# GEO/OC 103
Exploring the Deep…

Lab 5

Unit 3
Ocean-Atmosphere Interactions

In this unit, you will

- *Explore how the distribution of land masses affects global temperature patterns.*

- *Discover how the ocean and atmosphere transfer energy from equatorial regions toward the poles.*

- *Compare ocean and atmospheric conditions between normal, El Niño, and La Niña phases.*

- *Investigate the effects of El Niño Southern Oscillation on climate in different parts of the world.*

NASA/GSFC
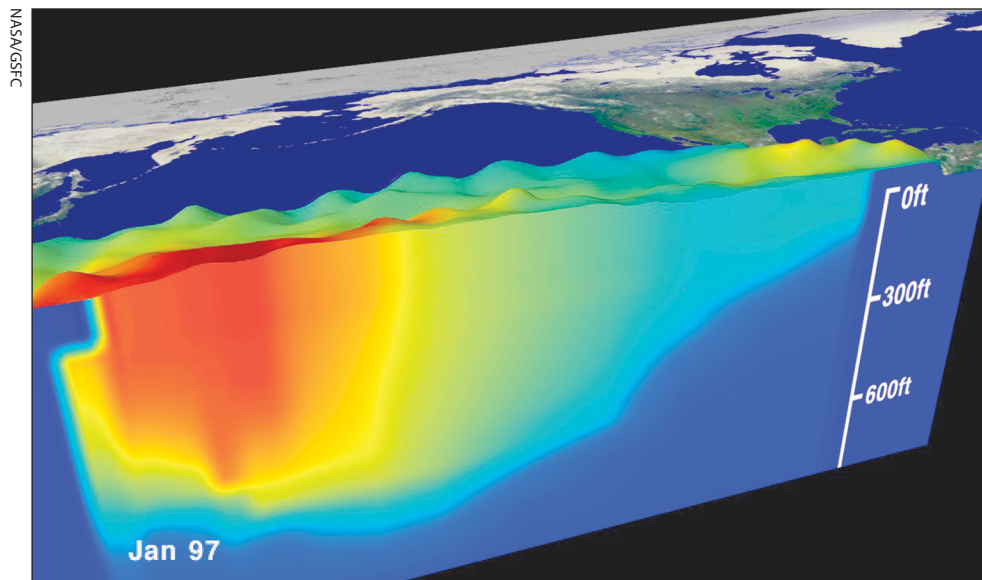
Cross section of the equatorial Pacific Ocean in January 1997. Warm temperatures are shown in red and orange, cold in blue. Ocean depths are greatly exaggerated.

Reading 3.3

Climate oscillations

Our climate is the product of interactions between the atmosphere, hydrosphere (Earth's liquid water), cryosphere (glaciers and ice sheets), geosphere (solid Earth), and biosphere (living organisms) that are driven by solar energy. The ocean and the atmosphere have the greatest influence on our climate. The oceans have a strong moderating effect on global temperatures, while the atmosphere reflects harmful solar radiation and traps heat and moisture near the surface. However, all of Earth's systems are linked together, and changes to any one system can have a substantial impact on the others. To fully understand the dynamics of our climate, we must examine the global energy balance and the transfer of energy among these systems.

Global energy balance

infrared radiation (IR) — invisible form of electromagnetic radiation that is sensed as heat.

latent heat — heat energy released or absorbed during a change of phase.

The Sun is the primary source of energy controlling temperatures on and near Earth's surface. When solar energy reaches Earth's atmosphere, approximately 30 percent is reflected back into space (~25% from clouds and ~5% from the ground); 51 percent is transmitted to the ground or ocean surface and absorbed; and 19 percent is absorbed by gases in the atmosphere (Figure 1 below). Of the 51 percent of the solar energy absorbed by the surface, 7 percent is used to raise the temperature of the atmosphere (sensible heat flux), 21 percent is radiated back to the atmosphere as **infrared radiation** (IR), and another 23 percent is used to evaporate water (**latent heat** flux) from the ocean and soils. Ultimately, all incoming solar energy is radiated back to space — otherwise, Earth would steadily heat up.
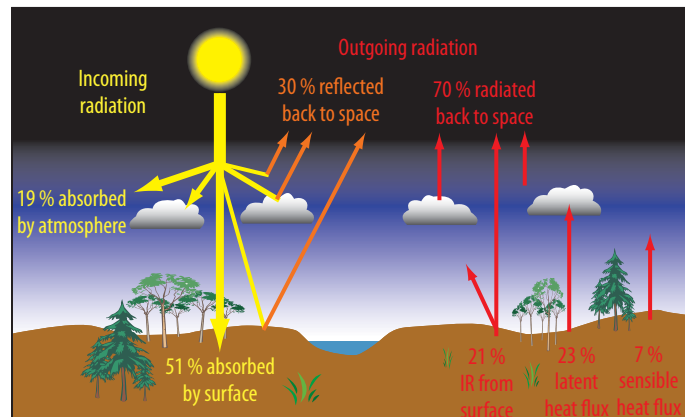

Figure 1. Annual mean global energy balance.

The total amount of solar energy reaching Earth each year is constant, but it is not distributed evenly across the globe. This uneven distribution of energy creates daily and seasonal temperature differences that drive winds, currents, precipitation, and evaporation (Figure 2 on the following page).
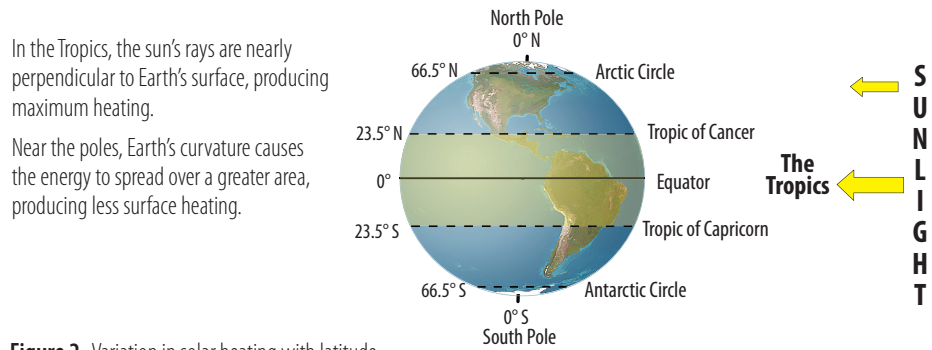
In the Tropics, the sun's rays are nearly perpendicular to Earth's surface, producing maximum heating.

Near the poles, Earth's curvature causes the energy to spread over a greater area, producing less surface heating.

Figure 2. Variation in solar heating with latitude.

Storing energy

To understand how solar radiation affects large-scale processes such as winds, currents, and climate, you need to know a few things about water and heat energy. Water can exist in three **states**—solid, liquid, or vapor (Figure 3). When water changes states, it absorbs or releases more heat (called latent heat) than do most other substances.

Liquid water can absorb more energy than any other liquid except ammonia, because it has a high **heat capacity**. Raising the temperature of water requires a lot of energy, so it is very difficult to change the temperature of the ocean even a small amount. This resistance to change is called **thermal inertia**. However, even small changes to the energy content of the ocean can have considerable effects on global climate. In contrast, the heat capacity and thermal inertia of the atmosphere are much lower, making it easier to change the temperature of the atmosphere.

heat capacity — the amount of energy required to raise the temperature of one unit of mass of a substance by 1 °C.
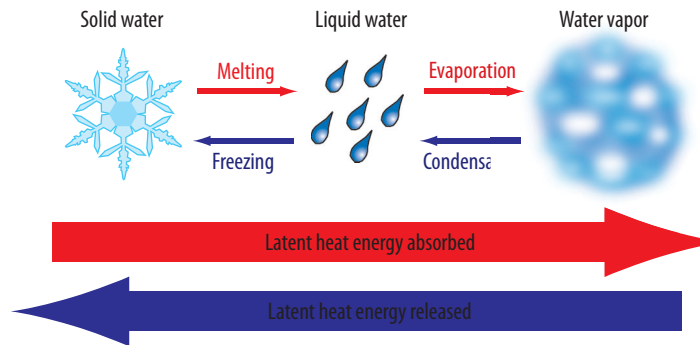
Figure 3. As ice melts or water evaporates, it absorbs latent heat; and as water vapor condenses or water freezes, it releases latent heat. The transition between liquid water and water vapor involves about seven times as much heat energy as the transition between liquid water and ice.

At the equator, where solar energy is highest, about 75 percent of Earth's surface is covered by water. Water's higher heat capacity allows the ocean to absorb and retain more solar energy than the land or atmosphere. In fact, the upper few hundred meters of ocean stores approximately 30 times more heat than the entire atmosphere. Without some type of circulation in the ocean and atmosphere, the equator would be 14 °C (25 °F) warmer on average than now, and the North Pole would be 25 °C (45 °F) colder. Fortunately, temperature imbalances drive atmospheric and oceanic circulation, which redistribute energy over Earth's surface.

1. How might global temperatures change if 75 percent of the area near the equator were covered with land instead of water? Explain.

Reflecting energy

Earth's ability to store solar energy is critical for regulating global temperatures. Equally important is its ability to reflect solar energy. The reflectivity of a material — the ratio of the amount of light reflected by an object to the amount of light that falls on it — is called its **albedo**. Albedo is determined principally by a material's texture and color: Rougher, darker surfaces tend to have lower albedos; whereas smooth, bright surfaces reflect more efficiently and have higher albedos. In addition, the angle at which the sun's rays strike the surface affects the albedo.

The albedos of various surface materials range widely, from extremely reflective to highly absorptive. For instance, different states of water — as ice, liquid water, and water droplets — have very different albedos. Ice and certain types of clouds have a high albedo and reflect 60 – 90 percent of the sun's energy. The oceans, on the other hand, generally have a low albedo (10%), which means that they absorb 90 percent of the sun's energy that strikes them. The albedo of the biosphere, meanwhile, varies according to the type of land cover; vegetated land has a much lower albedo than barren land. Thus, tropical rainforests absorb more solar energy than deserts.

The average albedo for the whole Earth is about 30 percent. This is not a permanent characteristic; any significant alteration of Earth's surface, such as melting of the ice sheets, desertification, or burning of tropical rain forests, can trigger changes in the amount of solar radiation absorbed or reflected. A change in albedo is significant, because global albedo is a key determinant of conditions on Earth. For example, if the ice sheets melted, the global albedo would decrease. Earth's surface would then absorb more energy, and the temperature of the atmosphere would rise. Evidence in the geologic record suggests this happened during the Cretaceous Period (144 to 65 million years ago). At that time, there was little or no snow and ice cover, even at the poles, and global temperatures were at least 8 – 10 °C warmer than today. Such global warming hinders the formation of sea ice and disrupts the development of cold, dense currents that sink to the depths of the ocean. In addition, warmer temperatures melt the ice sheets. This, in turn, increases the volume of the oceans, raises global sea levels, and triggers changes in Earth's energy balance.
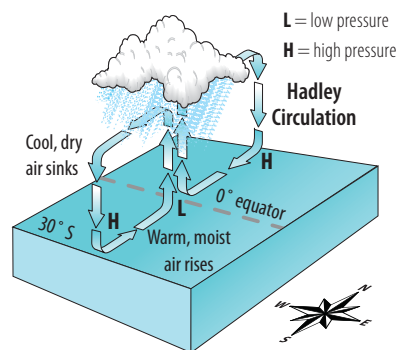
Circulating energy with winds and currents

The uneven distribution of solar energy produces circulation in the ocean and atmosphere that moderates temperatures across the globe. Near the equator, evaporation adds large amounts of water vapor and latent heat to the atmosphere (Figure 4). Hot, moist air rises from the ocean surface and cools, causing some of the water vapor to condense and fall back to Earth as rain. As water vapor condenses, it releases latent heat. This generates temperature differences and

Albedo of surface types at 45° N latitude

Surface Type	Albedo (%)
dense swampland	9 – 14
deciduous trees	13
grassy field	20
barren field	5 – 40*
farmland	15
desert or large beach	25*

* Depending on color of surface.

Figure 4. Simple convection cells between the equator and 30° N and 30° S move energy from the equator toward the poles. This process is called **Hadley circulation**.

winds higher in the atmosphere, which transport the remaining water vapor and latent heat toward the poles. As the air moves toward the poles, it continues to cool, becomes denser, and descends, flowing back towards the equator to complete the cycle.

Ocean currents contribute to the heat transfer between the equator and the poles by moving warm water toward the poles and cold water toward the equator. Warm surface currents at the equator are driven westward by the winds and deflect toward the poles as they near continents. As these warm currents flow toward the poles, they transfer heat to the atmosphere, warming the atmosphere and cooling the currents. The cooled surface currents then flow back toward the equator to be warmed again.

Deep-water density currents also play an important role in redistributing energy. Near the poles, cold, salty waters sink to great depths and flow slowly toward the opposite pole. These currents eventually rise to the surface where the water is reheated to begin the cycle again.

The Southern Oscillation

The ocean's high thermal inertia (slow response to change) helps stabilize Earth's climate. However, this stability is not a constant. Over the past century, scientists have observed **oscillations** in sea-surface temperature and air pressure that occur over years and decades. Localized ocean-temperature increases of only 2 – 3 °C have been linked to extended periods of drought and flooding globally. Heat transfer between the ocean and atmosphere, which causes changes in surface air pressure and winds, drives the oscillations. The best known of these is the **Southern Oscillation**, a seesaw shift in surface air pressure driven by changes in sea-surface temperature between the eastern and western Pacific Ocean in the Southern Hemisphere.

What drives the Southern Oscillation?

Strong evaporation and convection at the ocean's surface drive the Southern Oscillation. In a normal year, the average sea-surface temperature is warmer in the western Pacific than in the eastern Pacific (Figure 5). This **temperature gradient** causes air to circulate parallel to the equator in a pattern called the **Walker Circulation**. Warm waters of the western Pacific produce high levels

oscillation — back and forth pattern of change between one state or direction and its opposite.

temperature gradient — change in temperature over a distance.
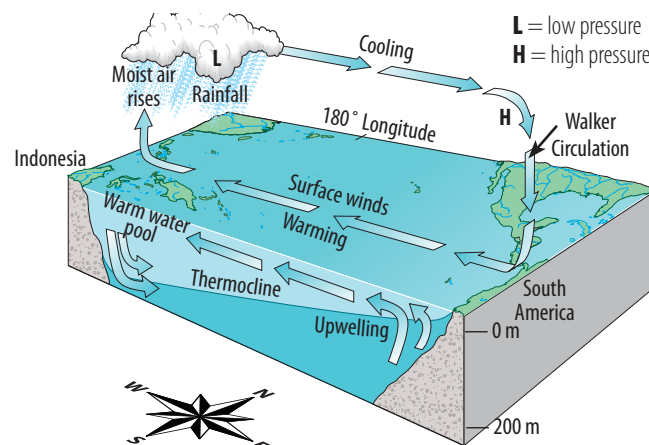
Figure 5. Normal conditions in the equatorial Pacific Ocean.

of evaporation and increased precipitation. The warm, rising air creates low pressure at the surface. As surface winds blow into this low-pressure center, they pile up water to form a small mound in the western Pacific. As a result, the layer of warm surface water is deeper in the western Pacific than in the east. This forces the deeper and colder waters in the western Pacific to flow eastward and up toward the surface, producing cooler sea-surface temperatures off the coast of South America. The rising, moist air in the western Pacific fuels the heavy monsoon rains of Southeast Asia, and the sinking dry air in the eastern Pacific creates the coastal deserts of South America.

2. Indicate word in each pair that correctly completes the sentence:

Warmer/Cooler surface temperatures cause increased evaporation and upward convection of air masses, which leads to higher/lower air pressure near the surface."

Changes to the Southern Oscillation — El Niño and La Niña

phase — stage in a periodic process or phenomenon.

About every three to eight years, the Southern Oscillation strengthens or weakens and we experience either El Niño or its sister **phase**, La Niña. During an El Niño phase (Figure 6), a 1–2 °C warming of the water in the eastern Pacific reduces the sea-surface temperature gradient from east to west. The reduced temperature gradient weakens the east to west trade winds in the South Pacific. This allows the mound of warm water piled up in the western Pacific to spread out and move eastward. The warm surface waters in the east and high air pressures prevent the typical upwelling of cold, nutrient-rich water off the west coast of South America.
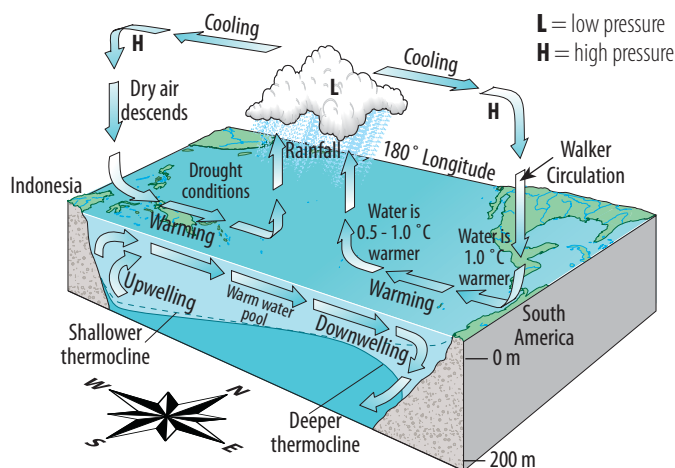
Figure 6. Conditions in the equatorial Pacific Ocean during an El Niño phase.

Although the El Niño Southern Oscillation occurs in the tropical Pacific Ocean, its impact on climate is observed globally. Variations in rainfall are significant, with reports of droughts in regions of Indonesia and Australia that are normally drenched by monsoons, and storms and flooding in Ecuador and parts of the United States. In addition to climate changes, El Niño phases can have devastating effects on fisheries, agriculture, and outbreaks of fire and disease. For example, in most years colder nutrient-rich water from the deeper ocean is drawn to the surface near the coast of Peru and Ecuador (upwelling). This produces abundant plankton, the food source of the anchovy, and the anchovy harvest increases. However, when upwelling weakens in an El Niño phase and warmer low-nutrient water spreads along the coast, the anchovy harvest plummets.

An El Niño phase that produces warming of the water in the eastern Pacific basin is counteracted in other years by a similar cooling phase known as La Niña. During a La Niña phase, trade winds are anomalously stronger than normal, and the sea-surface temperature gradient increases (Figure 7). This causes greater upwelling of cold water in the eastern Pacific Ocean and increased warming and evaporation in the western Pacific Ocean.
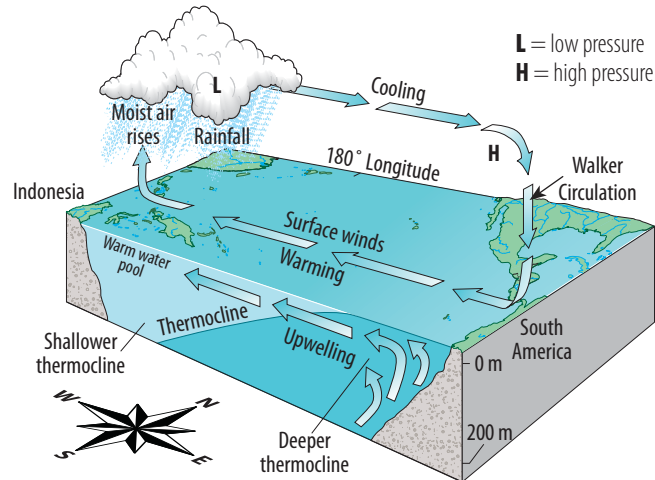
Figure 7. Conditions in the equatorial Pacific Ocean during a La Niña phase.

These oscillations and the conditions that produce them are the focus of extensive research because their climate impacts can be quite severe. A recent study suggests that El Niño can be triggered by volcanic eruptions. Climate and eruption records dating back to the 17th century suggest that a large eruption can double the likelihood of an El Niño phase the following winter. Volcanoes might alter the climate by spewing great quantities of dust and greenhouse gases into the air. The dust particles reflect sunlight and alter the amount of solar heat reaching Earth's surface.

3. List three ways in which El Niño might affect your everyday life. Consider both direct and indirect effects.

    a.

    b.

    c.

Other climate oscillations

The El Niño Southern Oscillation is the most studied and best understood ocean-atmosphere interaction. In recent decades, other patterns have been identified around the globe, including the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation. The Pacific Decadal Oscillation is the primary factor determining variations in monthly sea-surface temperature in the North Pacific (poleward of 20° N). The Pacific Decadal Oscillation has a distinct pattern of long-term sea-surface temperature oscillations in the North Pacific. However, it occurs over 20 – 30 years, whereas typical El Niño Southern Oscillation phases last for only 6 – 18 months.

A similar pattern of sea-surface temperature oscillations in the North Atlantic Ocean — the Atlantic Multidecadal Oscillation — occurs over a period of 50 – 80 years. Scientists believe that the Atlantic Multidecadal Oscillation and Pacific Decadal Oscillation are linked to the major droughts of the past 100 years in North America including the Dust Bowl in the 1930s, extended droughts in the 1950s and 1970s, and the drought in the southwestern United States that started in 1998. Understanding these ocean-atmosphere phenomena is critical to understanding global climate variability and improving climate-forecasting capabilities. For at least the past 400 years, people living around the equatorial Pacific Ocean have noted that in some years the surface waters of the central and eastern Pacific Ocean are warmer than usual. Because this change usually begins in December, the phenomenon was named El Niño — Spanish for "the boy child" (referring to the Christ child). Over time, scientists have come to realize that El Niño is not an isolated phenomenon. Subsequent years sometimes show a pattern of unusually cool surface waters in this region, an event now referred to as the La Niña ("the girl child") phase. Both phases can have dramatic effects on global climate. Too wet, too dry, too hot, or too cold — during an El Niño or La Niña phase, chances are good that the weather will be unusual.

Investigation 3.4

El Niño and La Niña

Normal phase

phase — stage in a periodic process or phenomenon.
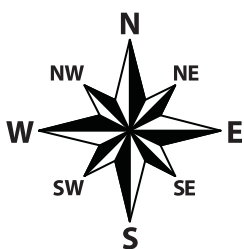
In the first part of this investigation, you will examine typical ocean and atmospheric circulation patterns in the Pacific Ocean under normal *phase* conditions. Later, you will compare these patterns to El Niño and La Niña phases to see how small changes can disrupt local circulation patterns and global weather conditions.

🖥 Launch ArcMap, and locate and open the **etoe_unit_3.mxd** file.

Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.

🖥 In the Table of Contents, right-click the **Normal Phase** data frame and choose Activate.

🖥 Expand the **Normal Phase** data frame.

The **Wind Speed** layer shows the average speeds and directions of surface winds around the globe. Arrows point in the average wind direction (Figure 1), and the color of each arrow represents the average wind speed at that location. Notice how, in this layer as well as many of the others, most characteristics of the ocean and atmosphere change more with latitude than with longitude.

🖥 Click the QuickLoad button 🔲.

🖥 Select **Spatial Bookmarks**, choose **Pacific Ocean**, and click **OK**.

1. Examine the surface winds over the Pacific Ocean between the equator and 30° latitude in both hemispheres, and describe any differences you observe

   a. *between* the Northern and Southern Hemisphere.

   b. from east to west in the Northern Hemisphere.

   c. from east to west in the Southern Hemisphere.

The winds blowing from east to west near the equator are called the *trade winds*, named for their importance in pushing the sailing ships that traveled between Europe and the Americas in the 17th and 18th centuries.

🖥 Turn off the **Wind Speed** layer.

🖥 Turn on and expand the **Surface Currents** layer.

Figure 1. Compass directions.

The **Surface Currents** layer shows the average directions of the world's ocean surface currents. Note the directions of the ocean currents between 30° N and 30° S.

2. Between 30° N and 30° S, in what direction do most surface currents flow? How does this compare to the average direction of the trade winds? (Hint: Trade winds are defined on the previous page.)

Next, you will look at the average sea-surface temperatures (SST) across the Pacific Ocean.

- 🖥 Turn off and collapse the **Surface Currents** layer.
- 🖥 Turn on and expand the **Average Sea-Surface Temperature** layer.

Examine the sea-surface temperatures across the Pacific Ocean, paying particular attention to the region between 30° N and 30° S.

3. Which part of the equatorial Pacific Ocean appears to have the warmer surface temperature, the eastern Pacific or the western Pacific?

Sea not-so-level

You may have been taught that sea level is a flat surface that extends all over the ocean, but in fact the ocean surface has many small hills and valleys that vary from mean sea level by tens to hundreds of centimeters. These are caused by temperature and pressure differences, tides, gravity, and the effects of wind blowing across the ocean surface.

Water expands as it warms and contracts as it cools. This phenomenon is called *thermal expansion*.

4. Based on the average surface temperature alone, what effect do you think this expanding warmer water would have on sea level in this part of the Pacific? (Hint: See sidebar for help.)

- 🖥 Turn off and collapse the **Average Sea-Surface Temperature** layer.
- 🖥 Turn on and expand the **Sea-Level Anomaly** layer.

An *anomaly* is anything that deviates from normal or average. In this layer, white represents places where sea level is at its normal height of 0 meters. Areas where sea level is higher than normal are colored pink and red, and areas that are lower than normal are colored blue. Next, you will see if the sea-level anomaly data support your prediction.

- 🖥 Turn on the **Eastern Pacific** layer.
- 🖥 Turn on the **Western Pacific** layer.

These layers define the regions you will use to compare the eastern and western equatorial Pacific Ocean. You will begin by using the **Sea-Level Anomaly** layer to look for differences in sea level between the two areas.

Next, you will calculate the sea-level anomaly for the western Pacific region.

⌨ Click the Select By Location button 🖳.

⌨ In the Select By Location window, construct the query statement:

I want to **select features from** the **Sea-Level Anomaly** layer that **intersect** the features in the **Western Pacific** layer.

⌨ Click **Apply.**

⌨ Close the Select By Location window.

The western Pacific region will be highlighted.

⌨ Click the Statistics button 🗙.

⌨ In the Statistics window, calculate statistics for **only selected features** of the **Sea-Level Anomaly** layer, using the **Anomaly (cm)** field.
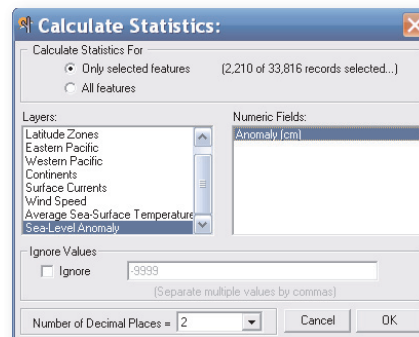
⌨ Click **OK**.

The average sea-level anomaly for the western Pacific region is given in centimeters as the **Mean** in the Statistics window.

5. Round the average sea-level anomaly for the region to the nearest 0.1 cm and record it in Table 1 on the following page.

Table 1 — Sea-level anomalies in the equatorial Pacific Ocean

Western Pacific Anomaly *cm*	Eastern Pacific Anomaly *cm*	Difference (W Pacific Anomaly – E Pacific Anomaly) *cm*

💻 Close the Statistics window.

💻 Click the Clear Selected Features button ⊠.

Repeat the Select By Location procedure to calculate the sea-level anomaly for the eastern Pacific.

💻 Click the Select By Location button 🔁.

💻 In the Select By Location window, construct the query statement:

I want to **select features from** the **Sea-Level Anomaly** layer that **intersect** the features in the **Eastern Pacific** layer.

💻 Click **Apply.**

The eastern Pacific region will be highlighted.

💻 Close the Select By Location window.

💻 Click the Statistics button $\overline{X}$.

💻 In the Statistics window, calculate statistics for **only selected features** of the **Sea-Level Anomaly** layer, using the **Anomaly (cm)** field.

💻 Click **OK**.

The average sea-level anomaly for the eastern Pacific region is given in centimeters as the **Mean** in the Statistics window.

6. Round the average sea-level anomaly for the region to the nearest 0.1 cm and record it in Table 1.

7. Calculate the difference between the average sea-level anomaly in the western Pacific and the eastern Pacific and record it in Table 1.

💻 Close the Statistics window.

💻 Click the Clear Selected Features button ⊠.

8. According to Table 1, is sea level higher in the western Pacific or in the eastern Pacific? Compare this result with your prediction in question 4.

This difference represents a low but very broad "hill" of water in the western half of the Pacific Ocean. This hill is essentially permanent, even though gravity is constantly pulling the hill down and outward.

9. Explain how the prevailing winds and ocean currents might help keep the hill of water in the Pacific Ocean from spreading out. (See sidebar at left.)

The Southern Oscillation

Long before they understood the causes of El Niño, scientists noticed seemingly independent weather phenomena in the Southern Hemisphere. One of these was an oscillation, or periodic strengthening and weakening, of the surface atmospheric pressure across the Pacific Ocean. Scientists now understand that this oscillation and the sea-surface temperature changes characteristic of El Niño and La Niña phases are directly related. Together, these phenomena are now known as the *El Niño Southern Oscillation*, or ENSO.

In this section, you will compare the average atmospheric pressure in the equatorial eastern and western Pacific Ocean for three different oscillation phases: the "normal" long-term average calculated with data from *all* years between 1950 and 2003, eight years of El Niño, and eight years of La Niña.

   💻 Click the QuickLoad button 🔍.

   💻 Select **Data Frames**, choose **Southern Oscillation**, and click **OK**.

The **Normal Surface Atmospheric Pressure** layer represents the average surface pressure for all years from 1950 to 2003. Low pressure is represented by light shades of blue, and high pressure is shown in darker shades of blue. Surface pressure decreases as the air temperature and humidity increase.

   💻 Click the QuickLoad button 🔍.

   💻 Select **Spatial Bookmarks**, choose **Pacific Ocean**, and click **OK**.

Next, you will calculate the normal average surface pressure for the eastern Pacific region.

   💻 Click the Select By Location button 🗺️.

   💻 In the Select By Location window, construct the query statement:

      I want to **select features from** the **Normal Surface Atmospheric Pressure** layer that **intersect** the features in the **Eastern Pacific** layer.

   💻 Click **Apply**.

The eastern Pacific region will be highlighted.

   💻 Close the Select By Location window.

   💻 Click the Statistics button ⊠.

   💻 In the Statistics window, calculate statistics for **only selected features** of the **Normal Surface Atmospheric Pressure** layer, using the **Pressure (mb)** field.

   💻 Click **OK**.

The average surface pressure for the normal phase in the eastern Pacific is given in millibars as the **Mean** in the Statistics window.

10. Round the average (**Mean**) surface pressure for the normal phase to the nearest 0.1 mb and record it in Table 2 on the following page. Data for the western Pacific have been entered for you.

Table 2 — Equatorial Pacific average surface pressure and climate phases

Region	Average surface atmospheric pressure *mb*		
	Normal phase	El Niño phase	La Niña phase
Western Pacific	1009.7	1010.1	1009.2
Eastern Pacific			
Difference (E – W)			

- Close the Statistics window.
- Click the Clear Selected Features button ⊠.
- Turn off and collapse the **Normal Surface Atmospheric Pressure** layer.
- Turn on and expand the **El Niño Surface Atmospheric Pressure** layer.

Repeat the Select By Location query process to calculate the average surface pressure for the eastern Pacific region during El Niño phases.

- Click the Select By Location button 🖳.
- In the Select By Location window, construct the query statement:

    I want to **select features from** the **El Niño Surface Atmospheric Pressure** layer that **intersect** the features in the **Eastern Pacific** layer. (Note: Make sure the **El Niño Surface Atmospheric Pressure** is the ONLY option checked.)

- Click **Apply**.

The eastern Pacific region will be highlighted.

- Close the Select By Location window.
- Click the Statistics button ⊠.
- In the Statistics window, calculate statistics for **only selected features** of the **El Niño Surface Atmospheric Pressure** layer, using the **Pressure (mb)** field.
- Click **OK**.

The average surface pressure during El Niño phases is given in millibars for the eastern Pacific as the **Mean** in the Statistics window.

11. Round the average El Niño surface pressure for the eastern Pacific to the nearest 0.1 mb and record it in Table 2.

- Close the Statistics window.
- Click the Clear Selected Features button ⊠.
- Turn off and collapse the **El Niño Surface Atmospheric Pressure** layer.
- Turn on and expand the **La Niña Surface Atmospheric Pressure** layer.
- Click the Select By Location button 🖳.
- In the Select By Location window, construct the query statement:

    I want to **select features from** the **La Niña Surface Atmospheric Pressure** layer that **intersect** the features in the **Eastern Pacific** layer. (Note: Make sure the **La Niña Surface Atmospheric Pressure** is the ONLY option checked.)

🖥 Click **Apply**.

The eastern Pacific region will be highlighted.

🖥 Close the Select By Location window.

🖥 Click the Statistics button ☒.

🖥 In the Statistics window, calculate statistics for **only selected features** of the **La Niña Surface Atmospheric Pressure** layer, using the **Pressure (mb)** field.

🖥 Click **OK**.

The average surface pressure for the La Niña phase is given in millibars for the eastern Pacific as the **Mean** in the Statistics window.

12. Round the La Niña average surface pressure for the eastern Pacific to the nearest 0.1 mb and record it in Table 2.

🖥 Close the Statistics window.

🖥 Click the Clear Selected Features button ☒.

13. Calculate the differences between the eastern and western Pacific regions for the three phases and record them in Table 2.

Winds blow from areas of high pressure to areas of low pressure, and the wind speed increases as the pressure differences increase. With this in mind, consider how the pressure difference between the western and eastern Pacific Ocean influences wind speeds during El Niño and La Niña phases.

14. Write the name *El Niño* or *La Niña* in each blank to correctly complete the following statement:

The pressure difference between the eastern Pacific and the western Pacific is greatest during the _____ phase, resulting in higher wind speeds than in the normal and _____ phases.

🖥 Turn off and collapse the **La Niña Surface Atmospheric Pressure** layer.

Next, you will measure wind speeds in the equatorial Pacific Ocean to see whether wind speeds during El Niño and La Niña phases respond to the east-west pressure difference in the way you predicted.

🖥 Turn on and expand the **Wind Speed** layer.

🖥 Click the Select By Location button 🖫.

🖥 In the Select By Location window, construct the query statement:

I want to **select features from** the **Wind Speed** layer that **intersect** the features in the **Eastern Pacific** layer.

🖥 Click **Apply**, but do not close the Select By Location window.

The eastern Pacific region will be highlighted. This process selected the average wind speed data for the eastern Pacific. Next, you will add the data for the western Pacific so you can calculate the average wind speed across the entire equatorial Pacific.

🖥 In the Select By Location window, construct the query statement:

I want to **add to the currently selected features in** the **Wind Speed** layer that **intersect** the features in the **Western Pacific** layer.

🖥️ Click **Apply**.

Both the eastern and western Pacific regions should be highlighted.

🖥️ Close the Select By Location window.

🖥️ Click the Statistics button ⊠.

🖥️ In the Statistics window, calculate statistics for **only selected features** of the **Wind Speed** layer, using the **El Niño Mean Wind Speed**, **La Niña Mean Wind Speed**, and **Normal Mean Wind Speed** fields. (Note: Hold down the Shift key to select multiple fields.)

🖥️ Click **OK**.

The average wind speeds (m/s) for the normal, El Niño, and La Niña phases are given for the entire equatorial Pacific region as the **Mean** in the Statistics window.

15. Round the average (**Mean**) wind speeds to the nearest 0.01 m/s and record them in Table 3.

Table 3 — Equatorial Pacific Ocean wind speed comparison

Average wind speed		
m/s		
Normal phase	**El Niño phase**	**La Niña phase**

🖥️ Close the Statistics window.

🖥️ Click the Clear Selected Features button ⊠.

16. Do the average wind speeds you recorded in Table 3 agree with the predictions you made based on pressure in question 14 about the wind speeds in La Niña years? Explain.

The effects of El Niño and La Niña on sea level

Now that you have seen how surface atmospheric pressure and wind speed vary during El Niño and La Niña phases, think back to the concept of sea level you explored earlier. As you observed, the warm waters of the equatorial western Pacific form a hill or mound due to thermal expansion, and are held in place by the trade winds and equatorial currents. You have also seen that trade winds strengthen or weaken in response to changes in surface pressure and ocean temperature associated with El Niño and La Niña phases.

Next you will examine how the strengthening or weakening of trade winds affects sea level.

🖥️ Turn off the **Wind Speed** layer.

🖥️ Turn on the **Sea-Level Stations** layer.

This layer shows the locations of sea-level monitoring stations in the Pacific Ocean. The points in the middle of the Pacific are located on islands.

🖥 Click the QuickLoad button 🔍.

🖥 Select **Layers**, choose **El Niño Sea-Level Anomalies**, and click **OK**.

A new **Sea-Level Stations** layer will appear at the top of the Table of Contents with the subheading, **Ave El Niño MSL anomaly**.

🖥 Turn on the **Sea-Level Stations** layer with the subheading **Ave El Niño MSL anomaly.**

The sea-level stations in this new layer are classified based on whether sea level during El Niño phases is below normal (blue) or above normal (red). In this case, normal is the mean sea level at that location.

17. Based on what you have learned about the effect of El Niño on trade winds and sea level, complete the following statement by circling the appropriate words where indicated and writing *higher* or *lower* in each blank.

During an El Niño phase, the speed of the trade winds is [_____] than in the normal phase, causing the hill of warm water in the western Pacific to [pile up? spread out?]. As a result, sea level is [_____] than normal in the western Pacific and [_____] than normal in the eastern Pacific.

🖥 Turn off the **Sea-Level Stations** layer with the subheading **Ave El Niño MSL anomaly.**

🖥 Click the QuickLoad button 🔍.

🖥 Select **Layers**, choose **La Niña Sea-Level Anomalies**, and click **OK**.

A new **Sea-Level Stations** layer will appear at the top of the Table of Contents with the subheading, **Ave La Niña MSL anomaly**.

🖥 Turn on the **Sea-Level Stations** layer with the subheading **Ave La Niña MSL anomaly.**

The sea-level stations in this layer are classified based on whether sea level during La Niña phases is below normal (blue) or above normal (red). In this case, normal is the mean sea level at that location.

18. Based on what you have learned about the effect of La Niña on trade winds and sea level, complete the following statement by circling the appropriate words where indicated and writing *higher* or *lower* in each blank.

During La Niña phases, the speed of the trade winds is [_____] than in the normal phase, causing the hill of warm water in the western Pacific to [pile up? spread out?]. As a result, sea level is [_____] than normal in the western Pacific and [_____] than normal in the eastern Pacific.

🖥 Turn off and collapse all **Sea-Level Stations** layers.

Effects of El Niño and La Niña on sea-surface temperature

Now you will explore how El Niño and La Niña affect sea-surface temperatures.

🖥 Turn on and expand the **El Niño SST Anomaly** layer.

This layer shows sea-surface temperature anomalies averaged over eight years of the El Niño phase. Reds represent positive anomalies, where the temperature

was higher than normal; and blues represent negative anomalies, where the temperature was lower than normal.

19. In the **El Niño SST Anomaly** layer, where are large, positive sea-surface temperature anomalies (warming) more common — in the eastern or the western Pacific Ocean?

⌨ Turn off and collapse the **El Niño SST Anomaly** layer.

⌨ Turn on and expand the **La Niña SST Anomaly** layer.

20. In the **La Niña SST Anomaly** layer, where are large, negative temperature anomalies (cooling) more common — in the eastern or in the western Pacific Ocean?

Now you will quantify the sea-surface temperature anomalies across the equatorial Pacific Ocean.

⌨ Click the Select By Location button 🖼.

⌨ In the Select By Location window, construct the query statement:

I want to **select features from** the **El Niño SST Anomaly** layer that **intersect** the features in the **Western Pacific** layer.

⌨ Click **Apply.**

⌨ Close the Select By Location window.

⌨ Click the Statistics button 𝗫̄.

⌨ In the Statistics window, calculate statistics for **only selected features** of the **El Niño SST Anomaly** layer, using the **SST Anomaly (C)** field.

⌨ Click **OK**.

The average sea-surface temperature anomaly for the El Niño phase is given in degrees Celsius for the western Pacific region as the **Mean** in the Statistics window.

21. Record the average (**Mean**) SST anomaly for the western Pacific region in the El Niño phase in Table 4. Round to the nearest 0.01 °C.

Table 4 — SST anomalies for El Niño and La Niña phases

Phase	SST Anomaly °C	
	Western Pacific	Eastern Pacific
El Niño		
La Niña		

⌨ Close the Statistics window.

⌨ Click the Clear Selected Features button 🔳.

⌨ Repeat the Select By Location and Statistics processes to determine the SST anomaly for the **El Niño SST Anomaly** layer in the **Eastern Pacific** and record your answer in Table 4.

⌨ Repeat the Select By Location and Statistics processes to determine the SST anomaly for the **La Niña SST Anomaly** layer in the **Western Pacific** and record your answer in Table 4. (Note: Make sure the **La Niña SST Anomaly** is the ONLY option checked.)

⌨ Repeat the Select By Location and Statistics processes to determine the SST anomaly for the **La Niña SST Anomaly** layer in the **Eastern Pacific** to complete Table 4.

⌨ When you are finished, close the Statistics and Select By Location windows.

22. Warming of the ocean surface produces increased evaporation and precipitation, whereas cooling decreases evaporation and precipitation. Answer the following questions on the basis of the data recorded in Table 4:

   a. Which part of the Pacific Ocean should experience the largest increase in precipitation and evaporation? During which phase of the oscillation does this occur (El Niño or La Niña)?

   b. Which part of the Pacific Ocean should experience the largest decrease in precipitation and evaporation? During which phase of the oscillation does this occur? (Normal, El Niño, or La Niña)

⌨ Turn off and collapse the **La Niña SST Anomaly** layer.

⌨ Turn off the **Eastern Pacific** and **Western Pacific** layers.

⌨ Click the Clear Selected Features button ⊠ .

Weather and climate effects

In addition to producing predictable weather and climate patterns in the equatorial Pacific, ENSO also influences weather and climate around the world. To illustrate this, you will examine the effects of El Niño and La Niña on global precipitation rates and drought patterns.

⌨ Click the Zoom to Full Extent button 🌐 to view the entire map.

⌨ Turn on and expand the **El Niño Precipitation Anomaly** layer.

This layer shows the deviation from normal precipitation averages during the El Niño phase, in centimeters per year. Negative anomalies (below average values) are shown in orange, and positive anomalies (above average values) are shown in purple.

⌨ Turn off and collapse the **El Niño Precipitation Anomaly** layer.

⌨ Turn on and expand the **La Niña Precipitation Anomaly** layer.

This layer shows the deviation from normal precipitation averages during La Niña phase, in centimeters per year. Again, negative anomalies (below average values) are shown in orange, and positive anomalies (above average values) are shown in purple.

What does "PDSI" stand for?

PDSI is a numerical value calculated using several climate measurements, but has no units itself. It is useful for comparing conditions of different regions or of the same region at different times.

23. Having viewed the maps of precipitation anomalies, what can you say about global precipitation patterns during El Niño and La Niña phases?

⌨ Turn off and collapse the **La Niña Precipitation Anomaly** layer.

ENSO and climate

To conclude your investigation, you will examine two layers that indicate whether the worldwide climate conditions were unusually dry or wet during El Niño or La Niña phases.

⌨ Turn off the **Continents** layer.

⌨ Turn on and expand the **El Niño PDSI** layer.

The Palmer Drought Severity Index (PDSI) is a measure of the relative wetness or dryness of an area. This layer shows PDSI values for areas around the world. This is also an anomaly layer—negative values, in brown, represent drought conditions; and positive values, in green, represent wetter than normal conditions. Next, you will identify countries that are wetter or drier than average during El Niño phases.

⌨ To determine the name of a country, click the Identify tool 🛈 .

⌨ In the Identify Results window, select the **Countries** layer from the drop-down list of layers.

⌨ Next, click within the borders of the country you wish to identify.

24. Identify three countries that appear to be wetter than average during El Niño phases, and three that appear to be drier than average.

a. Wetter-than-average countries.
   (1)
   (2)
   (3)

b. Drier-than-average countries.
   (1)
   (2)
   (3)

Next, you will find the average PDSI values for six selected countries, to assess how each is affected during an El Niño phase.
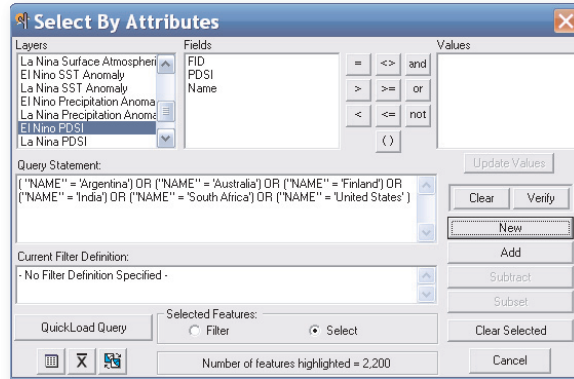
⌨ Close the Identify Results window.

⌨ Click the Select By Attributes button 🔍 .

⌨ Choose **El Niño PDSI** from the Layers menu.

⌨ Click **Quickload Query** in the Select By Attributes window, choose **El Niño PDSI by Country**. This will automatically enter the following query:

("NAME" = 'Argentina') OR ("NAME" = 'Australia') OR ("NAME"='Finland') OR ("NAME" = 'India') OR ("NAME" = 'South Africa') OR ("NAME" = 'United States')

▣ Click **New**.

The six selected countries should be highlighted. Now you will average the data for each country by creating a summary table.

▣ Close the Select By Attributes window.

▣ Click the Summarize button ▣.

▣ In the Summarize window, select **El Niño PDSI** as the **feature layer**.

▣ Select **Name** as the **field to summarize** in the drop-down menu.

▣ Double-click **PDSI** to display the statistics options and check **Average**.

▣ Check the **Summarize on Selected Records only** option and click **OK**.
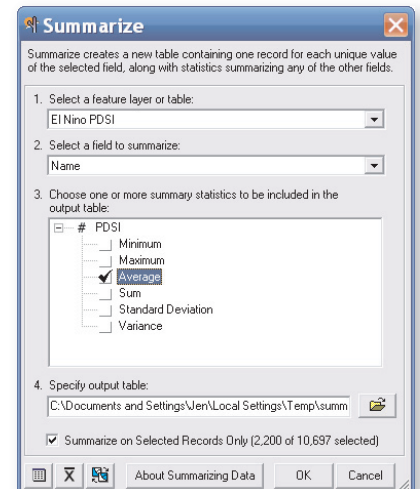
25. Round the average El Niño PDSI values for the six countries to the nearest 0.01 and record them in Table 5.

Table 5 — El Niño and La Niña PDSI values for selected countries

Country Name	PDSI value		
	El Niño	La Niña	Change +/−
Argentina			
Australia			
Finland			
India			
South Africa			
United States			

▣ Close the Summary Table window.

▣ Click the Clear Selected Features button ▣.

▣ Turn off and collapse the **El Niño PDSI** layer.

⌨ Turn on and expand the **La Niña PDSI** layer.

⌨ Click the Select By Attributes button 🔍.

⌨ Choose **La Niña PDSI** from the Layers menu.

⌨ Click **Quickload Query** in the Select By Attributes window, choose **La Niña PDSI by Country**. This will automatically enter the following query:

("NAME" = 'Argentina') OR ("NAME" = 'Australia') OR ("NAME"='Finland') OR ("NAME" = 'India') OR ("NAME" = 'South Africa') OR ("NAME" = 'United States')

⌨ Click **New**.

The six selected countries should be highlighted. Now you will average the data for each country by creating a summary table.

⌨ Close the Select By Attributes window.

⌨ Click the Summarize button **Σ**.

⌨ In the Summarize window, select **La Niña PDSI** as the **feature layer**.

⌨ Select **Name** as the **field to summarize** in the drop-down menu.

⌨ Double-click **PDSI** to display the statistics options and check **Average**.

⌨ Check the **Summarize on Selected Records only** option and click **OK**.

26. Round the average La Niña PDSI results to the nearest 0.01 and record them in Table 5.

27. Write a "+" or "–" sign in the fourth column of Table 5 to indicate if the PDSI increases or deceases from the El Niño to La Niña phases in each country.

28. According to your results, which of the six countries are most likely to experience

  a. drought during El Niño years?

  b. wet La Niña years?

29. Summarize how the general patterns in drought and wet years vary with El Niño and La Niña.

⌨ Close the Summary Table window.

⌨ Click the Clear Selected Features button 🗙.

⌨ Quit ArcMap and do not save changes.