Module 3, Investigation 1: Briefing 1
What are the effects of ENSO?

Background
The changing temperatures of the tropical Pacific Ocean affect climate variability all over Earth. Ocean warming and cooling dramatically affect human activities by changing weather patterns and ocean currents. Often, these climate variations cause heat waves, droughts, floods, mud slides, tornadoes, wildfires, and many other disasters that affect human activity. One result of dramatically changing ocean temperatures (both warm and cold) is called the *El Niño Southern Oscillation* (or ENSO). The warming period, often called "El Niño" or "the Christ Child," is so named because of its frequent late-December appearance. The cooling period is referred to as "La Niña." These ENSO events cause severe problems, but prediction and management of these periods can reduce human suffering and damage. In this investigation, you play the role of a Peruvian government policy maker deciding how to allocate Peru's resources to manage for possible ENSO-related problems. In order to play your role successfully, you will first need to learn how ENSO works, how it affects the environment, and how it creates problems for humans.

Objectives
In this investigation, you will
- interpret satellite images and maps to draw conclusions about the physical processes producing ENSO;
- explain how, when, and where ENSO events occur;
- give examples of how ENSO events affect humans in different places; and
- use geographic information to develop national plans and investments to prepare for ENSO events in Peru and other places.

Part 1. What is ENSO?
Atmospheric and oceanic variability affect the weather. Weather and climate change through complex links between the oceans and the atmosphere. Sources of variability in weather and climate around the world are changes in water currents, atmospheric pressure, and temperature in the oceans, especially the Pacific Ocean. These changes in the Pacific are often referred to as the El Niño Southern Oscillation, or ENSO. Two types of changes are referred to as El Niño and La Niña.

El Niño is the name given to the occasional warming of surface waters in the central and eastern equatorial Pacific Ocean. Under normal conditions, easterly trade winds blow from east to west along the equator and push warm surface water to the western tropical Pacific, where it piles up near Indonesia and the Australian continent (Figure 1). The persistent easterly trade winds are key ingredients of ENSO because they push warm water toward the western Pacific. This gives that area the warmest ocean temperatures on Earth. Usually above 28 degrees C (82 degrees F), parts of this pool are sometimes as warm as 31.5 degrees C (89 degrees F). Because this large pool of warm water is pushed towards the western Pacific, the

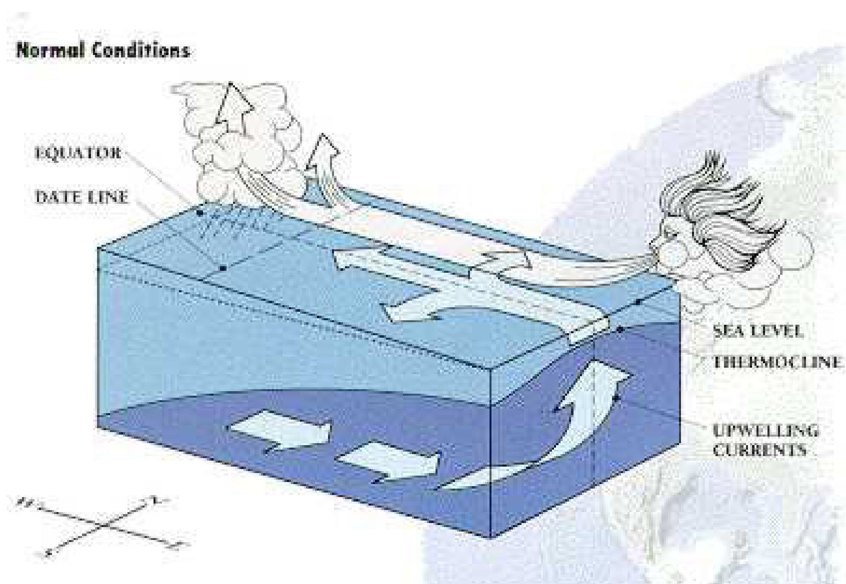

Figure 1: Normal atmospheric-oceanic circulation

Source: http://airsea-www.jpl.nasa.gov/ENSO/ElNino.html

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atmosphere above the ocean is heated, causing favorable conditions for convection and precipitation. In fact, the persistent oceanic heat surrounding Indonesia and other western Pacific islands leads to frequent thunderstorms and some of the heaviest rainfall on Earth.

As the easterly trade winds push warm surface water against the western boundary of the Pacific Ocean, colder, nutrient-rich water comes up from below along the coast of South America to replace it. This is called **upwelling**. Upwelling helps fish and other animals thrive. In addition, as the warm surface water moves westward, the layer dividing the warm surface water and deep cold water, known as the **thermocline**, is raised. Because warm water contains more volume than colder water, and because trade winds push the water westward, the sea level is higher on the western side of the Pacific. In fact, the sea level in the Philippines is normally about 60 centimeters (23 inches) higher than the sea level on the southern coast of Panama.

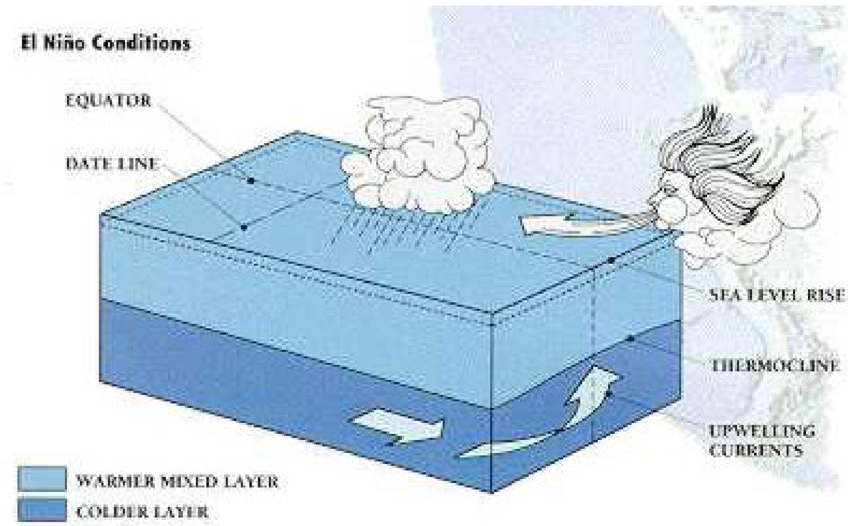

Figure 2: El Niño circulation

Source: http://airsea-www.jpl.nasa.gov/ENSO/ElNino.html

In the upper levels of the atmosphere, the winds blow from west to east, completing a large-scale atmospheric circulation known as the Walker Circulation, named after Sir Gilbert Walker who studied variations in the tropical Pacific atmosphere during the 1920s.

In an El Niño year (Figure 2), which typically occurs every three to seven years, the normal trade winds diminish and the warm pool of water in the western Pacific is free to move back along the equator toward the east and the South American continent. The sea level drops in the west and rises in the east as warm surface water surges along the equator in the form of a pulse, or a Kelvin Wave. In addition, the upwelling of cold water along the South American coast decreases, reducing the supply of nutrients to fish and other animals.

This displacement of the warm water affects the atmosphere. The convection and precipitation that previously occurred in the western Pacific shifts with the warm pool to the central and eastern Pacific and usually results in heavier than normal rains over areas such as northern Peru, Ecuador, and other areas in tropical South America. In the western Pacific, the mechanism for precipitation is shut off, and Indonesia and Australia will often experience drought conditions while an El Niño persists.

In a La Niña year, unusually cold ocean temperatures occur in the equatorial Pacific, which is the opposite of an El Niño. Generally, during a La Niña, the easterly trade winds increase in intensity, more upwelling occurs, and the water temperatures along the equator are reduced. This usually results in less cloudiness and rainfall for South America and more rainfall over Indonesia, Malaysia, and northern Australia.

Throughout this investigation, you should answer the questions on the Log at the end of this briefing. Here are the first three questions:

1. <u>Why are easterly trade winds key ingredients in ENSO?</u>
2. <u>What is the thermocline?</u>
3. <u>What are the indicators of a La Niña?</u>

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Part 2. How is ENSO measured?

In order to both understand how ENSO works more fully and predict its effects, better measurements of ocean conditions and climate change are needed. Scientists have begun a number of different measurement projects to identify El Niño and La Niña. For example, space-borne sensors are helping to monitor variations of surface wind, sea level, and sea surface temperature along the equator and the west coasts of the American continents.

Sea level measurements. NASA satellites can measure sea level for the entire Pacific Ocean within 5 centimeters (2 inches) (Figure 3). Images from these satellites can tell us where the warm water is located in the Pacific Ocean because it takes up more volume, thus raising the level of the ocean.

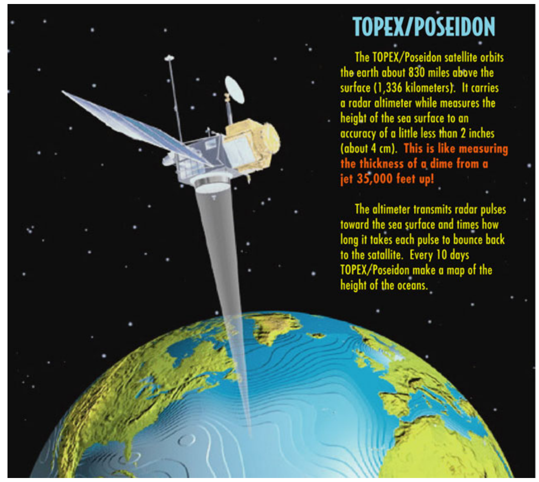
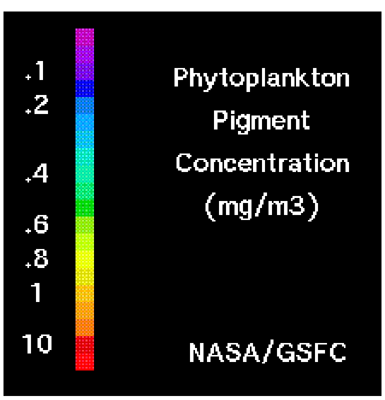


Figure 3: Topex-Poseiden satellite

Source: http://topex-www.jpl.nasa.gov/discover/image-gallery/gifs/tp-jpl-oh99-disp1.jpg

Upwelling measurements. Another way of measuring ENSO using satellites is by examining upwelling. Upwelling currents carry nutrients with them, which leads to phytoplankton growth and chlorophyll blooms. Satellites can detect the pigments of the phytoplankton from space. Figure 4 illustrates what satellite images of phytoplankton look like.



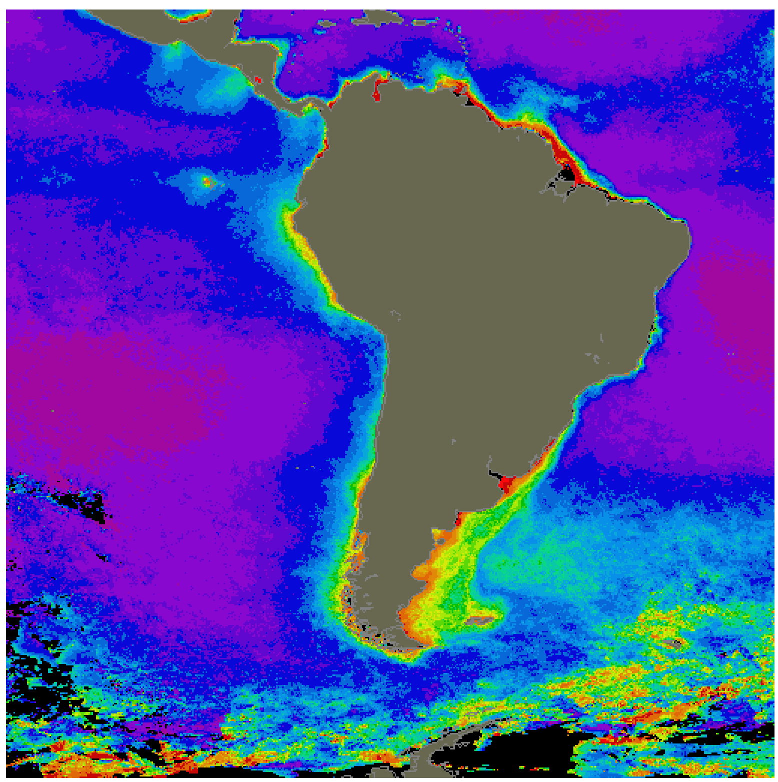


Figure 4: Upwelling along South American coast

Sources: http://seawifs.gsfc.nasa.gov/SEAWIFS.html
http://seawifs.gsfc.nasa.gov/SEAWIFS/CZCS_DATA/south_america.html

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Ocean-based measurements. Another method of identifying when an ENSO event is starting is through measurements taken in the water of the Pacific Ocean. Scientists have created an extensive system of floating and moored buoys, tide gage stations, and ship-based observation systems throughout the Pacific Ocean (Figure 5).

Answer Question 4 on the Log.

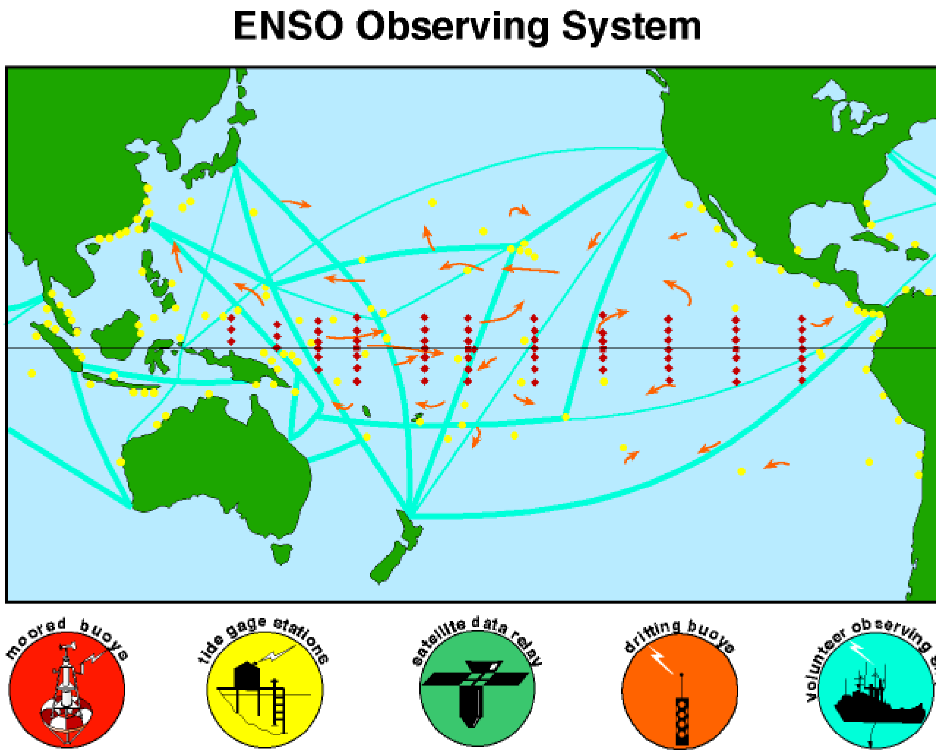

Figure 5: Ocean monitoring system

Source: http://www.pmel.noaa.gov/toga-tao/pmel-graphics/gif/enso-obs-sys.gif

Part 3. How do El Niño and La Niña affect the weather?

The large oceanic and atmospheric changes caused by El Niño and La Niña have a profound effect on Earth's weather. This is because ENSO occurrences have strong **teleconnections** to other weather patterns. Teleconnections are atmospheric interactions between widely separated regions. One way of thinking of teleconnections is that changes in the ocean and atmosphere in the Pacific can have a ripple effect on climatic conditions in other parts of Earth. This worldwide message is conveyed by shifts in tropical rainfall and 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 would occur in different places.

Scientists are studying the relationships between ENSO events and weather around the globe to determine whether links exist. Understanding these teleconnections can help in forecasting droughts, floods, tropical storms, and hurricanes. Based on ENSO patterns and on measurements of the general circulation of the atmosphere and oceans, scientists are predicting abnormally wet, dry, warm, or cold conditions for different regions at different times. Figures 6 and 7 illustrate the global weather patterns during an El Niño and a La Niña.

Answer Question 5 on the Log.

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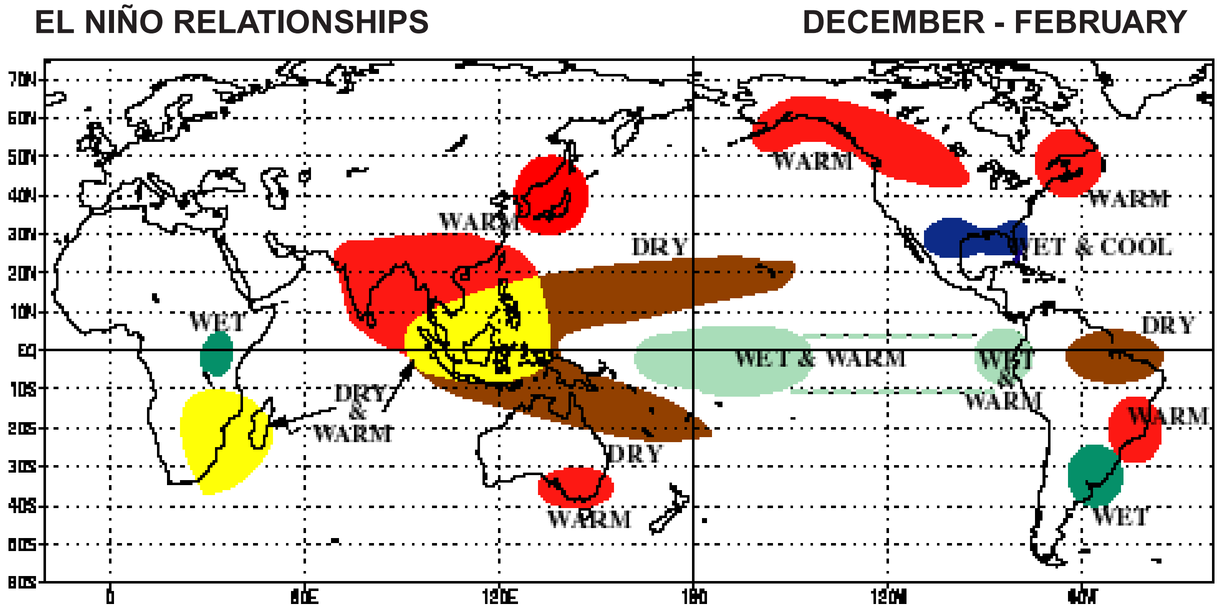

Figure 6: El Niño global weather effects

Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/warm.gif

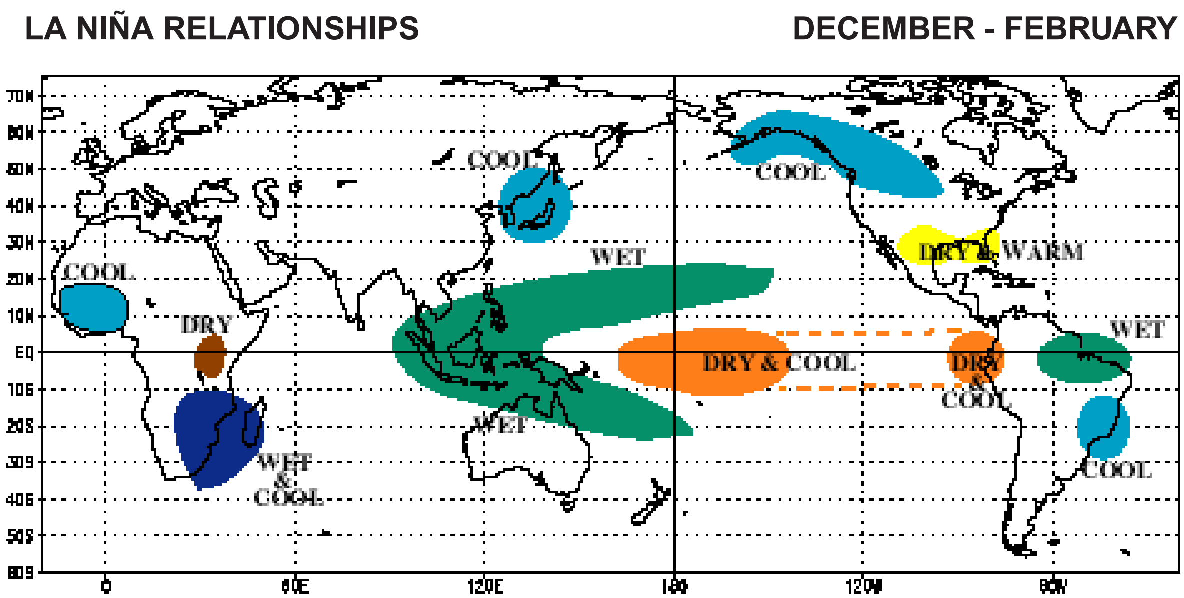

Figure 7: La Niña global weather effects

Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/cold.gif

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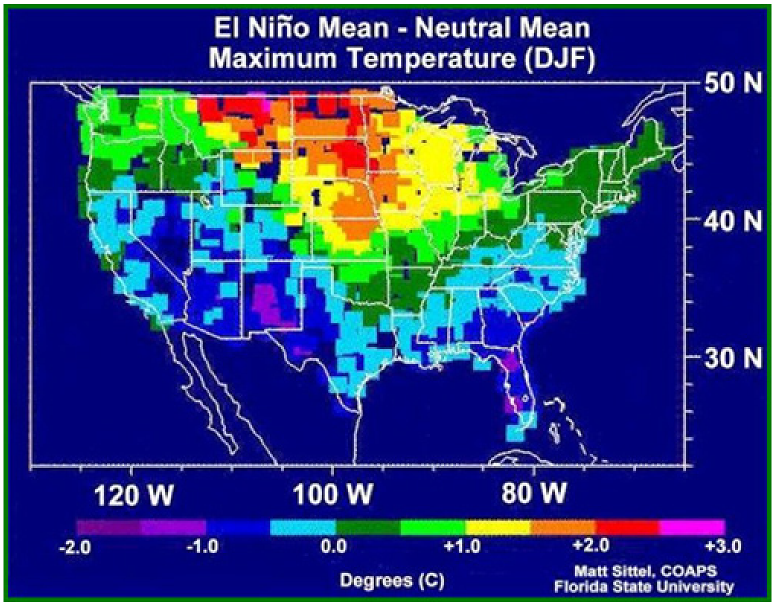

Figure 8: Temperature change during El Niño in the United States

Source: http://nsipp.gsfc.nasa.gov/enso/primer/englishprimer5.html

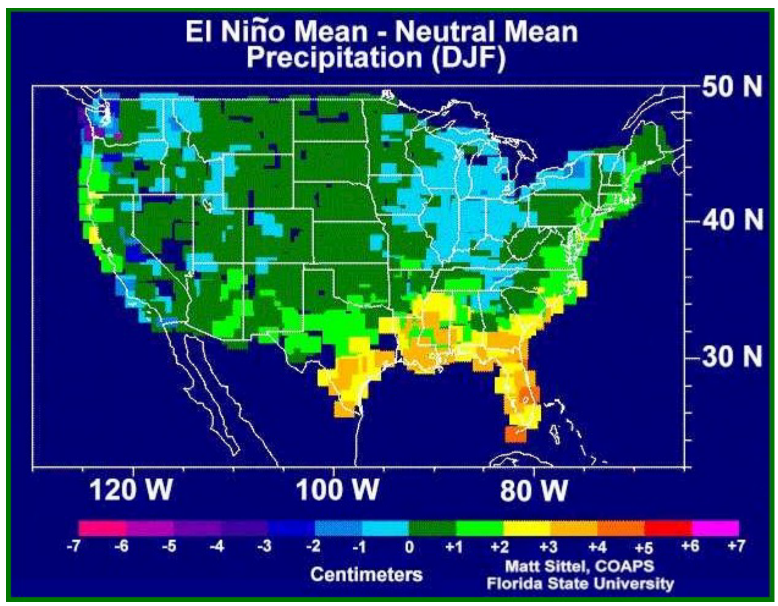

Figure 9: El Niño precipitation in the United States

Source: http://nsipp.gsfc.nasa.gov/enso/primer/englishprimer6.html

How does ENSO affect weather patterns in North America? During an El Niño, there is a tendency for higher than normal temperatures in western Canada and the upper plains of the United States. This is because the low-pressure system in the Pacific draws up warm air into Canada, some of which filters into the northern United States (Figure 8). Another low-pressure system draws cold moist air into the southern United States, bringing lower than normal temperatures.

The same low-pressure system in the southern United States is also responsible for increases in precipitation during an El Niño, especially in those areas close to the Gulf of Mexico (Figure 9).

Answer Question 6 on the Log.

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Part 4. How are human activities affected by ENSO?

ENSO has many effects on human activities. The economic impacts of the 1982-1983 El Niño, perhaps the strongest event in recorded history, are conservatively estimated to have exceeded $8 billion worldwide from droughts, fires, flooding, and hurricanes (Table 1). Virtually every continent was affected by this strong event. An estimated 1,000 to 2,000 deaths were blamed on El Niño and the disasters that accompanied it. In addition, the extreme drought in the Midwest Corn Belt of the United States during 1988 has been tentatively linked to the “cold event,” or La Niña, of 1988 that followed the ENSO event of 1986-1987.

The effects of El Niño and La Niña vary according to the strength of the episodes and the geographic distribution of weather changes. Some areas experience heat waves and droughts, while others have torrential rains and flooding. These specific weather events occur within wet, dry, warm, and cool zones associated with the episodes (Figure 10).

Table 1: The costs of the 1982-83 El Niño

Event/Region	Cost
Flooding	
Bolivia	$ 300,000,000
Equador, Northern Peru	650,000,000
Cuba	170,000,000
U.S. Gulf States	1,270,000,000
Hurricanes	
Tahiti	$ 50,000.000
Hawaii	230,000,000
Drought/Fires	
Southern Africa	$1,000,000,000
Southern India, Sri Lanka	150,000,000
Philippines	450,000.000
Indonesia	500,000,000
Australia	2,500,000,000
Southern Peru, Western Bolivia	240,000,000
Mexico, Central America	600,000,000
Total	**$8,110,000,000**

Source: http://nsipp.gsfc.nasa.gov/enso/primer

Generalized Effects of El Niño

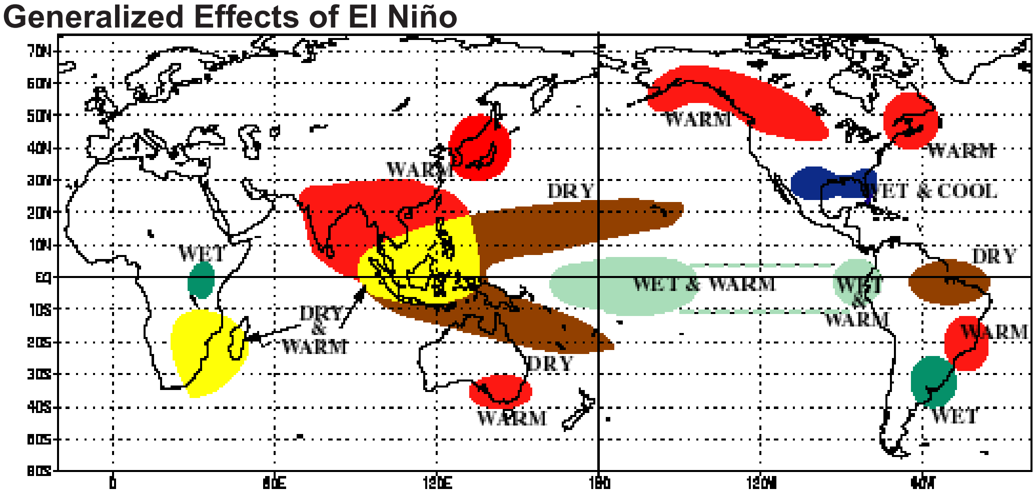

Figure 10: Generalized effects of El Niño

Source: http://globe.gsfc.nasa.gov/cgi-bin/show.cgi?l=en&b=g&rg=n&page=gallery-elnino-background.ht

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What are the effects of ENSO?

1. Why are the easterly trade winds key ingredients in ENSO?

2. What is the thermocline?

3. What are the indicators of a La Niña?

4. Why do you think ocean-based measurements are important?

5. Describe the different effects of El Niño and La Niña on each of the following regions:

   North America

   South America

   Africa

   Asia

   Southeast Asia

6. What are the El Niño temperature and precipitation predictions for your hometown?

Module 3, Investigation 1: Briefing 2

The ENSO game: Predicting and managing for El Niño and La Niña

Part 5. The ENSO game

How can prediction help avoid ENSO's tragic human consequences? Scientists from around the world are involved in forecasting, with computer models and sophisticated measurements, how ENSO affects various countries. These scientists are increasingly being asked by policy makers and political leaders to help them plan and manage for the effects of ENSO. In the ENSO game, you play the role of a policy maker in Peru. You must determine, based on information given to you by climate specialists, what sort of ENSO variation is occurring. Then you must decide how to allocate Peru's resources to manage for possible weather-related problems.

Background for the ENSO game

Long ago, Peruvians observed that the usually cool water along the Pacific coast of their country became warmer in some years. Because this happened around Christmas time, they called it El Niño, which means "Christ Child." Frequently, these warming spells were associated with increased rainfall and flooding within the country. Many times the flooding was disastrous. In fact, El Niño-related weather disasters in 1997-1998 led to massive flooding in the region, causing large negative economic effects and the loss of human life.

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. 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. Peruvians have reason to be concerned, not only about El Niño events, but about both extremes of the El Niño cycle.

Peruvian planners have three primary concerns: agriculture, fishing, and disaster preparedness.

Agriculture—Since 1983, forecasts of the upcoming rainy season have been issued each November based on observations of water temperatures and upwelling in the tropical Pacific region. Once the forecast is issued, policy makers meet to decide on the best combination of crops to plant in order to get the best 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. Cotton, with its deeper root system, can tolerate drier weather but cannot tolerate wet weather during the harvest season. Hence, a forecast of El Niño weather might induce farmers to plant more rice and less cotton than in a year without El Niño.

Fishing—Policy makers and fishermen also meet to decide how to manage for El Niño's effects on the fishing industry. El Niño is usually detrimental to Peru's coastal fisheries. Declines in coastal upwelling reduce the fish population. In addition, coastal flooding increases the amount of sediment in the water so that the fish either leave or die from unendurable water conditions. During El Niño years, the Peruvian fishing industry either reduces fishing or moves its fleets to the north or south to catch migrating fish as upwelling patterns shift away from the Peruvian coast.

Disaster preparedness—Policy makers meet with disaster preparedness teams to determine what weather-related problems associated with El Niño may occur. Usually, El Niño periods lead to intense rainfall and disastrous flooding and destruction of critical property such as roads, bridges, dams, and power lines—things referred to as **infrastructure**. Disaster teams need to prepare the country for this eventuality or the effects of flooding will create serious economic and social problems.

Data for the ENSO game

Climate specialists have submitted three key pieces of data to you in your role as a Peruvian planner and policy maker (Figures 11, 12, and 13). By interpreting these data correctly, you can determine whether an El Niño or a La Niña event is developing off the coast of Peru.

<u>Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.</u> Write your answer to this question on the ENSO Game Log.

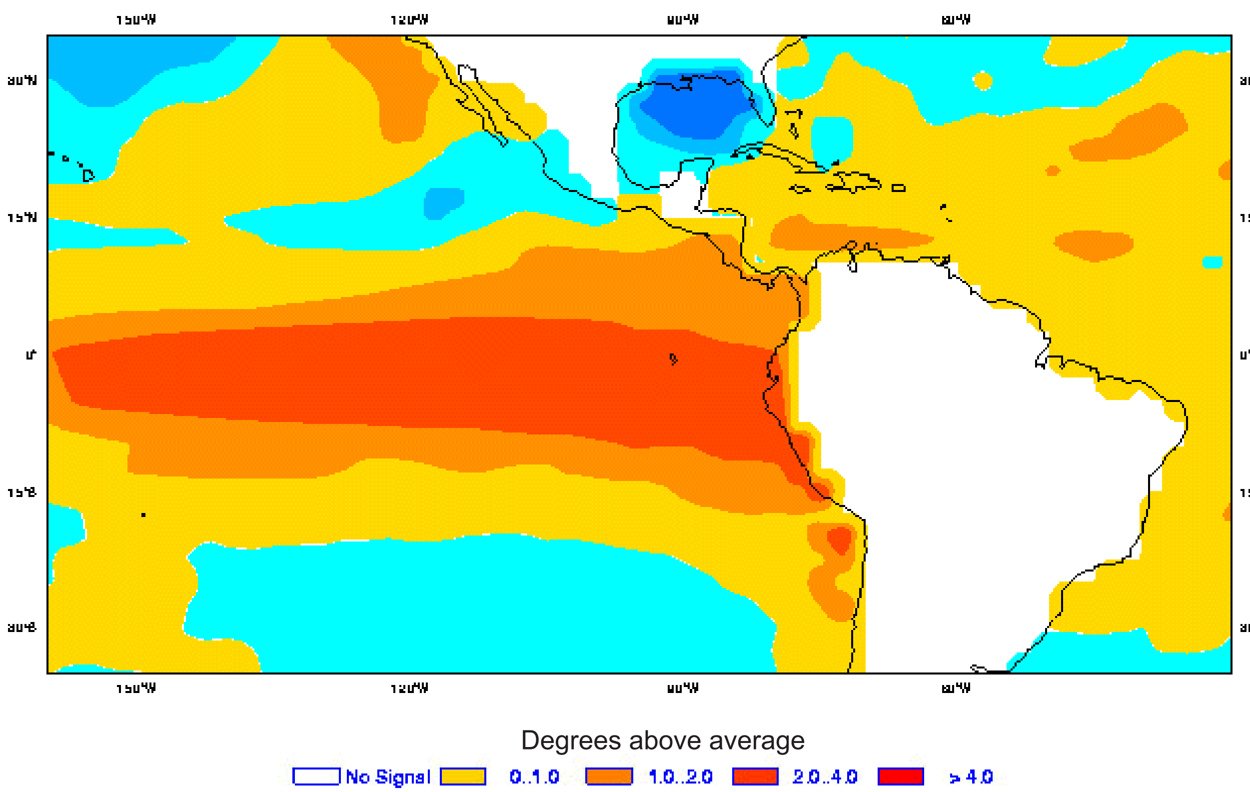

Figure 11: Average sea surface temperature anomalies (degrees above or below normal), measured in Celsius

Source: European Centre for Medium-Range Weather Forecasts (ECMWF) http://www.ecmwf.int/services/seasonal/forecast/index.jsp

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The ENSO game: Predicting and managing for El Niño and La Niña

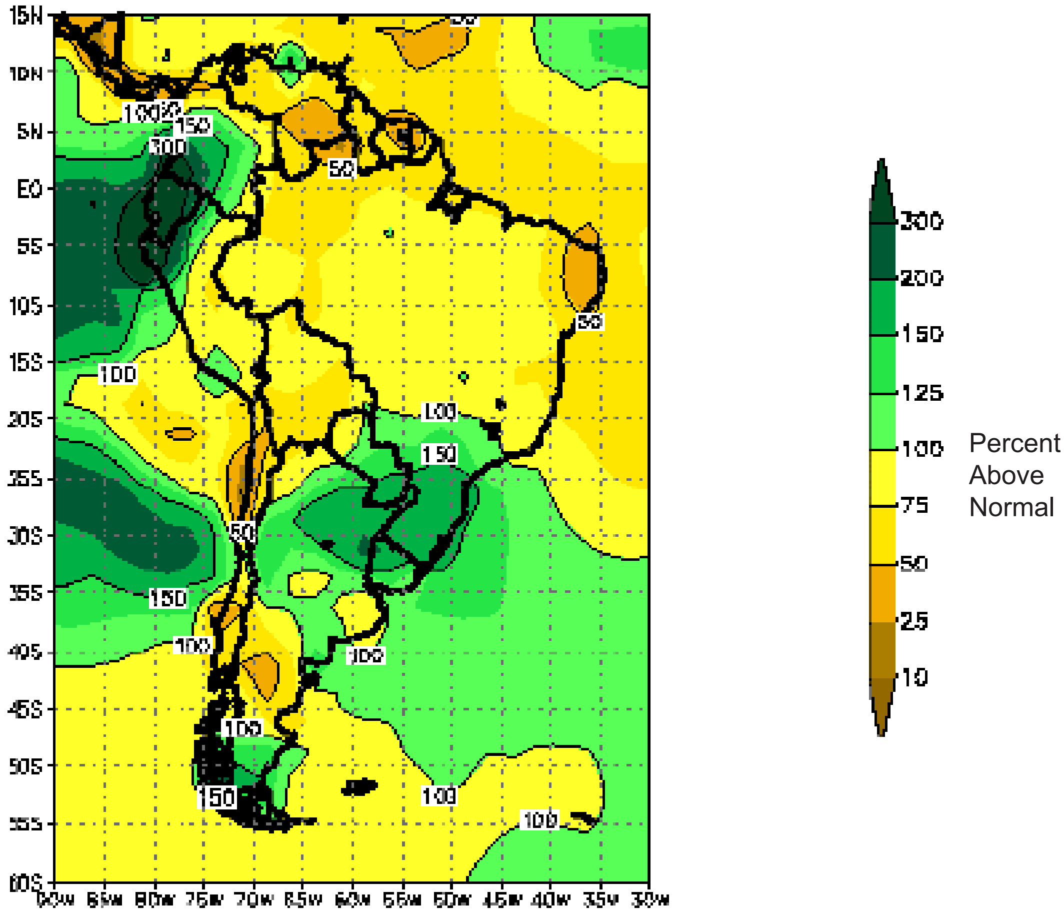
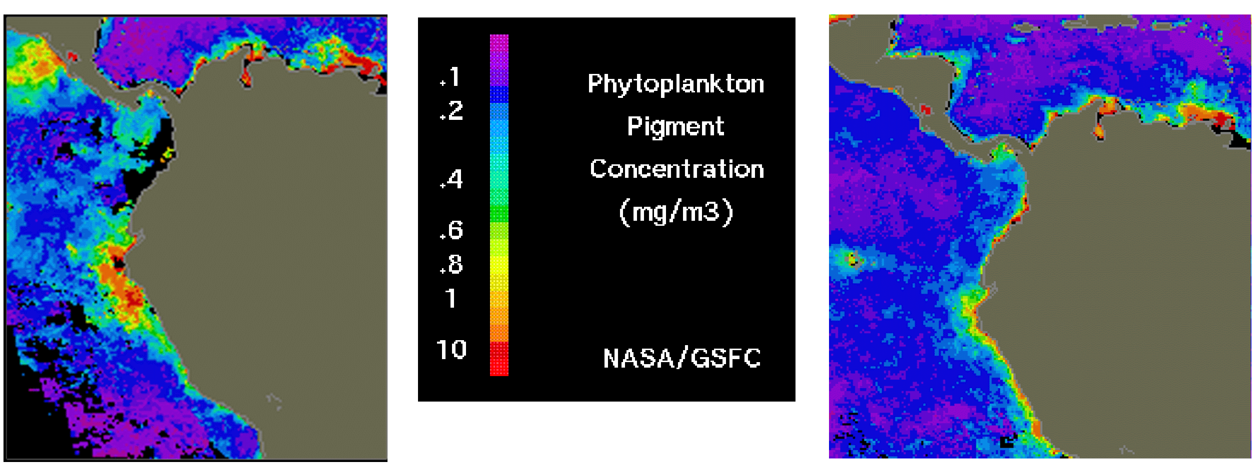


Figure 12: Precipitation forecast (percent above normal)

Source: International Research Institute for Climate Prediction (NOAA), http://iri.ldeo.columbia.edu/climate/forecasts/net_asmt/



Previous Year **This Year**

Figure 13: Upwelling

http://seawifs.gsfc.nasa.gov/SEAWIFS.html

Module 3, Investigation 1: Briefing 2

The ENSO game: Predicting and managing for El Niño and La Niña

Investments for the ENSO Game

Now that you have determined whether an El Niño or a La Niña is occurring, you need to decide how to allocate the resources you have, based on what is likely to happen. You will consider the effects of this event on agricultural productivity, the fishing industry, and weather-related damage to infrastructure.

The World Bank is lending Peru $200 million to invest in development efforts this year. The loan will fund efforts to improve agricultural productivity, the fishing industry, and infrastructure (flood management, highways, bridge supports, first aid, etc.). Based on the likelihood of an El Niño or a La Niña event, your investments will either contribute to the future prosperity of the country or result in disaster and economic decline. You have three categories to invest in, which are:

Agricultural Investments

A. Rice production
B. Cotton production

Fishing Industry Investments

A. More fishing boats and fishing production
B. Move the fleet north and south for the season
C. No investments in fishing this year

Disaster Preparedness Investments

A. Invest in disaster preparedness
B. No investments

You should allocate a total of $200 million on any combination of investments, based on your determination of whether the upcoming year will have an El Niño or a La Niña. Investments should be rounded up or down to the nearest $10 million.

<u>Use the table on The ENSO Game Log to make your investments and then give your reasons for them.</u>

To check on specific effects of El Niño, you can use the following Internet resources:

Indonesia

Resources at this site include forest fires, drought, and warm temperatures
http://www.ogp.noaa.gov/enso/asia.html#Fires

Southern Africa

Resources at these sites include famine and drought links
http://www.ogp.noaa.gov/enso/africa.html
http://enso.unl.edu/ndmc/enigma/elnino.htm
http://www.info.usaid.gov/fews/imagery/sat_nino.html#El Nino

Southeastern United States

Resources at these sites include flooding, cooler temperatures, and possible links to tornadoes
http://www.ogp.noaa.gov/enso/regional.html#Southeast
http://www.srh.noaa.gov/ftproot/sjt/HTML/science/elninosjt.html

California

http://twister.sfsu.edu/elnino/elnino.html

Module 3, Investigation 1: Log 2

The ENSO game: Predicting and managing for El Niño and La Niña

1. Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.

2. Use this table to allocate a total of $200 million on any combination of investments. Make investments in increments of $10 million.

Investment Category	Amount $ millions	Multiplier	Outcome $ millions
Agriculture			
Rice			
Cotton			
Fishing			
More boats/production			
Move fleet north and south			
No investment			
Disaster Preparedness			
Invest			
No investment			
Totals	200		

3. Give your reasons for your investment decisions in the spaces provided below.

- Agricultural production
- Fishing industry
- Disaster preparedness infrastructure