

The El Niño Phenomenon: From Understanding to Predicting

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[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/eln/home.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/eln/home.rxml)

Graphics by Yiqi Shao

The term El Niño—Spanish for “the Christ Child”—was originally used by fishermen to refer to the Pacific Ocean warm currents near the coasts of Peru and Ecuador that appeared periodically around Christmas time and lasted for a few months. Due to those currents, fish were much less abundant than usual. At the present time we use the same name for the large-scale warming of surface waters of the Pacific Ocean every 3-6 years, which usually lasts for 9-12 months, but may continue for up to 18 months, and dramatically affects the weather worldwide.

El Niño events happen irregularly. Their strength is estimated in surface atmospheric pressure anomalies and anomalies of land and sea surface temperatures. The El Niño phenomenon dramatically affects the weather in many parts of the world. It is therefore important to predict its appearance. Various climate models, seasonal forecasting models, ocean-atmosphere coupled models, and statistical models attempt to predict El Niño as a part of the interannual climate variability. Predicting El Niño has been possible only since the 1980s, when the power of computers became sufficient to cover very complicated large-scale ocean-atmosphere interactions.

Historical Observations

El Niño were observed as early as the 1600s. More systematic study began at the end of the 19th century, when Peruvian geographers noted unusual oceanic and climatic phenomena occurring periodically along the Peru coast. They noticed that eastern Pacific warming was sometimes very strong. In the 1920s The British scientist Sir Gilbert Walker empirically identified that some notable climate anomalies—changes in atmospheric pressure and circulation—happen around the world every few years. He invented the term for those climate oscillations, “the Southern Oscillation.”



Sir Gilbert Walker
<http://www.atmos.washington.edu/gcg/RTN/rtn.html>

While stationed in India studying the monsoon, Sir Walker observed pressure differences in the equatorial Pacific Ocean. He noticed “a seesaw” of atmospheric pressure measured at 2 sites: Darwin in Australia, the Indian Ocean, and in Tahiti, an island in the South Pacific. When atmospheric pressure rises at Darwin it falls in Tahiti, and vice versa.



Professor Jacob
Bjerknes
<http://www.atmos.washington.edu/gcg/RTN/rtnt>

In the 1950s, it was observed that climate anomalies connected with the Southern Oscillation coincided in general with El Niño occurrences. Around 1960, scientists realized that the warming of the eastern Pacific is only a part of the oceanic oscillations that extend westward along the equator, out to the dateline. At about the same time the famous meteorologist Jacob Bjerknes proposed that El Niño was just the oceanic expression of a large-scale interaction between the ocean and the atmosphere, and that the climate anomalies could be understood as atmospheric "teleconnections" spreading from the warm-water regions along the equator in the mid-Pacific.

Since approximately 1975 scientists have been researching El Niño and the Southern Oscillation phenomena together. Today we know that El Niño is a part of an interannual climate oscillation called the El Niño Southern Oscillation (ENSO) event. El Niño is a warm phase of ENSO, the cold phase of this event is called La Niña.

El Niño's Impact

The strongest El Niño events of the 20th century occurred in 1982-'83 and in 1997-'98. The effects of 1982-'83 included significant storms throughout the southwest United States and one of Australia's worst drought of the century.

According to the World Meteorological Organization, the 1997-'98 El Niño was a major factor in 1997's record high temperatures. The estimated average surface temperature for land and sea worldwide was 0.8°F higher than the 1961-1990 average of 61.7°F. According to the National Oceanic and Atmospheric Administration (NOAA), 1998 has set all-time highs of global land and ocean surface temperatures, above record high levels in 1997.

In 1998 the mean temperature was 1.2°F above the long-term (since 1880) mean of 56.9°F. The impact of the 1997/8 El Niño was felt in many parts of the world: Droughts occurred in the Western Pacific Islands and Indonesia as well as in Mexico and Central America. In Indonesia drought caused uncontrollable forest fires and floods, while warm weather led to a bad fisheries season in Peru, and extreme rainfall and mud slides in southern California. Corals in the Pacific Ocean were bleached by warmer than average water, and shipping through the Panama Canal was restricted by below-average rainfall.

El Niño phenomena dramatically affects the weather throughout the world. Among other weather anomalies, El Niño events are responsible for:



Drought scene near Narromine, New South Wales. 27 September 1982
<http://www.atmos.washington.edu/gcg/RTN/Figures/adrought.html>

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- A shift of thunderstorm activity eastwards from Indonesia to the south Pacific, which leads to abnormally dry conditions and severe droughts during both warm and cold seasons in Australia, the Philippines, Indonesia, southeastern Africa and Brazil
- During the summer season the Indian monsoon is less intensive than normal and therefore it is much less rainy than usual in India
- Much wetter conditions at the west coast of tropical South America

El Niño impacts on the United States, North America and the Atlantic regions include:

- Wetter than the normal conditions in tropical latitudes of North America, from Texas to Florida, including more intensive wintertime storms
- Extreme rainfall and flooding events in California, Oregon and Washington
- Much milder winters and late autumns in northwestern Canada and Alaska due to pumping of abnormally warm air by mid-latitude low pressure systems
- Below normal hurricane/tropical cyclone activity in the Atlantic (however, their strength is not limited by El Niño)
- Drier than normal North American monsoons, especially for Mexico, Arizona and New Mexico
- Drier than normal falls and winters in the U.S. Pacific Northwest

What Causes El Niño?

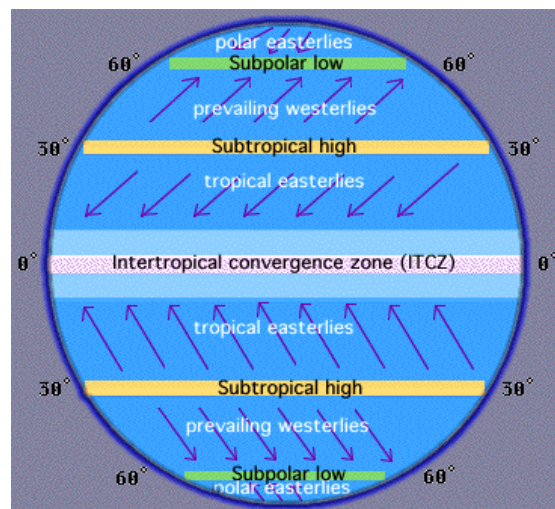
The warming of the Pacific occurs as a result of the weakening of trade winds that normally blow westward from South America toward Asia.

Global Wind Patterns: wind belts of the general circulation

The global wind pattern is also known as the "general circulation," and the surface winds of each hemisphere are divided into three wind belts:

- **Polar Easterlies:** From 60-90 degrees latitude
- **Prevailing Westerlies:** From 30-60 degrees latitude (aka Westerlies)
- **Tropical Easterlies:** From 0-30 degrees latitude (aka Trade Winds)

The prevalent surface winds across the Equatorial Pacific Ocean are easterly Trade Winds. These drag warm surface



[http://ww2010.atmos.uiuc.edu/\(Gh\)/wwhlpr/hurricane_globalwinds.rxml?hret=/guides/m](http://ww2010.atmos.uiuc.edu/(Gh)/wwhlpr/hurricane_globalwinds.rxml?hret=/guides/m)

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water away from the coast of Peru and cause colder deep ocean water to come to the surface (so-called “upwelling”). Upwelling causes the thermocline (the zone at the top part of the ocean in which temperature decreases rapidly with depth) to be much shallower in the Eastern Pacific than in the western. Trade winds and the equatorial upwelling maintain warm sea surface temperatures at the western equatorial Pacific and cold surface temperatures in the east. When trade winds weaken, the equatorial upwelling decreases, the thermocline gets deeper, the ocean surface along the coast of South America becomes warmer, and trade winds weaken even more. This in turn causes surface waters in the eastern Pacific to become even warmer and so on. This mechanism is known as the Bjerknes hypothesis and represents an onset of El Niño.

The questions remain: what stops warming in the eastern Pacific and why do El Niño events last approximately 12-18 months? The widely accepted (but not unique!) explanation is the delayed oscillator hypothesis.



<http://www.usafa.af.mil/dfp/physics/webphysics/jittworkshop/152Sp98GFelNino.html>

During the warming event in the eastern Pacific, the thermocline deepens along the equator and rises in the regions about 3 to 8 latitude degrees from the equator. These off-equator thermocline anomalies have little effect on the ocean surface temperature, but they propagate under the westerly ocean surface as so-called Rossby waves, with a speed of about 0.8 m/s. When Rossby waves reach the Indonesian archipelago they are reflected back as another type of the ocean underwater waves, namely equatorial Kelvin waves. Because of the deep thermocline in the western Pacific, the arrival of the Rossby signal does not affect surface temperature. Kelvin waves are much faster than Rossby waves and propagate eastward along the equator with an approximately 3 m/s speed as a shallower thermocline anomaly. When Kelvin waves reach the equatorial Eastern Pacific, they move the thermocline (and, therefore, cold deep waters) in this region even closer to the surface, cool the ocean’s surface and terminate the warm El-Niño event.

Detection and Prediction of El Niño

An ENSO observation system has been established over the past 10-15 years. Now scientists can observe the state of upper layers of the tropical Pacific Ocean in real time. Scientists use a variety of tools and techniques to detect the changes in the state of the Pacific Ocean, and therefore to detect El Niño conditions and the beginning and development of El Niño events. The changes in the tropical Pacific characteristics may be determined by satellites and different kind of buoys. Those observing ocean systems are part of the Tropical Ocean Global Atmosphere program (TOGA).

TOGA consists of scientific research ships, and radiosondes, which form the operational ENSO observing system. Satellites give the information on tropical rainfall, wind, and ocean temperature. Buoys include moored buoys, drifting buoys, and expandable buoys; all these provide the data on upper ocean and sea surface temperatures. Ships observe both the tropical ocean atmosphere and the upper oceanic layer. Radiosondes observe the state of the atmosphere and weather patterns worldwide.



<http://www.atmos.washington.edu/gc/g/RTN/rtnt.html>

Data from all ocean and atmosphere observing systems are processed by supercomputers. This information is used for both diagnostic and forecasting purposes by different kinds of models. Supercomputers, real-time data transmission via satellites, and modern diagnostic tools allow monitoring of El Niño in real time.

There are two major types of El Niño prediction models:

- Hydrodynamic coupled ocean-atmosphere models. In this type of model, the atmosphere and the ocean are treated as different types of fluids and their behavior is described by a complicated system of differential equations. Solving those equations involve a tremendous amount of computation, and requires the use of the most powerful supercomputers.
- Statistical models. In these models, statistical relationships, derived from the previous El Niño occurrences, are used to predict future El Niño events. These models are much more computationally effective than hydrodynamic models. However the period of meteorological and oceanographic observations is too short to produce reliable statistics, and therefore the statistical relationships introduced are usually subjective. The physics of the phenomena is not described, hence the accuracy of the prediction is limited.

There are also hybrid (intermediate) models, where an ocean model is coupled to a statistical atmospheric model. These hybrid models try to combine the computational efficiency of the statistical models with the accuracy of the hydrodynamic models.

The first successful forecasts of El Niño were made by Mark Cane and Steve Zebiak at Columbia University's Lamont-Doherty Geological Observatory in the US. They developed an intermediate ocean-atmosphere coupled model. The model successfully predicted the onset of the 1986-7 El Niño one year in advance. Since then, the field of El Niño prediction has grown and now there are several models that can predict El Niño up to 6-12 months in advance. However El Niño is hard to predict due to its chaotic nature, and its predictability is still the subject of debate. Two main factors limit predictability: the effects of high-frequency atmospheric variability and the growth of errors in the initial conditions of numerical models. Initial conditions in ocean-atmospheric models include the array of temperature, pressure, wind, and other data that describe the current state of

the ocean and atmosphere. Small errors in initial conditions may cause big changes in the results of a forecast.

Many models have been tested on already known El Niño events of the past, especially on those which took place during the period with relatively reliable meteorological and oceanographic data, that is during the last one and a half centuries. Some of those models present retrospective forecasting of El Niño and La Niña events for a period covering more than a century. The results are surprisingly successful: all the major climatic fluctuations of the twentieth century are reflected by these models. Obviously the most difficult aspects to forecast are the intensity of El Niño, the rapidity of its development, and its duration.

As already mentioned, the 1997-98 El Niño was one of the strongest in the 20th century. Many climate models predicted a high possibility of the 1997-98 El Niño event. The National Oceanic and Atmospheric Administration, for example, successfully predicted it six months in advance. But nobody expected this particular event to be so extremely strong.

In late 2001, ocean and atmosphere conditions were similar to those in 1996. So the scientists suggested a high probability of a new El Niño appearance in 2002. Those forecasting suggestions were right!

A moderate intensity El Niño event occurred in the Tropical Pacific in 2002-2003. The classic features of El Niño all were registered: abnormally warm sea surface temperatures of the tropical Pacific, weakening of trade winds, and changes in rainfall variability over the Pacific region. This event, though much less intensive than the 1997-98 El Niño, had a big impact on weather variability worldwide. Its evolution was registered by satellites and through in situ data of the ENSO Observing System.

One cannot underestimate the importance of El Niño forecasting for many regions of the world, especially for those countries in tropical regions where economic success is based on fisheries, agriculture and food production, all of which depend on weather patterns. Peru is an excellent example of a country that derives huge economic benefits from El Niño forecasting. Usually a warmer than normal year with moderate and strong El Niño onset is unfavorable for fisheries. When the state of equatorial Pacific is near normal conditions are favorable for agriculture. La Niña conditions (colder than normal ocean surface temperatures) are good for fishing, but not favorable for farmers, bringing them drought and crop failure. El Niño affects the amount of precipitation, so forecasts help to decide when it's better to sow rice (in expected wetter periods), and when to sow cotton (in drier periods).

Therefore ENSO forecasting in Peru presents four possibilities in ENSO phases:

- 1) near normal conditions
- 2) a weak El Niño with slightly wetter than normal precipitation

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- 3) El Niño conditions with flooding
- 4) La Niña conditions with colder than normal sea surface temperatures and higher possibility of drought

Predicting El Niño, and especially climatic extremes (floods, droughts, etc.) caused by El Niño, is very important for the United States as well, because this can save the country billions of dollars in damage costs. The U.S. economy is much more complicated than the economy of Peru, so detailed analysis is out of scope of this presentation, but interested readers will find abundant information in the abovementioned sources.

Numerous models of El Niño still are not as reliable as weather forecasting models, but they are able to represent the main features of the typical El Niño event.

Summary

El Niño is a warm phase of the interannual climate oscillation called El Niño Southern Oscillation (ENSO) event, an example of large-scale ocean-atmosphere interaction, and is characterized by large-scale warming of the surface tropical Pacific Ocean. El Niño events occur every 3-6 years, last 9-12 months, sometimes even up to 18 months, and have a big impact on world weather.

The major impacts of El Niño are temperature anomalies, changes in precipitation variability, floods and droughts throughout the world.

El Niño events happen irregularly and are hard to predict. However many numerical climate models predicted the last few El Niño events successfully. El Niño forecasting is becoming more and more reliable with our improving knowledge of the phenomenon's nature, with the help of more and more powerful computers, and with the operational El Niño Southern Oscillation observation system.

El Niño forecasting is especially important for tropical countries where El Niño impacts are the strongest.