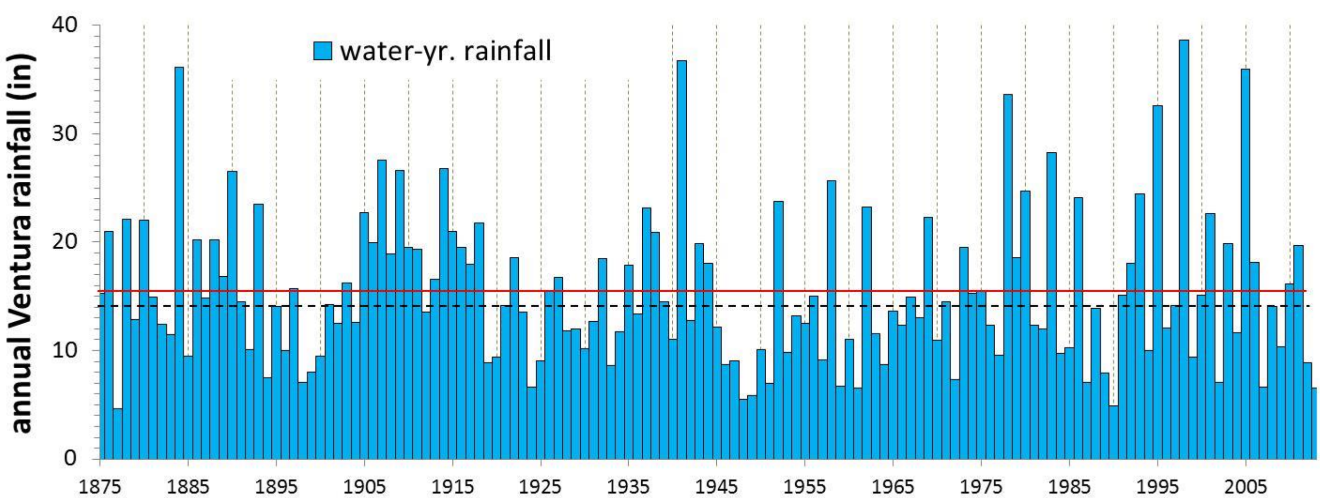
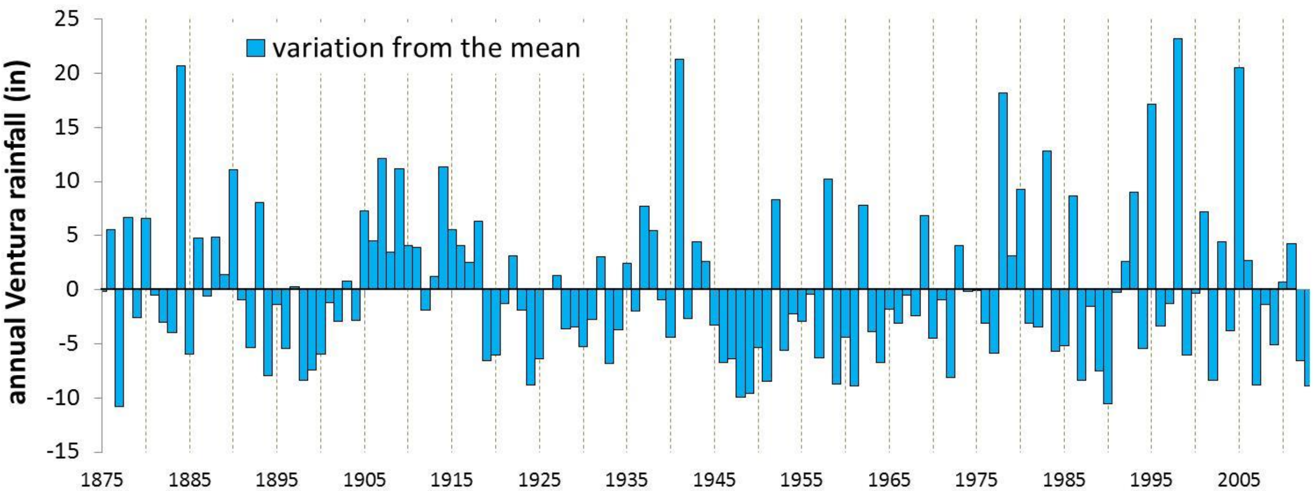
This is a story of rainfall, Ventura rainfall. But Ventura is just the example; it could also be Santa Barbara or LA rainfall or rainfall almost anywhere else in the western US; the numbers would change, but the pattern would remain the same. Local weather varies from place to place, but behind it all are major systems that exert their influence over large sections of the North American continent.

The first graph shows annual rainfall from 1875 – when Ulysses S. Grant was President – to the present (the data comes from Ventura County's various downtown – 066 – rain-gauge locations). Annual in this case is not your usual calendar year, but a water-year, a year based on hydrology that puts our annual rainy season into one year instead of two; the water-year begins on the first of October and ends on the last of the following September, i.e. water-year 2013 began on October 1, 2012 and will end on September 30, 2013.



Rainfall varies a lot: 37.8 inches during the wettest winter; 4.6 during the driest; on average 15.4 inches (represented by the red line on the chart). The dashed-line is the median: half the years of record had less than the median, the other half more. The median is 14.1 inches. That the median is less than the mean (i.e. average) indicates an uneven distribution: years with average or above average rainfall occur only 45% of the time. The average, or mean, is simply a mathematical construct; the "average" annual rainfall occurs almost never.

[*As mentioned, the actual numbers change were we to move within or outside the Ventura watershed. Moving north, average rainfall generally increases (it's 18.1 inches in Santa Barbara), moving south it generally decreases (14.9 inches in LA), and it increases as we move upslope to higher elevations in a watershed (21.1 inches in Ojai). But the pattern, the sequence of next year's rainfall being proportionally higher or lower remains the same*.]

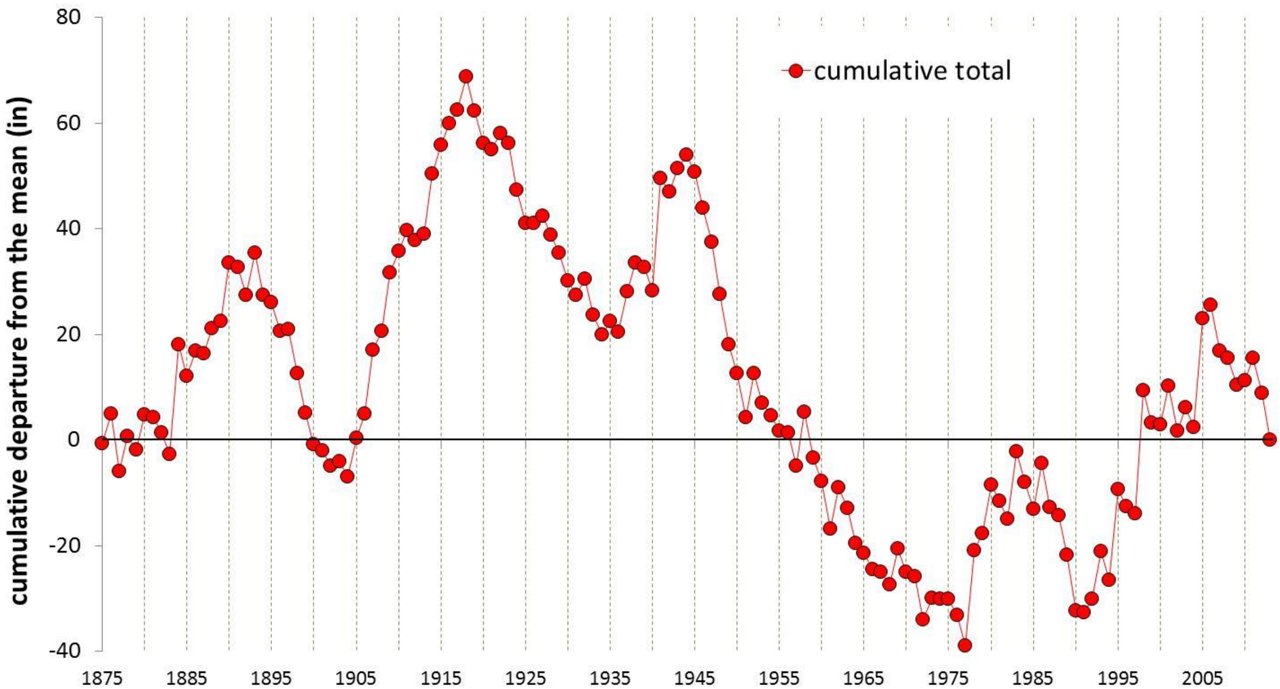


On the second chart I've simply taken the same annual rainfall data for downtown Ventura and plotted it to show how much each year's rainfall varied from the mean, e.g. if the rainfall was 10 inches I subtracted 15.4 (the mean) from 10 and plotted the result, -5.4; in other words, that year's rainfall was 5.4 inches below the mean.

This type of graph makes it a little clearer which years had above average rainfall (bars above the line), and which were below average (bars descending below the line). And we can begin to see that annual rainfall is not completely random, occurring, much like the flipping of heads or tails with a coin, without rhyme or reason: there are periods (like 1905 to 1918) where most years were above average, and periods (like 1919 to 1940) with almost no above average years.

And discerning a possible pattern is what we're about here. Is, or is not, annual rainfall merely a crapshoot? Are there some over-arching cycles visible in past data that might allow us to somewhat predict the future? As Yogi Berra said, "it's tough to make predictions, especially about the future." Especially if you'd like those predictions to bear some semblance to reality. Of course, if it's all random we could simply flip a coin: heads, we're in for a wet winter; tails, it'll be dry; two tails in a row, it'll be really dry . . .

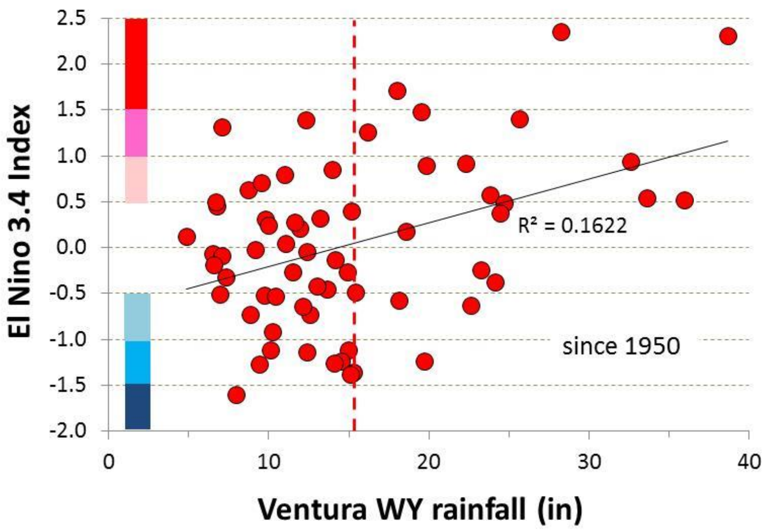
So, in the third chart I've plotted something called the "cumulative departure from the mean." It's a mouthful, but don't despair. I've simply taken each annual departure from the mean (from chart #2) and kept a running total of the accumulating surplus or deficit. For example: I simply plotted the 1875 deficit of -0.43 inches, but for 1876 I added that year's deficit (-0.19) to that of 1875 (-0.43 and -0.19 giving me -0.62) and plotted the total; in 1877 the rainfall was 5.57 inches above the mean, adding that to -0.62 gives 5.95 – instead of a growing deficit the there is now a small surplus and the trend has reversed. And the process continues: adding each year's departure from the mean to the cumulative total. The chart ends up looking like this:



And guess what? Annual rainfall looks far from random: there are patterns in the data. Long stretches of above average rainfall are followed by below average eras of decline. Sure, there are below average years during above average periods, and visa versa, but the cyclical trends are obvious. And leads to an obvious question as to the cause of these wet and dry cycles.

For southern Californians what first comes to mind is "El Niño." El Niño signifies the development of a tongue of anomalously warm water off of the coast of South America that reverberates in weather changes around the globe. For us it means warmer coastal water temperatures and the chance of greater rainfall – sometimes dramatically greater amounts of rain. The opposite development, the other half of the cycle, is termed "La Niña," a cold water tongue that brings us colder coastal ocean temperatures and a greater chance of drought. I'm deliberately using the word *chance*. El Niño doesn't always bring rain; neither does La Niña always bring drought. To show this my next graph plots annual (water-year) Ventura rainfall against an index measuring the strength of El Niño or La Niña conditions.

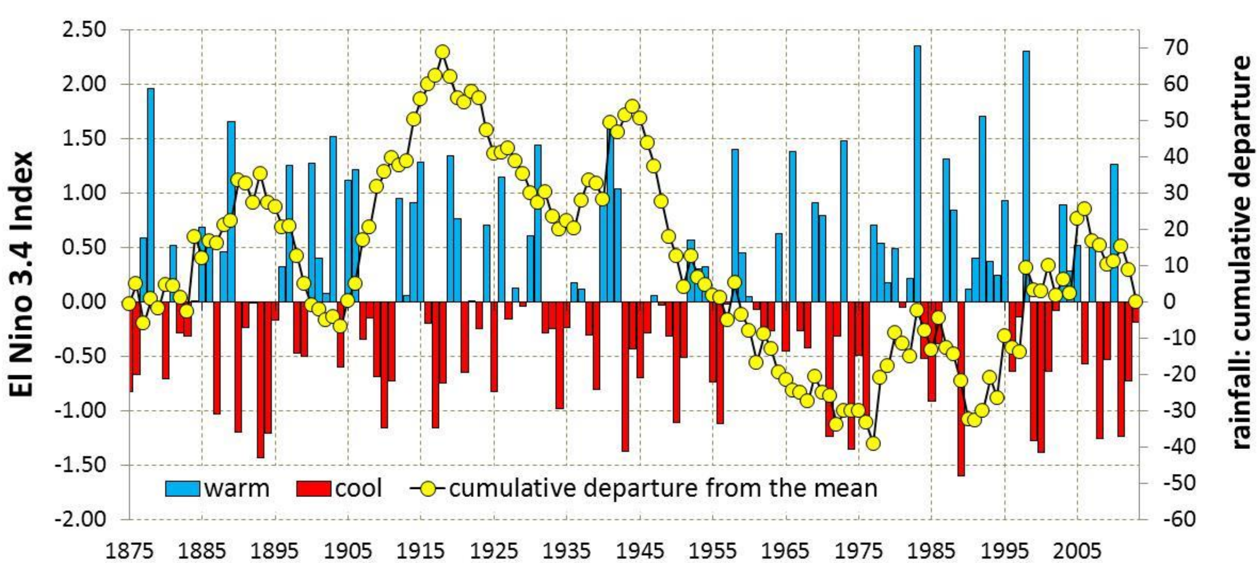
[*Different indices are available. I'll be using either a measure of ocean temperatures off of South America (El Niño 3.4) or the air pressure difference between Darwin, Australia and Tahiti (Southern Oscillation Index, SOI) that causes the temperature change.*]



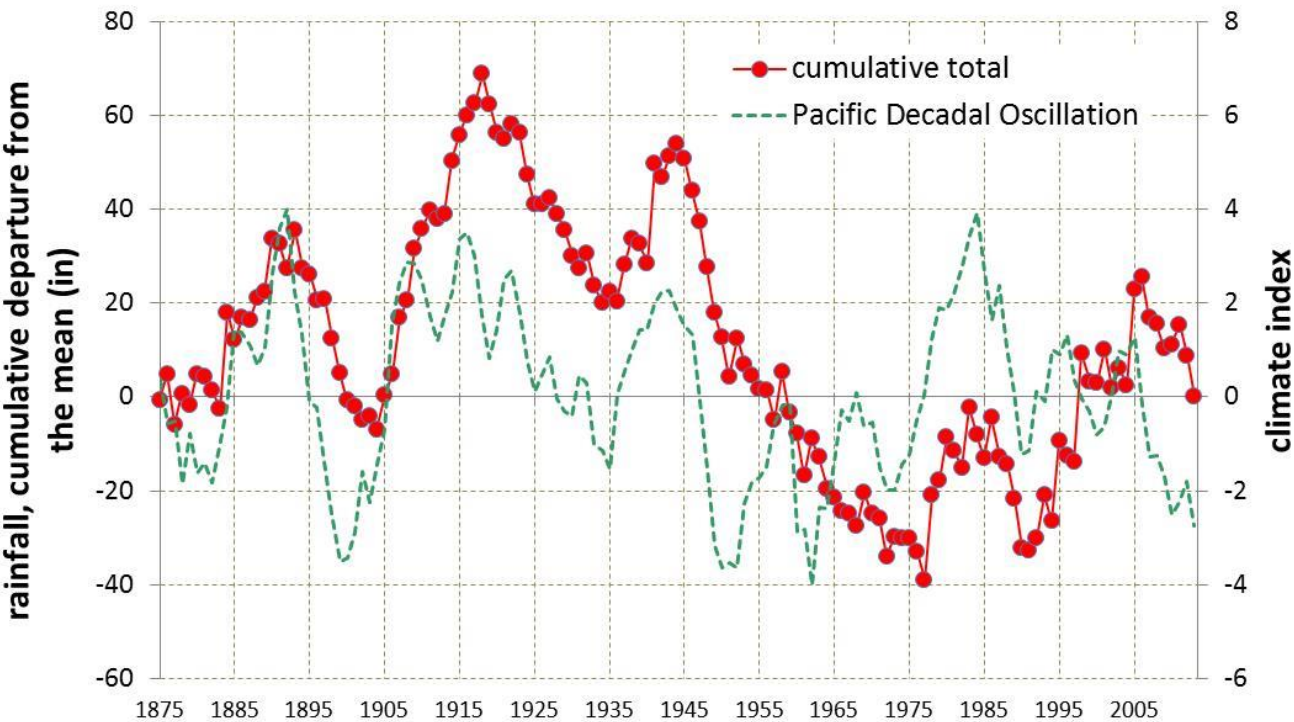
The color bars on the graph indicate the intensity of either the El Niño or La Niña: an index greater than 1.5 signifies *strong*, *moderate* lies between I and 1.5, and *weak* between 0.5 and 1. The dashed line is the average rainfall since 1950. Note that some La Niña years produce above average rainfall, and, conversely, we can have below average rainfall during an El Niño.

The overall correlation (more accurately, R^2) is 0.16; meaning that the El Niño cycle can explain 16% of the variation in rainfall in Ventura (although the data exhibit a wide spread, most big rainfall years are clustered in the upper right, or El Niño, quadrant of the graph, while most of the drier years can be found on the lower left).

The El Niño 3.4 index is plotted below for every year of Ventura rainfall data. Unfortunately, the swings from warm (El Niño) to cool (La Niña) and back to warm are rather short, lasting anywhere from 3 to 7 years and cannot explain the long, sustained swings we see in cumulative rainfall. Still, there is some correspondence: large up-ticks in rainfall are often associated with strong El Niño events and a disproportionate number of the stronger El Niños seem to occur during periods of cumulative increase.



But El Niño is not the only possibility: our weather is also influenced by another, longer range, climate cycle called the Pacific Decadal Osculation or PDO. Like the El Niño cycle, the PDO also involves the alternation of cooler and warmer waters but in the northeastern Pacific, i.e. along the Pacific coast from just below the Baja Peninsula to above Alaska. When this water turns warm (and it's just a matter of a degree or so above the long-term average) it drives the jet stream in a more southerly direction bringing us more rain. When it turns cool it has the opposite effect. A warm or positive PDO gives us El Niño-like conditions; a cold or negative PDO can resemble La Niña. The complete cycle – warm to cold and back again – takes anywhere from 17 to 28 years; 23 years being a ball-park average.



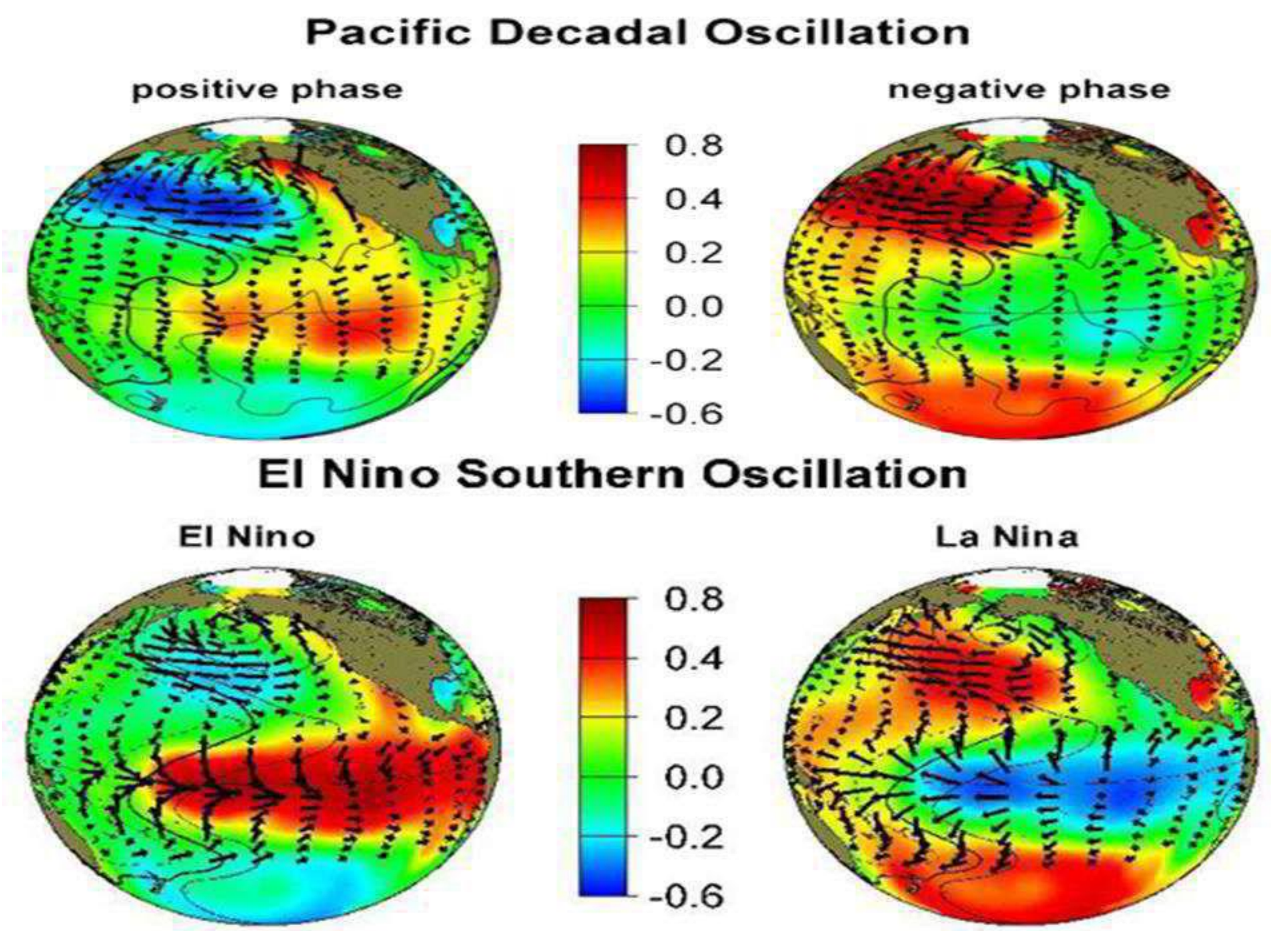
Here PDO is plotted on the same graph as cumulative Ventura rainfall. There is a resemblance, perhaps even a striking resemblance; the PDO would appear to explain a reasonable proportion of the overall rainfall pattern. However, it can not provide a complete explanation: the pattern is there, but the amplitudes seem wrong. Sometimes there is more rainfall than the index might indicate, sometimes less, in other words, there is no one-to-one correspondence between the index and rainfall. It's close, but no cigar.

[*Some explanation of the PDO index is necessary. The index is based on a statistical measure of the changes in northeastern Pacific sea-surface temperature (SST). However good measurements of SST over large expanses of ocean have only been available with the advent of reasonably advanced and dependable satellites, i.e.*

only recently. Earlier measurements were both fewer, unevenly dispersed, and less reliable.

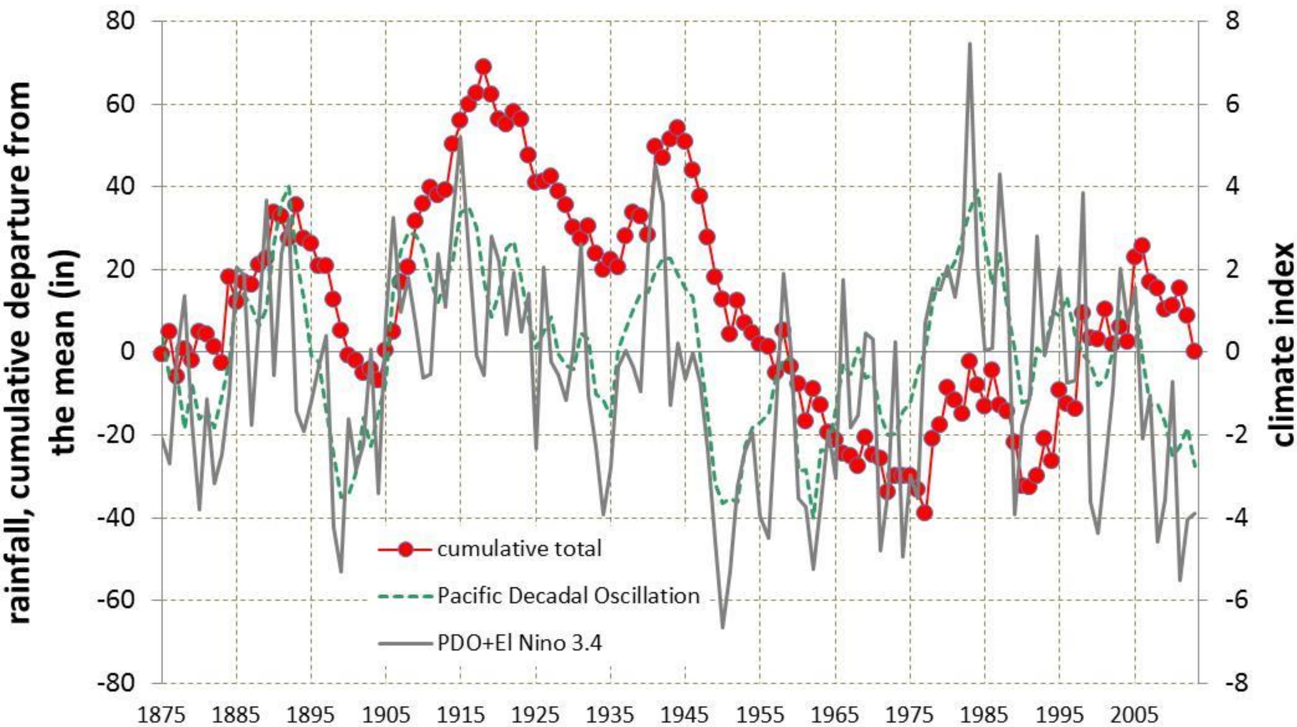
Extending the SST record back in time, prior to satellite measurements or any reasonable SST measurements at all, requires the use of some proxy. The one I've used was derived from tree ring data – specimens were collected from coastal mountain ranges extending from here down to Baja (in this coastal region it's rainfall and not temperature that determines tree growth). The tree ring proxy is a good match with the SST calculated PDO index back to about 1940-45. Further back the two diverge, probably because the SST data becomes less reliable (sea temperature PDO index values are unavailable for years earlier than 1900).

I've chosen to use both indices in the graph: the tree ring values up to 1991 (the year the record ends) and the regular PDO index thereafter. I've also chosen to "normalize," i.e. adjust the values so that they vary between -4 and +4; these are the PDO index values shown on the graph.]



Those thoroughly confused by all the talk about warm and cold ocean temperatures, and differences between the El Nino and PDO cycles, may be helped by this graphic.

The colors refer to sea surface temperature anomalies above and below the long-term average and the little arrows indicate prevailing wind directions. Since the differences between similar phases of the two cycles (e.g. El Niño vs. the positive or warm PDO) appear to be small (varying in extent but only slightly in temperature – putting aside the really big difference in duration) what might it look like if we added the PDO and El Niño indices together?



Glad you asked. Putting them together does improve the pattern, especially when it comes to explaining some of the abrupt increases and decreases in cumulative rainfall that occur during very strong El Niño or La Niña events, but the overall amplitude problem remains. In the graph I've normalized the EL Nino 3.4 index to the same -4 to +4 variation as I did earlier for the PDO. In practical terms this gave each index equal weight when they were added.

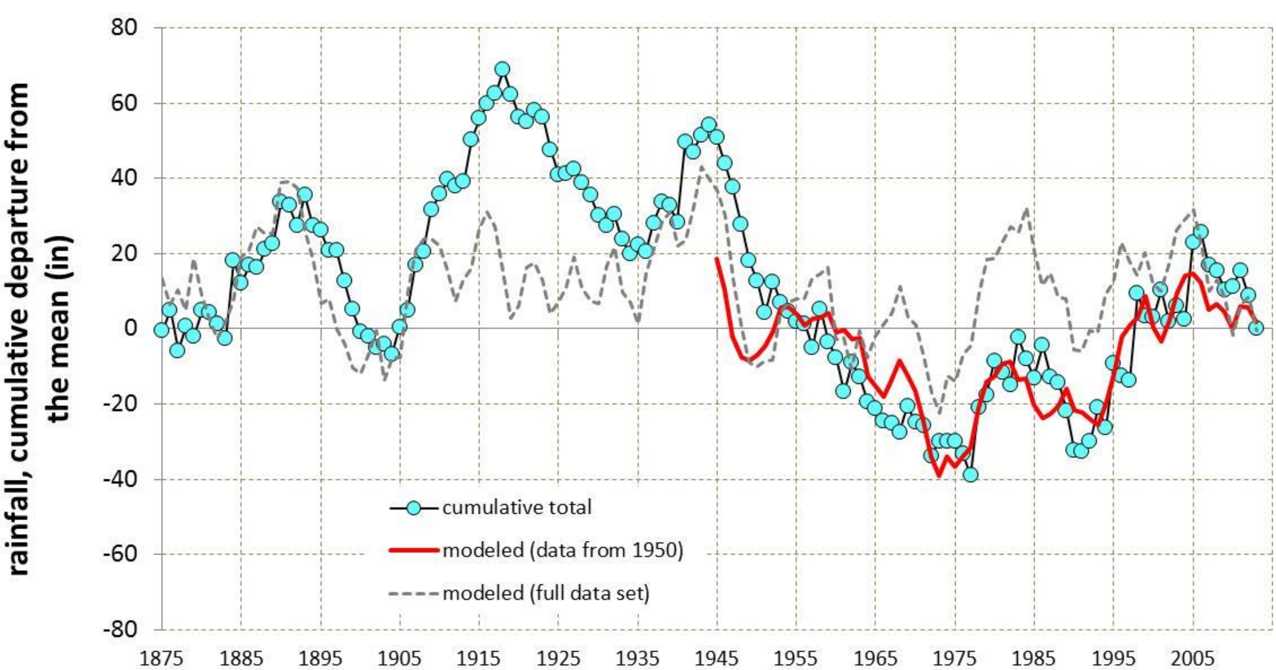
Taken together the two indices explain about 20% of the cumulative variation of rainfall from the mean. They do less well when it comes to annual rainfall: explaining only 12%. Still, think about it, measurements of ocean temperature somewhere off of the coasts of South America and the Pacific Northwest can explain a good chunk of our winter rainfall, and explain it back as far as 1874 . . . who'd have guessed?

[*On page 4 I mentioned the El Nino cycle as explaining 16% of the rainfall variation by itself, but I was being slightly deceptive. That correlation used only data from 1950 on; if all data since 1874 had been included El Niño would explain only about*

5% of the variation. Putting both the El Nino and PDO cycles together does not necessarily imply that they are totally independent. As the similarity between their ocean temperature patterns might indicate, El Niños appear to be more common during positive PDOs, La Niñas during negative PDOs.]

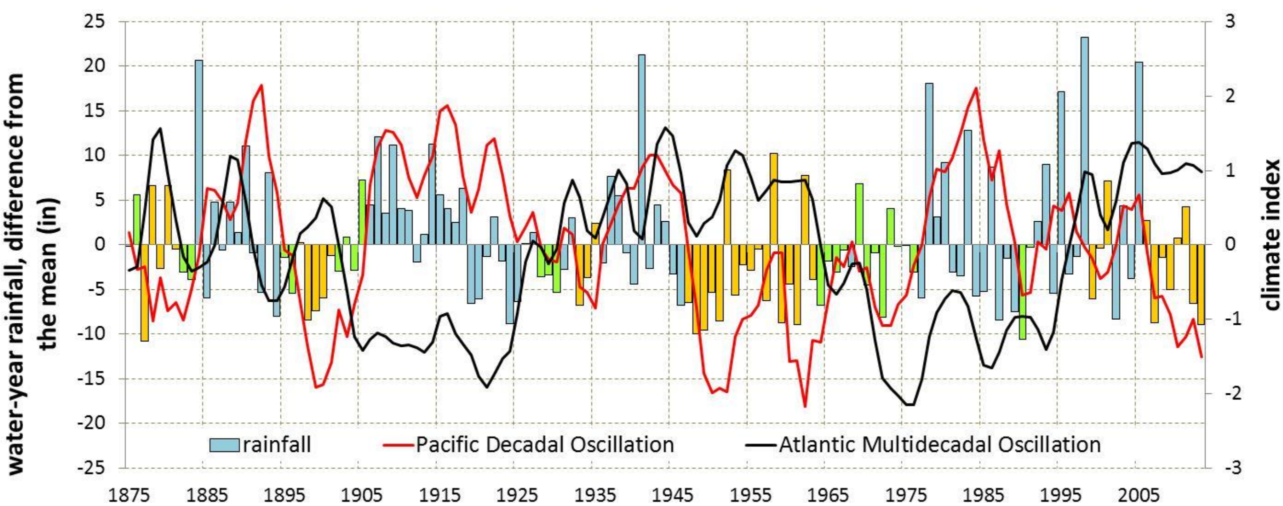
As for the rest? It could simply be chance. Some large storm zigging when it was expected to zag. Local factors, like topography, must exert some influence. Left out is any consideration of global warming and whatever effect it may have been having on intensifying the hydrological cycle.

I've also left out other major climate cycles like the Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO) or the Arctic Oscillation (AO) that also affect weather in the northern hemisphere. Although far distant from our south coast, these exert influence via air pressure differences that determine the magnitude and direct the path of major storm systems. The Atlantic Multidecadal Oscillation, an approximately 70 year cycle of shifting temperatures in the North Atlantic (roughly from the Equator to Greenland), is particularly interesting because of its association with drought in the western US. The shift is minor, only about 0.6 °C (keep that magnitude in mind whenever anyone suggests that a degree or two of global warming is nothing to be concerned about). I'll spare you the details, but if the AMO is combined with the PDO and El Niño indices the fit with cumulative Ventura rainfall improves appreciably: now explaining 26% of the pattern (the dashed grey line below) – up from the 19% using just PDO and El Niño alone. Even better, if only data since 1950 are used, a regression equation with all three indices explains 70% and is a close match with the cumulative pattern (the red line).



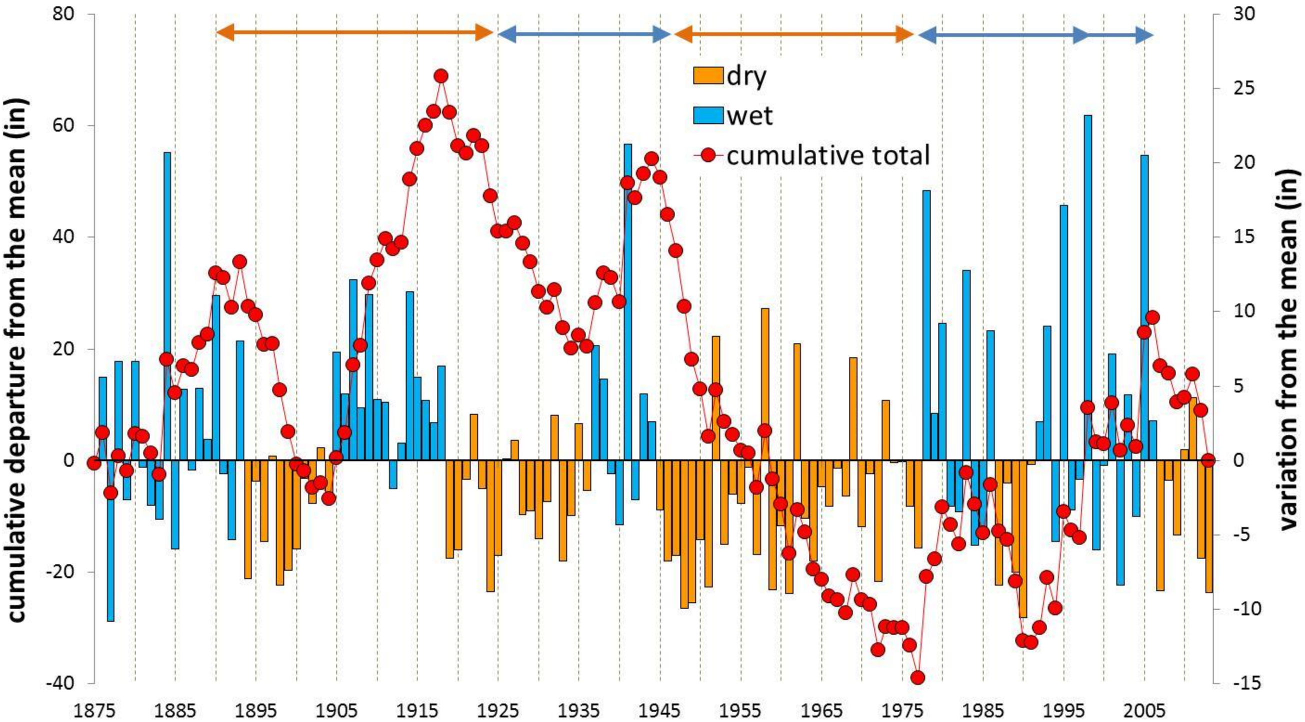
But it's the association with drought that makes the AMO particularly interesting. A paper by McCabe and others proposed that the combination of a positive (or warm) AMO combined with a negative (or cool) PDO produces drought throughout the west (with a 40% increased chance of a dry year in our region); and the combination of a cool AMO and a cool PDO can specifically affect our local area with a 20% increased probability of a dry year.

[*We can define a dry year as one in the lower quartile (the lower one quarter) of all years; this would be less than 10.2 inches in Ventura. Normally, we would expect a dry year to occur 25% of the time since it has occurred 25% of the time in the past; a 40 % increased chance means we could expect one 35% of the time*.]



To test these conclusions, I've plotted both the PDO and AMO in the above graph along with annual Ventura rainfall (shown as differences from the overall water-year mean of 15.4 in.). Years that meet the criteria of +AMO/-PDO are shown in a yellowish color, and they do tend to be below average years (the median rainfall of those years was 10.2, the average 12.7). Those that meet the criteria of -AMO/-PDO (light green) are also below average but not as much (median, 11.3, average 13.7). The remaining years (shown in blue) have a mean of 17.6 and a median of 15.4; that they are above average should come as no surprise.

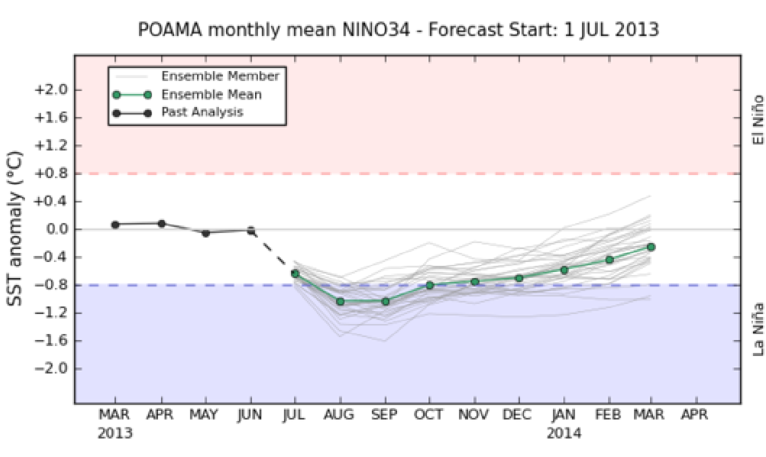
I want to finish up by taking a step back and returning to the "cumulative departure from the mean" graph; using it to define the various dry and wet cycles in Ventura rainfall. The graph that follows shows both cumulative and annual rainfall (as variation from the mean). Dry cycles, when annual rainfall consistently fell below the mean, are shown in yellow; wet cycles, of mostly above average rainfall, are shown in blue. Arrows at the top of the chart indicate the generally accepted warm (blue for wet, El Nino-like) and cold (yellow for dry, La Nina-like) PDO cycles.



They are not a perfect match, especially for the earlier years (there is good agreement from the late ’30s on). The double pointed blue arrow at the end indicates the disagreement in the literature about when the last warm period ended: some believe the 1998 El Nino marked the end, others think it was 2008. Still others decided it ended in 2005 or 06 (I’m with the ‘06 group). Whatever. The important point is the near total agreement that we are now in the cold half of the PDO cycle.

Let’s Predict 2014

Now that we’ve gone through all this, it’s time to predict what we might expect in the way of rainfall this coming winter. If you’re looking forward to a wet winter it doesn’t look good: we are in the cold part of the PDO cycle (monthly index values have been negative since June 2010); we are still in the warm half of the current AMO (monthly AMO index values have been positive since the beginning of the current water year); and the latest ENSO prediction is for a negative index, if not a mild La Niña.



All in all, it's looking like another dry year. I sure wouldn't bet against it. But probability is not fate. There's always a chance 2014 will be another 2005; not a good chance, but a chance.

In the process of writing this – completely unintended, I assure you; I initially set out to draw a single graph – I came across a number of interesting references. I've listed them below. I would particularly recommend the one from the Australian Bureau of Meteorology (a great website, Australia has very good web pages on all water quality issues), the USGS pamphlet on the Colorado River Basin (for those interested in the southwest and the over-budgeting of Colorado River water), and the Mantua paper on PDO and salmon (for the fish enthusiasts out there).

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