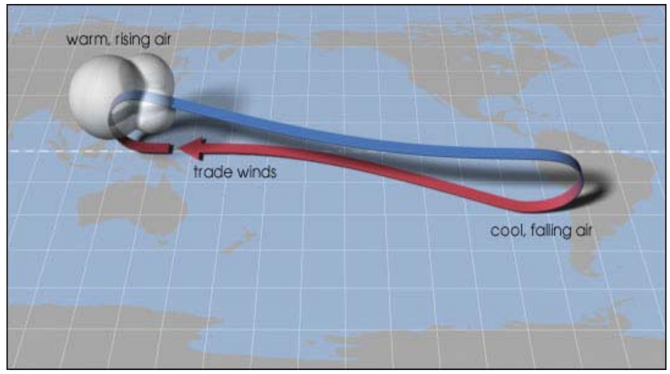
Earth Gauge
A National Environmental Education Foundation Program

The El Niño-Southern Oscillation (ENSO)

Now well known to scientists, the *El Niño-Southern Oscillation (ENSO)* was discovered in stages. The term El Niño ("the infant" in Spanish) was likely coined in the 19th century by Peruvian fishermen who noticed the appearance of a warm current of water every few years around Christmas. The cause of the current's appearance was a mystery to them. In 1899, India experienced a severe drought-related famine, prompting greater focus on understanding the Indian monsoon system, arguably the nation's most important source of water. In the early 1900's, the British Mathematician Sir Gilbert Walker noticed a statistical correlation between the monsoon's behavior and semi-regular variation in atmospheric pressure over the tropical Pacific. He coined this variation the *Southern Oscillation*, defined as the periodic shift in atmospheric pressure differences between Tahiti (in the southeastern Pacific) and Darwin, Australia (near Indonesia). It was not until 1969, however, that meteorologist and early numerical weather modeler Jacob Bjerknes proposed that the El Niño phenomenon off the coast of South America and the Southern Oscillation were linked through a circulation system that he termed the *Walker circulation* (see image right). ENSO has since become recognized as the strongest and most ubiquitous source of inter-annual climate variability.



Above: A schematic diagram of the "Walker Circulation," which connects the eastern and western parts of the tropical Pacific ocean through system of winds and rising and falling air masses. Image courtesy of NASA.

What is ENSO?

In the most basic sense, ENSO is a quasi-periodic shift in the distribution of heat across the tropical Pacific. But what drives this shift? ENSO is known as a *coupled system* because the different components drive and affect each other. A weakening or strengthening of one component can cause a weakening or strengthening of another component. What are ENSO's components and how do they work together?

Easterly Trade Winds: The high-pressure gyres that form in Earth's subtropics drive the prevailing winds that flow over the ocean basins. Sets of prevailing winds, known as the *trade winds*, blow from east to west on both sides of the equator (each hemisphere has its own trade winds). These winds move heat from East to West near the surface of the ocean.

Westerly Upper Atmospheric Winds: Warm, moist air rises over the western tropical Pacific, which is warmer than the eastern Pacific, as the trade winds move heat from East to West. Once this rising air reaches about 250 mb in height, it moves eastward and as it moves, the moisture it holds precipitates. By the time this eastern moving air reaches South America, it has literally "run out of steam" and masses of cool, dry air descend to the Earth's surface. This *subsidence* helps keep the climate of the eastern tropical Pacific dry and relatively cloudless. Abundant sunshine plus cold ocean water that is upwelled from below stimulates phytoplankton growth, making these waters productive ecosystems. The phytoplankton growth is so abundant that it actually influences the ocean's vertical structure, which in turn influences the whole ENSO cycle.

The Equatorial Thermocline: In large water bodies, there is a distinctive layer where the temperature drops rapidly with depth. This layer, which separates warm surface waters from cooler bottom waters, is known as the thermocline. In the tropical Pacific, the thermocline is deep in the West and shallow in the East. The shallower the thermocline, the more cold, nutrient rich water makes its way to the surface. Upwellings of nutrient rich water in the shallow eastern thermocline feed the phytoplankton that bloom under the sunshine.

Strong easterly winds in the equatorial Pacific pull nutrient rich cold water from the ocean depths, driving a temperature contrast between the eastern and western tropical Pacific, further strengthening the easterly winds. More easterly winds mean a warmer western Pacific as well, which strengthens the upper-atmosphere westerlies. If any one of these components weakens, for whatever reason, the ENSO system weakens. This system of coupling and rapid growth of initial perturbations, a positive feedback system, is known as the Bjerknes feedback.

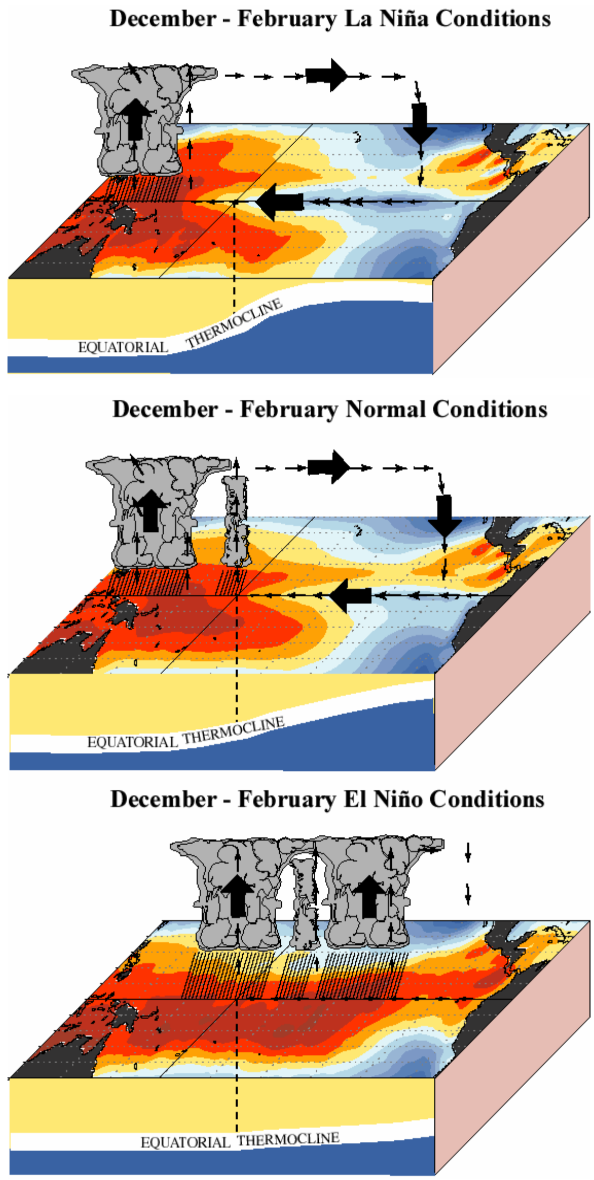
ENSO Phases and Effects

Conditions in the tropical Pacific appear to stabilize around at least three different states. Quasi-cycles when conditions transition amongst these states occur over periods of two to seven years. ENSO's effects on weather are most pronounced during each hemisphere's winter, when the temperature contrast between the land and oceans is at its annual maximum.

La Niña Phase: La Niña conditions correspond to an abnormally cool eastern tropical Pacific. These cool conditions are accompanied by a shallow equatorial thermocline in the East and strong trade winds blowing towards the West. These winds cause heat to concentrate in the western tropical Pacific, strengthening both convection and the upper-atmosphere westerly winds that blow back to the East. These conditions characterize a strong Walker circulation. The pressure difference between Tahiti and Darwin is large during La Niña phases and the measure of this difference, the *Southern Oscillation Index (SOI)*, is positive during such events. The cool surface conditions in the East cause divergence in the upper-atmosphere that shift the Northern Hemisphere storm tracks to the North. In the United States, La Niña winters correspond to above normal precipitation in the Pacific Northwest and below normal precipitation in the Southwest.

Normal or Neutral Phase: During normal or neutral conditions, the thermocline is deeper (the western Pacific warm pool covers a larger area), upwelling is not as strong and the Walker circulation is weaker than it is during La Niña phases, but is still functioning. Neutral phases, like the other two phases, have distinct and pronounced effects on America's weather. For example, both La Niña and El Niño phases (see next section) correspond to reduced winter precipitation throughout the Mississippi River Basin, while ENSO neutral conditions correspond to greater snow depth there.

El Niño Phase: El Niño conditions reflect a relaxation in the system linking the winds, ocean currents and water temperatures. During an El Niño phase, the Walker circulation is essentially non-functioning and warm waters cover all or most of the tropical Pacific. Little if any upwelling occurs off the coast of South America. During El Niño phases, the Southern Oscillation Index is negative, meaning there is little difference in temperature and atmospheric pressure between Tahiti and Darwin. During El Niño winters, the storm tracks are farther South than normal. In the U.S. this corresponds to above normal precipitation in the Southwest and below normal precipitation in the Pacific Northwest.



Above: Schematic diagrams of the different phases of ENSO. Note the absence of the Walker circulation when El Niño conditions are present. Also note the shifting position of the thermocline. Image Courtesy of NOAA.

New ENSO State

While the traditional El Niño/La Niña demarcation provides a reasonably accurate model for tropical Pacific variability, new research shows that there may be a fourth common ENSO state, which has been termed *El Niño Modoki* (Modoki is a classical Japanese word for a different but similar thing). El Niño Modoki events are similar to the classic El Niño events in that both feature warmer waters in the eastern Pacific, but during Modoki events the warmest waters are concentrated closer to the center of the Pacific Ocean. Modoki events have become more common in the last 20 years. One reason that this differentiation is important is because unlike classical El Niño events, Modoki events do not appear to suppress hurricane formation in the Atlantic (suppression that happens through accentuation of vertical wind-shear over that ocean). Like La Niña events, Modoki events also tend to steer Atlantic tropical storms to more southerly tracts towards the Gulf Coast and Central America.

ENSO Historic Behavior

After the last glacial period ended about 12,000 years ago, ENSO was likely consistently in a La Niña phase, with a strong and prevalent temperature contrast between the eastern and western tropical Pacific. Variability between the different phases became more pronounced between 5,400 and 4,600 years ago. More recent trends include the Walker circulation weakening over the second half of the 20th century. Also, eastern tropical Pacific upwellings in the late 1990s were about 25 percent weaker than those that occurred in the 1950s.

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