Name _____ Date _____
Lab Grade _____/10 Period _____

Lab # _____ - El Niño and La Niña

Introduction:

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 worldwide as a short-term (inter-annual) climate control can lead to major ecological, societal and economic disruptions. Within the ocean, especially in coastal areas, marine organisms from plankton to fishes and seabirds are impacted. Occurrence of El Niño every three 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.

Originally, El Niño was the name given to a short-term, weak seasonal warming of ocean water that ran southward along the coast of Peru and Ecuador around Christmas and resulted in poor fishing. Today, El Niño refers to a large-scale, persistent disturbance of ocean and atmosphere in the tropical Pacific Ocean. A persistent El Niño can be accompanied by major shifts in planetary-scale atmospheric and oceanic circulations and weather extremes worldwide.

El Niño lasts an average of 12-18 months and occurs about once every three to seven years. Ten occupied during a recent 42-year period, with one of the most intense of the 20th century in 1997-1998. Sometimes, but not always, El Niño is followed by La Niña, a period of unusually strong trade winds and vigorous upwelling in the eastern tropical Pacific. During La Niña, changes in SSTs (sea surface temperatures) and extremes in weather are essentially opposite those observed during El Niño. Associated with these changes are major impacts on marine ecosystems.

Objective:

- Describe how El Niño and La Niña change conditions in the tropical Pacific
- Explain how the ocean and atmosphere interact in the tropical Pacific

Materials: ESRT, globe, scissors, tape, Internet access (Part D only), RED and BLUE color pencils

Time: 2 Periods

Part A – The Tropical Pacific During Long-Term Average (Neutral) Conditions

Background Information: Examine the *¡El Niño!-¡La Niña!* slide chart 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 the slide is fully inserted, then pull the slide out, flip it over and reinsert the slider. 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.

1. Locate the large window on the slider. Fair weather appears in the eastern tropical Pacific while (fair, stormy) weather prevails in the western tropical Pacific.

2. Locate the small boxes above the large box. The small boxes give atmospheric conditions. The boxes give information about rainfall, and surface air pressure for the west, central and eastern tropical Pacific. In addition, trade wind information is given for the west and eastern tropical Pacific.

3. Locate the small boxes below the large window. The small boxes give oceanic conditions. Information is given for sea surface temperature (SSTs), sea surface height (SSH) and thermocline depth in the western and eastern tropical Pacific. The direction of the trade winds is also given.

4. 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 _____ the wind speed.

5. As indicated in the windows, neutral-condition (prevailing) winds blow toward the (east, west) and the wind speed in (higher, lower) in the eastern Pacific than in the western Pacific.

6. Arrows in the Surface Currents window indicate that during neutral conditions, surface water flows towards the (east, west).

7. 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 (eastward, westward), as evidenced by the direction of surface currents.

8. 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 (transition zone between warm surface water and cold deep water) to be (deeper, shallower) in the eastern Pacific than in the western Pacific.

9. 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. Associated with the upwelling are conditions favorable for (low, high) biological activity.

10. Cold surface water cools the air above it, which leads to increase 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.

11. 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).

12. 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 neutral conditions, rainfall is greatest in the (western, eastern) Pacific where SSTs are (highest, lowest)

Part B – The Tropical Pacific During El Niño

Background Information: Slowly pull the insert out of the slider while watching the changing scene in the large window. Note that the stormy conditions move (eastward, westward). Continue pulling until the El Niño label is lined up in the large window indication. 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!-iLa Niña!.

13. 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 neutral condition readings at those conditions. During neutral 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.**

14. In response to changes in the air pressure pattern across the tropical Pacific, the Trade Winds weaken (and may even reverse direction, especially over the western tropical Pacific). No longer being pushed toward and piled up in the western Pacific, the warm 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 long-term average values.

15. During the 1997-1998 time period when an El Niño event occurred, the eastern equatorial Pacific Galapagos Islands experienced record-high SSTs of about 29°C (_____°F, Hint: Use your ESRT!), well above the temperatures critical for coral bleaching. The result was the devastation of a rich coral reef ecosystem. These high SSTs (are, are not) consistent with those predicted form an El Niño episode by the ÆEl Niño!-¡La Niña! slide chart.

16. In response to surface currents, sea surface heights in the eastern tropical Pacific are (higher, lower) than neutral condition 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.

17. Differences between existing conditions and neutral conditions are called anomalies. If El Niño readings are higher than the respective neutral condition 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 is (negative, positive), the surface air pressure anomaly is (negative, positive), and the rainfall anomaly is (negative, positive).

Part C - The Tropical Pacific During La Niña

Background Information: The tropical Pacific at times experiences trade winds stronger than the neutral condition average with SSTs lower than usual in the eastern tropical Pacific and higher than usual in the western tropical Pacific. Associated with these La Niña conditions are anomalies generally opposite those occurring during El Niño. Remove the slide insert from the sleeve and flip over the slide. 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 are identical. Then continue pushing the insert in until La Niña appears in the indentation.

18. The stormy weather in the western Pacific has been displaced (westward, eastward) from its Neutral Conditions position.

19. During La Niña the stronger trade winds are driven by an air pressure pattern that (increases, decreases) westward across the tropical Pacific. The air pressure difference between the eastern and western tropical Pacific is (less, greater) than during the Neutral Conditions (as shown by the black marks along the windows). The trade winds drive surface currents toward the (west, east), resulting in sea surface temperatures in the western tropical Pacific that are slightly (higher, lower) than the Neutral Conditions while the eastern tropical Pacific experiences (positive, negative) SST anomalies.

20. The La Niña wind and current patterns produce a thermocline depth in the eastern tropical Pacific that is (deeper, shallower) than the neutral conditions value, leading to (weaker, stronger) upwelling than average (note the large curved arrows). These conditions (suppress, enhance) biological productivity.

Part D – Internet Resources

Background Information:

In parts A, B and C of this investigation, the *¡El Niño!-¡La Niña!* slide chart was employed to investigate the tropical Pacific ocean-atmosphere connection. In this online, component we will examine tropical Pacific conditions based on data collected by the TAO/TRITON (Tropical Atmosphere Ocean /Triangle Trans Ocean Buoy Network). A network of about 70 deep-ocean moored buoys was deployed following the strong 1982-83 El Niño event that was neither predicted nor detected until nearly its peak. The episode demonstrated the need for real-time data to monitor, predict, and improve our understanding of El Niño.

Measurements taken by the TAO/TRITON array, shown in the figure below, include wind speed and direction, sea surface temperature, relative humidity, air temperature, and subsurface temperature at ten depths in the upper 500 m of the ocean. Five buoys along the equator (red squares in the color view of the figure, dark squares if in black and white) are equipped with sensors that measure ocean velocity.

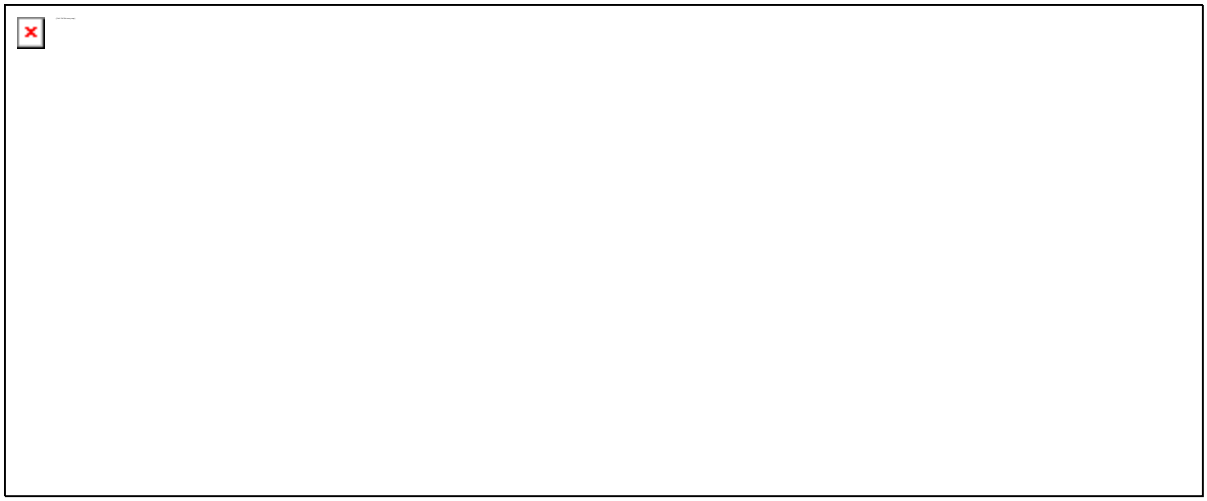
A. What is the approximate maximum and minimum latitudes found in the array of buoys? _____

B. What is the approximate maximum and minimum longitude of the array of buoys? _____

C. Open the ESRT to the Tectonic Plates map. Locate Hawaii. What is the latitude and longitude of the Hawaiian Hot Spot (_____, _____)

D. On the map of the array place an X where Hawaii is located.

E. Label Australia, New Zealand and Mexico on the map of the array



21. Observational data acquired with the TAO/TRITON array are available online in near real time. For the latest 5-day average conditions from the TAO/TRITON buoy array, click on http://www.pmel.noaa.gov/tao/jsdisplay/. At the top of the page in the blue boxes, click on "Lat Long Plots". Click on "Monthly". Select "Latest" in Year and "Latest" in Month. Click on "Make Plot" (red box to the right). When the new window opens, click on the image to enlarge it. Right click on the image, click on Print Image. In preferences choose landscape view.

22. Year of plotted data _____. Month of plotted data _____

23. The upper map in the current image you printed displays mean (average) sea surface temperatures (SSTs) from about 100°W to 140°E and from about 10°S to 10°N. SSTs are color coded (or shaded). What is the contour interval of the map?

24. The map shows the broadest area of highest SST in the (*eastern*, *western*) tropical Pacific and the lowest SST in the (*eastern*, *western*) tropical Pacific.

25. Winds are depicted with arrows. The longer the arrow the stronger is the wind. Most of the winds blowing over the tropical Pacific had a(n) (*west to east*, *east to west*) component.

26. The lower map is the anomalies map. It shows if a location is experiencing a sea surface temperature that is above or below the average sea surface temperature. The U.S., Canada, and Mexico have agreed to operational definitions of El Niño and La Niña events based on three-month averages of sea surface temperature departures from normal for a critical region of the equatorial Pacific. The critical region is defined between 120°W to 170°W and 5° N to 5°S.

27. Mark these latitude and longitude boundaries of the critical area on each map with a pencil. Use a YELLOW highlighter to highlight this box on each map.

28. A positive SST departure of 0.5 C° or greater from normal for three consecutive months defines **El Niño**. A negative SST departure of 0.5 C° or greater from normal for three consecutive months defines **La Niña**.

29. Assuming the SST anomalies within the boundaries you marked on this map are representative of a three-month average, the anomalies are consistent with a(n) (*El Niño*, *near-neutral*, *La Niña*) episode.

30. In the data section complete the boxes "Present Day Conditions" based on the two maps.

31. Cut out the average sea surface temperature and temperature anomaly plots. Be careful not to cut off the month and year for each map.

32. Using the NOAA website, you have looked at present day conditions in the Pacific Ocean. Now we will print out maps of the 1997 El Niño and 1998 La Niña of the Pacific Ocean. Return to the website http://www.pmel.noaa.gov/tao/jsdisplay/. Choose November of 1997 for the El Niño maps. Print out the enlarged maps. Choose November 1998 for the La Niña maps. Print out the enlarged maps. Cut them out. Be careful not to cut off the month and year for each map.

33. Now turn to your globe. Notice the latitude and longitude markings on the 1997 El Niño ANOMALIES map (not means map). Carefully try to line up the map on your globe. Tape the map on the globe.

34. Take the 1997 El Niño mean SST and surface winds maps and tape it directly on top of the anomalies map. You can now investigate a significant El Niño in its global context.

35. Flip up the average El Niño map at its east (right) end so you can see the anomalies map for November 1997 below. The anomalies map shows the temperatures in the eastern tropical Pacific were more than 4.5°C (*lower*, *higher*) than the long-term

average and the winds over much of the tropical Pacific had anomaly components directed from (*west to east*, *east to west*).

36. □ As you look at the El Niño maps on the globe, compare them to the present day maps (not taped on the globe). Use the table in the data section to describe differences between the El Niño and present day maps.

37. Go to http://www.elnino.noaa.gov/. Click on "Animations and Graphics". Click on "Comparison of this El Niño with previous El Niños". Scroll down to "SST Animations of Recent El Niño (warm) Events". Click on " Comparison of 2 Big El Niño events (82-83, 97-98)" Watch the animation.

38. Tape the 1998 La Niña ANOMALIES maps on top of the El Niño maps. Next tape the 1998 La Niña sea surface temperature map on top of the 1998 La Niña anomalies map.

39. By flipping maps, make some comparisons. The two means maps show that eastern Pacific SST were substantially (*lower*, *higher*) during the La Niña event. The November 1998 La Niña event showed equatorial SST more than 2 °C (*lower*, *higher*) than long-term averages (as shown by the anomalies view).

40. As you look at the La Niña maps on the globe, compare them to the present day maps (not taped on the globe). Use the table in the data section to describe differences between the La Niña and present day maps.

41. Go to http://www.elnino.noaa.gov/. Click on "Animations and Graphics". Click on "Comparison of this El Niño with previous El Niños". Scroll down to "SST Animations of Recent La Niña (cold) Events". Click on " Comparison of 2 BIG La Niña events (88-89, 98-99)" Watch the animation.

Data:

		Western Pacific	Central Pacific	Eastern Pacific
Present Day Conditions	**Temperature** (Warmer, Medium, Cooler)			
	Winds (N, S, E, W, NW, NE, SW or SE)			
El Niño	**Temperature Compared to Present Day Conditions** (Warmer, Medium, Cooler)			
	Winds (N, S, E, W, NW, NE, SW or SE)			
La Niña	**Temperature Compared to Present Day Conditions** (Warmer, Medium, Cooler)			
	Winds (N, S, E, W, NW, NE, SW or SE)			

An unusually intense El Niño developed rapidly in early 1997 and persisted until mid-May 1998. In late 1998, La Niña conditions were observed over the tropical Pacific, continued through 1999, and then gave way to neutral (near long-term average) conditions. A moderate La Niña episode reappeared over portions of the eastern and central tropical Pacific at the end of 2000 and continued through February 2001 and then gave way to essentially neutral conditions into early 2002. By late 2002, a moderate El Niño was underway.

During most of 2003, SSTs were slightly below average over the eastern tropical Pacific. In the spring of 2004, sea surface temperature anomalies were near zero through most of the tropical Pacific. But from July through October 2004, an area of anomalous warmth in the central and east-central equatorial Pacific increased and expanded eastward, signaling the early stages of a weak El Niño episode.

Through most of 2005, near-neutral conditions prevailed. By March 2006, a weak La Niña was underway with negative SST anomalies observed at most tropical Pacific locations between 90 degrees W and 180 degrees W. However, recently the tropical Pacific shifted to near-neutral conditions. The output of statistical and coupled ocean/atmosphere forecast models indicate considerable uncertainty regarding conditions for the last half of the year. Stronger than average easterly winds over the central equatorial Pacific and below average upper-ocean heat content support forecasts for La Niña conditions over the next 1 to 3 months.

In the next table, for any month that experienced an El Niño episode, shade in the box red. For any month that experienced a La Niña episode, shade in the box blue.

1997	1998	1999	2000	2001	2002	2003	2004	2005
Jan.	Jan.	Jan.	Jan.	Jan.	Jan.	Jan.	Jan.	Jan.
Feb.	Feb.	Feb.	Feb.	Feb.	Feb.	Feb.	Feb.	Feb.
Mar.	Mar.	Mar.	Mar.	Mar.	Mar.	Mar.	Mar.	Mar.
April	April	April	April	April	April	April	April	April
May	May	May	May	May	May	May	May	May
June	June	June	June	June	June	June	June	June
July	July	July	July	July	July	July	July	July
August	August	August	August	August	August	August	August	August
Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.
Oct.	Oct.	Oct.	Oct.	Oct.	Oct.	Oct.	Oct.	Oct.
Nov.	Nov.	Nov.	Nov.	Nov.	Nov.	Nov.	Nov.	Nov.
Dec.	Dec.	Dec.	Dec.	Dec.	Dec.	Dec.	Dec.	Dec.

42. TAO/TRITON data are also collected below the ocean surface. Go to http://www.pmel.noaa.gov/tao/jsdisplay/. Look for the blue boxes at the top of the page and click on "Animation." On the next screen click on the red box, "Animate". In the new window that opens click on "60 months". The sample image depicts the dynamic height of the sea surface and temperatures down to approximately 400 m depth as viewed westward along the equator from a location high in the Andes Mountains.

43. By clicking on the "stop and go" arrow, you can view the equatorial Pacific in three dimensions during any month.

44. What is the first month and year viewed? _____

45. What is the last month and year viewed? _____

46. Note the months that have "El Niño" written under the month and year. Return to the calendar you have already shaded in with red and blue color pencils. Based on the NOAA website, shade the box in red if there is an El Niño.

47. To view 3D animations go to http://www.elnino.noaa.gov/. Click on "Animations and Graphics". Click on "3D El Niño Animations". Look for "**Sea Surface Temperature, Winds, 20°C Isotherm, and Upper Ocean Temperature and Current at the Equator"** Click on "JavaScript Animation". Run the animation.

48. What is the first month and year viewed? _____

49. What is the last month and year viewed? _____

50. Go back. Look for "Virtual Reality Visualizations (VRML viewer required)". Click on Virtual Reality Animation of Temperature and Dynamic Height. Watch the visualization.

51. You can find more information on El Niño at http://www.elnino.noaa.gov/ and for La Niña at http://www.elnino.noaa.gov/lanina.html. Now we will read about NOAA's forecasts of El Niño conditions in the Pacific Ocean. Go to

http://www.elnino.noaa.gov/. In red, click on "Forecasts". Next click on "El Niño status". Read the El Niño/Southern Oscillation (ENSO) Diagnostic Discussion.

52. What is the date of this report?

53. Presently is the Pacific Ocean experiencing an El Niño, La Niña or average conditions?

54. Explain why in terms of temperature.

55. What conditions are expected in the Pacific in the near future?

Part E - Species Dominance and Ocean Properties

DATASTREME OCEAN SUPPLEMENTAL INFORMATION

DataStreme Ocean Week Eleven: 10-14 April 2006

Variations in the physical and chemical properties of ocean waters occur over a range of temporal and spatial scales. In some cases, changes in ocean properties are accompanied by changes in dominant species. The best known of such relationships is the response of the Peruvian anchoveta fishery to physical changes in the eastern tropical Pacific associated with El Niño. In fact, a sharp decline in anchovy population first signaled physical changes in the tropical Pacific as an El Niño event evolved. Changes in species dominance during El Niño typically last for 12 to 18 months. Today, scientists are investigating other changes in dominant species in response to longer-term (two to three decades) fluctuations in physical properties of the ocean.

Recent discoveries by researchers at the Monterey Bay Aquarium Research Institute (CA) and similar research centers in Mexico and Peru have unveiled an interesting

correspondence between changes in physical and chemical properties of the eastern Pacific Ocean and biological regime shifts between anchovies and sardines over periods of decades. Records of the harvest of these two fish species are available for a century or more and are bolstered by information on the populations of their prey (i.e., zooplankton) and predators (e.g., salmon, sea birds). Even changes in the production of sea bird guano, deposited in layers, provide an even longer-term (albeit proxy) record of biological regime shifts. Shifts in dominance between anchovies and sardines appear to be related to changes in Pacific basin-wide sea surface temperatures, upwelling, CO_2 flux from the ocean to atmosphere, and even mean global air temperature. While the correspondence between these elements may differ in timing and sometimes the sign is not exactly what would be initially expected, the correlation raises interesting questions for the scientific community and underscores the importance of an ecosystem approach in the study of population dynamics.

A better understood relationship between decadal-scale changes in ocean physical properties and species dominance involves the Pacific Decadal Oscillation (PDO). PDO is a long-lived ENSO [El Niño Southern Oscillation] -like climate variation over the North Pacific. PDO is better known in the eastern North Pacific and along the West Coast of North America, probably because of more intensive study of those areas. As noted in Chapter 11 of the *DataStreme Ocean* textbook, the PDO goes through warm phases and cold phases that persist for two to three decades. Coastal waters from the Pacific Northwest north to Alaska are higher than usual during a warm phase and lower than usual during a cold phase. Sardines dominate during a PDO warm phase and anchovies dominate during a PDO cold phase. During a warm phase, the warm surface waters in the eastern Pacific cut off coastal upwelling. Nutrient supply and plankton populations decrease followed by a decline in the anchovy population. Eventually sardines take over in the warmer waters and their populations soar. Their large numbers during PDO warm phases at times spurred the development of significant fishery operations until cooler waters returned and the numbers of sardines plummeted. Just such a rise in sardine populations in the 1930s and 1940s followed by their sudden decline in the late 1940s in Monterey, CA served as a backdrop of the John Steinbeck novel *Cannery Row*.

Biological shifts are also associated with much shorter term oscillations in sea surface temperature and more localized upwelling and mixing regimes associated with eddies (rings) that break off the Gulf Stream and the Gulf of Mexico Loop Current. The circulation in eddies alters the temperature and nutrient supply thereby impacting the local marine ecosystem over a period of about four months to a year.

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Reading Questions:

During a warm phase, upwelling is (enhanced, suppressed), nutrient supply (decreases, increases), plankton population (decreases, increases), anchovy population (decreases, increases) and sardine population (decreases, increases). During a warm phase, (sardines, anchovies) dominate and during a cold phase, (sardines, anchovies) dominate.

Self-Assessment Revisited: Respond to the statements below. Compare your responses now with those you made at the beginning of the investigation. Has learning taken place?

	True, False (T or F)	Confidence (H, M, L)
The tropical Pacific Ocean is characterized by weather that never changes.		
El Niño produces changes in climate on time scales of a few years.		

Conclusion: (*Answer in complete sentences*)

56. Is El Niño!-¡La Niña a random, annual, semi-annual or inter-annual event?

57. Describe at least one major ecological, societal and economic disruptions that is called by El Niño!-¡La Niña.

This laboratory investigation was modified from
DataStreme Ocean Benchmark Investigation 11B
El Niño/¡La Niña: The Ocean-Atmosphere Connection

Filename: Week 11 - El Nino and La Nina
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Subject:
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Keywords:
Comments:
Creation Date: 5/8/2006 8:24:00 PM
Change Number: 2
Last Saved On: 5/8/2006 8:24:00 PM
Last Saved By: Michael Passow
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Last Printed On: 5/8/2006 8:27:00 PM
As of Last Complete Printing
Number of Pages: 14
Number of Words: 4,718 (approx.)
Number of Characters: 24,583 (approx.)