Reports to the Nation
On Our Changing Planet

El Niño and Climate Prediction

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Why Predict Climate?

The march of the seasons imparts a rhythm to life on Earth. Over much of the world, climate swings like a pendulum between summer and winter. Even in the tropics, where the weather is warm year round, rainy seasons, known as *monsoons*, alternate with dry seasons and each has its own distinct pattern of prevailing winds.

To make its way in the world, the human race has learned to adapt to the changing seasons. Year after year, people have sown and harvested crops, bred livestock, deployed fishing vessels, and planned hunting expeditions according to a well-defined series of calendar dates. Centuries of tradition have influenced the way we schedule events and activities such as construction projects, military campaigns, school vacations, on- and off-season rates in hotels, and even the sales of umbrellas and swimwear.

But the rhythm of the seasons cannot always be relied upon. At times the tropical Pacific Ocean and large expanses of the global atmosphere seem to be marching to the beat of a different drummer, disrupting the normal patterns of life of countless species of plants and animals along with hundreds of millions of human beings. So that they may anticipate these occasional lapses in the march of the seasons and help societies plan accordingly, scientists are seeking to understand these competing rhythms: the strongest of which is the alternation between the "normal climate" and a different but still recurrent set of climatic conditions in the Pacific region called *El Niño*.

What is El Niño?

The term El Niño (Spanish for "the Christ Child") was originally used by fishermen along the coasts of Ecuador and Peru to refer to a warm ocean current that typically appears around Christmastime and lasts for several months. Fish are less abundant during these warm intervals, so fishermen often take a break to repair their equipment and spend time with their families. In some years, however, the water is especially warm and the break in the fishing season persists into May or even June. Over the years, the term "El Niño" has come to be reserved for these exceptionally strong warm intervals that not only disrupt the normal lives of the fishermen, but also bring heavy rains.

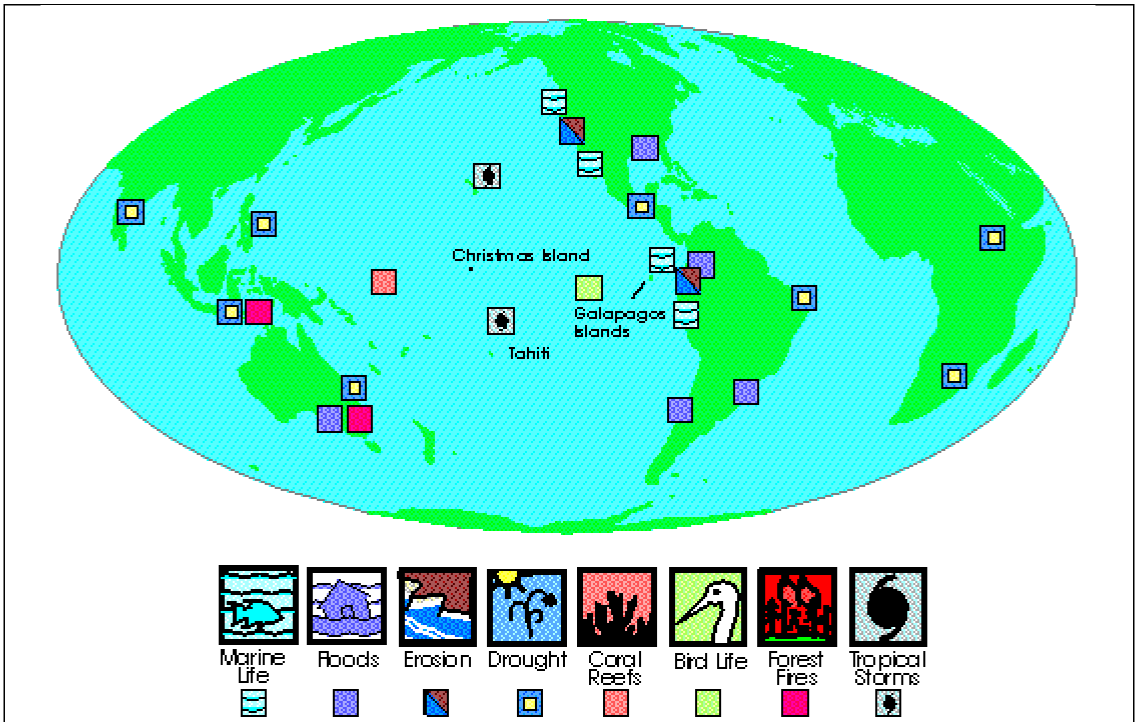
During the past 40 years, nine El Niños have affected the South American coast. Most of them raised water temperatures not only along the coast, but also at the Galapagos islands and in a belt stretching 5000 miles across the equatorial Pacific. The weaker events raised sea temperatures only one to two degrees Fahrenheit and had only minor impacts on South American fisheries. But the strong ones, like the El Niño of 1982-83, left an imprint, not only upon the local weather and marine life, but also on climatic conditions around the globe.

A Case Study

The 1982-83 El Niño, by many measures the strongest thus far this century, was not predicted and not even recognized by scientists during its early stages. In retrospect, its beginnings can be traced back to

May 1982, when the easterly (east to west) surface winds, that usually extend nearly all the way across the equatorial Pacific from the Galapagos islands to Indonesia, began to weaken. West of the dateline, winds shifted to westerly and a period of stormy weather set in.

Within the next few weeks, the ocean began to react to the changes in wind speed and direction. Sea level at Christmas Island in the mid-Pacific (see map below) rose several inches. By October, sea-level rises of up to a foot had spread 6000 miles eastward to Ecuador. As sea level rose in the east, it simultaneously dropped in the western Pacific, exposing and destroying the upper layers of the fragile coral reefs surrounding many islands. Sea-surface temperatures at the Galapagos islands and along the coast of Ecuador rose from typical levels in the low 70s (degrees Fahrenheit) well up into the 80s.



Subtle changes in the interplay of wind and water in the tropical Pacific can affect local ecosystems and human lives in far flung regions of the globe. Some of the documented environmental impacts of the 1982-1983 El Niño event, the strongest thus far this century, are indicated by symbols on this global map.

In the face of these Pacific Ocean-wide changes, marine life soon responded. Following the sea-level rises at Christmas Island, sea birds abandoned their young and scattered over a wide expanse of the ocean in a desperate search for food. By the time conditions along the coast of Peru returned to normal in mid-1983, 25 percent of the year's fur seal and sea lion adults and all of the pups had died. Many species of fish suffered similar losses. Along the expanse of Pacific coastline stretching from Chile to British Columbia, water temperatures were above normal, and fish that normally live in the tropical and subtropical waters either migrated or were displaced poleward. Yet some marine creatures also benefited from the turmoil, as evidenced by the unexpected harvest of warm-water scallops that washed ashore on the coast of Ecuador.

The 1982-83 El Niño produced equally dramatic effects on land. In Ecuador and northern Peru, up to 100 inches of rain fell during a six month period, transforming the coastal desert into a grassland dotted with lakes. Lush vegetation attracted swarms of grasshoppers, which fueled explosions in the toad and bird populations. The new lakes also provided a temporary habitat for fish that had migrated upstream from the sea during the floods and become trapped. Many of them were harvested by local residents as the lakes dried up. In some of the flooded coastal estuaries, shrimp production set records, but so, too, did the number of mosquito-borne malaria cases.

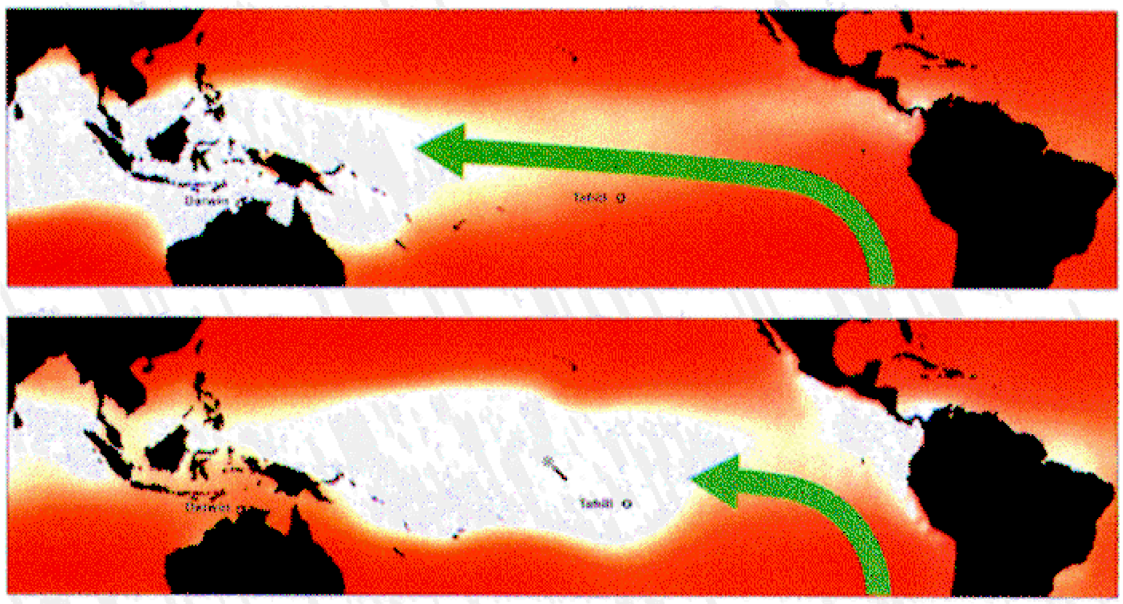
As these examples show, the economic impacts of the 1982-83 El Niño were large. Along the South American coast, the losses overshadowed the windfalls. The fishing industries in Ecuador and Peru suffered heavily when their anchovy harvest failed and their sardines unexpectedly moved south into Chilean waters. Farther to the west, abnormal wind patterns steered typhoons off their usual tracks to islands such as Hawaii and Tahiti, which are unaccustomed to such severe weather. They also caused the monsoon rains to fall over the central Pacific instead of on the western side, which led to droughts and disastrous forest fires in Indonesia and Australia. Winter storm battered southern California and caused widespread flooding across the southern United States, while northern ski resort owners complained of unusually mild weather and a lack of snow. Overall, the loss to the world economy in 1982-83 as a result of the climate changes amounted to over $8 billion. The toll in terms of human suffering is much more difficult to estimate.

El Niño and Climate

The link between these climatic effects in distant parts of the globe and El Niño is now well established. Yet it has taken some time for scientists to understand how the various pieces of the puzzle--from ocean currents to winds and heavy rains--fit together. Decades ago, the British scientist Sir Gilbert Walker provided the first clue.

During the 1920s, while scientists in South America were busy documenting the local effects of El Niño, Walker was on assignment in India, trying to find a way to predict the Asian monsoon. As he sorted through world weather records, he discovered a remarkable connection between barometer readings at stations on the eastern and western sides of the Pacific. He noticed that when pressure rises in the east, it usually falls in the west, and vice versa. Walker coined the term Southern Oscillation to dramatize the ups and downs in this east-west seesaw in Southern Pacific barometers.

When the seesaw is in its "high-index" (strongly tilted) state, pressure is high on the eastern side of the Pacific and low on the western side, as indicated in the upper panel of the figure below. Along the equator, the east-west pressure contrast drives easterly (east to west) surface winds which extend from the Galapagos Islands nearly all the way to Indonesia. When the seesaw switches into its "low-index" (weakly tilted) state, as shown in the lower panel, the easterly surface winds weaken. The biggest changes in the slope of the seesaw and in the strength of the easterlies occur over the western Pacific. West of the dateline the easterlies usually disappear altogether during low-index years, whereas east of the dateline they usually only weaken.



Sir Gilbert walker provided an important clue concerning El Niño when he discovered that air pressures at sea level in the South Pacific seesaw back and forth between two distinct patterns. In the "high index" phase of what Walker referred to as the "Southern Oscillation" (upper map for November 1988) pressure is higher (darker red) near and to the east of Tahiti than farther to the west near Darwin. The east-west pressure difference along the equator causes the surface air to flow westward, as indicated by the long arrow. When the atmosphere switches into the "low index" phase (lower map for November 1982) barometers rise in the west and fall in the east, signaling a reduction or even a reversal of the pressure difference between Darwin and Tahiti. The flattening of the seesaw causes the easterly surface winds to weaken and retreat eastward as shown. We now know that the "low index" phase is usually accompanied by El Niño conditions.

Walker noticed that monsoon seasons with low-index conditions are often marked by drought in Australia, Indonesia, India, and parts of Africa. He also claimed that low-index winters tend to be unusually mild in western Canada. One of his British colleagues chided him in print for suggesting that climatic conditions over such widely separated regions of the globe could be linked. In his reply Walker predicted, correctly, that an explanation would be forthcoming, but that it would require a knowledge of wind patterns above ground level, which were not routinely being observed at that time.

In the following decades, researchers added new pieces to the emerging picture of the Southern Oscillation. One such piece came from a remote part of the world for which Walker had no information: the desert islands of the central equatorial Pacific. According to standard climate statistics, these islands receive as much rainfall as many islands with much more luxuriant vegetation. One might wonder, then, "Why are they so barren?" The answer becomes apparent when one examines the rainfall records year by year. Most years, in fact, the islands receive little or no rainfall. But during "low-index" years, they experience torrential rains, day after day, month after month. Hence, Walker's pressure seesaw is linked to dramatic changes in the distribution of rainfall in the tropics.

In the late 1960s, University of California professor Jacob Bjerknes put another important piece of the puzzle into place. As a young scientist in Norway, Bjerknes had gained fame by publishing the first clearly understandable description of the life cycle of storms in temperate latitudes. Now, fifty years later, he was the first to see a connection between unusually warm sea-surface temperatures and the weak easterlies and heavy rainfall that accompany low-index conditions. Ultimately, Bjerknes' discovery led to the recognition that the warm waters of El Niño and the pressure seesaw of Walker's Southern Oscillation are part and parcel of the same phenomenon--sometimes referred to by the acronym ENSO.

Learning from the Past

In contrast to the march of the seasons, which is regular and therefore highly predictable, El Niño recurs at irregular intervals ranging from two years to a decade, and no two events are exactly alike. For example, the 1982-83 El Niño caught scientists by surprise because, unlike the El Niños of the previous three decades, it was not preceded by a period of stronger than normal easterlies on the equator. To further confuse scientists, this particular event also set in unusually late in the calendar year.

In order to guard against the possibility of being surprised by another "maverick" El Niño, scientists continue to document as many past events as possible by piecing together bits of historical evidence from many different sources, including:

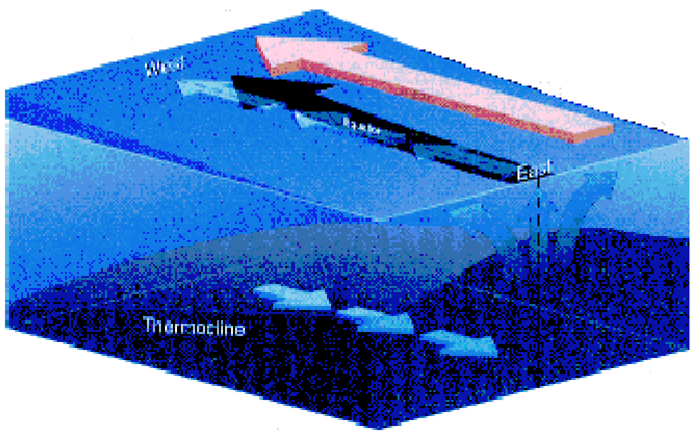
- sea-surface temperature records. Many millions of reports from merchant ships crossing the equator have been collected for over a century. Puerto Chicama on the Peru coast has reported water temperature regularly since the 1930s.
- daily observations of atmospheric pressure and rainfall. Some stations, like the one at Darwin, Australia, have records extending back more than 100 years.
- fisheries' records from South America.
- writings of Spanish colonists in settlements along the coasts of Peru and Ecuador dating back to the late 15th century.

So-called "proxy evidence" based on coral samples from, for example, the Galapagos Islands provides information on how the frequency of El Niño events may have varied on a time scale of centuries to, potentially, thousands of years. Even data from trees, in the varying widths of their annual growth rings, provide clues to El Niños of past centuries.

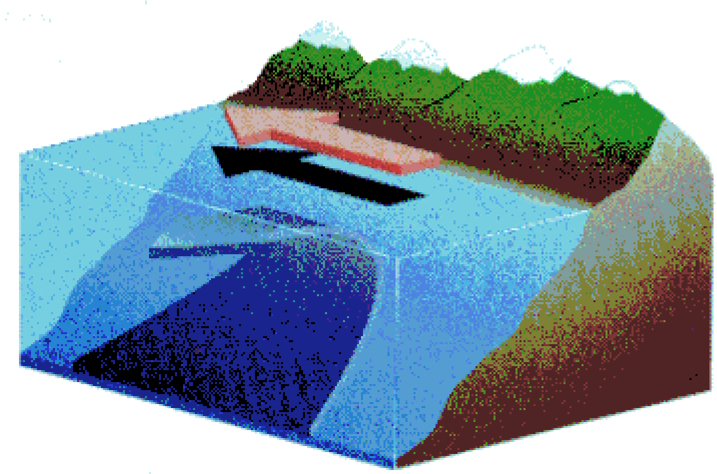
Winds, Upwelling, and the Food Web

To understand how El Niño affects the ocean, we first need to learn about how surface winds move the water during normal years, and how the resulting motions affect water temperatures and amounts of chemical nutrients available to the food web. We will consider two separate regions: the equatorial Pacific extending westward from the Galapagos Islands to beyond the dateline, and the coastal waters off Peru and southern Ecuador.

The easterly winds that blow along the equator and the southeasterly winds that blow along the Peru and Ecuador coasts both tend to drag the surface water along with them. The Earth's rotation then deflects the resulting surface currents toward the right (northward) in the Northern Hemisphere and to the left (southward) in the Southern Hemisphere. The surface waters are therefore deflected away from the equator in both directions and away from the coastline. Where the surface water moves away, colder, nutrient-rich water comes up from below to replace it, a phenomenon known as *upwelling*. Both the equatorial upwelling and the coastal upwelling (see figure below) are concentrated in narrow regions less than 100 miles wide which show up clearly in the satellite picture to the right.



Equatorial Upwelling
Easterly winds (red arrow) drag the surface water westward along the equator. The Earth's rotation deflects the western current toward the right in the Northern Hemisphere and toward the left in the southern Hemisphere, driving the surface water away from the equator and bringing up water from below (upward arrows). In addition, the winds cause warm surface water to accumulate on the western side of the Pacific. Because of the lower density of the warmer water, sea level is about two feet higher on the western side of the basin than on the eastern side when the winds are blowing at full strength. The thermocline, which marks the boundary between warm surface water and cold, deep water (deeper blue) is tilted. It reaches almost up to the sea surface in the eastern equatorial Pacific.



Coastal Upwelling
Strong southeasterly winds (red arrow) prevail along the coast of southern Ecuador and Peru. These winds, which blow during both normal and El Niño years, drag the surface water northwestward and cause cold, nutrient-rich water (dark blue) to upwell along the shore of the eastern Pacific.

The winds that blow along the equator also affect the properties of upwelled water. In the absence of the wind, the dividing layer between the warm surface water and the deep cold water, known as the *thermocline*, would be nearly flat; but the winds drag the surface water westward, raising the thermocline nearly all the way up to the surface in the east and depressing it in the west, as indicated in the figure above.

The cold water below the thermocline is rich in chemical nutrients. Wherever the thermocline is shallow enough, stirring by the wind mixes the nutrient-rich water with the surface water. In the presence of sunlight, tiny plant species called *phytoplankton* use the nutrients to produce a greenish plant substance called *chlorophyll*. These explosively growing "blooms" of phytoplankton use up all the available nutrients within a week, at which time they die and sink. During their brief lifetime in the sun they are visible in satellite images as greenish patches of water, which serve as markers for places where upwelling is bringing nutrients to the surface. The surface waters above the thermocline would soon become devoid of nutrients were they not continually being replenished by upwelling.

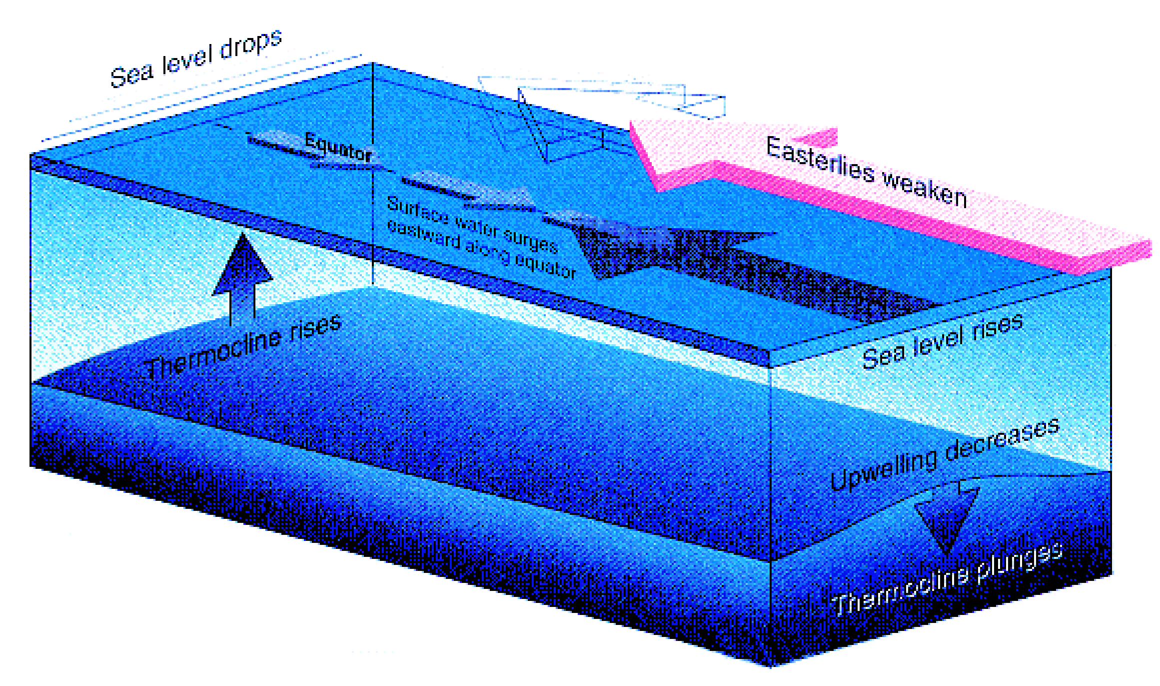
The newly upwelled water is colder than its surroundings. It can be tracked for several weeks using *infrared satellite imagery* that reveals the water temperature. Its signature in the infrared images takes the form of a distinctive "cold tongue" extending westward along the equator from the South American coast.

So it is that the winds control the upwelling and the upwelling controls the phytoplankton production. The phytoplankton production, in turn, affects the lives of the tiny sea animals called zooplankton, which "graze" on them and, ultimately, this affects all the creatures at higher levels of the marine food web. The winds are also responsible for the cold tongue in the sea-surface temperature pattern.

When the Winds Weaken

During El Niño years, when the easterlies retreat into the eastern Pacific (figure below), the ocean responds in the following ways:

- the thermocline along the equator flattens out, rising in the west and plunging several hundred feet below the surface in the east--deep enough so that coastal upwelling is no longer able to tap the cold, nutrient-rich waters from beneath it.
- equatorial upwelling decreases, further reducing the supply of nutrients to the food web.
- the cold tongue in sea-surface temperature weakens or disappears, as in the bottom figure on p. 11.
- sea level flattens out, dropping in the west and rising in the east. Surface water surges eastward along the equator.

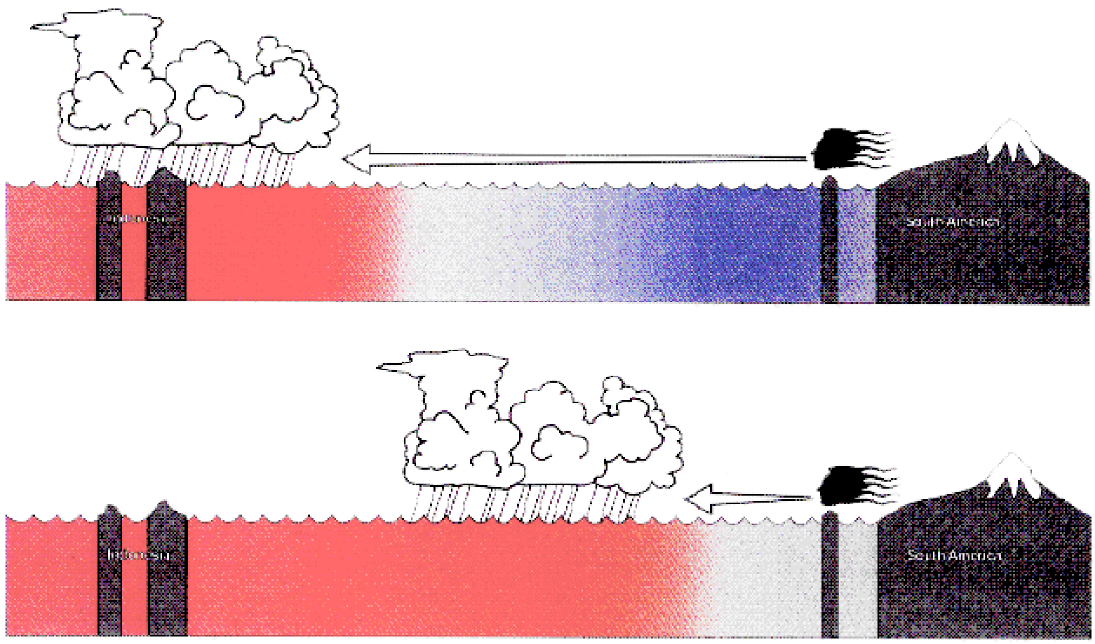


The easterly winds (red arrow) that usually extend nearly all the way across the equatorial Pacific retreat eastward with the onset of El Niño conditions. This triggers a change in the upper layer of the ocean. Along the equator the slope of the sea surface and the thermocline both flatten out, as shown.

When this impulse of relatively warm water reaches the eastern end of the basin, typically a few months later, it is forced to turn northward and southward along the coast, causing sardines and other species of fish to move and raising sea level as it goes. These effects have been felt as far north as Canada and as far south as central Chile.

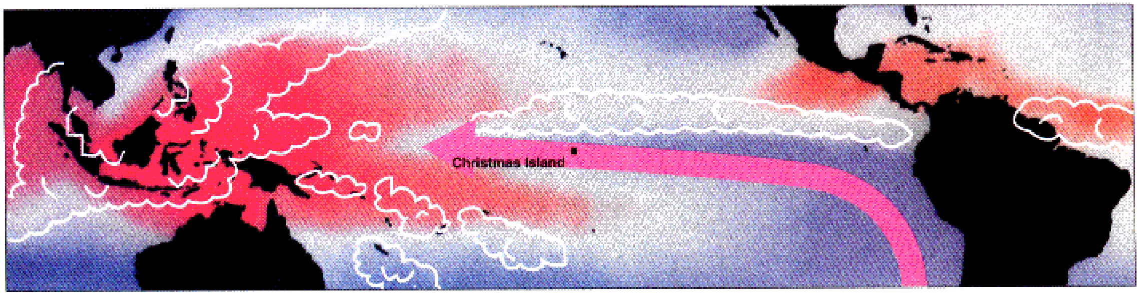
How the Sea Affects the Winds

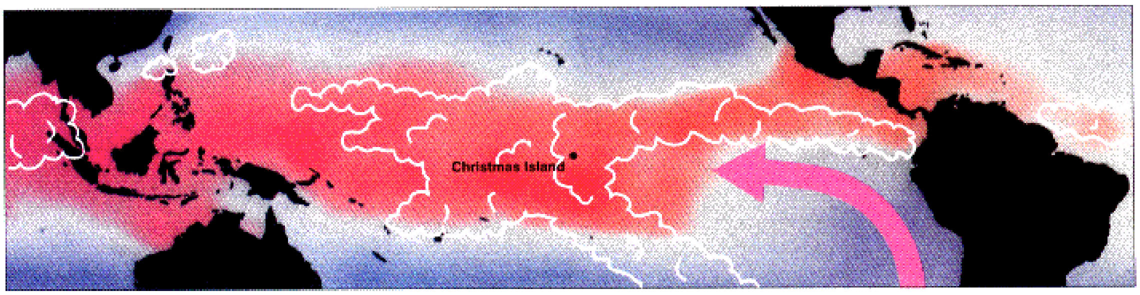
The oceans and the atmosphere carry on a continuous dialogue. Each listens to what the other is saying and responds. Up to now we have eavesdropped on one side of that conversation: how the winds along the equator influence the slope of the thermocline and the intensity of the upwelling. (See figures below showing winds, rainfall, and upwelling.) But the resulting changes in sea-surface temperature will, in turn, have an effect on the winds.



El Niño rearranges the distribution of rainfall in the equatorial Pacific. During normal years (top figure) upwelling induced by the easterly surface winds along the equator (arrow) keeps the surface waters of the central Pacific cool (blue). Heavy rainfall is confined to the warm (red) waters surrounding Indonesia at the western end of the Pacific.

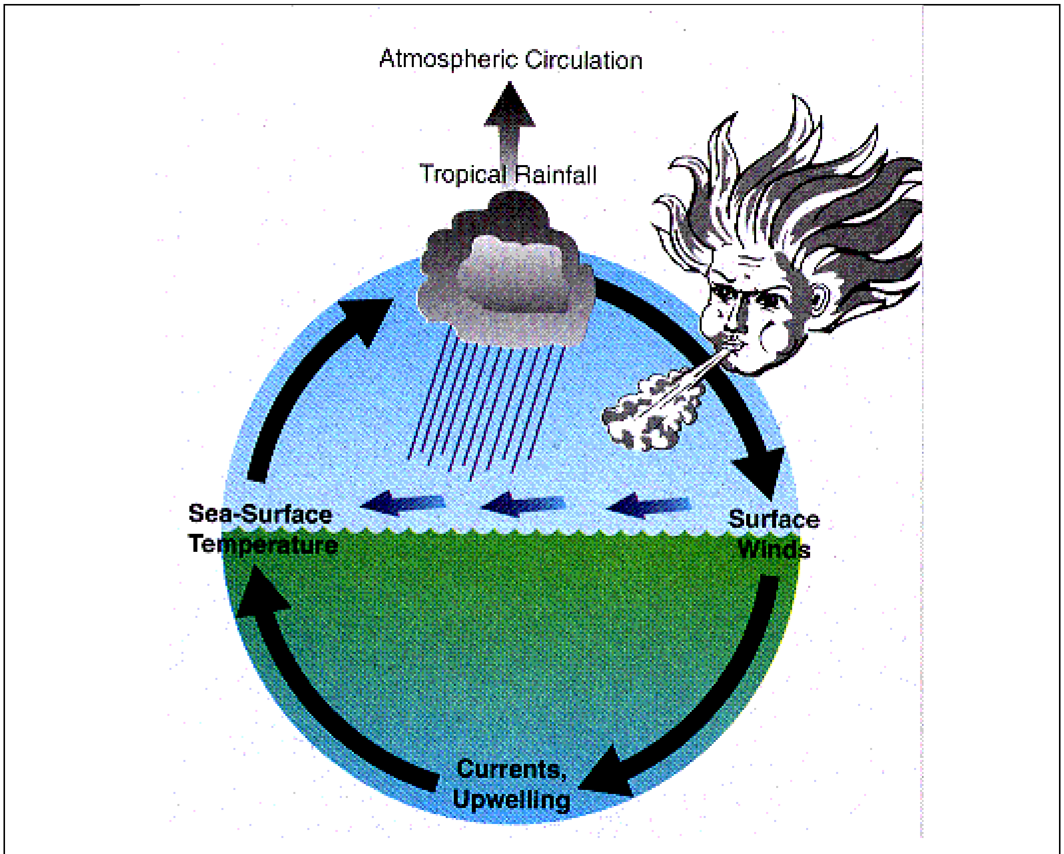
During El Niño (bottom) the easterly surface winds weaken and retreat to the eastern Pacific, allowing the central Pacific to warm, and the rain area to migrate westward.





Above is a more detailed view of how El Niño rearranges the distribution of rainfall over the tropical Pacific. The colors indicate the distribution of sea-surface temperature for the cold month of November 1988 and the warm (El Niño) month of November 1982, the same months for which the pressure patterns are shown on p.5. Red indicates warmer water, and blue indicates colder water. The regions of heavy rainfall is viewed by satellite are indicated by the clouds. The surface winds on the equator are indicated by the arrows. Note how tropical rainfall was suppressed wherever the sea-surface temperatures were lower than about 80 degrees-F (bluer colors).

When the easterlies are blowing at full strength, the upwelling of cold water along the equatorial Pacific chills the air above it, making it too dense to rise high enough for water vapor to condense to form clouds and raindrops. As a result, this strip of the ocean stays conspicuously free of clouds during normal years and the rain in the equatorial belt is largely confined to the extreme western Pacific, near Indonesia.



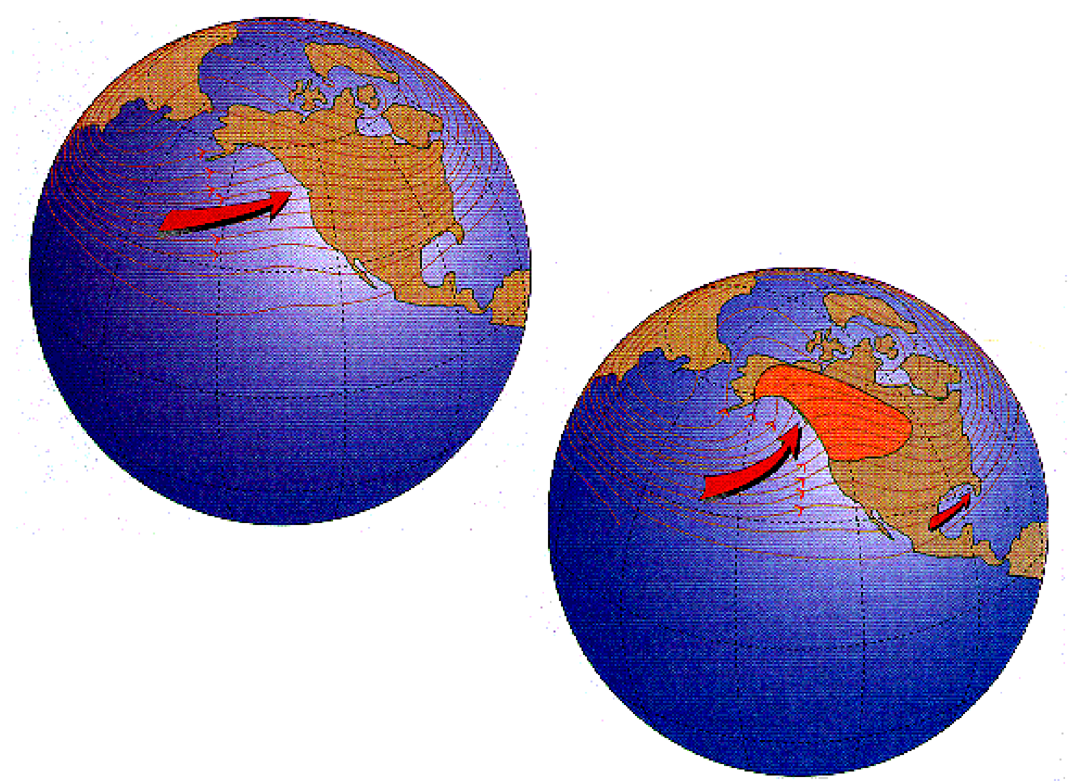
Like partners engaged in an ongoing dialog, the tropical Pacific Ocean and the overlying atmosphere influence and react to one another. Changes in the strength of the easterly surface winds along the equator induce changes in ocean currents and upwelling, which induces changes in sea-surface temperature, which alter the distribution of rainfall, which alters the strength of the easterlies, and so on...

But when the easterlies weaken and retreat eastward during the early stages of an El Niño event, the upwelling slows and the ocean warms. The moist air above the ocean also warms. It becomes buoyant enough to form deep clouds which produce heavy rain along the equator. The change in ocean temperatures thus causes the major rain zone over the western Pacific to shift eastward. Related adjustments in the atmosphere cause barometers to fall over the central and eastern Pacific and rise over Indonesia and Australia, resulting in a further weakening and eastward retreat of the easterlies.

In this way, the dialogue between wind and sea in the Pacific can become more and more intense, as each partner sends back a stronger message. Small perturbations in the ocean and atmosphere can amplify one another until eventually a full-fledged El Niño is under way. And, just as it is often hard to say which partner was responsible for a change in the mood of a dialogue, or precisely what they said that set the conversation off in a new direction, it is often difficult to identify the subtle change in the ocean-atmosphere system that initiates a transition into or out of El Niño conditions.

Global Consequences of El Niño

The twists and turns in the ongoing dialogue between ocean and atmosphere in the Pacific can have a ripple effect on climatic conditions in far flung regions of the globe. This worldwide message is conveyed by shifts in tropical rainfall, which affect wind patterns over much of the globe. Imagine a rushing stream flowing over and around a series of large boulders. The boulders create a train of waves that extend downstream, with crests and troughs that show up in fixed positions. If one of the boulders were to shift, the shape of the wave train would also change and the crests and troughs might occur in different places (see figure below describing global effects).



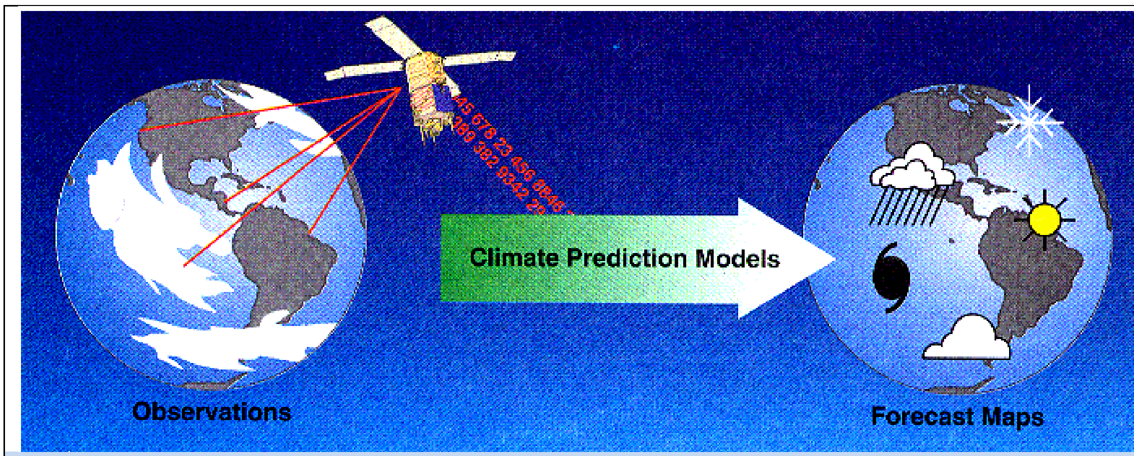
Winds at the jetstream level (small arrows), five to fifteen miles above sea level, change their course between normal (above) and El Niño (right) winters. A ridge of high pressure over North America's west coast during El Niño winters keeps temperatures normal in the orange region and steers storms that would otherwise pass through Washington and Oregon northward toward the coast of Alaska as indicated by the heavy arrow. El Niño also creates a favorable environment for storms to develop in the Gulf of Mexico, bringing heavy rains to much of the southern United States. An analogous strengthening of the westerlies in the Southern Hemisphere during its winter season brings heavy precipitation to parts of southern Brazil and northern Chile and Argentina (not pictured).

Dense tropical rain clouds distort the air flow aloft (5-10 miles above sea level) much as rocks distort the flow of a stream, or islands distort the winds that blow over them, but on a horizontal scale of thousands of miles. The waves in the air flow, in turn, determine the positions of the monsoons, and the storm tracks and belts of strong winds aloft (commonly referred to as *jet streams*) which separate warm and cold regions at the Earth's surface. In El Niño years, when the rain area that is usually centered over Indonesia and the far western Pacific moves eastward into the central Pacific, as shown above, the waves in the flow aloft are affected, causing unseasonable weather over many regions of the globe.

The impacts of El Niño upon climate in temperate latitudes show up most clearly during wintertime. For example, most El Niño winters are mild over western Canada and parts of the northern United States, and wet over the southern United States from Texas to Florida. El Niño affects temperate climates in other seasons as well. But even during wintertime, El Niño is only one of a number of factors that influence temperate climates. El Niño years, therefore, are not always marked by "typical" El Niño conditions the way they are in parts of the tropics.

El Niño Prediction

In the preceding pages, we have considered how El Niño develops, how it perturbs marine life in the Pacific, how it influences weather patterns throughout the world, and how the abnormal atmospheric and oceanic conditions during El Niño affect human beings. Scientists are now taking our understanding of El Niños a step further by incorporating the descriptions of these events into *numerical prediction models* (see figure below) (computer programs designed to represent, in terms of equations, processes that occur in nature). Such models are fed information, mostly in the form of sets of numbers, describing the present state of the atmosphere-ocean system (for example, observations of wind speeds, ocean currents, sea level, and the depth of the thermocline along the equator). Updated sets of numbers, which the models produce, indicate how the atmosphere-ocean system might evolve over the next few seasons or years.



Reliable data on existing conditions and realistic numerical models that project this picture forward in time are at the crux of researchers continuing efforts, not only to understand El Niño, but also to predict when future events will arise and what their impacts will be.

Such models allow scientists to test their understanding of how complex systems operate. One such test is to see whether the models are able to replicate past El Niños. If the models are realistic enough, researchers can even use them to make predictions of what will happen in the future.

Similar numerical models based on the laws of physics have been used since the 1960s to forecast weather. In the early years, these forecasts were no better than those made by skilled meteorologists relying on their own experience in watching weather systems evolve. But thanks to advances in our understanding of weather systems and in the numerical models that are used to represent them, today's weather prediction models consistently outperform even the most seasoned forecasters.

Numerical models of El Niño are not as reliable as those used in weather forecasting, but they have advanced to the point where they can reproduce the characteristics of a typical event. In recent years, several research groups have pioneered the use of models to predict the comings and goings of individual El Niño events and their effects on weather patterns throughout the world before these events actually occurred. The results thus far, though by no means perfect, give a better indication of the climatic conditions that will prevail during the next one or two seasons than simply assuming that rainfall and temperature will be "normal."

How Predictions Are Used: An Example

Peru provides a prime example of how even short term El Niño forecasts can be valuable. There, as in most developing countries in the tropics, the economy (and food production in particular) is highly sensitive to climate fluctuations (see figure below on economic impacts attributed to the 1982-83 El Niño).

Economic impacts attributed to the 1982-83 El Niño

Year-to-year swings between above- and below-normal sea-surface temperatures along the Peru coast produce a wide range of local impacts. Warm (El Niño) years tend to be unfavorable for fishing and some of them have been marked by damaging floods along the coastal plain and in the western Andean foothills in the northern part of the country. Cold years are welcomed by fishermen, but not by farmers because these years have frequently been marked by drought and crop failures. Such cold years often come on the heels of strong El Niño years. Hence, Peruvians have reason to be concerned, not only about El Niño events, but about both extremes of the El Niño cycle.

Before the flood waters from the record breaking 1982-83 El Niño event had fully receded, farmers in Peru were already beginning to worry that sea-surface temperatures might drop below normal the following year, bringing drought and crop failures. It was at this time that the Peruvian government decided to develop a program to forecast future climate swings.

The first task was to make a forecast for the next rainy season, which was expected to occur in early 1984. Information available in early November 1983 indicated that the climatic conditions in the equatorial Pacific were near normal and were likely to remain so through the rainy season, producing favorable conditions for agriculture. This information was conveyed to numerous organizations and to the Minister of Agriculture, who incorporated it into the planning for the 1983-84 growing season. The forecast proved to be correct, and the harvest was an abundant one. Since that time, forecasts of the upcoming rainy season have been issued each November based on observations of winds and water temperatures in the tropical Pacific region and the output of numerical prediction models. The forecasts are presented in terms of four possibilities: (1) near normal conditions, (2) a weak El Niño with a slightly wetter than normal growing season, (3) a full blown El Niño with flooding, and (4) cooler than normal waters offshore, with higher than normal chance of drought.

Once the forecast is issued, farmers' representatives and government officials meet to decide on the appropriate combination of crops to sow in order to maximize the overall yield. Rice and cotton, two of the primary crops grown in northern Peru, are highly sensitive to the quantities and timing of rainfall. Rice thrives on wet conditions during the growing season followed by drier conditions during the ripening phase. Cotton, with its deeper root system, can tolerate drier weather. Hence, a forecast of El Niño weather might induce farmers to sow more rice and less cotton than in a year without El Niño.

Looking Ahead

Peru is one of several countries that are already successfully using predictions of El Niño in connection with agricultural planning. Other countries that have taken similar initiatives include Australia, Brazil, Ethiopia, and India. It is not a coincidence that all these countries lie at least partially within the tropics. Tropical countries have the most to gain from successful prediction of El Niño because they experience a disproportionate share of the impacts summarized on pp. 3-4 and, coincidentally, they occupy the part of the world in which the accuracy of climate prediction models is greatest. But for many countries outside the tropics, such as Japan and the United States, more accurate prediction of El Niño will also benefit strategic planning in areas such as agriculture, and the management of water resources and reserves of grain and fuel oil.

Encouraged by the progress of the past decade, scientists and governments in many countries are working together to design and build a global system for (1) observing the tropical oceans, (2) predicting El Niño and other irregular climate rhythms, and (3) making routine climate predictions readily available to those who have need of them for planning purposes, much as weather forecasts are made available to the public today. The ability to anticipate how climate will change from one year to the next will lead to better management of agriculture, water supplies, fisheries, and other resources. By incorporating climate predictions into management decisions, humankind is becoming better adapted to the irregular rhythms of climate.

Credits

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