What are the causes and consequences of climate change?

Module Overview

This module investigates climatic variability. It focuses on the evidence for global climate change. It includes investigations of the El Niño Southern Oscillation (ENSO), the geography and politics of stratospheric ozone, and the theory of global warming.

***Investigation 1:* What are the causes and effects of ENSO?**

The changing temperatures of the tropical Pacific Ocean greatly affect climate variability. These variations often cause heat waves, droughts, floods, and other disruptive phenomena. One result of changing ocean temperatures is called the *El Niño Southern Oscillation* (or ENSO). Students role-play policy makers deciding how to allocate Peru's resources to manage for possible ENSO-related problems. They learn how ENSO works, how it affects the environment, and how it creates problems for humans.

***Investigation 2:* The loss of stratospheric ozone: Where are people at risk?**

Students learn about the recent declines of ozone concentrations above Antarctica and the Arctic. These declines increase the risk that unusually high amounts of harmful ultraviolet radiation will reach Earth's surface and threaten life, especially in the high latitudes. Students learn how human actions have affected the natural geography of stratospheric ozone, they estimate populations at risk from ozone destruction, and they learn how international complications obstruct solutions to the problem.

***Investigation 3:* Are we warming Earth?**

Students assess the theory of global warming—that human activities are enhancing the greenhouse effect and thus causing Earth's temperature to rise. Role-playing science writers for a major newspaper, students write a story about global warming focusing on (1) what facts point to global warming? (2) what are the possible causes of global warming? and (3) how might global warming affect physical and human systems?

Connection to the Curriculum

"What are the causes and consequences of climate change?" is an instructional unit—about three to four weeks in length—that can be integrated, either in whole or in part, into high school courses in world geography, physical geography, environmental geography, regional geography, earth science, and global studies. The material supports instruction about many physical processes, such as those affecting large-

Geography Standards

The World in Spatial Terms
- **Standard 1:** How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective

Physical Systems
- **Standard 7:** The physical processes that shape the patterns of Earth's surface

Human Systems
- **Standard 10:** The characteristics, distribution, and complexity of Earth's cultural mosaics

Environment and Society
- **Standard 14:** How human actions modify the physical environment
- **Standard 15:** How physical systems affect human systems

The Uses of Geography
- **Standard 18:** How to use geography to interpret the present and plan for the future

Science Standards

Unifying Concepts and Processes
- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement

Life Science
- Structure and function in living systems
- Populations and ecosystems

Earth and Space Science
- Structure of the earth system

Science and Technology
- Understandings about science and technology

Science in Personal and Social Perspectives
- Risks and benefits
- Science and technology in society

scale oceanic and atmospheric systems as well as the dynamic environmental interactions between physical and human systems at both regional and global scales of analysis. Connections to mathematics skills are easily made because the material requires students to work with quantitative data in both graphic and tabular form. The stratospheric ozone activity has links to chemistry.

Time

Investigation 1: Five to six 45-minute sessions
Investigation 2: Five to nine 45-minute sessions
Investigation 3: Four to seven 45-minute sessions

Mathematics Standards

Number and Operation

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Compute fluently and make reasonable estimates

Algebra

- Understand patterns, relations, and functions
- Analyze change in various contexts

Data Analysis and Probability

- Develop and evaluate inferences and predictions that are based on data

Communication

- Communicate mathematical thinking coherently and clearly to peers, teachers, and others

Connections

- Recognize and apply mathematics in contexts outside of mathematics

Representation

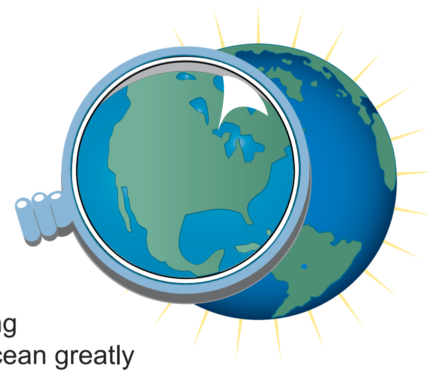
- Use representations to model and interpret physical, social, and mathematical phenomena

Technological Literacy Standards

Technology and Society

- **Standard 4:** The cultural, social, economic, and political effects of technology

What are the causes and effects of ENSO?



Investigation Overview

Investigation 1 shows that the changing temperatures of the tropical Pacific Ocean greatly affect climate variability. These variations often cause heat waves, droughts, floods, and other disruptive phenomena. Students learn how ENSO works, how it affects the environment, and how it creates problems for humans. The investigation concludes with students role-playing policy makers and deciding how to allocate Peru's resources to manage for possible ENSO-related problems.

Time required: Five to six 45-minute sessions (as follows):

- Introduction and Part 1: One session
- Parts 2 and 3: One or two sessions
- Part 4: One session
- Part 5: Two sessions

Materials

Briefings and Logs (one copy of each per student)

- Briefing 1: What are the effects of ENSO?
- Briefing 2: The ENSO game: Predicting and managing for El Niño and La Niña
- Log 1: What are the effects of ENSO?
- Log 2: The ENSO game: Predicting and managing for El Niño and La Niña

Computer with CD-ROM. The Mission Geography CD-ROM contains color graphics needed for this activity.

Optional: Access to the Internet, which offers opportunities for extending this investigation

Content Preview

Climate change is a major topic of scientific and popular interest and debate. Issues about global warming caused by a human-enhanced greenhouse effect dominate this debate, but it is important to know that natural variability is a fundamental feature of weather and climate. The El Niño Southern Oscillation (ENSO) is a major example of natural climatic variability, which also has significant effects on humans.

Classroom Procedures

Beginning the Investigation

1. Have students bring to class newspaper and magazine clippings and photos of severe *weather-related* events, such as storms, floods, mud slides, cold spells, heat waves, fires, and droughts. Alternatively, have students conduct Internet searches for this information.
   - Have students organize clippings on a bulletin board or Internet data in a database according to types and locations of events.

Geography Standards

Standard 1: The World in Spatial Terms

How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information

- Produce and interpret maps and other graphic representations to solve geographic problems.

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface

- Explain Earth's physical processes, patterns, and cycles using concepts of physical geography.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Standard 18: The Uses of Geography

How to apply geography to interpret the present and plan for the future

- Develop plans to solve local and regional problems that have spatial dimensions.

Geography Skills

Skill Set 4: Analyzing Geographic Information

- Make inferences and draw conclusions from maps and other geographic representations.
- Use the processes of analysis, synthesis, evaluation, and explanation to interpret geographic information from a variety of sources.

- Focus class discussion on (a) the locations and spatial patterns of these events, (b) the accompanying human costs in lost lives, injury, and property destruction (emphasizing that these costs are especially difficult to bear when they occur in poor, developing countries), and (c) suggestions for reducing these costs.
- Tell students that this investigation focuses on many of these issues.

Developing the Investigation

2. Hand out copies of **Briefing 1** and **Log 1: What are the effects of ENSO?** to each student or to small groups of students. Students can work on this activity individually, but it is recommended that they work in small groups—pairs or triads are especially recommended.

3. Leaf through the **Briefing** and **Log** with the students and point out the underlined questions, which are to be answered on the Log at the end of the materials. Give students a schedule for completing the questions in the Log.

4. Have students read the **Background** and **Objectives** and then assist them with any questions they may have.

5. Set students working through the materials, beginning with **Part 1. What is ENSO?** Emphasize the importance of carefully studying and discussing the images and working together on group answers to the Log questions. Figures 1 and 2 are especially important.

6. To monitor progress and to keep students moving through the materials at about the same pace, ask students to read aloud passages, give their interpretations of the images, and/or use the Log questions (or other questions) to generate class discussion.

7. **Part 4. How are human activities affected by ENSO?** contains some URLs that students may use to find specific examples of ENSO effects. You may wish to have students skip over these Internet resources or use them to extend their knowledge.

8. You may wish to have students complete the Log before moving on to the ENSO Game. Move on to the ENSO Game after debriefing the Log.

9. **Part 5. The ENSO game** may be played as individuals or in small groups. Direct students to proceed with the game as it is presented in **Briefing 2: The ENSO game**. After deciding whether the data point to an El Niño or La Niña, students can use the table in the ENSO Game Log to record their investment decisions. Tell them to leave blank the two columns marked "Multiplier" and "Outcome" because you will supply them with the multiplier information at the end of the game.

10. ENSO game scoring, examples, and explanations are in **Background** below. In debriefing the game, you may wish to hand out this information to the class or put it on a transparency. Also, you may wish to have students share their game decisions by showing their investment tables.

11. The evidence strongly points to an El Niño event: sea surface temperatures—current of warm water pushed against South American coast (Figure 11), increased precipitation forecasts for Peru—in many cases above 300 percent (Figure 12), and a severely curtailed upwelling (Figure 13). Students who miss this suffer greatly in the game scoring. The Peruvian background is critical for understanding how ENSO affects each of the categories.

12. The two keys to this game are to have students (1) recognize that the upcoming episode is an El Niño and (2) understand the effects of an El Niño on agriculture, fishing, and disaster preparedness. Students who invest all of the money on one item will lose money, as will students who think that it is a La Niña year. The highest scoring students will invest money in rice production, move the fishing fleets north and south for the season, and invest a substantial percentage of the funds in infrastructure and disaster preparedness. For illustration, three possible outcome scenarios follow:

    Student (or group) A, thinking that the upcoming event is a La Niña, invests in the following:
    $100 million—cotton
    $100 million—more fishing boats and fishing production

    Outcome: loses $50 million of the cotton investment (-50%) and $75 million on the fishing investment (-75%). The total before the disaster preparedness score would be $75 million. However, because the student (or group) did not account for the floods and other natural disasters, she/they suffer an additional $600 million loss, thus ending with a final loss of $525 million.

    Student (or group) B, thinking that the upcoming event is an El Niño, invests in the following:

$100 million—rice
$100 million—move the fleet north and south for the season

Outcome: earns $200 million for the rice investment ($100 million x 2) and $300 million on the fishing industry ($100 million x 3). The total score before disaster preparedness scoring is $500 million. But she/they lose $600 million because of no investment in disaster preparedness, so the final loss is $100 million.

Note: Students who do not invest in the fishing industry lose money because the fishing industry in Peru is based on large annual yields. If the fishing industry simply does nothing in the face of an El Niño, it is likely that it will still suffer economic losses.

Student (or group) C, thinking that the upcoming event is an El Niño, allocates investments as follows:
$100 million—rice
$50 million—move the fleet north and south for the season
$50 million—disaster preparedness

Outcome: students who invest across all three categories will always do best in this game. Student (or group) C earns $200 million for the rice investment ($100 million x 2) and $150 million ($50 million x 3) for moving the fleet north and south. Then, the $50 million invested in disaster preparedness earns $100 million ($50 million x 2), for final earnings of $450 million.

Concluding the Investigation

13. Use the ENSO Game Log key to debrief the game. Have students discuss the evidence they used to decide whether this was an El Niño or a La Niña event.

14. Generate further discussion around various students' investment strategies. If you wish to use more math, have students find out the range and average of total scores in the class.

15. Refer students to the **Objectives** to have them summarize what they learned with the activity:
    - interpretation of satellite images;
    - how, when, and where ENSO events occur;
    - how ENSO events affect humans in different places; and
    - how to use geographic information to plan and make decisions.

Background

The ENSO Game Scoring

Agricultural Investments:

Rice production

Multiplier: 2 x original investment
For example, for a $50 million investment in rice, the payoff is $100 million.

The upcoming El Niño episode brings torrential rains to the highlands and coasts of Peru. Rice, because it thrives in wet conditions, prospers this year. The rice industry in Peru experiences a bumper crop. Your investment helps to feed thousands of people and generates foreign exchange for Peru's economy when rice is exported to neighboring countries that do not invest in rice production.

Cotton production

Multiplier: 50% loss of original investment
For example, for a $50 million investment in cotton, the payoff is $25 million.

The torrential rains of the El Niño do not let up at the end of the growing season. Although your cotton crops grow fairly well this year, heavy rains at the end of the season seriously damage the cotton. Poor climate prediction leads to a serious economic hardship for cotton growers and a setback to economic development in the country.

Fishing Industry Investments:

More fishing boats and fishing production

Multiplier: 75% loss of original investment
For example, for a $100 million investment in boats and fishing, the payoff is $25 million.

The El Niño event reduces cold upwelling along the coast. Fewer nutrients are brought to the surface. Consequently, fewer phytoplankton grow, fewer fish arrive to feed on the phytoplankton, and fewer fish are caught by fishermen. The fishing industry along the coast suffers economic hardship. Investment in more fishing boats and production triggers overfishing along the coast of the few species in the waters. This, in turn, leads to unemployment in the fishmeal and manufacturing industries and a substantial loss of your investment.

Move the fleet north and south for the season

Multiplier: 3 x original investment
For example, for a $50 million investment to move the fleet, the payoff is $150 million.

During the El Niño, the fishing fleet moves to the north and south to take advantage of the shift in upwelling.

Because of good climate predictions, the fleet captures a great quantity of fish, which are processed in Peru, leading to substantial economic growth for the country.

<u>No investments in fishing this year</u>

Multiplier: $50 million penalty

Subtract $50 million from your total.

During the El Niño period, the fishing industry has no funds with which to fish. Fishermen and others working in the industry are unemployed and suffer economic hardship. Economic experts estimate that the fishing industry loses $50 million during the El Niño episode.

Disaster Preparedness Investments:

<u>Invest in disaster preparedness</u>

Multiplier: 2 x original investment

For example, for a $75 million investment in infrastructure for disaster preparedness, the payoff is $150 million.

During the El Niño episode, torrential rains fall on the coasts and mountains of Peru. This creates a potential for serious flooding problems. But your planning and investment in infrastructure saves much of the agricultural production from flooding, soil erosion, and destruction. In addition, roads, highways, bridges, and hospitals are saved from flooding, which provides for future economic growth in the upcoming years. Your wise planning and predictions save many lives and homes.

<u>No investment in disaster preparedness</u>

Multiplier: $600 million penalty

Subtract $600 million from your total.

During the El Niño episode, torrential rains lead to serious problems. Soil erosion and flooding destroy most of the cotton production in the country. In addition, flooding destroys highways, roads, bridges, and hospitals throughout the country. Furthermore, many homes are destroyed, and many people lose their lives. Poor climate predictions and failure to fully understand the potential threats of El Niño to Peru's infrastructure have led to consequences that have set the country back many years in economic development.

Evaluation

Log 1

1. Why are the easterly trade winds important in ENSO?
   Easterly trade winds push water toward the western Pacific, which gives that area the warmest ocean temperatures on Earth. This leads to a heating of the atmosphere above the pool of water and convection and precipitation. In fact, oceanic heat surrounding Indonesia and other western Pacific islands leads to frequent thunderstorms and some of the heaviest rainfall on Earth.

2. What is the thermocline?
   The thermocline is the layer dividing the warm surface water and deep cold water in the ocean. The thermocline is also a key ingredient in upwelling, nutrient cycling in the ocean, and fish and other animal well-being.

3. What are the indicators of a La Niña?
   First, unusually cold ocean temperatures occur in the equatorial Pacific. This also leads to an increase in the intensity of easterly trade winds and more oceanic upwelling.

4. Why do you think ocean-based measurements are important?
   A number of reasons might be mentioned for the importance of ocean-based measurements. First, ocean measurements can help us more accurately predict when an ENSO event is taking place. In addition, ocean-based measurements also allow scientists to predict ENSO events more rapidly. For example, as ocean temperatures change along the equator, buoys and ships can quickly detect these changes. Another possible reason for the importance of ocean-based measurements is that they will increase our understanding of how ENSO events occur and how they may be changing. Yet another response may be that ocean-based measurements will increase our understanding of how the oceans function and how tides, climate, and currents change and interact with the atmosphere.

5. Describe the different effects of El Niño and La Niña on each of the following regions:
   <u>North America</u>
   El Niño—Warmer temperatures in Alaska and western and eastern Canada. Wet and cool conditions in the southern United States.
   La Niña—Cool temperatures in Alaska and western Canada. Dry and warm conditions in the southern United States.

South America
El Niño—Wet and warm conditions in the northwestern region (Ecuador and Peru). Dry conditions along the northeastern portion of the region (French Guyana, northern Brazil). Warm conditions in eastern Brazil. Wet conditions in southern Brazil and Uruguay.
La Niña—Dry and cool conditions in the northeastern region. Wet conditions along the northwestern portion of the region. Cool conditions in eastern Brazil.

Africa
El Niño—Wet in central Africa and dry and warm in southern Africa and Madagascar.
La Niña—Cool conditions in western Africa. Dry conditions in central Africa. Wet and cool conditions in southern Africa.

Asia
El Niño—Dry and warm conditions throughout most of Asia.
La Niña—Wet conditions in the southern portion of Asia. Cool temperatures in Japan and the Korean peninsula.

Southeast Asia
El Niño—Dry and warm conditions throughout southeast Asia.
La Niña—Wet conditions throughout most of southeast Asia.

6. What are the El Niño temperature and precipitation predictions for your hometown?
   Answers to this question based on Figures 8 and 9 will vary depending on where students live.

Log 2

1. Is an El Niño or a La Niña forming? Support your answer by referring to Figures 11, 12, and 13.
   The evidence supplied to students strongly points to an El Niño event: sea surface temperatures—warm water pushed against South American coast (Figure 11), increased precipitation forecasts for Peru—in many cases above 300 percent (Figure 12), and a severely curtailed upwelling (Figure 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		2 x investment	
Cotton		50% loss of investment	
Fishing			
More boats/ production		75% loss of investment	
Move fleet north and south		3 x investment	
No investment		$50 million penalty	
Disaster Preparedness			
Invest		2 x investment	
No investment		$600 million penalty	
Totals	200	n/a	

3. Give your reasons for your investment decisions in the spaces provided below.
   Student reasons will vary but should be logical and based primarily on their knowledge of the effects of El Niño as well as of the Peruvian economy.

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

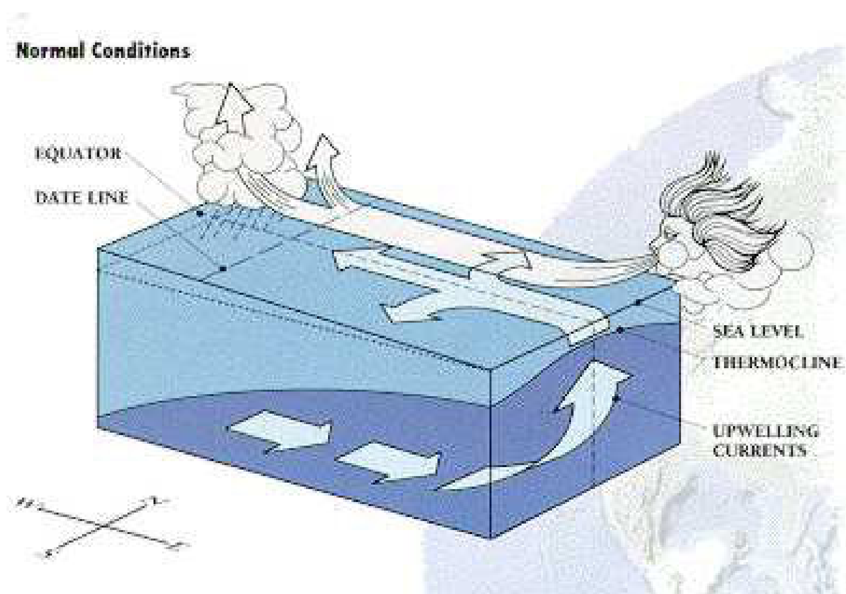


Figure 1: Normal atmospheric-oceanic circulation

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

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

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 thunder-storms 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 west-ward, 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 centi-meters (23 inches) higher than the sea level on the southern coast of Panama.

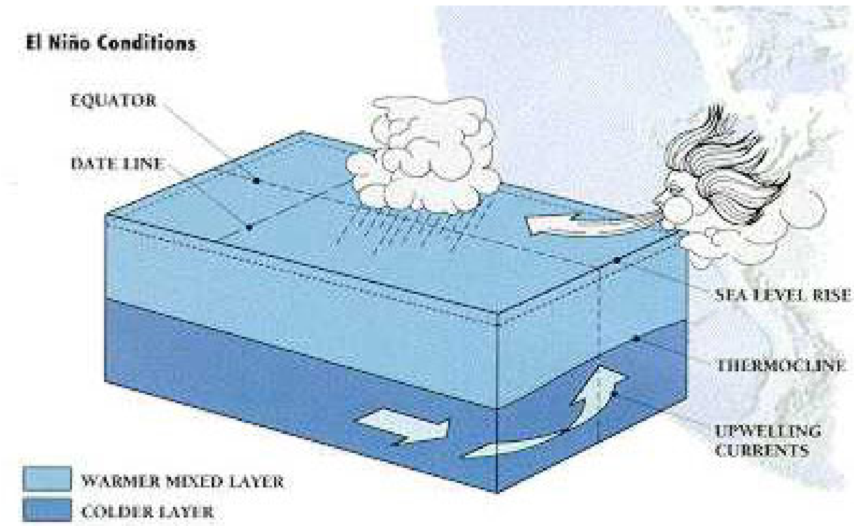


Figure 2: El Niño circulation

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 tempera-tures 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>

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

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.

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.

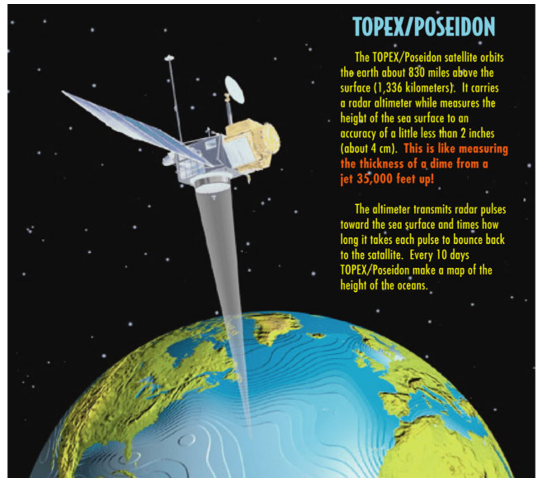
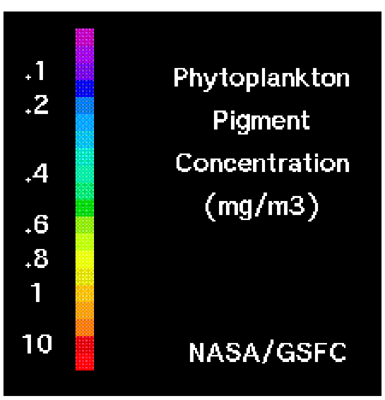


Figure 3: Topex-Poseiden satellite

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



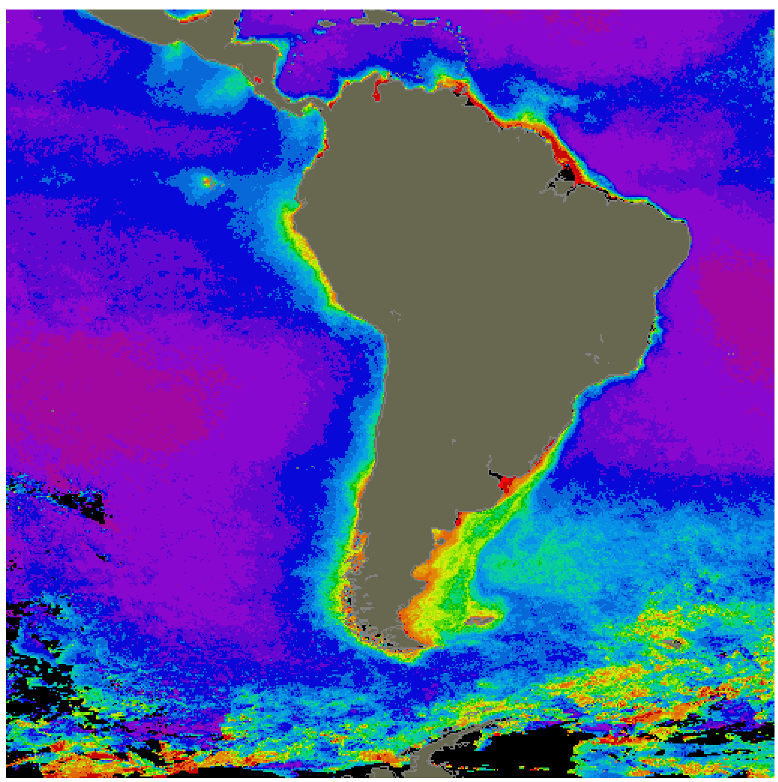


Figure 4: Upwelling along South American coast

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

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

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.

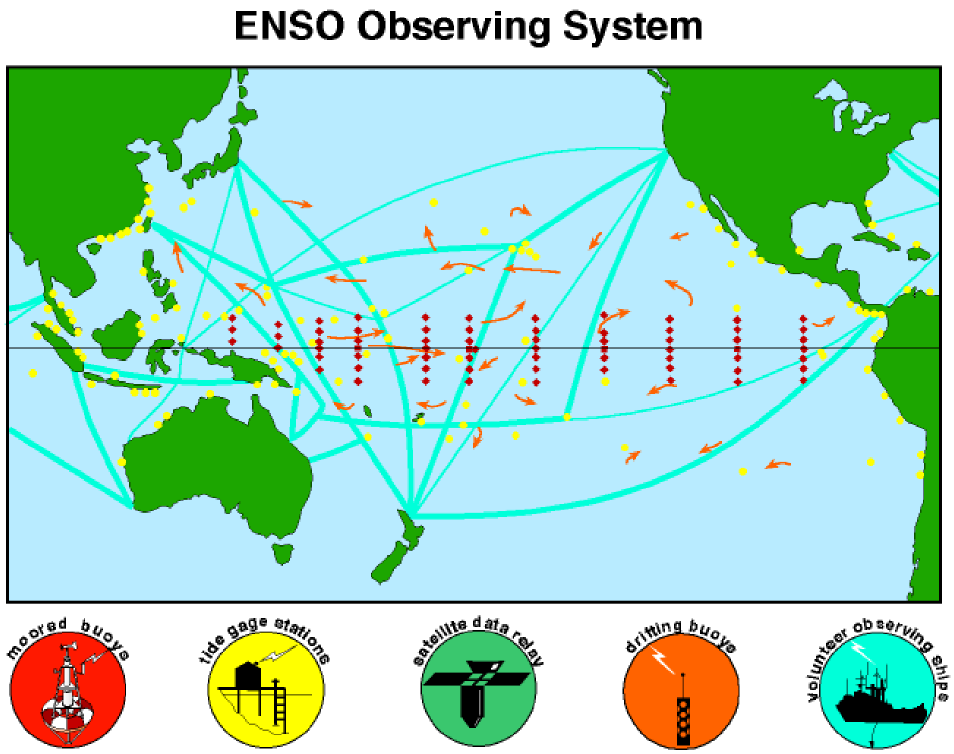


Figure 5: Ocean monitoring system

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.

EL NIÑO RELATIONSHIPS DECEMBER - FEBRUARY

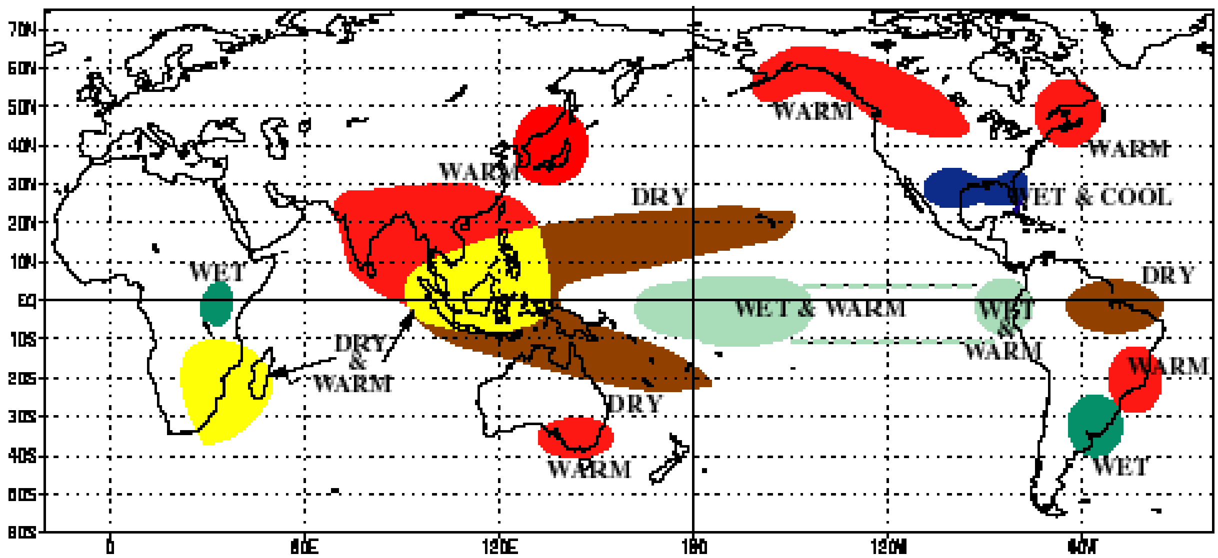


Figure 6: El Niño global weather effects

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

LA NIÑA RELATIONSHIPS DECEMBER - FEBRUARY

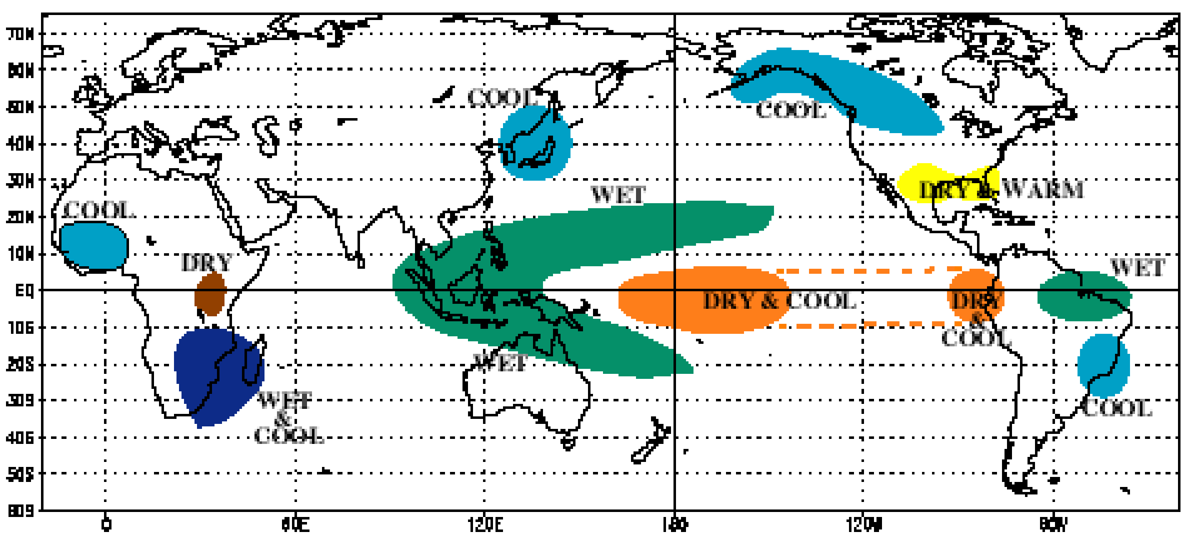


Figure 7: La Niña global weather effects

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

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

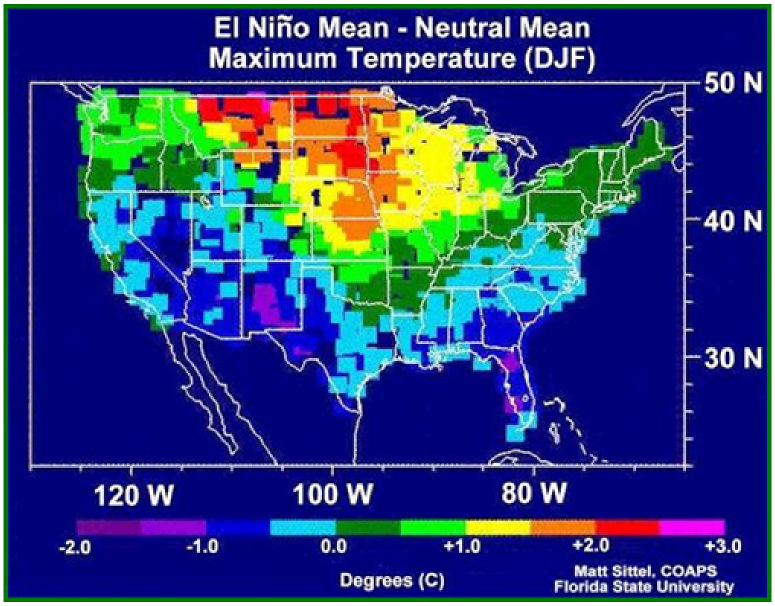


Figure 8: Temperature change during El Niño in the United States

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

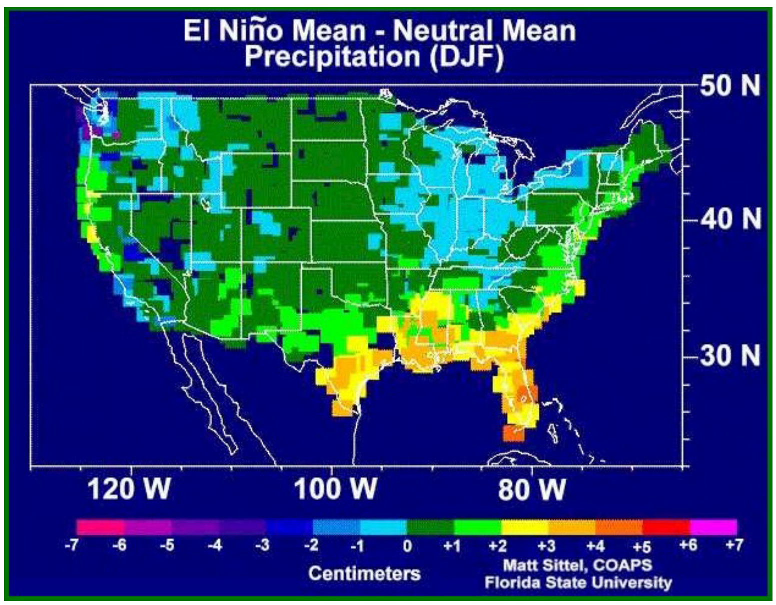


Figure 9: El Niño precipitation in the United States

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.

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

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

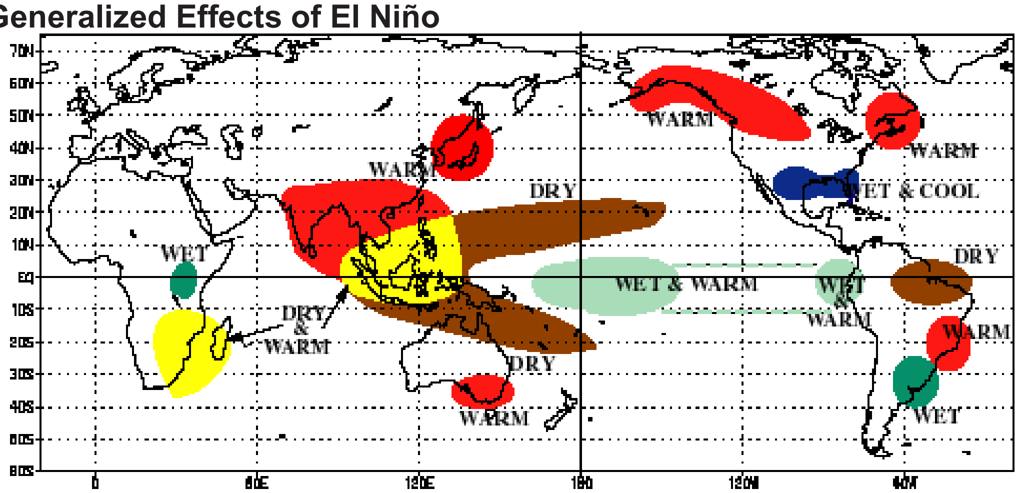


Figure 10: Generalized effects of El Niño

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

Module 3, Investigation 1: Log 1

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.

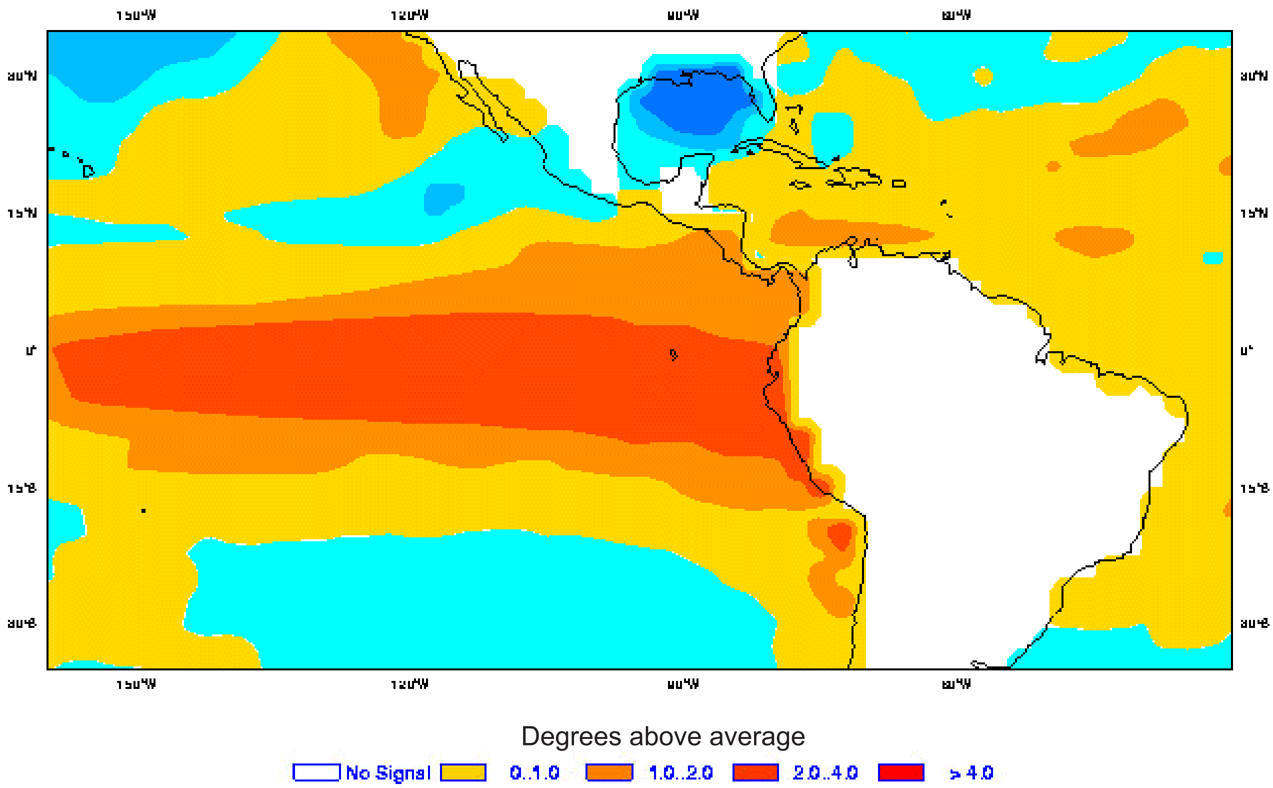


Figure 11: Average sea surface temperature anomalies (degrees above or below normal), measured in Celsius

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

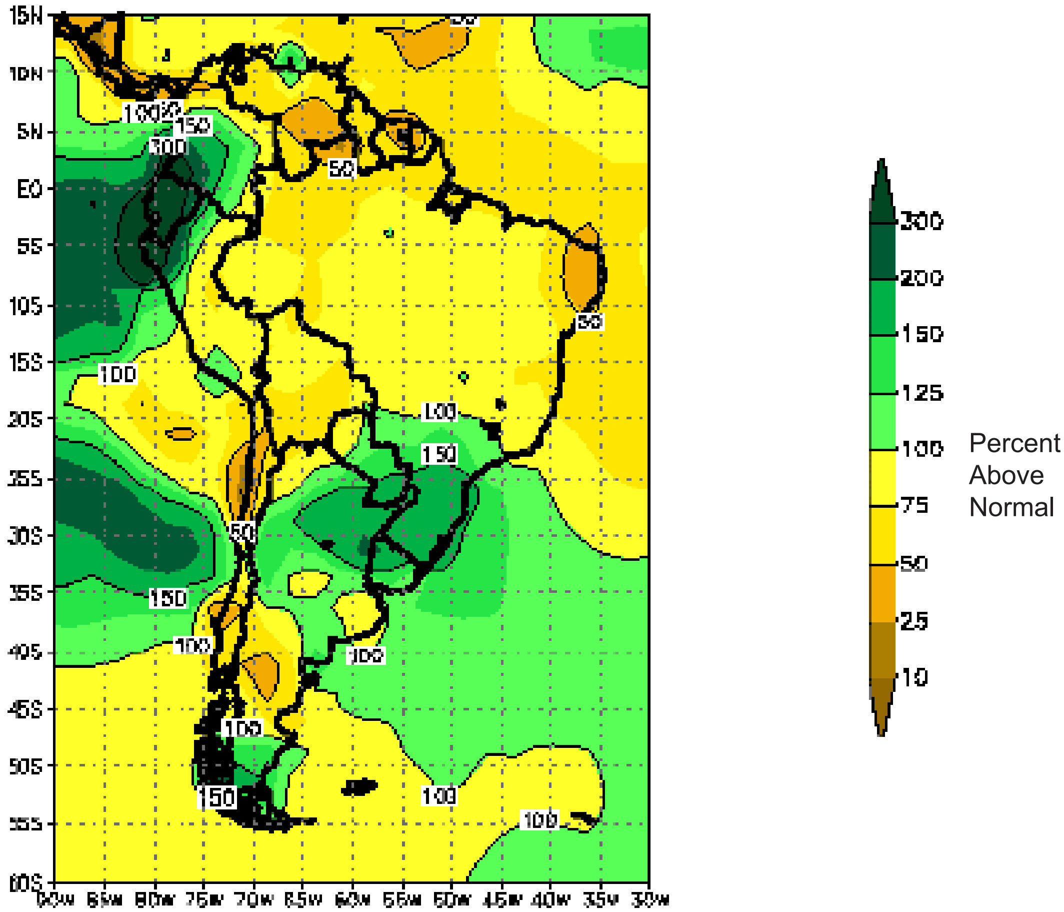


Figure 12: Precipitation forecast (percent above normal)

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

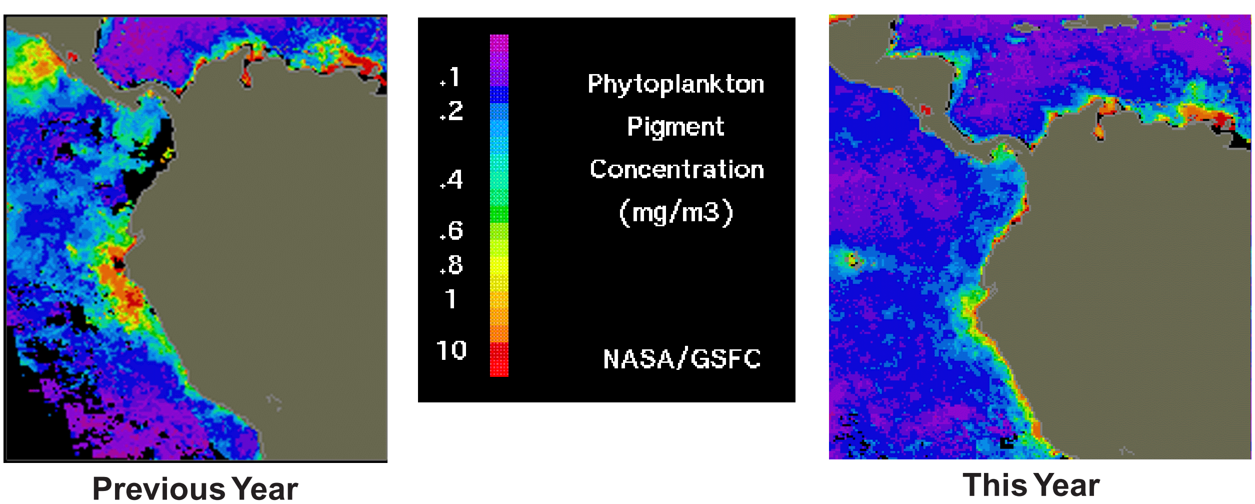


Figure 13: Upwelling

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