Pacific Climate Variability

Pacific Islands Climate Education Partnership

You may have heard the term **climate variability.** What does this term mean? In what ways is the climate variable? How does climate variability affect island communities in the Pacific? The purpose of this booklet is to answer these questions.

What is the difference between weather, climate, and climate variability?

The scientific terms **weather**, **climate** (**Figure 1**), and climate variability, all refer to different conditions of the **atmosphere**, the envelope of air that surrounds Earth and that contains the air we breathe.

Figure 1 *Climate among tropical Pacific islands is warm and humid.*

Weather is a common scientific term that is used by everyone. It describes the rain, wind, temperature, cloudiness and other characteristics of the atmosphere at a particular place and time. Examples of weather are rainstorms that might last from a few minutes to a few hours and tropical cyclones that may last for a day or two.

Weather is associated with the **atmospheric pressure**, the force exerted by the weight of the air above Earth's surface. In a place, high atmospheric pressure usually means sunny conditions with light winds and little rain. Low atmospheric pressure typically means the opposite, rainy and windy conditions, and very low atmospheric pressure means that a tropical cyclone may be developing.

Climate is the long-term average weather pattern in a specific place or region. The climate in a place has very big effects on the plants, animals, and people who live there. For instance, in Micronesia the climate is warm and humid. In the Arctic, the climate is cold and dry. To live comfortably and safely in a place, it is important to understand the climate (and the weather) in detail.

When scientists study the climate, they use measurements of the weather that have been collected frequently (such as measuring rain, wind, atmospheric pressure, and temperature every hour) over the course of decades. Scientists use **weather stations** to make these measurements automatically – most airports have a weather station. By studying these measurements, scientists have learned a lot about climate. One of the things they have learned is that climate is highly variable. That is, it changes frequently.

For example, during the course of one year we expect a wet season and a dry season. But from one year to the next the wet season might be very wet or less wet compared to the previous year, and the dry season might be very dry or less dry compared to previous dry seasons. In a similar way, the climate can be different from year to year, and even from decade to decade. This is why we say that climate is *variable*.

What causes climate variability?

Three natural climate processes cause climate variability in the tropical Pacific region:

1. Within a single year, movement of the **Intertropical Convergence Zone** (ITCZ) and the **South Pacific Convergence Zone** (SPCZ) causes wet seasons and dry seasons.
2. The **El Niño Southern Oscillation** (ENSO) causes climate variability from one year to another year.
3. The **Pacific Decadal Oscillation** (PDO) causes climate variability on the scale of decades.

Each of these three types of climate variability is discussed on the following pages.

Weather, climate variability, and **climate change** all operate over different lengths of time. If we think of days, months, years, decades and centuries, we can see by **Figure 2** that weather refers to hours, days and months; climate variability refers to months, years and decades; and climate change refers to decades and centuries.

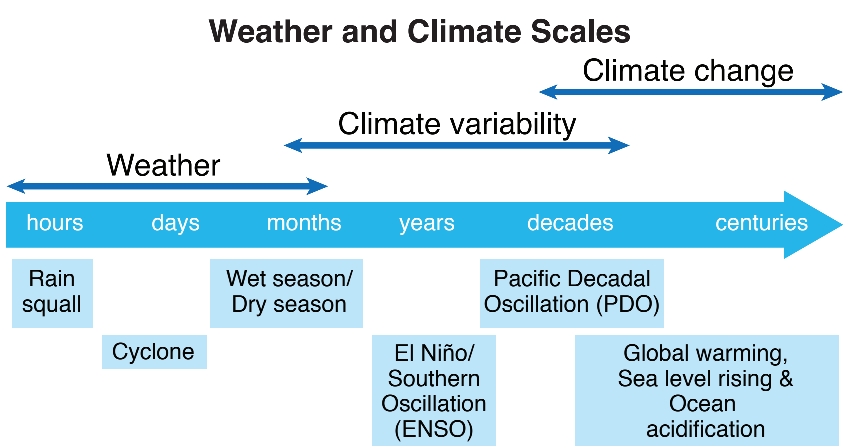

Figure 2 *Chart showing the time scales of weather, climate variability, and climate change.*

Seasonal climate variability

Pacific islands experience significant differences in rainfall from one season of the year to the next – this is called **seasonal climate variability**. For instance, American Samoa, in the southern hemisphere, has warmer and wetter weather from October through May. In the northern hemisphere, islands in Micronesia experience warmer and wetter weather at the opposite time of the year - from May to November. North of Micronesia, in Guam and Saipan, the drier season tends to be longer and drier than further south.

To understand seasonal climate variability, we need to understand the pattern of winds found in the tropical Pacific Ocean.

Tropical Pacific winds

Please refer to **Figure 3** for the following discussion.

In the northern hemisphere, tropical winds in the Pacific Ocean mostly blow from the east and northeast toward the west and southwest. The **North Pacific High**, an area where air sinks through the atmosphere all the way to the sea surface, makes these winds. As the air sinks it spins to the right, or clockwise. Thus air flowing away from the North Pacific High makes wind that blows toward the east and southeast. The North Pacific High is located to the north of Hawaii.

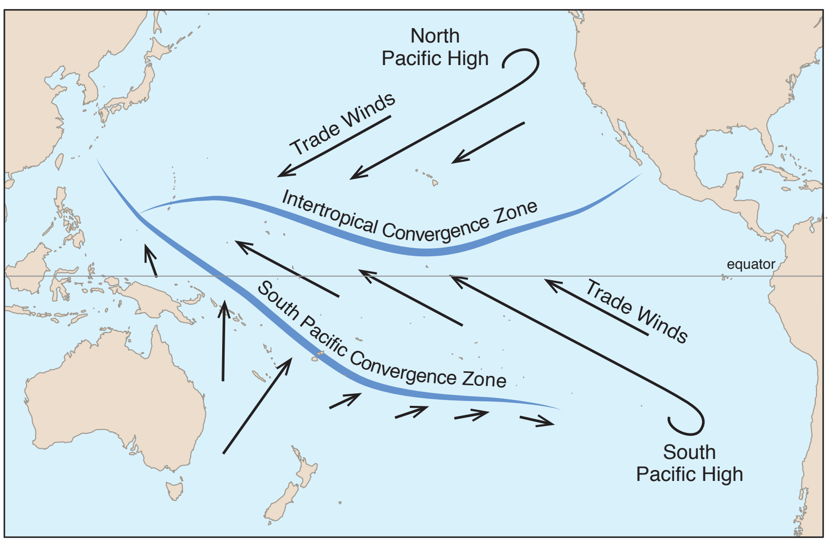

Figure 3 *The North Pacific High is a high-pressure region in the atmosphere that is located to the north of Hawaii. Air in the North Pacific High rotates in a clock-wise direction making winds that travel outward and arrive in the tropics from the east and northeast. The South Pacific High is a high-pressure region located near Rapa Nui that makes winds in the southern hemisphere.*

In the southern hemisphere, tropical winds mostly travel from the east to the west and from the southeast to the northwest. The **South Pacific High**, an area of descending air that spins counter-clockwise near Rapa Nui, makes these winds.

Winds made by the North Pacific High and the South Pacific High are called **trade winds**. When the trade winds are blowing, the weather is usually stable, producing two types of rain:

occasional short-lived squalls called **convective rain** on low islands, and **orographic rain** (as well as convective rain) on high islands.

Convective rain happens everywhere: over the open ocean, on low islands, and on high islands. This kind of rain happens because the air has so much water vapor in it that when the air rises above the ocean surface into cooler air above, the water vapor condenses, forms clouds, and then precipitates.

High islands produce orographic rain. When warm humid air is forced to rise up the slopes of a high island, the cool air it encounters causes the water vapor to condense, making clouds and rain.

The Intertropical Convergence Zone

Look again at Figure 3. Notice that north of the equator, trade winds from the northern and southern hemispheres come together and cause a band of rain called the Intertropical Convergence Zone or ITCZ. This very cloudy and rainy area can be seen in satellite photos (**Figure 4**) as a band of thunderstorm clouds somewhat north of the equator.

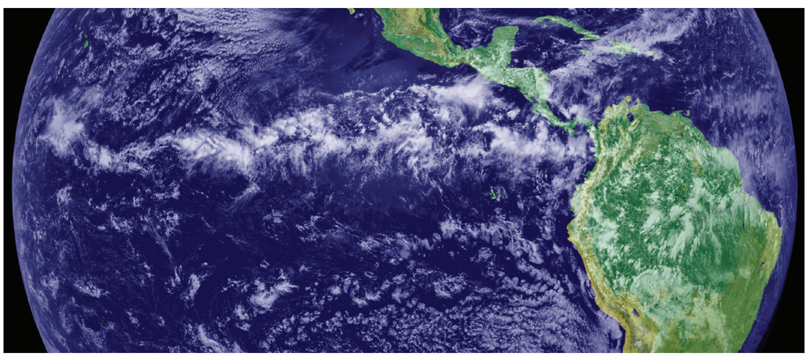

Figure 4 *The band of thunderstorms that form the ITCZ are created by the strong sun and warm water of the tropics that heat the air and increases its humidity. The warm humid air rises and becomes colder as it gets higher in the atmosphere. As the rising air gets colder, the water vapor condenses and forms big clouds that release the water in thunderstorms.*

This long band of rainy area near the equator does not just stay in one place. The wetter season in the northern hemisphere occurs in the summer months when the ITCZ shifts to the north, bringing it closer to the islands of Micronesia and other islands. The drier season occurs in the northern hemisphere winter, when the ITCZ moves further south, closer to the equator.

In the southern hemisphere, over American Samoa, trade winds from the tropics and winds from the southwest come together and cause a band of rain called the South Pacific Convergence Zone or SPCZ. This very cloudy and rainy area can be seen in satellite photos (**Figure 5**) as a band of thunderstorm clouds extending diagonally to the southeast from the equator.

Like the ITCZ, this long band of rainy area over the Pacific Ocean in the southern hemisphere also does not just stay in one place. The wetter and warmer season occurs from October through May when the SPCZ is located over American Samoa. The drier season occurs from June through September when the area of rain moves further north, toward the equator and away from American Samoa.

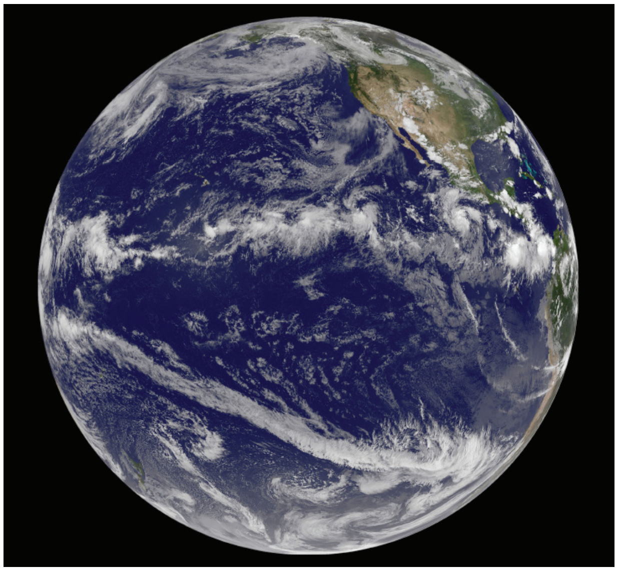

Figure 5 *The long band of clouds extending to the southeast is called the South Pacific Convergence Zone.*

The ITCZ, as it migrates to the north in the summer and back to the south in the winter results in wetter seasons (summer) and drier seasons (winter) among tropical communities of the north Pacific. The SPCZ also migrates from season to season and produces a wetter season over American Samoa from October through May, and a drier season the rest of the year. The movements of these two trade wind convergence zones are why we experience seasonal climate variability in the tropics.

Year to year climate variability

Figure 6 shows the annual rainfall measured on Majuro, in the Republic of the Marshall Islands, between the years 1955 and 2010. Note that the amount of rain changes a lot from year to year. Some years had 150 inches (381 centimeters) or more of rain, while other years had 90 inches (229 centimeters) or less of rain. This kind of change in rainfall from year to year is a natural feature of the climate in many Pacific islands that are near the equator. This is called **interannual climate variability.** The El Niño Southern Oscillation or ENSO, is the primary cause of interannual climate variability in the Pacific tropical region.

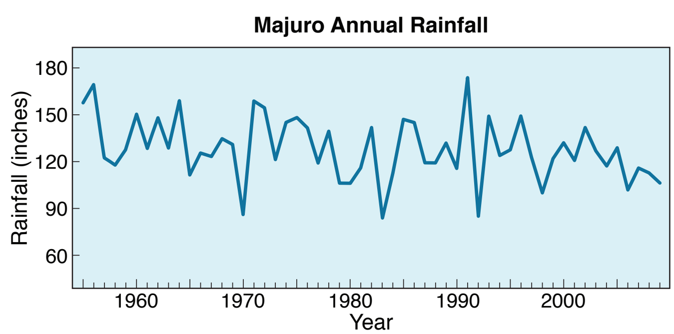

Figure 6 *The amount of rainfall on Majuro, in the Republic of the Marshall Islands, has a lot of variability from one year to the next.*

The El Niño Southern Oscillation

The east to west trade winds play a large role in the climate of the equatorial Pacific Ocean. These winds can change during a climate pattern that is called the El Niño Southern Oscillation (ENSO). ENSO has two parts. El Niño is a periodic fluctuation in sea surface temperature. The Southern Oscillation is a periodic fluctuation in the air pressure of the overlying atmosphere across the equatorial Pacific Ocean. Together, El Niño and the Southern Oscillation, have a big effect on the climate.

There are 3 types of ENSO patterns. 1) When trade winds are weaker than normal, or absent, scientists say that it is an **El Niño** year. 2) When the trade winds are stronger than normal, scientists call it a **La Niña** year. 3) When the winds are normal it is called a **neutral** year. These 3 types of ENSO patterns are discussed below and illustrated in Figures 7, 8, and 9.

In a neutral year (normal winds), the trade winds will blow seawater from the eastern part to the western part of the Pacific Ocean. This water forms the **West Pacific Warm Pool**, which straddles the equator. Seawater in this region is much warmer than seawater in the central or eastern portions of the Pacific Ocean (**Figure 7**). The warm water leads to strong evaporation and there is usually abundant rain

In the far eastern Pacific, off the coast of Central and South America, the water that has been blown to the west by the trade winds is replaced by cold-water that rises from the deep sea floor. This water is rich with nutrients and feeds an economically important fishing industry in the eastern Pacific Ocean.

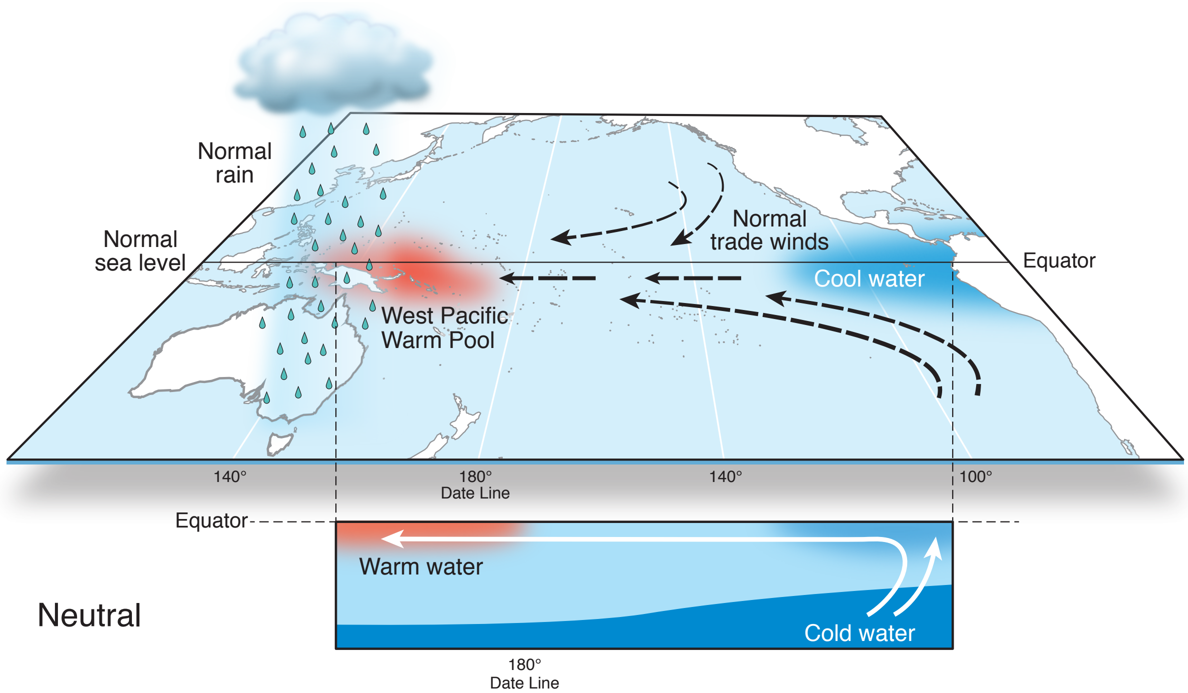

Figure 7 *In neutral ENSO years, the trade winds push seawater to the western tropical Pacific and create an area of warm water that readily evaporates and provides abundant rainfall in the region. The eastern Pacific region is characterized by cool, nutrient rich water that rises from the deep sea and supports an economically important fishing industry.*

In a La Niña year (**Figure 8**), strong trade winds blow across the ocean surface into the western tropical Pacific. The West Pacific Warm Pool grows larger and deeper and the level of the ocean surface is higher. This raises sea level and can cause **coastal erosion** (land loss due to wave action) and damaging **king tides** (flooding by the highest tides of the year). La Niña years also tend to be very rainy in the western Pacific and support a strong monsoon (rainy) season in nations around the Indian Ocean which is important for food production.

In an El Niño year (**Figure 9**), trade winds are weaker than normal (or absent). There may be gusts of wind in the tropics that blow from the west towards the east. This causes warm seawater to migrate into the central and eastern Pacific Ocean. The West Pacific Warm Pool is the source of this water and it largely disappears. Abundant rainfall and flooding occur in the Americas and the fishing industry collapses. In the western Pacific, the year following an El Niño year is usually drier and there is a greater chance of **drought** (an extended period of little rain).

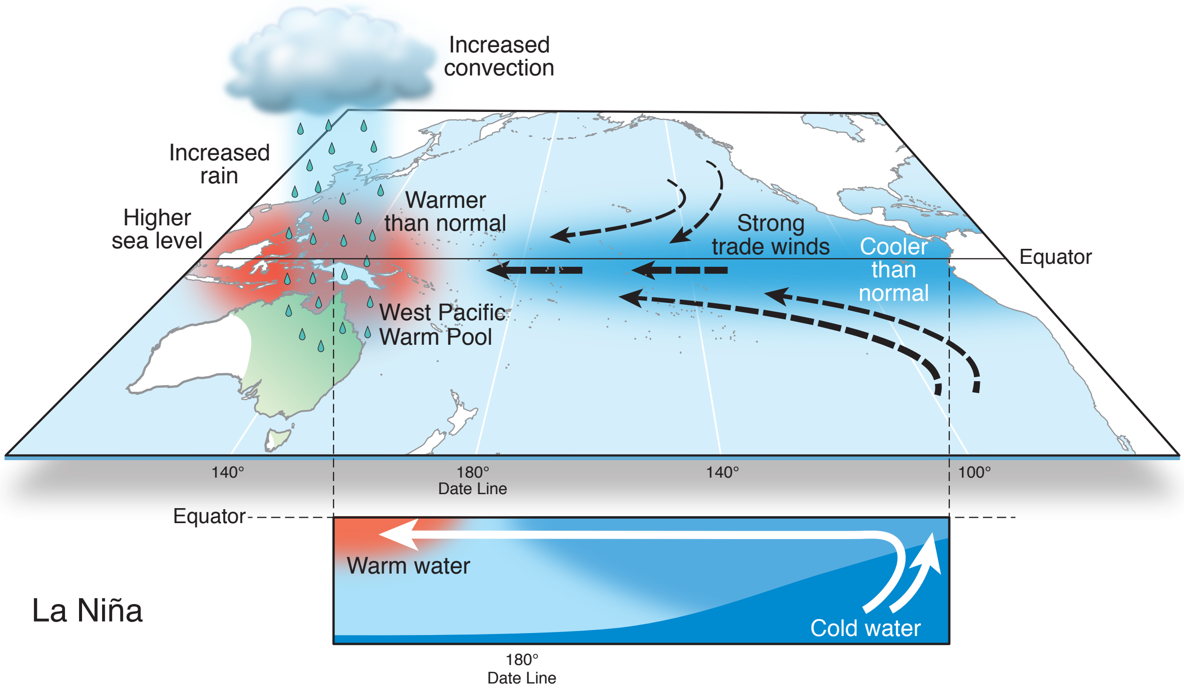

Figure 8 *In a La Niña year, the trade winds are strong. They push water to the western tropical Pacific and increase the size of the West Pacific Warm Pool. There is abundant rain throughout the region and higher than normal sea levels that can cause coastal flooding and erosion.*

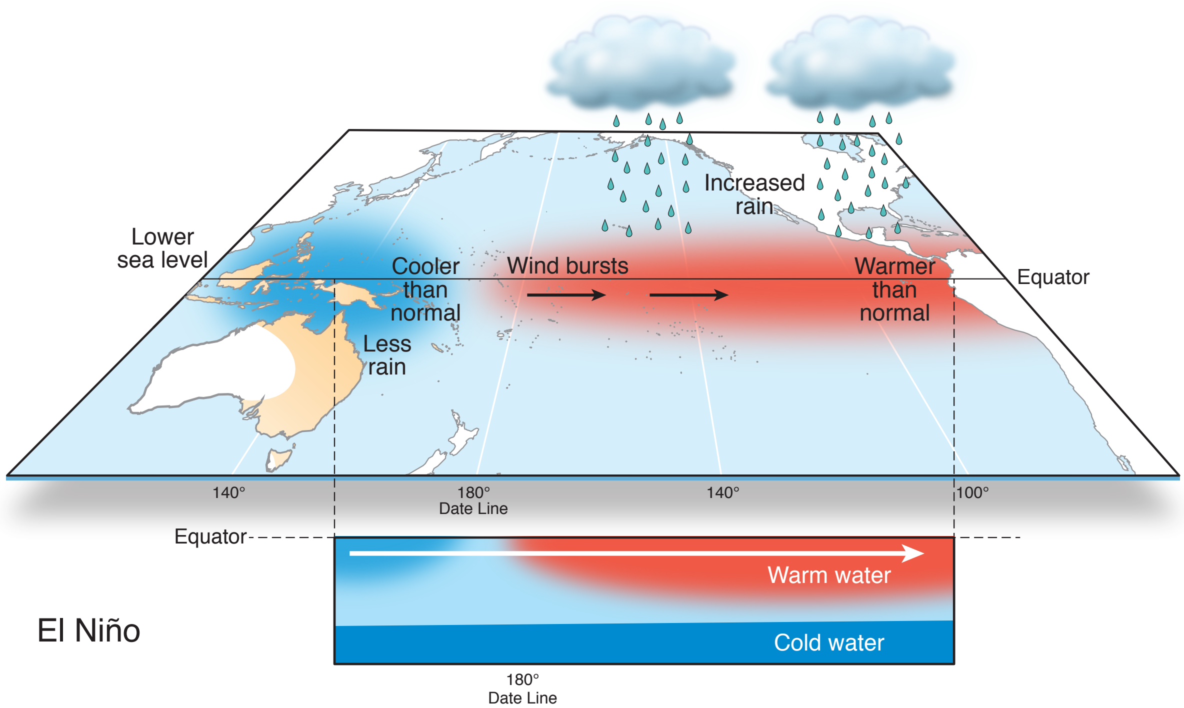

Figure 9 *In an El Niño year, the trade winds are weak and may be replaced by winds that blow from west to east. This pushes warm seawater into the central and eastern tropical Pacific. There is abundant rain throughout the region and higher than normal sea levels. The western Pacific, including the Philippines, Palau, and Micronesia, may experience drought.*

Table 1 summarizes the differences between neutral years, El Niño years, and La Niña years..

Table 1 ENSO Conditions and the Effects of ENSO Changes

Feature	Neutral ENSO Year	El Niño ENSO Year	La Niña ENSO Year
Wind	Normal east to west trade winds	Weak to absent trade winds; winds can even blow from west to east	Stronger east to west trade winds
Rainfall	Usual amounts of rainfall with normal variability	Western Pacific drier than usual, and can have long droughts. Eastern Pacific wetter than usual, can experience flooding and landslides.	Western Pacific wetter than usual, can experience flooding and landslides. Eastern Pacific drier than usual, can experience drought.
Sea Level	Usual sea level with normal tide variability	Western Pacific experiences lower sea level so high tides tend to cause less flooding Eastern Pacific experiences higher than normal sea level, can experience coastal erosion and flooding.	Western Pacific experiences high sea level so high tides tend to cause more coastal erosion and flooding. Eastern Pacific experiences lower than normal sea level so high tides cause less flooding and erosion.

The Pacific Decadal Oscillation

The Pacific Decadal Oscillation, or PDO, is a pattern of **decadal climate variability** consisting of a *positive* (or warm) phase, and a *negative* (or cool) phase. Each phase marks a periodic shift in ocean temperature over the span of years to decades (**Figure 10**).

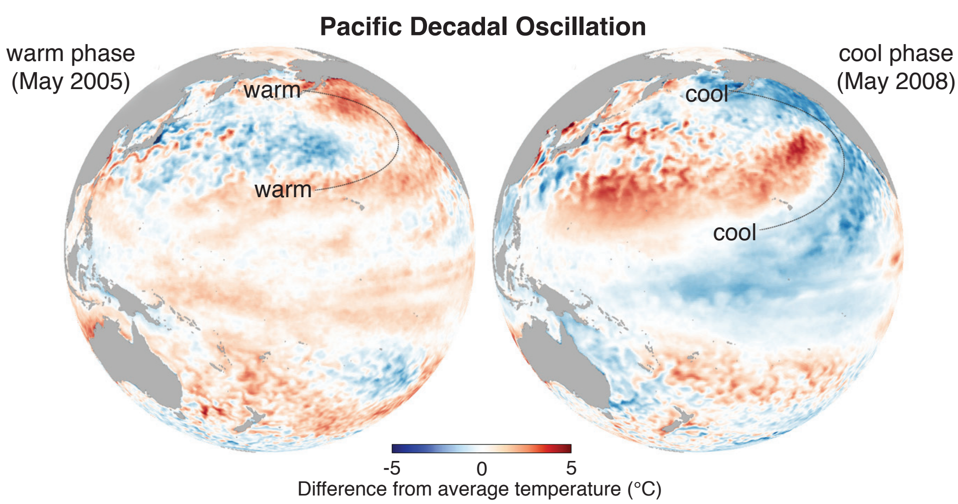

Figure 10 *The Pacific Decadal Oscillation, or PDO, is a pattern of climate variability characterized by 2 phases. The positive (or warm) phase consists of warmer than normal water in the eastern Pacific and cooler than normal water in the western Pacific. The negative (or cool) phase is characterized by cooler than normal water in the eastern Pacific and warmer than normal water in the western Pacific.*

During a positive (warm) phase, the western Pacific experiences cooler than normal sea surface temperatures and part of the eastern Pacific experiences warmer than normal temperatures. Crudely, this is similar to an El Niño-like condition, though the temperature differences are not as extreme as during the ENSO process.

During a negative (cool) phase, the opposite pattern occurs; waters in the western Pacific experience warmer than normal temperatures and the eastern Pacific tends to grow cooler.

Since the late 1990s, the Pacific Ocean has been in a negative phase of the PDO cycle. This has contributed to cooler sea temperatures in the eastern tropical (similar to La Niña) and northeastern Pacific. Stronger than normal trade winds during the negative phase of the PDO tend to push seawater to the west and cause a larger than normal West Pacific Warm Pool. Higher than normal sea levels produce coastal erosion and flooding at **high tides**. Strong trade winds also stir up the ocean and mix warm surface waters down into the deep ocean, allowing heat to penetrate to greater depths. Excess heat in the atmosphere due to **global warming** is stored in the ocean by this process and so the atmosphere may not warm as rapidly during a negative PDO phase as it does in a positive PDO phase.

Some scientists believe that in 2014 and 2015 the Pacific Ocean moved into a new phase of the PDO – a positive phase. Because the trade winds are not as strong in a positive phase, heat is less likely to be stored in the deep ocean. As a result, the air temperature may grow rapidly and thus global warming accelerates until the PDO changes back into a negative phase.

The history of the PDO from 1920 to 2015 is shown in **Figure 11**. The periods shaded in light blue are times when the PDO is in a largely negative phase; east to west winds are stronger than normal, sea level is higher in the western Pacific, and heat is stored in the deep ocean causing global warming of the air to slow.

In white are periods when the PDO is in a largely positive phase; east to west winds are slower than normal, sea level is not higher than normal in the western Pacific, and not as much heat is being stored in the deep ocean. Global warming tends to accelerate over these periods.

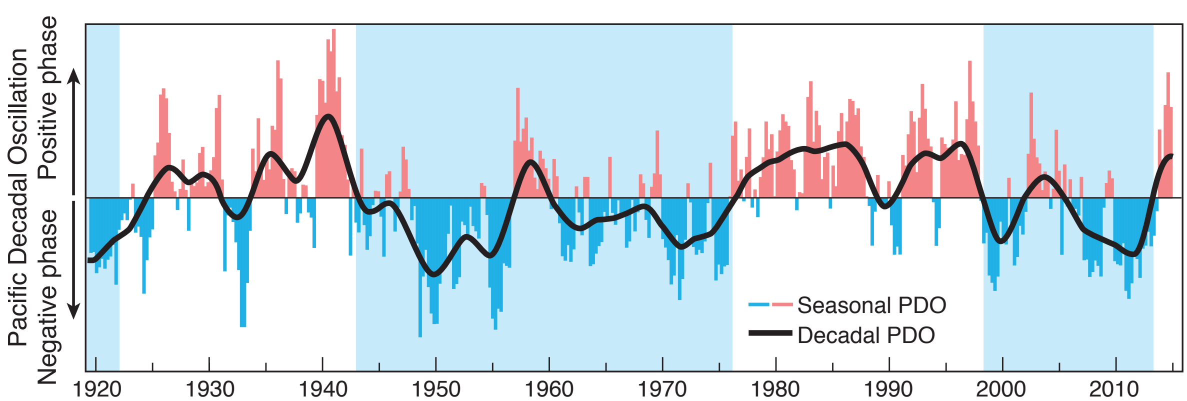

Figure 11 *The history of the Pacific Decadal Oscillation shows periods of positive (white) and negative (light blue) phases. In red (positive) and dark blue (negative) are individual seasons when PDO-type conditions dominated in the Pacific.*

Some scientists think that the negative PDO phase that began with the record-setting El Niño of 1998 is coming to a close with the strong El Niño that took two years to develop in 2014/2015. We won't know if a new, positive PDO phase has begun in 2015 for several years, but if it has, it could mean hotter temperatures for the eastern Pacific Ocean. This could result in more **tropical cyclones** in the eastern and central Pacific, coastal erosion and rainstorms in California, Latin America and the west coast of South America, and accelerated global warming of the atmosphere worldwide. The Pacific Decadal Oscillation is an important form of climate variability that has impacts around the entire planet.

Summary

We have seen how climate can vary from one season to another, and from one year to another. Seasonal climate change in the tropical Pacific is governed by migration of the ITCZ and the SPCZ over the course of a year. This produces wetter seasons and drier seasons because the two convergence zones are places where there is generally heavy precipitation. When one of the convergence zones is near, the climate is wetter, when it is far away, the climate is drier, and this changes on a seasonal basis.

Climate also changes from one year to another. El Niño Southern Oscillation governs interannual climate variability. During a neutral year, trade winds blow at normal levels, the western Pacific is characterized by warm seawater, and rainfall tends to be abundant. When the trade winds are more vigorous, a La Niña year, the region of warm seawater expands and rainfall can be so abundant that it causes flooding. In an El Niño year the trade winds can lessen, and be replaced by winds blowing from west to east. This leads to drought in the western Pacific and the potential for flooding in the eastern Pacific goes up.

The Pacific Decadal Oscillation causes climate variability over a period of decades. Scientists are busy studying the PDO because they do not understand how it forms or why it switches from a positive phase to a negative phase and back again. Positive phases of the PDO may enhance the affects of global warming and cause rapid heating of the atmosphere. Negative phases of the PDO may do the opposite; by exposing large areas of cool ocean water that absorb heat from the atmosphere, it has the effect of suppressing global warming.

Weather, climate, climate variability, and climate change are all different, but equally important processes that govern life on Pacific islands. The air temperature, rain, winds, storms, coastal erosion and flooding, and more all depend on patterns in the atmosphere related to ENSO, PDO, and the trade wind convergence zones. To best adapt to the influences of global warming and climate change, it is important to understand these patterns and how they impact our daily lives.

Glossary

Atmosphere The envelop of gases that surrounds Earth. The atmosphere contains the air that we breathe, and the weather that we experience.

Atmospheric pressure The force per unit area exerted against Earth's surface by the weight of the air above that surface. Low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. High pressure is generally associated with nice weather, while low pressure is generally associated with cloudy, rainy, and or windy weather.

Climate The weather conditions prevailing in an area in general or over a long period. The climate is the long-term average condition of the weather over 30 years or so.

Climate change A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the burning of oil, gas, and coal.

Climate variability Changes in climate that are caused by oceanographic and atmospheric influences. Climate is described as the average, long-term condition of the weather. Even though it is an average condition, it still experiences changes from one state to another and back again.

Coastal erosion Wearing away and loss of beaches and land due to waves. Coastal erosion gets worse when sea level rises.

Convective rain Convection of the air occurs when hot air moves upward. This develops when Earths surface becomes heated more than its surroundings leading to strong evaporation that makes clouds. The clouds produce convective rain that falls as showers with rapidly changing intensity. Convective rain falls over a certain area for a relatively short time, because convective clouds have limited horizontal extent. Most precipitation in the tropics appears to be convective.

Decadal climate variability When the climate of a region varies over the period of decades.

Drought An extended period of little rainfall.

El Niño A natural climate event, lasting typically less than 1 year, which occurs in the Pacific when the normal trade winds weaken (or die). This causes warm water in the western tropical Pacific to surge into the central and eastern Pacific. El Niño can cause temporary global changes in the climate and weather.

El Niño Southern Oscillation (ENSO) Refers to a Pacific climate event that has two states: El Niño and La Niña. These states govern the movement of a large body of warm water to the eastern (El Niño) or western (La Niña) regions of the tropical Pacific Ocean. ENSO states cause strong climate and weather changes around the globe.

Global warming When the air in the lowest portion of the atmosphere (the troposphere) gets significantly warmer than normal. Global warming is caused by an increase in the amount of heat-trapping greenhouse gases when humans burn fossil fuels (coal, petroleum, natural gas) for energy. Other types of greenhouse gases produced by humans also contribute to the problem.

High Tide High tide is the highest level reached by the tide. The tide is the alternating rising and falling of the sea, usually twice in each day, due to the gravitational attraction of the moon and sun.

Interannual climate variability Changes in the climate of a region occurring from one year to another.

Intertropical Convergence Zone (ITCZ) Known by sailors as "the doldrums", the ITCZ is a belt of low air pressure which circles Earth generally near the equator where the trade winds of the northern and southern hemispheres come together. The ITCZ tends to be a region of thunderstorms and high rainfall.

King tide A term that describes an unusually high tide, usually the highest tides of the year. King tides may cause flooding on low-lying coastal lands.

La Niña A natural climate event, lasting typically less than 1 year, which occurs in the Pacific when the trade winds grow stronger than normal. This causes a body of warm water to accumulate in the western tropical Pacific and is an opposite state to El Niño.

Neutral A year in which ENSO conditions are neither in the El Niño or La Niña states.

North Pacific High An area of high atmospheric pressure to the northeast of Hawaii that generates the trade winds.

Orographic rain Orographic rain occurs when humid air is forced upwards over rising terrain, such as a mountain, into colder air at higher elevations. This causes the rate of condensation to exceed the rate of evaporation, producing orographic clouds that yield orographic rain.

Pacific Decadal Oscillation (PDO) A decadal climate shift that occurs in the Pacific. The PDO has two phases. A positive or warm phase characterized by warm water in the eastern Pacific, and a negative or cold phase characterized by cold water in the eastern Pacific.

Sea level The average level of the surface of the ocean.

Sea level rise When the average level of the surface of the ocean rises, especially as a result of global warming that melts glaciers (increasing the amount of water in the ocean) and warms the ocean (causing ocean water to expand, upwards).

Seasonal climate variability Change in the climate of a region occurring from one season to another. For example, a region that experiences a wetter season and a drier season has seasonal climate variability.

South Pacific Convergence Zone (SPCZ) A band of cloudiness and precipitation that extends southeast from the western tropical Pacific towards French Polynesia. It is formed where trade winds converge.

South Pacific High An area of high atmospheric pressure in the region of Rapa Nui that generates trade winds in the Southern Hemisphere.

Trade winds A wind blowing steadily toward the equator from the northeast in the northern hemisphere or the southeast in the southern hemisphere, especially over the ocean.

Tropical cyclone A rotating system of strong winds, clouds and thunderstorms that produce heavy rain. Tropical cyclones are organized around a center, or eye, where there is low air pressure. Tropical cyclones cause storm surge and are responsible for severe damage where they make landfall in human communities.

Weather The state of the atmosphere at a place and time as regards heat, dryness, sunshine, wind, rain, and other conditions.

Weather station A weather station is a device consisting of several different sensors for measuring atmospheric conditions to provide information for weather forecasts and to study the weather and climate. Weather stations typically measure rainfall, wind speed and direction, atmospheric pressure, air humidity, and temperature.

West Pacific Warm Pool A region of warm water in the western tropical Pacific formed by the shear of the trade winds across the sea surface and the collection of warm seawater in the region of Papua New Guinea, the Philippines, Micronesia, and northern Australia.

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Illustrations by Nancy Hulbirt.

Photographs and Illustrations

Figure 1. Photograph of convective rain and atoll islands.
http://www.ctf76.navy.mil/gallery/2011/apr/20110428ran8100087_HDR002.jpg

Figure 2. Chart showing the time scales of weather, climate variability, and climate change from
http://www.pacificclimatefutures.net/en/help/climate-projections/understanding-climate-variability-and-change/

Figure 4. Photograph of Intertropical Convergence Zone (ITCZ).
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4028

Figure 5. Photograph of the South Pacific Convergence Zone (SPCZ)
http://goes.gsfc.nasa.gov/text/goes15results.html

Figure 10. Image of sea surface temperatures during positive (warm) and negative (cool) phase of the Pacific Decadal Oscillation.
https://www.climate.gov/sites/default/files/HR_PDO2005-2008.jpg

Figure 11. Graph of Pacific Decadal Oscillation from K.E. Trenberth, 2015, Has there been a hiatus? Science, 14 August, v. 349, Is. 6249, p. 691-692.

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