¡El Niño!-¡La Niña!

TEACHER'S GUIDE

Project ATMOSPHERE

This guide is one of a series produced by Project ATMOSPHERE, an initiative of the American Meteorological Society. Project ATMOSPHERE has created and trained a network of resource agents who provide nationwide leadership in precollege atmospheric environment education. To support these agents in their teacher training, Project ATMOSPHERE develops and produces teacher's guides and other educational materials.

For further information, and additional background on the American Meteorological Society's Education Program, please contact:

American Meteorological Society
Education Program
1200 New York Ave., NW, Ste. 500
Washington, DC 20005-3928
www.ametsoc.org/amsedu

This material is based upon work initially supported by the National Science Foundation under Grant No. TPE-9340055.

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Foreword

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further study.

El Niño: The Atmosphere-Ocean Connection

The term *El Niño* originally described a weak warming of the ocean water that ran southward along the coast of Peru and Ecuador about Christmastime each year and resulted in poor fishing. Today, *El Niño* refers to a large-scale disturbance of the ocean and atmosphere in the tropical Pacific. A persistent El Niño can be accompanied by major shifts in planetary-scale atmospheric and oceanic circulations and weather extremes that bring major ecological, social, and economic disruptions worldwide.

Most of the time, westward-blowing trade winds drive warm surface water westward, away from the west coast of South America. In the western tropical Pacific, this pool of transported warm surface water results in low air pressure and abundant rainfall. In the eastern tropical Pacific, the warm surface water is replaced by colder water that wells up from below, a process known as *upwelling*. Relatively cold surface water favors high air pressure and meager precipitation. Upwelling also exposes nutrient-rich water from below to sunlight, stimulating the growth of marine plant life which support fisheries.

The first sign of El Niño in progress is a weakening of the trade winds. Normally, the contrast between relatively high air pressure over the eastern tropical Pacific and low air pressure over the western tropical Pacific drive the trade winds. With onset of El Niño, air pressure falls over the eastern tropical Pacific and rises in the west, with the greatest pressure drop over the central Pacific. As the air pressure gradient across the tropical Pacific weakens, trade winds slacken and may even reverse in the west. The see-saw variation in air pressure between the western and central tropical Pacific is known as the Southern Oscillation. El Niño and Southern Oscillation are abbreviated as ENSO.

During El Niño, changes in atmospheric circulation over the tropical Pacific are accompanied by changes in ocean currents and sea-surface temperature (SST) patterns. The pool of warm surface water normally driven westward by the trade winds now drifts eastward. At the same time, changes take place in the thermocline, the zone of transition between relatively warm surface water and cold deep water. The thermocline sinks in the east, greatly weakening or even cutting off upwelling along the west coast of South America. Changes in the trade wind circulation alter tropical weather patterns. In turn, these shift the planetary-scale winds, including jet streams, which steer storms and air masses at higher latitudes, causing weather extremes in many areas of the globe outside of the tropics.

El Niño, lasting an average 12 to 18 months, occurs about once every two to seven years. Ten occurred during a recent 42 year period, with one of the most intense of the century in 1997-98. Sometimes, but not always, El Niño alternates with La Niña, a period of unusually strong trade winds and vigorous upwelling over the eastern tropical Pacific. During La Niña, changes in SSTs and extremes in weather are essentially opposite those observed during El Niño.

Basic Understandings: El Niño

El Niño, the Southern Oscillation, ENSO, and La Niña

1. Originally, *El Niño* was the name given by Peruvian fishermen to a period of warm waters and poor fishing that often coincided with the Christmas season.

2. Today, El Niño refers to a significant departure from the average state of the ocean-atmosphere system in the tropical Pacific that has important consequences, including those for weather and climate in the tropics and other regions of the globe.

3. El Niño typically persists for 12 to 18 months and recurs approximately every two to seven years. The ten recorded over a recent 42 year period include the extreme events of 1982-83 and 1997-98.

4. The Southern Oscillation is a see-saw variation in air pressure between the central and western tropical Pacific. These pressure changes alter the strength of the trade winds and affect surface ocean currents as part of El Niño. Scientists often combine El Niño and the Southern Oscillation as the acronym, ENSO.

5. Occurrence of ocean/atmosphere conditions essentially opposite those of El Niño is called *La Niña*. La Niña sometimes, but not always, alternates with El Niño.

Long-Term Average Conditions in the Tropical Pacific

1. Normally, strong trade winds drive warm surface water westward and away from the west coast of South America.

2. In the tropical eastern Pacific, colder water rising from the depths replaces the warm surface water that is driven westward from the area, a process called *upwelling*.

3. Upwelling delivers cold nutrient-rich water from below into sunlit surface regions, greatly enhancing biological productivity. Most of the important commercial fisheries are located in areas of upwelling.

4. In the tropical eastern Pacific, offshore transport of warm surface water results in a locally lower sea level, a rise in the thermocline (the transition zone separating warmer surface water from colder deep water), and a drop in sea-surface temperature. Cooler surface waters are responsible for relatively high air pressure and mostly fair weather. Low precipitation amounts over adjacent land areas give rise to desert conditions.

5. Piling up of wind-driven warm surface water in the western tropical Pacific causes a higher sea level, a deeper thermocline, and higher sea-surface temperatures than in

the central and eastern tropical Pacific. Warm surface waters produce relatively low air pressure and spurs atmospheric convection that is responsible for heavy rainfall.

El Niño Conditions in the Tropical Pacific

1. During El Niño, the trade winds are weaker than average over the tropical Pacific and may even reverse direction, especially in the west.

2. In the tropical western Pacific, weakening or reversal of the trade winds causes the pool of warm surface water in the western tropical Pacific to drift eastward along the equator toward the coast of South America.

3. In the tropical western Pacific, eastward transport of warm surface water is accompanied by a drop in sea level and a rise in the thermocline. Slightly cooler surface waters produce higher than usual air pressure, weaker atmospheric convection, and reduced rainfall.

4. Arrival of the pool of warm surface water along the coast of South America greatly diminishes or eliminates upwelling of nutrient-rich cold bottom water so that biological productivity declines sharply.

5. In the tropical eastern Pacific, the piling up of warm surface water results in a local rise in sea level, a deeper thermocline, and higher sea-surface temperatures. Warm surface waters produce relatively low air pressure and enhance atmospheric convection that brings more than usual rainfall.

6. The concurrent rise in air pressure over the western tropical Pacific and fall in air pressure over the central tropical Pacific (which weakens the trade winds) is part of a regular see-saw variation in surface air pressure known as the Southern Oscillation.

Global El Niño and La Niña Conditions

1. Changes in oceanic and atmospheric circulation in the tropical Pacific impact weather and climate in the tropics and well beyond.

2. Temperature governs the rate at which water molecules escape a water surface and enter the atmosphere; that is, warm water evaporates more readily than cool water. Regions of relatively warm surface waters heat the atmosphere and add moisture to the atmosphere. Thunderstorms more readily develop in this warm, humid air. Towering thunderstorms help shape the planetary-scale atmospheric circulation, altering the course of jet streams and moisture transport at higher latitudes.

3. Changes in the planetary-scale atmospheric circulation during El Niño and La Niña often give rise to weather extremes, including drought and excessive rainfall, in many areas of the globe outside the tropics.

4. No two El Niño or La Niña events are exactly the same, so that in some areas weather extremes may or may not accompany a particular El Niño or La Niña.

5. In the United States, El Niño winters tend to be cool and wet across the southeast and milder than usual over the Pacific Northwest and New England.

Ecological, Social, and Environmental Impacts

1. Many aspects of the environment and global economy are impacted by variations in the ocean/atmosphere system of the tropical Pacific. These impacts also have human and social consequences.

2. Too little or too much precipitation can have devastating effects. In some areas, drought, especially when accompanied by high temperatures, causes crops to wither and die, reduces the public water supply, and increases the likelihood of wildfire. In other areas, exceptionally heavy rains trigger flash flooding that drowns crops, washes away motor vehicles, destroys houses and other buildings, and disrupts public utilities.

3. Weather extremes associated with El Niño and La Niña have implications for public health by creating conditions that increase the incidence of diseases such as malaria, dengue fever, encephalitis, cholera, and plague. Also, smoke from wildfires in drought-stricken regions can cause respiratory problems for people living up to thousands of miles from the fires.

4. Advance warning of El Niño and La Niña and their accompanying weather extremes could save lives and billions of dollars in property and crop damage by allowing adequate time for preparedness and development of appropriate response strategies.

El Niño and La Niña Research

1. Scientists are actively investigating the tropical Pacific ocean/atmosphere system for answers to many questions including: What gets El Niño and La Niña started? Why do they stop? Why do regional impacts differ from one El Niño (or La Niña) to the next? When will scientists be able to reliably predict the duration and impact of El Niño and La Niña?

2. Observations of conditions in the tropical Pacific are essential for the investigation and prediction of short term climate variations like El Niño. A wide variety of sensors are used to obtain ocean and atmospheric data from this vast and remote region of the ocean.

3. Satellite-borne temperature sensors and altimeters are being used to track the movement of warm surface water across the tropical Pacific. Additional information is provided by a network of buoys that directly measure temperature, currents, and winds along the equatorial band.

4. Predicting the onset and duration of El Niño and La Niña is critical in helping water, energy, and transportation managers, and farmers plan for, mitigate, or avoid potential losses.

5. Advances in El Niño and La Niña prediction are expected to significantly enhance economic opportunities, particularly for the agriculture, fishing, forestry, and energy sectors, as well as provide opportunities for societal benefits.

¡El Niño!-¡La Niña!

The ***¡El Niño!-¡La Niña!*** is a slide chart that will help you explore the workings of the tropical Pacific marine environment. Stretching nearly one-third of the way around the globe and covering a fifth of the Earth's surface, the tropical Pacific is a coupled ocean/atmosphere system that makes its presence known far beyond its boundaries. Its influence on world-wide weather and climate can lead to major ecological, societal, and economic disruptions. Occurrence of ***El Niño*** every two to seven years and the less frequent ***La Niña*** demonstrates that there are swings in ocean/atmosphere conditions, weather, and climate which operate on other than annual timetables.

With ***¡El Niño!-¡La Niña!***, you can investigate and compare ocean and atmospheric conditions that occur during ***El Niño*** and ***La Niña*** with long-term average (Neutral) conditions.

The Tropical Pacific During Long-Term Average Conditions

Examine ***¡El Niño!-¡La Niña!*** with the slide insert pushed all the way into the device so that **Neutral Conditions** appears in the indentation along the bottom of the large window. (Note: If ***La Niña*** appears when fully inserted, pull the slide out, flip it to the other side, and reinsert.)

Look at the large window. It displays a schematic of the Pacific Ocean along the equator (greatly exaggerated in the vertical). The scene depicts the ocean surface with atmosphere above and a vertical cross-section of the ocean below. Note that numbered <u>East</u> longitudes occur to the west (left) of the International Dateline (180°) in the mid-Pacific while <u>West</u> longitudes occur to the east of the Dateline.

1. Fair weather appears in the eastern tropical Pacific while **[(*<u>fair</u>*)(*<u>stormy</u>*)]** weather prevails in the western Pacific.

2. Small windows depict conditions in the western, central, and eastern portions of the tropical Pacific. Dark blue triangles below the atmosphere windows and above the ocean windows point to the locations in the large window where conditions portrayed in the small windows are observed. The windows to your left represent a location in the **[(*<u>eastern</u>*)(*<u>western</u>*)]** tropical Pacific.

3. The arrows in the **Trade Winds** windows point in the direction toward which the prevailing winds are blowing. The lengths of the arrows denote relative wind speeds; the longer the arrow, the greater the wind speed. As indicated in the windows, winds during neutral conditions blow toward the **[(*<u>east</u>*)(*<u>west</u>*)]** and the wind speed is **[(*<u>higher</u>*)(*<u>lower</u>*)]** in the eastern Pacific than in the western Pacific.

4. The smaller windows below the large window provide ocean information. Arrows in the **Surface Currents** window indicate that during neutral conditions, surface water flows towards the **[(*__east__*)(*__west__*)]**.

5. According to the values reported in the windows, the highest sea surface temperatures (SSTs) during neutral conditions occur in the **[(*__eastern__*)(*__western__*)]** tropical Pacific. This SST pattern is caused by relatively strong Trade Winds pushing sun-warmed surface water **[(*__eastward__*)(*__westward__*)]**, as evidenced by the direction of surface currents.

6. Strong Trade Winds also cause the warm surface waters to pile up in the western tropical Pacific so that the sea surface height in the western Pacific is **[(*__lower__*)(*__higher__*)]** than in the eastern Pacific. Transport of surface waters to the west also causes the thermocline (the transition zone between warm surface water and cold deep water) to be **[(*__deeper__*)(*__shallower__*)]** in the eastern Pacific than in the western Pacific.

7. Warm surface water transported by the wind away from the South American coast is replaced by cold water rising from below in a process called upwelling. Upwelling of cold deep water results in relatively **[(*__high__*)(*__low__*)]** SSTs in the eastern Pacific compared to the western Pacific.

8. Cold surface water cools the air above it, which leads to increases in the surface air pressure. Warm surface water adds heat and water vapor to the atmosphere, lowering surface air pressure. As shown in the **Surface Air Pressure** windows, these effects result in tropical surface air pressure being **[(*__highest__*)(*__lowest__*)]** in the eastern Pacific and **[(*__highest__*)(*__lowest__*)]** in the western Pacific.

9. Whenever air pressure changes over distance, a force will act on air to move it from where the pressure is relatively high to where pressure is relatively low. The Trade Winds blow from east to the west because from east to west the surface air pressure **[(*__increases__*)(*__decreases__*)]**.

10. Rainfall in the tropical Pacific is also related to SST patterns. There are reasons for this relationship. The higher the SST, the greater the rate of evaporation of seawater and the more vigorous is atmospheric convection. Consequently, during long-term average conditions, rainfall is greatest in the **[(*__western__*)(*__eastern__*)]** Pacific where SSTs are **[(*__highest__*)(*__lowest__*)]**.

The Tropical Pacific During El Niño

Slowly pull the insert out of ***¡El Niño!-¡La Niña!*** while watching the changing scene in the large window. Note that the stormy conditions move eastward. Continue pulling until the **El Niño** label is lined up in the lower left corner of the window. Now you are viewing atmospheric and oceanic conditions that are expected during a typical ***El Niño***. While no two El Niño episodes are exactly alike, all of them exhibit most of the characteristics described in ***¡El Niño!-¡La Niña!***.

11. With the onset of ***El Niño***, tropical surface air pressure patterns change. Compare the red ***El Niño*** readings in the western and central tropical Pacific windows with the black marks along the sides of the windows. The black marks indicate long-term average readings at those locations. During long-term average conditions, the surface air pressure in the central Pacific is higher than to the west. During ***El Niño***, the surface air pressure to the west is **[(*higher*)(*lower*)]** than in the central Pacific. This seesaw pattern of pressure variation is called the **Southern Oscillation**.

12. In response to changes in the air pressure pattern across the tropical Pacific, the speed of the Trade Winds decreases (and wind directions can reverse, especially in the western Pacific). No longer being pushed toward and piled up in the western Pacific, the warm surface water reverses flow direction. As seen in the **Surface Currents** window, the surface water currents during El Niño flow toward the **[(*east*)(*west*)]**. As evident in the appropriate **Sea Surface Temperature** window, this causes SSTs in the eastern tropical Pacific to be **[(*higher*)(*lower*)]** than neutral values.

13. In response to surface currents, sea surface heights in the eastern tropical Pacific are **[(*higher*)(*lower*)]** than neutral levels. At the same time, the arrival of the warmer water causes the surface warm-water layer to thicken. Evidence of this is the **[(*shallower*)(*deeper*)]** depth of the thermocline compared to neutral conditions.

14. Differences between existing conditions and neutral conditions are called **anomalies**. If ***El Niño*** readings are higher than the respective long-term averages (shown by the black reference lines next to the windows), the anomalies are positive. If ***El Niño*** values are lower, the anomalies are negative. In the eastern tropical Pacific during ***El Niño***, the SST anomaly is **[(*negative*)(*positive*)]**, the sea-surface height anomaly is **[(*negative*)(*positive*)]**, the surface air pressure anomaly is **[(*negative*)(*positive*)]**, and the rainfall anomaly is **[(*negative*)(*positive*)]**.

The Tropical Pacific During La Niña

Remove the slide insert from the sleeve and turn it to the other side. Slide the insert back into the sleeve until **Neutral Conditions** appears in the indentation along the bottom of the large window. (Note that the Neutral Conditions on both sides of the insert are identical.) Then continue pushing the insert in until **La Niña** appears in the indentation.

15. The stormy weather in the western Pacific has been displaced **[(*westward*)(*eastward*)]** from its Neutral Conditions position.

16. During **La Niña** air pressure difference between the eastern and western Pacific is **[(*less*)(*greater*)]** than during Neutral Conditions (as shown by the black marks along the windows). The stronger trade winds are driven by an air pressure pattern that

[(*__increases__*)(*__decreases__*)] westward across the Pacific. The trade winds drive surface currents toward the **[(*__west__*)(*__east__*)]**, resulting in sea surface temperatures in the western Pacific that are slightly **[(*__higher__*)(*__lower__*)]** than Neutral Conditions while the eastern Pacific experiences **[(*__positive__*)(*__negative__*)]** SST anomalies.

17. The **La Niña** wind and current patterns produce a thermocline depth in the eastern Pacific that is **[(*__deeper__*)(*__shallower__*)]** than the long-term average value, leading to **[(*__weaker__*)(*__stronger__*)]** upwelling than average (note the large curved arrows).

Continue your investigations of the tropical Pacific ocean/atmosphere system by predicting how the changes shown by ***¡El Niño!-¡La Niña!*** might impact people living along the Peruvian coast and on the island nations of the western tropical Pacific. Turn to the back of ***¡El Niño!-¡La Niña!*** to study the potential impacts of **El Niño** in those areas and elsewhere, including the United States.

Extensions

1. Satellites provide unique views of Earth's oceans. Imagery acquired by various sensors aboard these space platforms reveal broad-scale circulation patterns that can be seen in their entirety. Describe how each of the following remote sensors could be used to track the progress of El Niño: (a) infrared (IR) sensors that measure sea surface temperatures, (b) altimeters that monitor sea-surface height; and (c) ocean color sensors that observe visible light reflecting from pigments such as chlorophyll in phytoplankton.

2. Not all observations of ocean conditions can be obtained remotely by sensors aboard satellites. Some measurements must be made "in situ," that is, by instruments actually in the water. Describe how each of the following unmanned platforms could be used to track the progress of El Niño: (a) tide gage stations that measure the height of local sea level, (b) moored buoys that monitor surface winds and water temperatures at several levels below the ocean surface, and (c) drifting buoys that observe the motion and temperature of surface ocean water.

3. One of the best sources of data on ocean/atmosphere conditions are the sensors and scientists aboard oceanographic research ships. What are some of the advantages and disadvantages of using these resources to monitor El Niño?

4. Reliable data obtained from remote and direct sensors help describe the existing conditions in the tropical Pacific. These data are now being used by scientists to develop realistic numerical models of the coupled ocean and atmosphere. Computers that are programmed with these models can project future states of the tropical ocean/atmosphere and foresee a future El Niño. What might be the value of such predictions?

Real World Applications

Following the intense El Niño episode of 1982-83 with its worldwide weather impacts, an instrumented array of buoys (Tropical Atmosphere Ocean (TAO) or TAO/TRITON array) was deployed across the tropical Pacific from ten degrees North latitude to ten degrees South latitude. **Figure 1** is a map showing the buoy locations. This array, along with satellite observations, has allowed real-time monitoring of tropical Pacific ocean and atmosphere conditions and provided input for models used to predict future episodes.

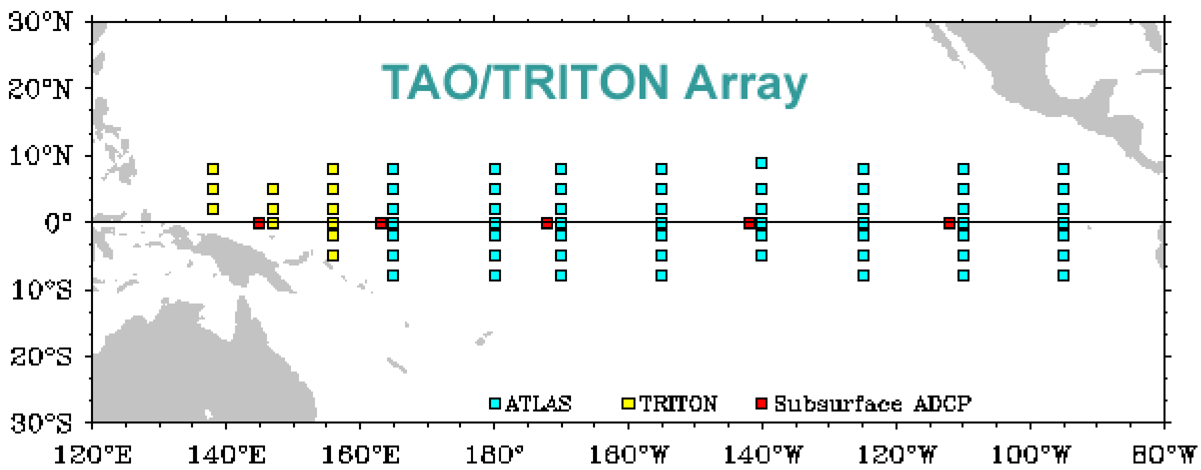

Figure 1. The locations of TAO-TRITON instrumented buoys in the tropical Pacific Ocean. [http://www.pmel.noaa.gov/tao/proj_over/map_array.html]

1. An example of reporting of TAO surface data is presented in **Figure 2**. The upper panel of Figure 2 depicts the five-day mean tropical Pacific sea surface temperatures (SST) and wind conditions ending on December 28, 2011. The SST are shaded with isotherms drawn at one-half Celsius degree intervals. Wind directions are shown by arrows originating at the buoy site while the length of the arrow depicts the relative wind speed. The shading and isotherms indicate that the warmest waters across the tropical Pacific are located at about **[(*140° E*)(*180°*)(*140° W*)]** longitude. [Note, the Pacific east of 180° longitude (the International Dateline) has ***W***(est) numbered longitudes while the Pacific west of 180° has ***E***(ast) numbers.]

2. Across most of the equatorial tropical Pacific, winds were flowing generally from **[(*west to east*)(*east to west*)]**.

The lower panel of Figure 2 displays *Anomalies*, that is, departures from the long-term average. Positive temperature anomaly isotherms are thin solid lines, negative anomaly isotherms are dashed lines. The anomaly interval between lines is also one-half degree Celsius. A bold solid line denotes the 0-degree departure (*i.e.* average).

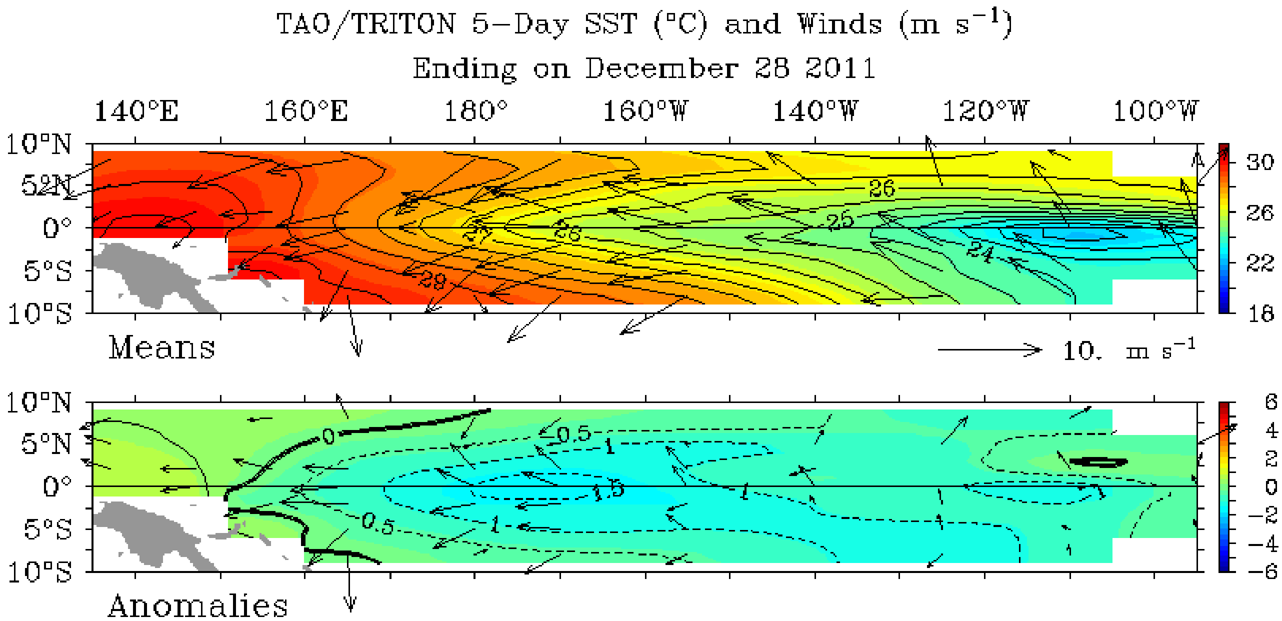

Figure 2. tropical Pacific conditions and anomalies on 28 December 2011.

3. The broad pattern of current SST anomalies over the tropical Pacific region generally shows values that are essentially:
   [(*__negative across most of the tropical Pacific__*)
   (*__positive across most of the tropical Pacific__*)
   (*__negative in the west and positive in the east__*)].

4. The magnitudes of the greatest negative SST anomalies are more than **[(*__–1.5__*)(*__–2.5__*)(*__–3.5__*)]** Celsius degrees.

Anomalous winds are departures from the average of both speed and direction. For example, the anomalous winds (lower panel) in the western tropical Pacific are also from east to west. That is, the departures are in the same direction with arrow lengths meaning greater actual speed than the long-term averages.

Now go to your ***¡El Niño!-¡La Niña!*** slide chart. Compare the SST pattern anomalies seen in the small windows below the large central window and the Trade Winds arrows above the large central window in both the **El Niño** and the **La Niña** settings with the actual observed conditions and anomalies seen in Figure 2. Recall the SST anomalies in the western and eastern Pacific are given by the red and blue lines respectively of the small windows compared to the black indicator marks.

5. The tropical Pacific conditions displayed in Figure 2 are most similar to those depicted in the ***¡El Niño!-¡La Niña!*** chart occurring during a(n) **[(*__El Niño__*)(*__La Niña__*)]** event.

On September 8, 2011, NOAA's Climate Prediction Center issued an advisory statement that La Niña conditions were strengthening and would continue through the Northern

Hemisphere winter of 2011-2012 (http://www.noaanews.noaa.gov/stories2011/20110908_lanina.html).

For more information on El Niño, see: http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html and for La Niña, http://www.pmel.noaa.gov/tao/elnino/la-nina-story.html. For the latest Pacific conditions such as shown in Figure 2, go to: http://www.pmel.noaa.gov/tao/jsdisplay/.

Information Sources

Books

Moran, Joseph M. Weather Studies: Introduction to Atmospheric Science, 5th Ed. Boston, MA: American Meteorological Society, 2012.

Periodicals

Weatherwise. Bimonthly magazine written in association with the American Meteorological Society for the layperson. Weatherwise, 1319 Eighteenth St., NW, Washington, DC 20036.

USA Today. National newspaper with extensive weather page. Available at local newsstands and by subscription.

Radio and Television

NOAA Weather Radio. The voice of the National Weather Service and All Hazards Emergency Alert System. Local continuous broadcasts from over 1000 transmitting stations nationwide.

The Weather Channel. A continuous cable television program devoted to reporting weather. Includes frequent broadcast of local official National Weather Service forecasts.

Internet

DataStreme Atmosphere (*www.ametsoc.org/amsedu/dstreme/*). Atmospheric education distance-learning website of the AMS Education Program.

JetStream – Online School for Weather (*www.srh.noaa.gov/jetstream/*). Background weather information site from the National Weather Service.

NOAA's El Niño webpage (*www.elnino.noaa.gov/*). A beginning page for information on El Niño, La Niña and current tropical Pacific Ocean conditions.