Geo Factsheet

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El Niño 2015-16

The 2015-16 El Niño was one of the top three El Niño events ever recorded, along with those in 1997-8 and 1982-3 (**Figure 1**). It had a significant impact across many parts of the globe and is thought to be responsible for countless extreme weather events. **El Niño** events (warm) are often, but not always, followed by a **La Niña** event (cold), when normal conditions return but are intensified. These terms are used interchangeably with "**El Niño Southern Oscillation (ENSO)**" as they represent its fluctuating swings. This Factsheet will explain the physical event and outline the environmental impacts, within the Pacific region and globally. Finally, it will place El Niño within the context of climate change and its current status in 2017.

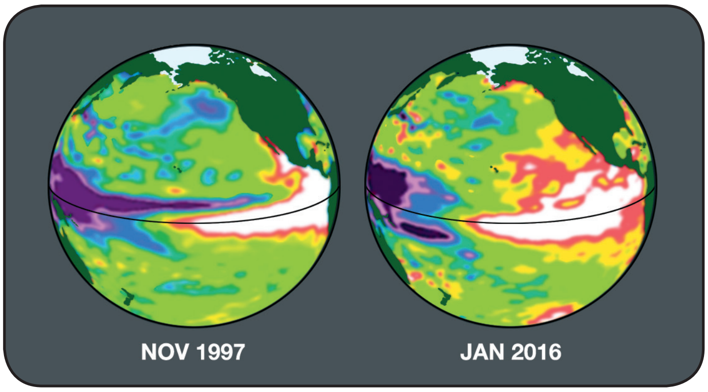


Figure 1 *The 1997/98 & 2015/16 El Niño events at their peaks*
Source: NASA/JPL-Caltech

What is the El Niño-Southern Oscillation (ENSO)?

It is now known that the climate system around the equatorial Pacific undergoes irregular changes approximately every 3-7 years. The surface waters of the ocean and atmosphere interact and reinforce changes in the other, known as a **coupled** ocean-atmosphere system. A **positive feedback** is created which amplifies small changes in ocean temperature.

Oceanic component

An El Niño occurs when sea surface temperatures are 0.5°C or more higher than average (**Figure 2**). This may seem a small increase but it is significant because it represents a huge store of energy in the deep ocean. Water heats up more slowly than land and stores heat for longer. Large changes at depth mean that surface waters remain warm and sustain an ENSO event. For example, in 1997-98 sea surface temperatures were 3.5°C higher than average in the eastern Pacific, and at 150m depth temperatures were 8°C above average.

Atmospheric component

Air pressure will change in response to sea surface temperatures and if the pressure gradient decreases, winds will have less strength and can even reverse direction. The winds pull a huge cell of warm water across the Pacific, from west to east during an El Niño.

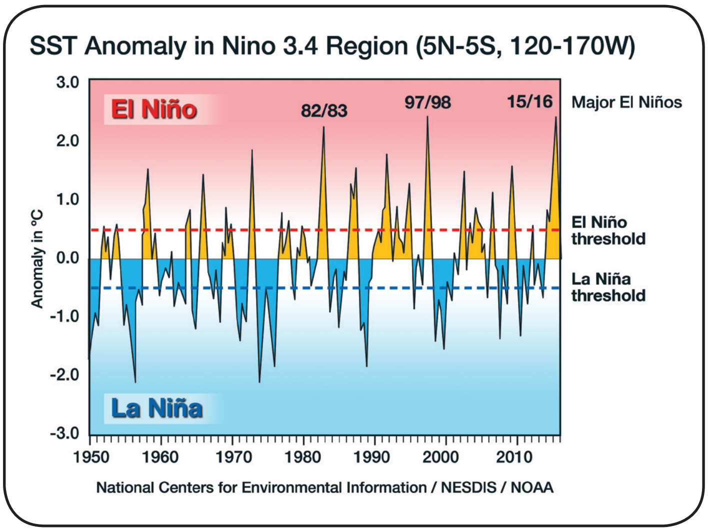


Figure 2 *ENSO events since 1900*

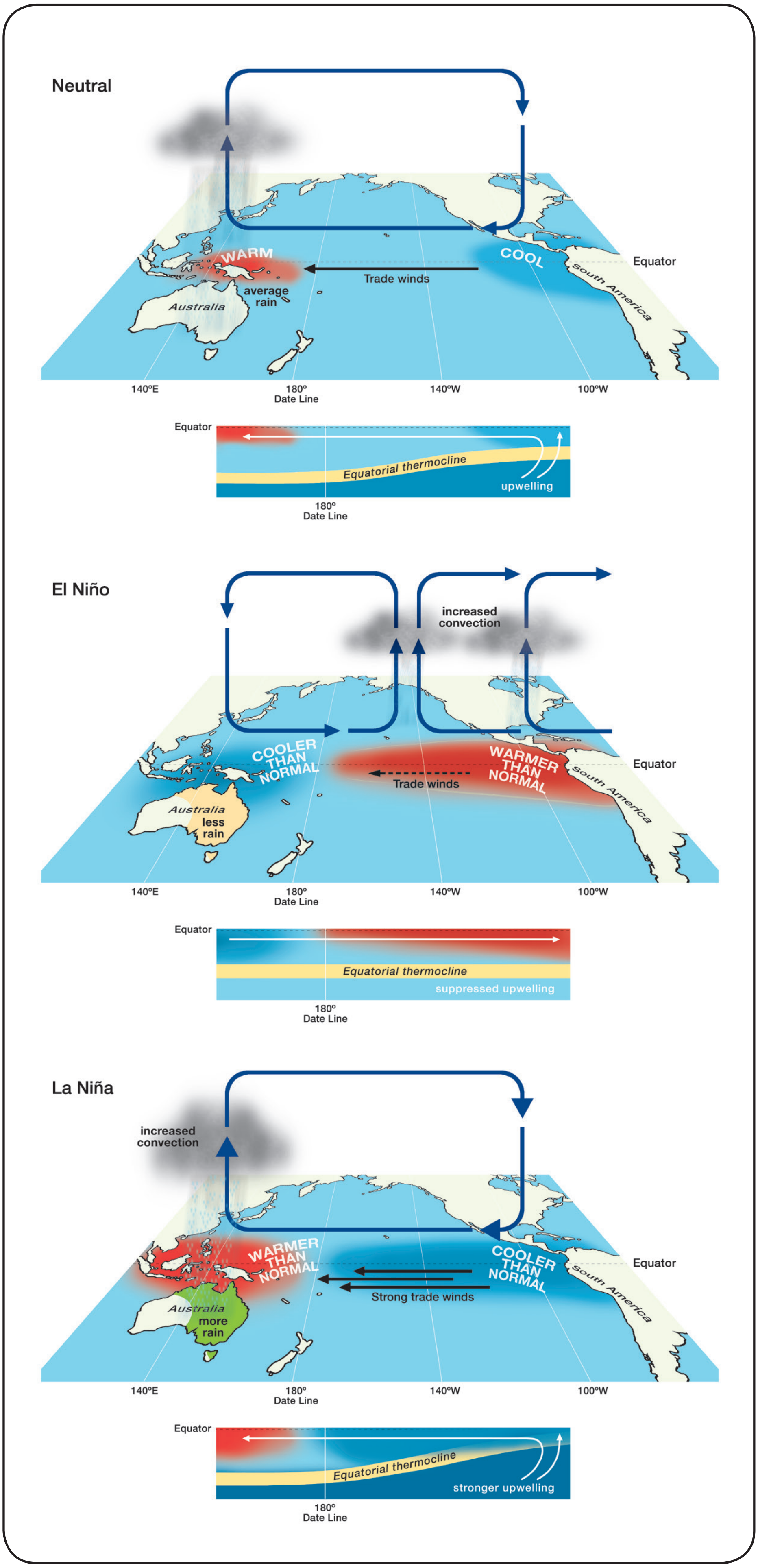
What causes ENSO?

It is not known why the oscillation exists, but records of coral and its chemical composition indicate that ENSO has been happening for at least 125,000 years. Going back even further to 5 million years ago, when the Isthmus of Panama was closed by tectonic forces, scientists generally assume that ENSO has been operating since the modern day Pacific boundary was formed.

The sheer scale of the Pacific Ocean is thought, by some, to be responsible for ENSO event. Planetary scale equatorial waves take time to cross the Pacific, and so the ocean adjusts to wind variations slowly, giving time for temperature and pressure anomalies to develop. This is positive feedback, because deviation from the equilibrium position of the atmosphere-ocean coupled system becomes reinforced over time. The narrower Atlantic and Indian Oceans adjust more quickly to wind variations.

Another explanation based on the relative sizes of the oceans is that land masses bordering the narrower Indian and Atlantic Oceans have a greater effect on seasonal climate than the Pacific. Heating of land in summer, combined in places such as the Indian monsoon, and cooling in winter means that land-sea temperature contrasts compete with and interrupt the larger scale ocean-atmosphere interactions that are critical for ENSO generation.

Figure 3
El Nino-Southern Oscillation: The Three Phases
a) neutral; b) El Nino; c) La Nina



The Three Phases

To understand the El Niño-Southern Oscillation (ENSO), it can be thought of as three phases – neutral conditions, El Niño and La Niña (**Figure 3**). The most important driver is the **thermocline,** the zone that separates warm surface water (above 25°C) and cool deep ocean water (below 15°C).

A - Neutral phase

During normal Pacific Ocean circulation, known as the Walker circulation, NE trade winds blow from east to west across the Pacific Ocean, driving warm, moist air and warm surface water towards the western Pacific, deepening the thermocline. This creates warm water at depth and sea level is typically 1m higher on Australia's east coast than on South America's west coast. The warm water drives atmospheric convection, forcing warm moist air upwards to form cumulonimbus clouds that produce heavy rain, hence the tropical rainforest in northern Australia and Indonesia. Once the air has released its moisture, it travels east at the top of the troposphere before descending over the cooler eastern Pacific.

In the ocean, the cold Humboldt Current passes northward along the South American coast. Cold water from deep is drawn up to replace the surface waters that are being driven westward. This **upwelling** brings nutrients from depth and supports major fisheries.

B - El Niño phase

This starts when the trade winds die down, or even reverse direction, allowing the warm surface waters to move eastward, and associated convection produces rain clouds over the Peruvian and Chilean coast. The warmer coastal waters are less rich in nutrients and can badly affect fisheries, as the phytoplankton are deprived of nutrients and so the base of the food chain is disrupted.

C - La Niña phase

This follows El Niño when the **Walker Circulation** reverts to the neutral phase, but is intensified by very strong, westerly-blowing trade winds. Sea surface temperatures are warmer than average in the western Pacific and cooler in the east, with upwelling of cold water from the deep ocean also contributing to lower sea temperatures. In 1998, sea surface temperatures were 2°C lower, but deep ocean water was 7°C colder than average.

How can an El Niño be detected?

- The first signs of an emerging El Niño or La Niña event are seen in the ocean. Indicators may include the following:
- Water temperatures at the surface and at depth
- The amount of stored energy in the ocean
- Ocean currents
- The strength of the Walker circulation, measured by the Southern Oscillation Index
- Atmospheric air pressure
- Upper atmosphere wind strength
- Cloudiness in the tropics

These variables are used in dynamic climate models to predict future events. Data is obtained from satellite observations, networks of buoys and radiosondes, supplied by national and international observing systems. This data is fed into supercomputers. Many models and scenarios are produced, depending on the data, and predictions are based on the mid-range values. They are continuously updated as new data is inputted. Statistical methods using historical patterns estimate the likelihood of an event. The data is used in various indices:

1. The Southern Oscillation Index (SOI)

This is a measure of the intensity of the Walker circulation that controls the strength of ENSO. It is determined by measuring the difference in sea-level air pressure between Tahiti and Darwin (**Figure 4**). Monthly averages are used as any shorter timescale is subject to too many fluctuations. A SOI value of below -8 heralds an El Niño, +8 indicates a La Niña event. However, the main disadvantage of using these sites are that they are quite far south of the equator (Tahiti 18'S; Darwin 12'S), whereas ENSO is focused closer to the equator.

2. Equatorial Southern Oscillation Index

To overcome this spatial problem, differences in sea-level air pressure between two large regions centred over the equator (**Figure 4**) (Indonesia in the west and the eastern equatorial Pacific) are used. The problem here is that records only go back to 1949, whereas the SOI has data extending back to the 1890s.

3. Sea surface temperature index

As the ocean shows the first indication of an emerging ENSO event, sea surface temperatures have long been recorded in zones along the equator, often using cargo ships. Subsequently, the most representative region showing temperature anomalies was located and named as Niño 3.4 (**Figure 4**).

4. Outgoing longwave radiation index

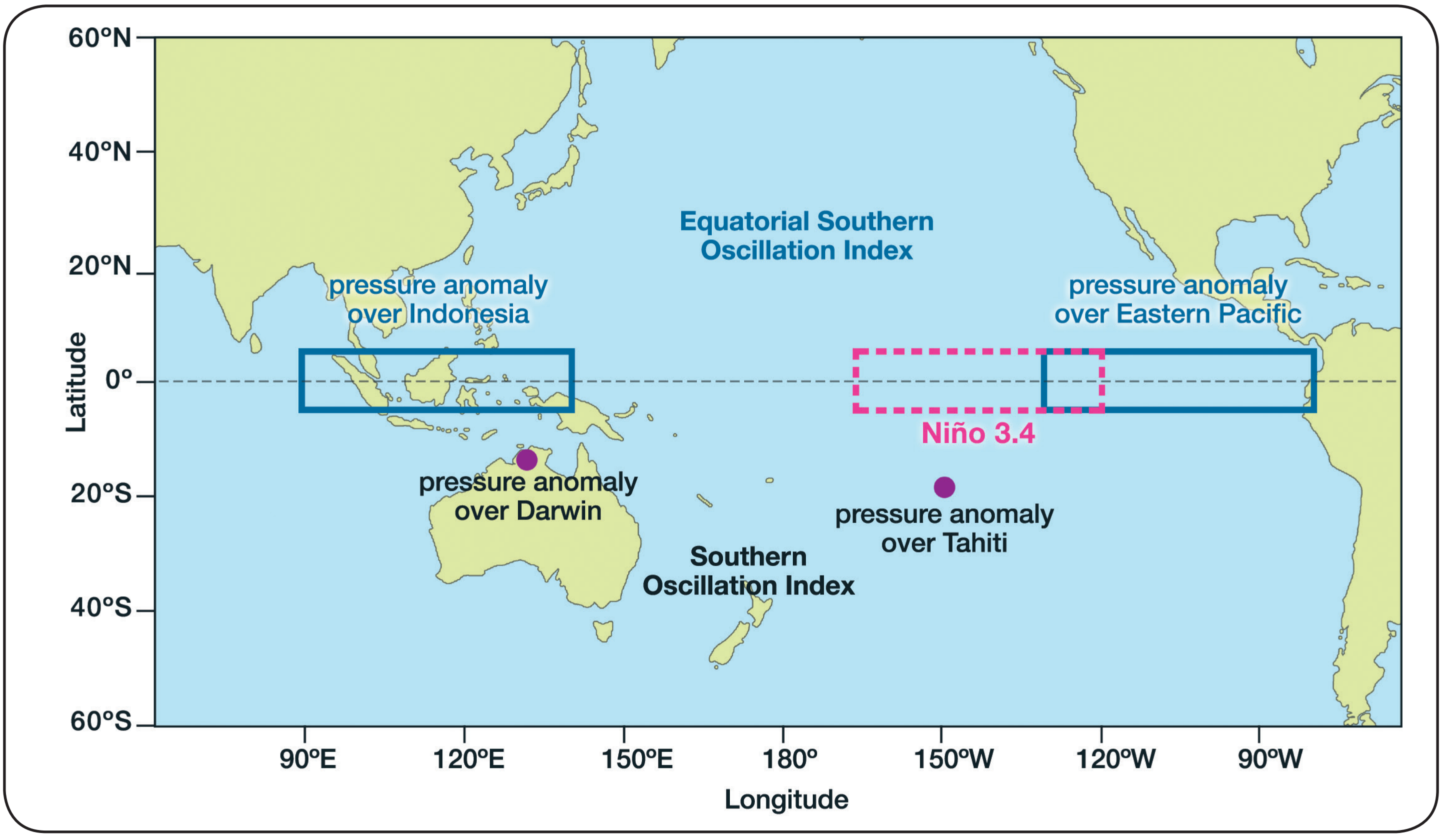
Satellite technology can monitor outgoing longwave radiation i.e. how much energy is leaving the Earth. It is reflected off cloud tops and gives a measure of convection and thus thunderstorm activity, allowing mapping of wetter and drier regions of the Pacific. Above-average thunderstorm activity is often associated with warmer sea surface temperatures.

5. Wind index

Other useful information is obtained by measuring wind strength in the upper and lower atmosphere, which indicates the strength of the Walker circulation.

The combination of these various indices is important because ENSO has many contributing factors and it is impossible to measure all of them accurately over such a vast area as the Pacific Ocean. Also, some locations within the tropical Pacific may be more interested in sea surface temperatures, whereas places further away may need data on large-scale changes in air pressure.

Figure 4 *The location of data sources for monitoring ENSO events (Source: F. Martin, NOAA)*



Technical Terms

Anomalies	Data outside the normal measurement range of values.
Coupled systems	Systems that interact and influence each other.
Positive feedback	When a small change in a system leads to an even greater change in the same direction.
ENSO	El Niño - Southern Oscillation, occurring every 3-7 years.
El Niño	A warming of the eastern Pacific, with accompanying changes in weather.
La Niña	A reversal from El Niño to neutral, but intensified, conditions.
SOI	Southern Oscillation Index indicates the intensity of the Walker atmospheric circulation.
Teleconnections	Unusual weather patterns across the world, driven by El Niño.
Thermocline	Literally "heat slope": the temperature gradient at depth in the ocean.
Walker Circulation	The result of differences in surface pressure and temperature over the western and eastern tropical Pacific Ocean.
Upwelling	Removal of warm surface water pulls up cold water from the deep ocean, rich with nutrients.

Features of the 2015-16 El Niño

No two El Niños are ever the same, but the one in 2015-16 was, in some places, the strongest ever recorded. However, the subsequent La Niña was much weaker than expected. The strength of the El Niño in 2015 was partly due to a pool of warm water that hovered around the equator in the central Pacific during 2014, but which failed to build and develop into an El Niño. Nevertheless, it provided a higher starting point for 2015, allowing an early build up and continual strengthening, peaking in January 2016, which is late for an El Niño – the peak is usually in November.

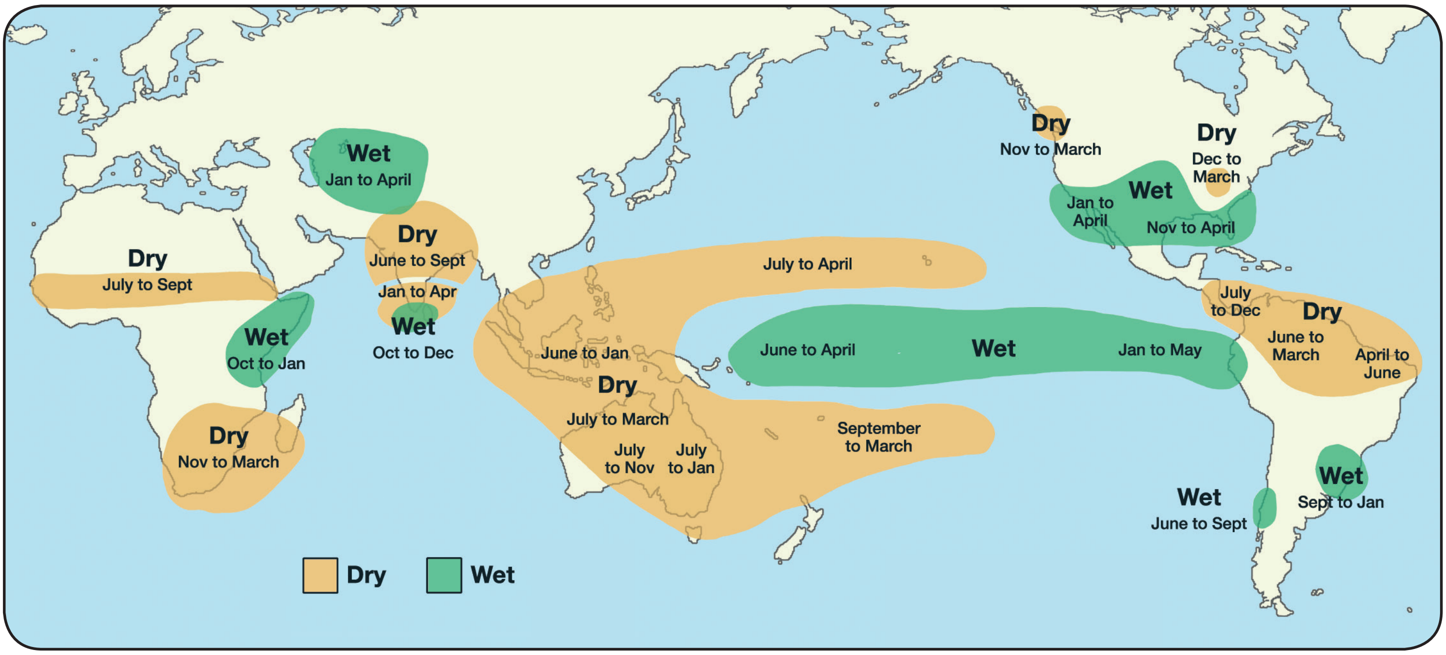
Apart from its longevity, the 2015 El Niño covered an extremely large area, extending northward to Hawaii at 21°N. Even when the El Niño began to wane in March 2016, this pool of warm water remained and may be the reason why a strong La Niña did not develop. The warm water would have reduced the temperature gradients and hence the wind strength of the trade winds in the eastern and central Pacific.

ENSO is not the only oscillation that occurs in the Pacific. The Pacific Decadal Oscillation (PDO) is a large-scale, longer-term pattern of sea temperature changes, occurring at intervals of 5-20 years and it has an impact on the strength of ENSO. It has a warm positive phase that enhances El Niño, and its cold phase intensifies La Niña. The PDO became positive in 2014 and has remained so for three years, again partly explaining the strength of the 2015-16 El Niño, and the relatively weak 2016 La Niña.

Impacts of 2015-16 El Niño

An El Niño creates short-term natural changes in weather conditions, affecting fisheries and agricultural production, and this can have a severe impact on human populations in terms of food security and health. The most reliable effects of El Niño are excessive rainfall in south-eastern South America, eastern equatorial Africa, and southern USA and reduced rainfall over Indonesia, Australia, southern Africa and northern South America (**Figure 5**). The latter makes these areas more vulnerable to forest fires. The burning of trees and peat increases the buildup of carbon dioxide in the atmosphere and reduce air quality.

Figure 5 *Characteristic (but not guaranteed) changes in rainfall during El Niño (Source: IRI)*



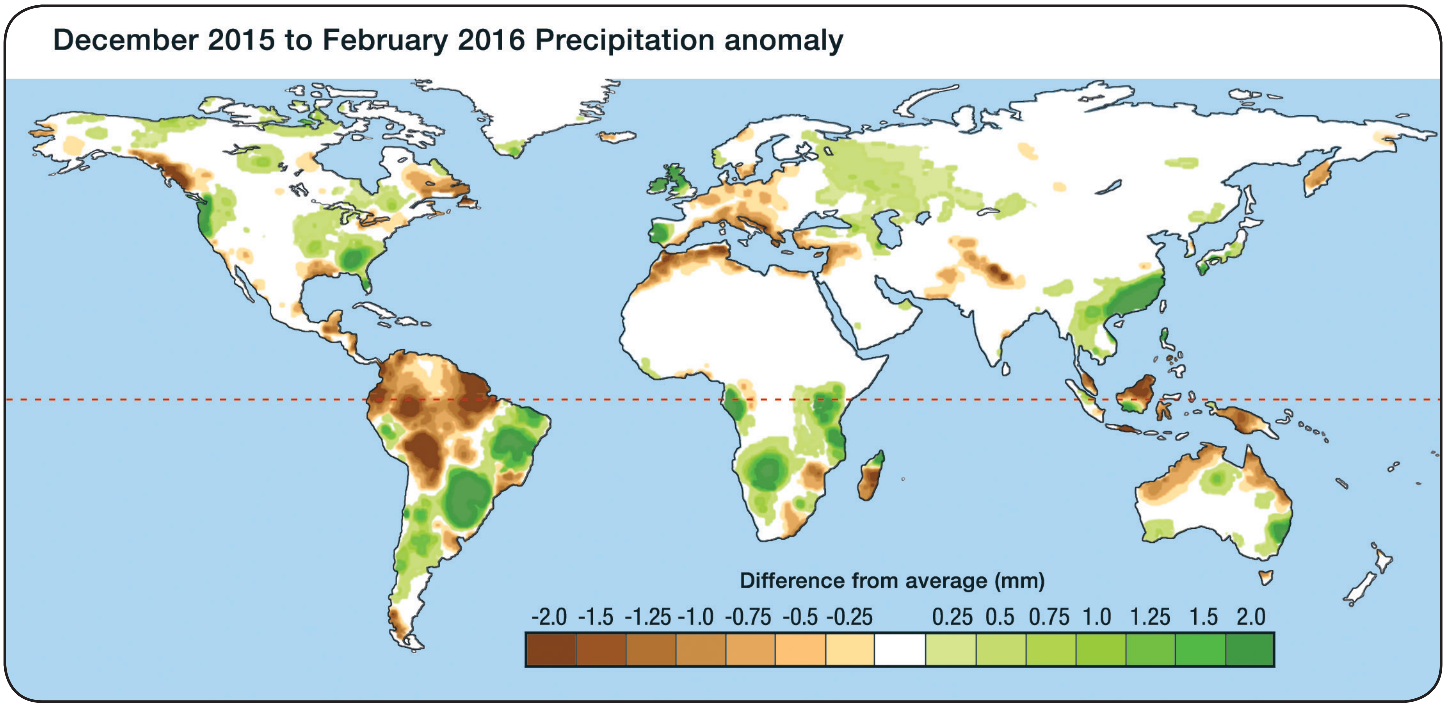


Figure 6 *Precipitation anomalies during the 2015 El Niño (NOAA)*

The map above shows rainfall anomalies in the 2015 El Niño, showing broad agreement with expected precipitation patterns in some regions, and digression in others.

Cyclone Winston

It is expected that in any El Niño event, more tropical cyclones than normal occur in the Pacific, and conversely, less in the Atlantic. In both cases the main reason is the amount of vertical wind shear. In the eastern Pacific region, trade winds weaken and air is more moist and unstable, factors suited to cyclone development. Stronger westerly winds increase wind shear in the Atlantic that hinders the development and intensification of cyclones. The Accumulated Cyclone Energy (ACE) for the 2015 season was only 68% of the long term median value.

The 2015–16 South Pacific cyclone season was one of the most severe on record, with a total of 50 deaths and damage amounting to $1.405 billion. The most destructive was Cyclone Winston, which reached Category 5 status on the Saffir-Simpson scale.

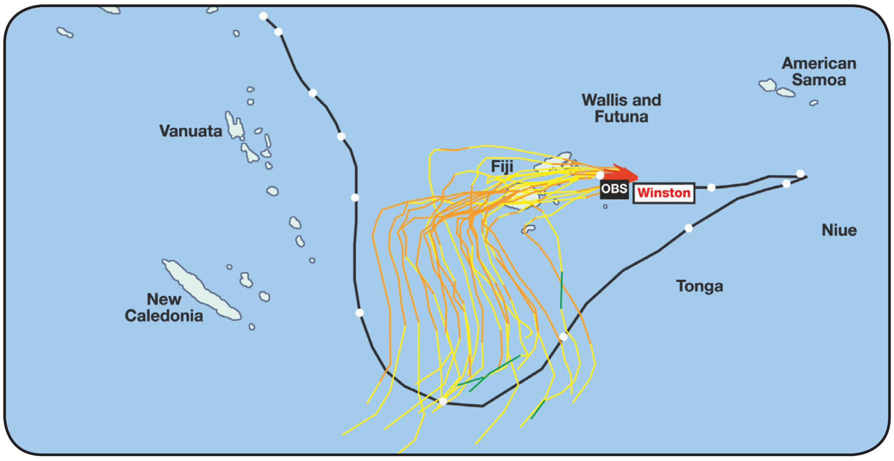


Figure 7 *Cyclone Winston - yellow lines mark possible tracks as it decayed (NOAA)*

On 12 February, 2016 there was a rapid intensification over the warmest part of the El Niño system, which was 2^{o} C higher than average. Conditions then weakened and the system stalled before it tracked back on itself (**Figure 7**). It approached Fiji from the east where people were least prepared in experiencing cyclones. Winston reached Category 5 again on 19 and 20 February, and was the strongest cyclone ever to hit this island. In preparation, shelters were opened and a national curfew was announced, but 44 deaths were recorded and $1.4 billion damages meant it was the costliest cyclone to ever hit the South Pacific Basin.

Impacts in USA

In the United States, a strong, classic El Niño usually heralds a warmer Northwest and colder Southeast. Atmospheric rivers, narrow bands of concentrated moisture in the upper atmosphere, are common features, in that 3-5 exist at any one time in a hemisphere, but they intensify during an El Niño event and are associated with extreme flooding in southern California. In 1997-98, rains caused 17 deaths and damage amounting to $883million across California. 40 out of 58 counties were declared disaster zones, especially in Southern California where 30 inches of rain fell. So, when the 2015 El Niño was predicted well in advance, there was a state-wide 30% increase in purchased flood insurance policies and in Los Angeles County, the value of insured property doubled. Other preparatory activities included the clearance of drains, pruning of vegetation and stocking up on sandbags.

Teleconnections

An El Niño affects local conditions within the tropical Pacific but also has far-reaching global effects (**teleconnections**) caused by changing storm tracks due to pressure differences and cloud cover. For example, circulation patterns that cause wildfires in Indonesia are the same that affect rainfall in California.

Predictions of heavy rain and floods did not materialise in Southern California, despite the experience of 1997-98. Only average rainfall fell in the north of the state, despite the El Niño-strengthened jet stream, and the hoped-for restoration of water supplies in drought-stricken southern California did not occur. This was against expectations because strong El Niños in the past have always been associated with wet Californian winters, floods and mudslides. The unused preparations were not considered a waste as they make the communities more resilient in future floods.

Ethiopia drought

Severe drought over much of Ethiopia, triggered by El Niño, caused 80% of the harvest to fail and affected 22 million people. As a consequence, malnutrition and internal and external migration have risen, increasing the vulnerability to communicable diseases. Limited supplies of safe water were prioritised for drinking and cooking, rather than personal hygiene. The drought was followed by unusually heavy rain, raising the risk of insect-borne diseases, Rift Valley fever and cholera outbreaks. The World Health Organisation (WHO) estimated that health impacts would last a year.

WHO and partners have supported the national government in preparedness measures for El Niño. Disease monitoring, vaccinations, promotion of hygiene programmes, improving access to medical services and specialised health personnel are all part of an integrated plan to increase resilience to the impacts of El Niño in Ethiopia.

Paraguay floods

El Niño exacerbated the summer rains and the worst floods for many decades forced 100,000 people to evacuate their homes, mostly in the capital Asuncion where a State of Emergency was declared, and in areas bordering Argentina and Uruguay. Schools and military buildings were used as temporary shelters as well as makeshift wood and tin shelters. Many people did not leave their homes for fear of looting. Government aid was very slow; families spent their savings in reconstruction, as they could not wait for official funds to arrive. There was criticism that permanent solutions to flooding are needed.

It is estimated that 60 million people worldwide were affected by the 2015 El Niño. The only response to ENSO events is to monitor conditions, predict events and adapt to its consequences. It requires the combined efforts of scientists, economists, politicians, business leaders and citizens to build resilience in communities that are regularly affected by such events.

2017 – is a new El Niño beginning?

During February-March 2017, Peru and Colombia suffered excessive rainfall, resulting in massive floods. In Peru, the death toll reached 94 and 700,000 were made homeless across half of the country. The cost to Peru's economy in lost productivity has been estimated at $3.1 billion, or 1.6% GDP. In the same period, a single mudslide in Mocoa, Colombia, following torrential rain, caused more than 450 deaths. This is in an equatorial region considered to be the most affected by changing weather patterns.

Typical La Niña patterns of cold, dry weather were expected in February 2017, with neutral ENSO conditions returning in Spring. However, coastal waters off Peru are warmer than normal, which would suggest El Niño conditions. Due to the limited area of warm water, it is being called a coastal El Niño, or a mini-El Niño. It may be a sign that a more severe El Niño will develop later in 2017, or it could be due to changing weather patterns driven by global warming.

El Niño 2015-16 and climate change

The strong ENSO event of 2015-16 needs to be seen in the context of global climate change. 2016 was the hottest year on record, a combination of global climate change and the El Niño effect, the latter directly contributing to the 2016 global temperature by 0.12°C. Average global sea level rose by 7mm due to thermal expansion. For 12 consecutive months, global temperatures reached new records, never before experienced. Equally, the seven highest monthly global ocean temperature values also occurred in this time.

El Niño is associated with extreme events and, across the whole of the USA, records were set during the winter of 2015-16, although they may not all have been wholly attributable to El Niño.

These records include:

- Warmest winter on record (in 48 states).
- Wettest December ever recorded (in 48 states).
- Highest snowfall from a single snowstorm in Philadelphia, Newark, and New York City.
- Second wettest winter on record in Atlanta.

It is unclear whether global warming will produce stronger or more frequent El Niños. Both phenomena involve large changes in the earth's heat balance but climate models are not yet sophisticated enough to combine the effects of global warming and El Niño. Understanding of the physical processes, such as the role of clouds, is still at early stages and more scientific investigations are necessary.

Further Reading

Growth of the 1997 and 2015 El Niños:
https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20009

Excellent FAQs at NOAA:
https://www.pmel.noaa.gov/elNiño/faq#fact

Also see: *Geography Factsheet 61: El Niño Explained - 'The Little Child with the Big Kick'* http://www.curriculum-press.co.uk

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