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Earth's Dynamic Systems: El Nino and La Nina

The Pacific's Global Reach

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

El Niño-Southern Oscillation (ENSO) is a global climate phenomenon that emerges from variation in winds and sea surface temperatures over the tropical Pacific Ocean. Those variations have an irregular pattern but do have some appearance of cycles. The occurrence of ENSO is not easily predictable. It affects the climate of much of the tropics and subtropics, and has links (teleconnections) to higher-latitude regions of the world.

The warming phase of the sea surface temperature is known as "El Niño" and the cooling phase as "La Niña". The Southern Oscillation is the accompanying atmospheric oscillation, which is coupled with the sea temperature change. El

Niño is associated with higher than normal sea level air pressure over Indonesia and Australia, and across the Indian Ocean to the Atlantic Ocean.

La Niña has roughly the reverse pattern: high pressure over the central and eastern Pacific and lower pressure through much of the rest of the tropics and subtropics. The two phenomena last a year or so each and typically occur every two to seven years with varying intensity, with neutral periods of lower intensity interspersed. El Niño events can be more intense, but La Niña events may repeat and last longer.

A key mechanism of ENSO is the Bjerknes feedback (named after Jacob Bjerknes in 1969) in which the atmospheric changes alter the sea temperatures that, in turn, alter the atmospheric winds in a positive feedback. Weaker easterly trade winds result in a surge of warm surface waters to the east and reduced ocean upwelling on the equator.

In turn, this leads to warmer sea surface temperatures (called El Niño), a weaker Walker circulation (an east-west overturning circulation in the atmosphere) and even weaker trade winds.

Therefore, the relative frequency of El Niño compared to La Niña events can affect global temperature trends on timescales of around ten years. The countries most affected by ENSO are developing countries that are bordering the Pacific Ocean and dependent on agriculture and fishing.

El Niño episodes are defined as sustained warming of the central and eastern tropical Pacific Ocean, thus resulting in a decrease in the strength of the Pacific trade winds, and a reduction in rainfall over eastern and northern Australia.

The story of this understanding is a study in scale. The pattern named El Niño was first noticed by fishermen on one coast of one country, as a warm current that arrived around Christmas and emptied their nets; a century and a half

later its fingerprint is read in the price of wheat, the monsoon's arrival, the number of hurricanes in the Atlantic, and the temperature of the whole planet's surface, and the forecasting of its swings has become a permanent branch of applied science on which governments, farmers, and insurers quietly depend. The two phases, warm and cool, are the planet's loudest year-to-year voice, and this book follows that voice from its discovery to the present state of its prediction.

Chapter 1: The Discovery of El Nino and La Nina

El Niño events cause short-term (approximately one year in length) spikes in global average surface temperature, while La Niña events cause short term surface cooling. In climate change science, ENSO is known as one of the internal climate variability phenomena. Future trends in ENSO due to climate change are uncertain, although climate change exacerbates the effects of droughts and floods. The IPCC Sixth Assessment Report summarized the scientific knowledge in 2021 for the future of ENSO as follows: "In the long term, it is very likely that the precipitation variance related to El Niño-Southern Oscillation will increase".

The scientific consensus is also that "it is very likely that rainfall variability related to changes in the strength and spatial extent of ENSO teleconnections will lead to significant changes at regional scale". The El Niño-Southern Oscillation is a single climate phenomenon that recurs in three phases: Neutral, La Niña or El Niño.

La Niña and El Niño are opposite phases in the oscillation which are deemed to occur when specific ocean and atmospheric conditions are reached or exceeded.

The "Southern Oscillation" is the oscillation in surface air pressure between the tropical eastern Pacific Ocean waters and the tropical western Pacific Ocean waters.

An early recorded mention of the term "El Niño" ("The Boy" in Spanish) to refer to climate occurred in 1892, when Captain Camilo Carrillo told the geographical society congress in Lima that Peruvian sailors named the warm south-flowing current "El Niño", referring to the Christ Child, because it was most noticeable around Christmas.

Over time, the term has evolved and now refers to the warm and negative phase of the El Niño-Southern Oscillation (ENSO).

The original phrase, El Niño de Navidad 'The Christmas Boy', arose centuries ago, when Peruvian fishermen named the weather phenomenon after the newborn Christ. La Niña ("The Girl" in Spanish) is the colder counterpart of El

Niño, as part of the broader ENSO climate pattern. In the past, it was also called an anti-El Niño and El Viejo 'the old man'.

A negative phase exists when atmospheric pressure over Indonesia and the

West Pacific is abnormally high and pressure over the East Pacific is abnormally low during El Niño episodes, and a positive phase is when the opposite occurs during La Niña episodes. On average, the temperature of the ocean surface in the tropical East Pacific is roughly 8-10 °C (14-18 °F) cooler than in the tropical West Pacific.

The sea surface temperature (SST) of the West Pacific northeast of Australia averages around 28-30 °C (82-86 °F). SSTs in the East Pacific off the western coast of South America are closer to 20 °C (68 °F). Strong trade winds near the equator drive water away from the East Pacific and into the West Pacific.

This water is slowly warmed by the Sun as it moves west along the equator, the wind stress acting on the ocean surface being balanced by a sea surface slope.

One result of this is that sea levels near Indonesia are typically around 0.5 m (1.5 ft) higher than that near Peru.

The warm surface waters collect in the western Pacific, with the result that the thermocline, the transitional zone between the warmer waters near the ocean surface and the cooler waters of the deep ocean, lies much deeper in the western Pacific, where it has an average depth of around 140 m (450 ft) compared to around 30 m (90 ft) in the East Pacific.

At depth, the sloping surface thermocline helps reduce the east-west pressure difference due to the sea level slope, but below the thermocline, the pressure difference is still enough to drive the eastward flowing cold equatorial undercurrent. The cooler deep ocean water replaces the outgoing surface waters in the East Pacific, rising to the ocean surface in a process called upwelling.

Along the western coast of South America, water near the ocean surface is pushed westward due to the combination of the trade winds and the Coriolis effect. This process is known as Ekman transport. Colder water from deeper in the ocean rises along the continental margin to replace the near-surface water.

This process cools the East Pacific because the thermocline is closer to the ocean surface, leaving relatively little separation between the deeper cold water and the ocean surface.

Currently, each country has a different threshold for what constitutes an El Niño event, which is tailored to their specific interests, for example:

In the United States, an El Niño is declared when the Climate Prediction Center, which monitors the sea surface temperatures in the Niño 3.4 region and the tropical Pacific, forecasts that the sea surface temperature will be.5 °C

(0.90 °F) above average or more for the next several seasons.

The IPCC Sixth Assessment Report summarized the state of the art of research in 2021 into the future of ENSO as follows:

The northward-flowing Humboldt Current carries colder water from the Southern Ocean to the tropics in the East Pacific. The combination of the

Humboldt Current and upwelling maintains an area of cooler ocean waters off the coast of Peru. The West Pacific lacks a cold ocean current and has less upwelling as the trade winds are usually weaker than in the East Pacific, allowing the West Pacific to reach higher temperatures.

These warmer waters provide energy for the upward movement of air.

As a result, the warm West Pacific has, on average, more cloud and rain than the cool East Pacific. ENSO describes a quasi-periodic change of both oceanic and atmospheric conditions over the tropical Pacific Ocean. These changes affect weather patterns across much of the Earth. The tropical Pacific is said to be in one of three states of ENSO (also called "phases") depending on the atmospheric and oceanic conditions.

When the tropical Pacific roughly reflects the average conditions, the state of ENSO is said to be in the neutral phase. However, the tropical Pacific experiences occasional shifts away from these average conditions. If the trade winds (blowing from east to west) are weaker than average, then both the upwelling in the East Pacific and the flow of warmer ocean surface waters towards the West Pacific lessen.

This results in a cooler West Pacific and a warmer East Pacific, leading to a shift of cloud and rain towards the East Pacific. This situation is called El Niño. The opposite occurs if trade winds are stronger than average, leading to a warmer West Pacific and a cooler East Pacific. This situation is called La Niña and is associated with increased cloudiness and rainfall over the West Pacific.

The close relationship between ocean temperatures and the strength of the trade winds was first identified by Jacob Bjerknes in 1969. Bjerknes also hypothesized that ENSO was a positive feedback system where the associated changes in one component of the climate system (the ocean or atmosphere)

tend to reinforce changes in the other. This process is known as Bjerknes feedback.

For example, during the growth of El Niño, the reduced contrast in ocean temperatures across the Pacific results in weaker trade winds, further reinforcing the El Niño state. Although these associated changes in the ocean

and atmosphere often occur together, the state of the atmosphere may resemble a different ENSO phase than the state of the ocean or vice versa.

Because their states are closely linked, the variations of ENSO may arise from changes in both the ocean and atmosphere and not necessarily from an initial change of exclusively one or the other. Conceptual models explaining how

ENSO operates generally accept the Bjerknes feedback hypothesis. However, ENSO would perpetually remain in one phase if Bjerknes feedback were the only process occurring.

Several theories have been proposed to explain how ENSO can change from one state to the next despite the positive feedback.

These explanations broadly fall under two categories. In one view, the Bjerknes feedback naturally triggers negative feedbacks that end and reverse the abnormal state of the tropical Pacific. This perspective implies that the processes that lead to El Niño and La Niña also eventually bring about their end, making ENSO a self-sustaining process.

Other theories view the state of ENSO as being changed by irregular and external phenomena such as the Madden-Julian oscillation, tropical instability waves, and westerly wind bursts.

Bjerknes proposed that ENSO was due to an east-west overturning atmospheric cell above the Pacific, which he named the Walker Circulation after Gilbert Walker who discovered the Southern Oscillation during the early twentieth century.

Bjerknes proposed that the strength of the cell depended on the east-west temperature gradient along the Equator, the rising branch of the cell being associated with high sea temperatures, convection and rainfall in the western Pacific, while the downward branch occurs over cooler sea surface temperatures in the central and eastern Pacific.

During the growth of El Niños, the increased sea surface temperature in the east reduces the east-west temperature gradient and reduces the strength of the overturning.

This, in turn, reduces the easterly winds at the ocean surface, reduces the upwelling of cold water and eventually results in even warmer sea surface temperatures in the eastern Pacific. The Southern Oscillation is the atmospheric component of ENSO. The strength of the Southern Oscillation is measured by the Southern Oscillation Index (SOI).

The SOI is computed from fluctuations in the surface air pressure difference

between Tahiti (in the Pacific) and Darwin, Australia (on the Indian Ocean). El Niño episodes have negative SOI, meaning there is lower pressure over Tahiti and higher pressure in Darwin. La Niña episodes on the other hand have positive SOI, meaning there is higher pressure in Tahiti and lower in Darwin.

The ENSO is considered to be a potential tipping element in Earth's climate.

Global warming can strengthen the ENSO teleconnection and resulting extreme weather events. For example, an increase in the frequency and magnitude of El Niño events have triggered warmer than usual temperatures over the Indian Ocean, by modulating the Walker circulation.

A study of climate records has shown that El Niño events in the equatorial Pacific are generally associated with a warm tropical North Atlantic in the following spring and summer. About half of El Niño events persist sufficiently into the spring months for the Western Hemisphere Warm Pool to become unusually large in summer.

Occasionally, El Niño's effect on the Atlantic Walker circulation over South America strengthens the easterly trade winds in the western equatorial Atlantic region.

The 2023-2024 El Niño was regarded as the fifth-most powerful El Niño-Southern Oscillation event in recorded history, resulting in widespread droughts, flooding and other natural disasters across the globe.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.