Re-examining Drought in Utah

Atmospheric scientists in the Plant, Soils & Climate department and the Utah Climate Center, (UCC) have spent the past eighteen months taking a renewed and more thorough look at the nature of drought and precipitation in Utah. Their efforts have uncovered patterns that were previously unknown, clarified patterns long suspected, and revealed a sobering truth about the nature of drought in Utah.

So exactly what have these scientists discovered?

For one thing, droughts in Utah aren't random. Instead, there is a natural periodicity to them — distinct, multi-year wet and dry cycles of various durations. This is important, because cyclic behavior suggests some potential for prediction. It's also important because historically, climatic precipitation data are viewed in 30-year averages. It's a practice that makes sense in places where yearly rain and snow totals tend to cluster around an average value . But here in the Great Basin, climate is more complex. The presence of multi-year wet and dry cycles means yearly precipitation is rarely near the 30-year average. So while one can certainly calculate such averages, they have little value from the standpoint of 'what to expect this year.'

Second, changes in Utah's precipitation patterns appear to be linked to sea surface temperatures (SST) in the Pacific Ocean. This had previously been suspected, and indeed a somewhat modest connection to El Niño, though weak and ill-defined, has been previously observed. But now, focusing on a somewhat different region of the Pacific, a much stronger correlation has been found—along with an actual physical mechanism for the connection. Further, this mechanism appears to announce it's impact on Utah with a lead time of several years, possibly presenting us with a valuable tool for prediction.

Finally, and perhaps most dramatically, precipitation estimates extending back nearly a thousand years reveal a history of Utah droughts much deeper and much longer than those of the recent past. In fact, in the context of the past thousand years, 20th-century Utah — and the latter half in particular — has been exceptionally wet. This is important because it suggests that in future years we cannot count on the relatively high levels of precipitation that have coincided with the state's explosive growth.

The path to these discoveries has been classic science: a trail of subtle clues, uncovered and connected, one by one.

Wet and Dry Cycles

Even a simple look at Utah's precipitation records reveals two things. First, the year-to-year variability (deviation from the 30-year average) is high. In other words, 30-year averages don't give us a very good idea of what to 'expect' in a given year. Second, this variability is not random, but has structure—a repeating pattern of distinct, multi-year wet and dry cycles of varying intensity and duration. The cyclic behavior suggests some sort of mechanism in the climate system — like an on-off switch—toggling us back and forth, wet to dry, like a sprinkler system on a timer: sprinkler on (wet cycle); sprinkler off (dry cycle). As a result, simple averaging conceals important information about how the climate works and what to expect (it hides the very presence of the sprinklers). For example, Figure 1 shows the most recent 30-year average for Logan's precipitation (grey), compared to typical wet and dry cycles contained in this same period (green and red,

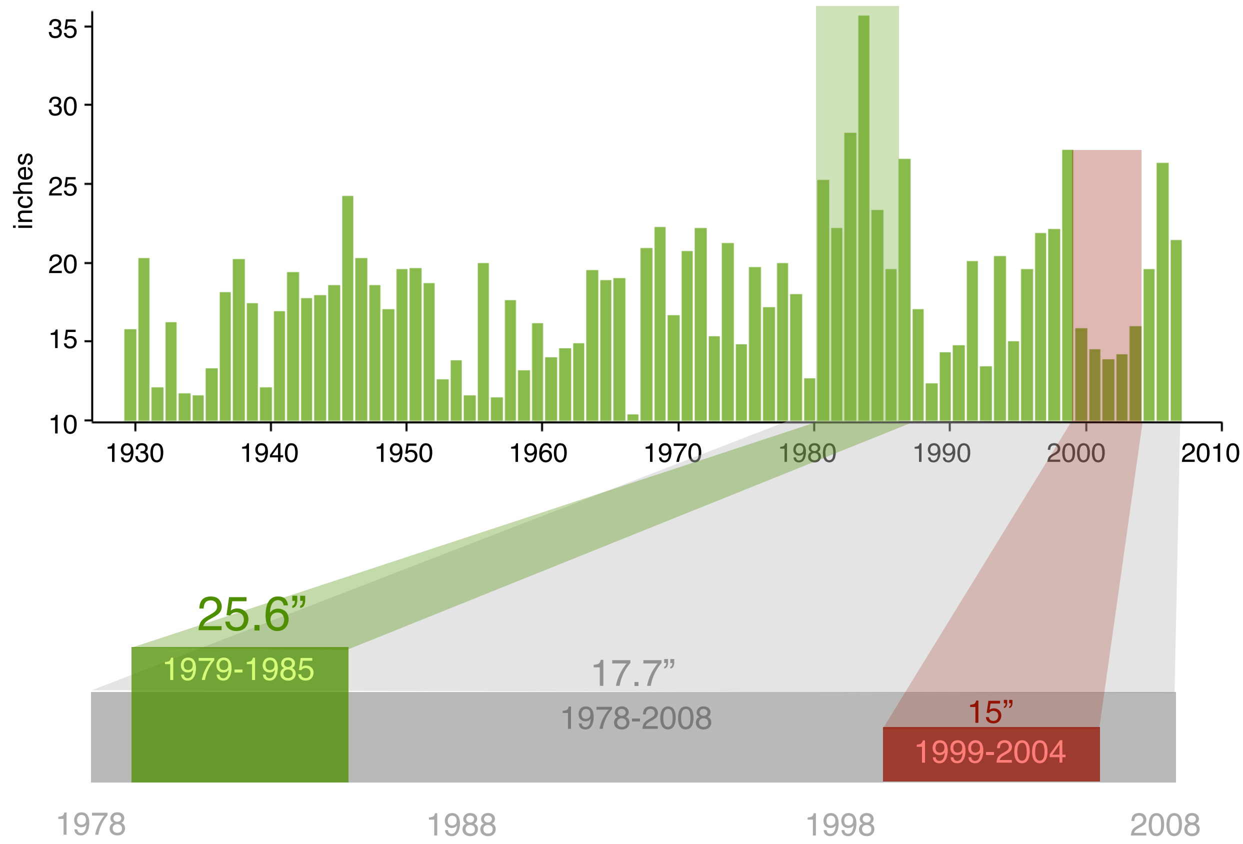


Figure 1. Utah precipitation follows cycles. Even without mathematical analysis, cyclic behavior is clear in the annual precipitation records for the USU campus in Logan (top graph). Further, we see that 30-year averages are misleading in gauging 'what to expect' in any given year (bottom graph).

respectively). Here we see that 'what to expect' is very different, depending on what period you're in. Specifically, if you're in the seven-year wet cycle of 1979-1985, you should expect 50% more precipitation than the 30-year average; and if you're in the five-year dry cycle of 1999-2004, you should expect about 20% less. These are significant differences, with real implications for water supply and planning.

That precipitation is cyclic and not random is important, but not surprising (and likely long suspected by most of Utah's farmers). If UCC's discovery were simply that northern Utah goes through wet and dry cycles, it would hardly raise eyebrows. But there's more. Once you've discovered a pattern, you'd like to understand it's underlying cause. That is, you'd like to uncover the sprinkler system and, more importantly, the timer. This is just what UCC scientists believe they've done.

Untangling complex patterns ...

Cycles in nature are rarely simple, arising not from single causes, but combinations of underlying elements. Like rich, complex harmonies that emerge from an orchestra's many instruments, myriad natural processes overlay one another—some dominant, others subtle—to compose the final result.

Beginning with monthly precipitation records from a single location — Utah State University's Logan campus — and applying some powerful mathematical techniques, the team uncovered not only patterns in the record, but some of the individual building blocks underlying those patterns. Embedded in nature's cacophony, their analysis unveiled a symphony of water and drought, along with the major instruments in the orchestra, their musical scores, and how loudly they play. In all they discovered a half-dozen or so identifiable patterns, each overlaying the others, but one in particular—a 12-year cycle — is the most emphatic. To better map the symphony's reach, they applied the same analysis to a collection of stations throughout the intermountain west. They found the 12-year pattern is broadly valid across northern Utah, but fades in the south.

While tantalizing, the data underlying this discovery stretch back only sixty years or so—a short time in the context of climate. The next step was to delve further back in the historical record, to see how long-lived these patterns are and further support their findings with additional, independent lines of evidence.

They found find two such lines.

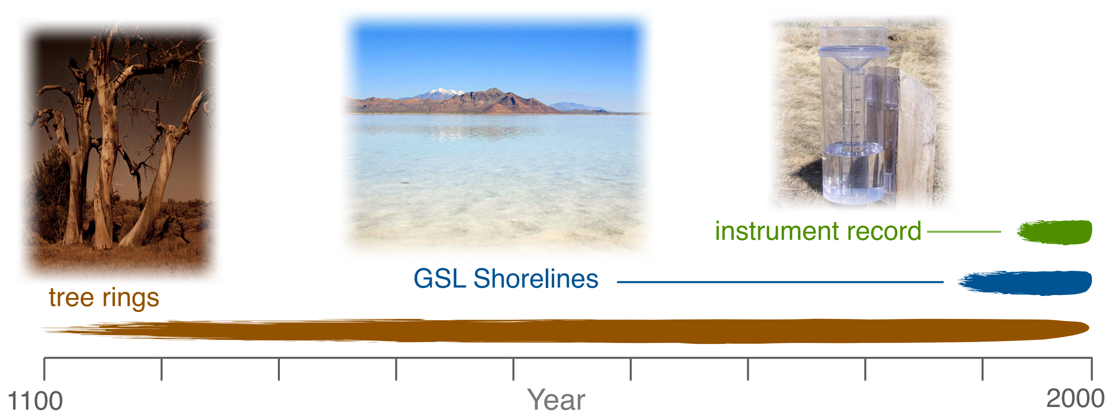
More clues ...

With the rise and fall of their shorelines driven largely by precipitation, closed-basin lakes — that is, lakes with no outlet for the water — can be excellent witnesses to a region's historical precipitation patterns. In other words, lake levels can serve as proxy precipitation measurements for the region that feeds the lake. In the case of the Great Salt Lake, this region is large, comprising much of northern Utah, southwestern Wyoming and southeastern Idaho, with reliable records stretching back to 1900.

A nice feature of using lake levels to explore precipitation patterns is a somewhat delayed response time. That is, depending on the size and nature of the lake and the drainage that feeds it, it can take several year's-worth of increased or decreased rainfall to induce a response (and the response itself can take several more years to appear). The result is a measurement that essentially ignores short-term fluctuations — what climatologists often term 'noise'—instead recording only longer-term patterns.

In addition to lakes, tree rings are another valuable resource for climate scientists. Dendrochronology—the science of extracting past climate information from tree rings—has evolved dramatically in recent years. Taking

Figure 2. Multiple lines of evidence. Short-term (~12-year cycles) are evident in the instrumental records dating back 60 years; Great Salt Lake shoreline data dating back a century; and tree ring data dating back 900 years. Longer-term cycles are also evident in the shoreline and tree ring data.



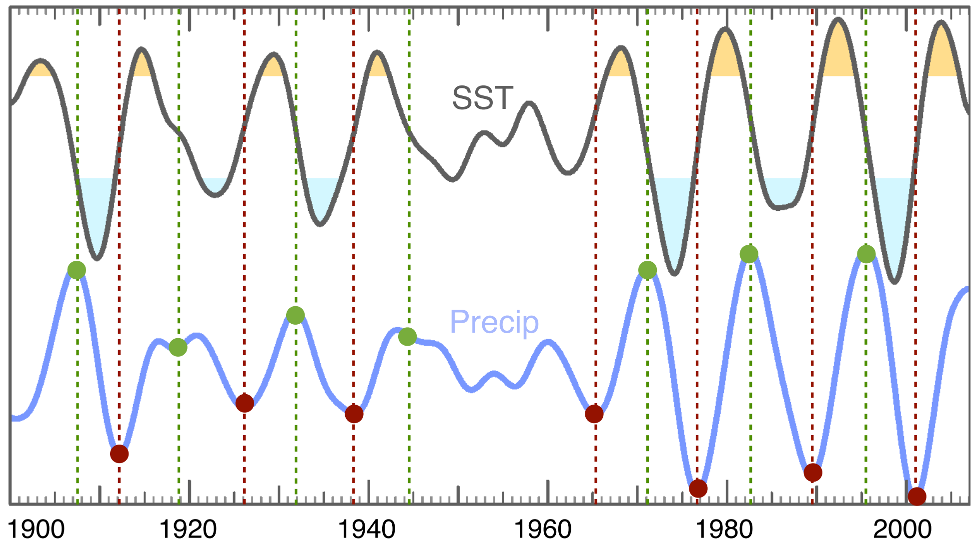


Figure 3. Correlation between sea surface temperature (SST) of the Pacific QDO region and (smoothed) precipitation in northern Utah. Both graphs exhibit an approximately 12-year cycle, but offset from each other by about 3 years. Peak precipitation (green dots) occurs 3-4 years after peak SST (orange shading); minimum precipitation (red dots) occurs 3-4 years after the minimum SST (blue shading).

advantage of these advances and the detailed work of expert researchers in the field, the UCC was able to extend their drought analysis even further into the past—to more than 900 years.

Comparing all three lines of evidence—the tree ring data, lake level data and direct precipitation records—has been immensely productive. The 12-year pattern of the past sixty years is evident in all three, and indeed continues throughout the full extent of the lake level and tree ring records.

That is, these three lines independently confirm the 12-year signal, and suggest that whatever drives this pattern has been a discernible climate feature for at least the last 900 years.

But there's more.

With the addition of the lake level and tree ring data the symphony of cycles is richer. Not only is the 12-year cycle confirmed and extended, but two more strong patterns emerge — a 40-year cycle and a 150-200 year cycle. Because of their longer lengths these patterns are not visible in the 60-year precipitation records, but are clearly present in the longer duration data sets.

Uncovering connections…

So what exactly is driving these cycles? Which instruments in the orchestra are making themselves heard at 12-, 40- and 150-year intervals? One thought is to look for other climate patterns that repeat with a similar timescale. For example, if you notice your IBM stock makes a big move every three months, you might look for a reason, and you might expect that the reason is also something that happens every three months (like a quarterly financial report, perhaps).

As it happens, there is a particular climate pattern in the Pacific Ocean — called the Pacific Quasi-Decadal Oscillation (QDO) — with just the right timescale. Details of the QDO are complex. But broadly, it comprises cold phases, warm phases, and transitions in between—each lasting about three years, forming a 12-year cycle. UCC scientists have found that Northern Utah's wet periods occur during the QDO transition from warm to

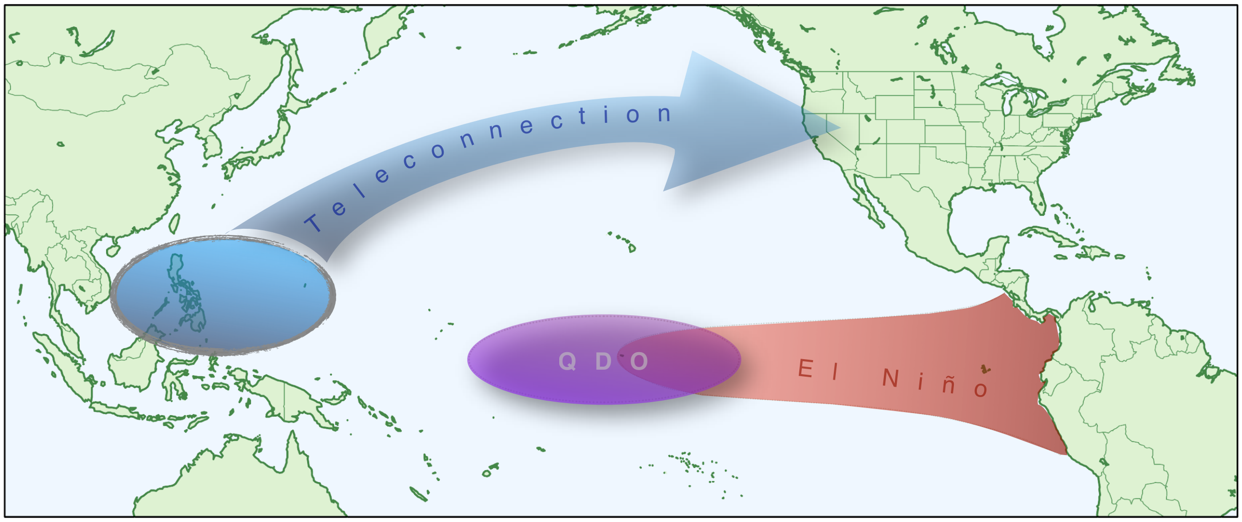


Figure 4. (Red) El Niño — the periodic emergence of warm surface waters in the eastern equatorial pacific—has been previously linked to precipitation across the Pacific northwest and northern Utah. (Purple) UCC's current work, however, demonstrates that the link is much more strongly tied to the roughly 12-year temperature cycle of the western edge of the El Niño region — the "Quasi-Decadal Oscillation." (Blue) Further, they've identified a physical mechanism — an atmospheric "teleconnection" — that forms in association with the periodic sea surface temperature fluctuations in the QDO region.

cool, and our dry periods occur during the transition from cool to warm. More specifically, we're at our wettest when the QDO half-way through it's six-year transition from warmest to coolest, and at our driest when the QDO is half-way through it's transition from coolest to warmest (Fig. 3). We're finding these cycles are part of a regional pattern, driven by forces thousands of miles away and, though not perfectly regular, may be predictable years in advance.

While the shorter, 12-year cycle is connected to the QDO, the long-period patterns are not so well understood. Nevertheless, when they peak, they dominate all other cycles. It's a bit like the brass in an orchestra: it can lay back or blow hard. When it blows hard, it's hard to hear anyone else.

What's the use?

Identifying correlations between Utah's precipitation and changes in the Pacific Ocean is satisfying scientifically, but it also has important practical application. Even if the pattern isn't perfectly regular, exhibiting some variability in how often it repeats, watching the driving mechanism helps more accurately identify the transition from one cycle to another. Such knowledge would help water managers put any given year's precipitation in perspective and better manage supplies—based not only on what has been received in the current year, but on expected trends in the coming years. For example, if precipitation is on the high side for the current year, but the QDO signal suggests we're heading into a dry period, the water manager knows to play it conservative, despite the surplus.

Understanding connections …

Finally, and very exciting for the scientists trying to better understand this problem, this discovery is supported by identification of a specific physical mechanism that makes it possible — one connecting sea surface temperatures in the tropical pacific, with precipitation in northern Utah (Fig. 4). While the details of this connection are complex, mathematical analyses and models suggest that

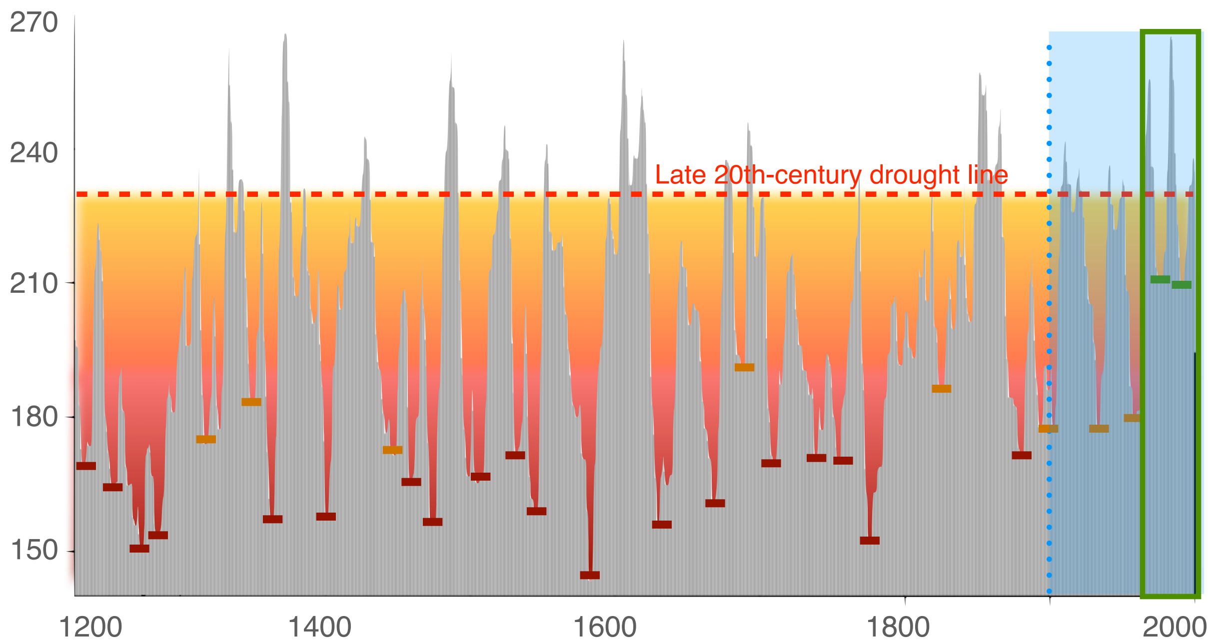


Figure 5. Depth and duration of Utah droughts. Eight hundred years of precipitation data for the Uinta Basin, as determined by tree-ring analysis, reveal an anomalously wet 20th century (blue box) notably distinct from a long-term history of deep and persistent dry conditions. Using the late-20th century as a reference (green box) we can identify those periods of relative drought (colored region below the red line) and surplus (grey regions above the red line).

key changes in ocean temperatures result in modifications in the the jet stream. A set of waves or 'wavetrain' appears and transfers energy from southeast Asia all the way to the northwestern US, resulting in wet winters for northern Utah. The opposite change in ocean temperatures creates changes in the jet stream that lead to high pressure and drought in our region. It's an exciting discovery, one UCC scientists continue to explore.

A hard look at a hard past …

Finally, in addition to the cyclic behavior, the tree ring data also make clear a sobering truth: strong precedent for much deeper and longer droughts than those of our recent past. Put another way, the data indicate that the period of Utah's most dramatic growth — the late-20th Century — is also a period that experienced more precipitation than any of the past eight centuries.

If we examine the 1971-2001 precipitation record for the Uinta's (the most recent 30-year period covered by the tree ring data), we find an average value of 232 millimeters per year at the location of the trees sampled. If we simply call any year with more than this amount a wet year, and any year with less a dry year, and do this for all of the years in the record, we can begin to compare precipitation patterns of the distant past with more recent patterns. It helps us get a sense of the past in terms we're familiar with. Such a comparison is presented in Figure 5, and the results are startling. In particular, we find that — using our late-20th century concept of wet and dry — most of the last millennium has been dramatically drier. Not only are much deeper droughts evident, but their durations are also much longer. For example, while dry periods of the late-20th century persisted less than a decade, we find droughts swallowing most of the 13th and 17th centuries. What this means for the coming decades is uncertain. The causes of these much larger droughts remain a mystery; but their presence in the past record suggests much larger droughts than we're familiar with are inevitable; the only question is when. It's clear that the climate scientists at Utah State University still have work to do.