

Using observations and proxies to assess the strength of decadal signals in North American drought

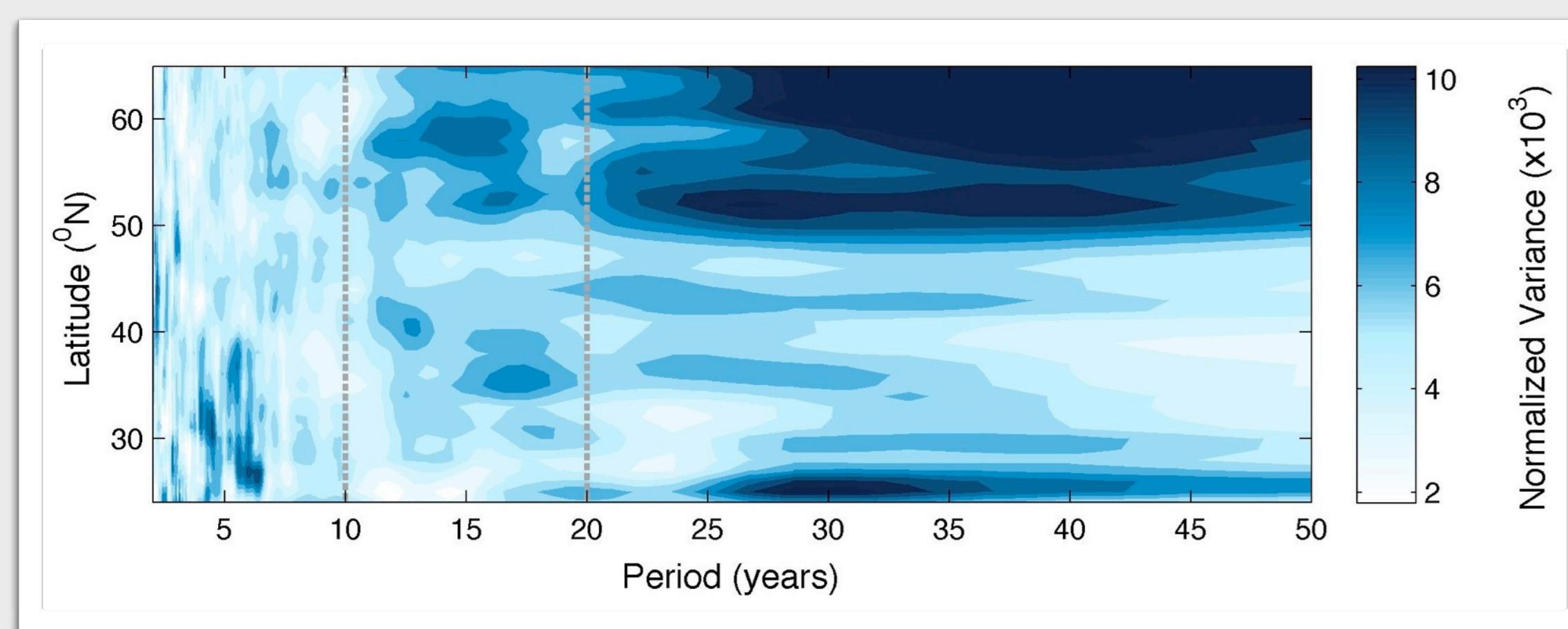
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Abstract

We highlight regions in North America where precipitation and drought indices exhibit exceptionally strong variability at decadal-to-multidecadal (D2M) timescales, and test the ability of drought-sensitive tree-ring records to track variations in decadal climate modes. Although D2M signals in precipitation are quite modest in most places, highly energetic behavior at low frequencies occurs in Minnesota and northern California (during winter), the central Rocky Mountains (during autumn) and Eastern Québec (over the entire year). Regions where precipitation is strongly decadal or multidecadal do not exhibit consistent teleconnections with major climate modes, and this strong, low-frequency behavior shows little correspondence with sea surface temperatures. In the North American Drought Atlas, the teleconnection patterns linking reconstructed drought to decadal climate modes appear to be influenced by geographic differences in the seasonality of moisture signals encoded into local tree-ring records. Drought reconstructions from the southwestern United States and northern Mexico, which are tuned primarily to winter precipitation, display connections to ENSO, the PDO and the AMO that are strong, symmetrical and coherent at the dominant timescales of variability. In other areas, tree-ring estimates track summer conditions and the association between drought reconstructions and the three modes are weak and inconsistent. Studies of past low-frequency drought variability in North America should consider regional differences in the strength of both local D2M signals and the teleconnections between local climatology and remote forcings.

Motivation

Recent studies have suggested that the risk of drought over North America changes at timescales of one to several decades, and that these changes are linked to variations in ocean temperatures. An improved understanding of decadal or multidecadal (D2M) drought variability [e.g., Enfield et al., 2001; McCabe et al., 2004] would be a major boon for resource planning and management, but several important aspects of this behavior are poorly understood. How strong are decadal or multidecadal signals in drought, and does their magnitude vary across North America? Can D2M signals in terrestrial climate be conceptualized as linear responses to major decadal or multidecadal modes in the oceans? And is it appropriate to use proxy drought records derived from North American tree rings to estimate the behavior of these modes prior to the instrumental period?



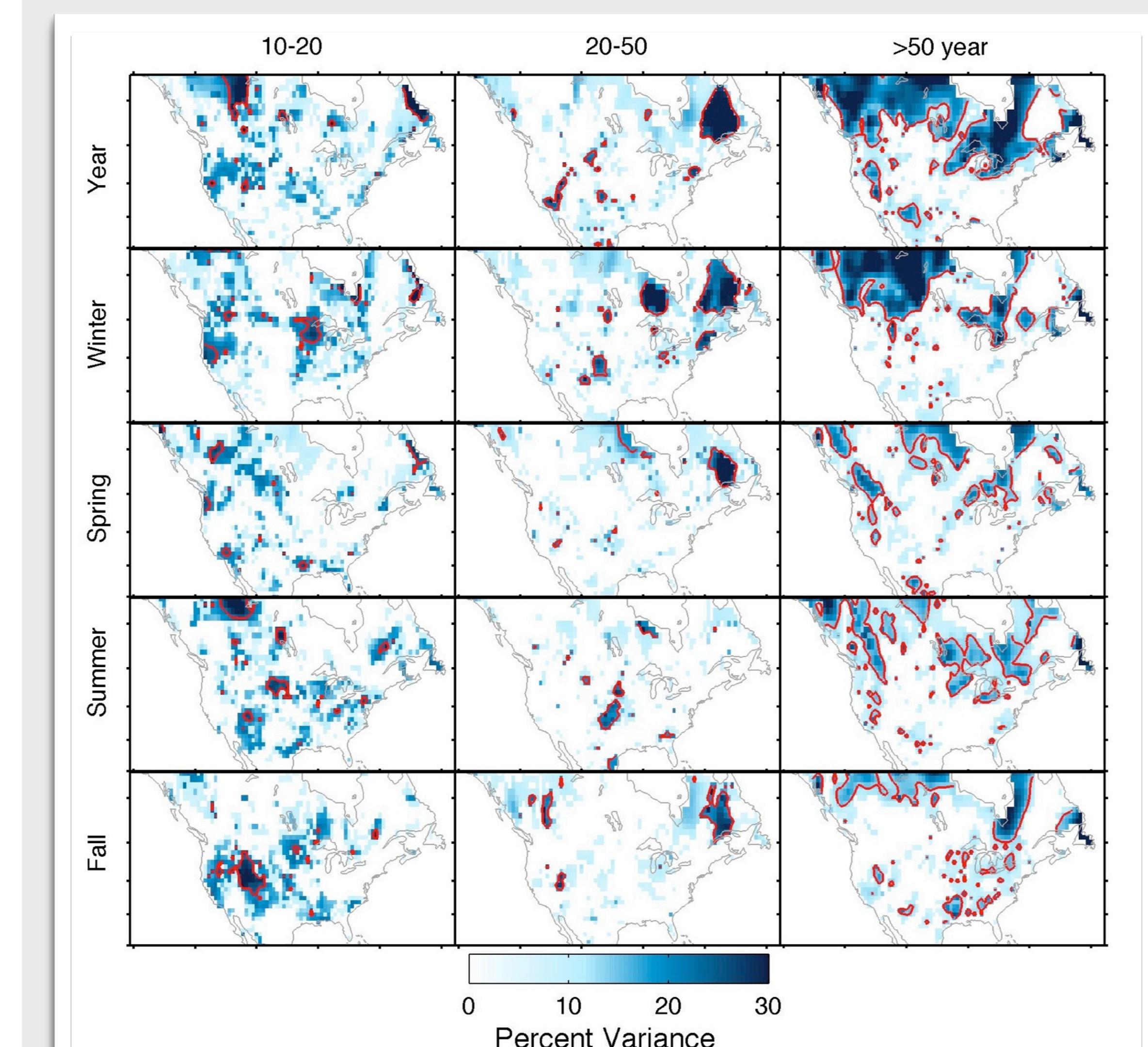
Low-frequency variability strongest in mid, high-latitudes
Spectral estimates derived using the multi-taper method show that the dominant timescales of precipitation vary with latitude: 2 - 7 yr variability is strongest south of 40° N, variability between 10 and 20 yr is greatest in the mid and high latitudes, and variance above 20 yr is most prominent north of 50° N. There are also spectral gaps in variance from 7 to 10 yr at lower latitudes, and 18 to 20 yr poleward of 35° N. The upper limit of our multidecadal band is constrained by the length of the gridded precipitation dataset: at twice the Raleigh frequency (1/N), variance at periods greater than ~50 years cannot be distinguished from secular trends.

Citations Cook, E.R., and P.J. Krusic (2004), The North American Drought Atlas, Lamont-Doherty Earth Observatory and the National Science Foundation; Cook, E.R., R. Seager, M.A. Cane and D.W. Stahle (2007), North American drought reconstructions, causes and consequences, *Earth Science Reviews* 81, 93-134; Enfield, D.B., A.M. Mestas-Nuñez, and P.J. Trimble, 2001: The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S., *Geophysical Research Letters* 28, 2077-2080; Florschuetz, J.L. and M.D. Dettinger, 2007: Climate and floods still govern California levee breaks, *Geophysical Research Letters* 34, doi:10.1029/2007GL031702; McCabe, G.J., M.A. Palecki, and J.L. Bentancourt, 2004: Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States, *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.0306738101.

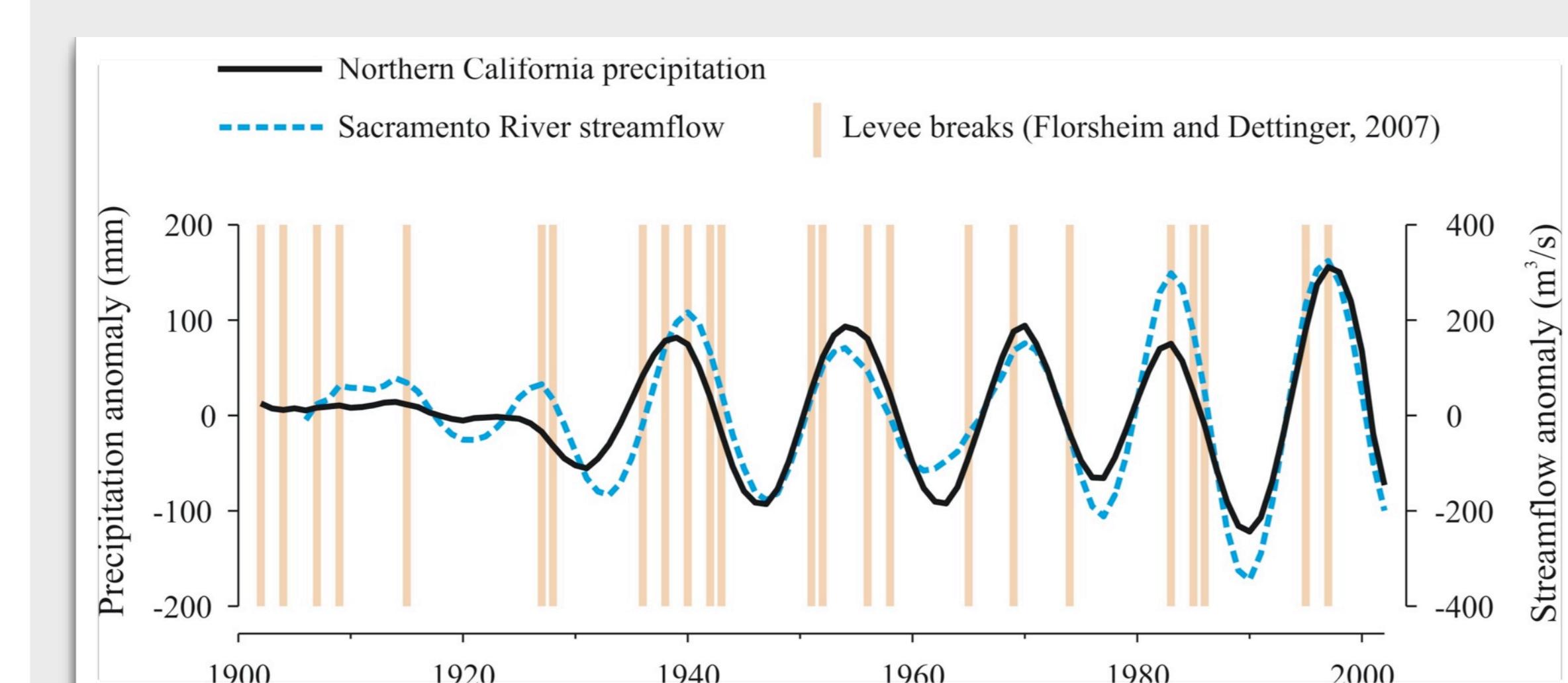
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DecVar in precipitation

We used singular spectrum analysis (SSA) to decompose annual and seasonal precipitation series across North America into interannual, decadal and multidecadal bands and secular trends. We estimated the periodicity of each reconstructed component (RC) using the Fourier transform, and expressed the cumulative variance of the leading RCs within each band as a percentage of the total variance in annual or seasonal precipitation. Significance levels were estimated using a Monte Carlo approach that applied SSA to 1,000 white noise time series the same length as the precipitation record.



The strength of D2M signals varies across North America
Over most of North America, low-frequency variability in either annual or seasonal precipitation contributes less than ten percent of the total variance, and interannual variability or secular trends are much more prominent. Decadal variability is most prominent (contributing 25 to 30 percent of the total variance) in Minnesota and northern California during winter, and the central Rocky Mountains in autumn. Eastern Québec is the only major region where precipitation exhibits significant variance in the multidecadal band. Precipitation across much of Canada has significant energy at extremely low frequencies (greater than 50 years) but variability at these timescales cannot be separated from secular trends.

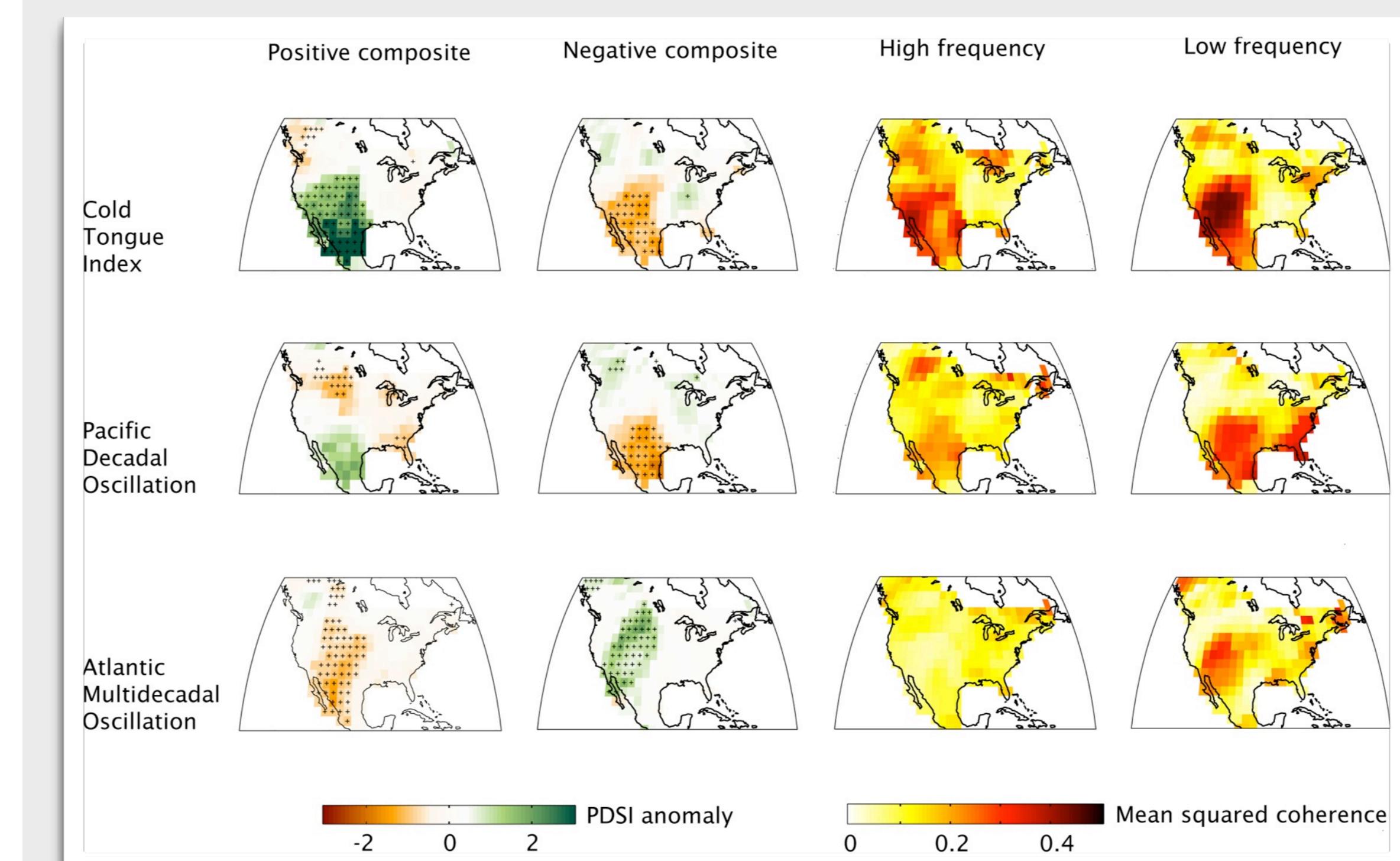


Northern California signals influence discharge, hazards
Applying SSA to naturalized flow records for the Sacramento River shows that one-quarter of the variance in annual discharge is contributed by decadal signals, and that this behavior has the same period and timing as the decadal mode in northern California winter precipitation. This signal also appears to influence geomorphic activity in northern California, as levee breaks in the Sacramento-San Joaquin River [Florschuetz and Dettinger, 2007] tend to cluster near peaks in the decadal component of precipitation and streamflow.

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Tree-ring PDSI and modes

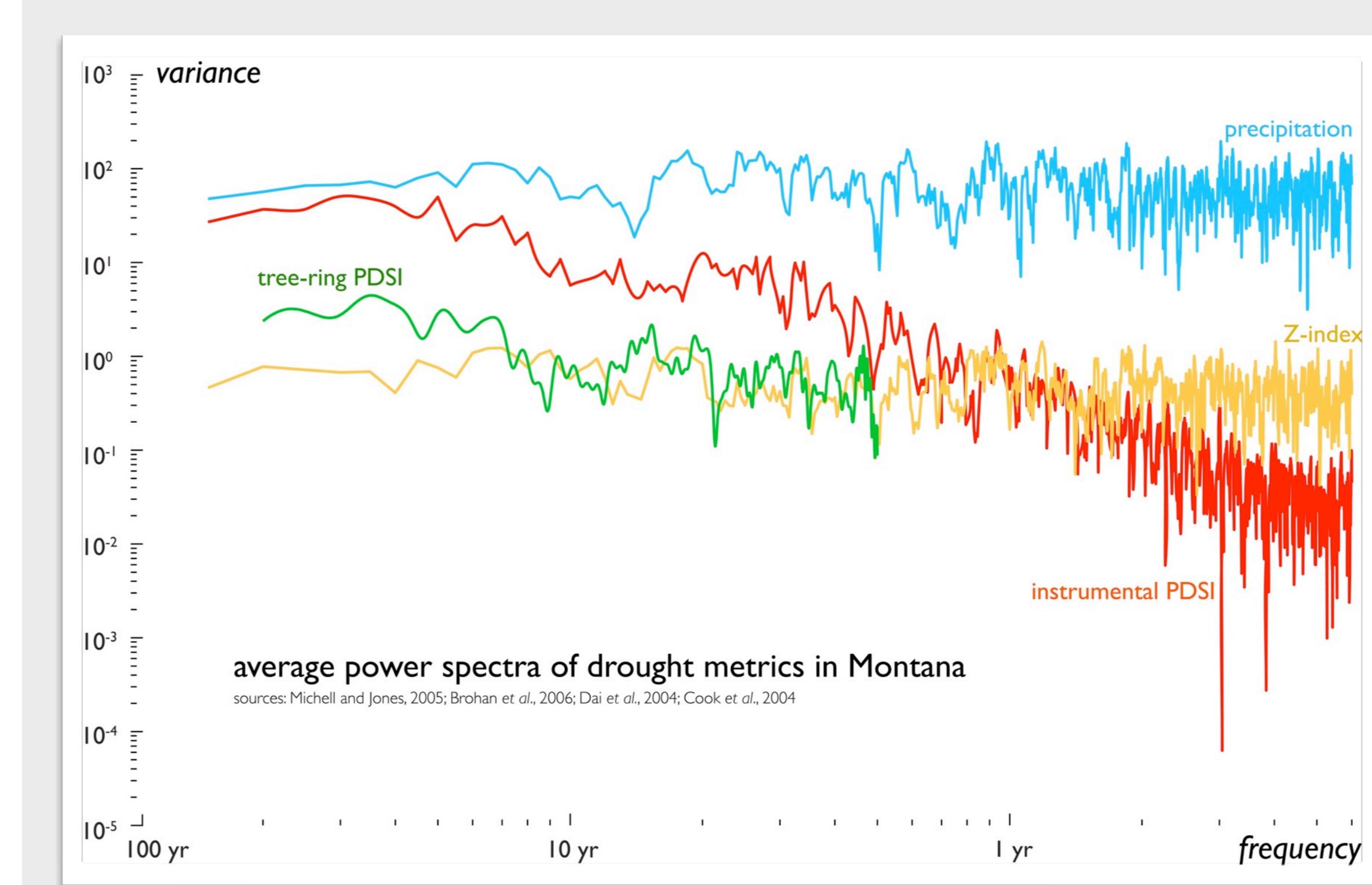
The North American Drought Atlas [Cook and Krusic, 2004; Cook et al., 2007] uses a network of moisture-sensitive tree-ring records from Canada, the United States and Mexico to estimate changes in drought conditions across the continent during the past two millennia. We evaluated the association between summer PDSI reconstructed from tree rings and three major modes of climate variability (the El Niño-Southern Oscillation, the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation) using version 2a of the Drought Atlas and three simple tests based on correlation, compositing and coherence.



Modes linked to tree-ring PDSI in the SW, Tex-Mex regions
Drought reconstructions from the Southwest or Tex-Mex regions display connections to ENSO, PDO and AMO that are strong, symmetrical, and coherent at the dominant timescales of variability for each mode. In other parts of North America, the association between tree-ring PDSI and the three climate modes is either inconsistent or non-significant.

Because of the absence of a strong northwestern response, the overall patterns described by the Drought Atlas do not resemble the classic dipole structure of ENSO teleconnections in North America. The PDO is significantly correlated with summer PDSI in the western Canada but the coherence maps suggest this relationship is driven mainly by shared variance at interannual timescales.

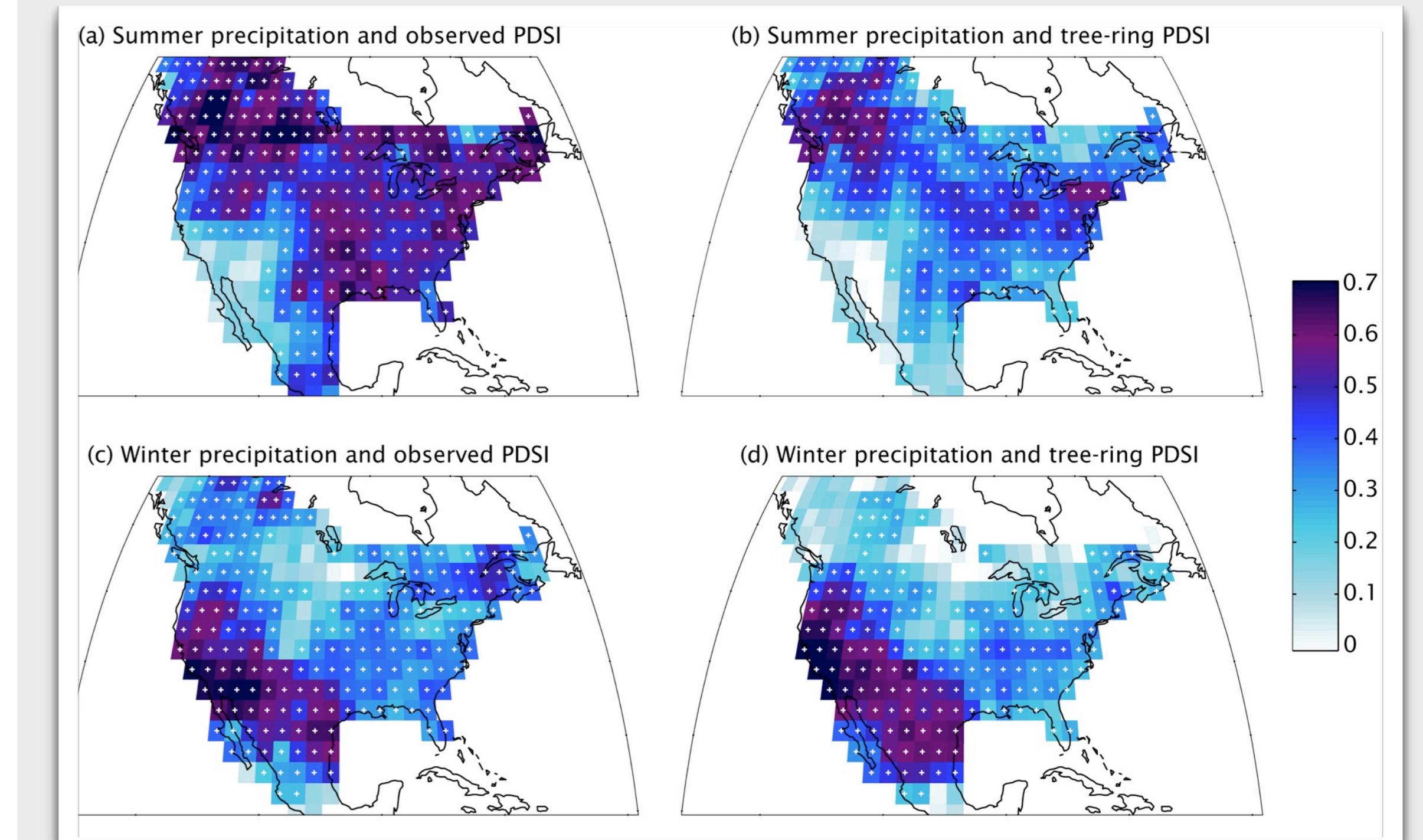
These results confirm that drought-sensitive tree-ring records from the Southwest or Tex-Mex regions are useful inputs for proxy reconstructions of ENSO, PDO or AMO, but also sound a note of caution on the use of similar records from elsewhere in North America for the same purpose.



PDSI (and proxies) are 'red', precipitation is 'white'
Whereas precipitation and the Z-index are relatively 'white', PDSI has a redder spectra due to carry-over terms that mimic the societal impacts of drought or the effects of hydrological storage. Because of these differences, it is important to distinguish between climatic and non-climatic signals when linking past droughts to potential forcings.

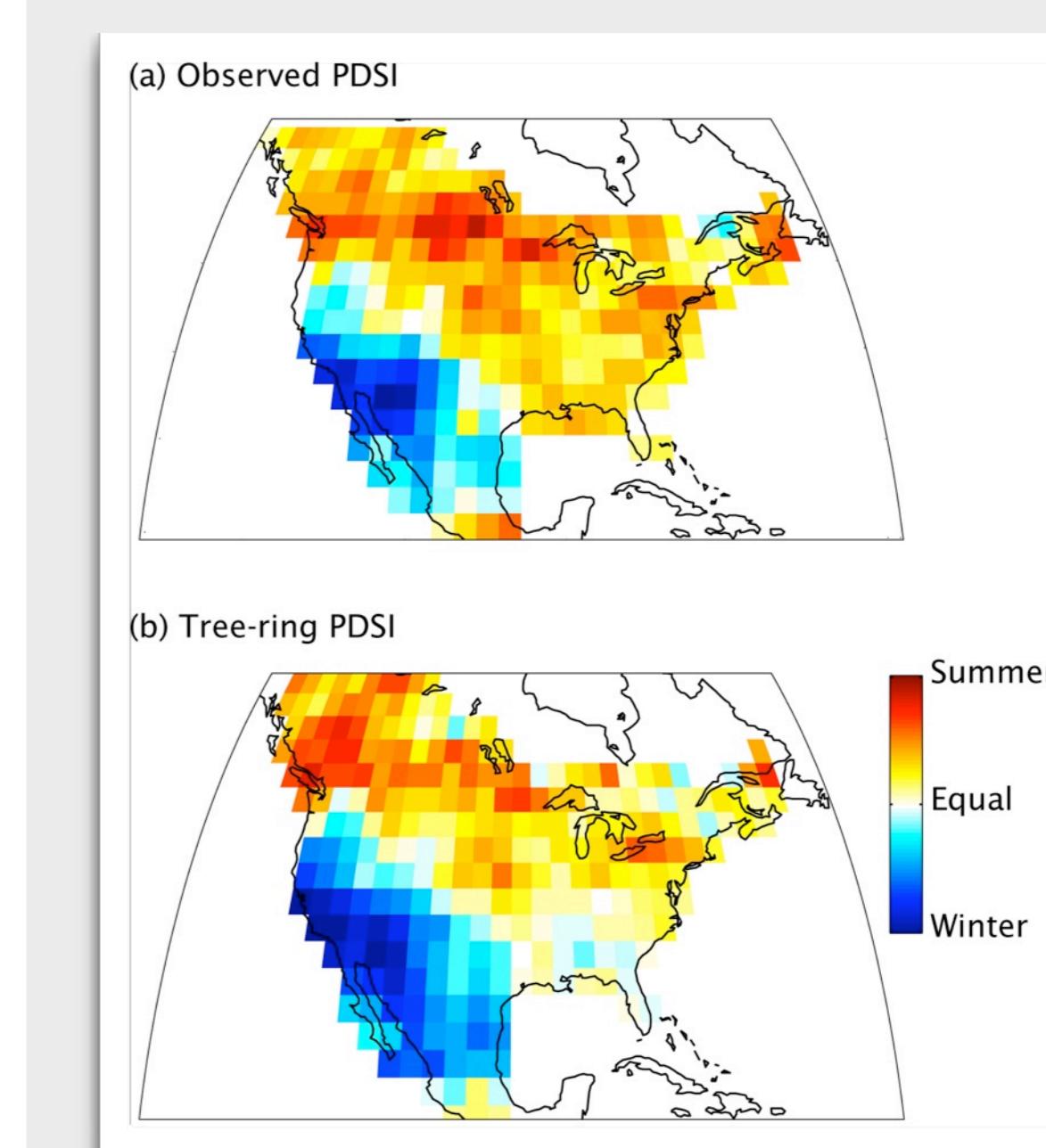


PDSI and seasonality



PDSI biased towards summer, winter in some regions

The spatial patterns of correlation of seasonal precipitation with observed summer PDSI. In most parts of North America, summer PDSI is significantly correlated with both summer and winter precipitation but in some regions, the index is tied more closely to precipitation during either winter (the southwestern US and northwestern Mexico) or summer (western Canada). It may be counter-intuitive that *summer PDSI* is not correlated with *summer precipitation* everywhere, but this finding reflects the importance of winter precipitation to the overall water budget of the southwestern US.



Despite being targeted at the same drought parameter (summer PDSI), the reconstructions that make up the North American Drought Atlas still show major regional differences in the relative influence of seasonal precipitation.

Tree-ring estimates from the Southwest and western Canada show a greater bias towards either winter or summer precipitation than is evident in observations, which suggests that these differences are amplified by the climate-growth response of drought-sensitive trees.

Main points

D2M signals are strong in some places, weak in others

Prominent D2M signals in precipitation do not resemble the low-frequency components of major climate modes such as ENSO or the PDO, which implies that that this behavior is not a product of a simple linear translation of a single climate forcing.

Mode fingerprints clear in SW trees, uncertain elsewhere

Because drought reconstructions from outside of the Southwest are not strongly tied to either ENSO, PDO or AMO, reconstructions that are based on drought-sensitive tree-ring records outside of the centers of action identified in the Drought Atlas run a greater risk of producing unreliable estimates of the past variability of these systems.

Tree-ring PDSI means different things in different places

The relative strength of seasonal precipitation signals in drought-sensitive tree-ring records varies markedly across the continent. We recommend that studies using the Drought Atlas and, more generally, drought-sensitive tree-ring records to investigate the patterns and mechanisms of past drought in North America must consider seasonality as a potential complicating factor.