Human-induced temperature changes in the mountainous western United States

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Context

Since 1950, over western U.S., are observed:

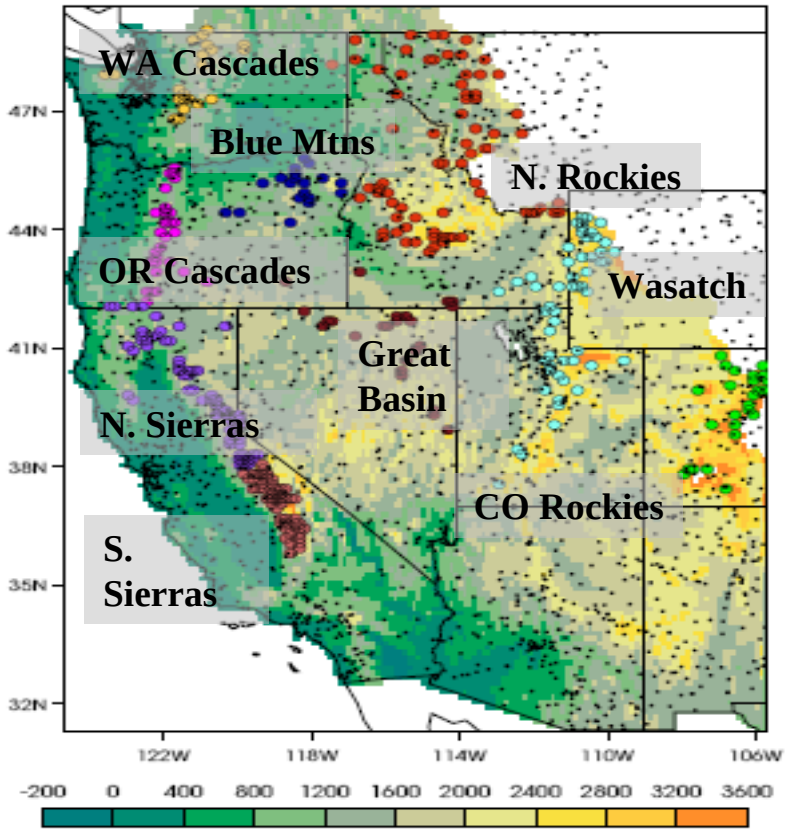
- an earlier green-up
- a reduction in the amount of rainfall arriving as snow
- a decline in snowpack in spring & a shift towards earlier snowmelt
- a shift towards earlier streamflow peaks

Are these changes primarily naturally-driven or human-induced?

Goal

We conduct a formal D&A analysis over 9 mountainous regions of the west using 4 different hydrologically-related temperature variables.

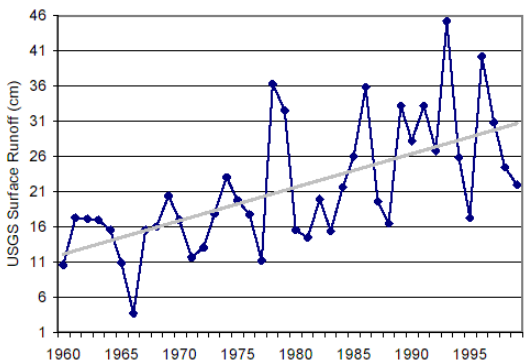
- JFM Tmin
- JFM Tmax
- JFM number of frost days (FD)
- JFM number of degree-days > 0°C (DD>0, proxy for T-driven snowmelt)



Observational and model data

Observational dataset

University WA, 1/8°x1/8° resolution (Daily Coop + monthly USHCN)



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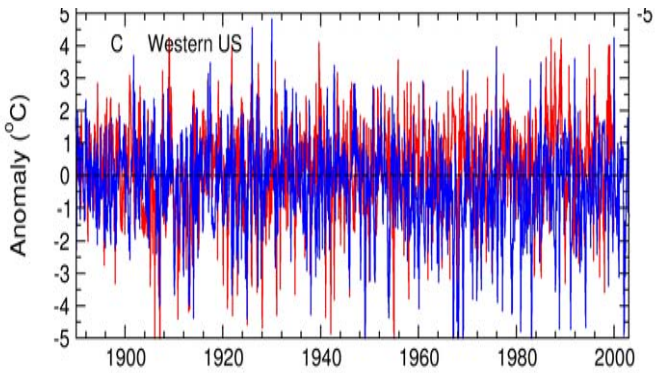
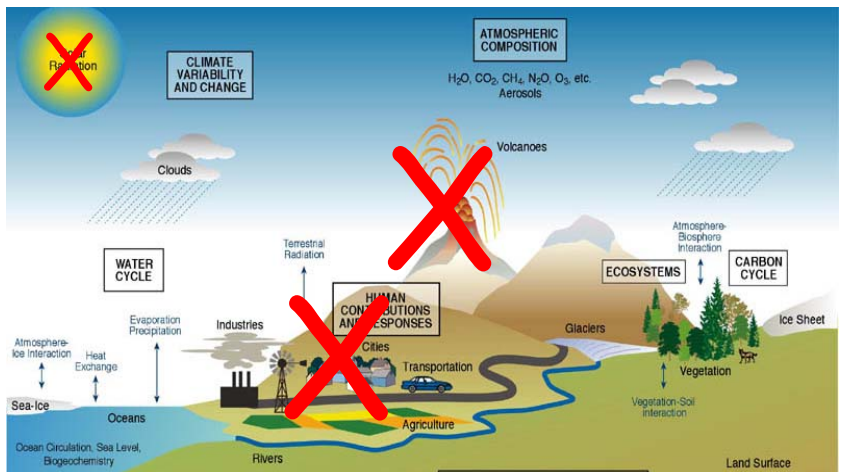
2 multi-century pre-industrial CTL runs (PCM-CTL, CCSM3-CTL)





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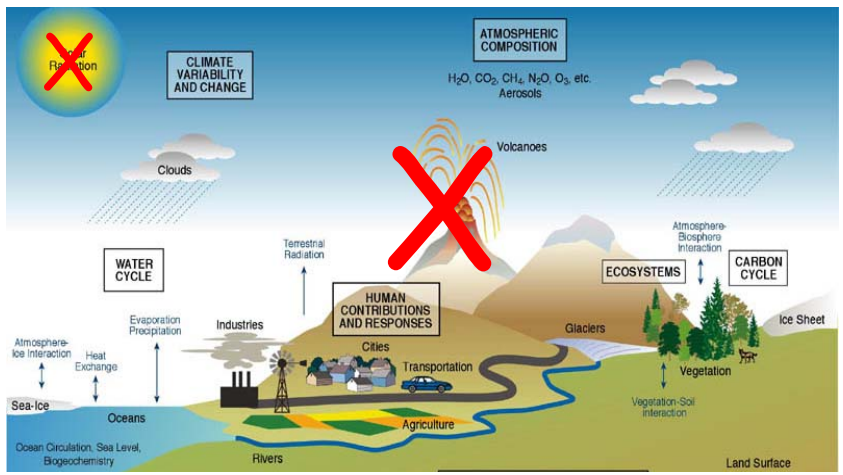
1 ensemble PCM-ANTH of 4 historical runs
1 ensemble MIROC-ANTH of 10 historical runs



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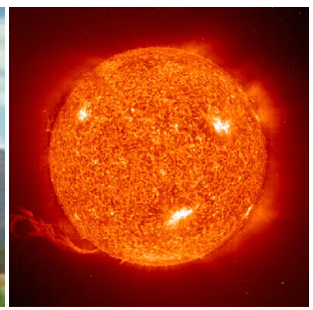
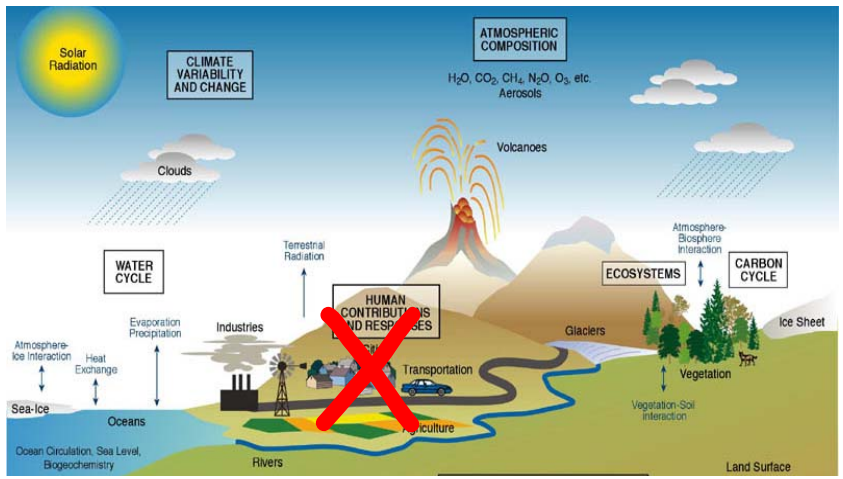
Characterization of the climate response to solar and volcanic forcings

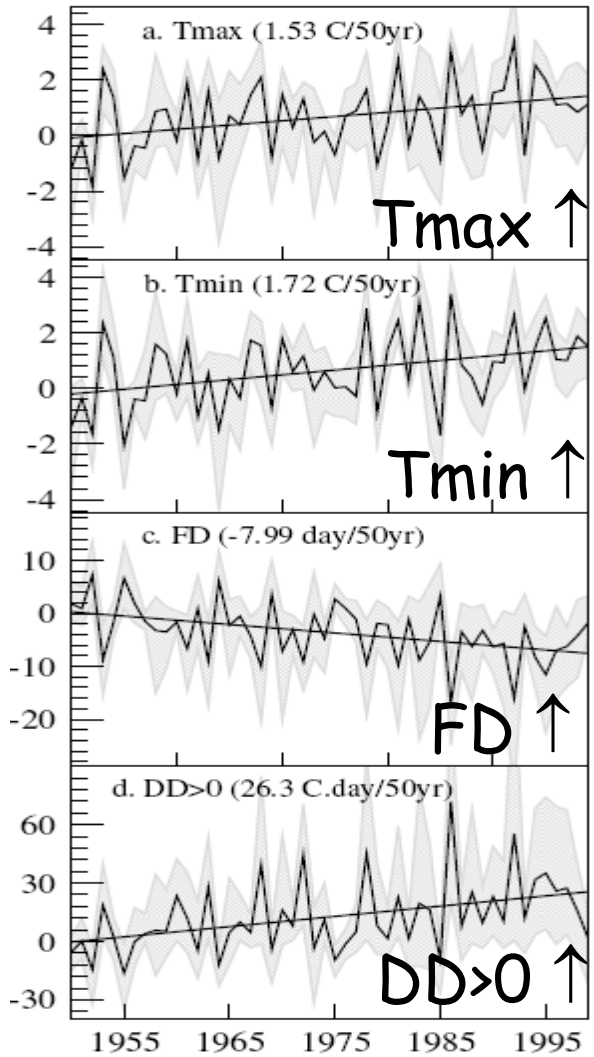
1 ensemble PCM-NAT of 2 runs





Observed changes

- Daytime and nighttime warming
- Decrease in the number of frost days



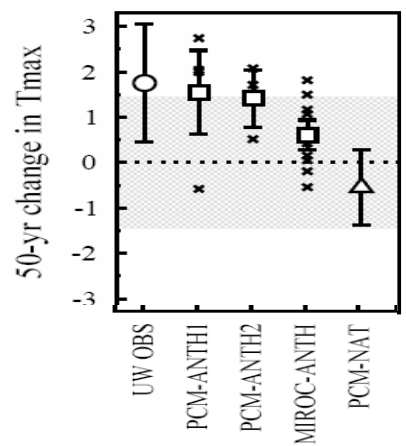
Challenges → Solutions

	Challenges	Solutions
1.	Climate in western U.S. is diverse and strongly influenced by climate variations (ENSO, PDO)	Models are chosen for their ability to capture the features of ENSO and PDO.
2.	Separation of climate change contributions from different forcings is difficult form observations alone	Use of different runs using either the natural or the anthropogenic forcings
3.	Fine-scale orography on temperature is not resolved by global models	Use of 2 statistical downscaling techniques to get data at $1/8^{o}$x$1/8^{o}$ resolution
4.	Influence of land-use is often neglected in models	Less of a concern in mountainous regions
5.	The strength of the conclusions of the analysis depends on the ability of the models to represent well the internal climate variability	There is no evidence that the CTL runs systematically underestimate the observed high- and low-frequency variability

A simple D& A analysis

An example: Blue Mountains - Changes in Tmax over 1950-1999

- ○ Obs
- □ ANTH ens-mean trend
- △ Sol/Volc ens-mean trend



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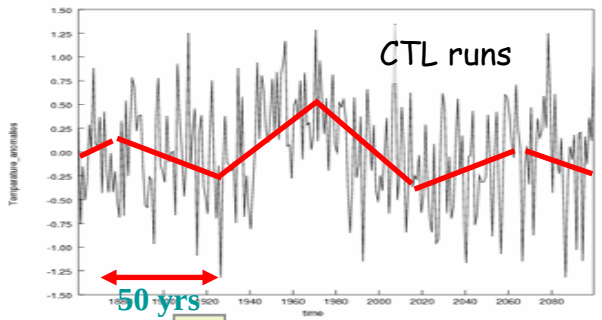

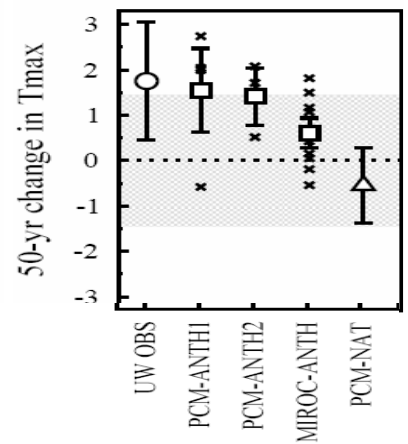

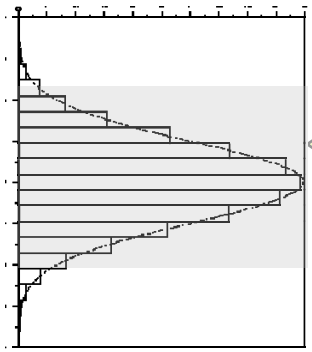

sampling distribution of combined 50-year unforced trends

A simple D& A analysis

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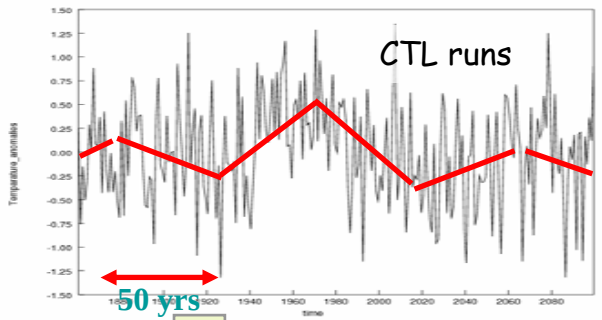
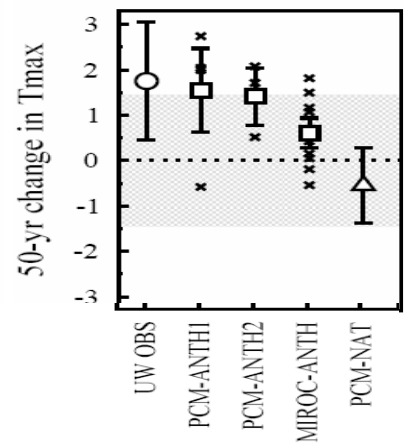
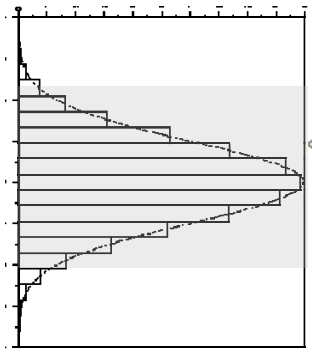


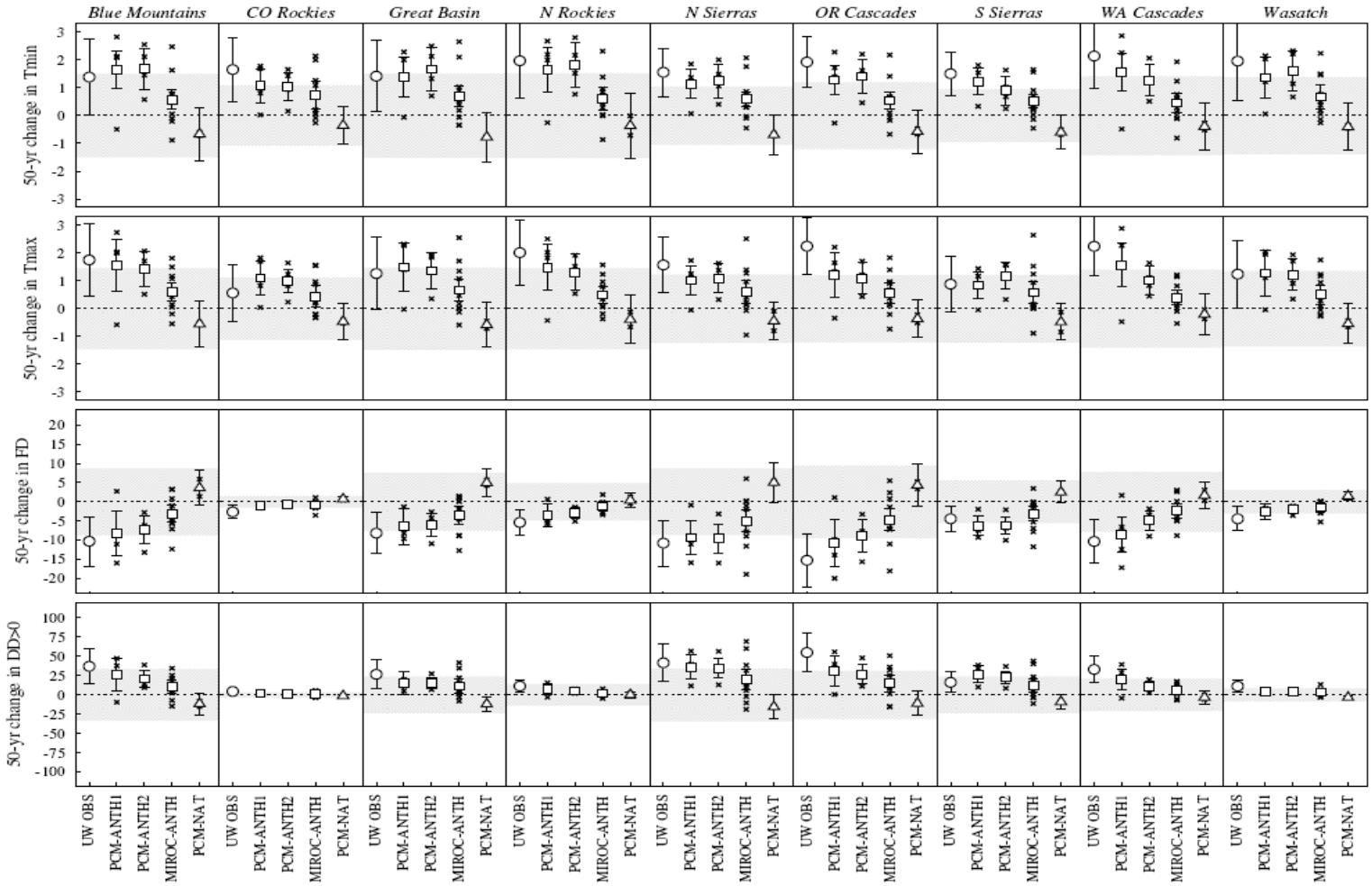




sampling distribution of combined 50-year unforced trends

Detection : the observed trends are not the results of climate noise.
Attribution : they cannot be explained by the solar and volcanic forcings, but they are compatible with the climate response to human forcings.

four variables, nine regions :

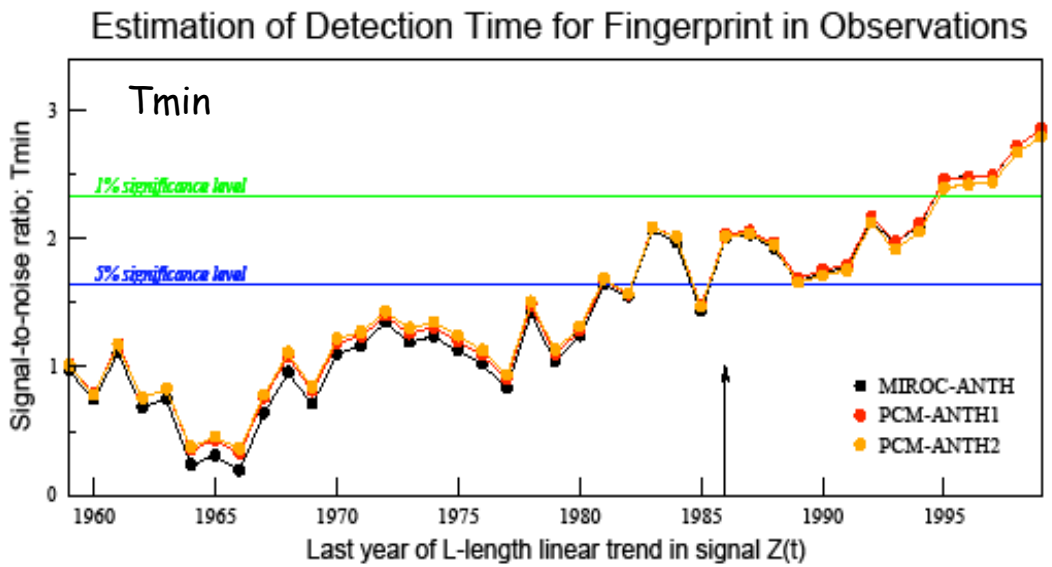


- Detection in 27 out of 36 cases.
- Attribution in the majority of the cases.

Formal D&A analysis

Goal: Search expected pattern of climate response to anthropogenic forcings (i.e. the "fingerprint") in observations.

- **F**: Anthropogenic fingerprint estimated from one ANTH ensemble
- **S**: Signal trend obtained by projecting the observational dataset onto **F**
- **N**: CI of the distribution of noise trends obtained by projecting one CTL run onto **F**
- **S/N**: computed for increasing length trends (1950-59, 1950-60, … 1950-99 for S, 10, 11, … 50 years for N)
- **Signal is detected when S/N > 1.64 (5% sign. Level)**



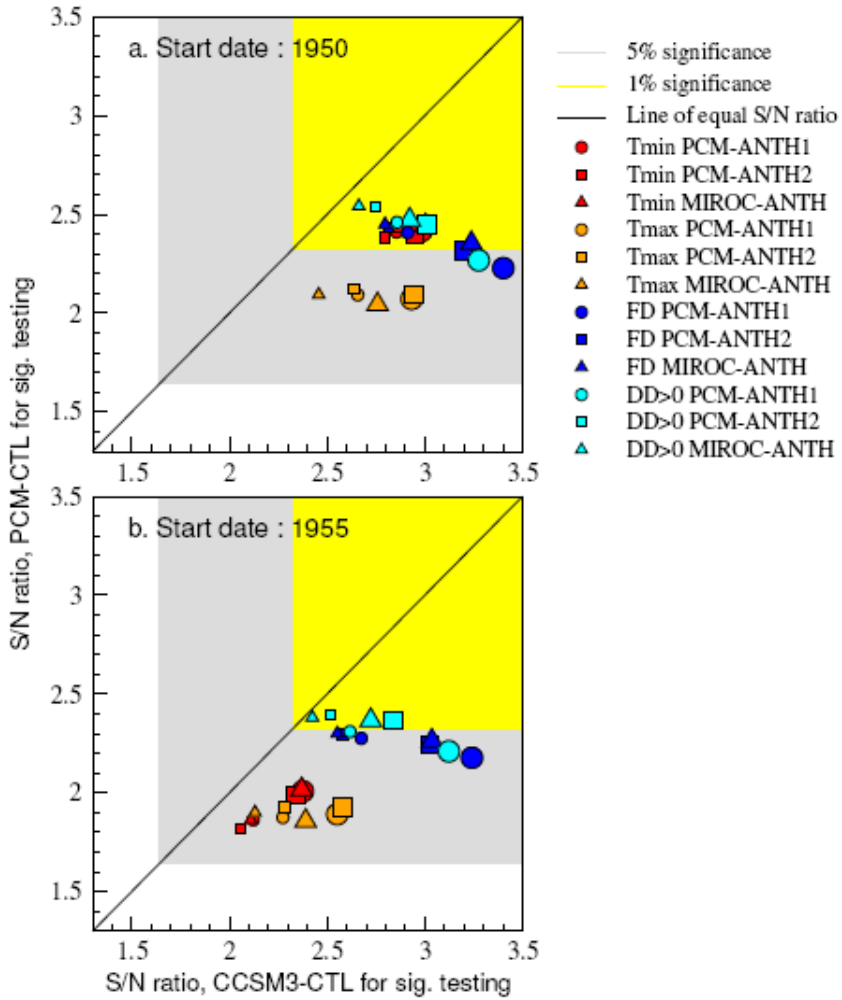
The anthropogenic fingerprint is identifiable in the late 80's.

Sensitivity of our D&A results to a range of processing choices

We also found positive detection of anthropogenic fingerprints in all four indices, as early as 1986 and no later than 1994.

Results insensitive to:

- the choice of model used to estimate the model chosen to estimate the fingerprint or the noise (2x2 options)
- the method used to downscale the fingerprint (2 options)
- the applied areal weighting (unit weighting or areal weighting).
- the start dates (1950, 1955)



Summary

- We performed the first D&A analysis for the western U. S.
- This is the first D&A study involving a multi-stage modeling, from global scale to basin scale.
- We conclusively attribute the warming observed over western U.S. mountainous regions to human activities.
- We found that this warming is responsible for reductions of snowpack and the shifts in the timing of the streamflow (Barnett et al., 2008).
- Models of climate change unanimously project an acceleration of the warming in western U.S. (+~1-3 °C by 2050).
- With such substantial warming, serious implications for water infrastructure and water supply sustainability can be expected in the near future.

Acknowledgements and Publications

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