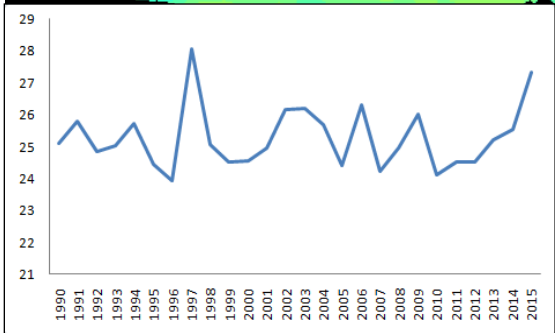
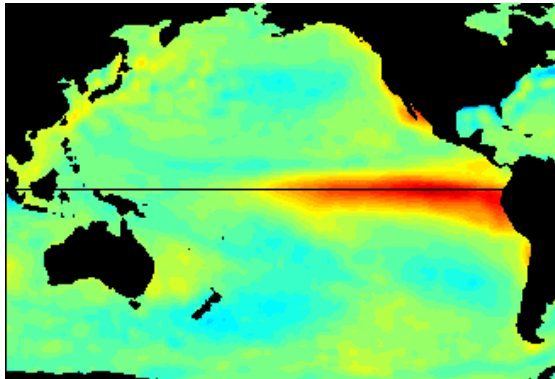
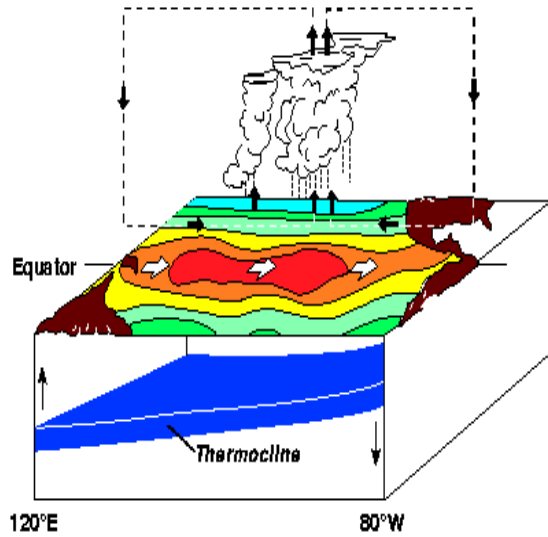


El Niño Conditions



What is El Niño? Unit Plan

Part 1

More Lessons from the Sky
Satellite Educators Association
<https://SatEd.org>

Please see the Acknowledgements section for contributions to the development of this lesson plan. Part 1 of “What is El Niño Unit Plan” was first published in February 2016 in *More Lessons from the Sky*, a regular feature of the SEA Newsletter, and archived in the SEA Lesson Plan Library. Both the Newsletter and the Library are freely available on-line from the Satellite Educators Association (SEA) at this address: <https://SatEd.org/>.

Content, Internet links, and lesson materials in the SEA Lesson Plan Library Resources revised and updated, May 2023.

SEA Lesson Plan Library Improvement Program

Did you use this lesson plan with students? If so, please share your experience to help us improve the lesson plan for future use. Just click the Feedback link at <https://SatEd.org/library/search.htm> and complete the short form on-line. Thank you.

What is El Niño?

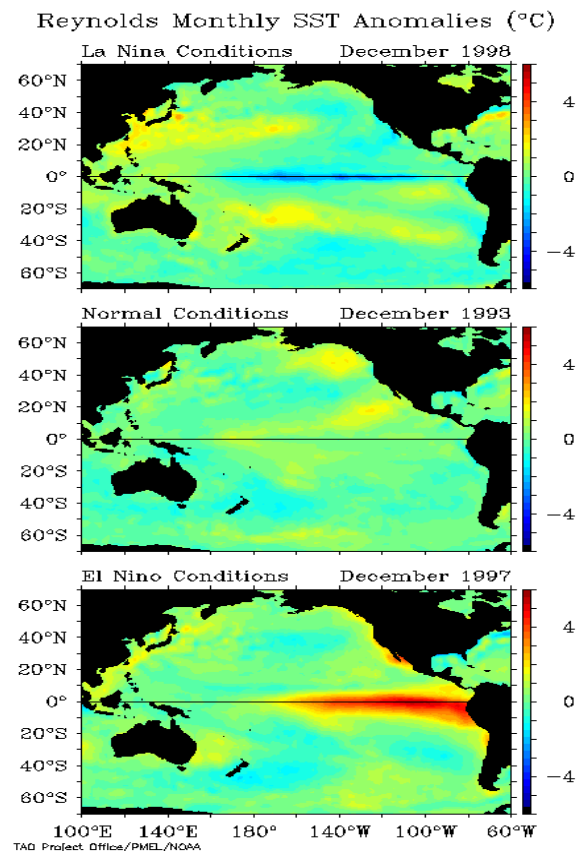
Part 1: Using Satellite-Based Sea Surface Temperature Data

Invitation

What is El Niño, anyway? Take a look at these maps of sea surface temperature (SST) for major El Niño/La Niña events in the 1997 and 1998. How do they compare? What differences do you notice? What do the displayed colors indicate? Which map shows highest temperatures? Where? Which shows lowest temperatures? Where? How would you describe these three graphics?

El Niño conditions are characterized by unusually *warm* ocean temperatures in the Eastern Equatorial Pacific while conditions known as **La Niña** are characterized by unusually *cool* ocean temperatures in the same area. These sea surface temperature variations effect changes in weather systems around the world.

This is the first of three lesson plans in a lesson set guiding learners to investigate the “El Niño” phenomenon. In this inquiry lesson, learners access, visualize, analyze, and interpret sea surface temperature data recorded from satellite-based remote sensors to define the terms "El Niño" and "La Niña." In the succeeding lessons, learners investigate the impact of a strong El Niño event on their local areas compared to other regions and explore solutions to mitigate the impacts of such weather changes. The ultimate end-product of the lesson set is the construction of “The Next El Niño Survival Guide.”



Grade Level:	6-12
Time Requirement:	2-3 class periods
Prerequisites:	Basic computer skills
Relevant Disciplines:	All

Student Learning Outcomes

By the end of this lesson, students should be able to do the following:

- Define El Niño as the term relates to ocean temperature and weather
- Compare El Niño conditions to La Niña conditions
- Access satellite-based remote sensing sea surface temperature data

Teaching Notes

- Analyze and interpret sea surface temperature data
- Construct explanations for the interpretations
- Communicate findings with others
- Apply lesson skills in Your Turn extension activities

Lesson Description

The lesson utilizes a modified 5E inquiry strategy: Engage, Explore, Explain, Extend, Evaluate. Once engaged and thinking about observable differences between El Niño and La Niña events and how they differ from the norm, learners will follow a tutorial guide to access, visualize, and analyze sea-surface temperature data archived by the National Oceanic and Atmospheric Administration (NOAA). Learners will construct their own interpretation from their analyses and present their findings. The tutorial guides can be completed in three separate activities depending on the skill level and needs of the learners. At appropriate points learners will be asked to answer a series of questions to emphasize key concepts, check for understanding, and explain interpretations. A class discussion following the tutorial helps students explain and clarify key concepts. Completion of one or more of the Your Turn application/extension activities is essential for learners in testing themselves through application of learned skills and demonstration of analytical thinking.

Notice in this adaptation of the 5E inquiry strategy, Evaluate occurs throughout as frequent checks for understanding in the form of formative and summative assessment by the teacher and student self-assessment.

This is a web-based activity that requires computer terminals with Internet access for each learner or learner group. It is recommended that no more than two to four students be assigned to a computer at one time.

Engage

Materials: Sea Surface Temperature Anomalies sheet – 1 per group

Organize students into groups of four. Distribute Anomalies maps. In a Think-Pair-Share cooperative learning group activity, ask students to quietly think about following questions as they look at the Anomalies sheet:

- What differences do you notice?
- What do the displayed colors indicate?
- Which map shows the highest temperatures? Where?
- Which map shows the lowest temperatures? Where?
- How would you describe these three graphics?

Next, have students exchange answers with one other student in the group. There will likely be a lot of agreement. Then ask the pairs in the group to exchange answers.

This should not take more than 10 minutes. Then announce the next activities will help learners check their answers.

-Evaluate

The purpose of this brief introductory activity is to engage learners by having them

think about the topic, to set the focus of their attention on the subject at hand. Did each student participate or is there a need to refocus and try again?

Explore

Materials: Internet enabled computers with acceptable browsers – 1 per group
ImageJ installed on the computer
Image file SST-199012-201512.tif pre-loaded on each computer
From Student Activity pages:
“Using NOAA View” tutorial – 1 per group
“Using ImageJ” tutorial – 1 per group
“Graphing Measurement Results” tutorial – 1 per group
“SST Answer Sheet” – 1 per student

Following the Engage activity, learners will utilize three computer-based tools to access and analyze imaged maps of sea surface temperature data for December of each year from 1990 to 2015. Keep learners in the same groups of four with one computer for each group. Using the tutorial guides found in the Student Activity pages, learners will find and access images of sea surface temperature from NOAA View. These images are constructed from archived, satellite-based, remote sensing data and displayed on-demand. Learners will visualize and analyze the data using image processing software called ImageJ. Then learners will graph the temperature changes over time for a specified region of interest using a graphing program such as Excel or Vernier’s Graphical Analysis. Learners should use the tutorials found in the Student Activity pages. Learners familiar with ImageJ are likely to complete the tutorial more quickly. It is vital that every learner leave the exercise with her/his own hard copy of the graph.

-Evaluate

Circulate to monitor group work. Answer questions; make suggestions if a group is off-track or stalled. Ask questions of groups or individuals occasionally as checks for understanding and to insure they do not skip or misinterpret any of the directions in the tutorial guides or questions on the answer sheet.

Explain

Materials: Internet enabled computer with acceptable browser – 1 per group
From Student Activity pages:
“El Niño 3-D Diagrams” – 1 per group
“3-D Summary” sheet – 1 per student

This is a Jigsaw type cooperative learning group activity in which learners will gather more information to interpret and begin to explain the differences between “normal conditions,” “La Niña conditions,” and “El Niño conditions” in the Eastern Equatorial Pacific Ocean. Rearrange students into groups of 4 if not already so grouped. Tell students these will be their “Home” groups – they must remember where they are so they can return here shortly. Have students in each home group select a different number from 1 to 4. Tell them each will become an expert in a different subject. Each will be meeting with experts of the same number from other home groups to learn more. Then they will return to their home groups to share their expert information. Each expert in the home group will have different information to share. Assign each expert group a number corresponding to a reading assignment from the following list:

Teaching Notes

1. “What is El Niño” and “Recognizing El Niño”
2. “Animations of Important and Recent El Niño Events” and “Historical El Niños”
3. “What is La Niña” and “Historical La Niña and El Niño Events”
4. “La Niña Impact on the Global Climate” and “The Origin of the Names La Niña and El Niño”

Expert groups 1-2 can access the reading at

<https://www.pmel.noaa.gov/elnino/what-is-el-nino>

Expert groups 3-4 can access the reading at

<https://www.pmel.noaa.gov/elnino/what-is-la-nina>

The number of expert groups and their sizes depends on the size of the class. For example, if there are 28 students in the class, there will be 7 home groups of 4 each and seven students meeting in each expert group. If there are 27 students in the class, the teacher may volunteer to fill in as an expert when experts report back to their home teams. If there are 25-26 students in the class, one or two home teams could be assigned an extra expert who will share the expert duties with another expert in the home team. If the class is very large, you might divide the reading selections between more than four expert groups.

Before the expert groups start their reading research and discussion, remind them that they must be ready to share what they learned in a report to their home groups lasting no more than 2 minutes.

Allow expert groups 5-10 minutes - more or less time as needed but not enough to access materials outside the group assignment. Then return students to their home groups. Each expert in the home group will have 2 minutes to share his/her information. Time them and stop each expert at 2 minutes. Learners should be currently unaware there will be more discussion time following the expert reports.

Following the expert reports, distribute the El Niño 3-D Diagrams for reference and have learners answer Questions 7-16 on the SST Answer Sheet. Learners should be free to discuss the answers in their home groups but take steps to ensure they answer in their own words rather than copying the works of a single student in the group or agreeing on a common answer that each copied onto the worksheet. If time permits and if needed as an additional check for understanding, you can have learners individually summarize what they have learned on the 3-D Diagram Summary sheet.

-Evaluate

Monitor activity during the discussion periods of the expert groups and home groups to ensure all participate. Review the answers to Question 7-16 in a brief class discussion. Elicit responses from learners for each question. Help learners unearth misconceptions, if any, and rewrite answers if needed. This provides checks for understanding for both the teacher and the learners. You can also ask students to comment on their own participation in the Jigsaw process and how it impacted what they discovered about El Niño/La Niña.

Extend

Armed with information from the Jigsaw, learners now return to the graph. They are

asked to interpret the graph by locating any high spikes. There are two: 1997 and 2015. Learners can identify the 1997 spike based on the information gathered during the Jigsaw. They should be able to explain the 2015 spike as strong El Niño event characterized by unusually warm sea surface temperatures in the Eastern Equatorial Pacific. Additionally, learners should be able to identify La Niña events on the graph characterized by unusually cool sea surface temperatures in the Eastern Pacific. Encourage discussion in each group before asking each to write a 5-paragraph essay (or other writing format familiar to them) answering the question, “What is El Niño?” and explaining the graph produced in the lesson. Be sure to collect the essays when finished.

-Evaluate

The graph and essay can be a summative assessment to this point in the lesson. Definitive summative assessment comes when the learner is able to apply lesson skills to a study of a different region of interest in the Eastern Equatorial Pacific or any other area visible in the provided SST images or others accessed by the learner using NOAA View. See the list of Your Turn extension activity suggestions in the Student Activity pages.

Important Terms

Anomaly	El Niño	Pixel
Calibrate	Equator	Scale
Cold tongue	La Niña	Temperature

Assessment Suggestions

It is recommended that formative assessment be made continuously throughout the lesson while monitoring student participation and checking for understanding of both lesson concepts and investigative skills. Opportunities for summative assessment include the following: (1) the completion and quality of responses in student activity sheets; (2) quality of interpretation and explanation presented in the essay; (3) quality of application of lesson skills in a Your Turn extension activity.

Standards

The following Next Generation Science Standards are addressed in this lesson.

Performance Expectations & Disciplinary Core Ideas

Grades 6-8: Earth’s Systems

- PE- MS-ESS2-4 – Develop a model to describe the cycling of water through Earth’s systems driven by energy from the sun and the force of gravity.
- DCI- MS-ESS2.C – Water continually cycles among land, ocean, and atmosphere via transportation, evaporation, condensation and crystallization, and precipitation as well as downhill flows on land.

Grades 9-12: Earth’s Systems

- PE- HS-ESS2-4 – Use a model to describe how variations in the flow of energy into and out of Earth’s systems result in changes in climate.
- DCI- HS-ESS2.D- The foundation for Earth’s global climate systems is the

Teaching Notes

electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems and this energy's re-radiation into space.

Science & Engineering Practices

- Develop a model to describe unobservable mechanisms.

Crosscutting Concepts

- Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Preparation

This entire lesson module is provided in portable document format (PDF). A PDF reader such as Adobe Reader or equivalent is required to view or print the lesson plan file. In addition, the Student Activity pages are provided in Microsoft Word document format (docx) to more easily adapt these pages to the needs of the students, curriculum, and classroom situation.

A number of files needed for this lesson, mentioned below, are accessible for download directly from this lesson's online Resources page. Point your browser to <https://SatEd.org/library/Resources.htm>, scroll to the title of this lesson, select and download the needed files.

During this lesson, students or student groups will require access to an Internet enabled computer with an acceptable browser.

The **Sea Surface Temperature Anomalies** sheet and **“El Niño” 3-D Diagrams** should be printed in color for distribution to students. Alternatively, the pages can be downloaded separately from the Resources page and projected for the entire class or copied to each computer.

The expert group readings for the Jigsaw can be read online given the appropriate URL. Unfortunately, this method allows access to all materials assigned to every group in addition to each group's unique assignment. Monitoring and timing are important teacher behaviors during the Jigsaw activity.

If time permits, additional animations for Expert Group 2 can be found here:

- https://psl.noaa.gov/map/clim/sst_olr/el_nino_anim.shtml
- http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_update/sst_anim.shtml

NOAA View does not require special software – only an up-to-date browser such as Mozilla Firefox, Google Chrome, Safari, or Microsoft Edge. If needed, an introduction to NOAA View and its features is available from <https://SatEd.org/library/Tools.htm>, the SEA Lesson Plan Library Analysis Toolbox.

The ImageJ installer is downloaded from <https://imagej.nih.gov/ij/>. It is available for

all major operating systems and both 32-bit and 64-bit versions. ImageJ comes bundled with a run-time version of Java that is self-contained and does not interfere with any other Java installations on your computer. Documentation files and sample images files can also be downloaded. It is recommended Windows users install ImageJ in any folder except the default Program Files folder to avoid this folder's built-in protection protocols that prevent the user from updating ImageJ.

To save class time and download time, the 26 images needed for analysis have already been downloaded with size and position pre-adjusted for student use. These are 8-bit grayscale images of infrared data. The grayscale has 256 shades of gray numbered 0 (black) to 255 (white) where brighter pixels represent warmer temperatures. The images have been stacked into a single file for use with ImageJ. Please download the file **SST_199012-201512.tif** from the Resources page, place it in a new folder called **SSTData**, and copy the folder to each student group's computer.

ImageJ outputs measurement results in a comma delimited text file and adds the extension CSV to the file name to facilitate importing the file to Excel. The Graphing Measurement Results tutorial is based on Excel 2016. The teacher is free to adapt the tutorial for use with different Excel versions or other graphing programs.

Once the graph has been produced, each learner will need his/her own hard copy. If printing from the computers for the entire class is a problem, it is suggested the teacher download the file **Graph-Monthly_Mean_SST_199012-201512.pdf** from the Resources page and print a class set to be distributed to learners as each group shows its completed graph on the computer screen.

Background

Most of the following is freely adapted from information provided by NOAA's Pacific Marine Environment Laboratory. Please visit <https://www.pmel.noaa.gov/el-nino/what-is-el-nino>

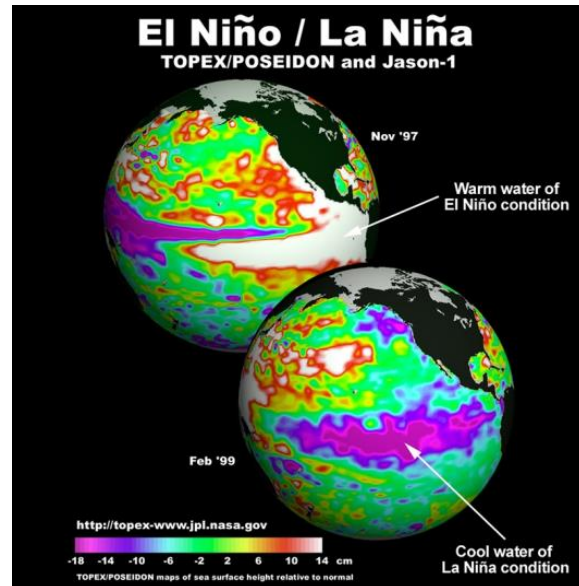
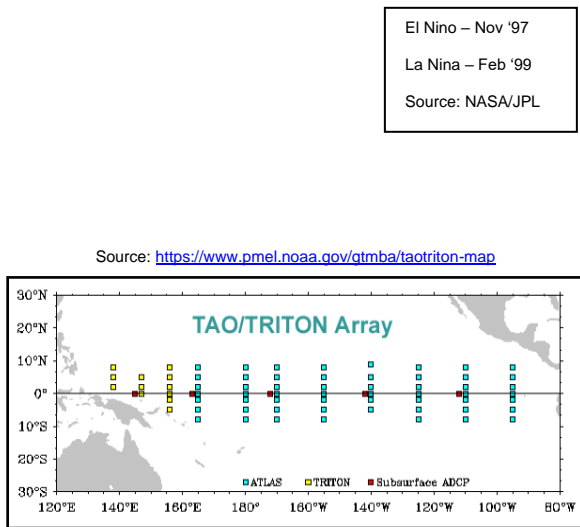
Years ago, fishermen off the coast of South America, especially Ecuador and Peru, noticed that periodically the ocean water was unusually warm and commercially viable fish were harder to find. The phenomenon seemed to start in December. The fishermen referred to it as El Niño, Spanish for "The Little Child" or the Christ child. Later investigations revealed an interesting cycle of sea surface temperature changes and ocean-atmosphere interactions now called the El Niño-Southern Oscillation or ENSO.

El Niño is characterized by unusually warm ocean temperatures in the Eastern Equatorial Pacific Ocean, as opposed to La Niña which is characterized by unusually cold ocean temperatures in the Eastern Equatorial Pacific. El Niño is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the world.

Among these consequences is increased rainfall across the southern tier of the U.S. and in Peru, which has caused destructive flooding, and drought in the Western Pacific, sometimes associated with devastating brush fires in Australia. Observations of conditions in the tropical Pacific are considered essential for the prediction of short term (a few months to 1 year) climate variations.

Teaching Notes

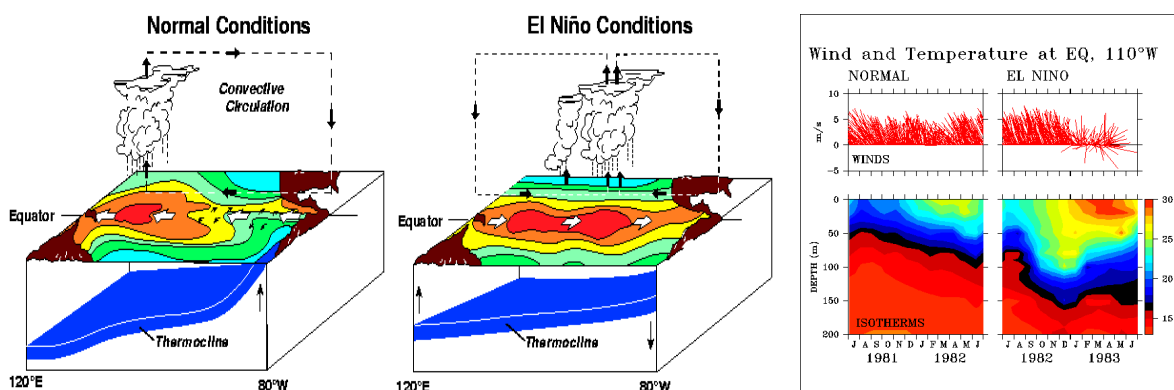
To provide data necessary for studying the ENSO cycles, NOAA operates the TAO/TRITON array of moored buoys that measure temperature, currents and winds in the equatorial band. These buoys daily transmit data that are available to researchers and forecasters around the world in real time. The water temperature measurements are made at the surface and at regular intervals to a depth of 500m. The advantages of moored buoys are accuracy at a fixed point and multiple simultaneous measurements surface to depth.



Sea surface temperature is also measured by remote sensors on several environmental satellites and has been for more than thirty years. The advantage of satellite-based remote sensors is the continuous coverage over broader, global areas – the big picture versus the precise point data of buoys. Both methods help determine trends over time.

The El Niño events in 1982-1983 and in 1997-1998 were the strongest of the twentieth century. Let's look more closely at these two events.

In normal, non-El Niño conditions (left diagram below), the trade winds blow towards the west across the tropical Pacific. The winds pile up warm surface water in the Western Pacific to a sea surface height about 1/2 meter more at Indonesia than at Ecuador.

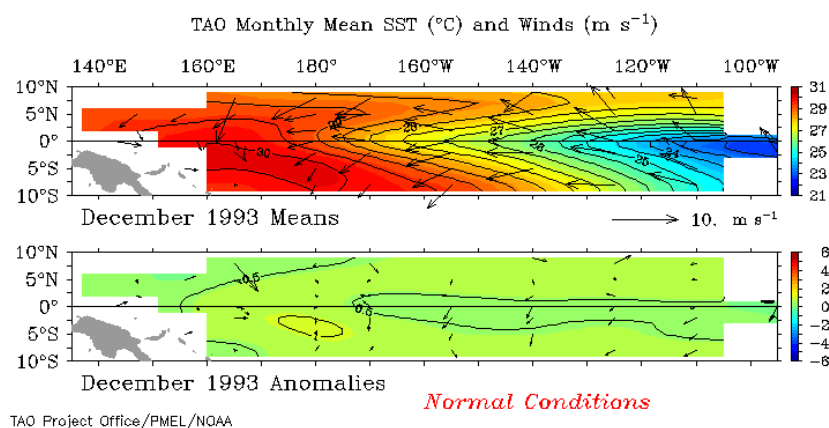


The sea surface temperature is about 8°C higher in the west, with cool temperatures off

South America, due to an upwelling of cold water from deeper levels. This cold water is nutrient-rich, supporting high levels of primary productivity, diverse marine ecosystems, and major fisheries. Rainfall is found in rising air over the warmest water, and the Eastern Pacific is relatively dry. The observations at 110° W (right diagram above) show that the cool water (roughly, 17°C or less - the black band in these plots) is within 50m of the surface.

During El Niño events (center diagram above), the trade winds relax in the Central and Western Pacific leading to a depression of the thermocline in the Eastern Pacific, and an elevation of the thermocline in the west. The observations at 110° W show, for example, that during **1982-1983**, the 17° isotherm dropped to about 150m depth. This reduced the efficiency of upwelling to cool the surface and cut off the supply of nutrient rich thermocline water to the euphotic zone. The result was a rise in sea surface temperature and a drastic decline in primary productivity, the latter of which adversely affected higher trophic levels of the food chain, including commercial fisheries in this region. The weakening of easterly trade winds during El Niño is evident in this figure as well. Rainfall follows the warm water eastward, with associated flooding in Peru and drought in Indonesia and Australia. The eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific.

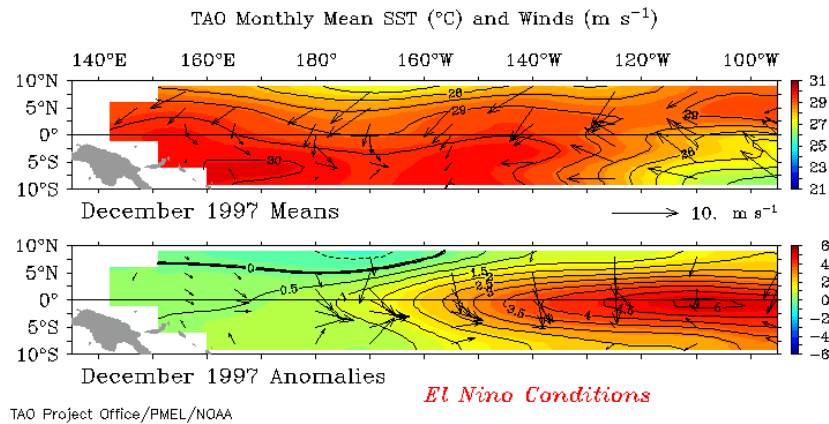
In **December 1993**, the sea surface temperatures and the winds were near normal, with warm water in the Western Pacific Ocean (in red on the top panel of December 1993 plot below), and cool water, called the "*cold tongue*" in the Eastern Pacific Ocean (in green on the top panel of the December 1993 plot below). The winds in the Western Pacific are very weak (see the arrows pointing in the direction the wind is blowing towards), and the winds in the Eastern Pacific are blowing towards the west (towards Indonesia). The bottom panel of the December 1993 plot shows anomalies, the way the sea surface temperature and wind differ from a normal December. In this plot, the anomalies are very small (yellow/green), indicating a normal December.



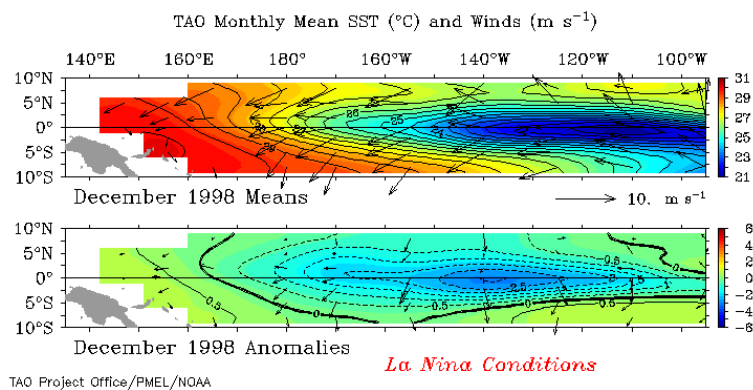
December 1997 was near the peak of a strong El Niño year. In December 1997, the warm water (red in the top panel of the December 1997 plot below) has spread from the Western Pacific Ocean towards the east (in the direction of South America), the cold tongue (green color in the top panel of the December 1997 plot below) has weakened,

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and the winds in the Western Pacific, usually weak, are blowing strongly towards the east, pushing the warm water eastward. The anomalies show clearly that the water in the center of Pacific Ocean is much warmer (red) than in a normal December.

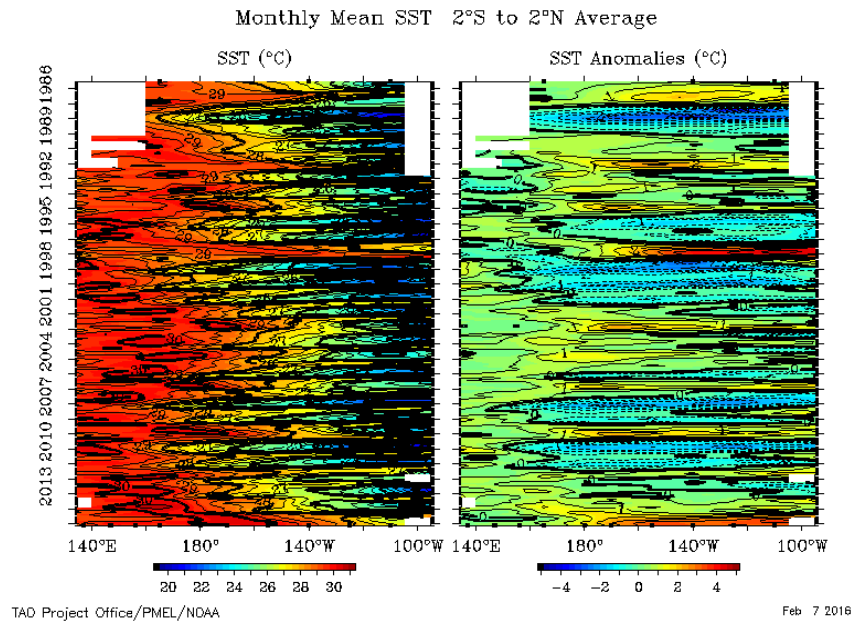


December 1998 was a strong La Niña (cold) event. The cold tongue (blue in the December 1998 image below) is cooler than usual by about 3°C . The Eastern Pacific is cooler than usual, and the cool water extends farther westward than is usual (see the blue color extending further to the left). Compare the December 1998 panel below to the December 1997 panel above. Strong El Niño conditions in December 1997 are shown in the panels above, with warm water (red) extending all along the equator. El Niño and La Niña are opposite phases of the **El Niño-Southern Oscillation** (ENSO) cycle, with La Niña sometimes referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. The cold La Niña events sometimes (but not always) follow El Niño events.

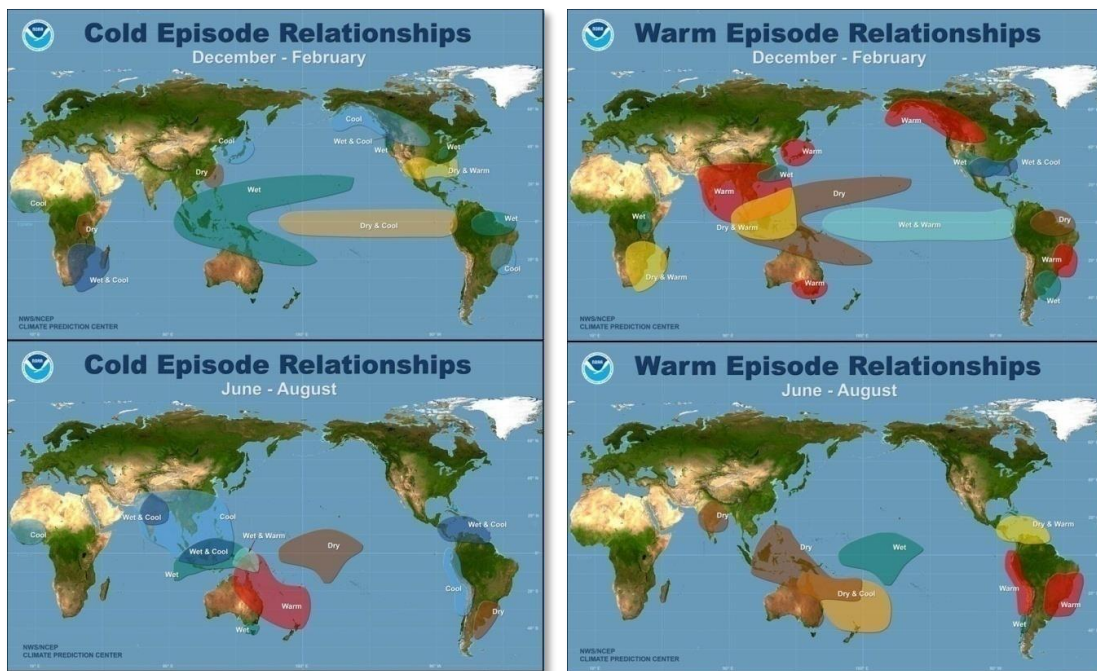


Although the cyclic nature of the relationship between the two opposites becomes apparent over time, different La Niña and El Niño events vary in strength. Below are two plots of monthly mean sea surface temperature within two degrees of the equator in the Eastern Pacific Ocean. In the left-hand panel, you see the sea surface temperature at the Equator (Indonesia is towards the left, South America is towards the right). Time is increasing downwards from 1986 at the top of the plot to 2015 at the bottom of the plot. The first thing to note is the blue "scallop" on the right side of the plot, in the Eastern Pacific. These indicate the cold tongue, the cool water typically observed in the Eastern Pacific. Cold tongue temperatures vary seasonally, being warmest in the northern hemisphere springtime and coolest in the northern hemisphere fall. The red color on the left is the warm pool of water typically observed in the Western Pacific Ocean. El Niño

is an exaggeration of the usual seasonal cycle.



During the El Niño in 1986-1987, you can see the warm water (red) penetrating eastward in the spring of 1987. There is another El Niño in 1991-1992, and you can see the warm water penetrating towards the east in the northern hemisphere spring of 1992. The El Niño in 1997-1998 is a very strong event. El Niño years are easier to see in the anomalies on the right-hand panel. The anomalies show how much the sea surface temperature is different from the usual value for each month. Water temperatures significantly warmer than the norm are shown in red, and water temperatures cooler than the norm are shown in blue.



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In the U.S., winter temperatures are warmer than normal in the Southeast and cooler than normal in the Northwest during La Niña years. The impacts of La Niña events on global climate tend to be opposite those of El Niño impacts. In the tropics, ocean temperature variations in La Niña tend to be opposite those of El Niño.

At higher latitudes, El Niño and La Niña are among a number of factors that influence climate. However, the impacts of El Niño and La Niña events on these latitudes are most clearly seen in wintertime. In the continental US, during El Niño years, temperatures in the winter are warmer than normal in the North Central States, and cooler than normal in the Southeast and the Southwest. During a La Niña year, winter temperatures are warmer than normal in the Southeast and cooler than normal in the Northwest.

Impacts and global effects will be explored more fully in the second lesson of the set. However, if desired now, data comparing precipitation with El Niño and La Niña events are available from the Climate Prediction Center:

https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

Side-by-side animations of the same comparison can be found at this address:

<https://earthobservatory.nasa.gov/world-of-change/enso.php>

Acknowledgements

This lesson plan draws heavily remote sensing data and image resources from NOAA and NASA as listed in the Resources section below.

The 5E Inquiry strategy was first described by Rodger Bybee for BSCS. The modification used here was suggested in a workshop by Dean Gilbert when he was Science Consultant for the Los Angeles County Office of Education.

The image stack used for analysis was prepared by the author using NOAA View imagery and processed with ImageJ. The ImageJ analysis results using this stack agree with the temperatures displayed on screen in NOAA View.

The ImageJ techniques in this lesson were freely adapted from “Images for Science, Importing Scientific Data into ImageJ” appearing in *Discover Image Processing*, © 2006 by the Center for Image Processing in Education.

These Teaching Notes and the Student Activity pages for this lesson plan were developed by Richelle Brooks and J.P. Arvedson for the non-profit Satellite Educators Association as part of *More Lessons from the Sky*, a regular feature of the SEA Newsletter on-line. *More Lessons from the Sky* has its roots in an original collection of more than fifty lessons compiled by Satellite Educators Association, Inc. and published in *Lessons from the Sky*, © 1995 by Amereon, Ltd. The SEA Newsletter is published online and is available without charge. More information about the Satellite Educators Association, its annual Satellites & Education Conference for teachers, international student environmental research collaborative, and online access to the SEA Newsletter can be found at <https://SatEd.org>.

All *More Lessons from the Sky* lesson plans are archived in the on-line SEA Lesson Plan Library available at <https://SatEd.org>. The web site features a description of the library

contents, Next Generation Science Standards addressed, several search tools for finding lessons easily, separate resource files for lessons where needed, and the library's Analysis Toolbox.

When duplicating or otherwise using any portion of this lesson or its associated materials, full credit to all contributors to the lesson and its associated materials must be included.

Resources

Note: All of these URLs were current and active as of this writing. If any are unreachable as printed, the use of on-line search engines such as DuckDuckGo, Google, or Bing is suggested to find current links.

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Answers to Questions – SST Answer Sheet

1. Make a note of the date and temperature at this location.

- In December 1997, the mean temperature was 28.4°C (83.1°F).
2. Again, make a note of the date and temperature.
In December 1998, the mean temperature was 21.4°C (70.5°F).
 3. In this region of interest, which date had higher temperature water? Which date showed the lowest temperature?
The temperature was highest in December 1997 and lowest in December 1998.
 4. How do these answers relate to the information you discovered in your earlier discussion?
The unusually warm temperature in December 1997 may indicate an El Niño event whereas the unusually cool temperature in December 1998 may be a La Niña event.
 5. What is the image scale expressed in pixels/degree?
The scale is 2.844 pixels/degree.
 6. What are the lowest and highest temperatures found in the image?
The temperature range in the image is -2°C to 32°C.
 7. Complete this table on your answer sheet.
The pixel counts in the right column are (top to bottom) 23, 11, 751, and 247.
 8. From the graph you generated using Excel, in which years were El Niño conditions found?
From the graph, strong El Niño conditions were found in December of 1997 and 2015. Weak El Niño conditions were evidenced in 1994, 2002-2003, 2006, and 2009.
 9. How is El Niño characterized??
El Niño is characterized by unusually warm ocean temperatures in the Eastern Equatorial Pacific. The easterly trade winds normally pushing warm water westward weaken. The thermocline is depressed in the east resulting in reduced cold water upwelling along the coast of South America cutting off the nutrient-rich materials from lower depths that support the fish closer to the surface.
 10. What are some consequences of unusually warm ocean temperatures in the Eastern Equatorial Pacific?
Consequences include increased rainfall across the southern United States and Peru, and drought in the West Pacific.
 11. How can El Niño be recognized?
El Niño can be recognized by unusually warm sea surface temperature in the Eastern Equatorial Pacific Ocean.
 12. What is the “cold tongue?”
The term “cold tongue” designates the normal or unusual cool water in the Eastern Pacific extending westward from Ecuador along the Equator.
 13. How is La Niña different from El Niño?
Whereas an El Niño event is characterized by unusually warm water in the Eastern Equatorial Pacific, La Niña events are characterized by unusually cool water in the same area. Essentially, a La Niña event is the opposite of an El Niño event.
 14. What does the red color represent in the “**El Niño**” 3-D Diagrams images?

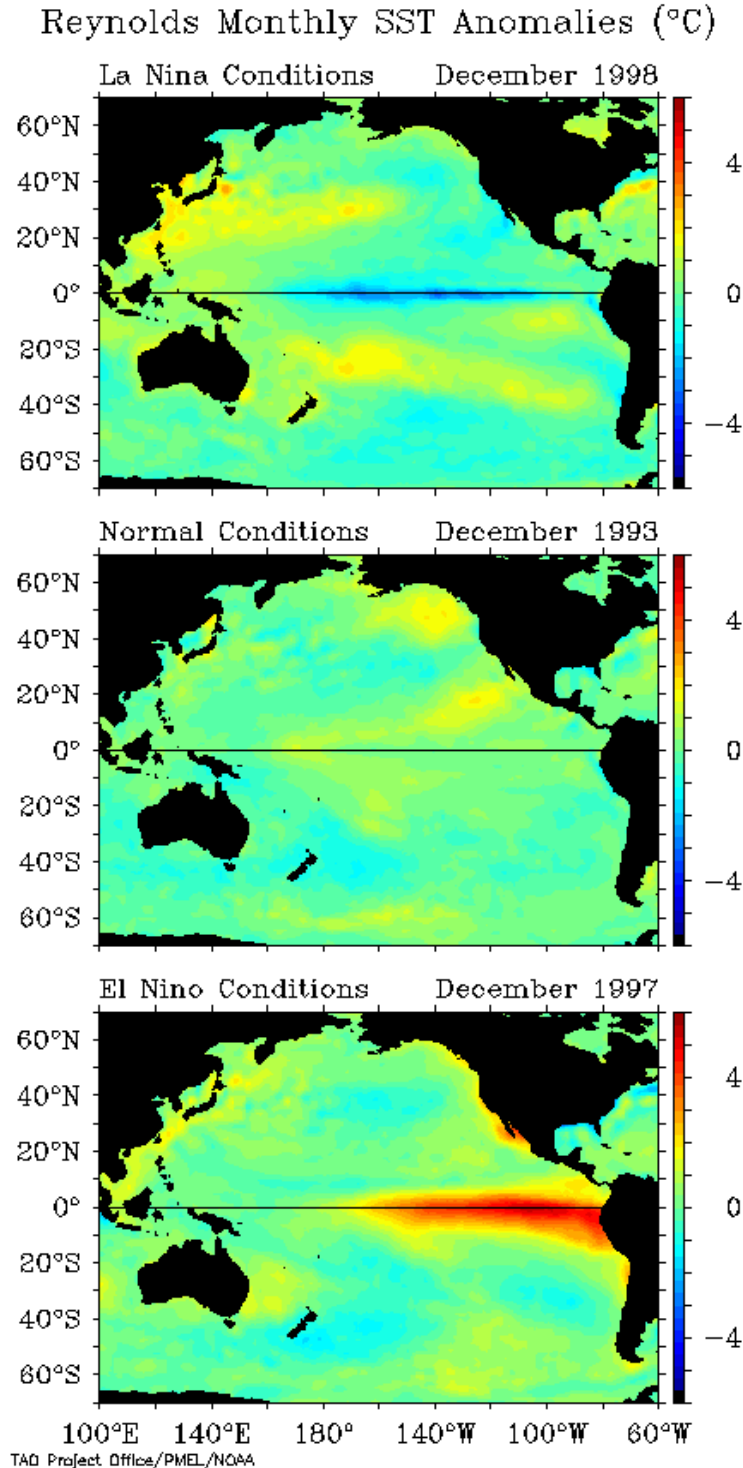
Teaching Notes

Red is used here to indicate water temperatures much warmer than normal. NOTE: These are false colors added during image processing to enhance certain features and make them easier to see.

15. Why do El Niño and La Niña vary in strength?
Answers will vary. El Niño-Southern Oscillation events are part of the larger Pacific Decadal Oscillation, and both are related to and affected by numerous other large scale weather systems that make up global weather. It may be difficult for students to make connections on that scale at this time.
16. What is an anomaly?
An anomaly is a departure from the normal, regular pattern.
17. What does the green color indicate in the **Sea Surface Temperature Anomalies** plots you examined at the beginning of this lesson?
The green color is used here to indicate normal temperature or a 0° departure from the norm. NOTE: These are false colors added during image processing to enhance certain features and make them easier to see.
18. What is the origin of the name El Niño?
El Niño means “The Little Boy,” specifically, the Christ child, in Spanish. Periodically, fishermen off the coast of South America noticed that unusually warm waters appeared in the Pacific Ocean resulting in a marked reduction of the normal commercial fishing catches. The phenomenon seemed to arrive around Christmas, thus the name El Niño.
19. Does your graph have any high spikes? If so, how many? At what years?
There are two high spikes: 1997 and 2015.
20. What do the high spikes represent?
The high spikes represent El Niño events.
21. What explanation can you offer to account for the high spikes?
El Niño events are characterized by unusually warm sea surface temperatures as indicated by the high spikes.
22. Describe and explain what happens on the graph in the year following each high spike?
In 1998 the temperature was significantly cooler – a La Niña condition, but not a strong event.
23. What can be expected on the graph in December 2016?
Answers will vary. It is likely the mean sea surface temperature will drop in December 2016 – a possible La Niña event.
24. What evidence do you have to support your answer to Question 21?
Answers will vary. Normal and La Niña conditions occur more frequently in the Eastern Equatorial Pacific than El Niño conditions. December 2015 seems to be a strong El Niño event. It is not likely that the El Niño conditions will be sustained for more than a year.
25. Is every El Niño event followed by a La Niña event?
No.

Sea Surface Temperature Anomalies

These maps show anomalies in sea surface temperature – that is, the difference between the measured temperature and the “normal” temperature. For example, blue indicates an anomaly of -5°C to -4°C ($4^{\circ}\text{--}5^{\circ}$ colder than normal) while red indicates an anomaly of $+4^{\circ}\text{C}$ to $+5^{\circ}\text{C}$ ($4^{\circ}\text{--}5^{\circ}$ warmer than normal).



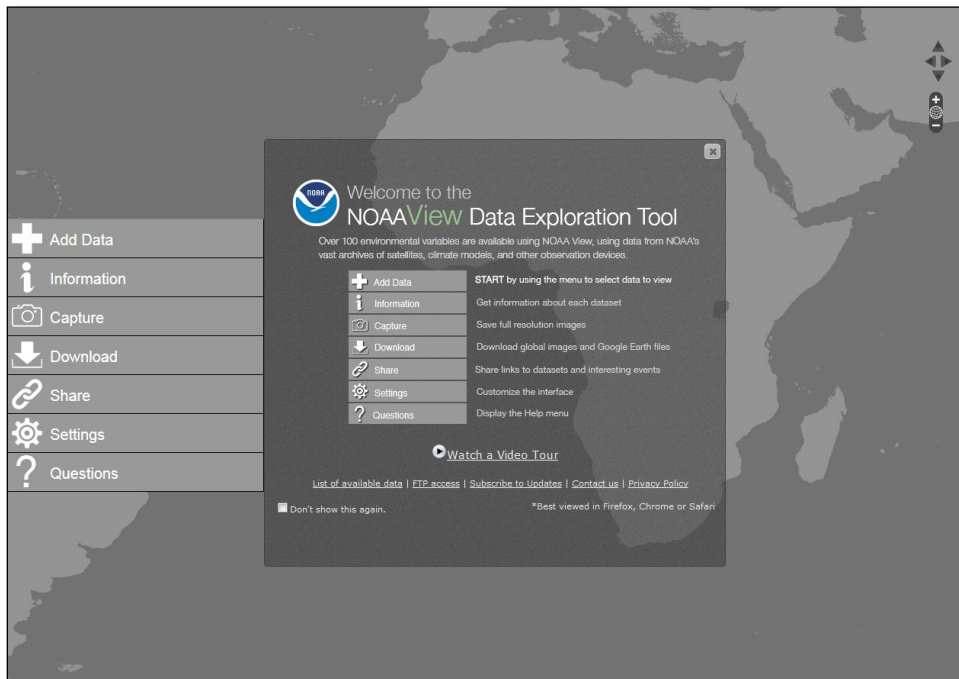
Source: <https://www.pmel.noaa.gov/elnino/anomalies>


Using NOAA View

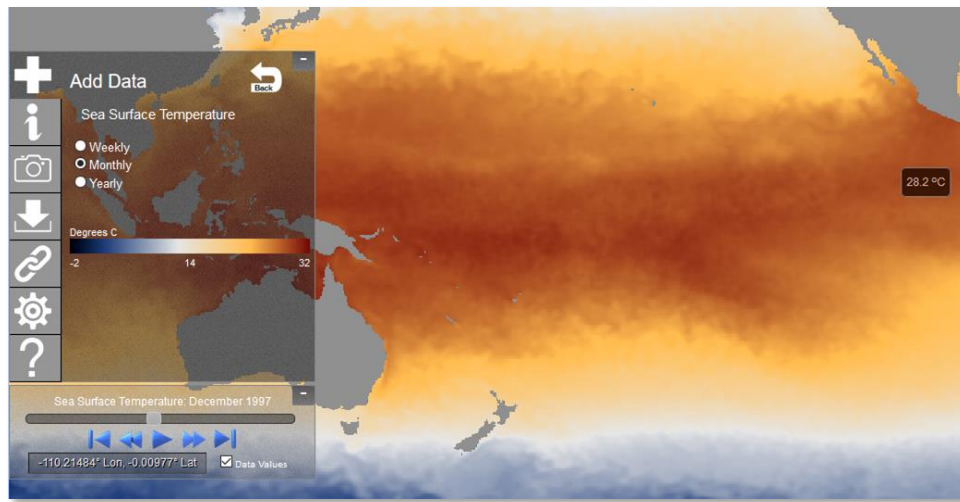
Accessing and Visualizing Sea Surface Temperature Data



Your goal is to determine how the temperature of the ocean surface, in a specific area, changes over time. First, you must have data to work with. This interactive tutorial will guide you through the acquisition of relevant sea surface temperature data measured by remote sensors on several environmental satellites over a quarter century. NOAA View is one of many online tools that can help you find and visualize digital sea surface temperature data with ease.

- 🖥️ **Ensure your computer is Internet enabled.**
- 🖥️ **Launch your browser. Point the browser to NOAA View's front page at this address:**
<https://www.nvpl.noaa.gov/view/globaldata.html>.




- 🖥️ **Find the Menu panel on the left. Click the Add Data button . In the Add Data menu, click Ocean, then Temperature, and At the Surface.**
- 🖥️ **Click the radio button for Monthly.**
- 🖥️ **Move the cursor to the center of the displayed map, click and hold, and drag the map to the right until the Pacific Ocean is centered in the display.**
- 🖥️ **You can change the monthly image by using the animation controls found below the Menu panel. Move the slider until image data for December 1997 is displayed. Wait for the display to update.**



-  **Turn on Data Values by checking the checkbox below the slider.**
-  **Move the cursor to a position on the displayed map that is as close to -110° longitude and 0° latitude as you can. The cursor now points to a pixel representing the temperature shown in the small box next to the cursor.**

Record important information on your SST Answer Sheet by answering the questions as you come to them in the tutorial. Use the questions and your answers to guide your thinking and check your progress.

1. *Make a note of the date and temperature at this location.*
-  **Move the slider right until the December 1998 image is displayed. Move the cursor back to the same longitude and latitude as before.**
2. *Again, make a note of the date and temperature.*
3. *In this region of interest, which date had higher temperature water? Which date showed the lowest temperature?*
4. *How do these answers relate to the information you discovered in your group discussions?*

Monitoring sea surface temperature change in the Equatorial Pacific Ocean can help us detect unusually warm or cool conditions. A good month for year-to-year comparison is December. To save time, an image data set has been prepared for you using NOAA View. Now, continue with the next tutorial.

-  **Close your browser.**

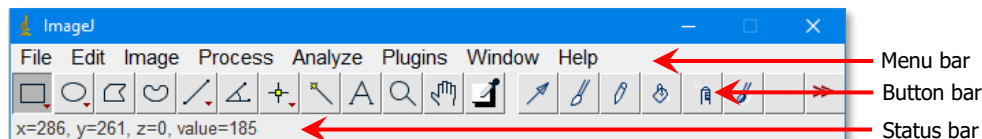
Using ImageJ

Analyzing Sea Surface Temperature Data

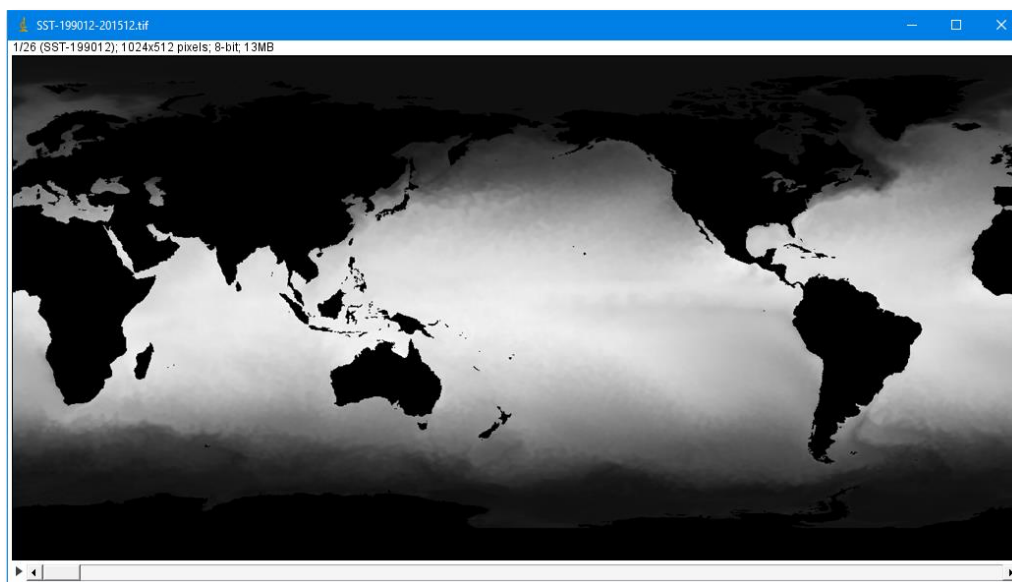
ImageJ is powerful image processing software developed at the National Institute of Health for medical image analysis and research. ImageJ has special features valuable for analyzing geographically gridded data – that is, image data that includes latitude and longitude in addition to temperature for every pixel that has been arranged on a gridded map. You will use several of these features here to analyze sea surface temperature changes.

- 📁 **Ensure your computer has ImageJ installed. Follow your teacher’s directions to find your SSTData folder. Store all files for this lesson in your SSTData folder.**
- 📁 **Launch ImageJ.**

The ImageJ control window is displayed.



- 📁 **On the ImageJ menu bar, click File, select Open, navigate to your SSTData folder and open the file SST_199012-201512.tif.**



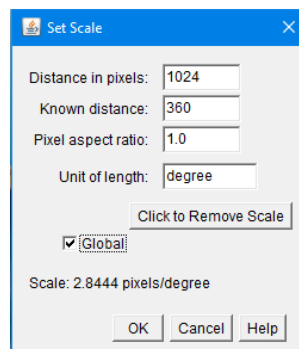
This file is a stack of 26 images. You can change to the next slice or image in the stack by using the less-than (<) and more-than (>) keys (without the shift key): > to move forward one frame and < to move back one frame. You can automate the sequence by


pressing the back-slash (\) key to start and pressing it again to stop. The 26 images show average sea surface temperatures for December of each year from 1990 to 2015. All satellite-based remote sensors send their information to receiving stations on Earth in digital data streams. Specialized software is used to interpret the data stream and convert it to an image representing what the remote sensor "saw." Each picture element or pixel is independently registered by the remote sensor and recreated from the data stream in the digital image seen on the computer monitor. During image processing, you, the user, can manipulate the appearance of the pixels on the screen to clarify selected portions of the image and the features they represent.

The pixels are arranged in an array of columns and rows to duplicate what the remote sensor "saw." Each pixel has a location designation in the image similar to the row and seat number of each reserved seat in a sports stadium or theater. If one thinks of the image as a grid of X,Y coordinates, the column number is designated by the X coordinate and Y indicates the row number with the origin (0,0) in the upper left corner. The width of the image is the number of X pixels; the height is the number of Y pixels.

Setting Scale

 On the ImageJ menu bar, click Analyze and select Set Scale.



 In the Set Scale window, the Distance in pixels is the width of the image. (See the Information bar at the top of the image for image dimensions expressed as width X height.) The Known distance is 360 degrees ("around" the world), and the Unit of length is degree. Check Global so it applies to all images in the stack. Note the scale. Click OK.


5. What is the image scale expressed in pixels/degree?

Now, when you see the Status bar, the X and Y values are expressed in degrees of longitude (X) and latitude (Y) instead of pixel position. The width of the image is now 360 degrees of longitude with 0° on the left edge of the image. The height is now 180° of latitude. Unfortunately, ImageJ counts the Y-pixels from the top to the bottom of the image. So, at the top edge of the image Y=0° in the Status bar instead of 90° north, the equator is Y=90° instead of 0°, and the bottom edge is Y=180° instead of 90° south. You must keep that in mind when attempting to locate particular latitudes. A little simple logic and arithmetic can help identify the correct latitude on the screen.

Calibrating Pixel Value to Temperature

Notice the information bar at the top of the image window. This is an “8-bit” image meaning each pixel can have 2^8 or 256 pixel values shown (numbered 0 to 255).

In the ImageJ control window, the Status bar displays pixel **value** or pixel brightness as well as pixel location (**X** and **Y**). A pixel value of 0 is black in the image while a pixel value of 255 is white. The 254 values between 0 and 255 are shades of gray. These sea surface temperature images do not display the visible light the eye can see but rather infrared energy that indicates temperature. The lowest temperature in the image has a pixel value of 0, and the highest temperature a pixel value of 255.


 **Leave the ImageJ windows open. Your teacher will provide a text file of metadata (information about the image data) for this sea surface temperature image. With your browser or a text editor, open the file About_SURF.txt.**

 **Scan through the text file and note the temperature range indicated for this image.**

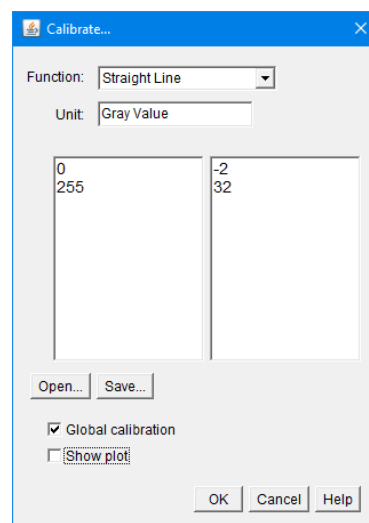
6. *What are the lowest and highest temperatures found in the image?*

 **Close your browser (or text file). On the ImageJ Menu bar, click Analyze and select Calibrate.**

 **The simplest calibration uses the formula for a straight line ($y=mx+b$). Set Straight Line in the Function field; type degrees Celsius in the Unit field.**

 **In the left column, type the range of pixel values in the image (0 and 255), one number per line. In the right column type the temperatures that correspond to the pixel values of 0 and 255 (-2 and 32 degrees, respectively). Be sure to check Global calibration so it will apply to all slices in the stack. Click OK.**

 **If the plot window opens, close it.**



As you move the cursor around the image, notice the pixel value in the Status bar is now shown in parentheses and is preceded by the Celsius temperature represented by that pixel value.

Selecting an Area to Measure

Rather than measuring the temperature of the entire Pacific Ocean, we will select a representative area – a “region of interest” (roi). As you scan through the slices in the stack, look for a small area in the Eastern Equatorial Pacific that seems to demonstrate unusually warm and unusually cool temperatures. Start with an area 8° wide by 4° located just north of the Galapagos Islands. The upper left corner of this roi is -96° longitude (west) and 3° latitude (north). Remembering the way ImageJ counts degrees

on the map, that translates to a pixel location of X=264 and Y=87. Once the region has been selected in ImageJ, it will be applied automatically to all slices in the stack. After observing all the images in the stack, it seems like an area just north of the Galapagos Islands might be a good place to start.



To select this region, you need to know the coordinates of the upper left corner and the height and width of the study area. These coordinates are given in degrees (as shown in the Status bar) in the following table.

Selection	Degrees (from upper left)	Pixels (degrees x scale)
Width	8	8 x 2.844 =
Height	4	
Upper Left X	264	
Upper Left Y	87	

7. Complete this table on your answer sheet.



-  **Convert each of the values in the table by multiplying by the scale (from Question 5 above). Round each value to the nearest whole number.**

You could use the Rectangular Selection tool  to select this area, but there is an easier way to make the selection.

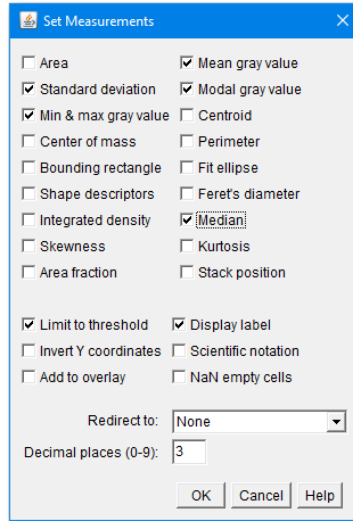
-  **Click Edit, then Selection and select Specify. Then enter the pixel values you calculated in the table to define the study area.**
-  **It's a good idea to save the selection outline in case you accidentally change or delete it. Click File and Save as, and select Selection. Navigate to your SSTData folder and save the selection boundary with this file name: SST_199012-201512.roi. You can restore this exact selection outline at any time by opening this saved file.**

Setting Measurement Options

The first step in the analysis process is to select the measurement options you want to use. You are mostly interested in the mean temperature within the selected area. In discussion with your teacher, you may find that making a few other statistical measurements might be useful.

-  **Click Analyze and select Set Measurements.**
-  **Clear all checkboxes; then re-check Mean Gray Value and Limit to threshold. Check any others measurements your teacher recommends. Click OK.**

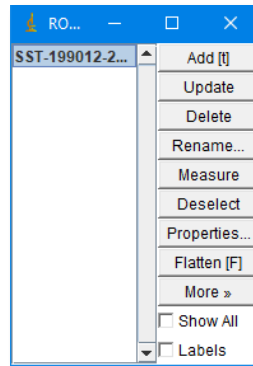
Student Activity



Measuring

Now you are ready to measure the SST data within the study area. Since the images are in a stack, ImageJ makes it easy to measure all the slices of the stack.

 **Click Analyze, then Tools, and select ROI Manager.**



 **Click the More button and select Open. Navigate to SST_199012-201512.roi in the SSTData folder. Click Open.**

 **Click the SST_199012-201512.roi file name in the ROI Manager to highlight it.**

 **Click the More button and select Multi Measure. In the Multi Measure pop-up, check only Measure all 26 slices and One row per slice. Click OK.**

ImageJ has just calculated the mean temperature in the region of interest (roi) on each slice or image in the stack and listed the results in a Results window.

Mean(SST-199012-201512)	StdDev(SST-199012-
25.115	0.911
25.115	0.911
25.115	0.911
25.045	1.057
25.744	0.668
24.437	1.229
23.925	1.327

- 📁 In the Results window, click File and select Save As. Navigate to your SSTData folder. Accept the default file name, Results.csv, and click Save.
- 📁 Close the Results window. Close the ROI Manager.
- 📁 Click Edit, then Selection, and select Select None to clear the roi selection in the image.

The measurements you just made have been stored in a file called Results.csv. This file can be easily imported into an Excel spreadsheet and graphed using Excel or other appropriate graphing program. Your teacher will give you more directions for graphing.

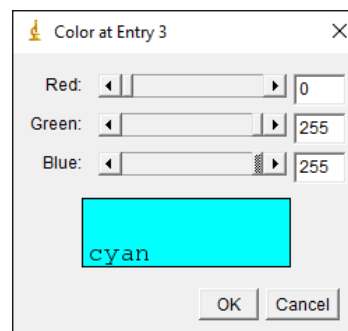
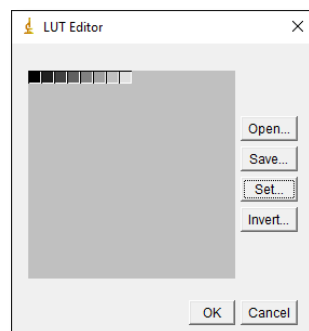
The next step, then, is to graph the results. But, before you do...

Adding Color to a Grayscale Image

It is difficult to visually pick out temperature differences from the shades of gray. Would the temperature differences be easier to see if you could substitute contrasting colors for the gray tones? In ImageJ, custom color palettes can be created by assigning various colors to numerical pixel values. This information is then stored in the image's "lookup table" and appears in the image.

This is not a necessary part of the analysis process, but you may wish to apply a color lookup table (LUT) or color palette to give the images more visual impact for publishing or displays.

- 📁 Click Image on the Menu bar, then Color and select Edit LUT to display the current grayscale lookup table.

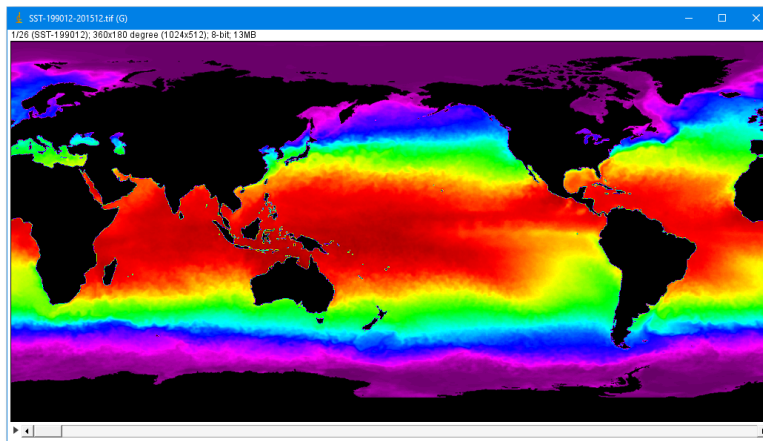


Student Activity

- Click the **Set** button. Change **Number of Colors** to **8** and click **OK**. The lookup table now consists of **8** color entries numbered **left to right, 0 through 7**.
- Click each color entry to edit its color. Use the following table of **red, green, and blue** values to set the color for each entry.

Entry	0	1	2	3	4	5	6	7
Red	0	255	0	0	0	255	255	128
Green	0	0	0	255	255	255	0	0
Blue	0	255	255	255	0	0	0	0

- After setting all eight color entries, click **Set** again, and change the **Number of Colors** back to **256**.
- To save the custom color palette, click the **Save** button in the **LUT Editor**, navigate to your **SSTData** folder, and name the file **SST.lut**.
- Click **OK** to close the **LUT Editor**.



- To apply this color table later, Click **File** on the **ImageJ** Menu bar, select **Open**, and open **SST.lut**.

You have done a great job so far. There is just a little more to do.

At this point, follow your teacher's directions to graph your measurement results for interpretation.

Graphing Measurement Results


Analyzing Results from ImageJ

The Results file you saved can be opened and graphed in many graphing programs including spreadsheets like Excel.

 **Launch Excel.**

 **Click File and select Open. Navigate to your SSTData folder and open the Results.csv that was created by ImageJ.**

Depending on the version of Excel you are using, the program may ask you a question or two about converting the file. Your teacher can help you here.

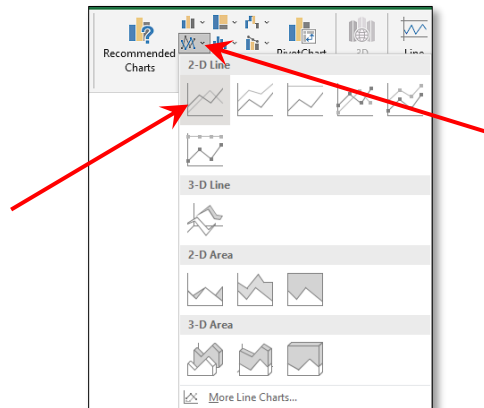
 **Once the data are shown in the spreadsheet, type Year in the top cell of the next blank column to the right. Press the down-arrow key and type 1990. Continue using the down-arrow key to type consecutive years until you reach 2015 for the bottom row of the data.**

	A	B	C	D	E	F	G	H
1		Mean	StdDev	Mode	Min	Max	Median	Year
2	1	25.657	0.929	26.696	23.024	26.968	25.744	1990
3	2	25.657	0.929	26.696	23.024	26.968	25.744	1991
4	3	25.657	0.929	26.696	23.024	26.968	25.744	1992
5	4	25.586	1.078	26.56	22.888	27.24	25.744	1993
6	5	26.299	0.681	26.696	24.792	27.376	26.424	1994
7	6	24.966	1.253	26.288	21.936	26.696	25.336	1995
8	7	24.444	1.353	25.88	21.528	26.288	24.656	1996
9	8	28.681	0.26	28.6	28.056	29.824	28.6	1997
10	9	25.598	1.329	26.696	22.072	27.104	26.016	1998
11	10	25.025	1.212	25.88	21.528	26.56	25.472	1999
12	11	25.096	1.353	26.56	22.072	26.832	25.336	2000
13	12	25.504	0.923	26.016	22.752	26.832	25.88	2001
14	13	26.728	0.489	26.696	25.608	27.648	26.832	2002
15	14	26.783	0.768	27.24	24.52	27.648	27.104	2003

	A	B	C	D	E	F	G	H
1		Mean	StdDev	Mode	Min	Max	Median	Year
2	1	25.657	0.929	26.696	23.024	26.968	25.744	1990
3	2	25.657	0.929	26.696	23.024	26.968	25.744	1991
4	3	25.657	0.929	26.696	23.024	26.968	25.744	1992
5	4	25.586	1.078	26.56	22.888	27.24	25.744	1993
6	5	26.299	0.681	26.696	24.792	27.376	26.424	1994
7	6	24.966	1.253	26.288	21.936	26.696	25.336	1995
8	7	24.444	1.353	25.88	21.528	26.288	24.656	1996
9	8	28.681	0.26	28.6	28.056	29.824	28.6	1997
10	9	25.598	1.329	26.696	22.072	27.104	26.016	1998
11	10	25.025	1.212	25.88	21.528	26.56	25.472	1999
12	11	25.096	1.353	26.56	22.072	26.832	25.336	2000
13	12	25.504	0.923	26.016	22.752	26.832	25.88	2001
14	13	26.728	0.489	26.696	25.608	27.648	26.832	2002
15	14	26.783	0.768	27.24	24.52	27.648	27.104	2003

 **Highlight the numbers in the Mean column.**

 **Click the Insert tab in the Excel menu bar. Move across the Excel ribbon to the Charts section. Click the drop-down arrow next to the Line or Area Chart icon and select the first 2-D Line graph format.**



Student Activity

- 📄 **If the ribbon does not automatically change to Chart Design, click once on the chart. In Chart Design, click one of the chart styles to select it.**

Now you will change the X-axis labels to display years.

Right-click the X-axis numbers on the chart. In the pop-up context menu, click Select Data... to display the Select Data Source dialogue. Find the Horizontal Axis Labels section and click Edit. The Axis Labels dialogue replaces the Select Data Source dialogue. Move the cursor to the spreadsheet; click, drag, and highlight the numbers in the Year column. (If you need to move the Axis Labels dialogue or the chart out of the way, just grab the its title bar with the mouse cursor and drag it elsewhere on the screen.) You should now see a data range reference in the Axis Labels dialogue (something like this: =Results!\$K2:\$K27). Click OK and click OK in the Select Data Source dialogue. You should now see years on the graph's X-axis.

Next you will add some titles to your chart.



- 📄 **Click once on the chart to display three square icons to the right of the chart: Green Cross = Chart Elements; Paint Brush = Chart Styles; Funnel = Chart Filters**



- 📄 **Click the Green Cross to open Chart Elements context menu. Ensure Axes, Axis Titles, Chart Title are checked. All others are unchecked. Then move the cursor to the right of Axis Titles and click the expansion arrow. Ensure both Primary Horizontal and Primary Vertical are checked. Click outside the chart to hide these lists.**

- 📄 **Click Axis Title on the horizontal axis. Highlight it and change it to Year. Similarly, change the vertical axis title to Celsius Temperature. Change the Chart Title to Mean SST – Eastern Equatorial Pacific.**

- 📄 **Save the spreadsheet with graph in your SSTData folder using the file name Graph_SST-199012-201512.xlsx.**

- 📄 **STOP here and have your teacher check your graph.**

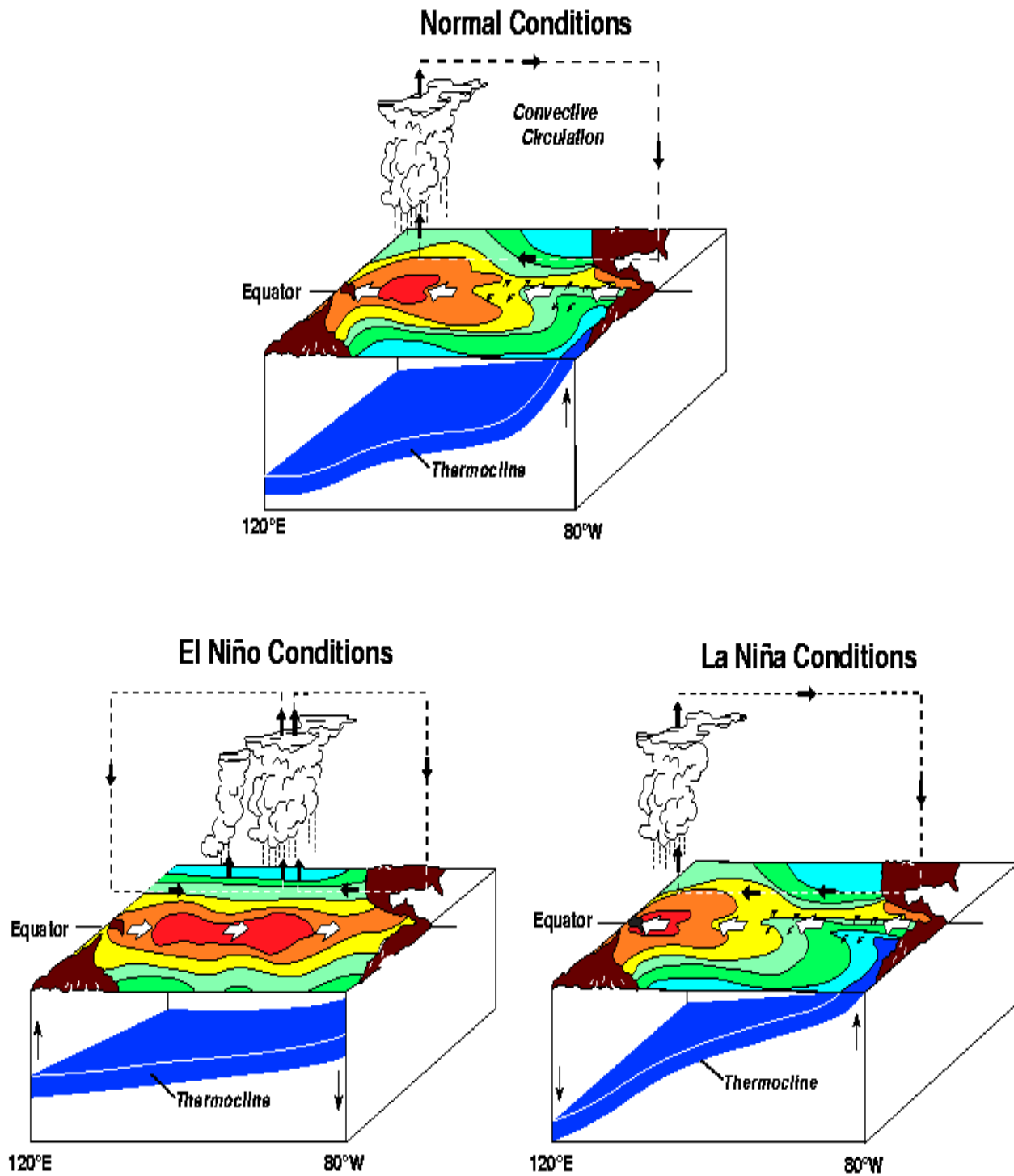
Follow your teacher's directions to obtain a printed a copy of your graph for each member of your group.

8. *From the graph you generated using Excel, in which years were El Niño conditions found?*

If time allows, you may wish to explore resizing your graph or adding color.

- 📄 **Close the spreadsheet and exit Excel.**

“El Niño” 3-D Diagrams



3-D Diagram Summary

	Description What is it?	Illustration How does it look?
Normal		
El Niño		
La Niña		

SST Answer Sheet

Answer Questions 1-4 while using **NOAA View**.

1. Make a note of the date and temperature at this location.
2. Again, make a note of the date and temperature.
3. In this region of interest, which date had higher temperature water? Which date showed the lowest temperature?
4. How do these answers relate to the information you discovered in your earlier group discussion?

Answer Questions 5-7 while using **ImageJ**.

5. What is the image scale expressed in pixels/degree?
6. What are the lowest and highest temperatures found in the image?
7. Complete this table on your answer sheet.

Selection	Degrees (from upper left)	Pixels (degrees x scale)
Width	8	8 x 2.844 =
Height	4	
Upper Left X	264	
Upper Left Y	87	

Answer Question 8 while **Graphing Measurement Results**.

8. From the graph you generated using Excel, in which years were El Niño conditions found?

Answer Questions 8-17 while using **"El Niño" 3-D Diagrams and 3-D Diagram Summary**.

9. How is "El Niño" characterized?
10. What are some consequences of unusually warm ocean temperatures in the Eastern Equatorial Pacific?

Student Activity

11. How can El Niño be recognized?
12. What is the “cold tongue?”
13. How is La Niña different from El Niño?
14. What does the red color represent in the “**El Niño**” **3-D Diagrams** images?
15. Why do El Niño and La Niña events vary in strength?
16. What is an “anomaly”?
17. What does the color green indicate in the **Sea Surface Temperature Anomalies** plots you examined at the beginning of this lesson?
18. What is the origin of the name El Niño?

Answer Questions 18-24 during the **Your Turn** extension activity.

19. Does your graph have any high spikes? If so, how many? At what years?
20. What do the high spikes represent?
21. What explanation can you offer to account for the high spikes?
22. Describe and explain what happens on the graph in the year following each high spike?
23. What can be expected on the graph in December 2016?

24. What evidence do you have to support your answer to Question 21?
25. Is every El Niño event followed by a La Niña event?

Your Turn

Work with your teacher to decide which of these Your Turn activities you should complete...

- ✚ You measured and analyzed sea surface temperature for only a small section of the Eastern Equatorial Pacific Ocean. Select another representative section of the tropical East Pacific and repeat the process. Consider examining an area 8°-10° west to east by 4°-5° north to south centered on longitude -110° and latitude 0° – an important buoy location. Compare and contrast the graphs of Results in both cases. How are they similar? How are they different? Account for both similarities and for any differences? Prepare a poster illustrating your findings.
- ✚ In 2015, high school students in Xiamen, China, noticed a correlation between the frequency and intensity of typhoons (tropical cyclones in the West Pacific) in the South China Sea and the El Niño-Southern Oscillation. Using the same procedure used in this lesson, produce a graph of sea surface temperature changes over the same 26-year time span. Compare and contrast the graphs of Results from this lesson and the South China Sea. How are they similar? How are they different? Account for any similarities and any differences? Prepare a poster illustrating your findings.
- ✚ Explore coastal upwelling. How is the fishing industry affected by upwelling along the coast of Ecuador and Peru? Using the procedure learned in this lesson, produce a graph of the sea surface temperature changes over time in the areas closest to the coastline. Using your research into upwelling, prepare an informative presentation using PowerPoint (or other presentation software) to explain the relationship between upwelling and the fishing industry.
- ✚ The terms El Niño and La Niña tend to focus attention on the Eastern Equatorial Pacific Ocean. How do these conditions affect the sea surface temperature in the West Pacific – either the Sea of Japan in the north or the Great Barrier Reef in the south? Use the skills practiced in this lesson to graph SST changes in that area. Compare the results to the Eastern Equatorial Pacific. Account for similarities and differences. Prepare a short talk for your class stating and explaining your findings.
- ✚ Use the skills practiced in this lesson to graph an area of the North Atlantic Ocean where hurricanes (tropical cyclones in the East Pacific and Atlantic Oceans) are known to form. How do El Niño and La Niña conditions in the Pacific affect the SST in the North Atlantic. Remembering that ocean water must be at least 80°F (26.7°C) to a depth of 50m for a cyclone to form, what conclusion can you reach, if any, about the relationship between El Niño-Southern Oscillation and the warm water conditions needed for hurricane formation in the North Atlantic? Work with your teacher to decide the best format for reporting your results and the evidence to support your conclusion.