Predicting Colorado Streamflow Based on Historic Climate Variability: A Case Study of the Cache La Poudre River

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1.0 Introduction to Natural Climate Variability and Global Atmospheric Circulations that are Important to Colorado

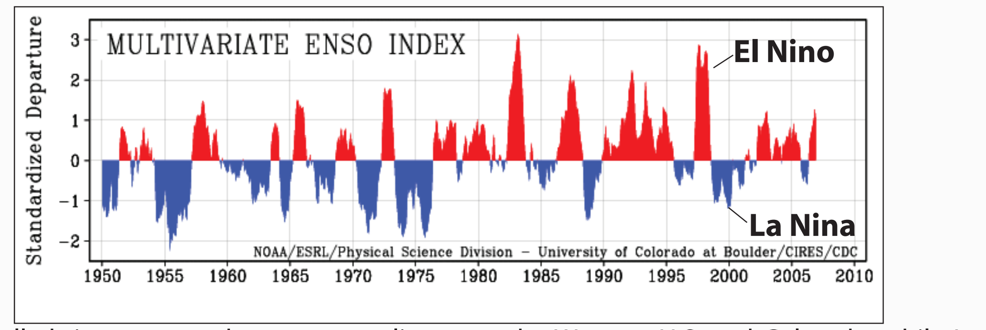
A prominent aspect of Colorado's climate is its natural variability. This variability ranges over time and space, and includes localized thunderstorms to larger-scale storm systems, to droughts or drier than average periods that last for many years to many decades.

Some examples of this longer time-scale variability in climate might include a series of abnormally mild or exceptionally severe winters, and even a mild winter followed by a severe winter. Such variations are sometimes associated with the year-to-year changes in global weather patterns, such as the naturally occurring phenomena known as El Niño and La Niña.

This poster demonstrates that natural climate variability influences surface-water resources in Colorado. Understanding the controls of this natural climate variability can benefit the management of Colorado's water resources, especially during drought, and for water resources near the limits of sustainability. Using the Cache La Poudre River as an example, the response of streamflow to natural climate cycles is quantified, and the probability of future climate-variability shifts and corresponding streamflow are predicted. The resulting models are valuable tools for water managers interested in estimating how surface-water resources will respond to future climate-variability shifts.

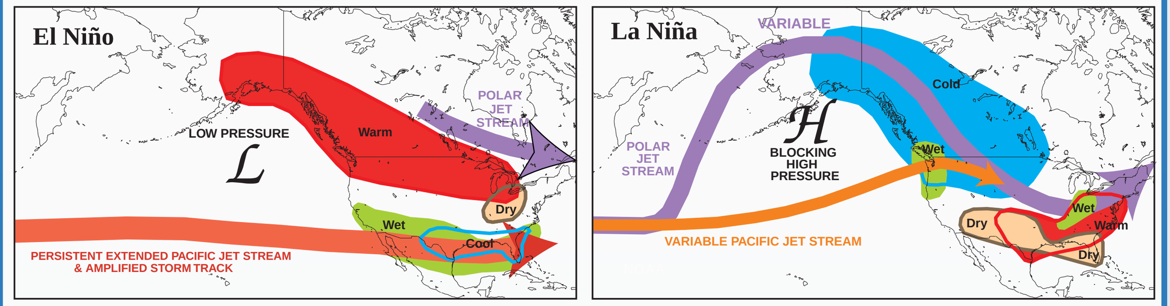
Example of How the El Nino/Southern Oscillation (ENSO) Affects Colorado's Climate Variability:

ENSO Index from 1950 to 2007:



El Nino typically brings wetter than average climate to the Western U.S. and Colorado, while La Nina typically brings drier than average climate.

Typical January-March Atmospheric Circulation during Moderate to Strong El Nino and La Nina



Currently (winter 2006-07), North America is experiencing a moderate to strong El Nino, which may partially explain the above average snowfall across some of Colorado this winter.

Global Atmospheric Circulations that Influence Colorado's Climate Variability

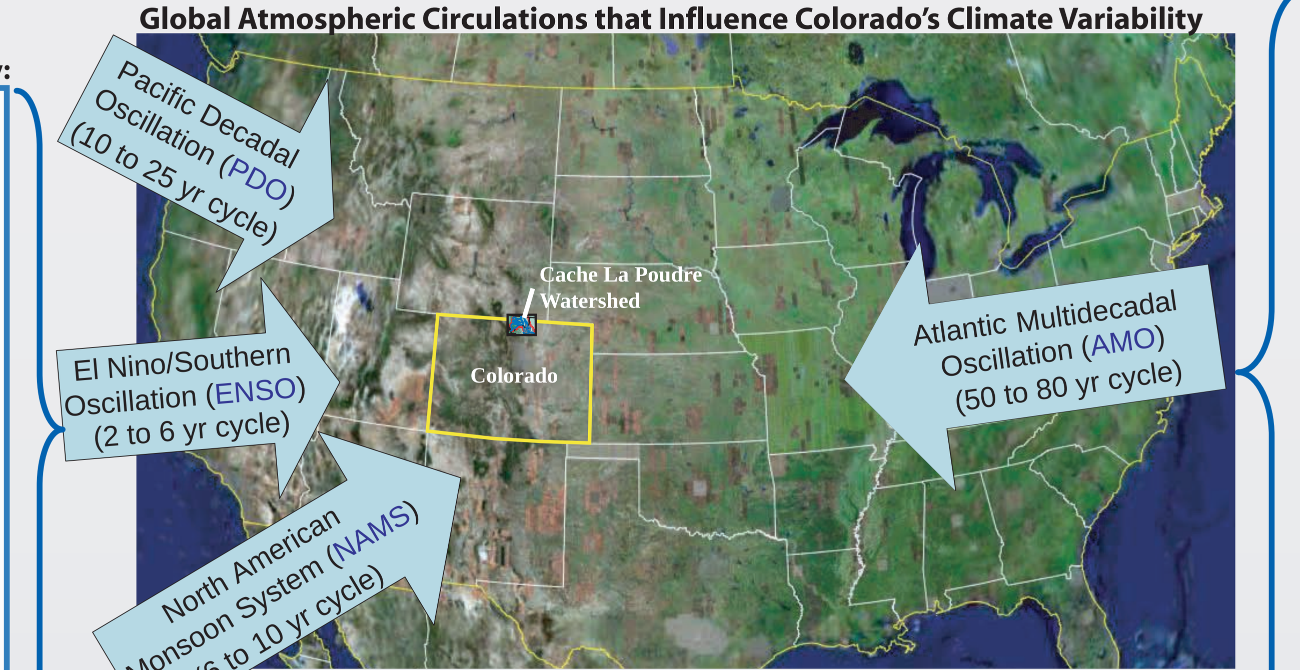
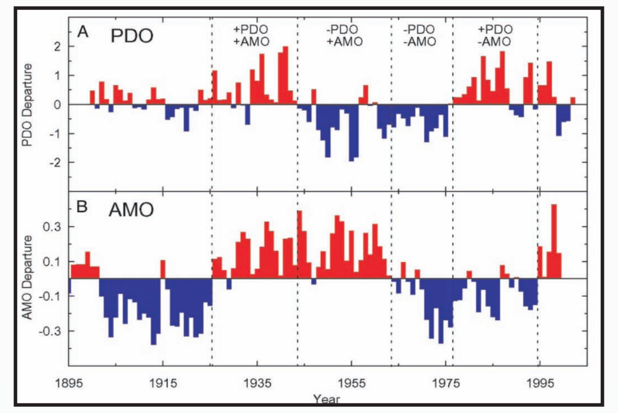


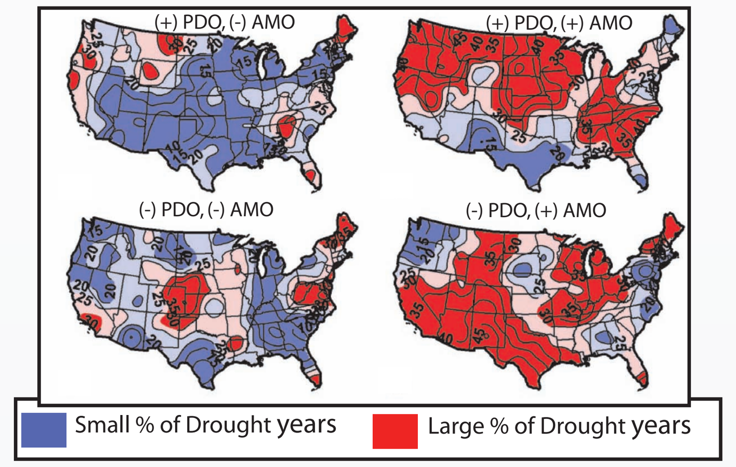
Figure 1.1 Colorado's climate is partially controlled by variability in global atmospheric circulation patterns, with cycles of multi-year (ENSO and NAMS) and multi-decade (PDO and AMO) in length. For example, the Atlantic Multidecadal Oscillation (AMO) (50 to 80 year cycle) is an index of sea-surface temperatures averaged over the North Atlantic that has recently been identified as having a strong influence on the jet-stream, summer rainfall, drought frequency, and may partially control winter precipitation over the conterminous U.S. (McCabe et al., 2004). McCabe et al. (2004) suggest that the current positive AMO and PDO variability may lead to continuing of above normal frequencies of U.S. drought.

Example of How the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO) Affect Climate Variability:

PDO and AMO Indices from 1895 to 2004:

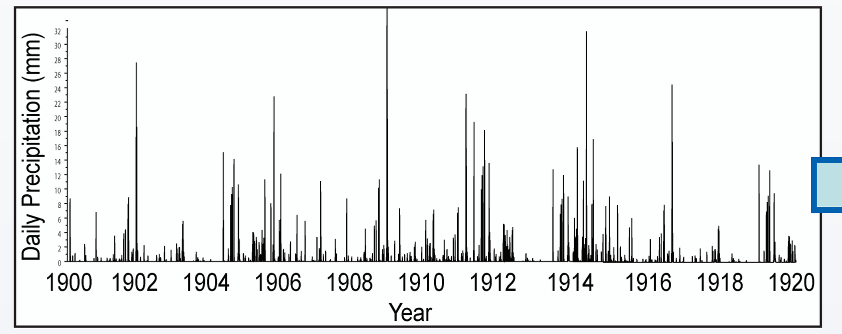


U.S. Drought Frequency by PDO and AMO Variability (from McCabe et al., 2004):



Synthetic Example of the Cumulative Effect these Cycles in Global Atmospheric Circulation Can Have on Colorado's Climate

Synthetic time series of daily precipitation from 1900 to 1920:



Using a type of frequency analysis, the "noise" from this precipitation time series is removed to reveal major components of variability. These components of variability have cycles of 1-year (annual), 6-years, and 10-years. These components of variability are often caused by the important global atmospheric circulation patterns.

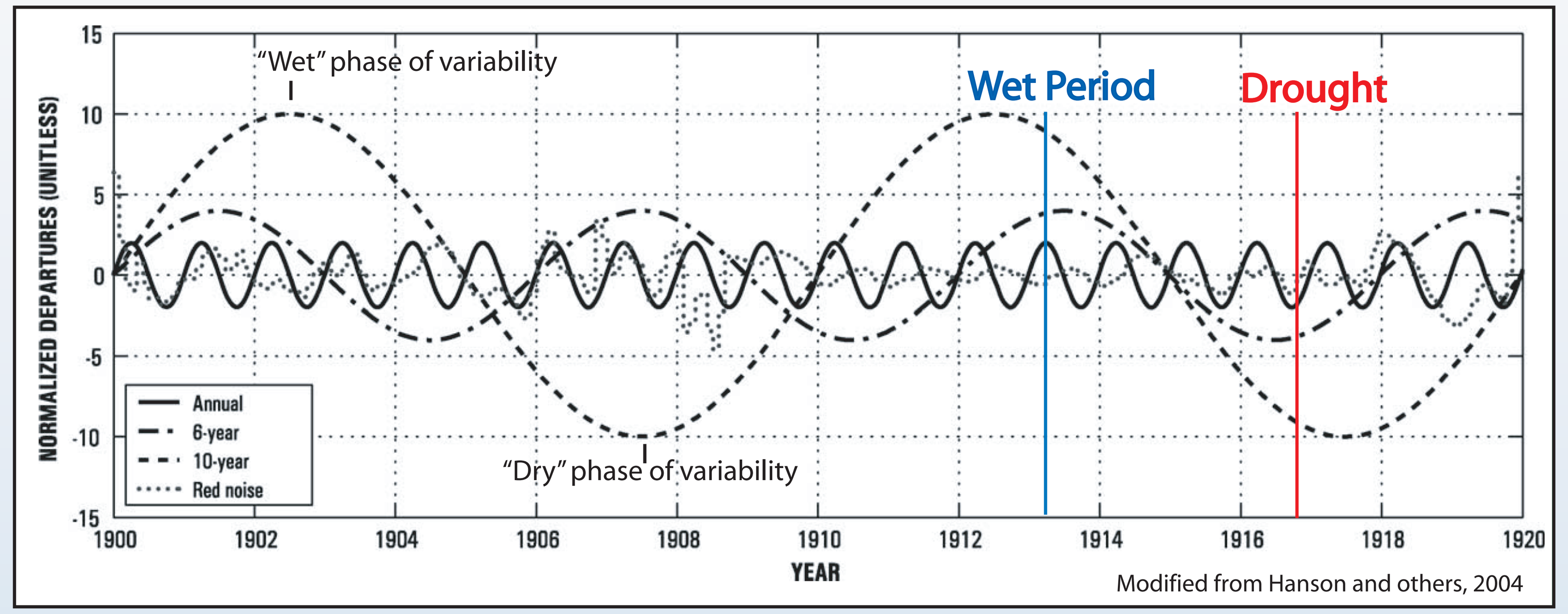


Figure 1.2 The cumulative effect of the components of variability (1-yr, 6-yr, and 10-yr) within the precipitation can result in periods of above average rainfall or periods of extended drought. For example, all components of variability are aligned in the "dry" phase beginning in 1917, resulting in drought conditions.

2.0 Case Study to Quantify the Effect of Global Atmospheric Circulation on a Colorado Watershed: Cache La Poudre Watershed

Cache La Poudre Watershed

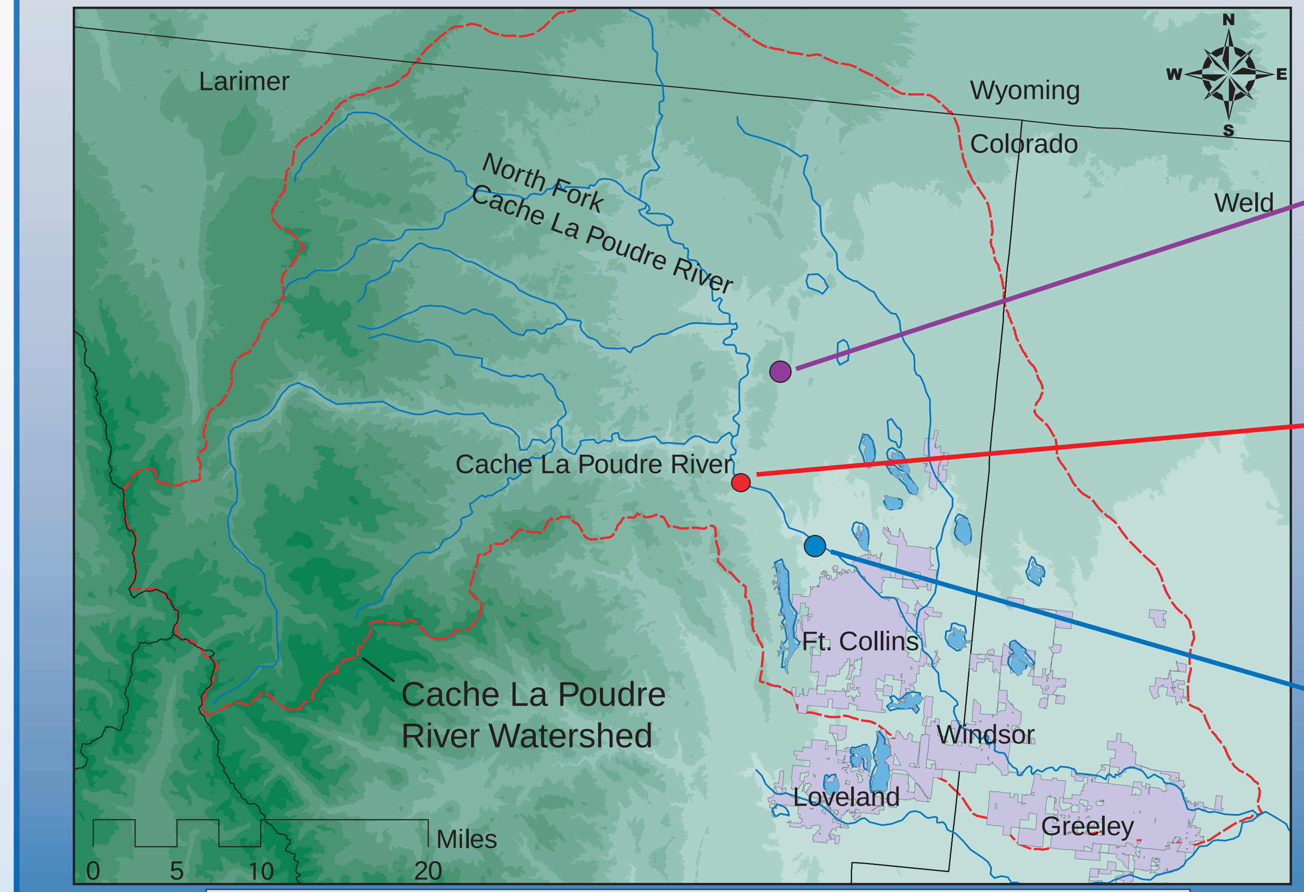


Figure 2.1 Cache La Poudre River study area. Site locations of tree-ring time-series (purple circle), streamflow time-series (red circle), and precipitation time-series (blue circle) are shown.

Data Used to Identify Influence of Global Atmospheric Circulation

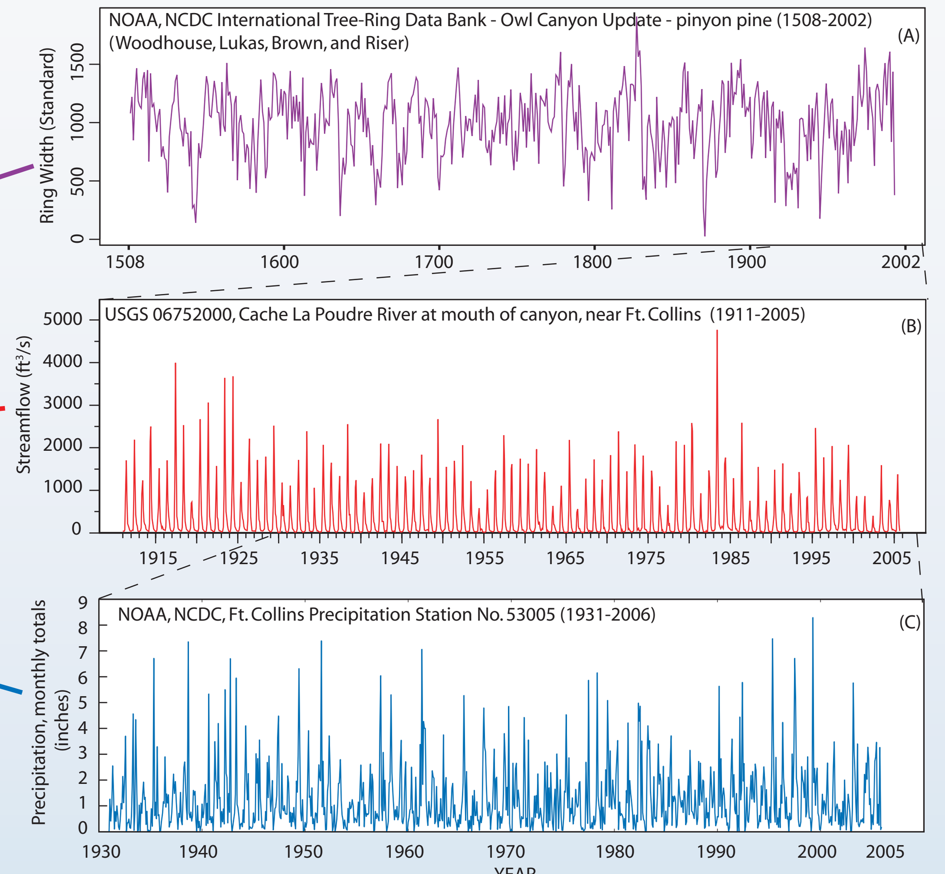


Figure 2.2 Raw hydrologic time-series: (A) tree-ring from Owl Creek (1508 to 2002); (B) Cache La Poudre River streamflow (1911 to 2005); and (C) monthly precipitation totals at Ft. Collins (1931 to 2006).

3.0 Streamflow, Tree-Ring Indices, and Precipitation of the Cache La Poudre are Strongly Correlated to AMO and PDO Cycles

3.1 Summary of Correlations Between Hydrologic Time Series and AMO or PDO Cycles:

(A) AMO Correlations	Correlation (r-squared): (1) AMO, (3) Tree-ring	% Variance of Total
Tree-Ring Index	(1) -0.95	92 %
Streamflow	(1) -0.63 (3) -0.98	60 % 5 %

(B) PDO Correlations	Correlation (r-squared): (1) PDO, (2) Precipitation, (3) Tree-ring	% Variance of Total
Tree-Ring Index	(1) 0.99	6 %
Streamflow	(1) 0.41 (2) 0.60 (3) 0.97	25 %
Precipitation	(1) 0.51 (3) 0.99	68 %

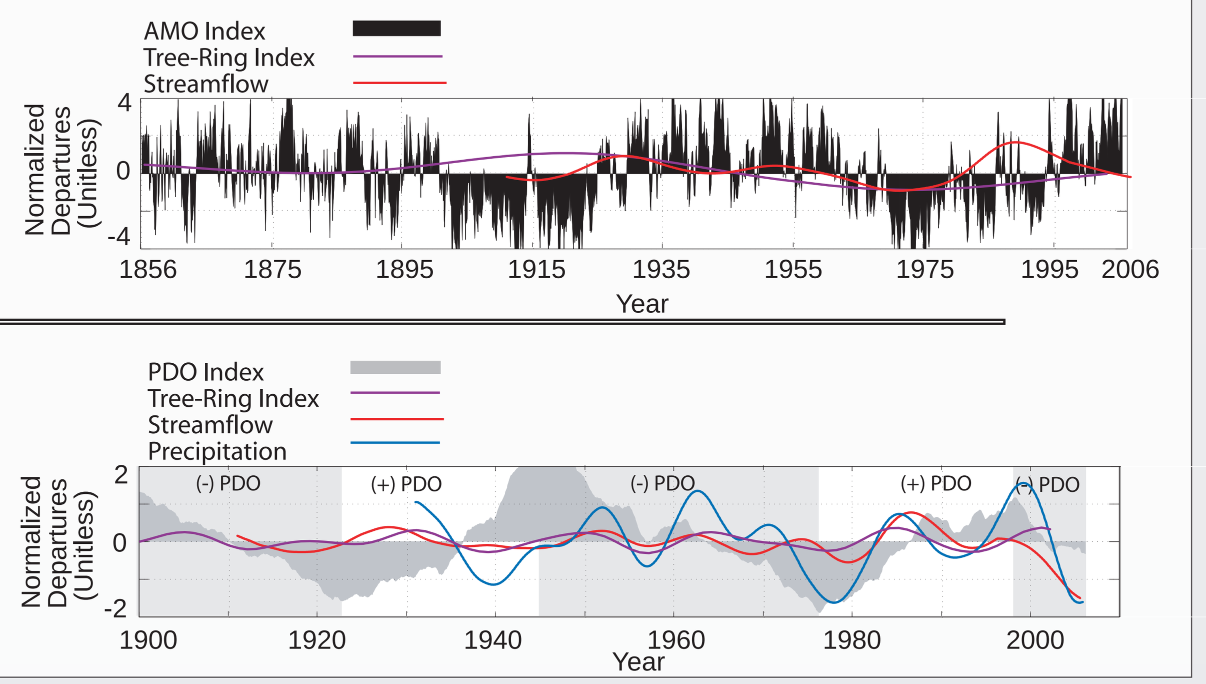
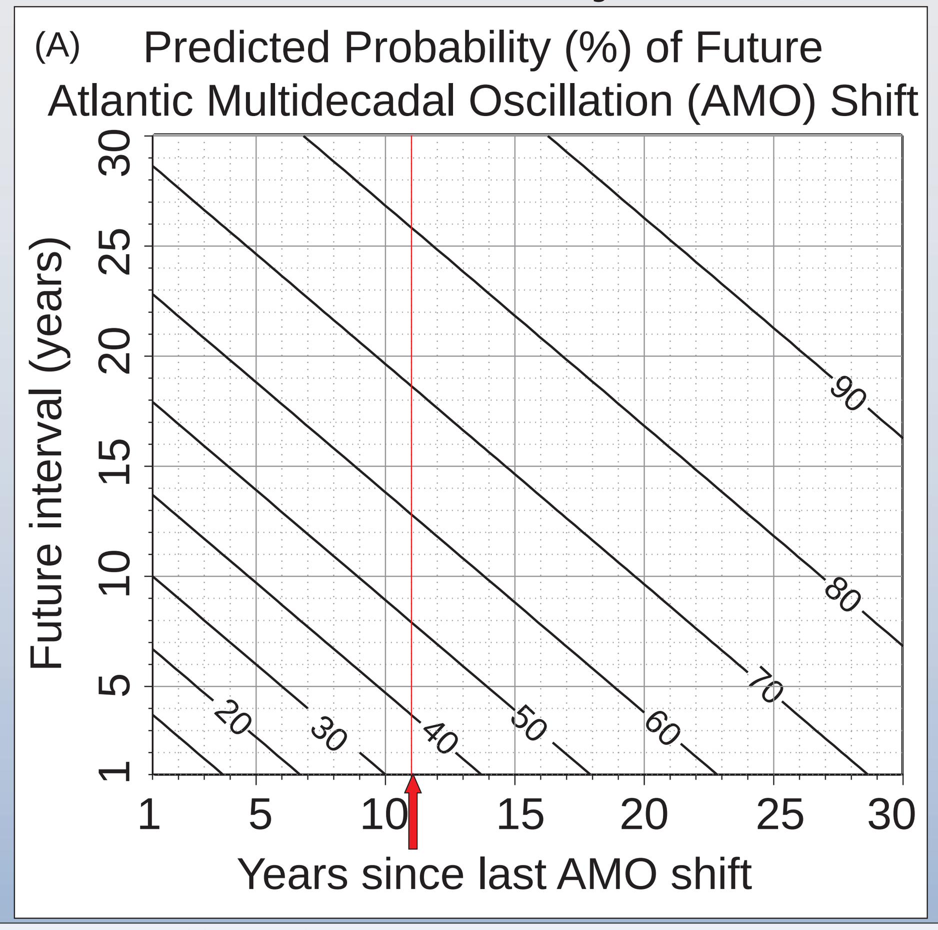


Figure 3.1 Strong correlations were observed between hydrologic time-series and (A) AMO and (B) PDO cycles. These correlations, expressed as r-squared values, indicate that variability in the tree-ring indices, precipitation, and streamflow are significantly controlled by AMO and PDO cycles. For example, relatively greater streamflow of the Cache La Poudre River is negatively correlated (r-squared = -0.63) to AMO and positively correlated (r-squared = 0.41) to PDO. The correlations are shown graphically for each hydrologic time series and respective AMO and PDO cycles. Additionally, the percent total variance within each hydrologic time series are dominated by AMO and PDO cycles. This summary indicates that predictions of AMO and PDO cycle shifts will likely provide reliable estimates of relative wet or dry periods of precipitation and streamflow in the Cache La Poudre watershed.

3.2 Predicting Future Shift in (A) AMO or (B) PDO Cycles:



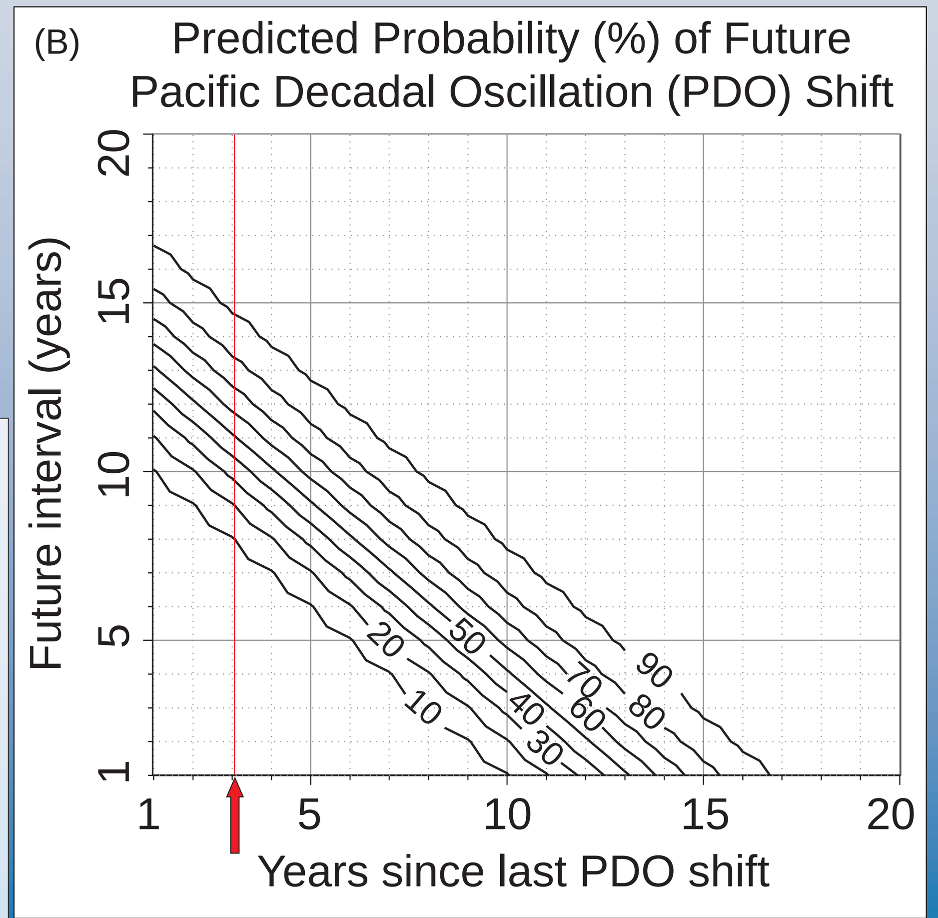


Figure 3.2 The probability of future shifts in (A) AMO and (B) PDO cycles have been calculated using the tree-ring time-series as a proxy of AMO and PDO variability.

How to use the predictions in (A) and (B):
The predicted probability of future shifts in (A) AMO or (B) PDO cycles is dependent upon the time since the last shift (or change) in the cycle (Enfield and Cid-Serrano, 2006).

For example, AMO shifted about 11 years ago (see A above) from the wet phase of variability to the dry phase of variabiltiy (see Figure 1.2). Using the red line at 11 years as a guide, the predicted probability of a shift within the next 5 years is about 45%, while a shift within the next 20 years has about a 75% probability of occurring. Similarly, the PDO (see B at right) shifted about 3 years ago, and has <10% probability of shifting within the next 5 years, while a shift within the next 20 years has >90% probability of occurring.

Why these predictions are useful:
Because precipitation and streamflow are strongly correlated to AMO and PDO cycles (see 3.1 above), the predictions demonstrated in Figure 3.2 can be used to forecast shifts in AMO and PDO, and thus, when to expect future periods of relative wet or dry conditions in surface-water resources.

4.0 Additional Science Needs

Findings from this investigation indicate that global atmospheric circulation cycles, especially the Atlantic Multidecadal Oscillation (AMO) and Pacific Decadal Oscilliation (PDO), are important controls on natural variability in precipitation and streamflow of the Cache La Poudre watershed.

This case study illustrates a number of additional science needs:

1. An improved understanding is needed of how other surface- and ground-water resources across Colorado and the Western U.S. respond to natural cycles in global atmospheric circulation patterns, such as ENSO, NAMS, PDO, and AMO.

2. Such an improved understanding of the control that natural climate variability has on the timing and magnitude of precipitation, runoff, and recharge can be implemented as decision-support tools toward best management of vulnerable resources (Gurdak and Hanson, 2005). For example, decisions regarding water storage or drought management could be made with more confidence by knowing whether the next 5, 10, or 15 years are likely to be relatively wet or dry compared to long-term precipitation averages.

3. Currently, general circulation models (GCMs) do not do well in simulating the long-term atmospheric circulation cycles, especially NAMS, PDO, or AMO. However, as shown in this investigation, existing hydrologic data, such as long-term streamflow, precipitation, and tree-ring indices contain information about how the hydrologic cycle responds to these natural global climate cycles. Most importantly, these long-term hydrologic data can be used to predict how future water resources will respond to likely global climate cycles.

4. In this investigation, the timing of future shifts in AMO and PDO cycles were predicted independently (Figure 3.2A, B). More accurate predictions could be developed using the joint probabilities of shifts in AMO and PDO (i.e., +AMO/+PDO; +AMO/-PDO; -AMO/+PDO; and -AMO/+PDO). This is because Colorado's climate is the cumulative response to ENSO, NAMS, PDO, and AMO (see Figure 1.2).

5. A better understanding is needed of how global change (i.e. global warming) will effect the global atmospheric circulation cycles. A warmer Earth, with warmer oceans, may possibly contribute to more intense and/or more frequent cycles in ENSO, NAMS, PDO, and AMO. However, it is likely that future water resources will be dependent upon changes in global climate, as well as, responses in natural climate cyles to global change.

5.0 References

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Hanson, R.T., M.W. Newhouse, and M.D. Dettinger. 2004. A methodology to assess relations between climatic variability and variations in hydrologic time series in the southwestern United States. J. Hydrology 287:252-269.

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