El Niño–Southern Oscillation: the causes, impacts in the Southwest, and future

By Zack Guido

El Niño and La Niña are words frequently tossed around to explain weather conditions in the Southwest. The sibling events, born thousands of miles away in the air over the tropical Pacific Ocean and in its waters, can deliver copious rain and snow to the region or cause widespread drought.

Perhaps no other natural phenomenon influences the weather and climate of the Southwest more than El Niño and La Niña. However, the causes and consequences of these events are mysterious to many people. How can changes off the coast of Peru ripple across the globe to steer rain away from Arizona? Why does El Niño soak southern Arizona during the winters but reduce snowfall in parts of the Rocky Mountains? Will climate change cause more El Niño or La Niña events, and if so, what does this mean for Arizona and New Mexico? Understanding the weather and climate of the Southwest isn't complete without a working knowledge of El Niño and La Niña.

The forces at play

El Niño and La Niña are part of the El Niño–Southern Oscillation (ENSO), a natural seesaw in oceanic sea surface temperatures and surface air pressure between the eastern and western tropical Pacific Ocean. The causes for this fluctuation have been studied since the 1950s, when ENSO became widely accepted in the scientific community.

ENSO's inner workings are complicated. The rotation of the Earth causes trade winds in low latitudes to blow hard from the east, pushing warm surface water in the tropical Pacific Ocean westward near the northern coast of Australia like a snow plow.

As the warm water pools, it works in tandem with intense solar rays to heat the surrounding air. The hot air then rises like a balloon, creating a zone of low air pressure.

As the air ascends, it cools and condenses, forming cotton-ball clouds that burst with rain. That air then travels east and descends near the coast of Peru and Ecuador. Sinking air piles on the Earth's surface, forming a high pressure zone that acts like a vice. The pressure difference squeezes air in the east toward the west, where it fills the void created by the hot, rising air.

In this way, a large circular pattern known as the Walker circulation is completed. Although the Walker circulation is always in motion, its movement is tuned by El Niño and La Niña events, which regulate sea surface temperatures and wind speed.

During El Niño events, the trade winds slacken, enabling an eastward migration of warm water. The center of rain follows, moving east to the middle of the Pacific Ocean near Tahiti.

La Niña events behave in the opposite way; the trade winds intensify and stack the warm surface water in the west even more than in normal years—the waters near Australia are often five feet higher than the ocean surface in the east during La Niña episodes (Figure 1). The area of intense rainfall is dragged back toward Australia.

One event often lasts less than a year and returns two to seven years later. In the meantime, the ocean and atmosphere are either in the la Niña or El Niño phase or

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Walker Circulation and the La Niña phase of ENSO

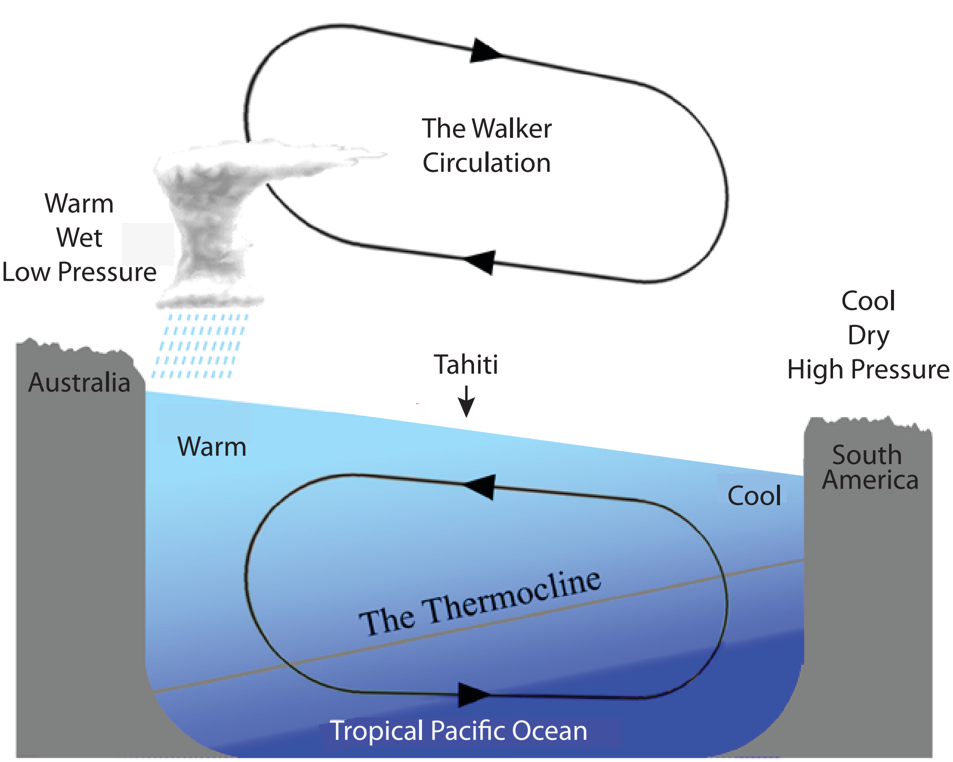

Figure 1. La Niña events modify the Walker circulation—the circular flow in air over the tropical Pacific Ocean—while moving the location of warm sea surface waters and intense rain. These changes, and those caused by El Niño episodes, impact the weather in the US Southwest.

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hovering around the historical average, deemed "neutral" conditions.

The transition from one event to another is a natural example of a climate system regulating itself. ENSO events would become stronger and stronger without a switch. In a La Niña, for example, a self-reinforcing cycle would begin with strong trade winds, which would enhance the pressure difference between the east and west. This would in turn cause stronger winds, amplifying La Niña on and on.

This doesn't occur. Instead, El Niño and La Niña events flip-flop because the air and oceans respond to each other at different speeds. Winds react to the warming or cooling sea surface temperatures within days. It takes the ocean months to respond to changes in the winds. A memory of the departed winds is expressed as a wave that develops and propagates along a temperature boundary called the thermocline, which separates deeper, cold water from warmer, surface water.

For example, strong winds push warm water westward during a La Niña, which creates a valley in the thermocline and increases the thickness of the pool of warm water. The valley then migrates east toward Peru. When it reaches the coastal region it warms the water there, setting up conditions for an El Niño. The interval between one El Niño or La Niña and another is therefore determined by the speed of the subsurface wave.

Defining El Niño and La Niña

ENSO events are commonly defined by how high or low sea surface temperatures are compared to the average. An El Niño event is judged to have taken hold when average monthly temperatures in a defined region in the middle tropical Pacific Ocean exceed 0.4 degrees Celsius (approximately 0.7 degrees Fahrenheit) and endure for more than five consecutive months.

Higher temperature differences create stronger events. In the winter of 1997–1998, during one of the strongest El Niño events recorded, the average sea surface temperature difference was about 2.4 degrees C above average (approximately 4.3 degrees F). La Niña events have the same criteria but require that the temperature difference be greater than 0.4 degrees C below average.

To reveal how ENSO events alter atmospheric circulation, the Southern Oscillation Index, or SOI, evaluates the pressure difference in the central and western Pacific Ocean. The SOI is calculated based on the differences in air pressure anomalies between Tahiti and Darwin, Australia. A negative SOI, which is characteristic of El Niño events, indicates air pressure over Tahiti is less than at Darwin. Both the sea surface temperature index and the SOI are used together to help evaluate several factors, including the early and late stages of an ENSO event when conditions are not obvious, the duration of the events, and their strength.

The effect of ENSO on weather in the Southwest

El Niño and La Niña episodes tend to develop between April and June and peak between December and January, when sea surface temperatures reach their warmest and coldest states, respectively. As a result, changes to atmospheric circulation, and therefore weather, are most prominent in the winter.

The ENSO fingerprint on the Southwest is principally caused by shifting jet streams. During El Niño events, the Pacific jet stream is straighter and is pulled south (Figure 2), and storms form in the Pacific Ocean just west of California, in part because waters are warmer than average in this region during El Niño events. The combination of the jet stream and storms often results in a wet winter and increased rain and snow across California and the southern United States.

La Niña events, on the other hand, often bring dry conditions to Arizona and New Mexico. In La Niña winters, the jet streams take a more serpentine path. The Pacific jet stream usually carves north and enters North America through the northwestern US, bringing wetter-than-average conditions to that region and diverting storms away from the Southwest.

The effect El Niño and La Niña events have on the weather is nuanced. An El Niño does not always cause wet winters, nor does a La Niña consistently deliver dry conditions. Between 1896 and 2002 in Arizona, for example, about 50 percent of the winters experiencing an El Niño event received more than 115 percent of average precipitation, while roughly 25 percent of the winters received less than 85 percent of the average.

The amount of precipitation during ENSO events also changes by region in Arizona and New Mexico and beyond. During an El Niño, the southern regions of both states often receive more winter rain and snow than northern regions.

Critical winter precipitation for the Southwest also falls as snow in the headwaters of Arizona's most important river, the Colorado. About 70 percent of that water originates in the mountains of Utah, Wyoming, and Colorado. However, when the southern regions of the Southwest are wet, precipitation in the Upper Colorado River Basin is often average or below average.

For example, during El Niño events between 1896 and 2002, the Colorado portion of the Upper Colorado River Basin received less than 115 percent of average precipitation about 60 percent of the time; it experienced dry conditions in which rain and snow measured less than 85 percent of average nearly one-third of the time. During this same period, the Arizona portion of the Lower Colorado

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River Basin experienced wet conditions with rainfall greater than 115 percent of average about half of the time.

The impact of ENSO on summer weather is not as clear-cut as the changes that occur in winter. El Niño events often are associated with two phenomena that have opposite effects on precipitation in the Southwest. On one hand, an El Niño can stifle summer rains in Arizona and New Mexico because they can weaken and reposition the subtropical high that guides moisture into the Southwest. On the other hand, El Niño events also can foment a higher number of tropical storms, some of which deliver copious summer and fall rains to the region.

The future of ENSO

Debate continues about whether the character of ENSO events will change as the world warms in response to increased levels of greenhouse gases. One hypothesis suggests that a warmer world will cause stronger or more frequent El Niño events, which would help moderate warming because much of the heat released from the ocean during El Niño years eventually makes its way into space.

The other hypothesis calls for a spike in La Niña events, which would help mitigate global warming by sequestering some of the incoming heat into deeper waters. Because both El Niño and La Niña play a prominent role in the weather of the Southwest, changes will have consequences. A more La Niña-like future could strain already limited water resources, and more intense events could deliver more frequent floods or droughts.

To help resolve this debate, scientists are monitoring ENSO and using climate models to simulate future conditions. A recent study shows that the easterly trade winds have weakened and suggests this may be behind the prevalence of more El Niño-like conditions in recent years.

Other studies have documented a change in the location of intense rainfall and the pattern of sea surface temperatures of El Niño events, and a decrease in the vigor of the Walker circulation. Although these observations and projections are insufficient to foretell the future, it is clear that ENSO is on the move.

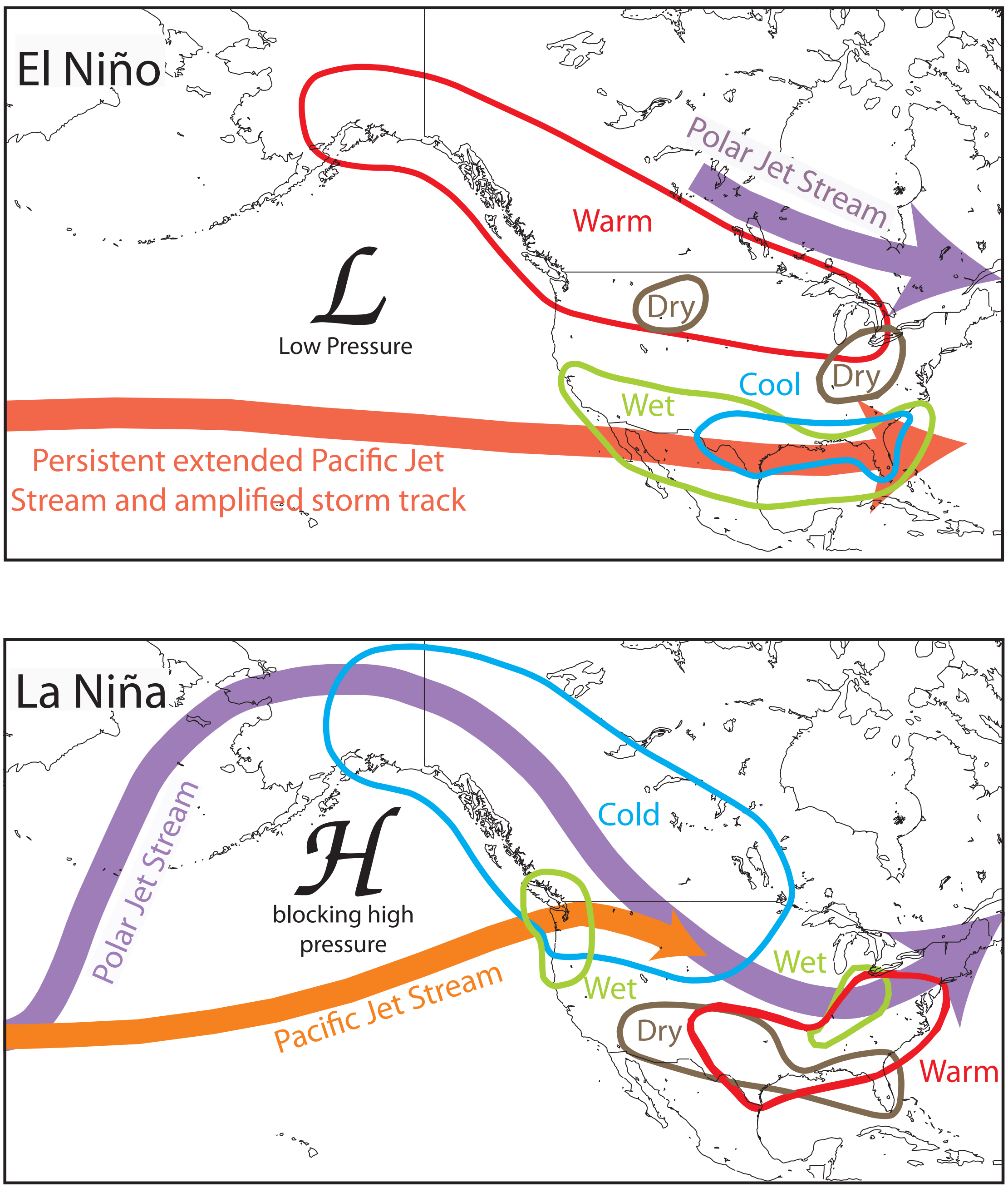

Figure 2. El Niño and La Niña events cause the path of the jet streams to move over the US in different locations, often causing wet winters during El Niño episodes and dry winters during La Niña events in the Southwest.