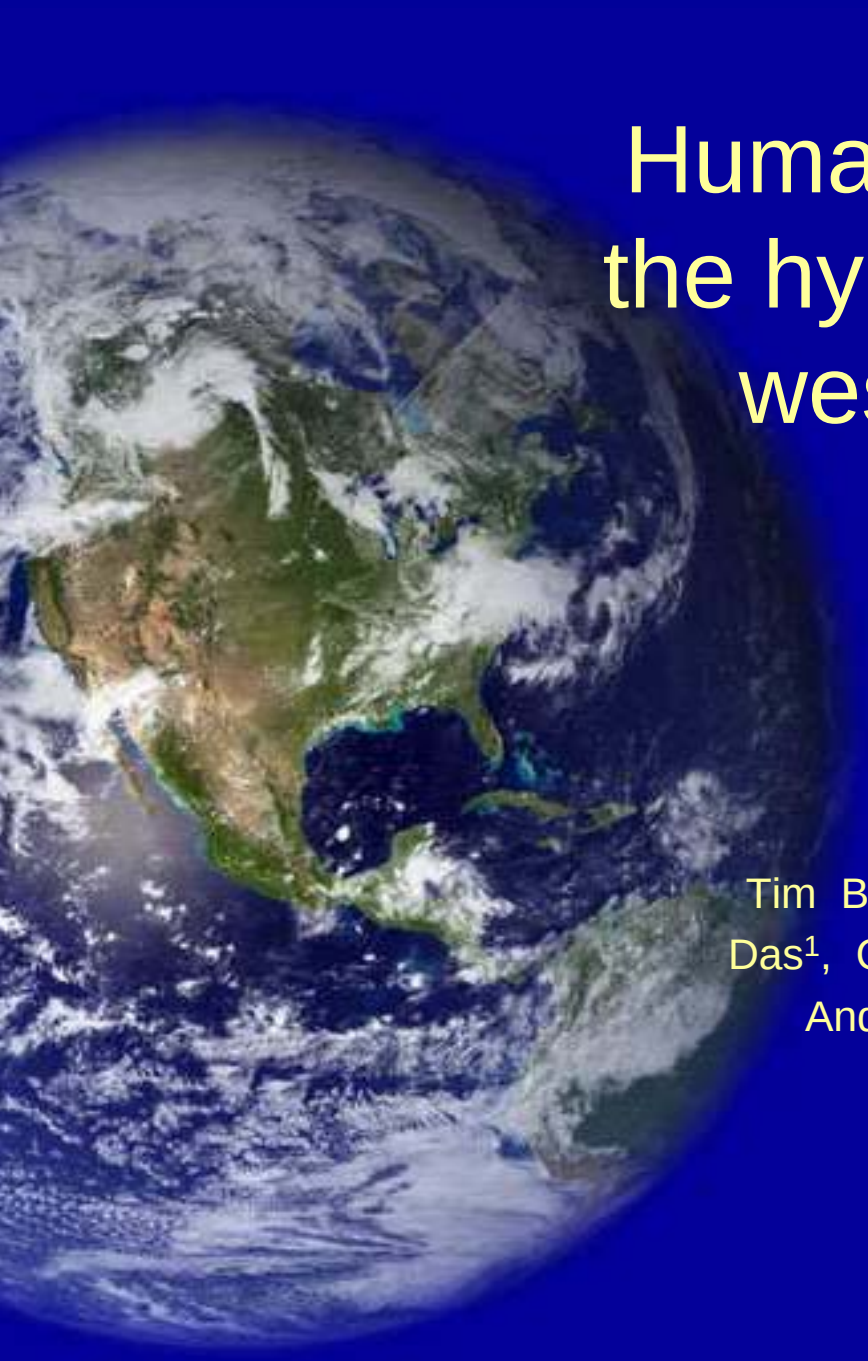


Human-induced changes in the hydrological cycle of the western United States

Tim Barnett[1], David Pierce[1], Hugo Hildalgo[1], Tapash Das[1], Celine Bonfils[2], Ben Santer[2], G. Bala[2], Art Mirin[2], Andy Wood[4], Toru Nozawa[3], Dan Cayan[1], Mike Dettinger[1]

[1]*Scripps Institution of Oceanography*

[2]*Lawrence Livermore National Lab*

[3]*National Inst. Environmental Sciences (Japan)*

[4]*Univ. Washington*


Snowpack
Fraction of SWE/P
0.4
0.2
0.0
-0.2
-0.4
-0.6
1950
1970
1990

The Problem

The hydrological cycle is changing over the western United States

WHY?

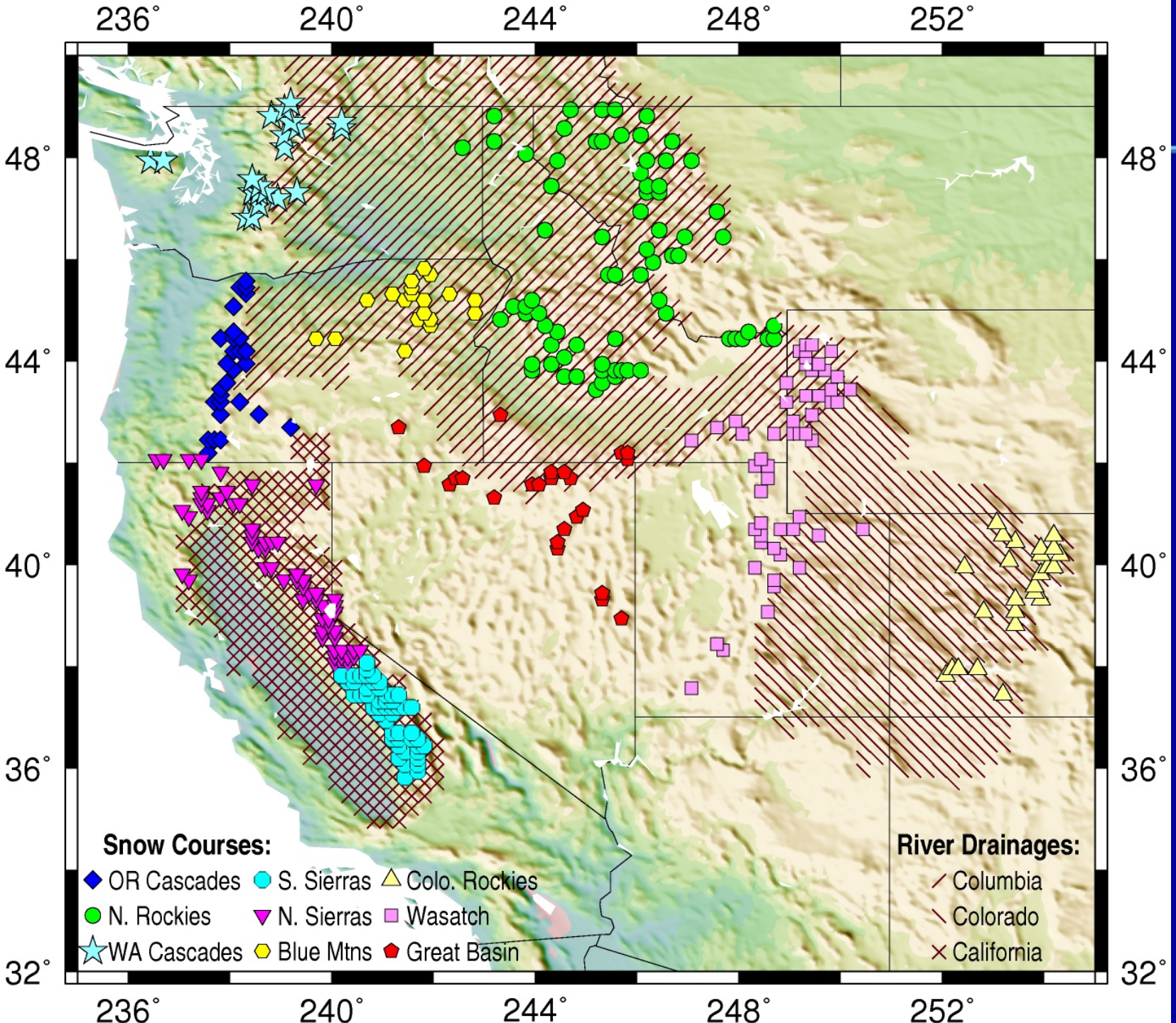
Natural variability or man made?

WHY? Detection and Attribution (D&A)

- Detection: are the changes *inconsistent* with natural variability?
- Attribution: are the changes *consistent* with anthropogenic (or other) forcing?
- Generate a *"fingerprint"* that encapsulates changes expected (from model runs)
- Match fingerprint in obs and forced models

Detection & Attribution: Overall scheme

1. Start with global GCMs: control and anthropogenically forced runs
2. Downscale to region of interest (Wood, et al, 2004;Hidalgo, et al, 2007)
3. Run VIC hydrological model w/ downscaled data
4. D&A on 3 variables:
   - SWE/P (1 April Snow Water Equv. / Oct-Mar precip)
   - Temperature (examined JFM daily minimum temperature)
   - River flow (examined JFM fraction and CT, center of timing)



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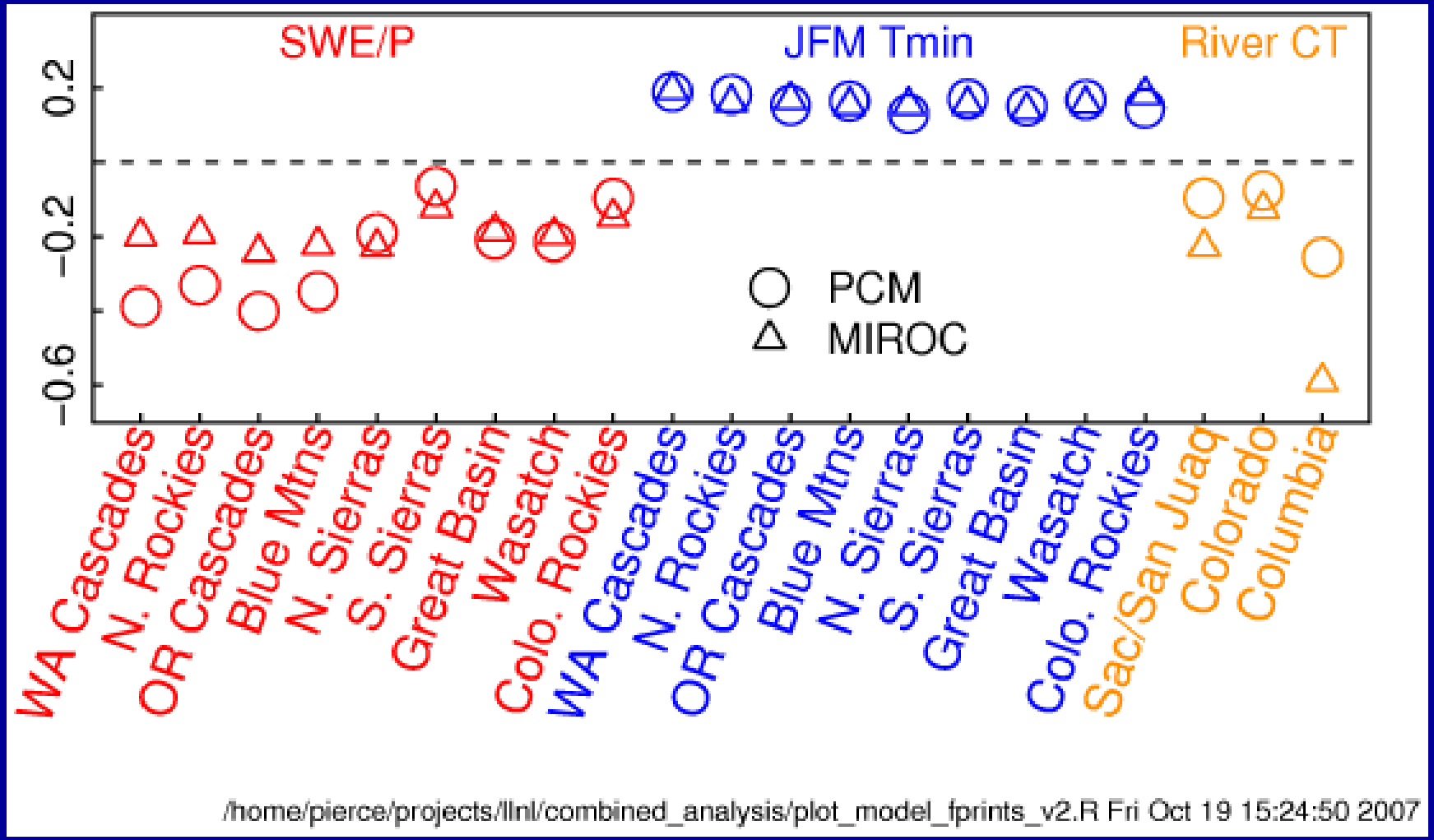
Multivariate fingerprint: PCM vs. MIROC

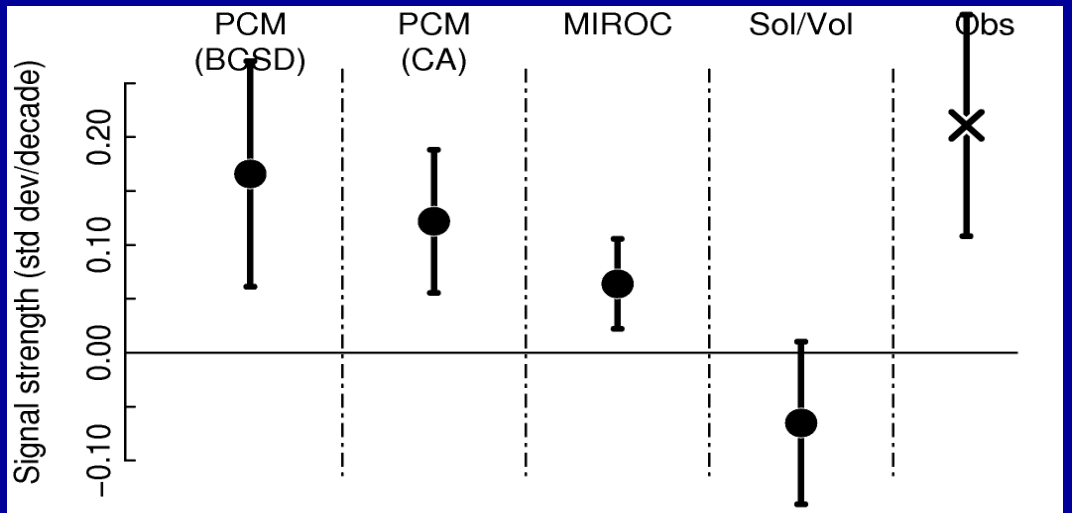


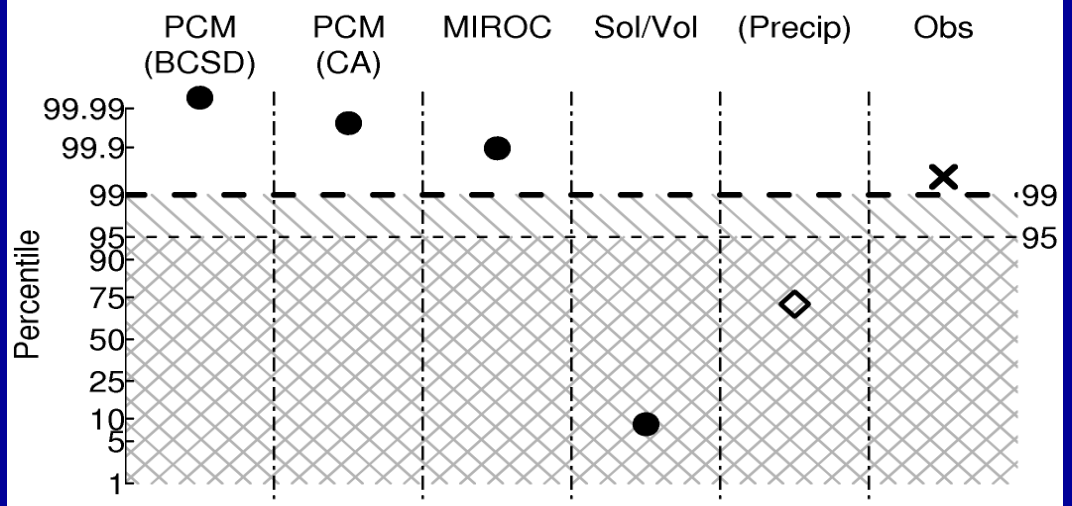
Ensemble signal strength & significance

Fingerprint

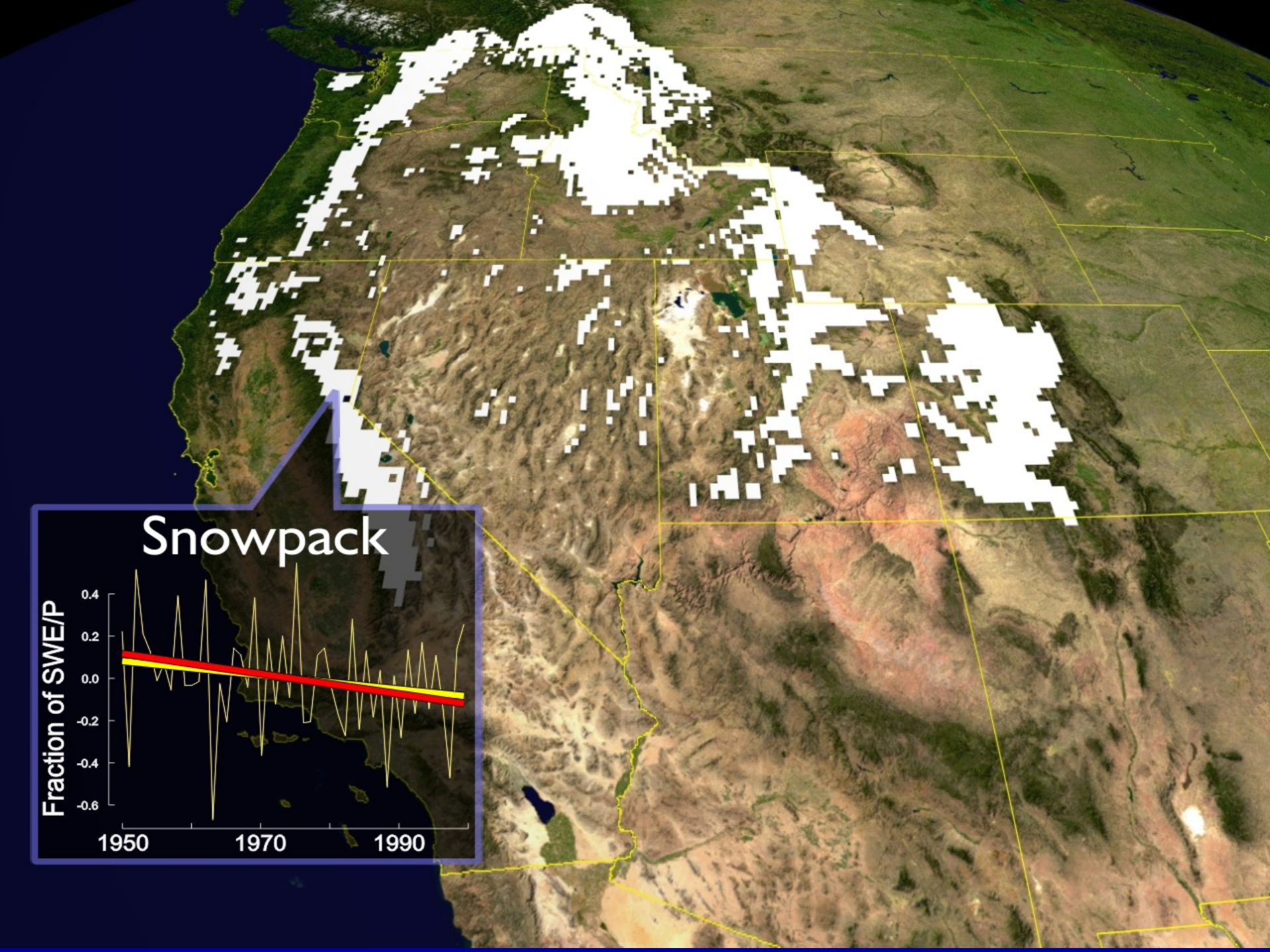
Signal Strength

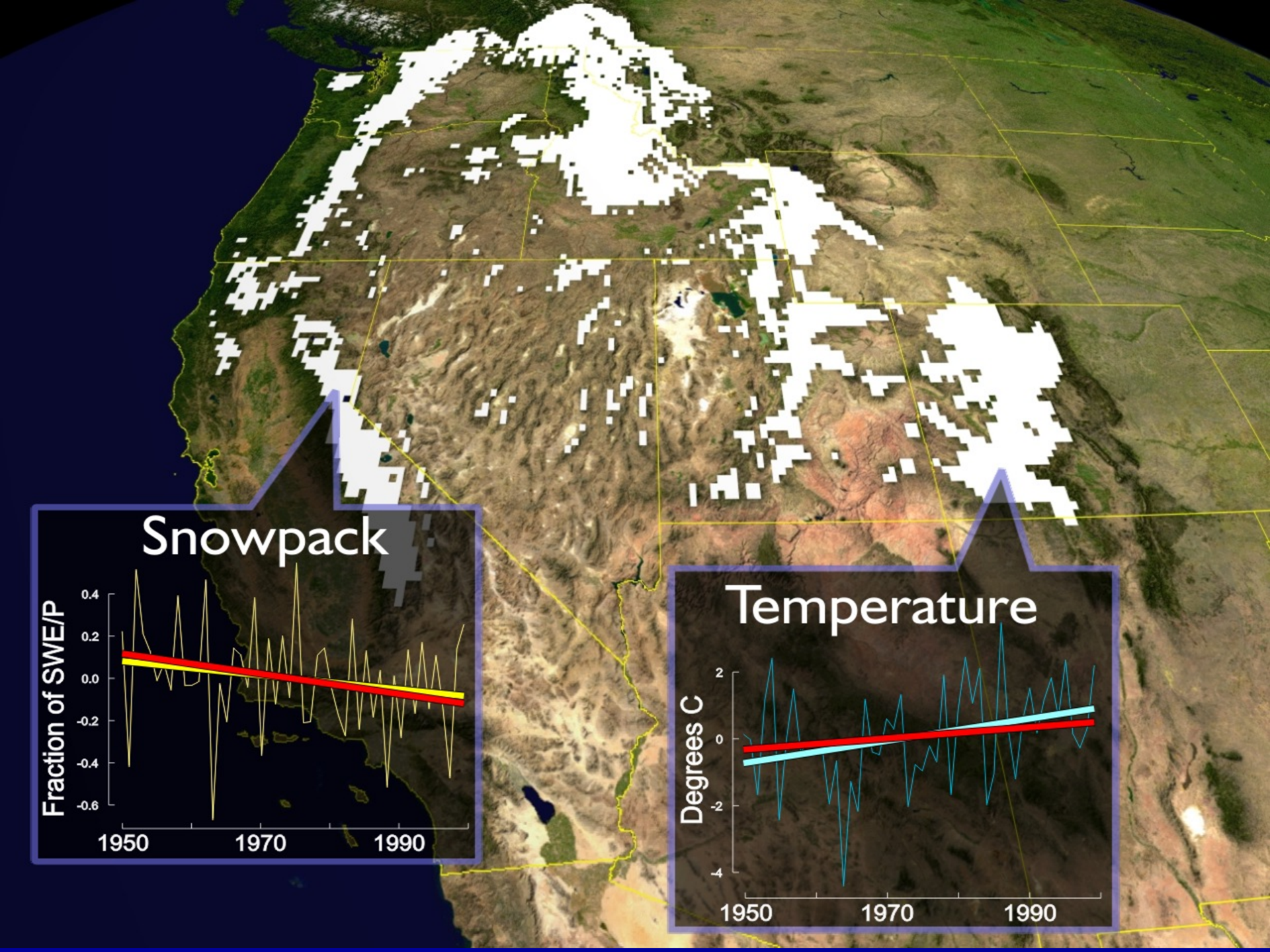
Significance

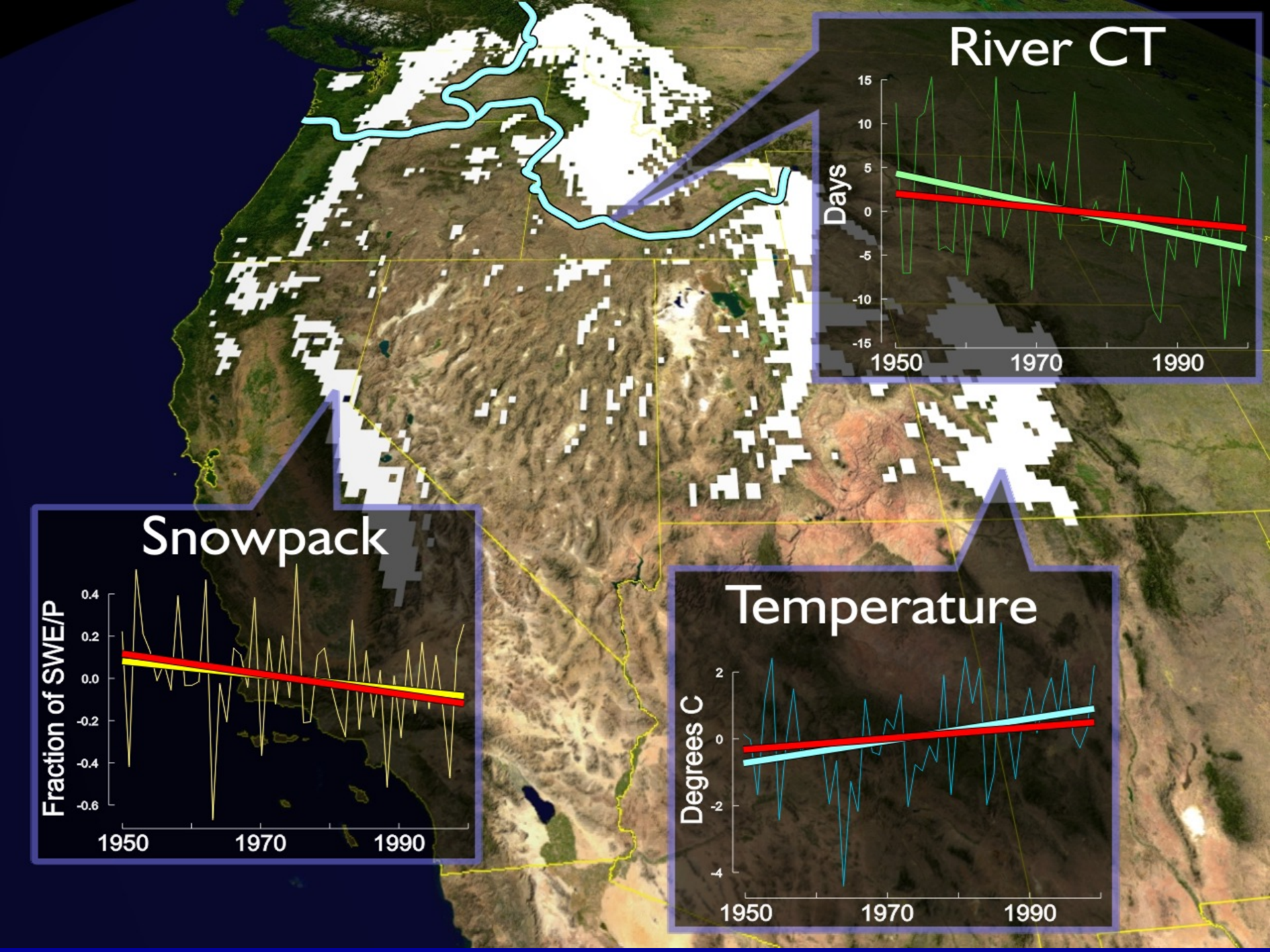




/home/pierce/projects/llnl/combined_analysis/project_fingerprint.2007−10−25.R Thu Oct 25 18:33:11 2007


Snowpack
Fraction of SWE/P
0.4
0.2
0.0
-0.2
-0.4
-0.6
1950
1970
1990


Snowpack
Fraction of SWE/P
0.4
0.2
0.0
-0.2
-0.4
-0.6
1950
1970
1990
Temperature
Degrees C
2
0
-2
-4
1950
1970
1990


River CT
Days
15
10
5
0
-5
-10
-15
1950
1970
1990
Snowpack
Fraction of SWE/P
0.4
0.2
0.0
-0.2
-0.4
-0.6
1950
1970
1990
Temperature
Degrees C
2
0
-2
-4
1950
1970
1990

D&A summary

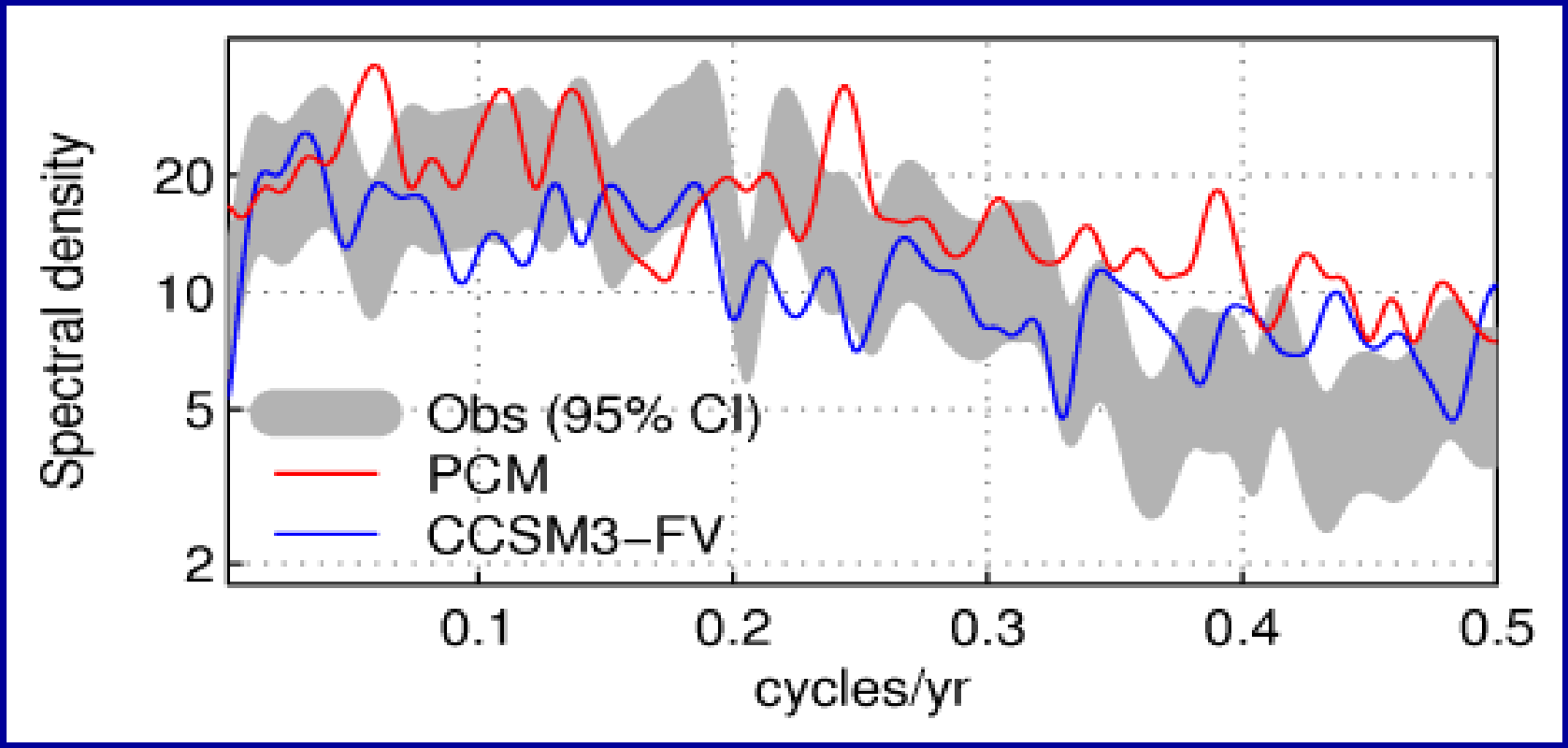
- Natural variability cannot explain obs.
- Solar/volcanic forcing cannot explain obs
- Changes in precipitation cannot explain obs

- ANTHROPOGENIC warming CAN explain obs. changes very well

Q: WHY? ANS: It is ‘US’!

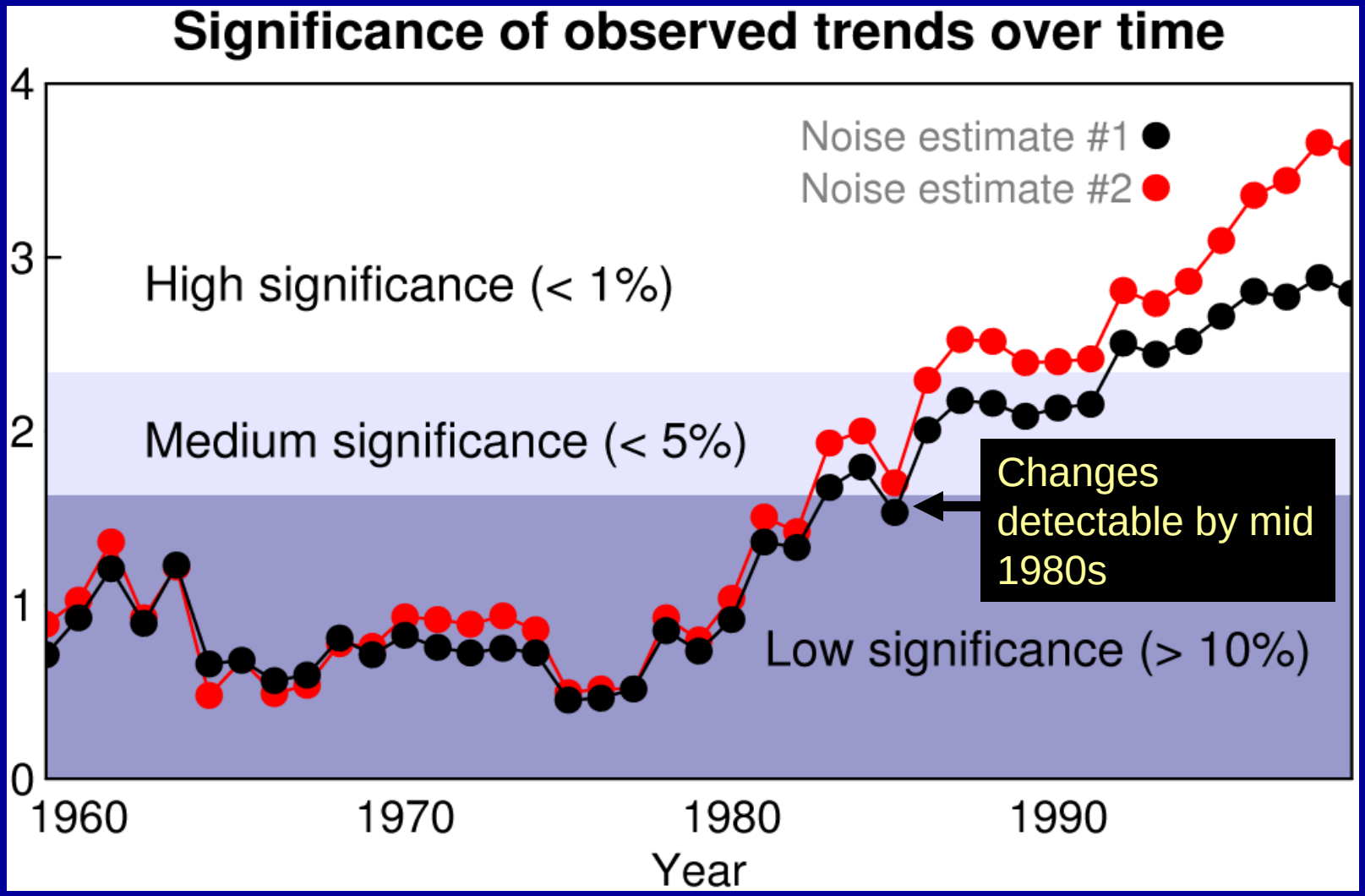
How good are estimates of Natural Variability?

Spectra reconstructed Colorado River flow last 1000+ years



Detection and Attribution of Human-induced changes in the western water supply

Signal to noise ratio

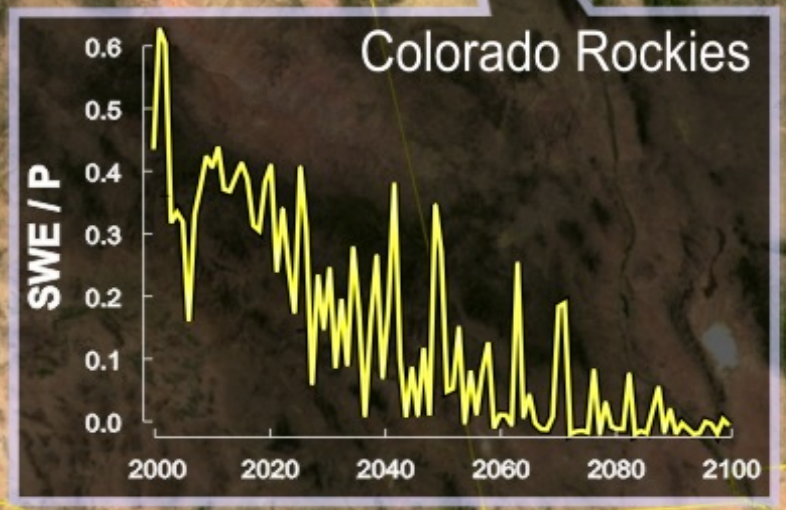


Barnett et al., *Science*, 2008

Conclusions

- The changes in western hydrology over 1950-99 are largely due to human-induced warming; PCM captures 74% of low frequency signal
- The PCM, run in forecast mode, shows a grim view of western U.S. water supplies within the next 30 years (ACPI). If PCM worked so well over the last 50 years, we have good reason to believe these predictions

April 1st snowpack



Colorado River drainage

Water supply for:

- 27 million people
- 3.5 million acres of farmland

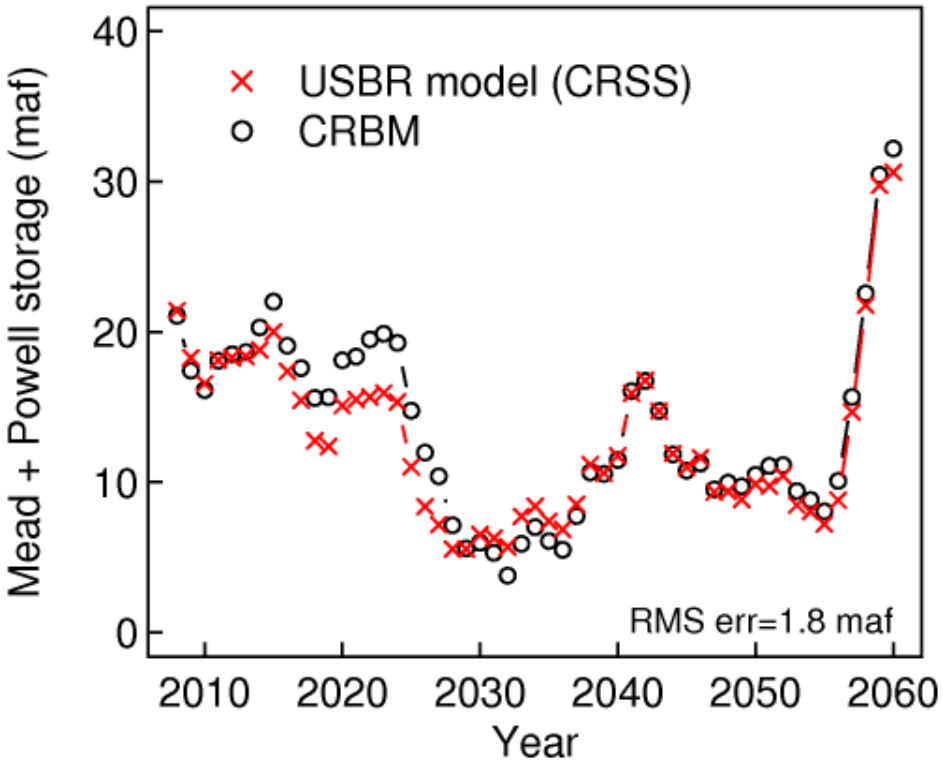
Users in:

- 7 states
- 2 countries
- Several Native American tribes

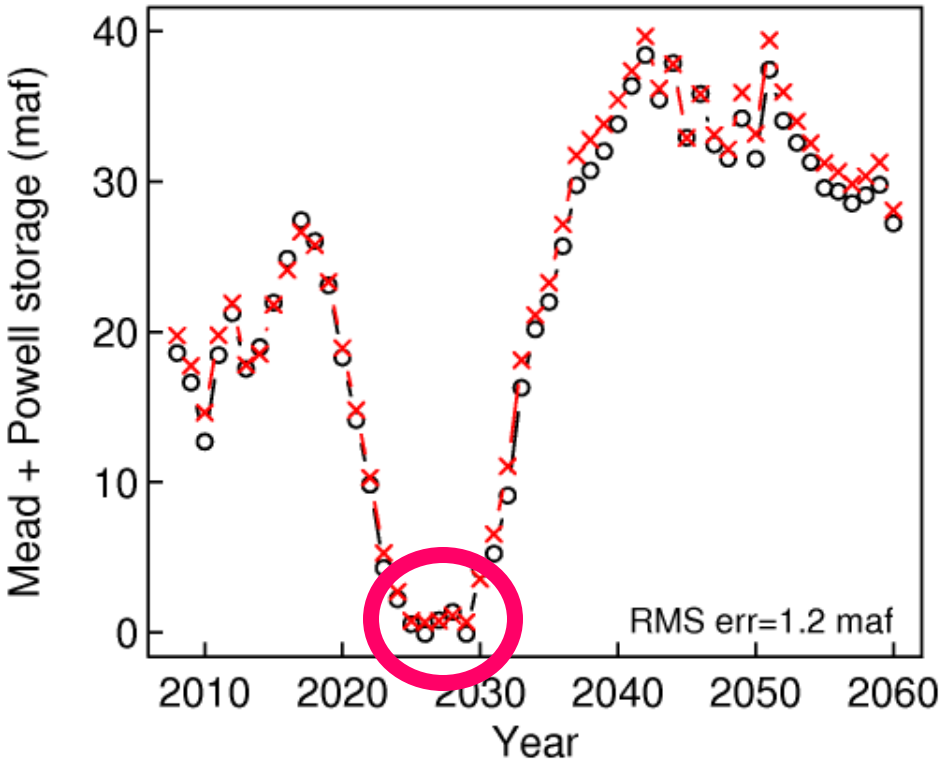
Current deliveries: ~13.5 maf/yr, increase to ~14.4 maf/yr by 2060

Model Calibration

After figure N–8 from USBR 2007 Env. Impact Stmt.



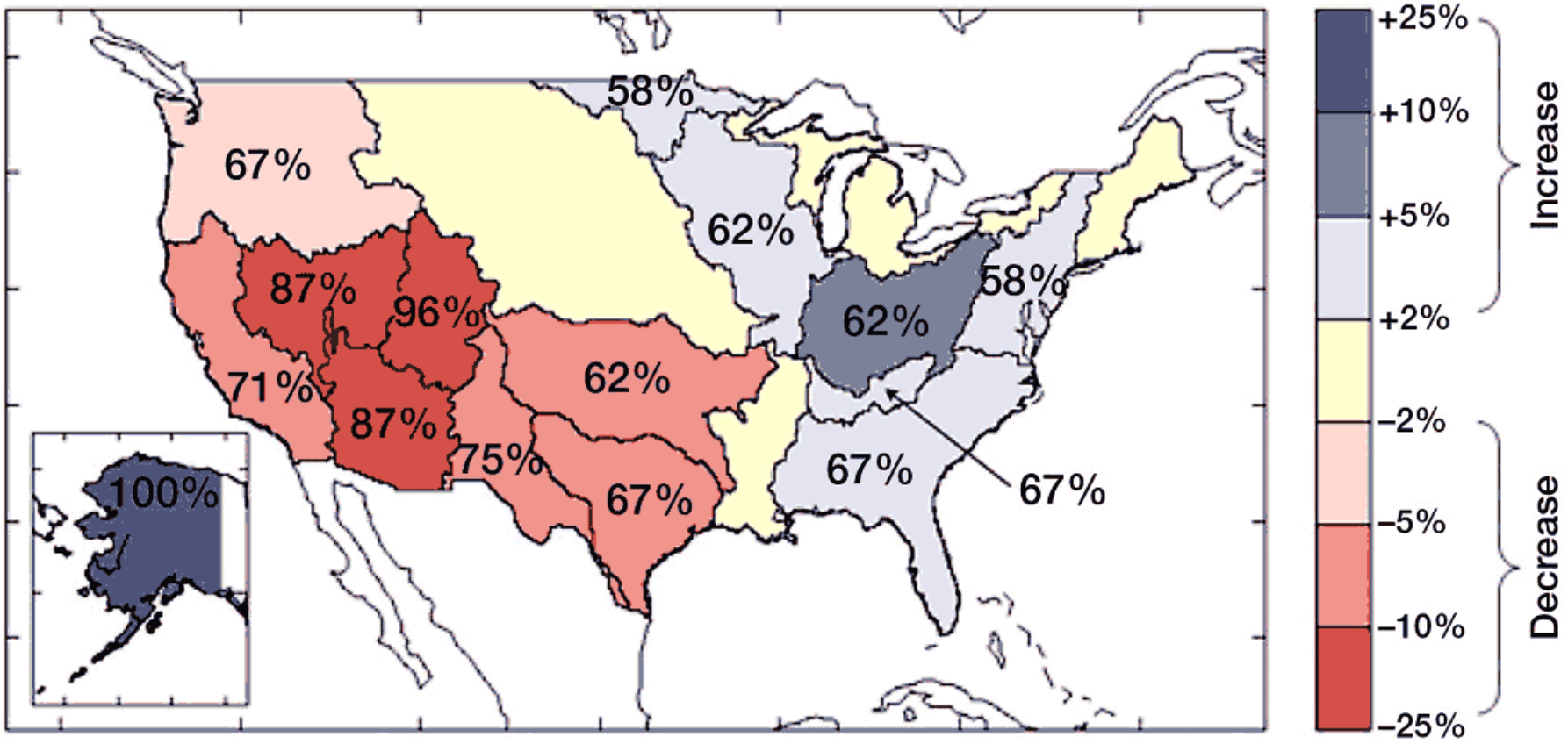
After figure N–10 from USBR 2007 Env. Impact Stmt.



"Modeling assumptions…allowed a maximum shortage of 3.3 maf, resulting in the inability to absolutely protect Lake Mead elevation 1,000 feet msl." (pg. N-18)

Changes in Runoff by midcentury

(Numbers show *model agreement*; colors show *change*)



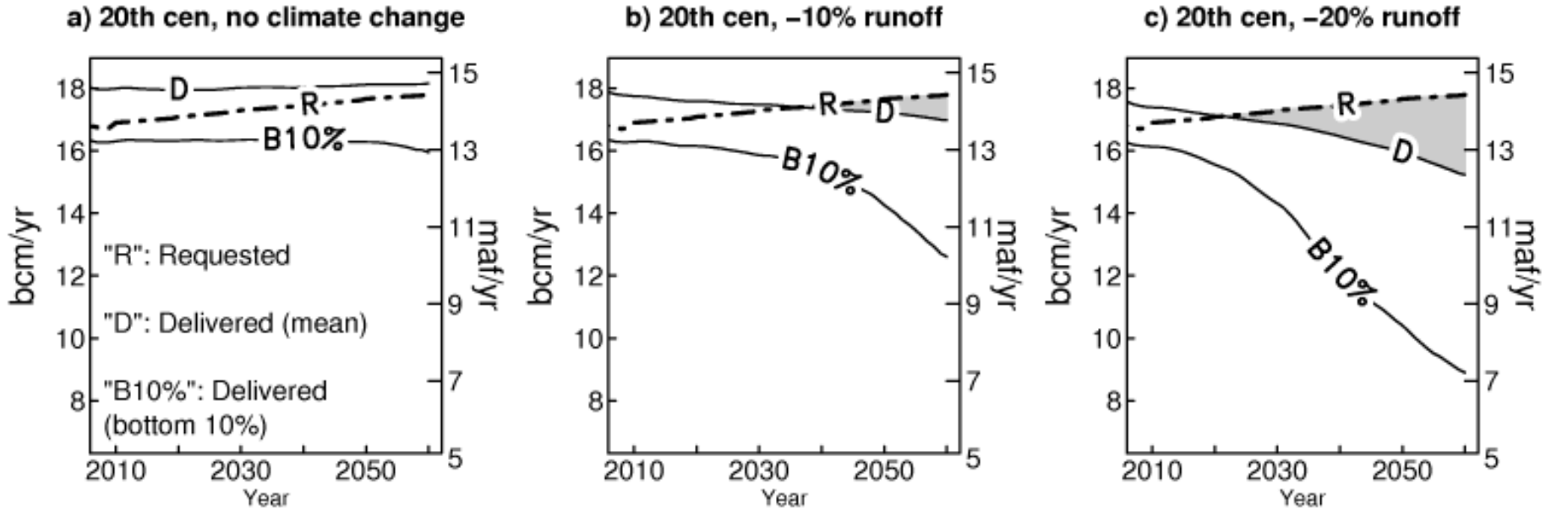
From Milly et al., *Nature*, 2005, as redrawn in Lettenmaier et al., CCSP report SAP 4.3, 2008

Climate change assumptions

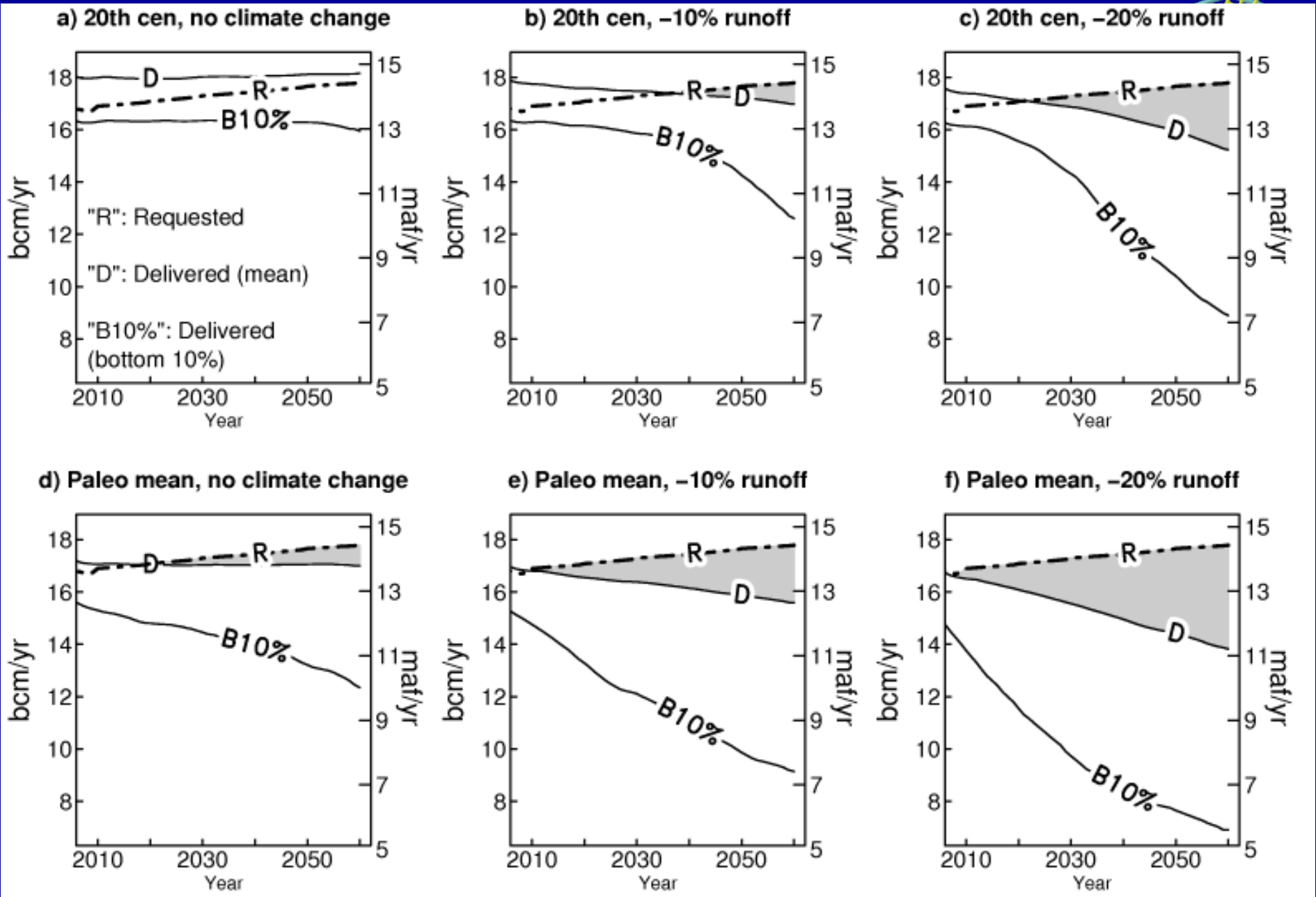
- Two areas of inquiry
  1. How will the *river runoff change?*
  2. How will the change *affect deliveries?*

Source	Runoff reduction
Nash and Gleick (1991)	12-31% (depends on scenario)
Nash and Gleick (1993)	8-20%
Christensen et al. (2004)	18%
Milly et al. (2005)	10-25%
Seager et al. (2007)	15-20%
Christensen & Lettenmaier (2007)	6-7%
Hoerling and Eischeid (2007)	45% (under revision)
McCabe and Wolock (2007)	8-17%

How much water can the river supply?



Assuming 20th century flows:
-10% runoff: ~13.7 maf/yr
-20% runoff: ~12.5 maf/yr


a) 20th cen, no climate change
b) 20th cen, –10% runoff
c) 20th cen, –20% runoff
d) Paleo mean, no climate change
e) Paleo mean, –10% runoff
f) Paleo mean, –20% runoff
bcm/yr
maf/yr
Year
2010
2030
2050
D
R
B10%
"R": Requested
"D": Delivered (mean)
"B10%": Delivered (bottom 10%)

Do we have time to change directions??

Lake Mead, Oct 2007(&Feb,2010)

Lake Mead's elevation is 15 feet lower than last year at this time!
Lake Mead is 118 feet below maximum elevation!
Lake Mead has fallen to 46% of capacity!

From K. Dewey, HPRCC