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PDO: Where will the footprints lead?

The Pacific Decadal Oscillation (PDO) is a long-term shift in several climatic indicators, or "footprints," including sea surface temperatures (SSTs), sea level pressures, and air temperatures, which may influence the climate of North America for 20- to 30-year periods. Researchers are just beginning to understand the internal dynamics of this climatic factor and are wading through sometimes contradictory data that show different results depending on what types of climatic records are examined and at what time scales.

Although the internal dynamics that cause the PDO to shift are not yet fully understood, studies of its impacts are already helping climate forecasters to improve seasonal forecasts (1, 8). The PDO has important implications for improving forecasts, because it appears to be the type of regularly occurring pattern that imposes at least some order on the climate system at fairly long time scales.

A Little History…

The PDO was first identified not by changes in the indicators that some scientists now believe signal a shift in its pattern, but rather by its impacts on salmon runs in the Pacific Northwest. Around 1977, biologists began taking note of dramatic changes in and around the North Pacific that appeared to be affecting the number and species of salmon caught (2).

In 1991, researchers at the University of Washington School of Fisheries published a paper that correlated local air and sea temperatures with changes over time in catches of Gulf of Alaska pink salmon versus West Coast coho salmon. They found that climate changes generated sudden shifts in fishery productivity for multi-year periods. Researchers examining related decadal-scale climate variability coined the term Pacific Decadal Oscillation, which came to apply to both phenomena (2). Since that time, researchers have documented PDO impacts not only on salmon, but also on a variety of ecosystems and organisms.

What We Know About PDO

Sea surface temperatures between the central North Pacific and the North American Pacific Coast tend to vary in opposite manners. SSTs in the central North Pacific tend to be cooler than average when they are unusually warm along the Pacific Coast, and vice versa (1). Sea level pressure and wind also vary in synch in a similar manner. Scientists monitor these variations to identify whether the phase of the PDO associated with warmer coastal SSTs, or the one indicated by cooler SSTs, is currently dominant.

Some researchers believe that a recent shift in the PDO may affect climate in the Southwest for decades to come. The index of PDO indicators shifted from warm to cool during the fall of 1998 and have stayed below or near zero since that time (1). Coastal waters around the Gulf of Alaska and along the U.S. West Coast have been unusually cool since around the fall of 1998; in fact, a species of plankton normally found much farther north has been dominant along the West Coast for the past four years. Fish species, including salmon, are beginning to show the effects of these changes and will be monitored in the coming years to verify if a regime shift has indeed taken place, or whether this is merely a short-term fluctuation in a longer warm PDO cycle.

Impact on the Southwest

Current studies conclude that the PDO is strongly, but not uniformly, correlated with winter precipitation in the Southwest. Brown and Comrie (3) found that winter precipitation in most areas of central New Mexico is significantly influenced by the PDO, while only limited areas of northern Arizona and the Tucson area exhibit strong relationships (see Figure 1). Some areas of New Mexico also exhibit significant correlations with the PDO for spring rainfall (particularly important to ranching and agriculture), although none of Arizona does.

A different study (4) also reveals strong correlations between the PDO and precipitation in New Mexico. As summarized in Table 1, the warm

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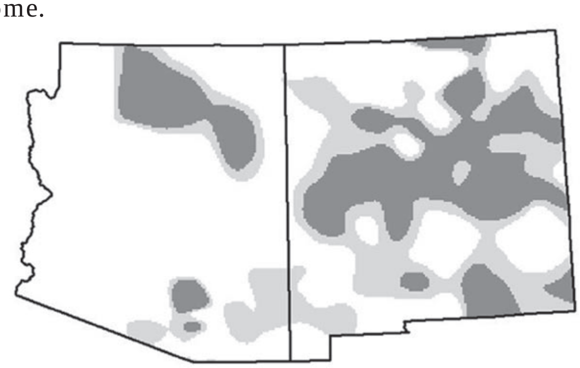

Figure 1. Winter precipitation and the PDO; darker areas indicate the strongest relationships. From Brown and Comrie (3).

PDO, continued

Table 1. PDO Effects in New Mexico, 1900–1999 (4).

Phase	Measure	Wet	Dry	Normal
Warm PDO	Spring precipitation	41	7	56
	Annual precipitation ratio	5	1	
Cool PDO	Spring precipitation	19	63	54
	Annual precipitation ratio	1	4	

phase of the PDO resulted in more wet years, while the cool phase was associated with more dry years.

Based on historical data from the 20th century, the study contends that precipitation totals during the next cool phase of the PDO could be 25 percent lower than those experienced during the most recent warm PDO period (the 20 to 30 years preceding 1998). At the same time, it is important to note that there is considerable variability from year to year during different phases of the PDO.

ENSO and PDO Interactions

The PDO is not the only climate pattern that impacts the Southwest; the effects of the El Niño-Southern Oscillation (ENSO) and its associated El Niño and La Niña events have been better documented. Recent research indicates that ENSO and PDO impacts interact. A warm ENSO event (El Niño) that coincides with the warm phase of the PDO tends to result in higher than average precipitation in the Southwest. When the cool phase of ENSO (La Niña) occurs during cool phase PDO conditions, La Niña's drying effects on the Southwest are amplified. In fact, some of the most persistent and severe droughts on record have occurred when these latter two phases were synchronized.

Hints at what the possible recent shift in PDO-related indicators might mean for the Southwest can be found by examining climate records, particularly for La Niña events. A typical La Niña leads to unusually dry winters in the Southwest. Its impacts on hydrologic systems in the region are among the more reliable impacts of ENSO and are much more consistent than El Niño-related effects, although they do vary in intensity.

To explore the relationship between U.S. multi-year droughts and Pacific Ocean variability over time, researchers (5) combined a new record of ENSO, a gridded reconstruction of the Palmer Drought Severity Index, and an extended index of the PDO. Their research focused on persistent droughts, defined as those with low rainfall for at least six consecutive years.

One of the most significant extended droughts they found was centered on 1860; tree-ring records indicate that this was the driest year between 1698 and 1980, exceeding the 1930s Dust Bowl in intensity. The researchers note that this drought occurred during La Niña conditions and conclude from this and other examples that La Niña is a major cause of drought in the United States. Although recent La Niñas rarely last longer than two years, new ENSO data from central Pacific coral growth bands show that much longer La Niña events took place during the 1800s. One that lasted between 1855 and 1963 coincides with prolonged drought across the Western United States. Earlier periods also show more persistent La Niña-like drought patterns.

The researchers also found that in the cool PDO phase, La Niña tends to be strong and stable; the drought of 1860 appears to have occurred during both La Niña and a cool PDO. Multi-year droughts in the 1950s, which occurred during the last cool phase of the PDO, caused tremendous disruption to social, agricultural, ecological, and economic systems. Such droughts have recurred about twice per century over the past 400 years.

The aforementioned Brown and Comrie study (3) finds that impacts are not evenly distributed throughout the Southwest. These uneven effects have important implications in the Southwest for issues such as fire fuel buildup, snow-pack accumulation (important for water resource managers), and providing useful climate information to ranchers, farmers, and other stakeholders.

Multi-year climate patterns such as ENSO and PDO determine climatic conditions in the Southwest during fall, spring, and winter. In the summer, however, the North American monsoon dominates. By examining weather records for 188 stations in Arizona and New Mexico for the period 1950–2000, Brown and Comrie (3) discovered that only winter precipitation correlated well with both ENSO and PDO influences. Spring precipitation was correlated with the PDO. ENSO is strongly linked with winter precipitation across western and southern Arizona, as well as parts of southern New Mexico, but not as strongly associated with the remainder of New Mexico and northeastern Arizona (see Figure 2).

Exactly what these trends will mean in a given area, under specific conditions, remains uncertain. The patterns indicating which PDO phase is dominant emerge when the indicator data are aggregated to the decadal scale. However, according to Robin Webb of

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Figure 2. Winter precipitation and ENSO conditions; darker areas indicate the strongest relationships. From Brown and Comrie (3).

References

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PDO, continued

NOAA's Climate Diagnostic Center, citing research by his colleague Matt Newman (6), a closer examination of SSTs, sea surface pressure, and wind patterns within decades reveals inconsistencies, showing that the signals during warm and cold phases of the PDO are little better than a random sampling of dates. This contrasts markedly with the stronger, more consistent signals that ENSO produces.

Limits of PDO Understanding

Despite the wealth of research that has been conducted on the PDO during the last 10 years, scientists have not yet been able to pin down what causes this phenomenon—and therein lies the controversy over its status as a separate phenomenon from ENSO, or as merely a longer-term set of ENSO indicators. The first step in understanding what the PDO is, its impacts, and its potential to help forecasters create better seasonal and longer-term predictions may be to identify where ENSO ends and the PDO begins. The two climatic patterns are so closely connected that the PDO has been described as a long-lived ENSO-like pattern of Pacific climate variability (7).

The PDO has many similarities to ENSO and other longer-term climatic patterns. Both have characteristic footprints comprising patterns of wind, air temperature, and precipitation. Like ENSO, PDO extremes are marked by widespread variations in Pacific Basin and North American climate. As with ENSO, PDO can be characterized as being in its warm or cool phase, based on ocean temperature changes in the northeastern and tropical Pacific Ocean. Each pattern also has a typical lifetime, or duration, for which these signature conditions will last. These are important clues to forecasters trying to understand how, when, and whether climatic conditions are likely to change.

Despite the similarities, there are major differences between PDO and ENSO. Most scientists see ENSO as having a fairly predictable internal dynamic that guides its variations. They lack concrete evidence of this dynamic to explain PDO shifts, or to signal in advance when shifts are about to occur. Further, indicators of PDO don't always present as clear a picture as ENSO-related signals do. For example, SST swings during ENSO cycles follow a predictable pattern for a predictable period of time, whereas, according to Webb, SST effects of PDO are much less consistent or predictable (6).

The PDO's longer time scales are another part of the difficulty in pinning down its existence. Several studies find evidence of just two full PDO cycles in the past century: cool PDO phases lasted from 1890–1924 and again from 1947–1976 and warm phases from 1925–1946 and again from 1977 through perhaps the mid-1990s (8). Scientists only have instrumental records of climatic fluctuations over the past 50–100 years. Demonstrating that the PDO has fluctuated three times in 20- to 30-year cycles over a century does not tell us enough about what might have happened in the past to verify that these fluctuations were not simply exceptions in a larger pattern.

In an effort to fill in some of the data required to validate PDO as a regularly occurring, internally driven phenomenon, scientists are exploring the usefulness of natural records such as tree rings and coral. When scientists look at evidence of longer-term PDO fluctuations in tree rings, the pattern of 20- to 30-year cool and warm cycles is not always clear.

Until scientists better understand the internal mechanisms of the PDO, its usefulness in helping create better forecasts is limited. Scientists are able to create forecasts up to a year in advance of the observable impacts of ENSO phases by observing changes in ocean currents, temperatures, and winds. When researchers are able follow the PDO's footprints better, they may be able to predict PDO-shifts and its related climate conditions with greater lead-time.

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