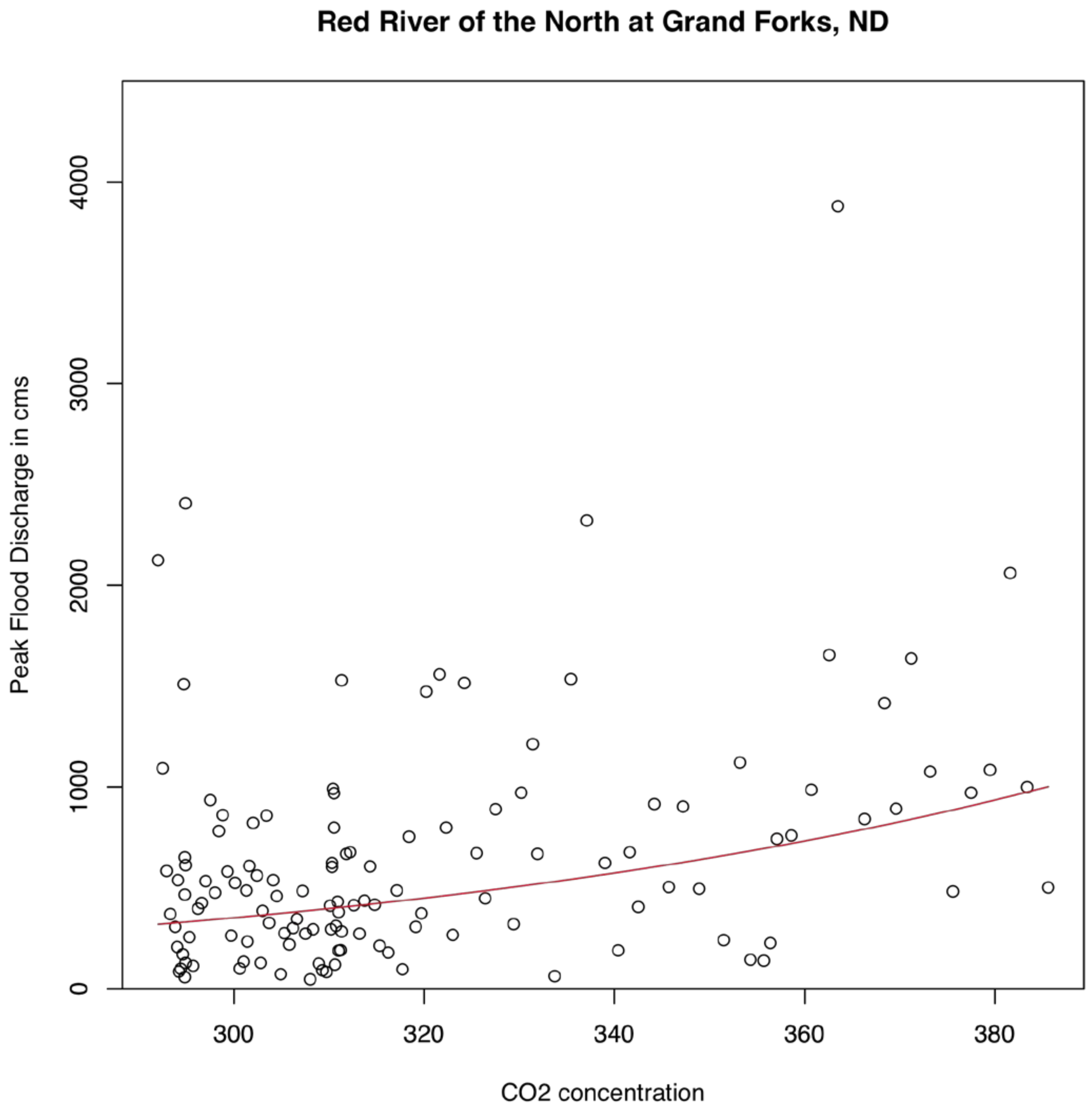
p<0.001



USGS

Slope= +14% per 10 ppm CO_2

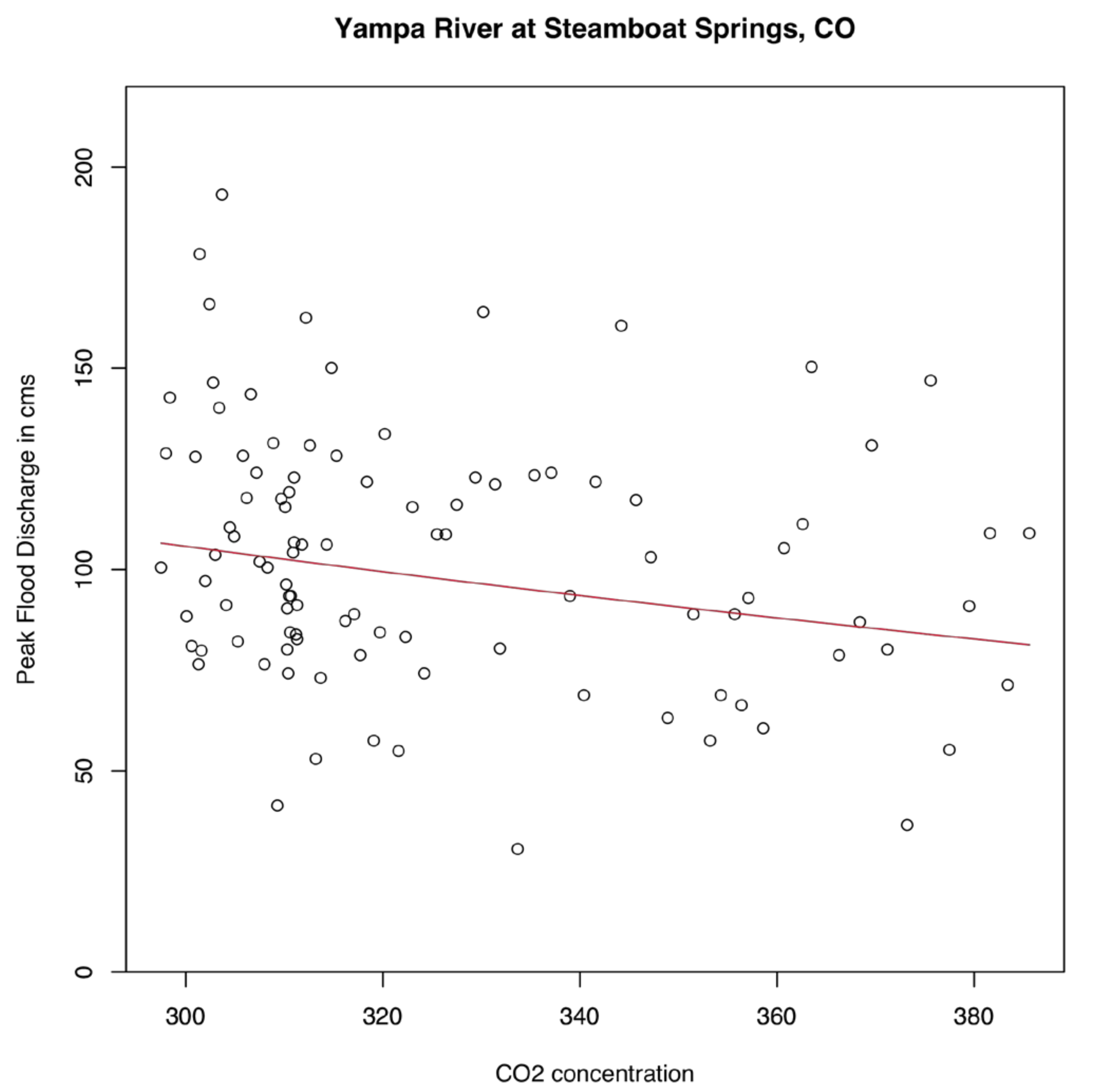
$p<0.001$



USGS

Slope= -3 % per 10 ppm CO_2

p=0.022

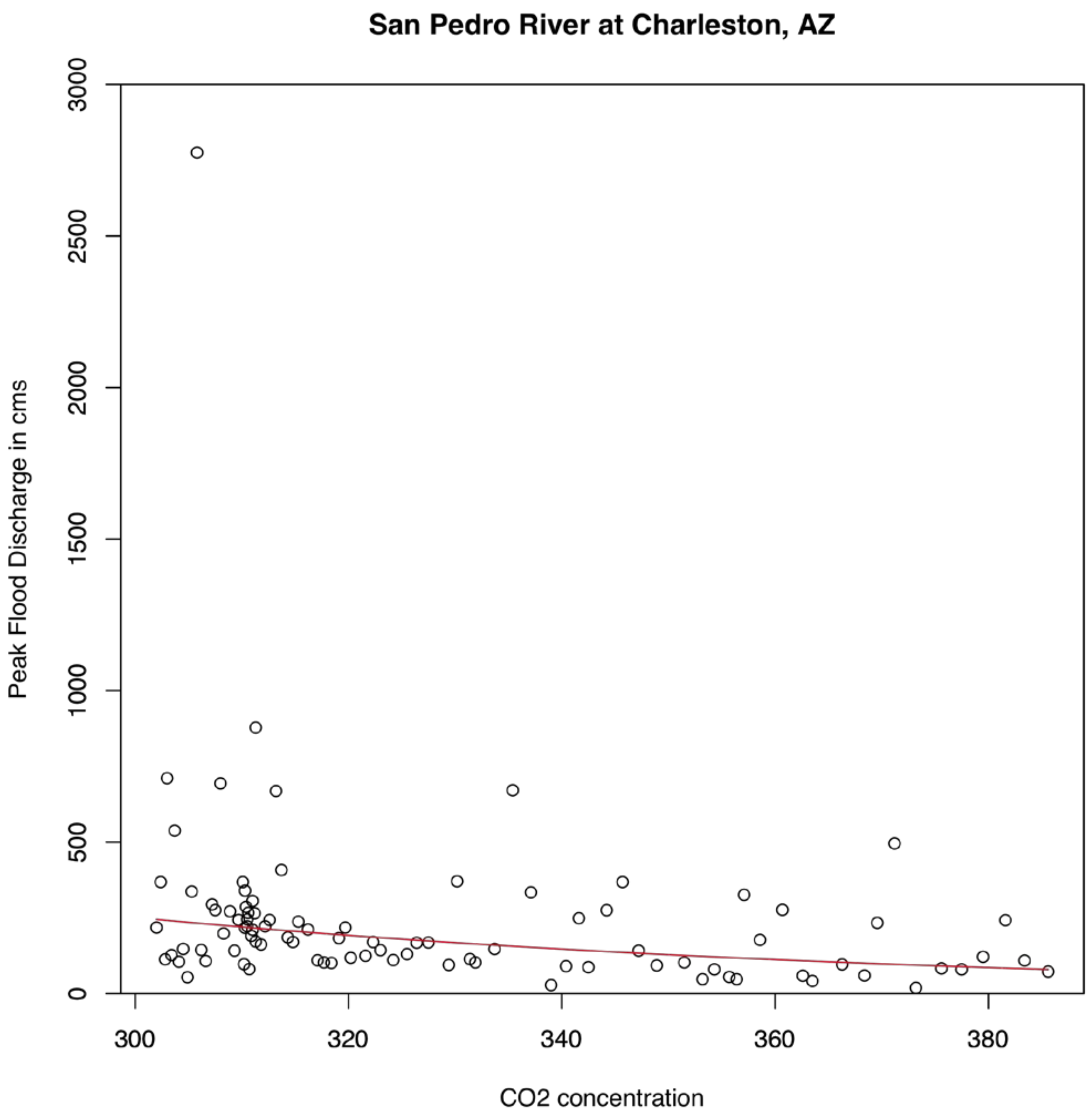


USGS

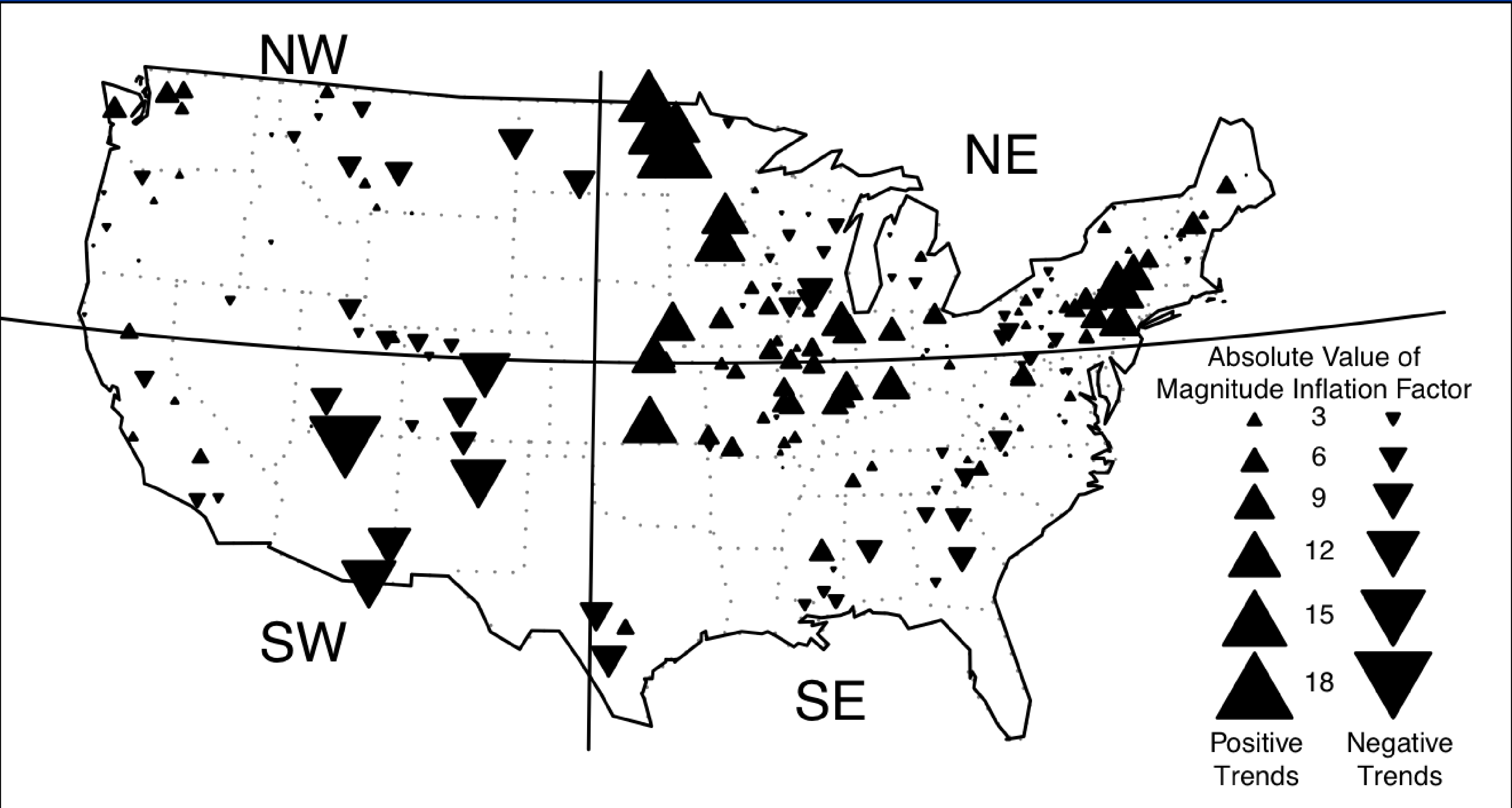
Slope= -12 % per 10 ppm CO_2

# p<0.001

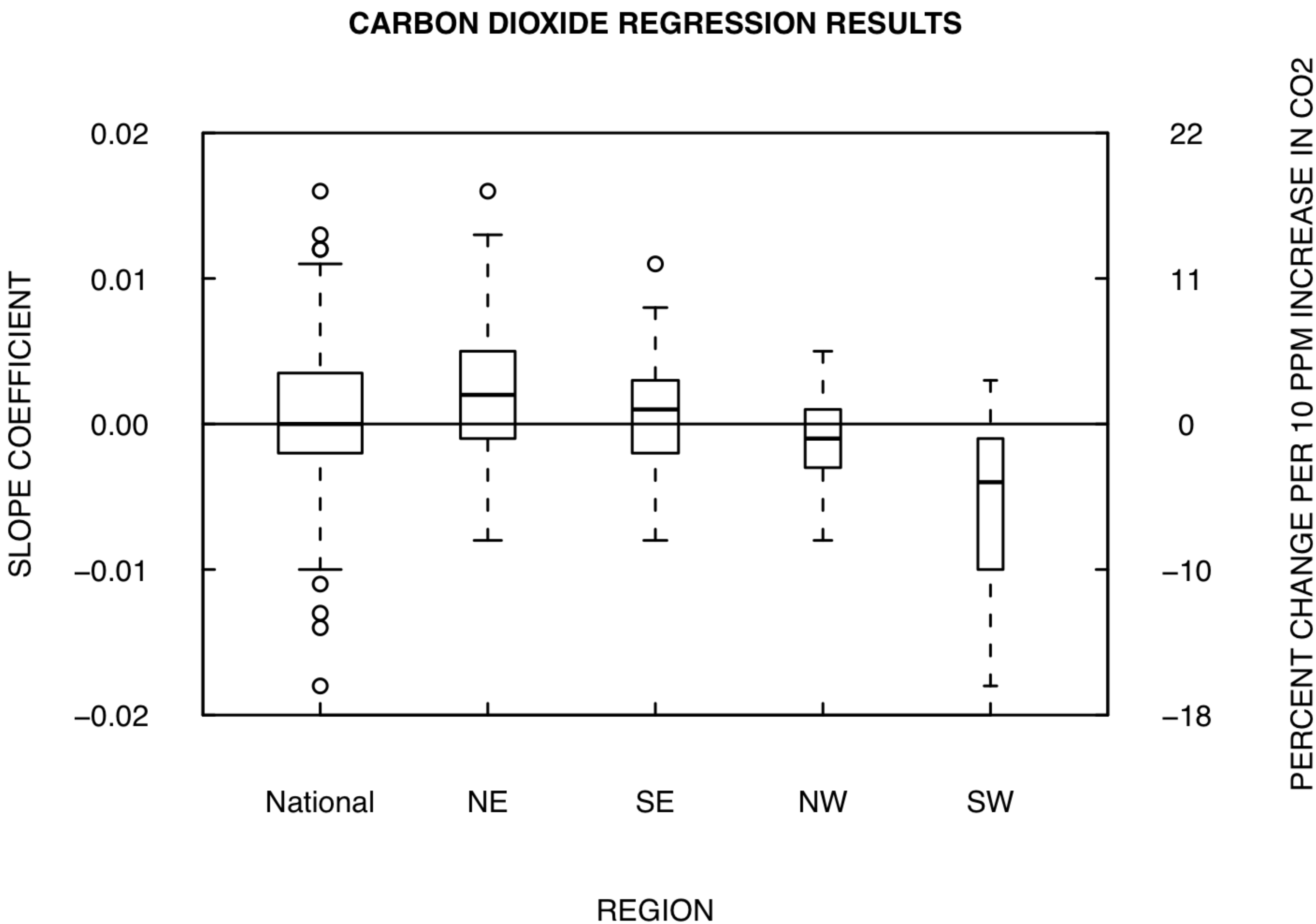
USGS

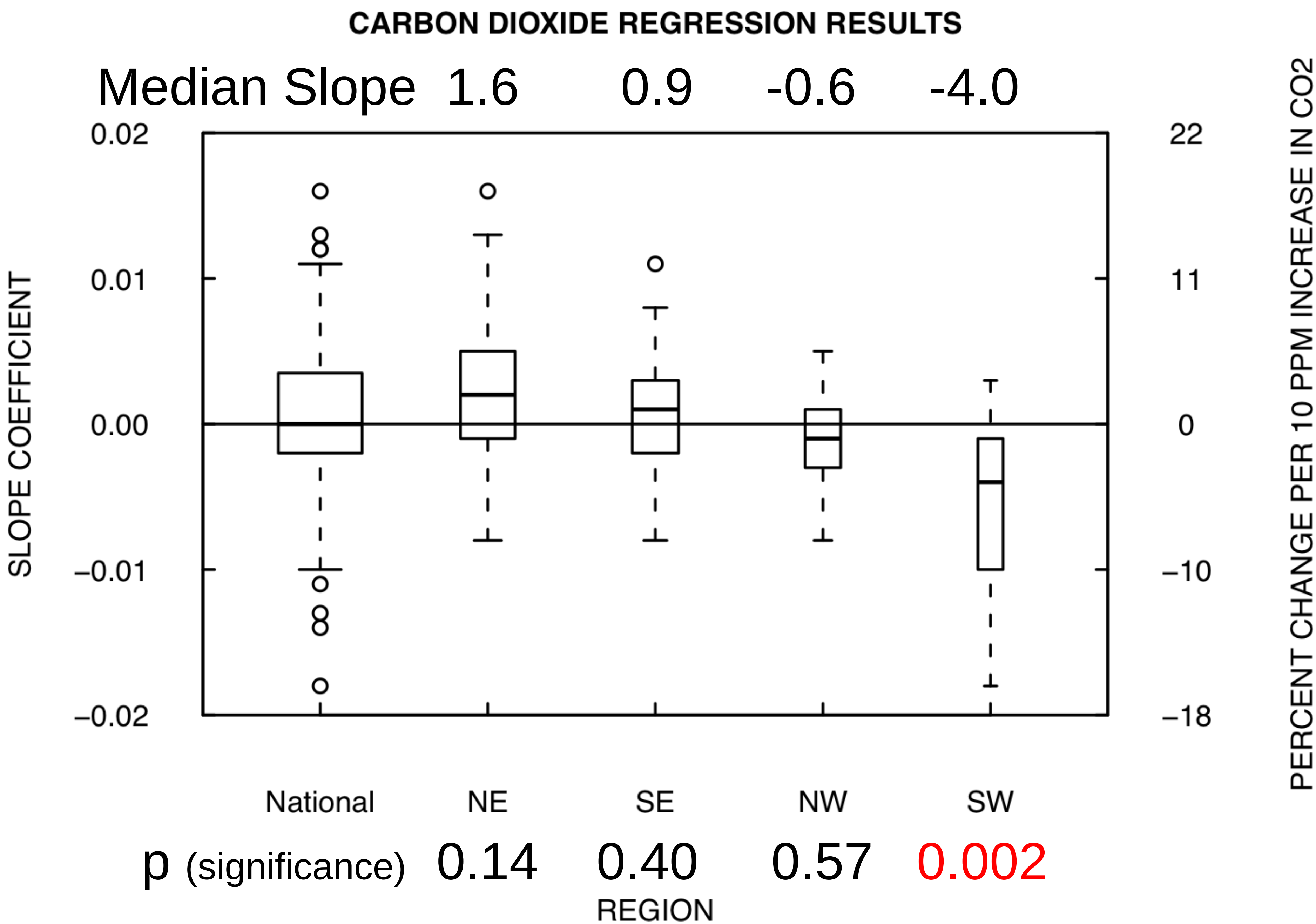


National results: 200 streamgage records



USGS


CARBON DIOXIDE REGRESSION RESULTS
0.02
0.01
0.00
−0.01
−0.02
SLOPE COEFFICIENT
22
11
0
−10
−18
PERCENT CHANGE PER 10 PPM INCREASE IN CO2
National
NE
SE
NW
SW
REGION



CARBON DIOXIDE REGRESSION RESULTS
Median Slope 1.6 0.9 -0.6 -4.0
0.02
0.01
0.00
–0.01
–0.02
SLOPE COEFFICIENT
22
11
0
–10
–18
PERCENT CHANGE PER 10 PPM INCREASE IN CO2
National
NE
SE
NW
SW
p (significance) 0.14 0.40 0.57 0.002
REGION

Take away message:

- The only region in which there is strong statistical evidence of an association between floods and global CO_2 is in the southwest, and the relationship there is negative.
- All approaches to understanding the flooding/greenhouse gas question have flaws. But we need to **look at the data regularly** and **with diverse approaches** to see what might be emerging.

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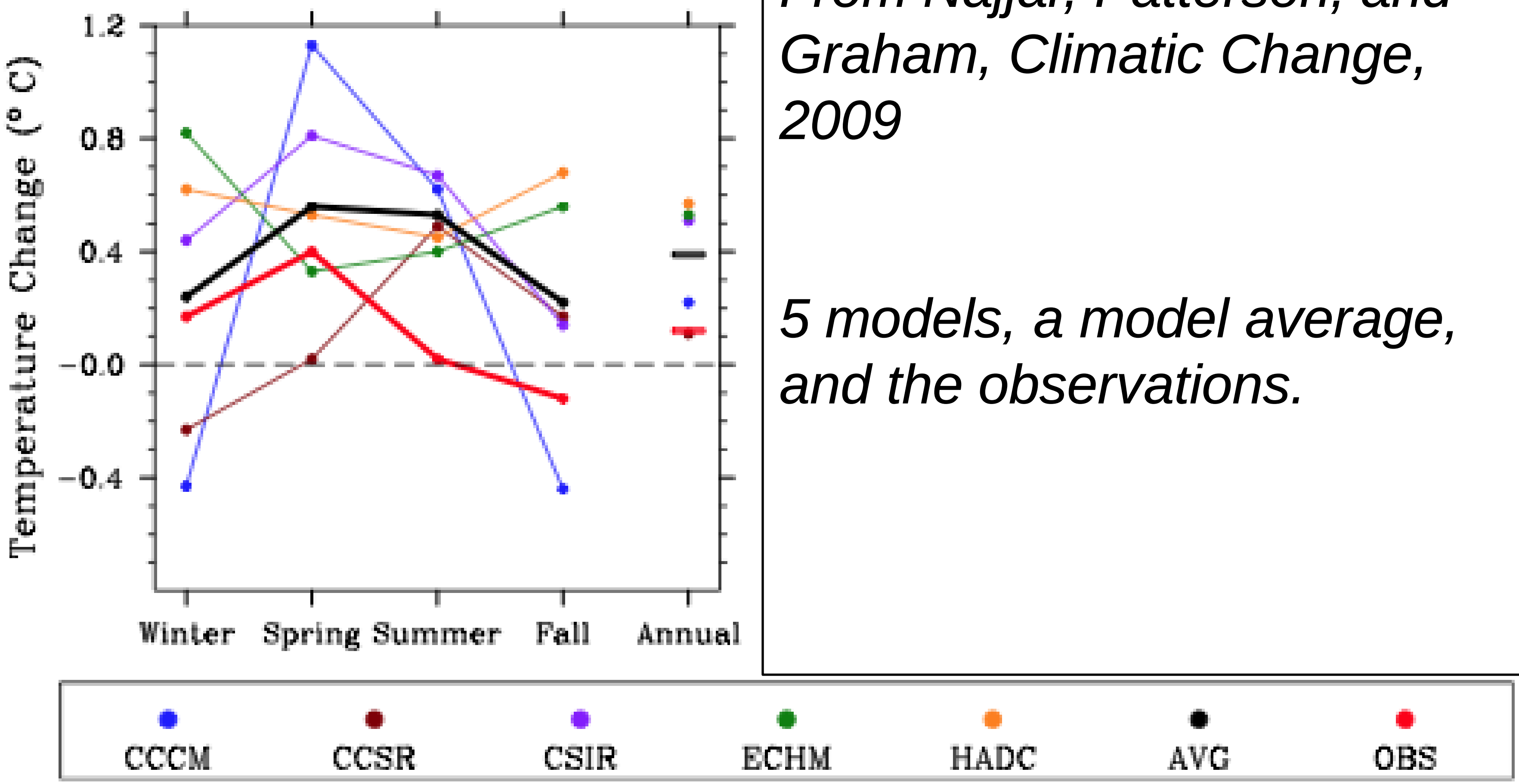
Can climate models be our bridge to the future?

Chesapeake Bay watershed. Climate-model outputs and observations, Changes between 1911-1940 and 1971-2000.

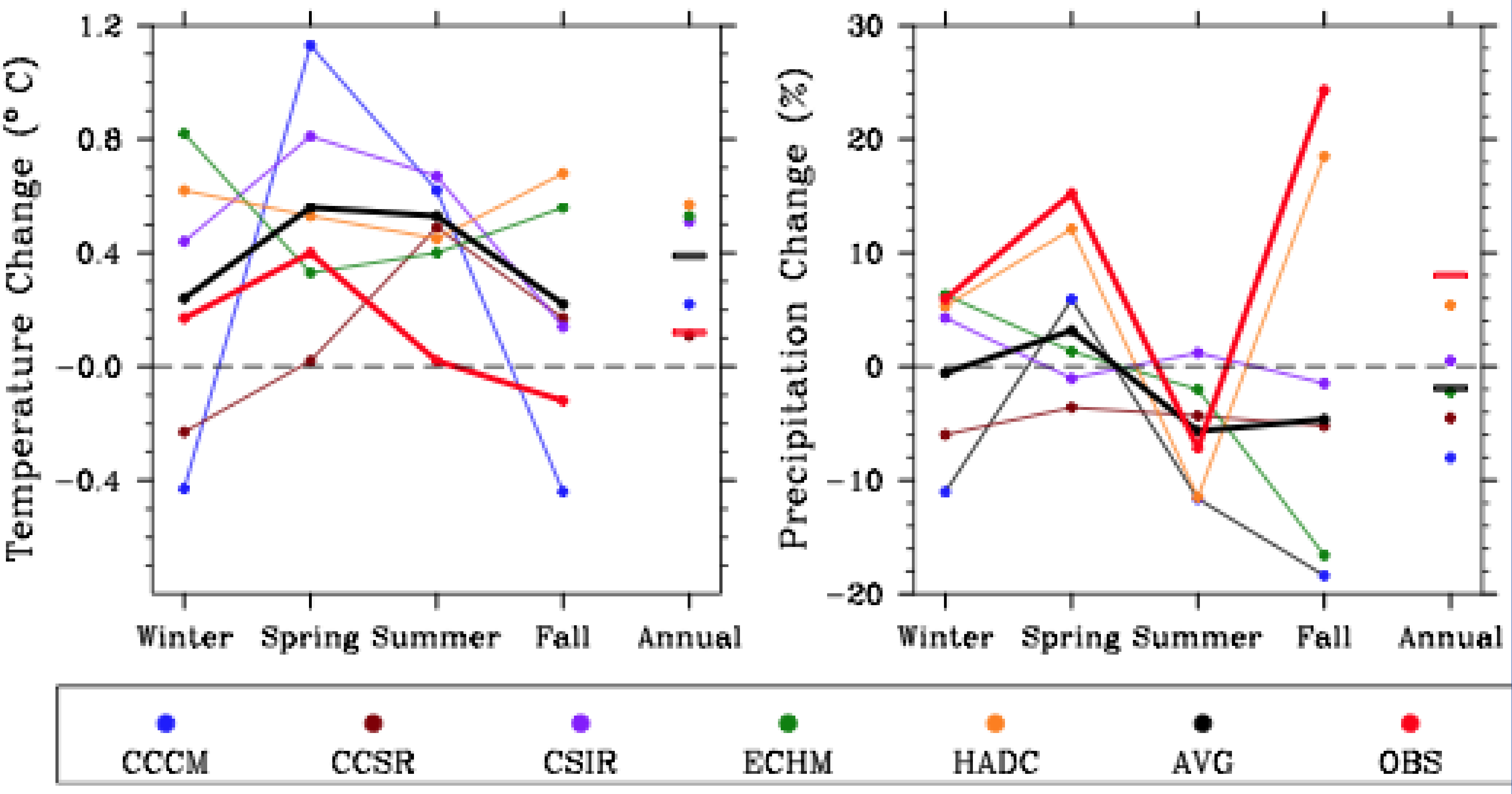
Temperature results



From Najjar, Patterson, and Graham, Climatic Change, 2009

5 models, a model average, and the observations.

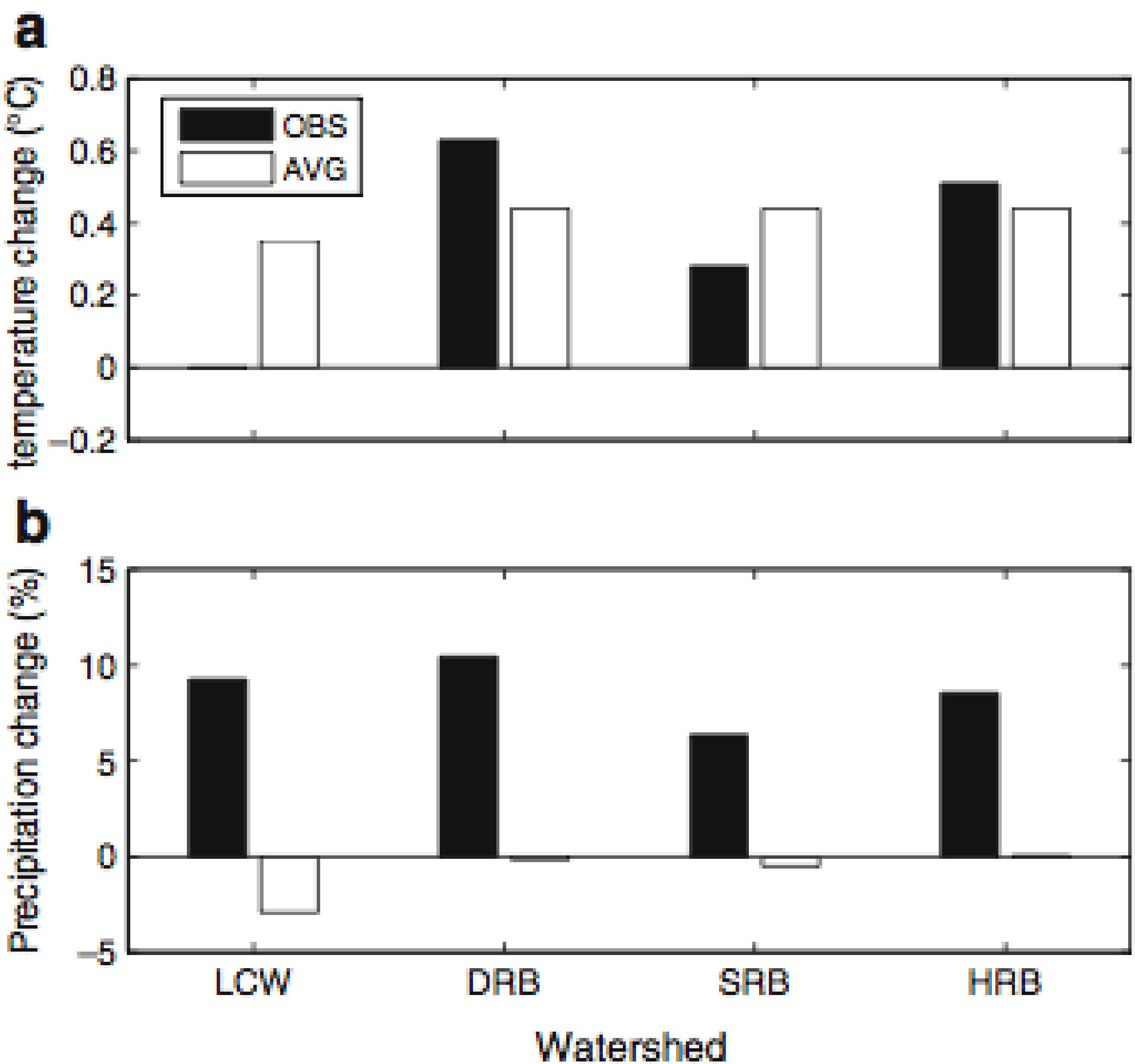
Next: Precipitation results



More from Najjar et al. 2009,

Comparing 1911-1940 to 1971-2000

Climatic Change (2009) 95:139–168



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What are we to conclude?

- **Looking at real hydrologic records my refrain always seems to be:**
- **“And you know something's happening but you don't know what it is…..do you, Mr. Jones?”***
- **** Words and music by Bob Dylan, “Ballad of a Thin Man”, Highway 61 revisited.***

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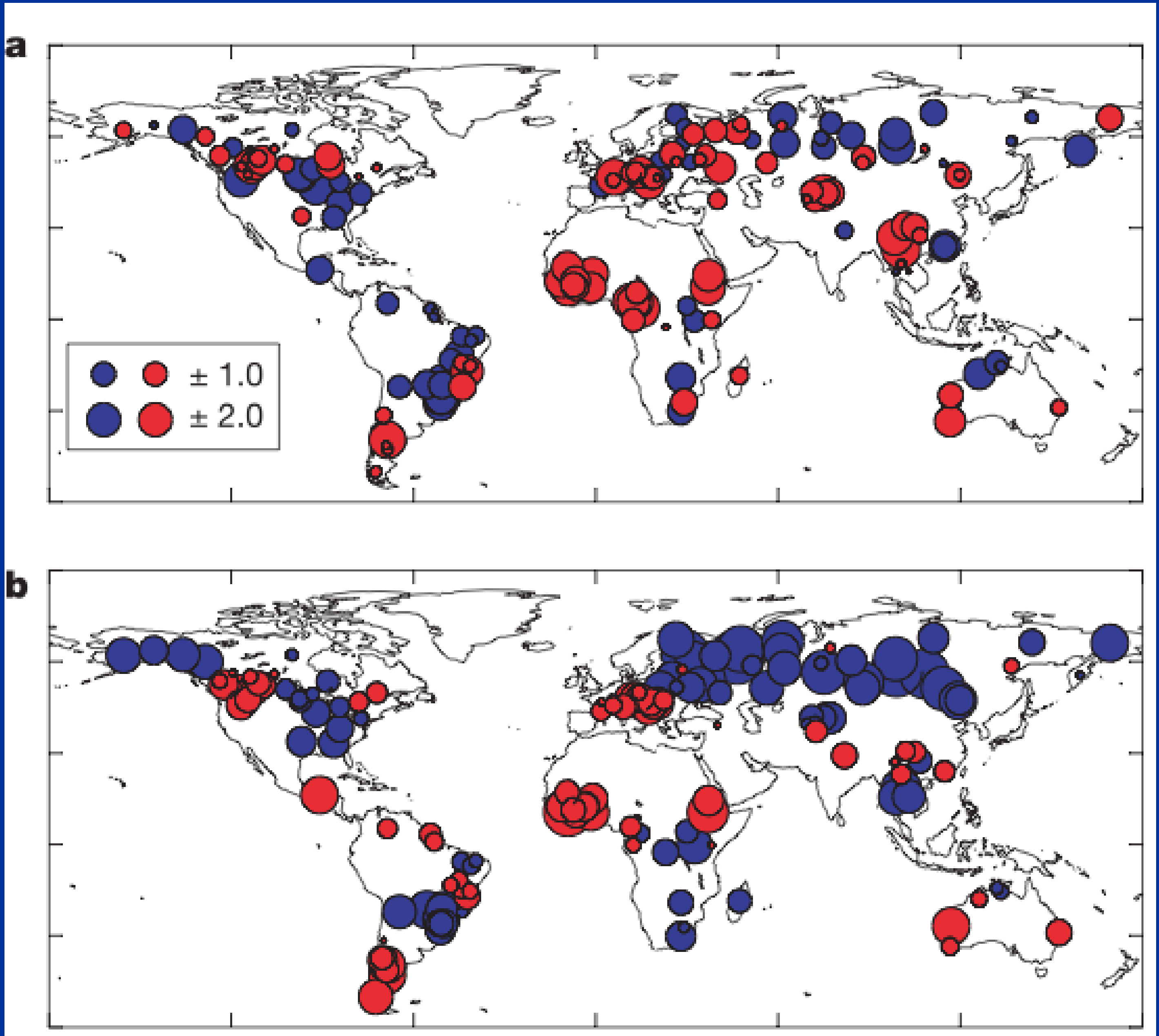
Milly, Dunne, and Vecchia, Nature, 2005: Comparison of streamflow: 1900-1970 to 1971-1998

Streamgage data

Averaged results of 35 GCM runs



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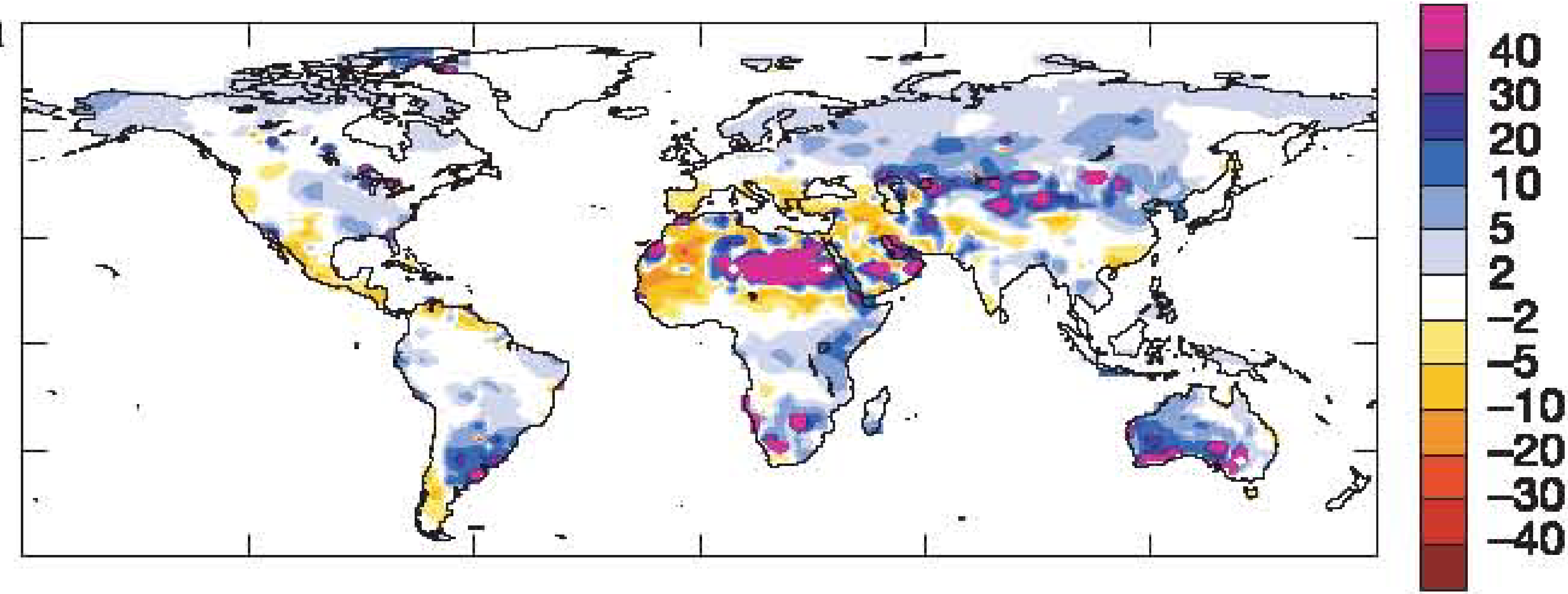
Milly, et al. (2005, Nature)



Estimated percentage change in runoff for 1971-98 vs. 1900-1970 due to global atmospheric forcing, ensemble of GCM model runs

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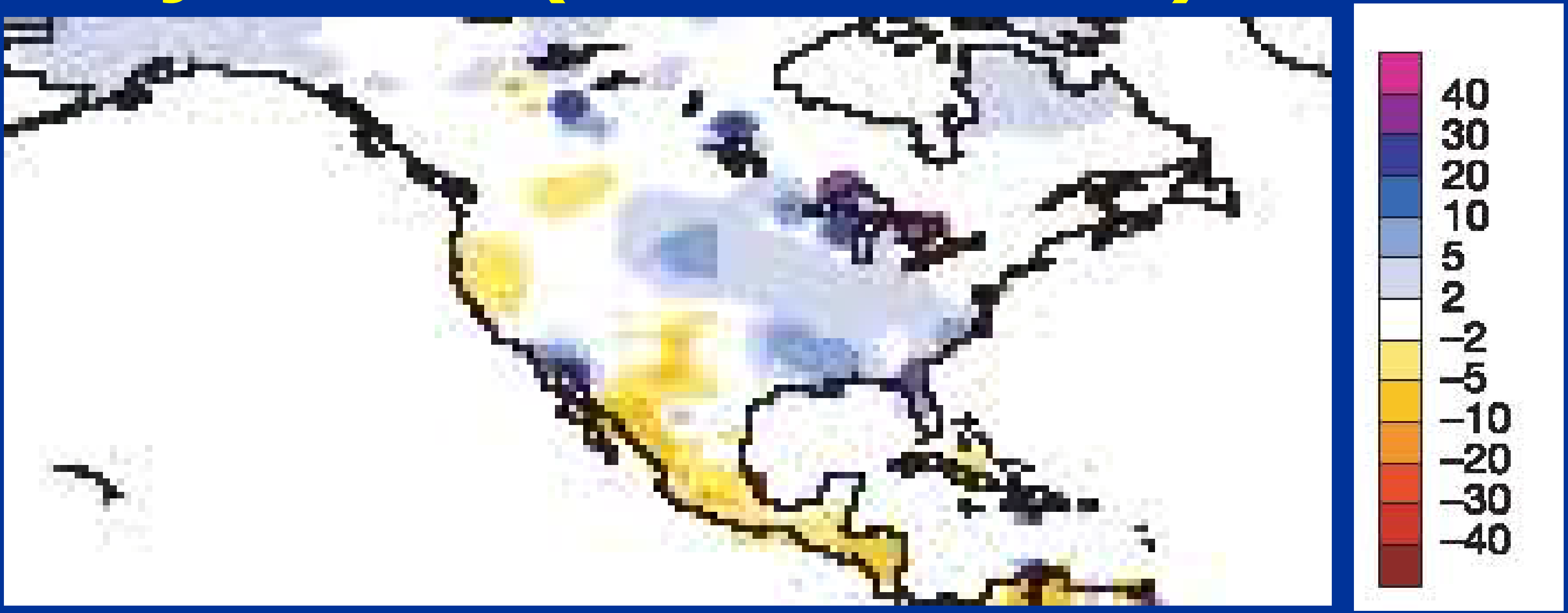
Milly, et al. (2005, Nature)



Actual examples:

Potomac River, Point of Rocks, MD +23%

Mississippi River, Keokuk, IA +24%

Red River of the North, Grand Forks, ND +65%

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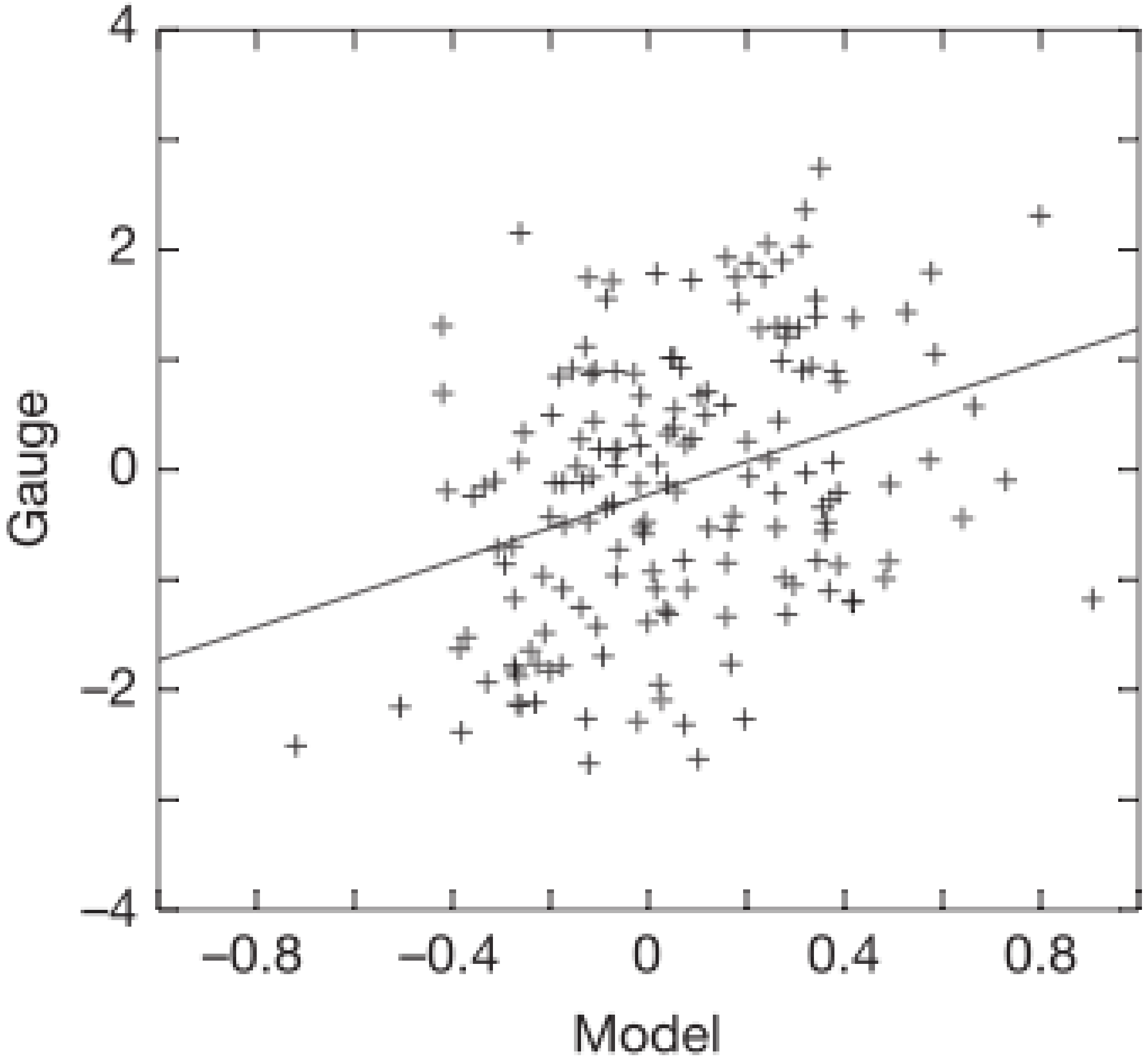
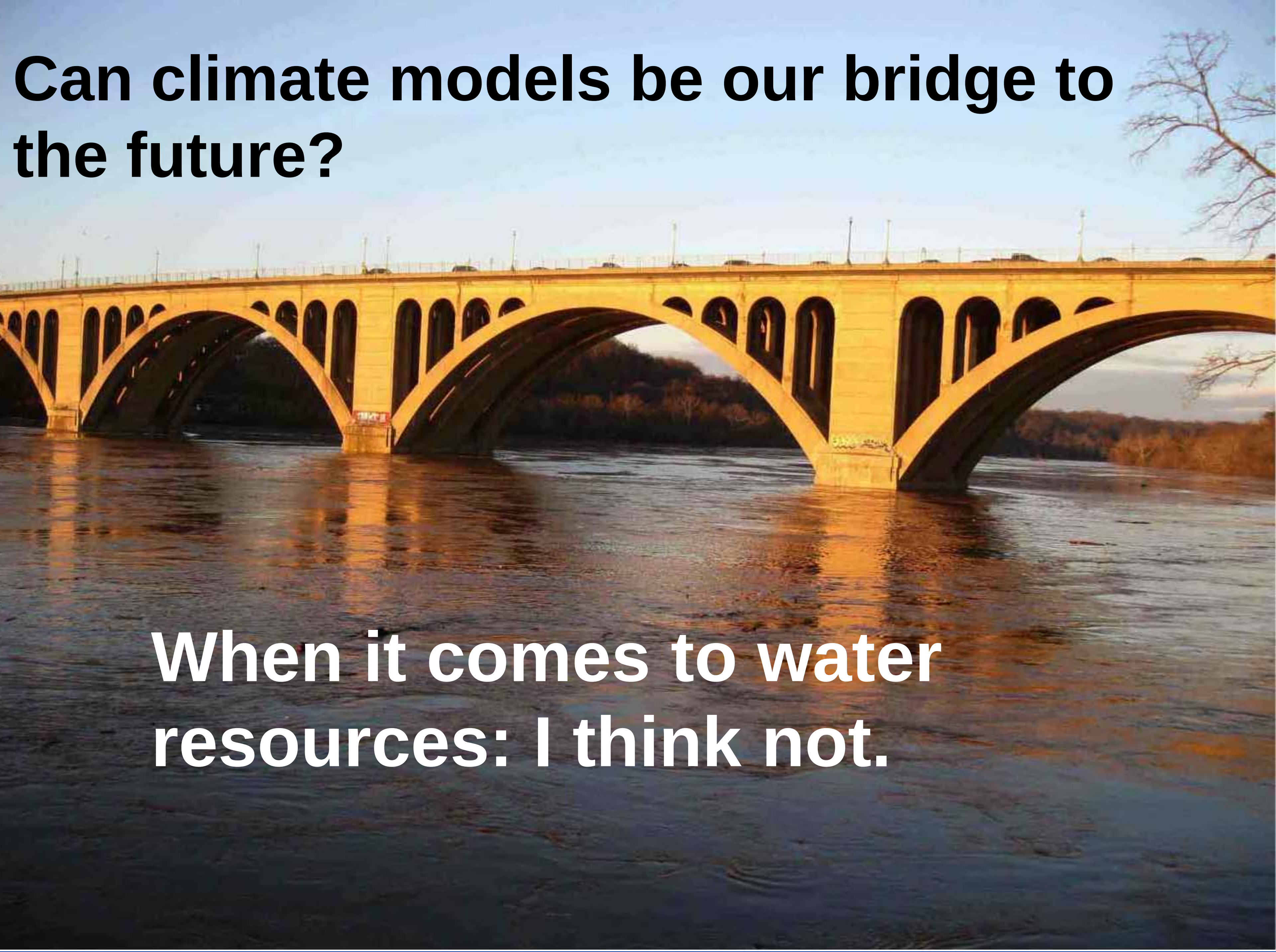
Milly, Dunne, and Vecchia, Nature, 2005: Comparison of streamflow: 1900-1970 to 1971-1998

Plotting all those pairs of model versus streamgage data.

Results are "statistically significant" but R^2 = 12%



Can climate models be our bridge to the future?



When it comes to water resources: I think not.

Seven Steps to Adaptation to Climatic Uncertainty

1. Deny Uncertainty
2. Debate Uncertainty
3. Investigate Uncertainty
4. Attempt to Reduce Uncertainty
5. Accept Uncertainty
6. Plan for Uncertainty
7. Adapt to Uncertainty

Marc Waage, Denver Water & Water Utility Climate Alliance

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Approach to planning & operations

- Pay attention to what is actually happening hydrologically, don't wait for the models to provide "answers"
- Expect surprises, quasi-periodic shifts, unrelated to the "greenhouse"
- Reduce risk, diversify "portfolio" of resources, build in flexibility and cooperation

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An approach to science

- It is not stationary – get over it! Don’t get hung up on hypothesis testing

- Focus on describing & understanding change, considering the full range of possible drivers

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Milly et.al. 2008, Science

"Modeling should be used to synthesize observations; it can never replace them."

"In a nonstationary world, continuity of observations is crucial."

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So now what?

- Keep collecting the data (including paleo-data)
- Keep our analyses up to date: e.g. flood frequency, low-flow, safe yield…
- Recognize that nature is “trendy” -- keep the uncertainty bands wide

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From Ralph Keeling

A continuing challenge to long-term Earth observations is the prejudice against science that is not directly aimed at hypothesis testing.

At a time when the planet is being propelled by human action …. We cannot afford such a rigid view of the scientific enterprise.

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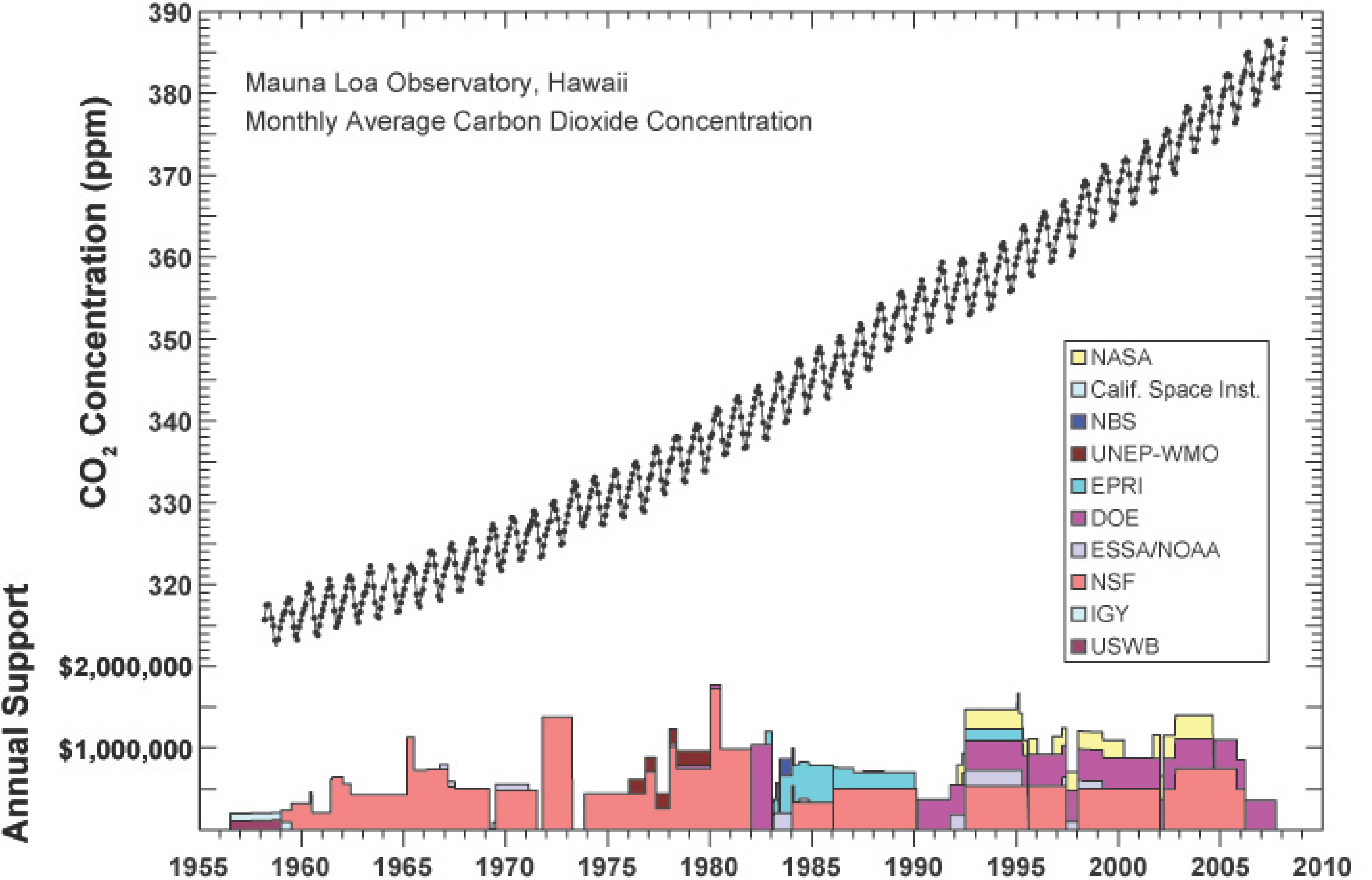
“Recording Earth’s Vital Signs”, Science, 2008, p.1771-1772

Funding sources for C.D. Keeling CO_2 measurements 1956-2005

(amounts adjusted to 2007 dollars)



From Ralph Keeling

The only way to figure out what is happening to our planet is to measure it,

and this means tracking changes decade after decade

and poring over the records.

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How do we build a bridge to the future?

- Be humble
- Reduce risk
- Keep learning from the data