
My NASA Data - Lesson Plans

What are the causes and effects of ENSO?

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Overview

This investigation is part of the NASA: Mission Geography Module "What are the causes and consequences of climate change?" that guides students through explorations in climatic variability and evidence for global climate change.

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. In this investigation, students play the role of a Peruvian government policymaker deciding how to allocate Peru's resources to manage for possible ENSO-related problems. In order to play the role successfully, students first learn how ENSO works, how it affects the environment, and how it creates problems for humans.

Learning Objectives

- interpret satellite images and maps to draw conclusions about the physical processes producing ENSO;

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- 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.

Why Does NASA Study This Phenomenon?

One of the most well-known climate patterns that we have come to recognize and better understand is El Niño. Every three to seven years during the months of December and January, the balance between, wind, ocean currents, oceanic and atmospheric temperature and biosphere breaks down, resulting in a severe impact on global weather.

In a normal year the trade winds blow westward and push warm surface water near Australia and New Guinea. When this warm water builds up in the western Pacific-Ocean, nutrient-rich cold waters are forced to rise up from the deeper ocean just off of the west coast of South America. This colder nutrient-rich water fosters the growth of the fish population.

During an El Niño event the trade winds weaken. Warm, nutrient-poor water is not pushed westward and comes to occupy the entire tropical Pacific Ocean. The cold water is not forced to the surface and the coastal waters of Peru and Ecuador are unusually warm. This warmer water has a devastating impact on their fishing crops which rely on cool waters to thrive. The region also experiences an extremely higher than average amounts of rainfall.

While the impact of an El Niño is most dramatic off of the coast of Western South America its impact is felt in weather around the world. A severe El Niño will enhance the jet stream over the western Pacific and shift it eastward, leading to stronger winter storms over California and southern United States, with accompanying floods and landslides. In contrast, El Niño may also cause severe droughts over Australia, Indonesia, and parts of southern Asia. Further, while El Niño is known to lower the probability of hurricanes in the Atlantic, it increases the chances of cyclones and typhoons in the Pacific.

Oceanography from Space

El Niño is one example of how observing the ocean from space leads to significant insights. Researchers use data from NASA Earth observing satellites to create telling images of how El Niño events form in the ocean, and the factors that may impact its strength and duration in a given climate cycle.

Temperature

NOAA's AVHRR and NASA's Aqua satellite have provided scientists over 25 years of sea surface temperature data. The vast tropical Pacific Ocean receives more sunlight than any other region on Earth. Much of this sunlight is stored in the ocean in the form of heat. During an El Niño water temperatures in the Pacific Ocean may rise on average 3 - 5 degrees above average. This happens as the water in seas around Indonesia, referred to as the Pacific Warm Pool are not forced westward due to weakened east to west trade winds. This pool of warmer water expands westward toward North and South America. Scientists have observed that the size and the frequency of an El Niño is impacted by the fluctuations in the Pacific Warm Pool.

Topography

Currents and tides influence topography, as does temperature. Water expands as it gets warmer, and the lack of cold water dependent nutrients make it less dense. This expanded, less dense water results in a rise in sea level, observable from space. Ocean surface height may rise as much as 6 to 13 inches above normal in some ocean regions during an El Niño.

Winds

The QuikSCAT satellite tracks vector winds, and the Jason and Topex/Poseidon missions track their effects. Typically, the Pacific trade winds blow from east to west, dragging the sunlit warm waters westward where they accumulate in Pacific Warm Pool mentioned above. Weakened east to west trade winds during an El Niño event result in the Pacific Warm Pool waters expanding westward. NASA's QuikSCAT satellite data have shown how trade wind irregularities of less than a few months in duration leading up to an El Niño may have dramatic results on the weather events to follow.

Currents

Currents, or circulation within ocean is influenced primarily by two physical factors, the sinking and rising of warming and cooling water, and movement due to the forcing of the surface waters due to wind. The interactions of ocean water temperature and the strength and direction of winds create currents within the ocean that define the strength and duration of the El Niño. NASA satellite data in combination with data collected from buoy systems and ships provide scientists an expanding understanding of the relationship between ocean currents, weather and climate.

Salinity

Ocean water salt content or salinity is a key variable in understanding the ocean's capacity to store and transport heat. Salinity and temperature combine to dictate the oceans' density. Greater salinity, like colder temperatures, results in an increase in ocean density with a corresponding depression of the sea surface height. In warmer, fresher waters, the density is lower resulting in an elevation of the sea surface. These ocean height differences are related to the circulation of the ocean. Beginning in 2009 the Aquarius mission will take regular measurements of the changes in ocean surface salinity. By knowing the how changes in salinity impact the physical processes in the ocean scientists will be able to create computer models that may more accurately predict El Niño episodes.

Sea Ice

Sea ice modulates planetary heat transport by insulating the ocean from the cold polar atmosphere, and also by modulating the thermohaline circulation of the world ocean. Moreover, the high albedo of snow-covered ice further insulates the polar oceans from solar radiation and introduces another positive feedback in the climate system. The El Niño and its related Southern Oscillation appear to affect regional ice distributions around Antarctica. Understanding this connection between the Southern Oscillation and southern ocean climate and the sea ice cover will substantially improve our understanding of global climate. El Niño episodes affect the Weddell and Ross Seas, areas that are regarded as key sources of cold and dense bottom water that influences global ocean circulation. The strongest links were observed to be in the Amundsen, Bellingshausen and Weddell Seas of the west Antarctic. Within these sectors, higher sea level pressure, warmer air temperature and warmer sea surface temperature are generally associated with the El Niño phase.

Future

By combining data sets from various satellite and in situ measurements we have been able to learn a great deal about how the physical properties of the ocean interact to create climate patterns. Scientists will continue to create models that combine data allowing them to better understand and predict complex ocean processes.

By using data collected from discrete measurements of physical properties of the ocean scientists have learned a great deal about El Niño and how it is impacted by the ocean system. Scientists are just beginning to have data of a time span sufficient to allow them to begin to predict climate patterns longer than the 3 to 7 year El Niño pattern. The ability to study the El Niño climate pattern and create models to simulate conditions, has helped us better predict its impact on our climate and weather.

El Niño is only one of the climate anomalies that scientists have observed; others include the North Atlantic Oscillation, the Atlantic Intertropical Convergence Zone oscillation, the Pacific Decadal Oscillation. Together with El Niño these systems are believed to be responsible for well over fifty percent of the climate variability on Earth. As models are created to simulate the individual patterns they will be combined to create a global model of climate change. If scientists get to the point to where they understand all of these climate cycles they may be able to predict major weather patterns months in advance.

Essential Questions

1. How does a change of energy in one sphere of the Earth System affect another sphere?
2. How the energy transferred among the various spheres of the Earth System?
3. How is matter shared within the various spheres of the Earth System?
4. What other parts of the Earth System may experience the effects of El Niño and how?
5. What phenomena are associated with changes in different spheres of the Earth System?
What variables appear to be correlated?

Cross-Curricular Connections

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

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- 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

Materials Required

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

Procedure

Beginning the Investigation

1. Have students bring to class newspaper and magazine clippings and photos of severe weather-related events, such as storms, floods, mudslides, 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.
- 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.



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?

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Log 1:

(Distribute Log and Module 3, Investigation 1: Briefing 1 "What are the effects of ENSO?" and review

with students.)

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 lead 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:
 - North America
 - **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.

Move on to the ENSO Game after debriefing the Log.

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.

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.

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.

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

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.

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.



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

Log 2:

(Distribute Log and Module 3, Investigation 1: Briefing 2 The ENSO game: Predicting and managing for El Niño and La Niña and review with students.)

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 the table to the right 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.*

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 on 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

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- 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.

No investments in fishing this year

- 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:

Invest in disaster preparedness

- 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.

No investment in disaster preparedness

- 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.