Understanding Sierra Nevada Cool Season Precipitation from Tree-Ring Reconstructions

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Lamont-Doherty Earth Observatory
Columbia University

These trees thrived in this Sierra Nevada river bed under severe, extended drought 1000 years ago
Photo by Gary Hayes

Tree rings as proxies for past climate

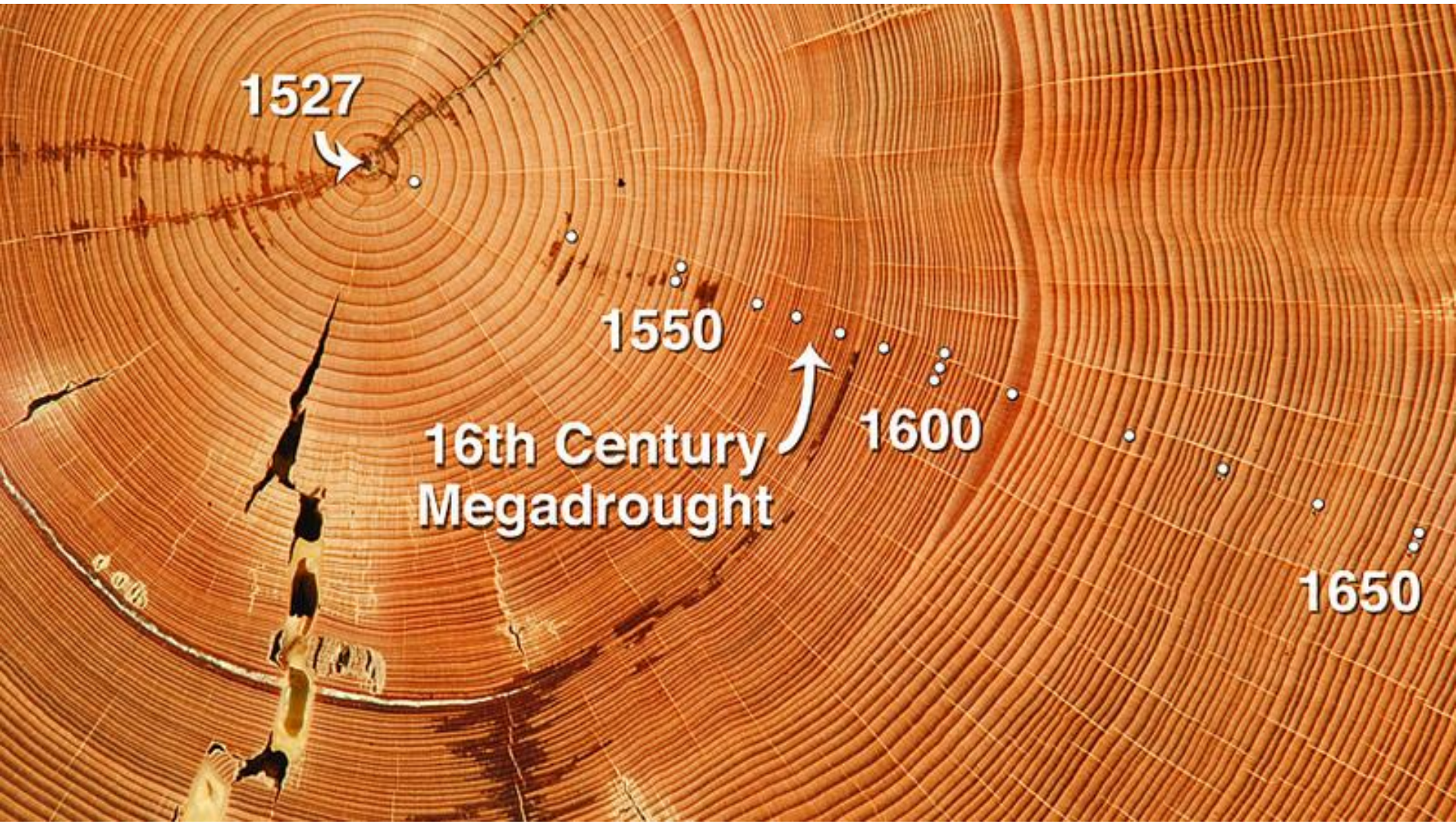
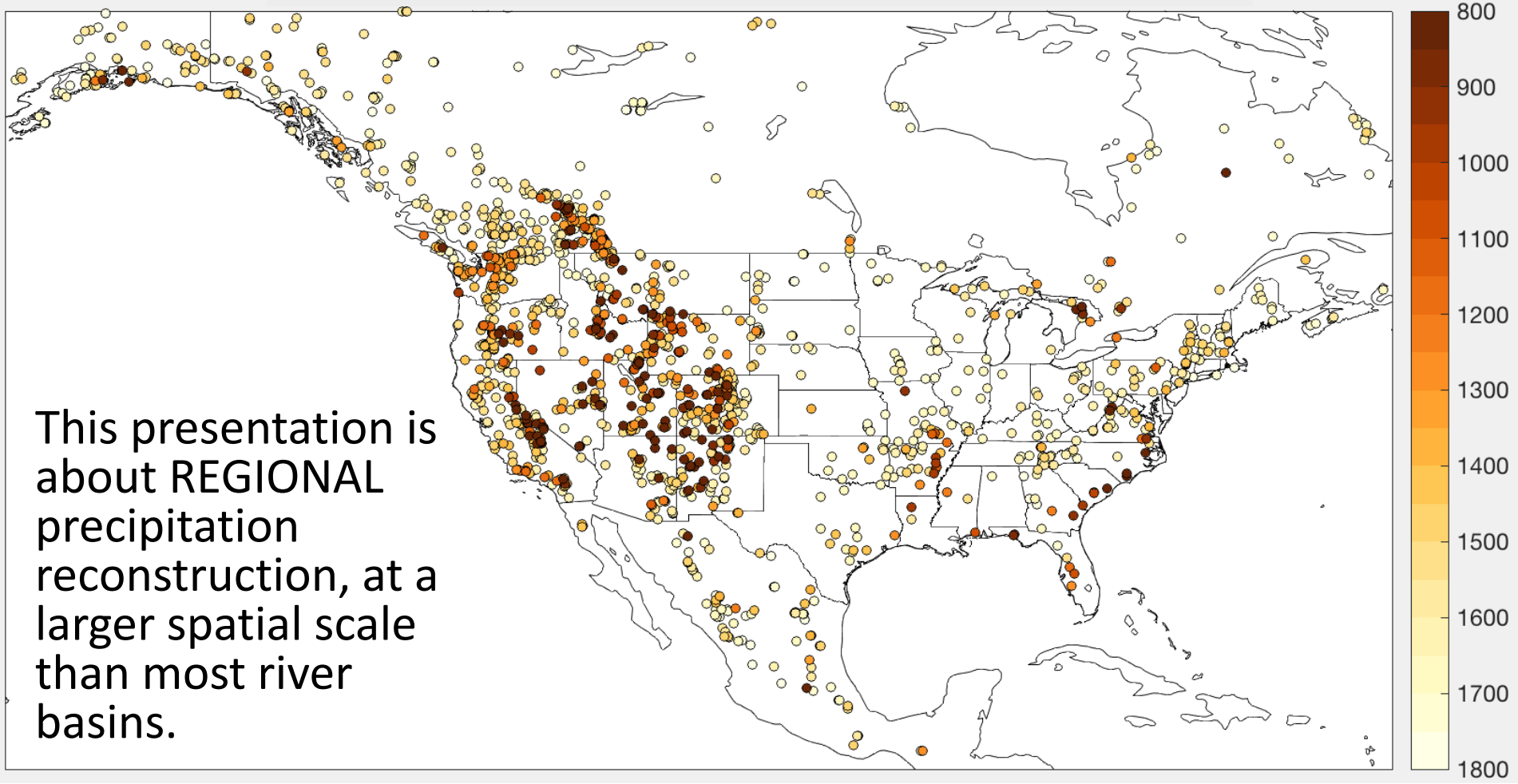


Photo: Douglas-fir tree from AZ
Daniel Griffin

2,757 North American tree-ring records that extend beyond AD 1800. (311 go back to ≤1200 AD)

First year of tree-ring record



This presentation is about REGIONAL precipitation reconstruction, at a larger spatial scale than most river basins.

Outline

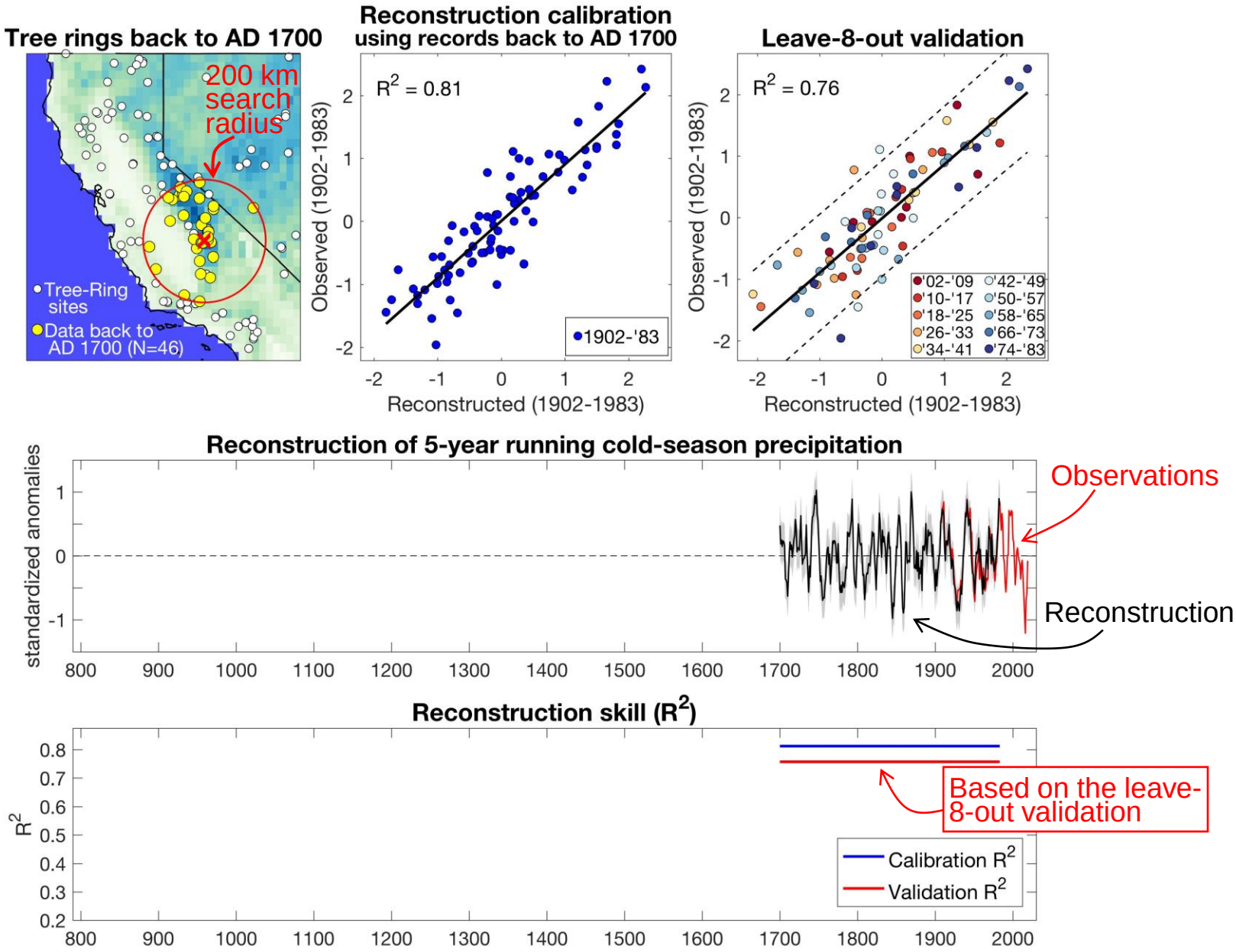
1. How are tree-ring reconstructions of precipitation produced?

2. 1200 years of Sierra Nevada precipitation.

3. A dominant but still poorly understood mode of atmospheric variability.

1. Development of a precipitation reconstruction from tree rings

Example: Reconstructing Nov-Mar Precipitation in southern Sierra (36.5°N, 118.5°W)



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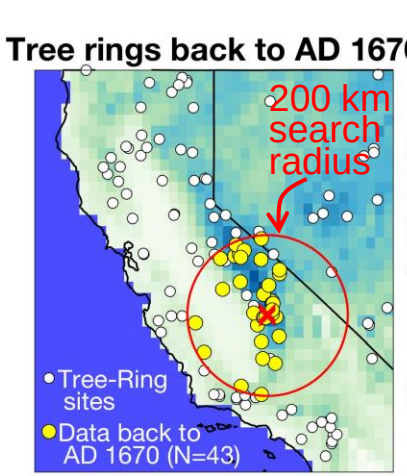

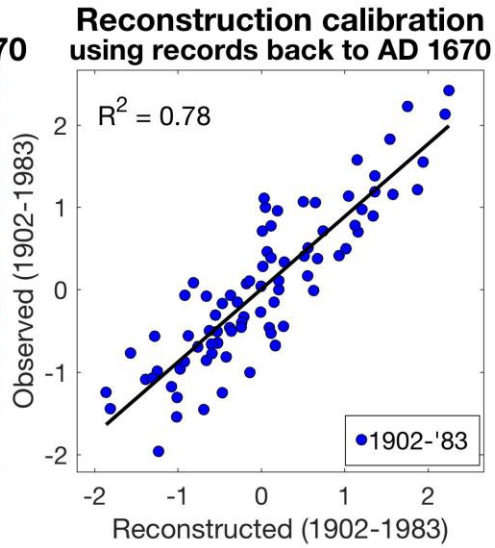

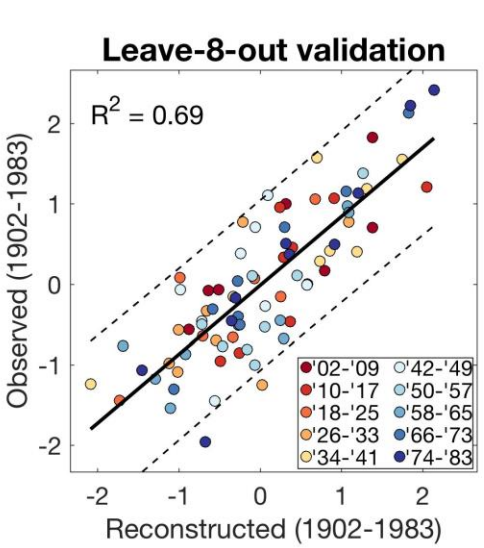

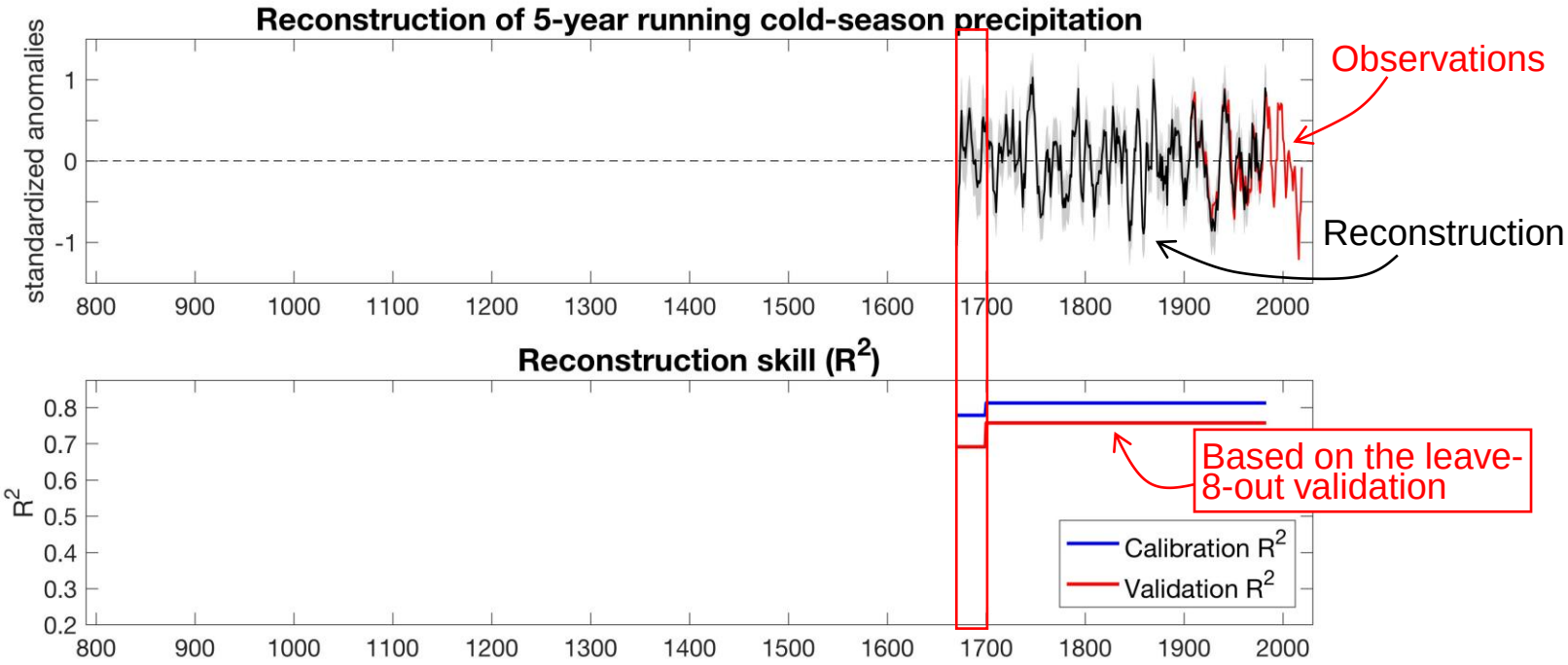

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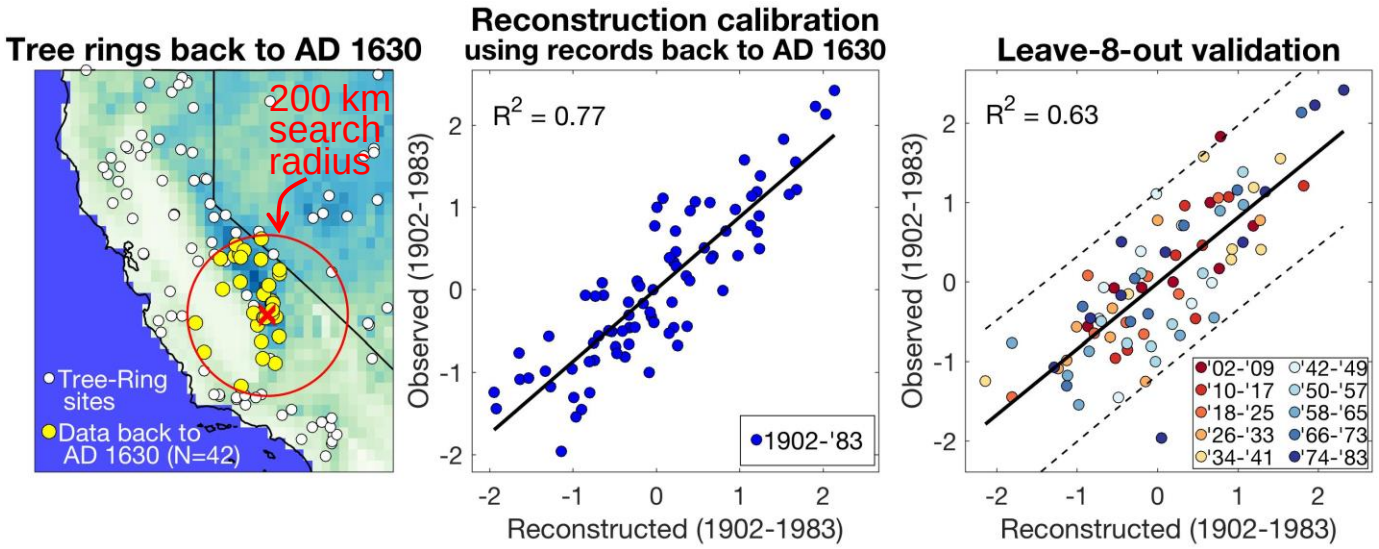

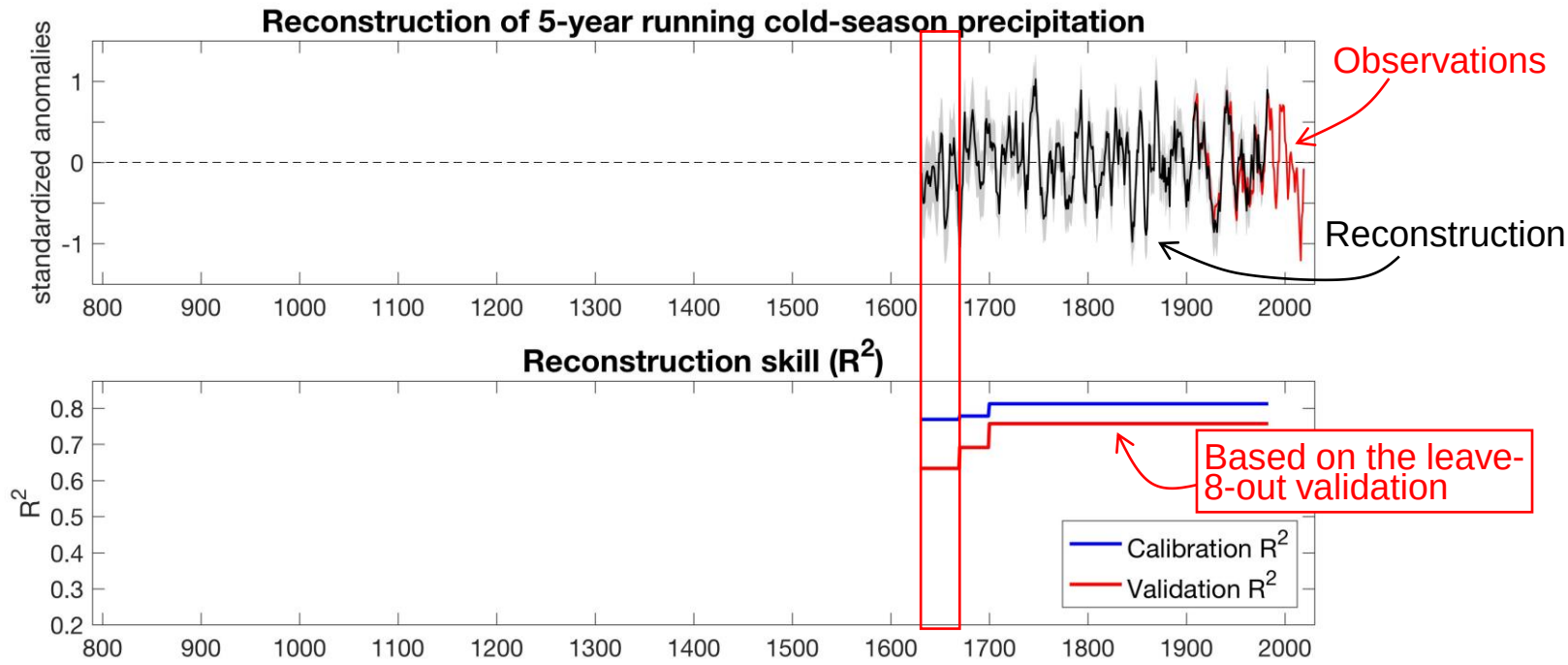

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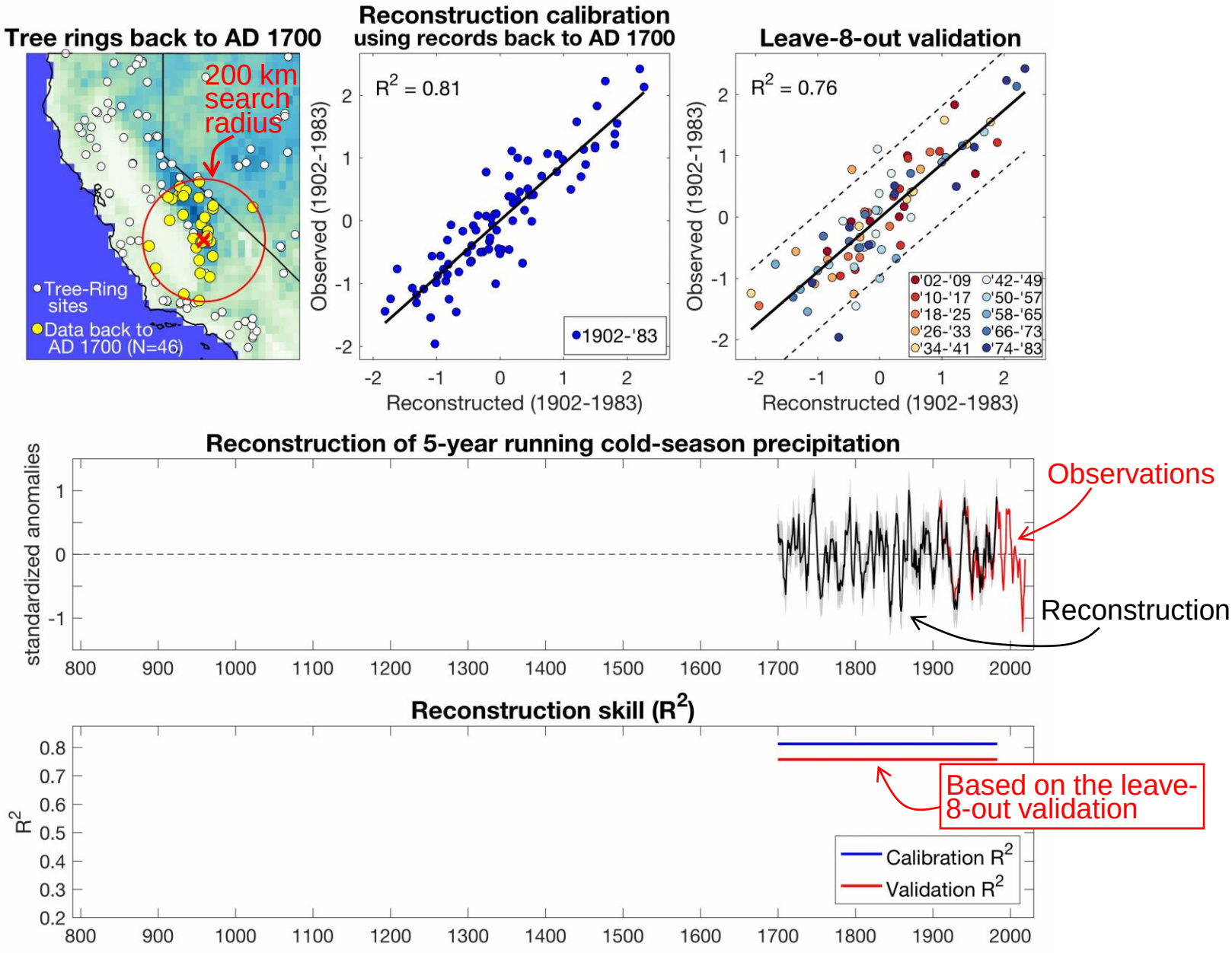

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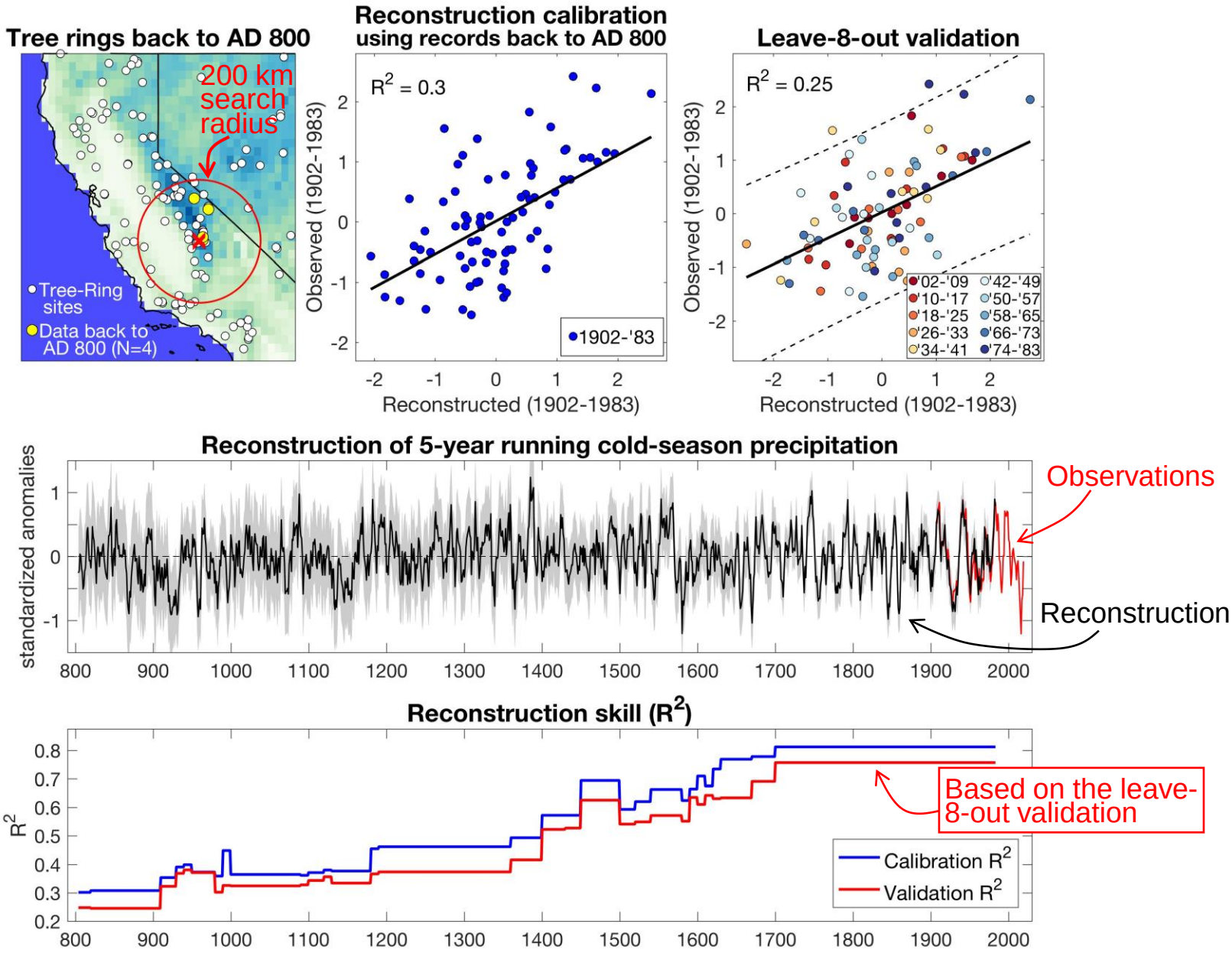
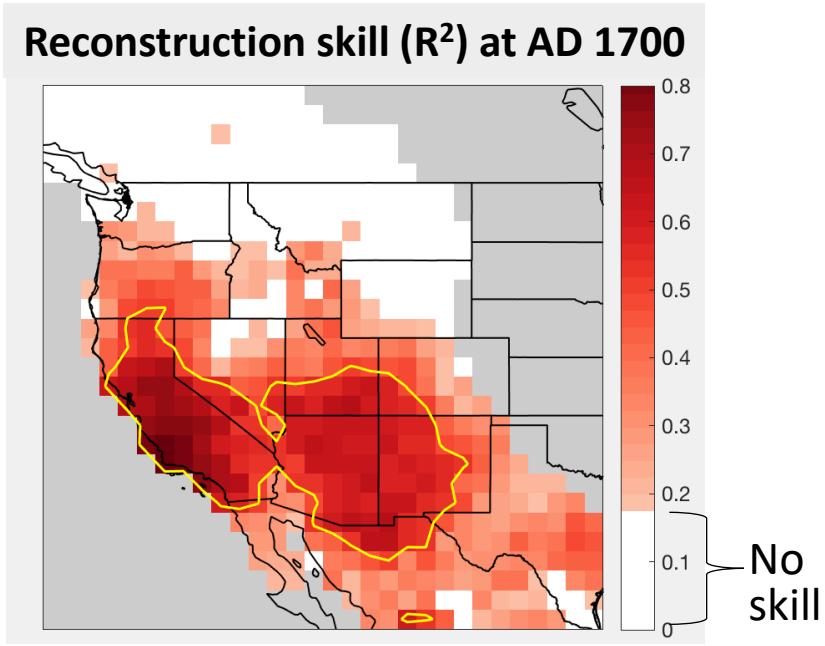
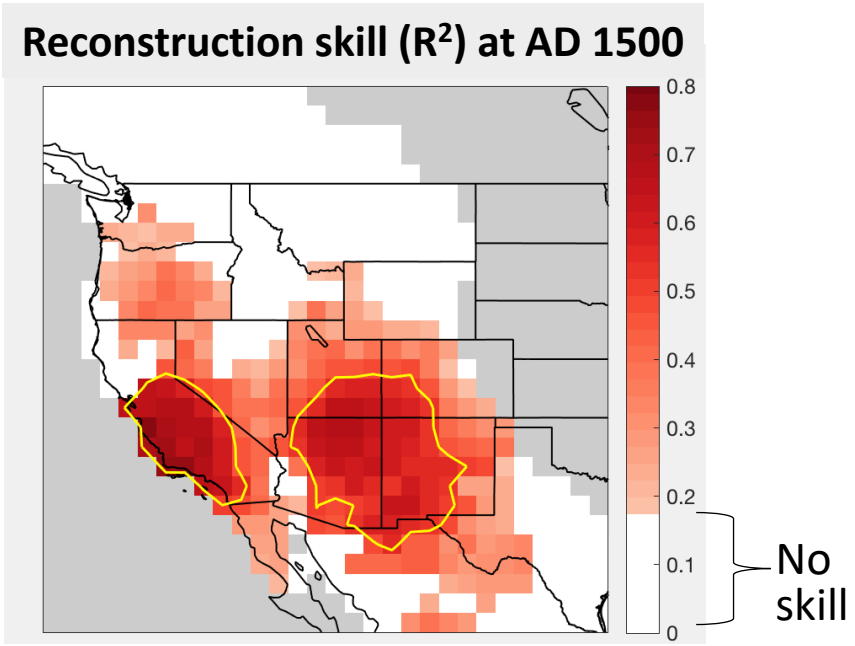
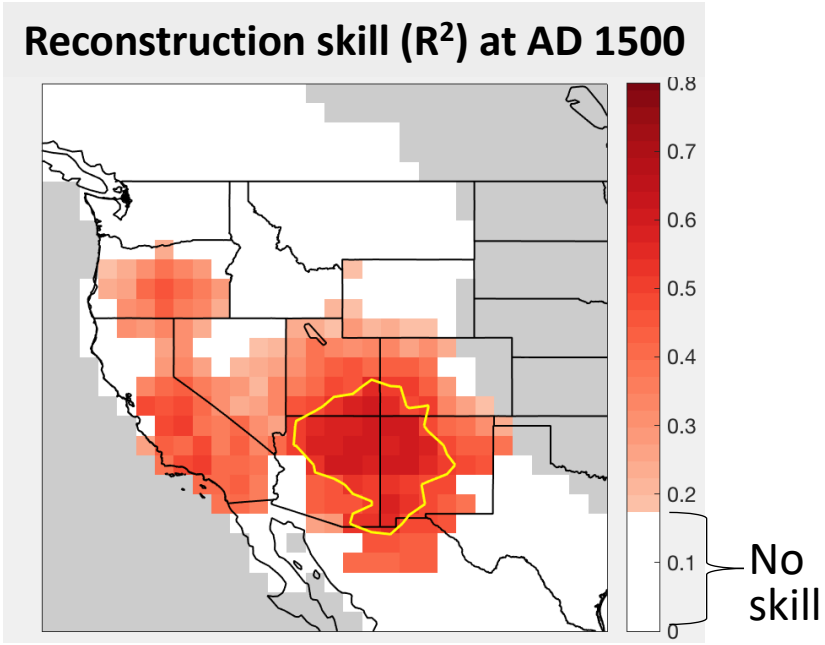
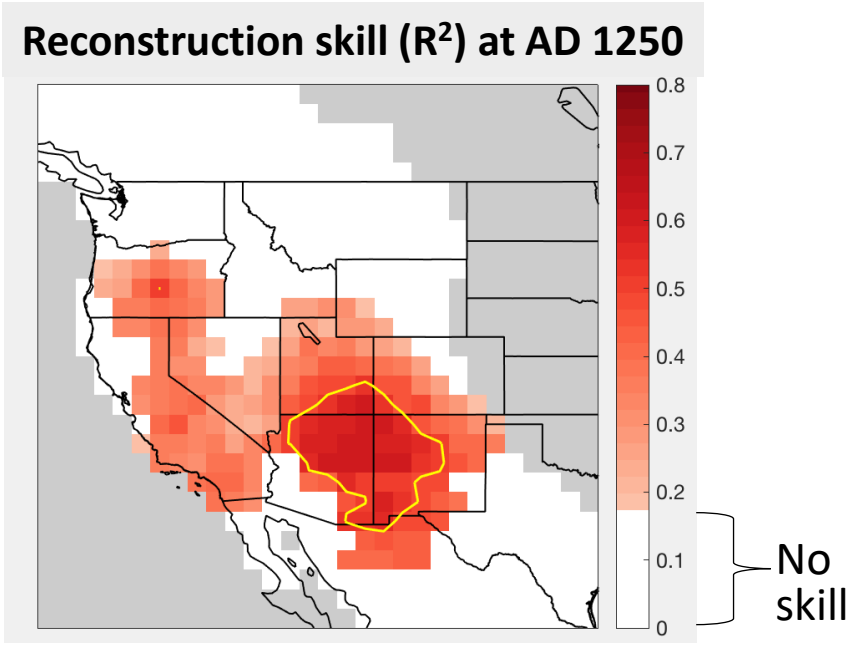


Gridded reconstructions of Nov-Mar Precipitation



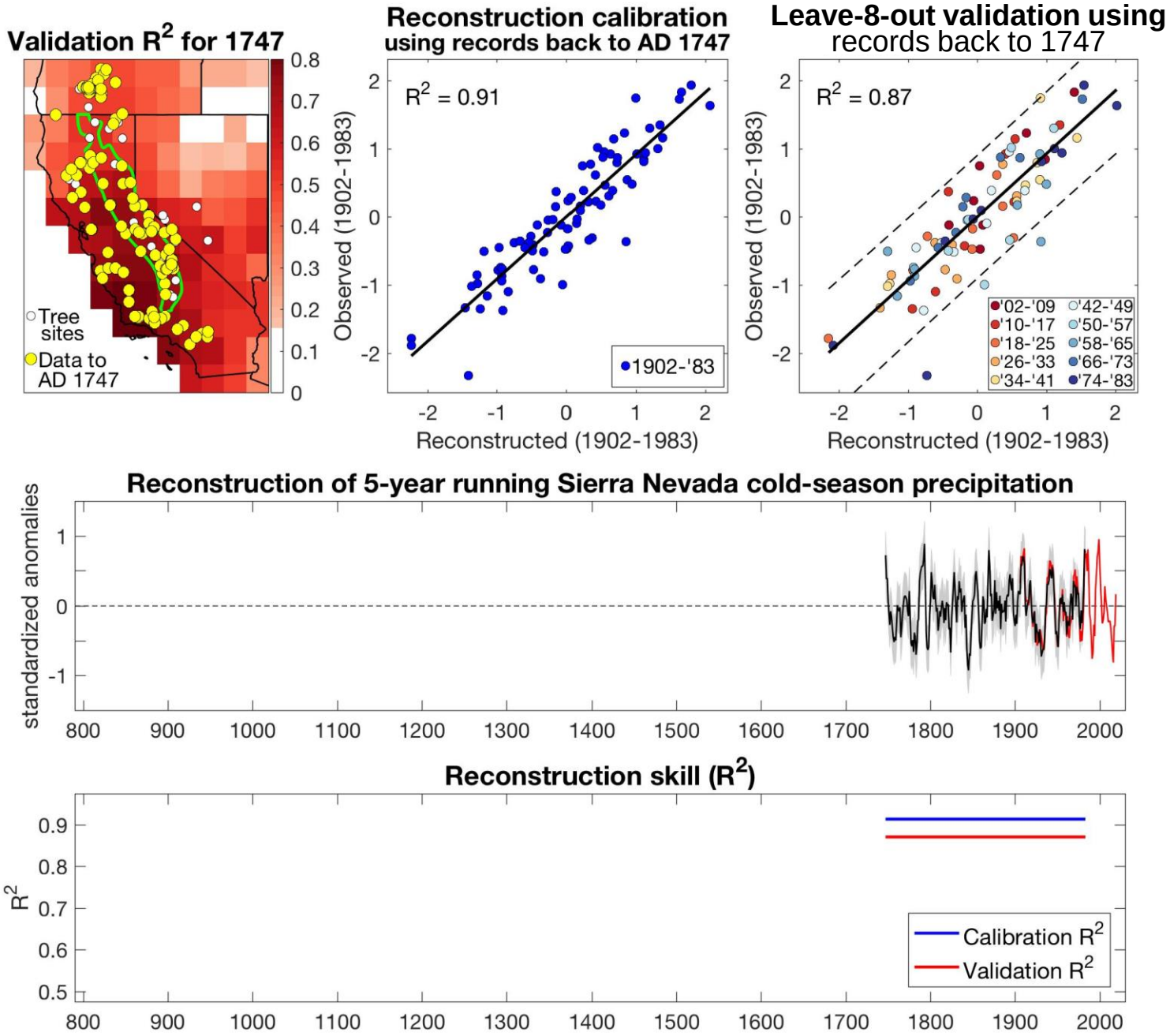




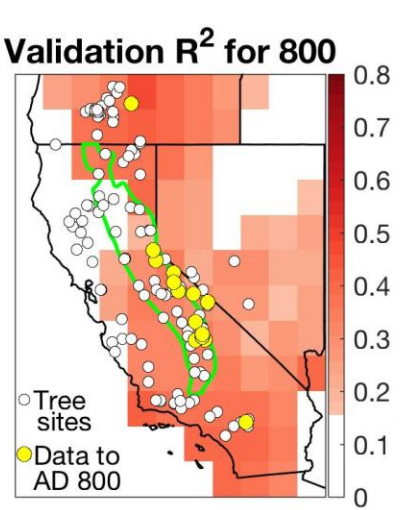


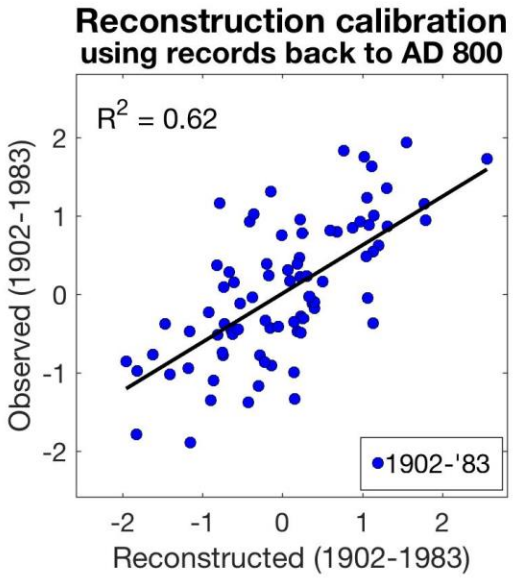
2. Sierra Nevada regional cold-season (Nov-March) precipitation

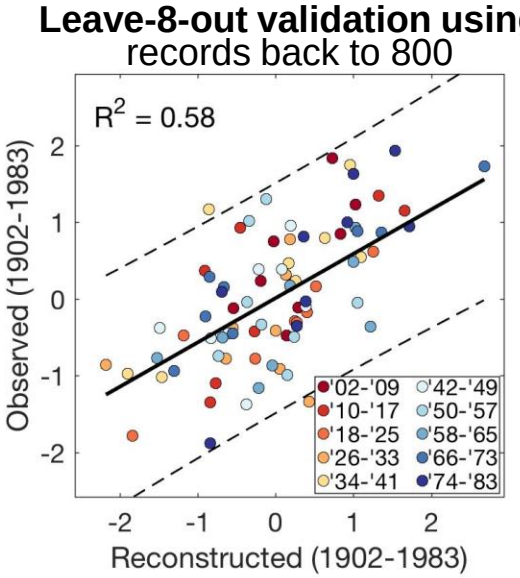
Reconstructing Nov-Mar Sierra Nevada Precipitation

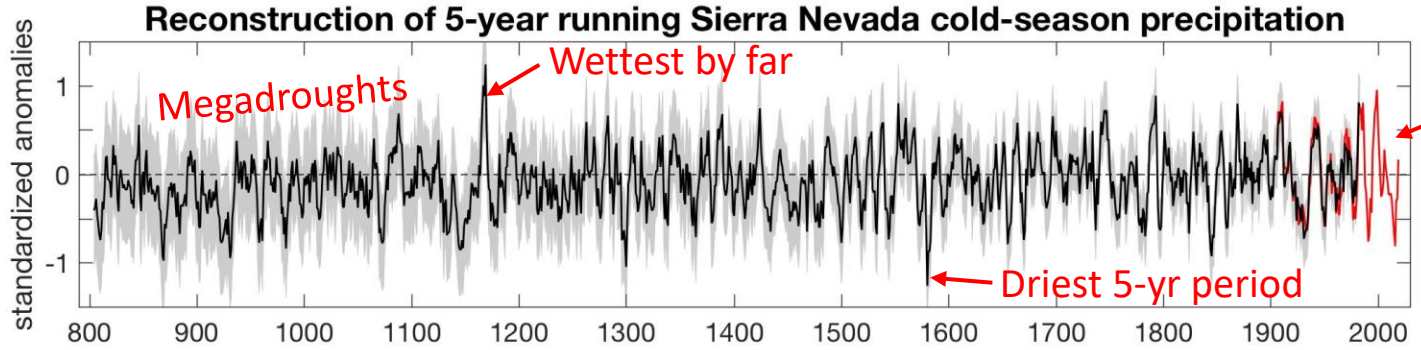


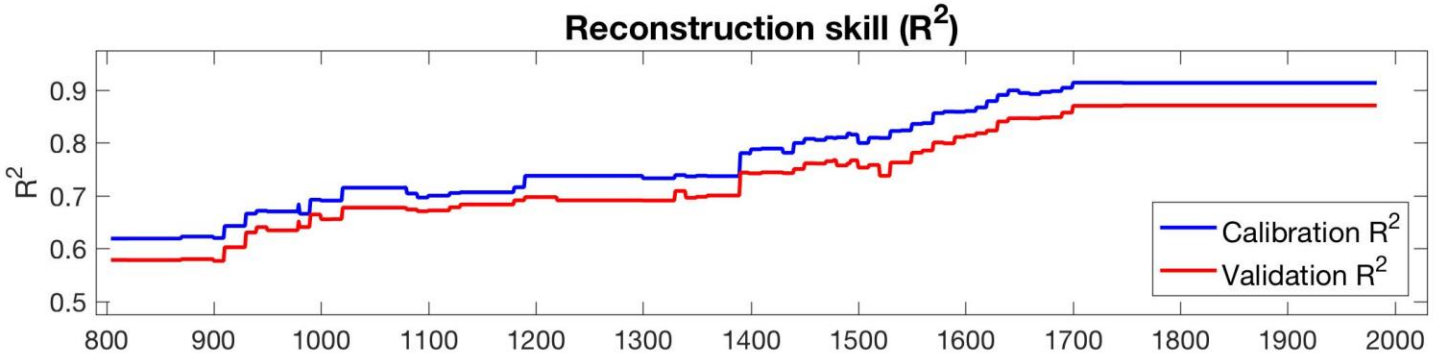
Reconstructing Nov-Mar Sierra Nevada Precipitation



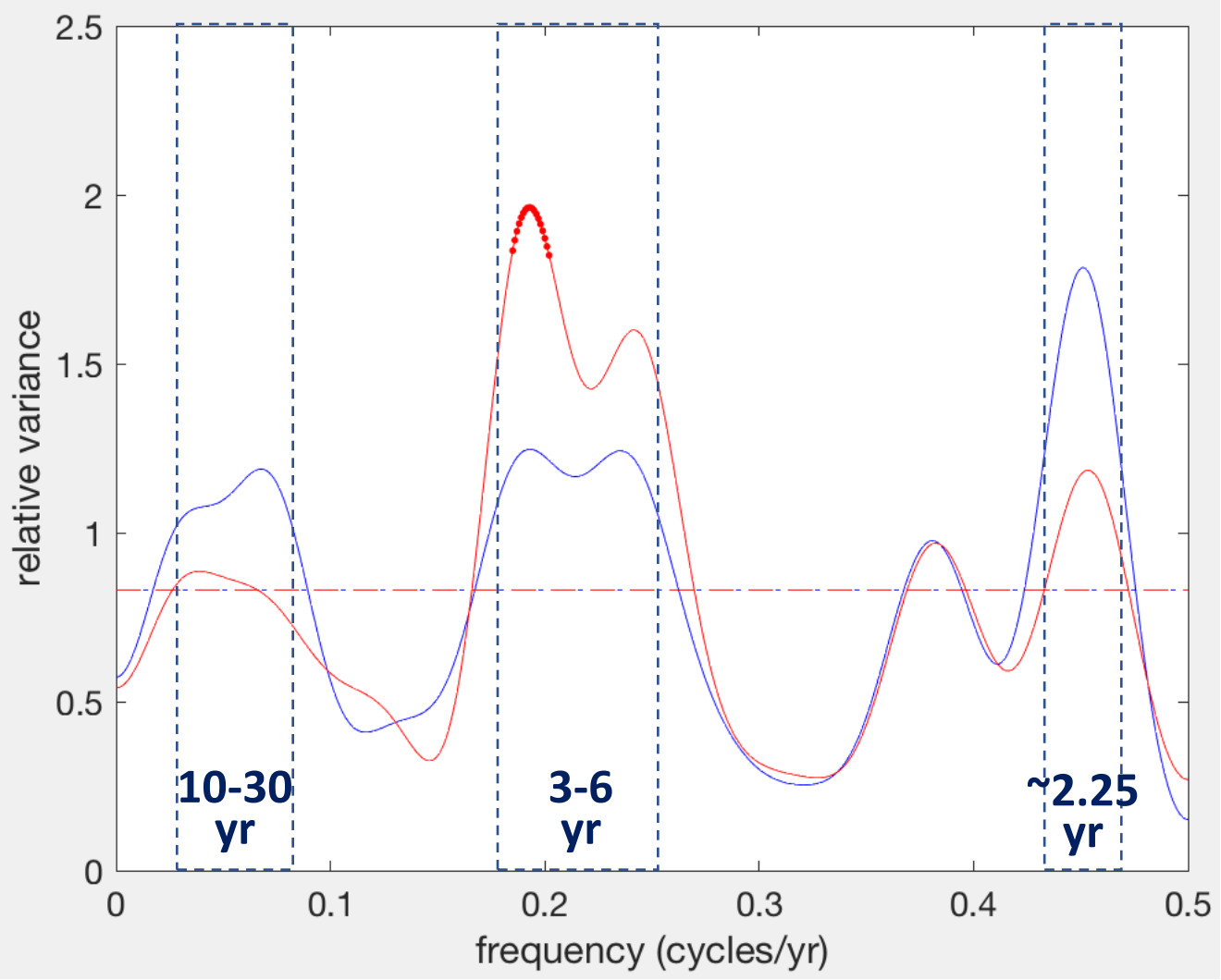








Spectra of Observed and Reconstructed Sierra Nevada Nov-Mar Precipitation during the period of overlap (1902–1983)



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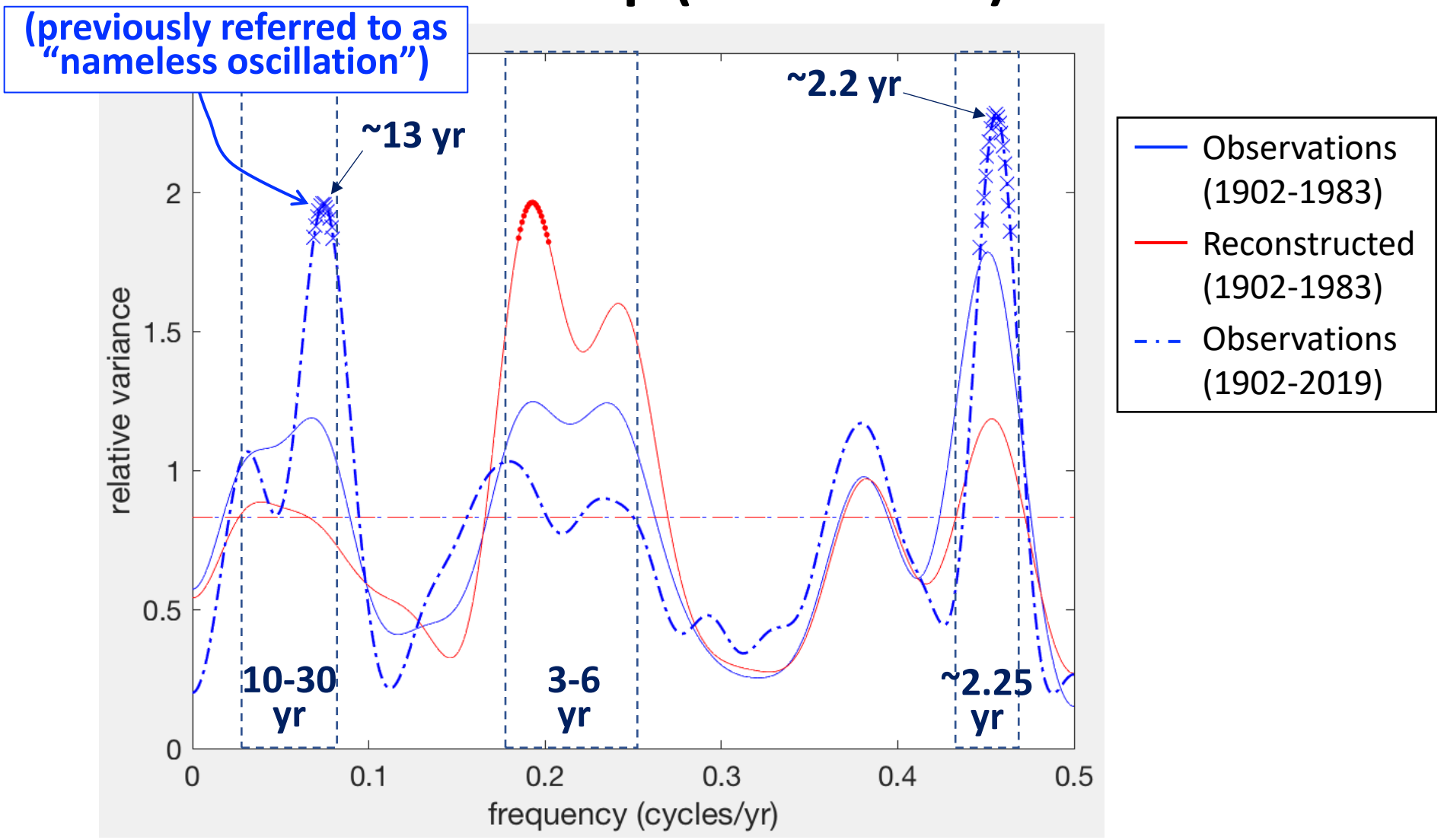
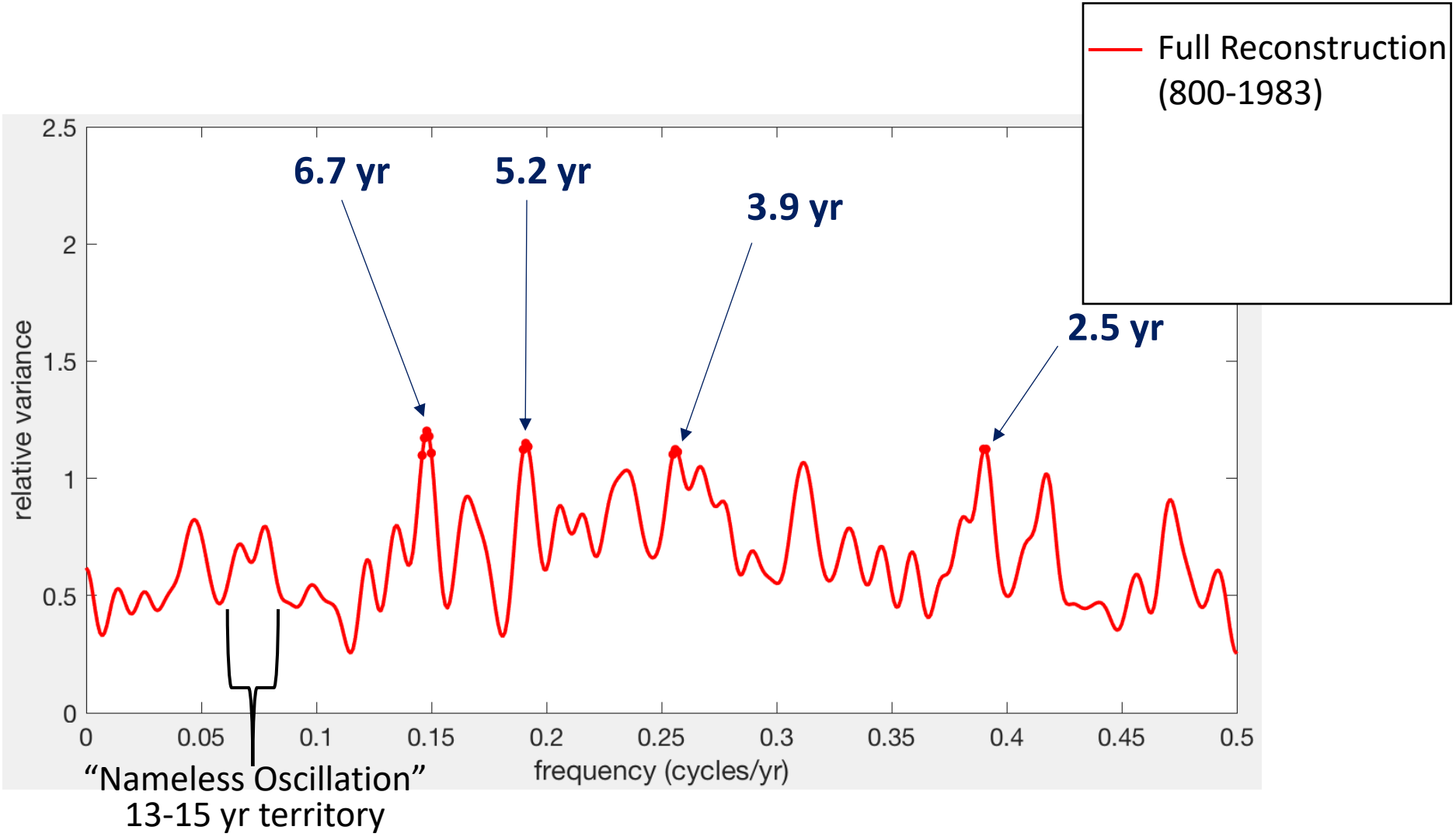


Spectra of Full Reconstruction of Sierra Nevada Nov-Mar Precipitation (AD 800–1983)



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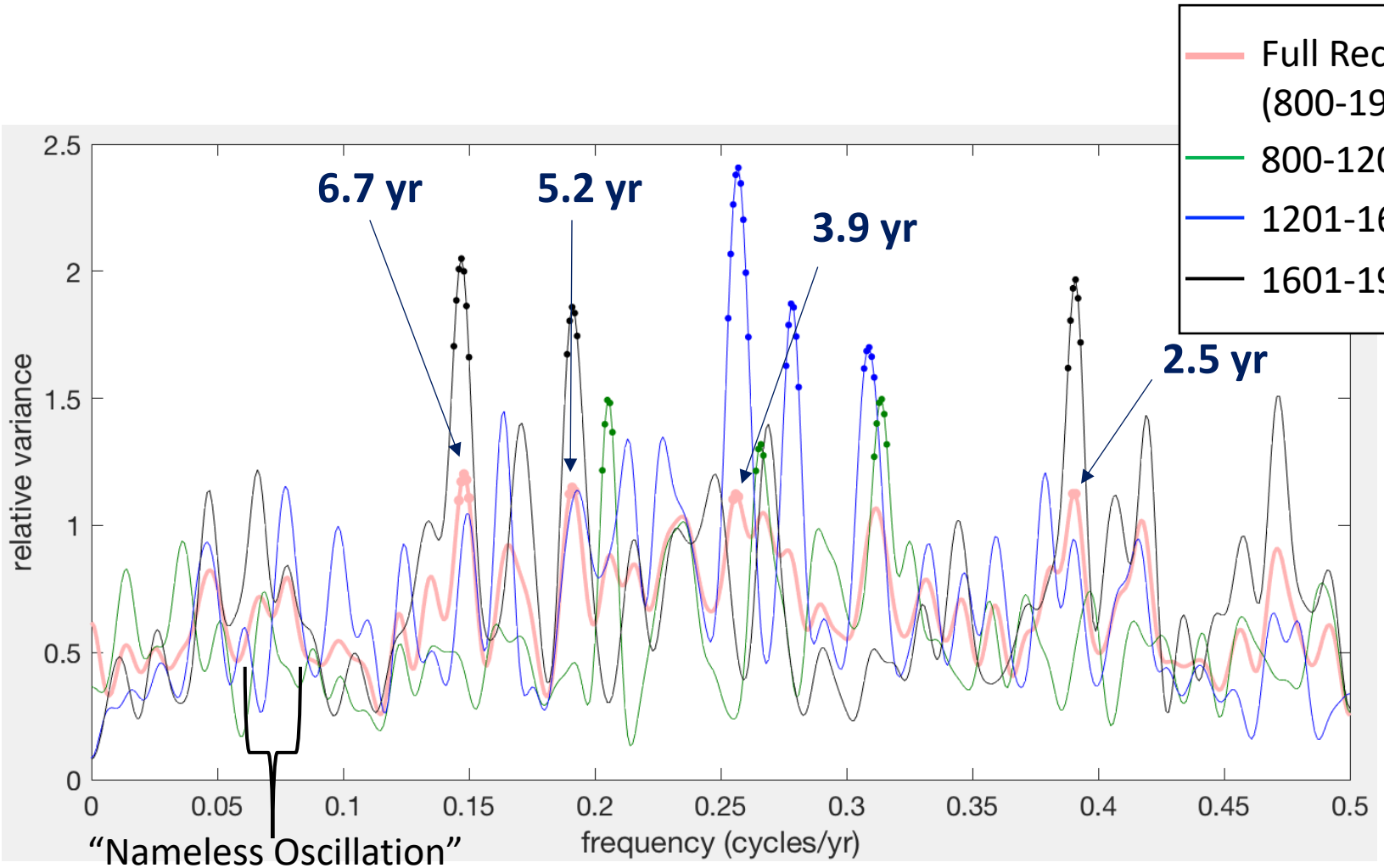
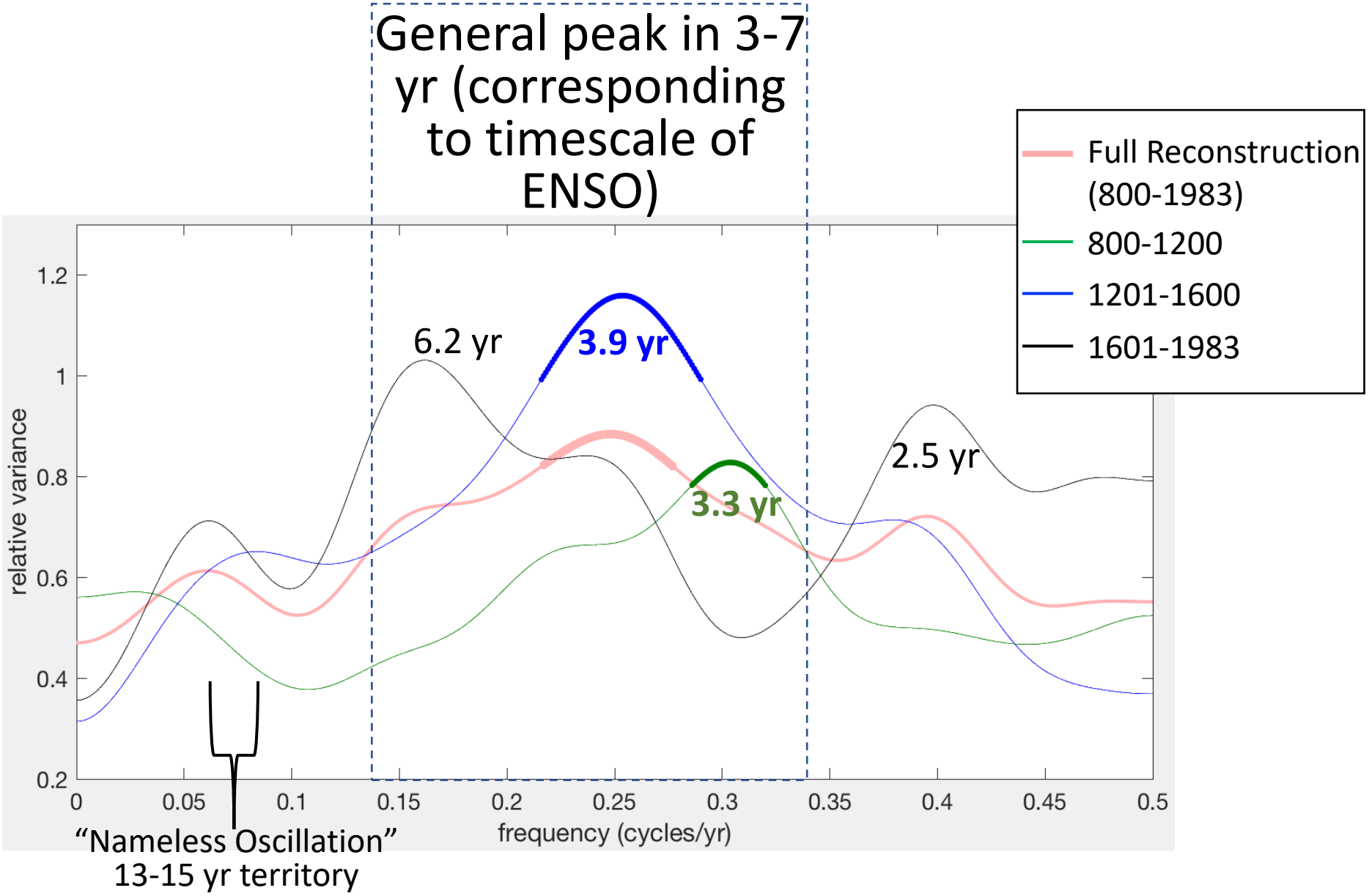
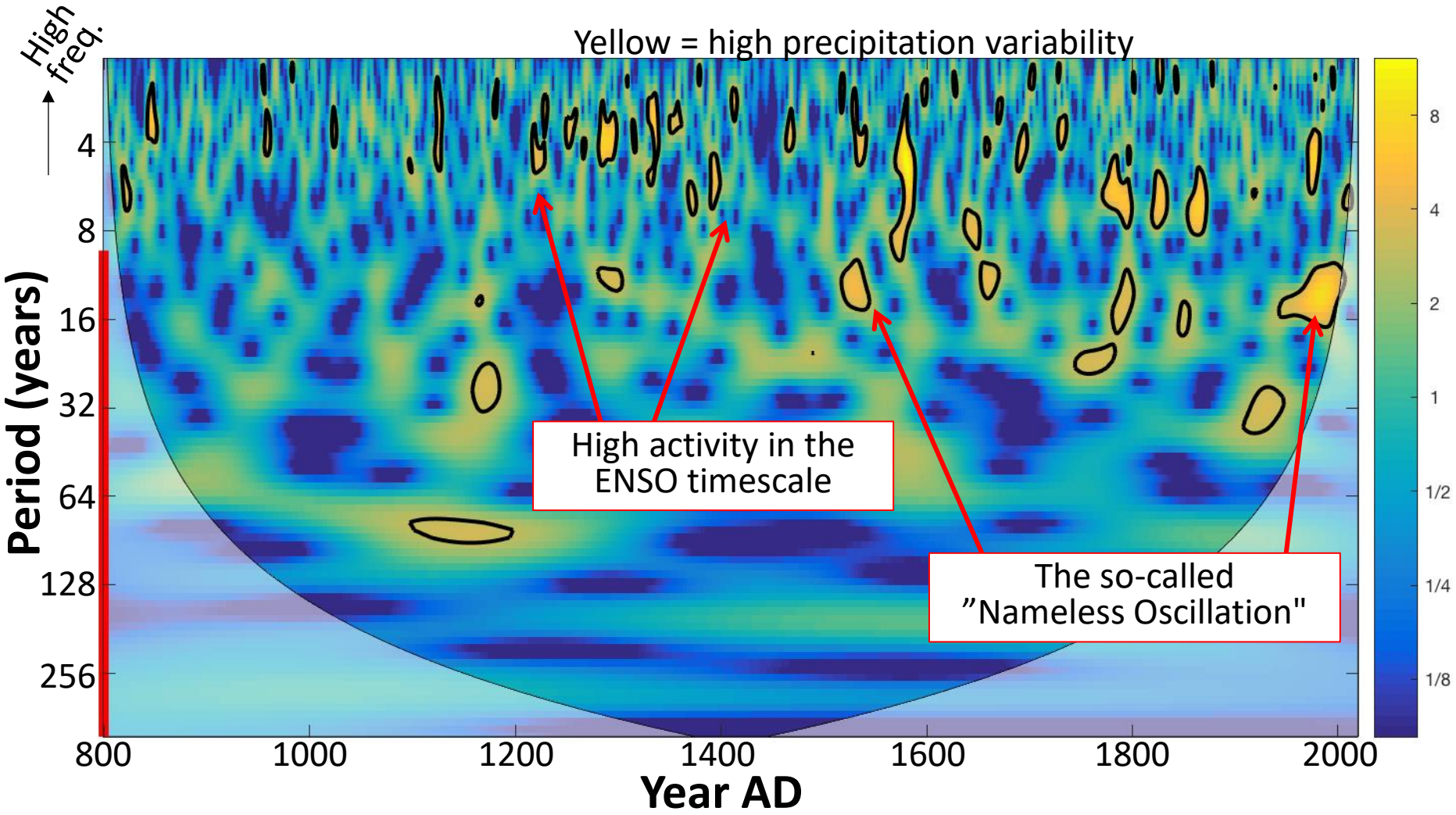


Spectra without squinting so hard

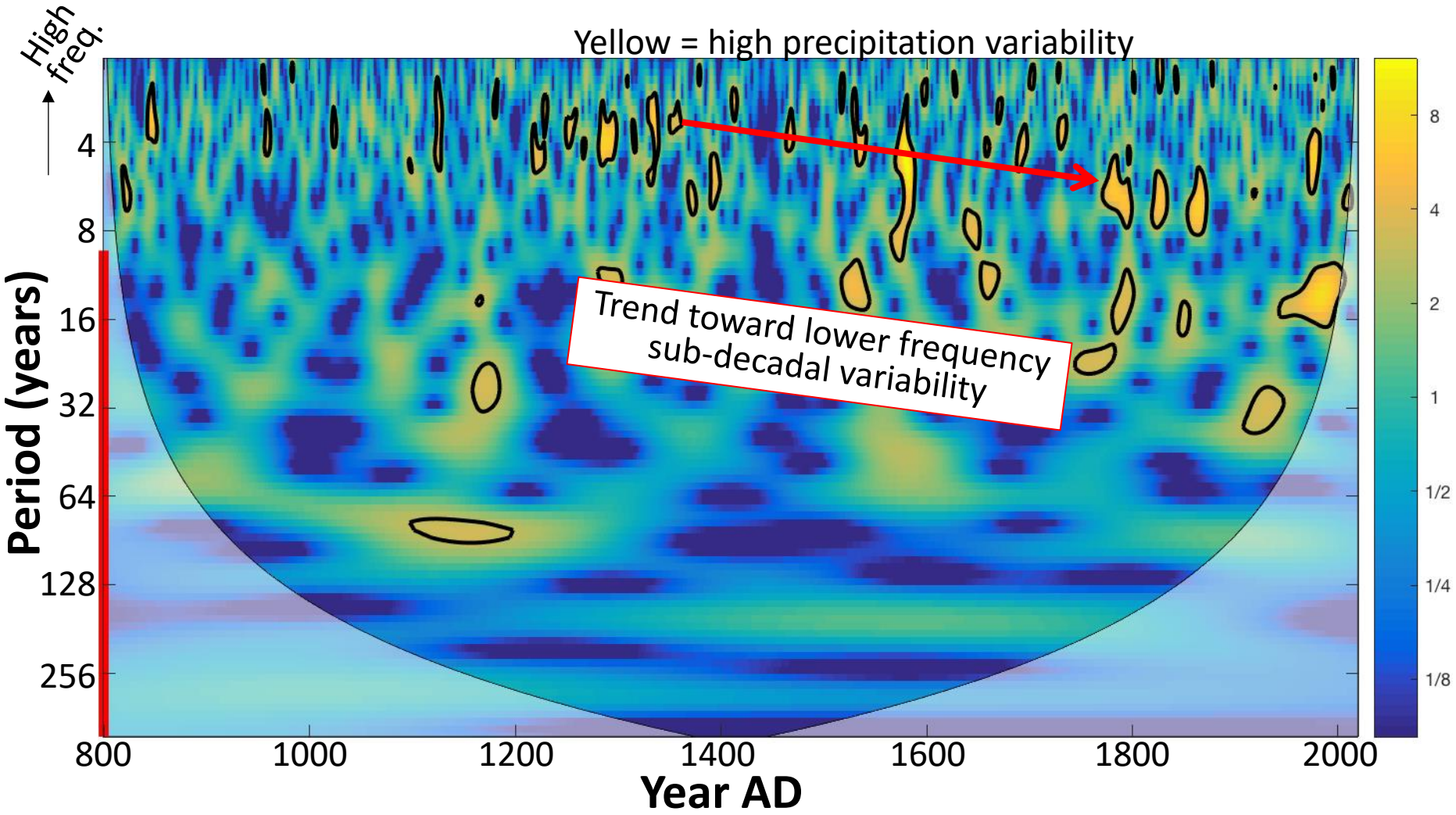


Wavelet analysis of Sierra Nevada reconstruction



*This figure was made using a Matlab package developed by Dave Meko (U of A)

Wavelet analysis of Sierra Nevada reconstruction



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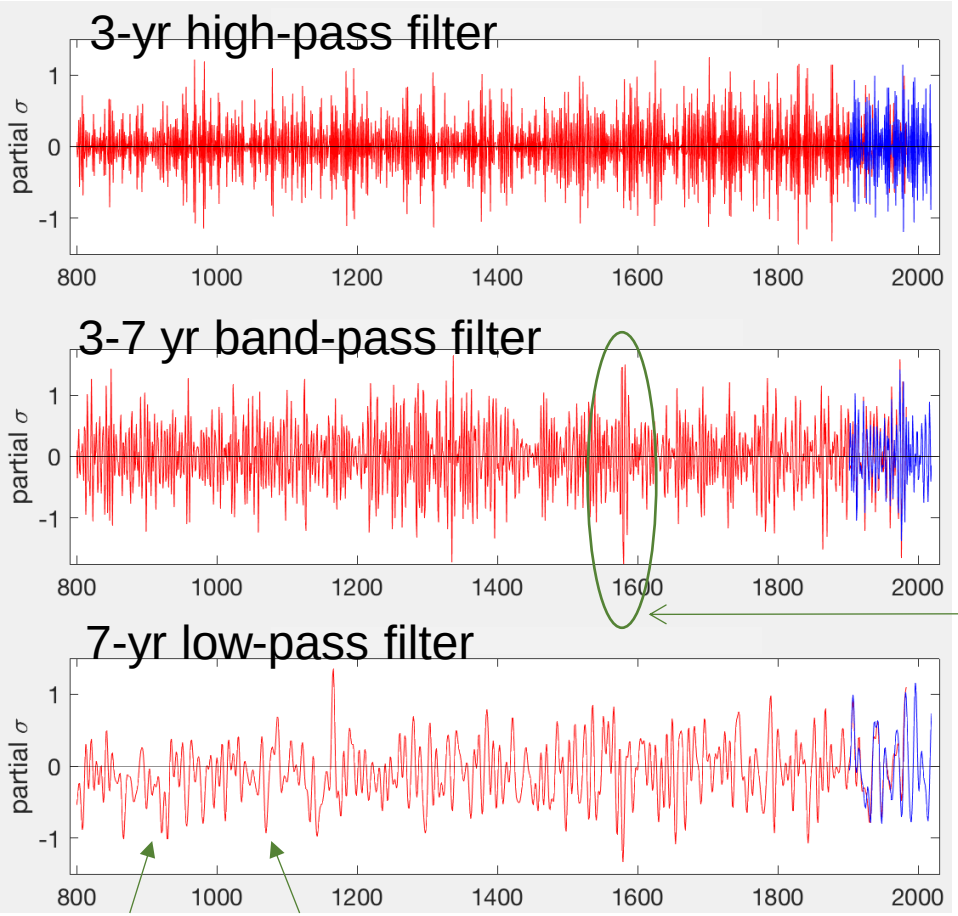
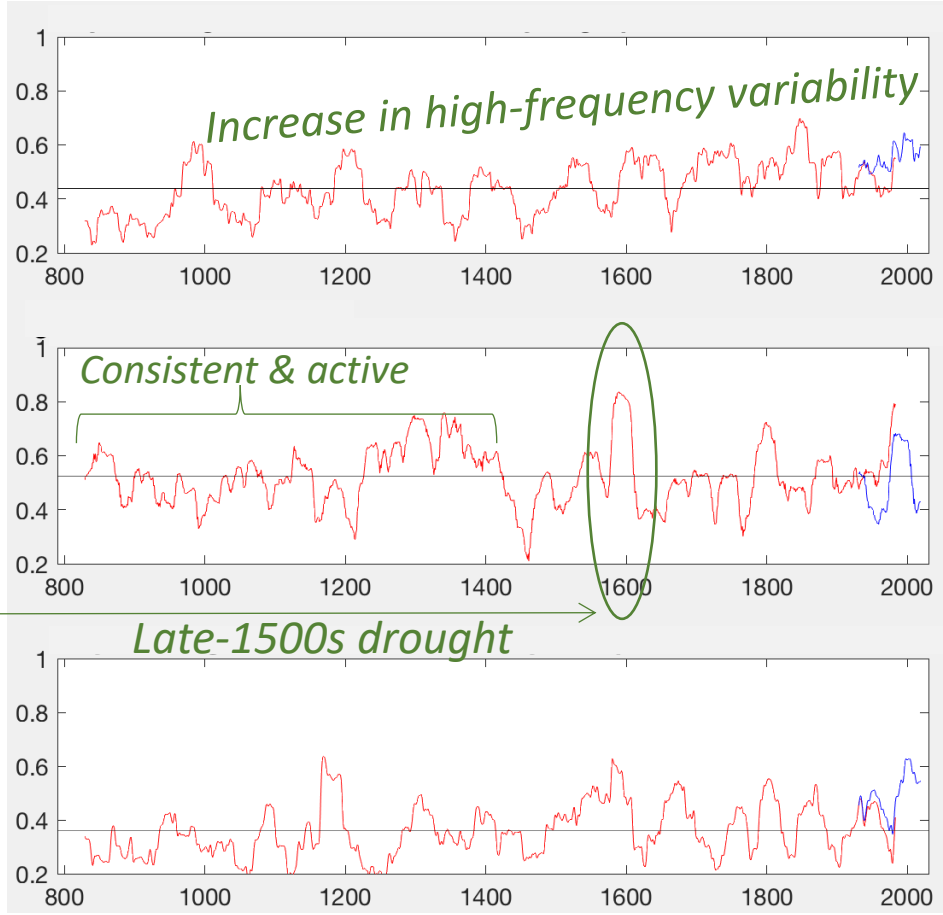
Contribution to Sierra Nevada Nov-Mar precip from high, mid, and low frequency

Filtered time series of Sierra Nevada precipitation

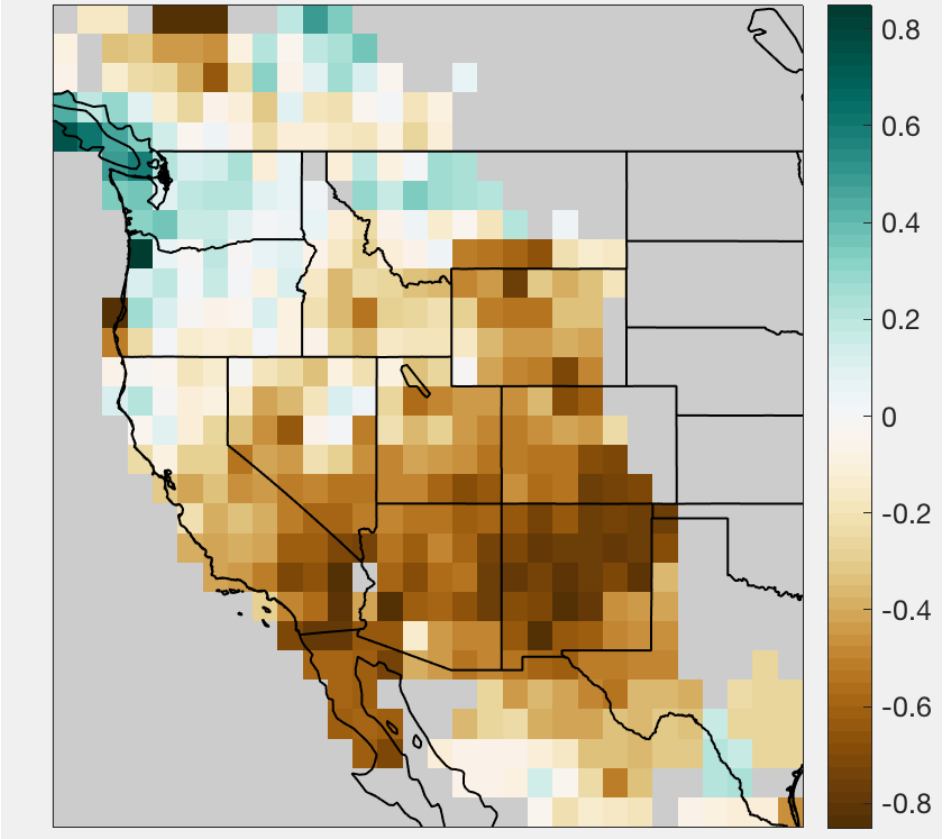


30-yr running standard deviations

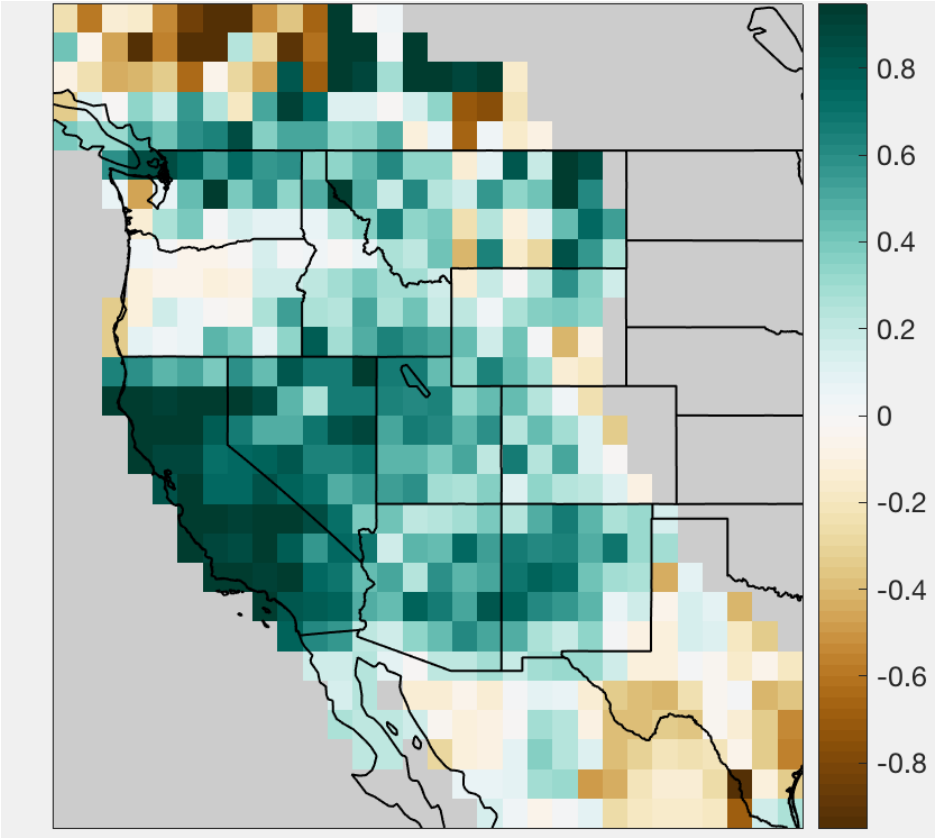


3. Reconstruction of modes of climate variability

Reconstructed Nov-Mar Standardized Precip. Anomaly 1570–1590



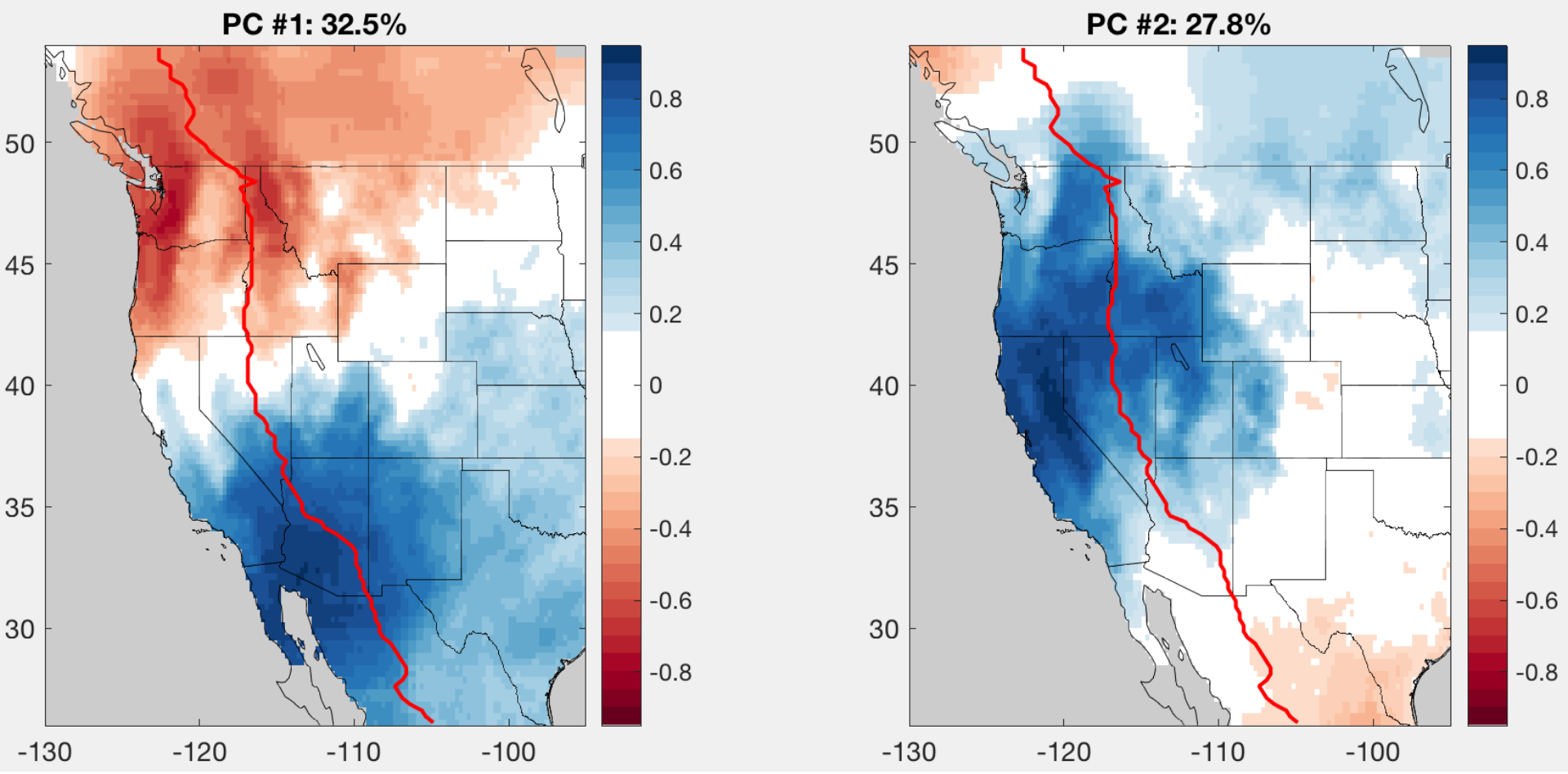
Reconstructed Nov-Mar Standardized Precip. Anomaly 1789–1793



West-Coast Cold-season (Nov-Mar) precipitation

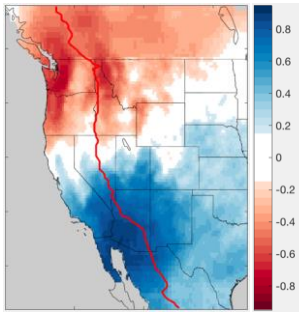
First 2 principal components (1902–1919)

Correlation between Nov-Mar Precip vs PCs 1 and 2

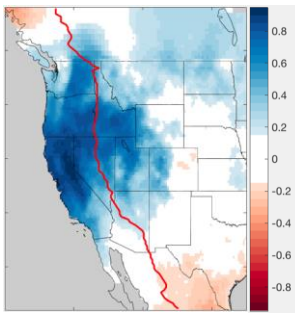


West-coast Nov-Mar precipitation Principal Components

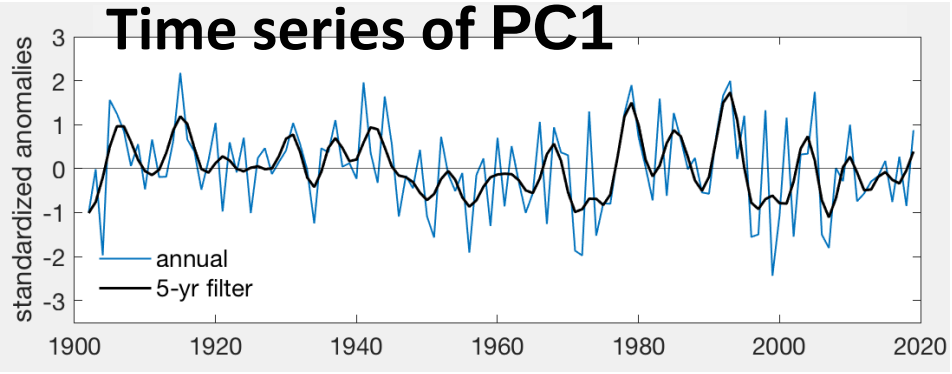
Mode #1



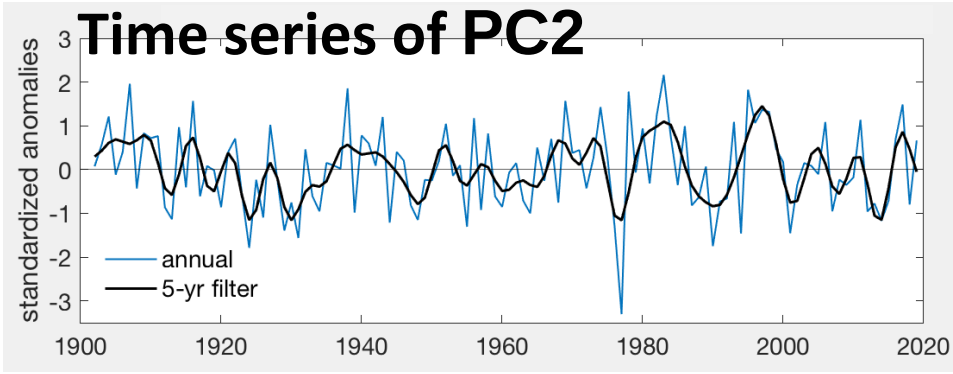
Mode #2



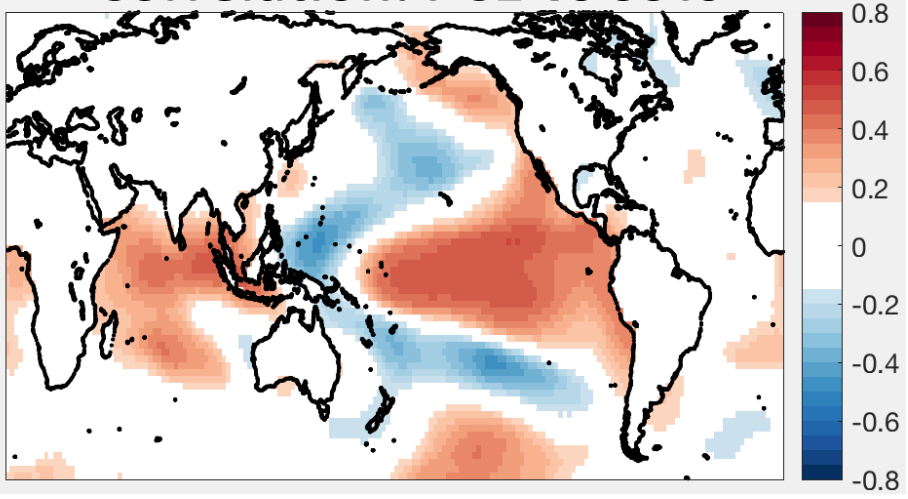
Time series of PC1



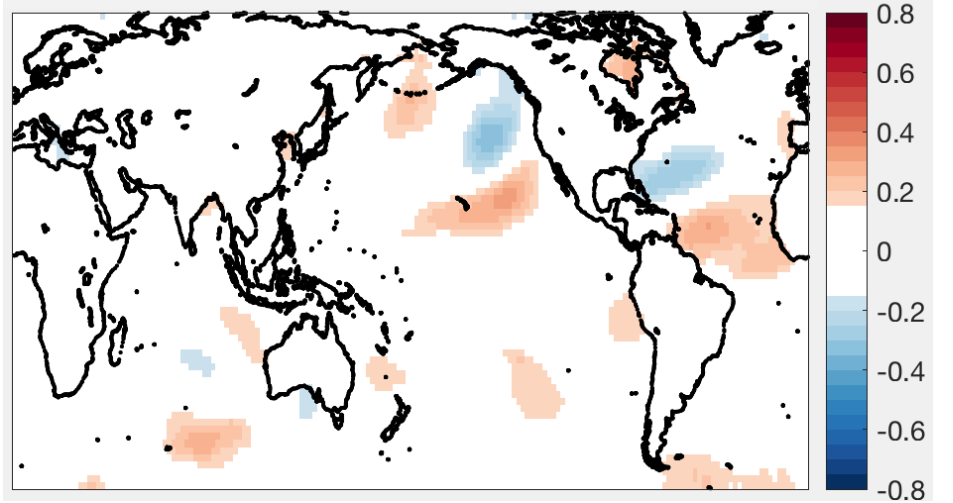
Time series of PC2



Correlation: PC1 vs SSTs



Correlation: PC2 vs SSTs



West-coast Nov-Mar precipitation Principal Components

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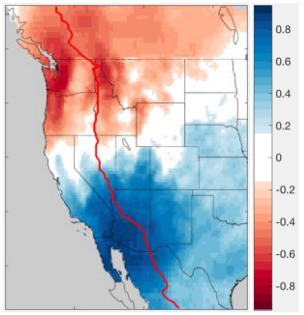
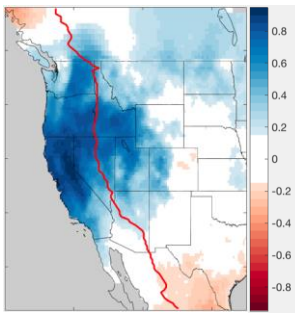
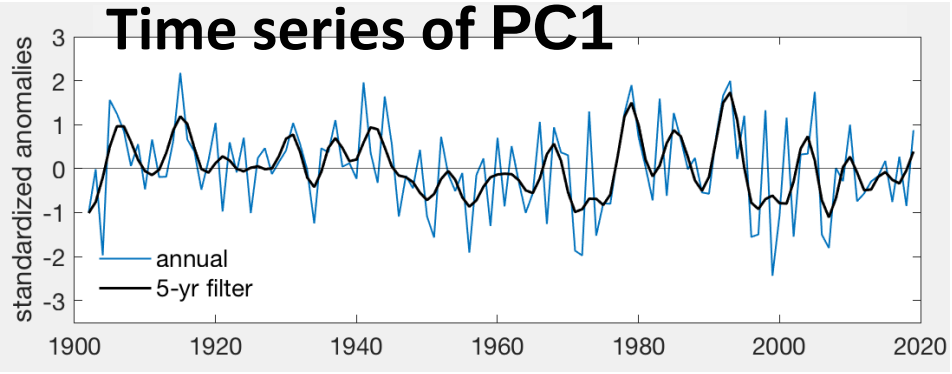


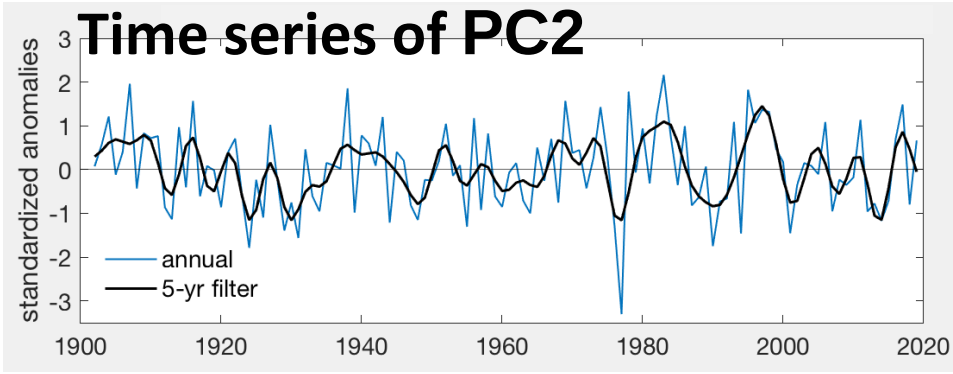
Mode #2



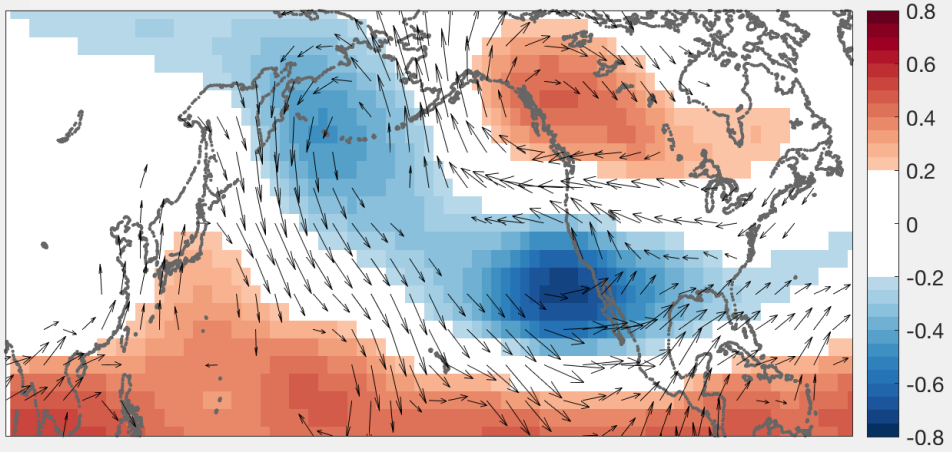
Time series of PC1



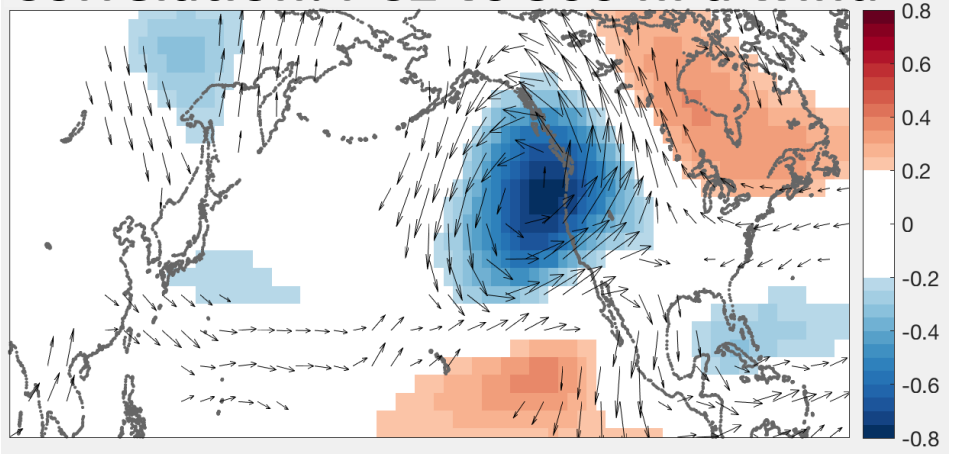
Time series of PC2



Correlation: PC1 vs 500 hPa wind

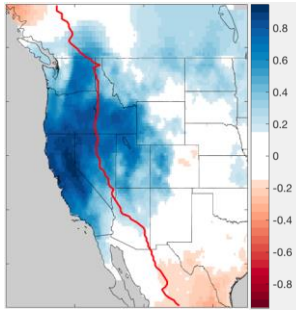


Correlation: PC2 vs 500 hPa wind

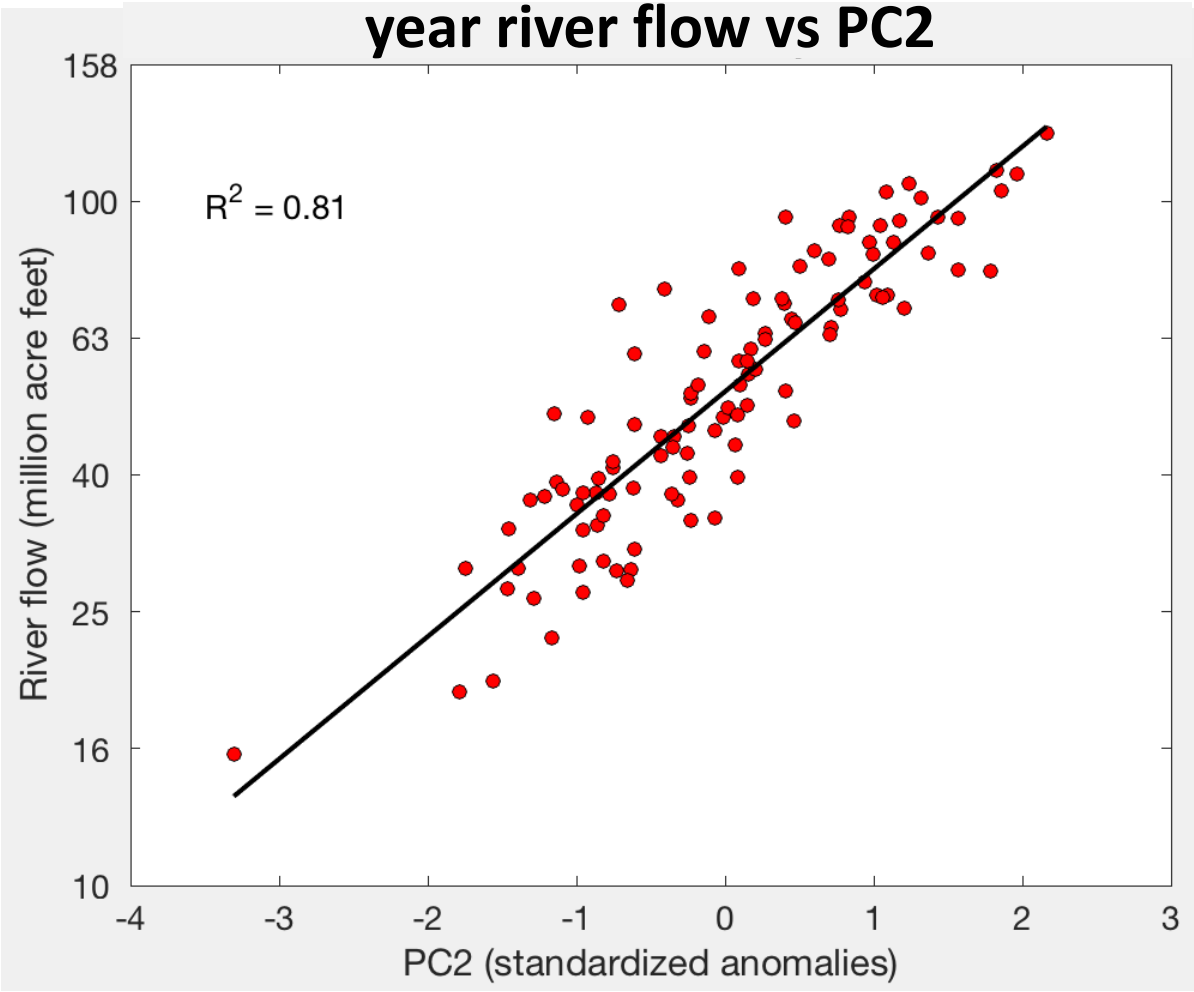


This non-ENSO component of cold-season precip variability controls runoff out of Sierra Nevada

Mode #2



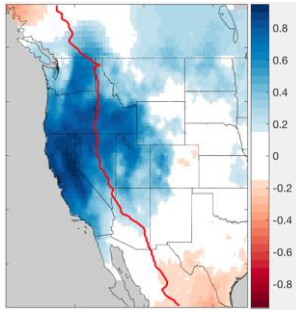
Sacramento and San Joaquin water-year river flow vs PC2



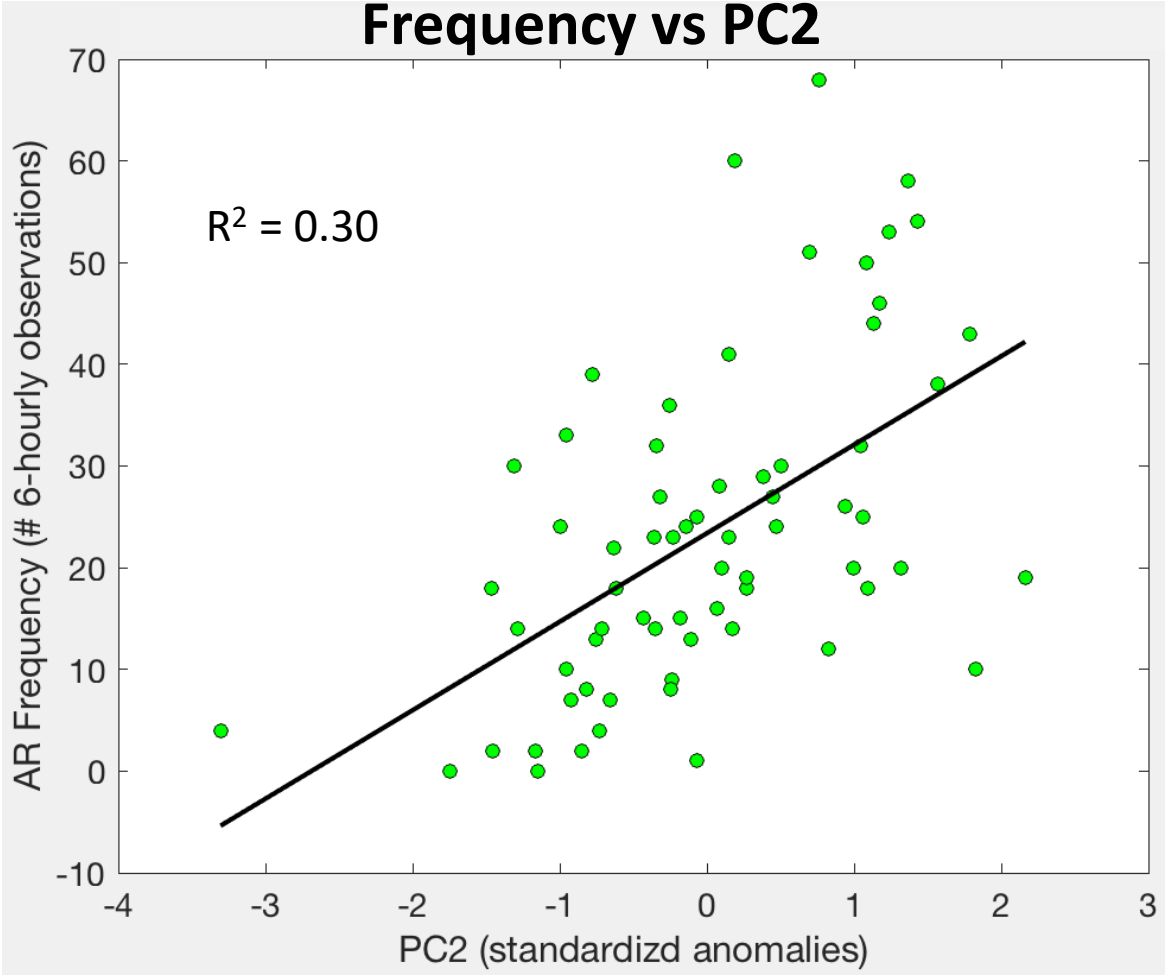
*Streamflow data from CDWR

This non-ENSO component of cold-season precip variability controls runoff out of Sierra Nevada

Mode #2



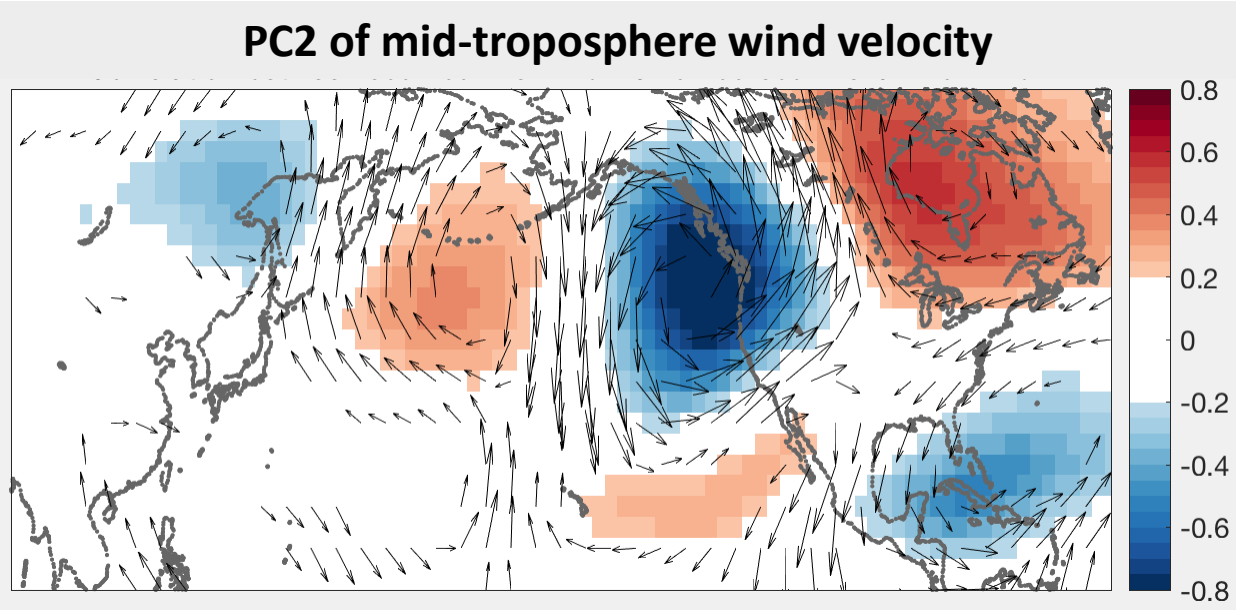
CA Land-falling Atmospheric River Frequency vs PC2

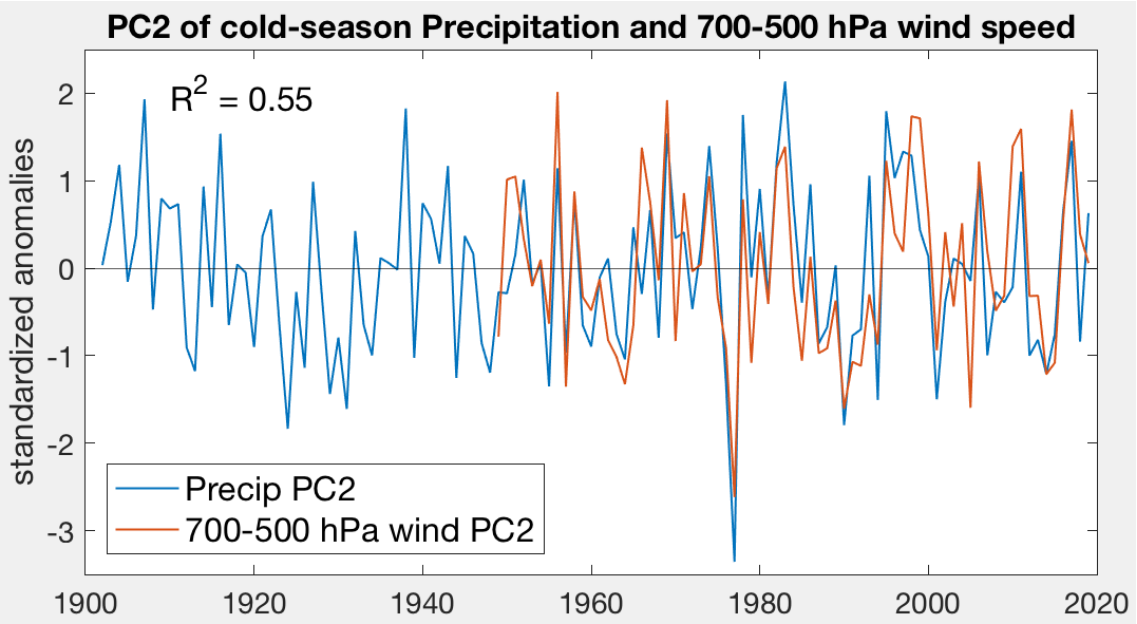


*AR data from Guan & Waliser (2015; JGR-Atmos)

Is Mode 2 a real mode of climate variability
or just a statistical artifact?

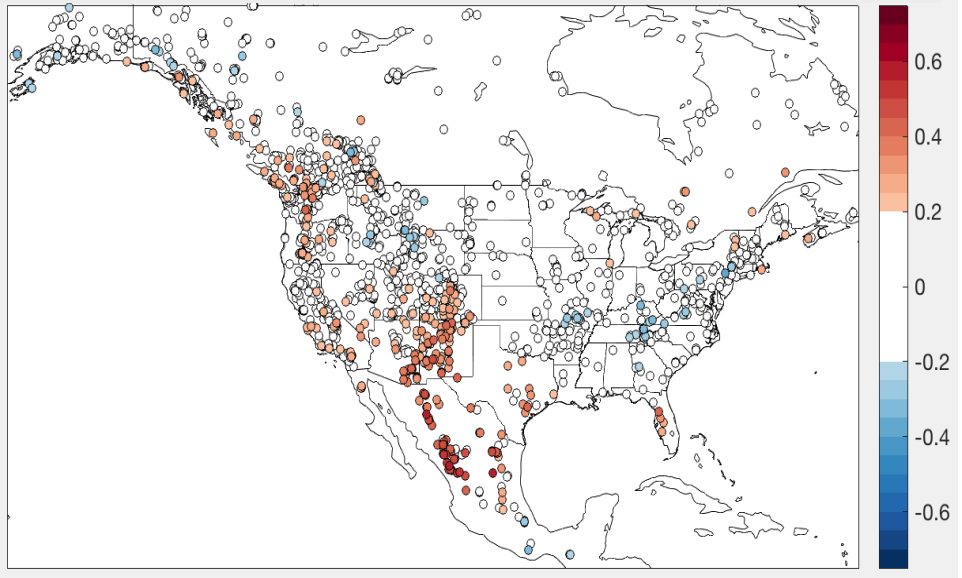
This mode of non-ENSO precipitation variability appears to be a naturally arising mode of climate variability



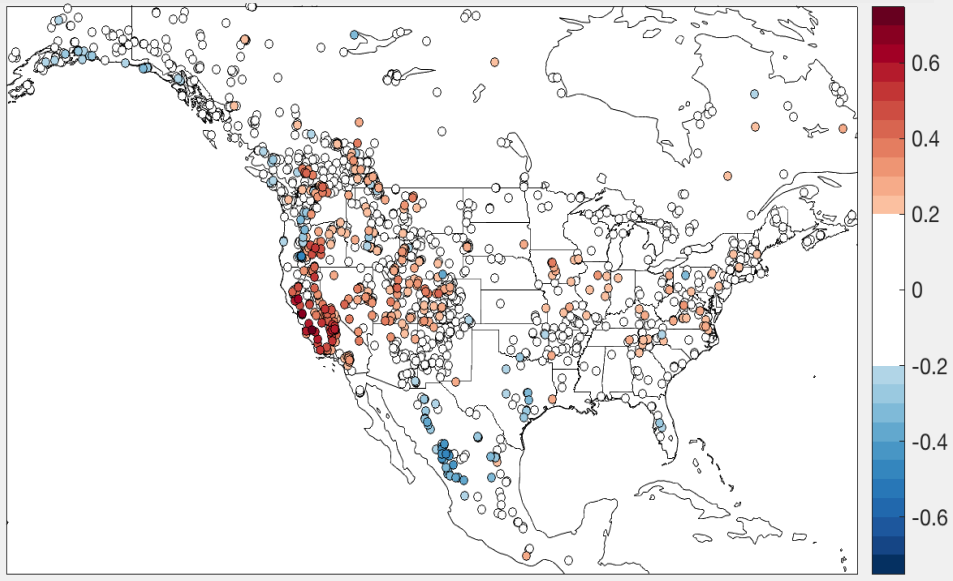


Tree-ring correlations with the two leading modes of west-coast cold-season precipitation variability

Correlation with PC1

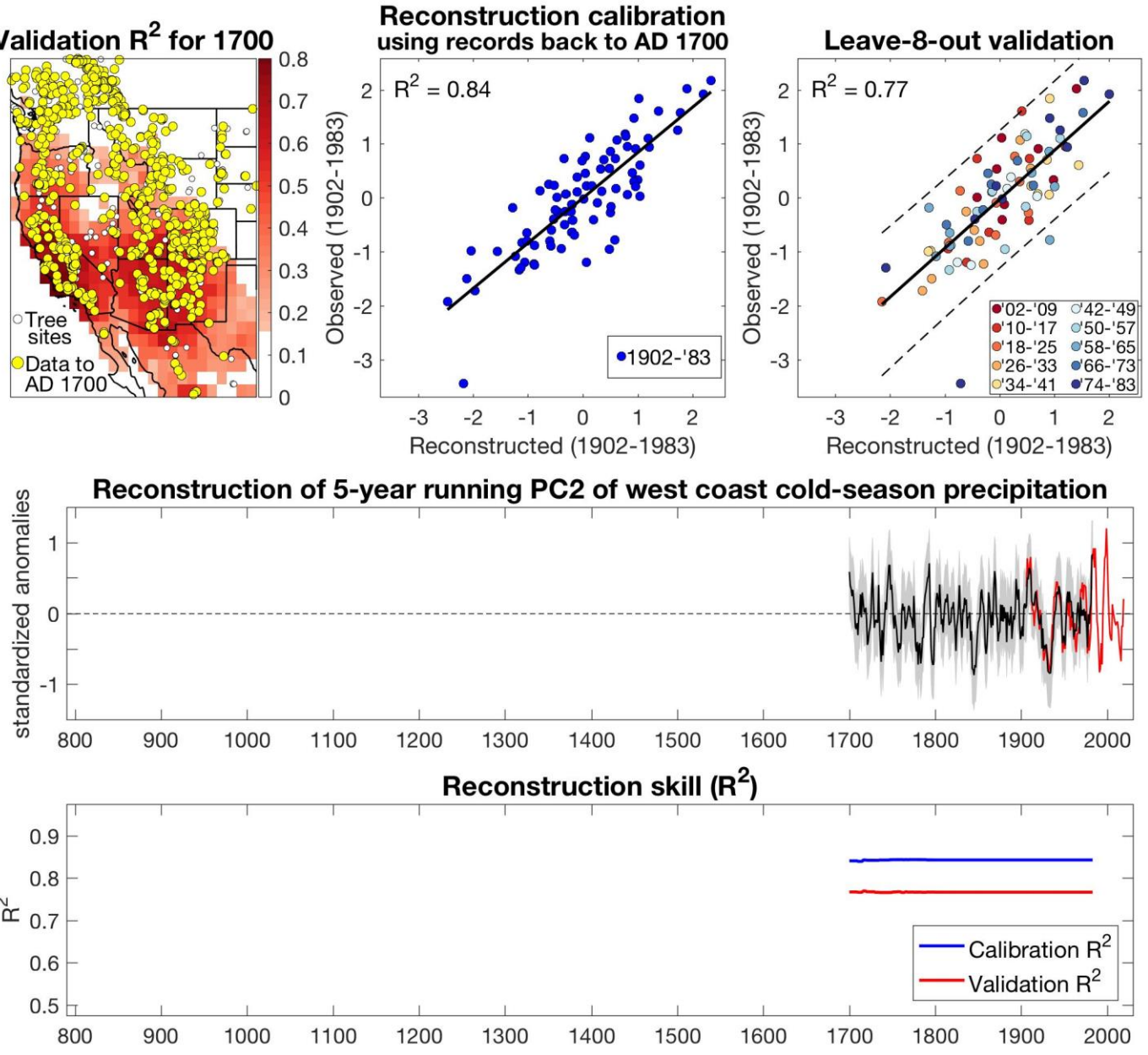


Correlation with PC2



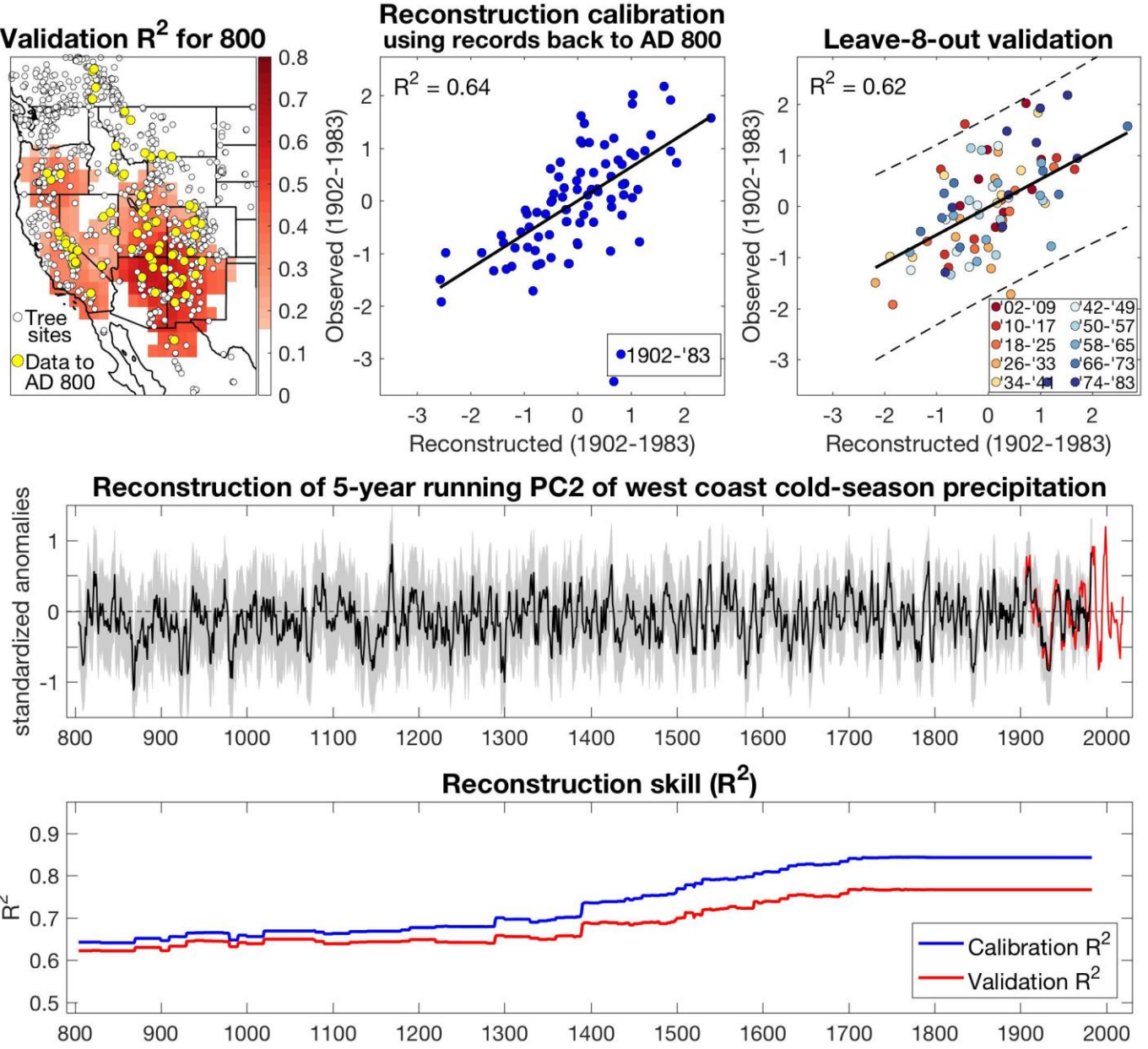
Using the gridded precipitation reconstruction to extend PC2 back in time

Red areas have precipitation reconstructions back to at least 1700



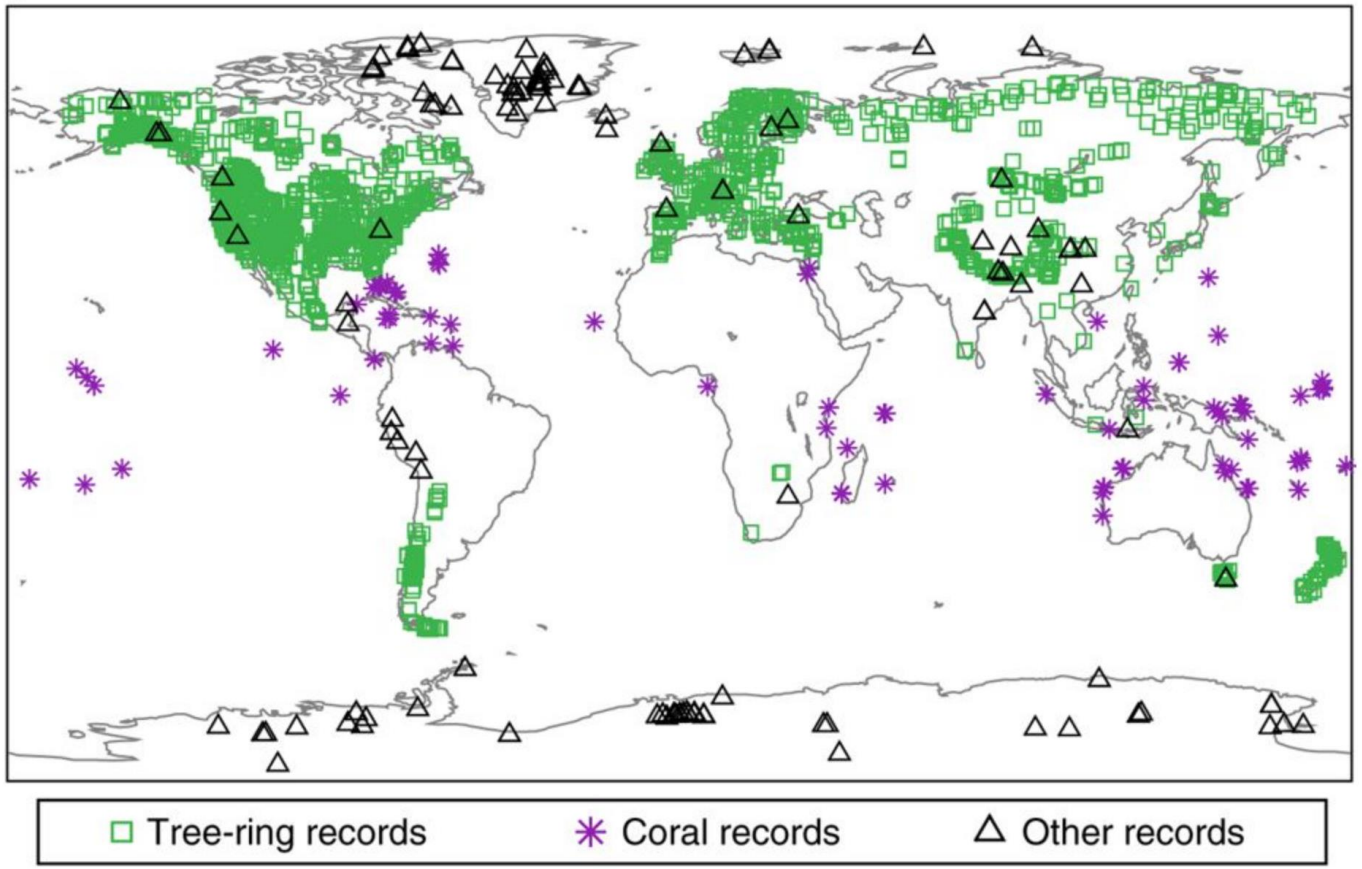
Using the gridded precipitation reconstruction to extend PC2 back in time

Red areas have precipitation reconstructions back to at least 800



Locations of tree-ring records globally

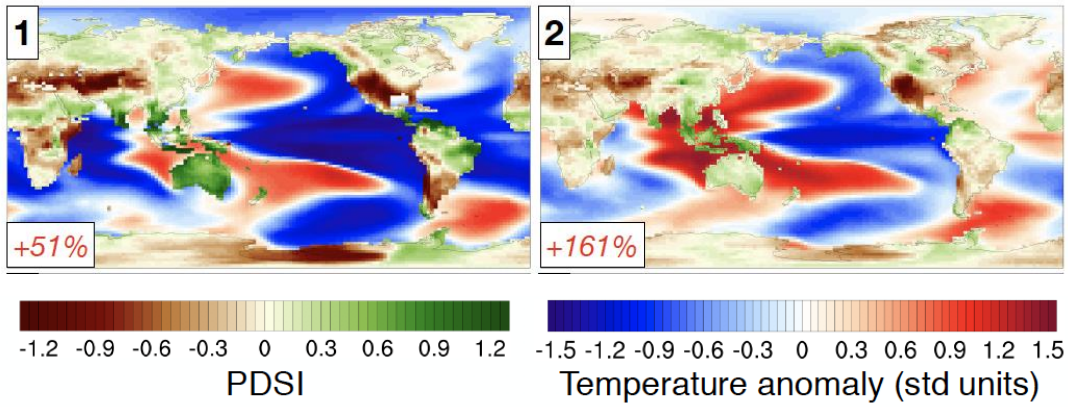
We are beginning to combine the global network of paleo records with climate models to infer GLOBAL climate variations over the past millennium

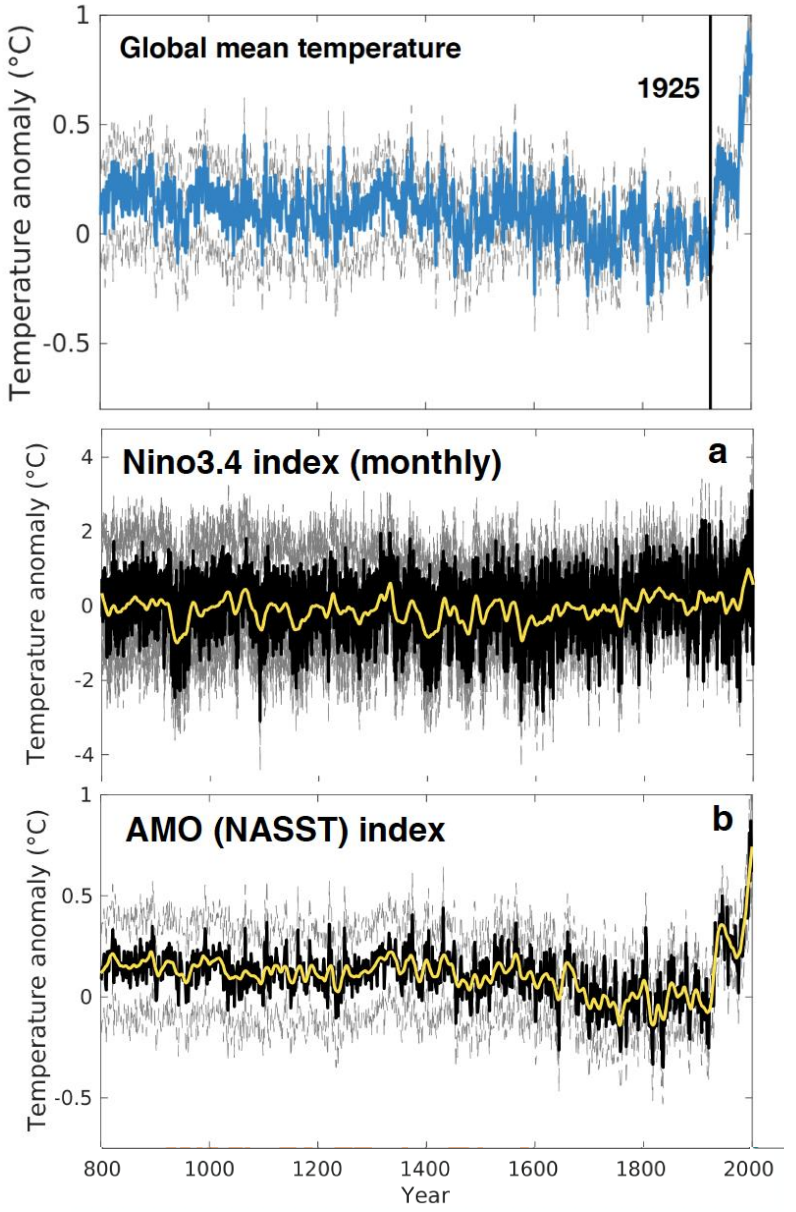


Steiger et al. (2018; Scientific Data)

Reconstructions of global climate fields

2 most common reconstructed SST patterns that correspond to western North America drought





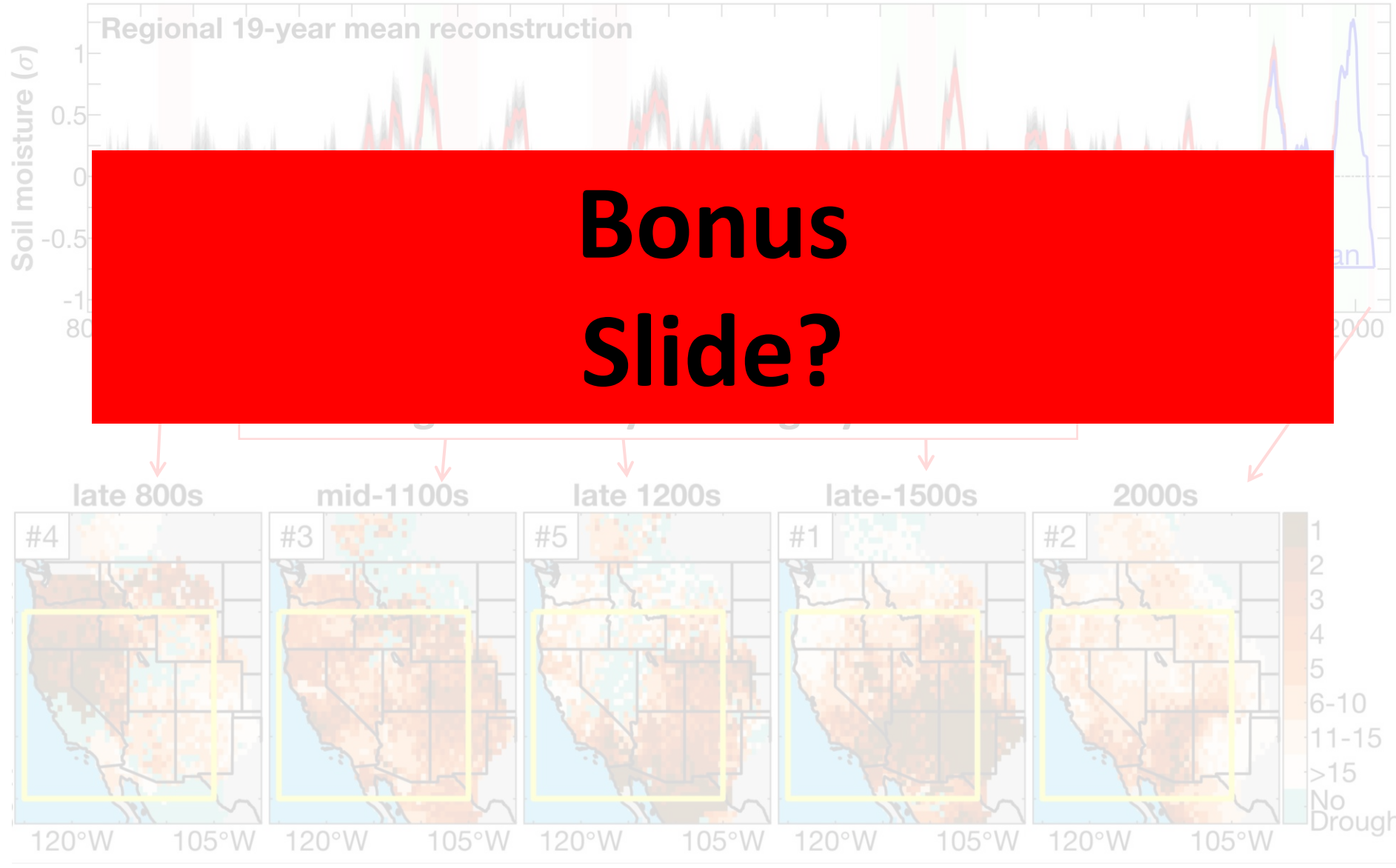
Steiger et al. (2019; Science Advances)

Conclusions

- Tree-ring records have been used for decades to broaden our perspective about the range and nature of precipitation variability.

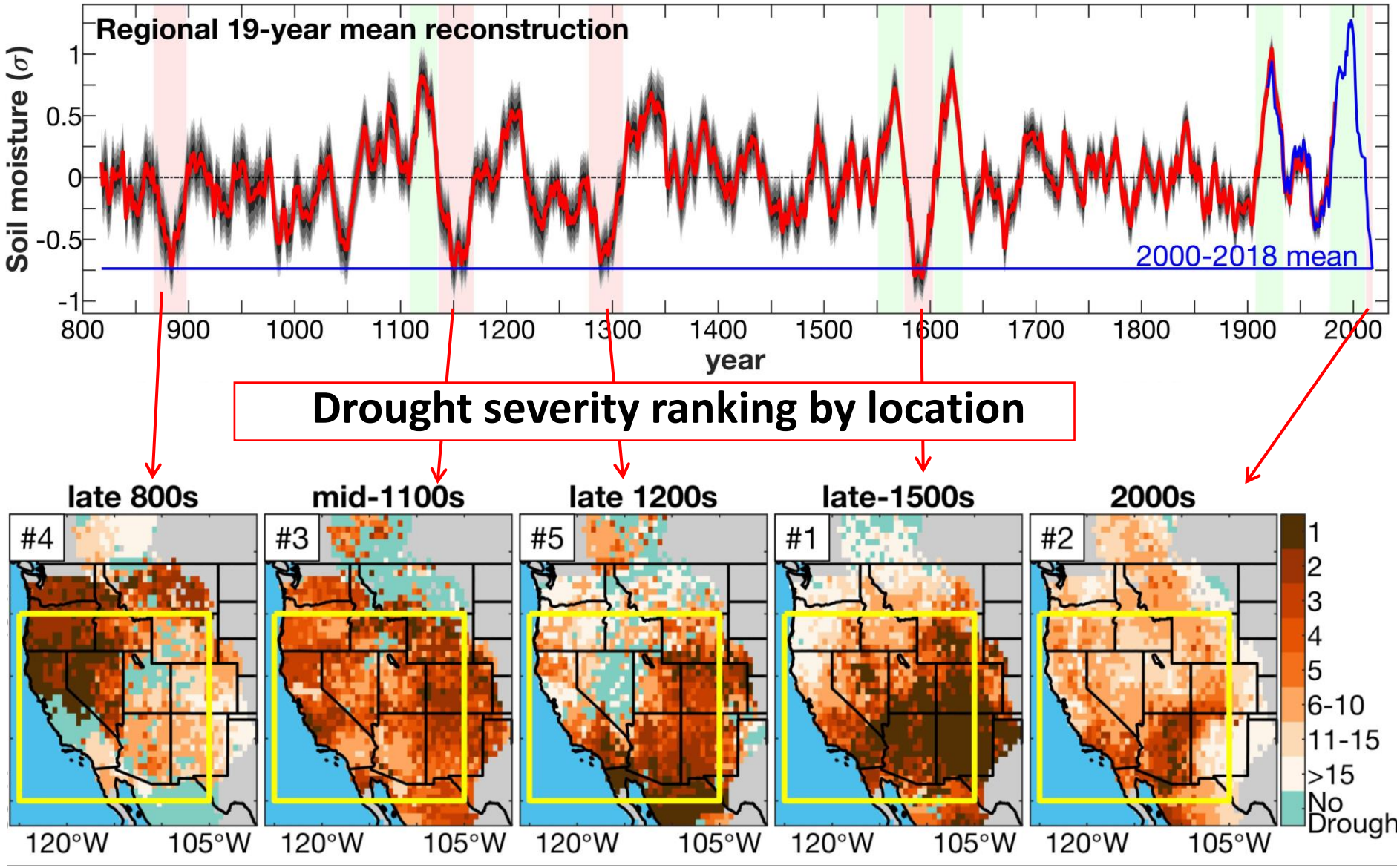
- There is still much more that can be done with tree-ring records, especially in the western US
  - Very high density of tree-ring records
  - Trees are uniquely sensitive to winter precipitation

Western U.S. Soil moisture reconstruction



Bonus Slide?

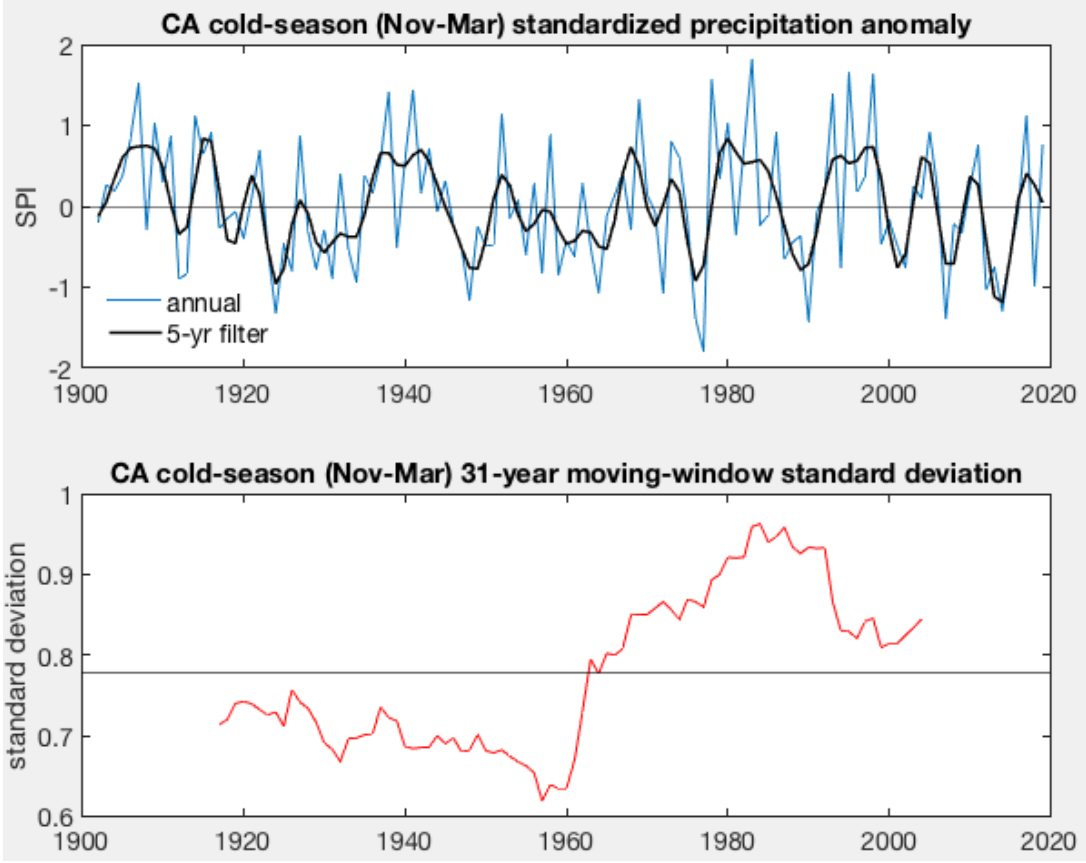
Western U.S. Soil moisture reconstruction

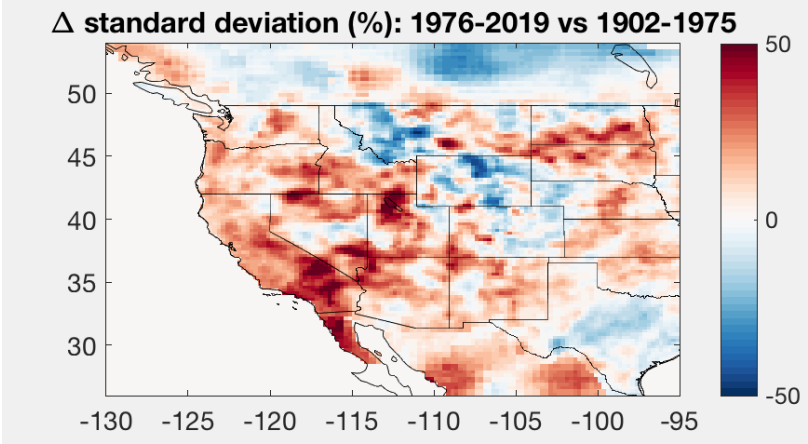


Cold season (Nov-March) precipitation shifted to higher variability and more severe droughts in the mid-1970s.

How abnormal is this?

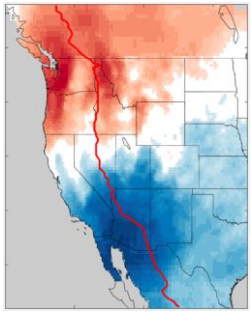
What was the cause?

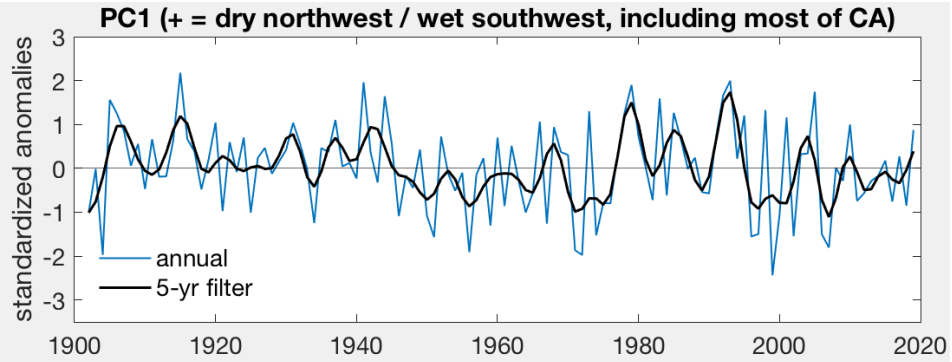


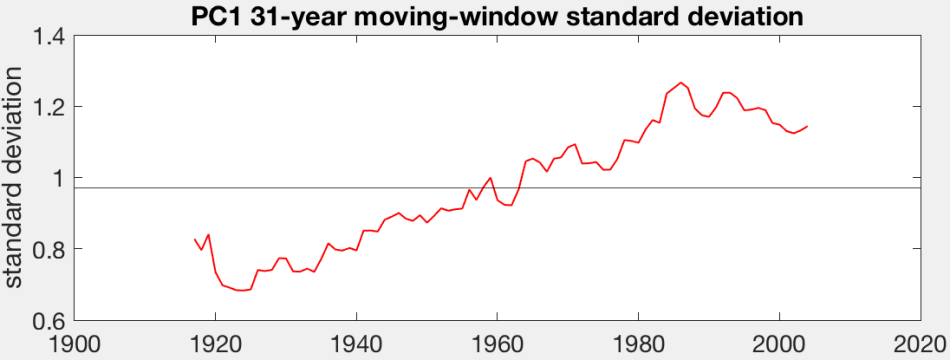


Time series of west-coast cold-season precipitation Principal Components

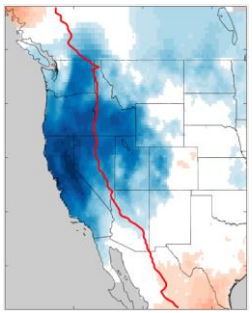
Mode #1

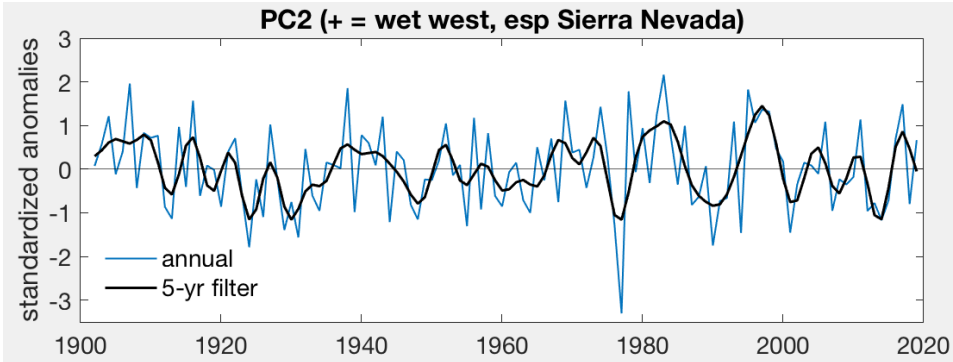


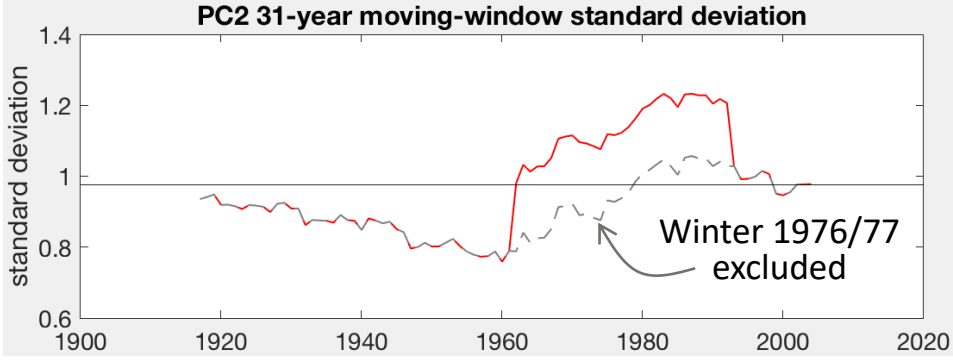




Mode #2

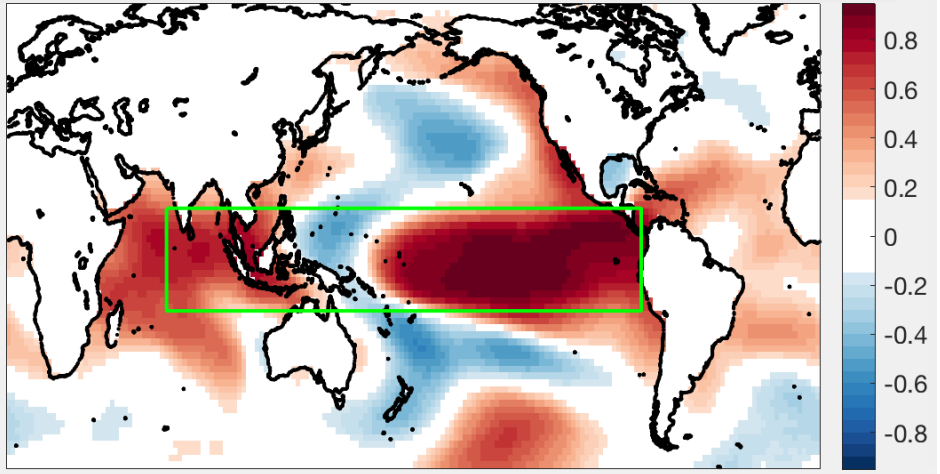




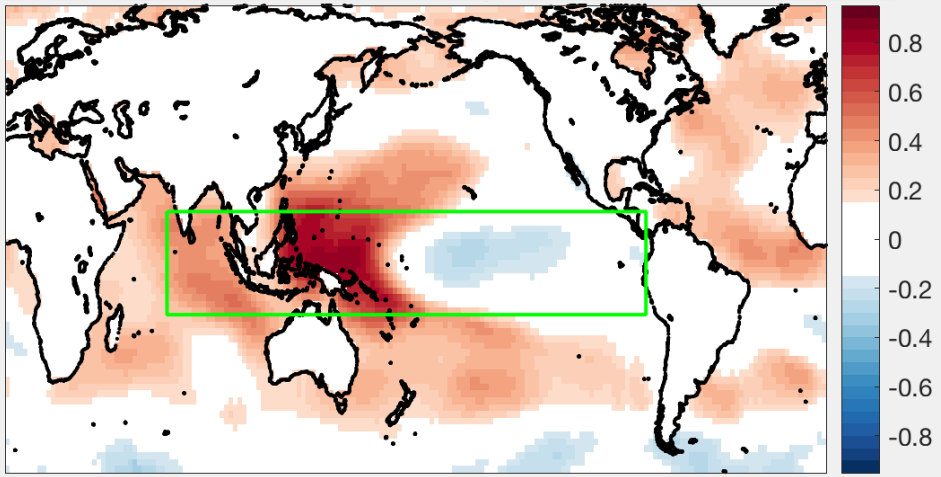


Primary modes of Nov-Mar tropical Indo-Pacific SSTs

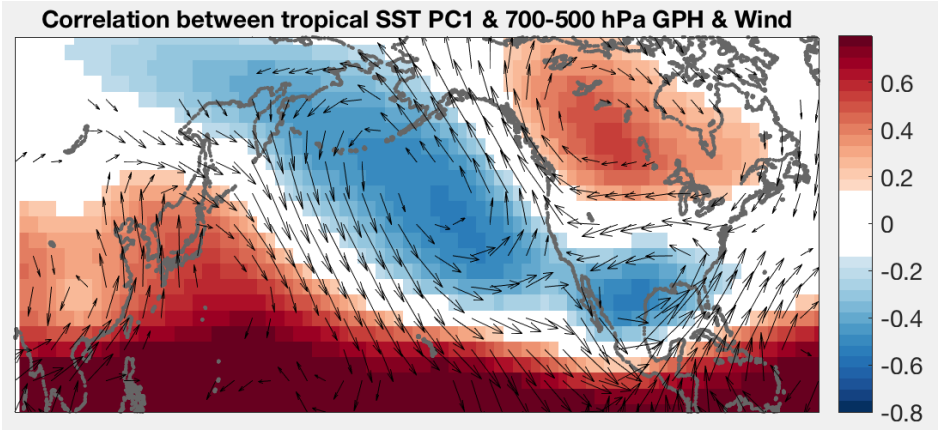
Tropical SST PC1



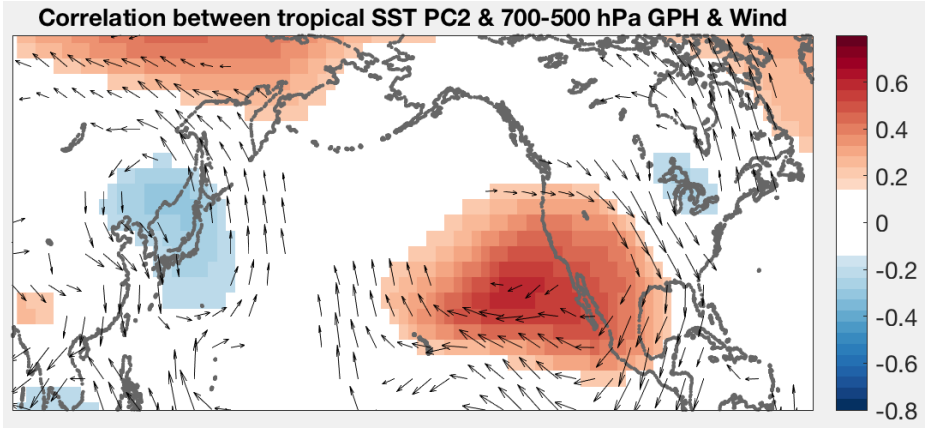
Tropical SST PC2



Mid-tropospheric correlation with tropical SST PC1



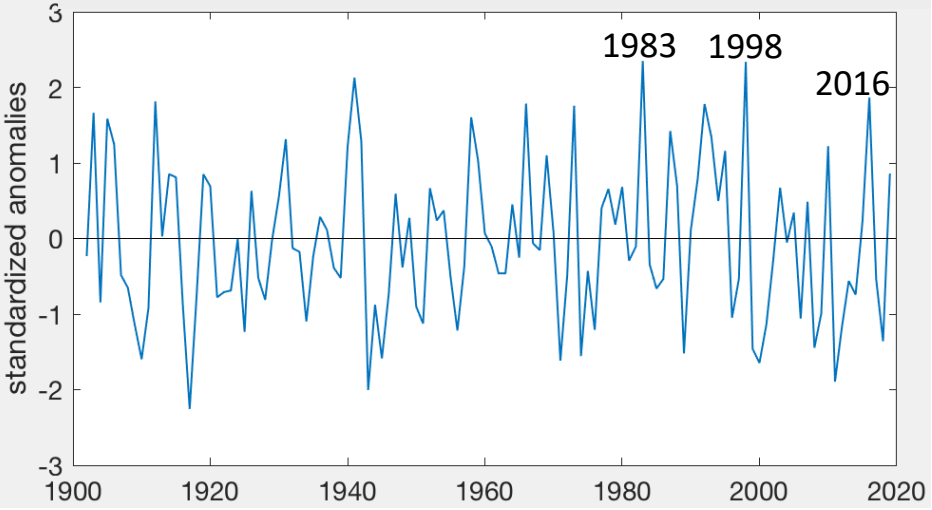
Mid-tropospheric correlation with tropical SST PC2



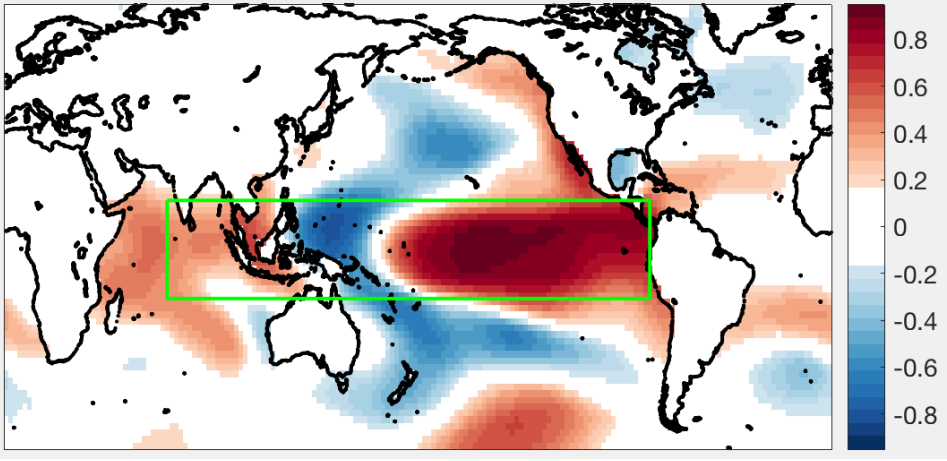
ENSO effect on the atmosphere may be approximated as tropical SST PC1 minus PC2

Accounting for the effect of ENSO

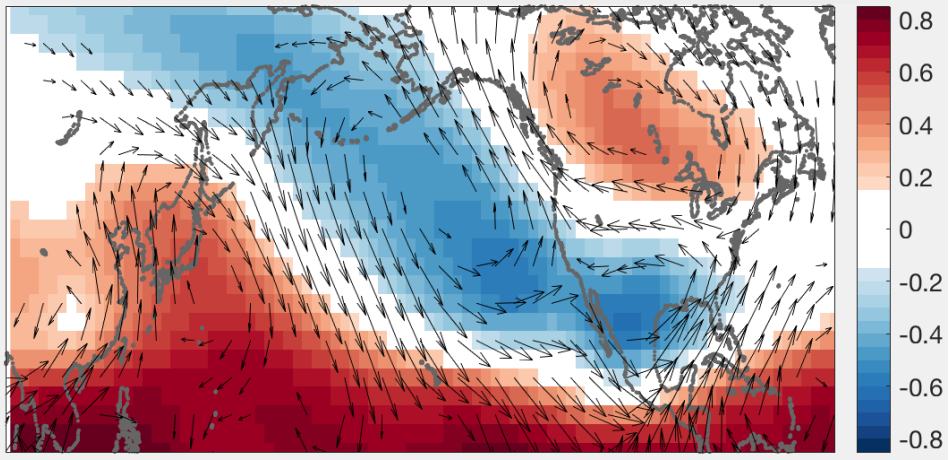
ENSO mode: Tropical SST PC1 minus PC1



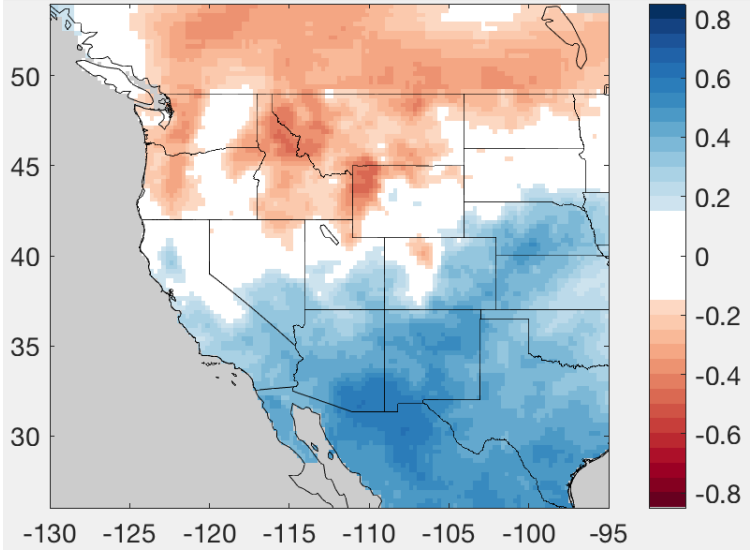
Correlation: ENSO mode vs SSTs



Correlation: ENSO mode vs mid-troposphere circulation

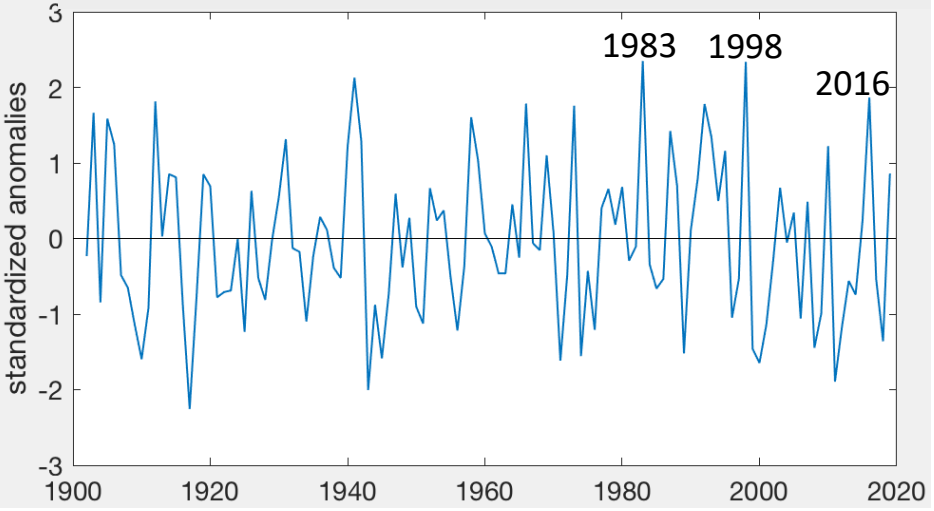


Correlation: ENSO mode vs Precipitation

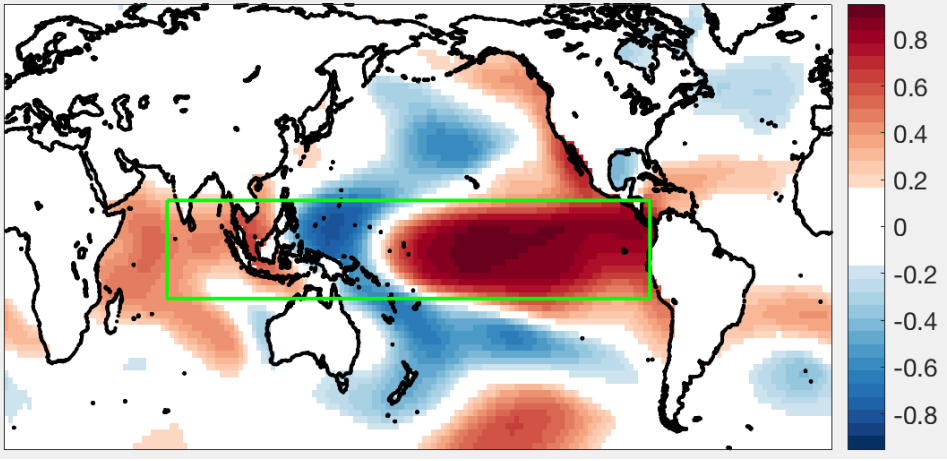


Accounting for the effect of ENSO

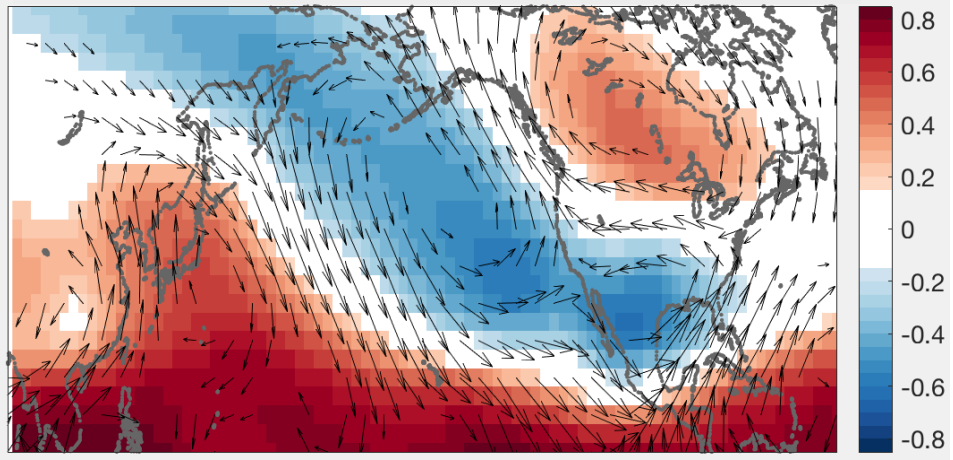
ENSO mode: Tropical SST PC1 minus PC1



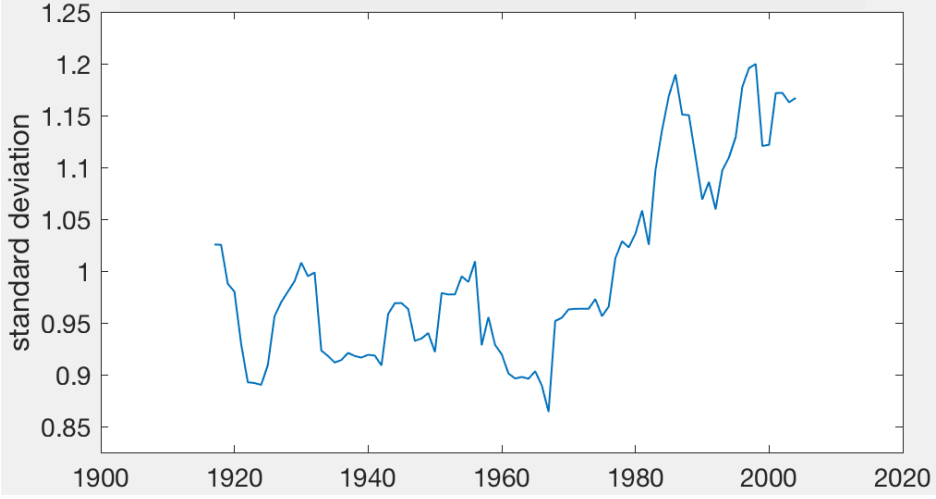
Correlation: ENSO mode vs SSTs



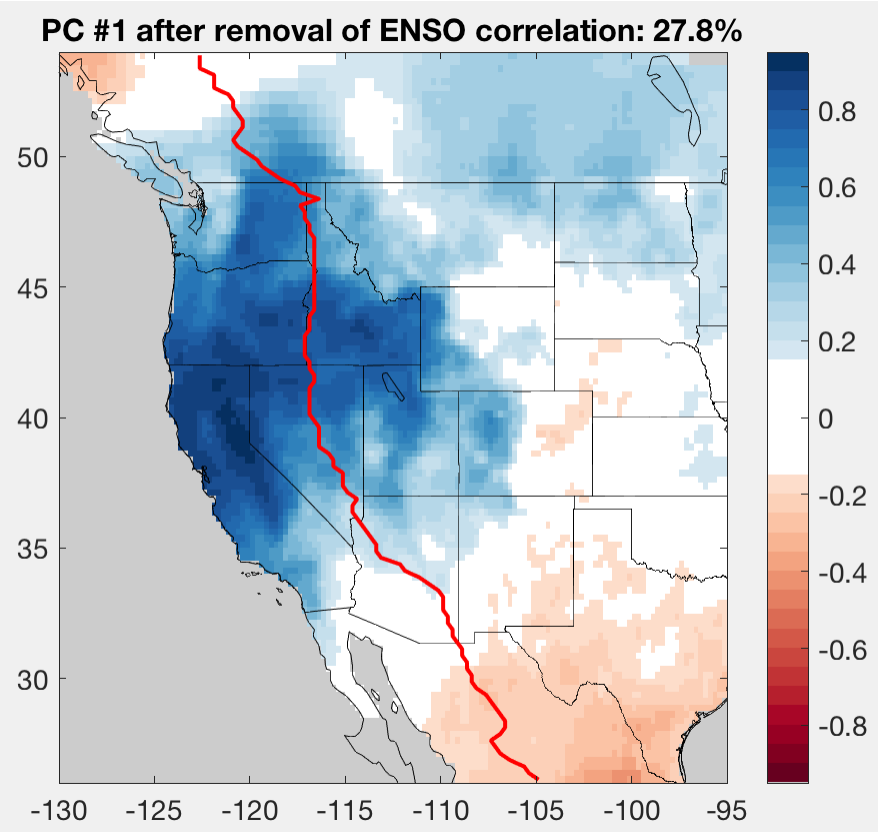
Correlation: ENSO mode vs mid-troposphere circulation

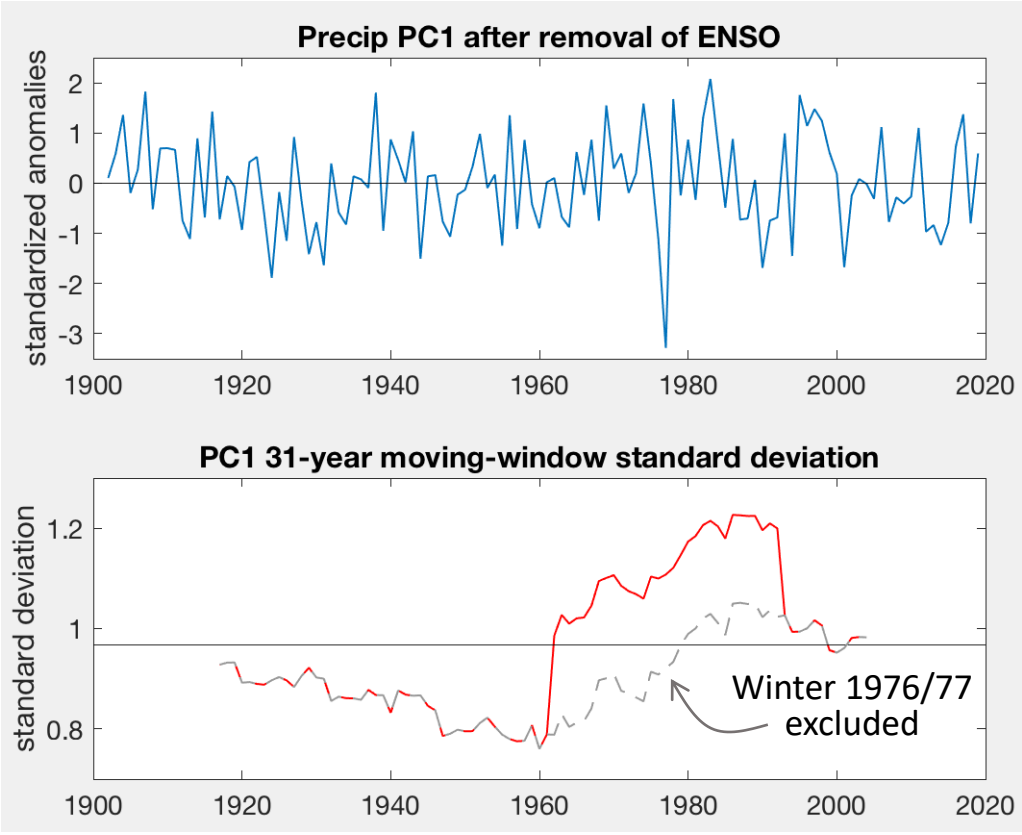


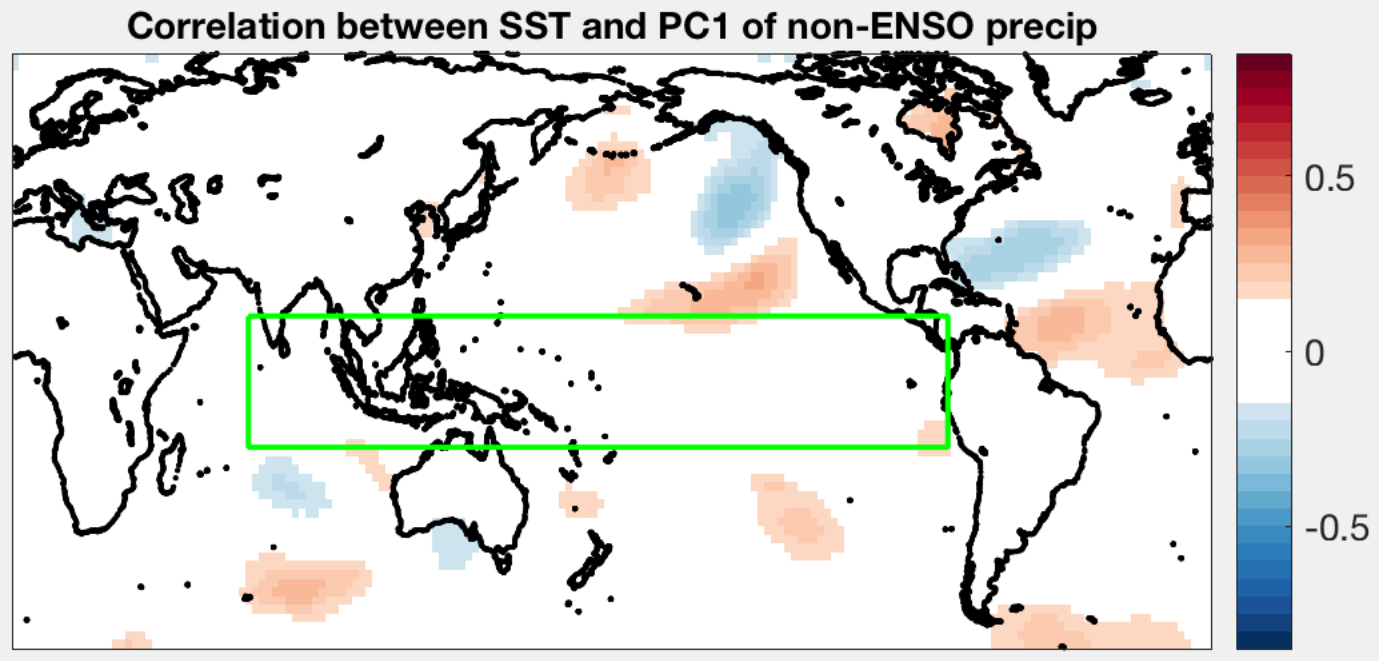
31-yr running standard deviation of ENSO mode

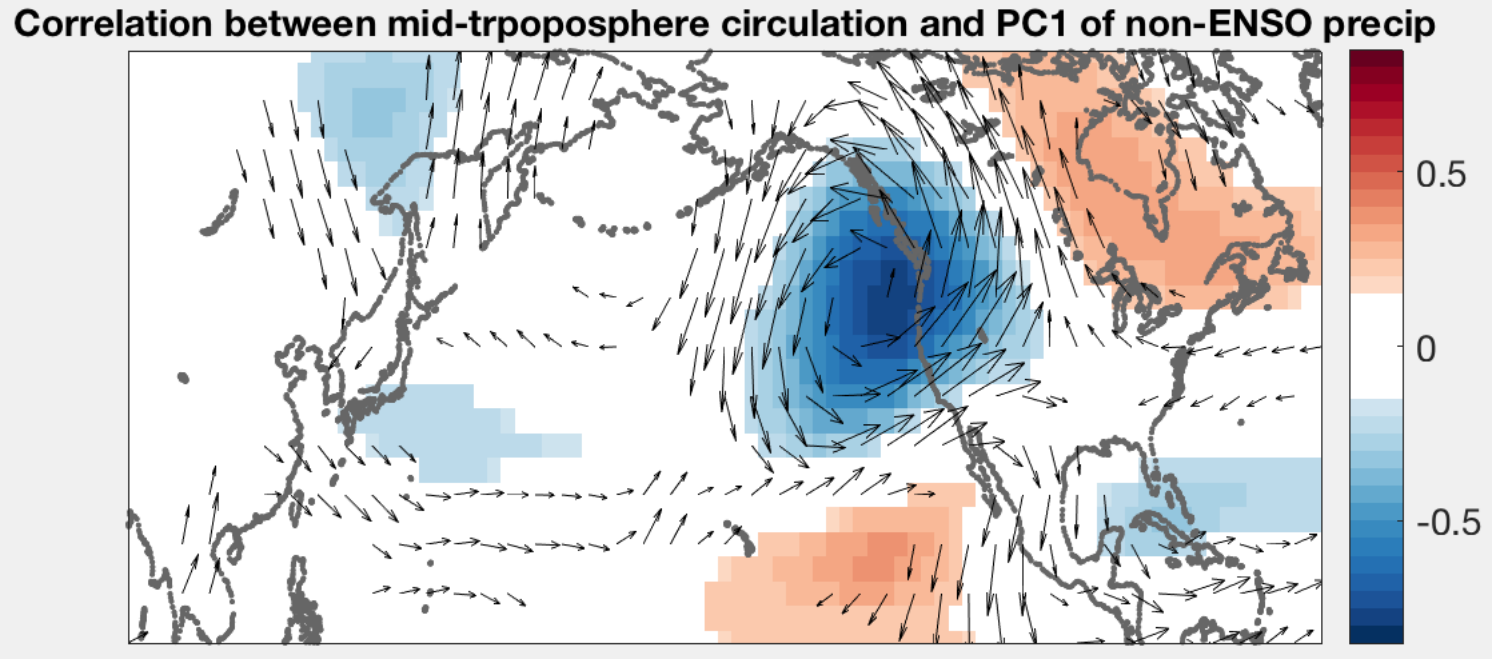


Primary mode of Nov-Mar precipitation variability after effect of ENSO is removed






Correlation between SST and PC1 of non-ENSO precip
0.5
0
-0.5


Correlation between mid-trpoposphere circulation and PC1 of non-ENSO precip
0.5
0
-0.5