Homework-10: ENSO - Background

(Pipkin et al.)

OBJECTIVES:

- To know the atmospheric and oceanographic factors leading to El Nino/Southern Oscillation (ENSO) "events."
- To understand the impact of El Nino on humans and on marine life.

Based broadcast and print media before the winter of 1997-98, only oceanographers and Pacific fishermen were familiar with El Nino – an eastern equatorial Pacific Ocean phenomenon. Fishermen along the Pacific coast of Peru and Ecuador originally noticed periodic appearances of warm, nutrient-poor ocean waters that accompanied decreases in the local fishing industry. In 1892, fishermen in the Peruvian port of Paita called an invasion of warm water off the coast around Christmas time "Corriente del Nino" (current of the Christ Child). In 1958, it was proposed that the term *E1 Nino* be used for the combined oceanographic and meteorological events which occurred across the Pacific Ocean during December 1958; and persisted for several months before the restoration of "normal" ocean currents and surface-water temperatures. By 1972, oceanographers and meteorologists broadened the definition of these events and coined the term **El Nino-Southern Oscillation** *(ENSO),* to include periodic climate-related shifts in weather patterns in the equatorial Pacific and Indian Oceans. To complicate matters further in the 1990s, the news media began to refer to *La Nina* events - times of anomalously *cold* surface waters in the eastern equatorial Pacific Ocean.

The Generation of El Nino Events

The occurrences of unusually warm surface water in the Pacific Ocean are episodic; with eight severe El Nino events having occurred since the late 1950s. Although the 1997-98 El Nino was widely reported in news broadcasts, it remains to be proved whether its effects exceeded those of the 1982-83 El Nino - the strongest event of the twentieth century; affecting the entire Pacific Rim and the Indian Ocean.

The El Nino-Southern Oscillation is a departure from the "normal circulation" of the equatorial Pacific Ocean (Figure 10-1). During "normal times", the Pacific coastal current known as the Peru Current (previously the Humboldt Current) moves cold waters from the Antarctic regions equatorward. In the equatorial Pacific Ocean, southeast trade winds, combined with Coriolis deflection to the left in the Southern Hemisphere (SH), push Peru Current westward offshore. This offshore Ekman transport of surface waters near the coast induces the upwelling of cool, nutrient-rich water from below the thermocline (Figure 10-2). This cold upwelled inshore water is so distinct that it is called the *Peru Coastal Current* to distinguish it from the offshore Peru Current. The Peru Coastal Current supports one of the richest fisheries in the world, and commercial fishermen from southern California travel thousands of miles to the coastal waters off Peru.

Under normal conditions, the North Equatorial Current and the South Equatorial Current force surface waters westward across the Pacific. These surface waters are warmed in their transit across the ocean, forming a distinct "bulge" of warmer water in the western equatorial Pacific, which may be seen on satellite images showing relative sea level. During EI Nino years, the usual low atmospheric pressure in the western equatorial Pacific is replaced by high-pressure cells. This shift in pressure is known as the Southern Oscillation. Since this change lessens the pressure differential that drives the trade winds from east to west, those winds decrease or even reverse direction, allowing the huge mass of warm surface water in the western Pacific to surge back toward South America in an intensified Equatorial Countercurrent (see Figure 10-1).

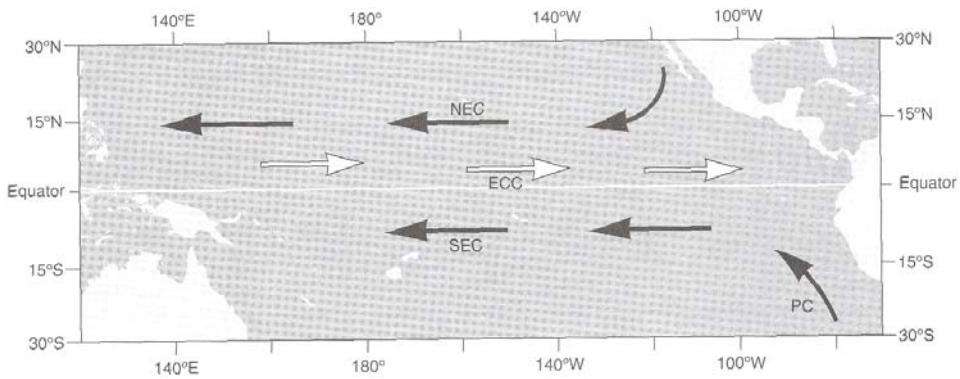


Figure 10-1 Surface currents in the equatorial Pacific Ocean. N EC = North Equatorial Current; SEC = South Equatorial Current; ECC = Equatorial Countercurrent; PC = Peru Current.

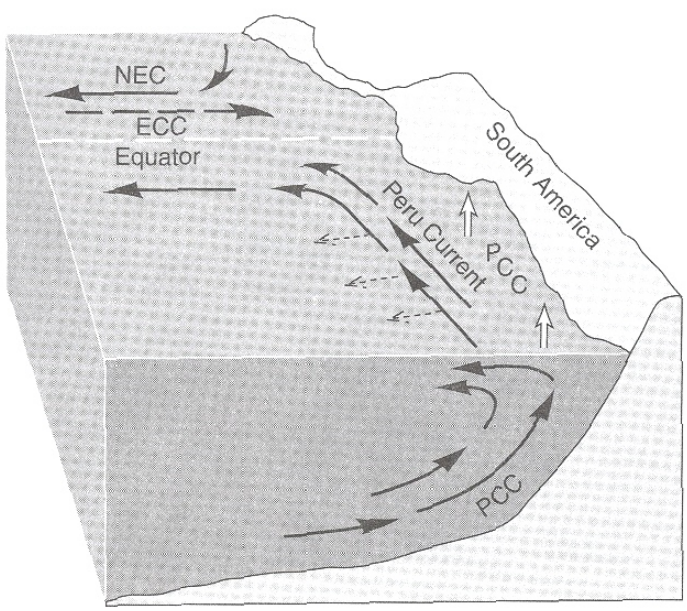


Figure 10-2 Peruvian Upwelling Three-dimensional view of upwelling off the western coast of South America. The cool, nutrient-rich upwelled waters of the Peru Coastal Current (PCC) create a rich fishing ground off Peru and Ecuador. The cessation of upwelling during EI Nino events leads to the collapse of the fishery in this area. NEC = North Equatorial Current; SEC = South Equatorial Current; ECC = Equatorial Countercurrent.

When this warm, dilute, nutrient-poor water strikes the coast of South America, it moves southward over the cooler coastal waters, forming a "lid" that stops the upwelling of the Peru Coastal Current. Lower nutrient concentrations in surface waters result in the collapse of the food chain, that supports fish species, and thus the collapse of the local fishing industry. The disappearance of these fish also leads to the deaths of millions of seabirds that normally feed on them. In turn, the local guano fertilizer industry vanishes because of the decrease in seabird abundances. Eventually, coastal communities in Peru and Ecuador experience economic hardship and sometimes even famine.

Monitoring EI Nino

The onset of EI Nino events can be predicted by oceanographic changes in the central equatorial Pacific Ocean before they affect the west coasts of North and South America. NOAA has attempted to track and predict the onset and relative impact of EI Nino events. As part of this effort, the NOAA Pacific Marine Environmental Laboratory maintains the **Tropical Atmospheric Ocean Array** *(TAO)*, an array of 70 buoys moored in the central Pacific, between 160ºE and 150ºW and from 5ºS to 5ºN - an area termed the *Nino-4 Region* (Figure 10-3). NOAA *TAO* buoys measure temperature, winds, and currents in the Nino-4 region, and transmit these data back to the Pacific Marine Environmental Laboratory.

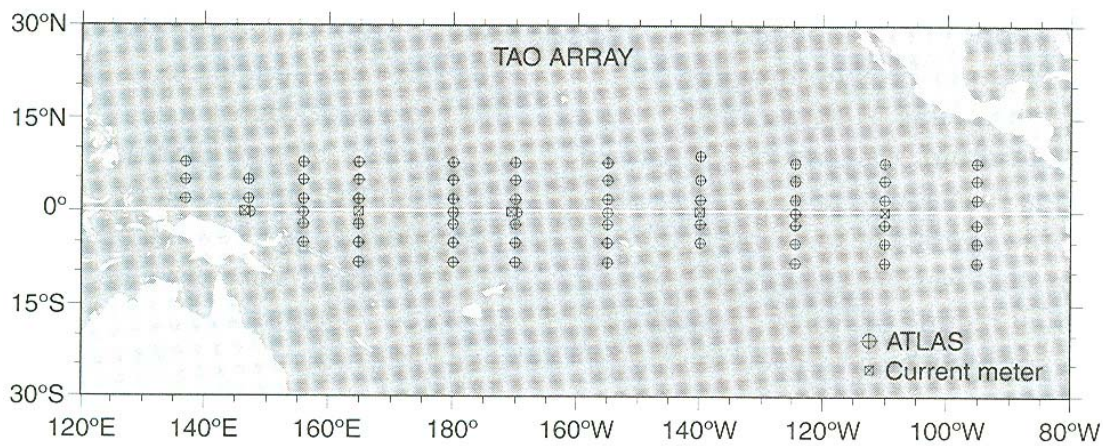
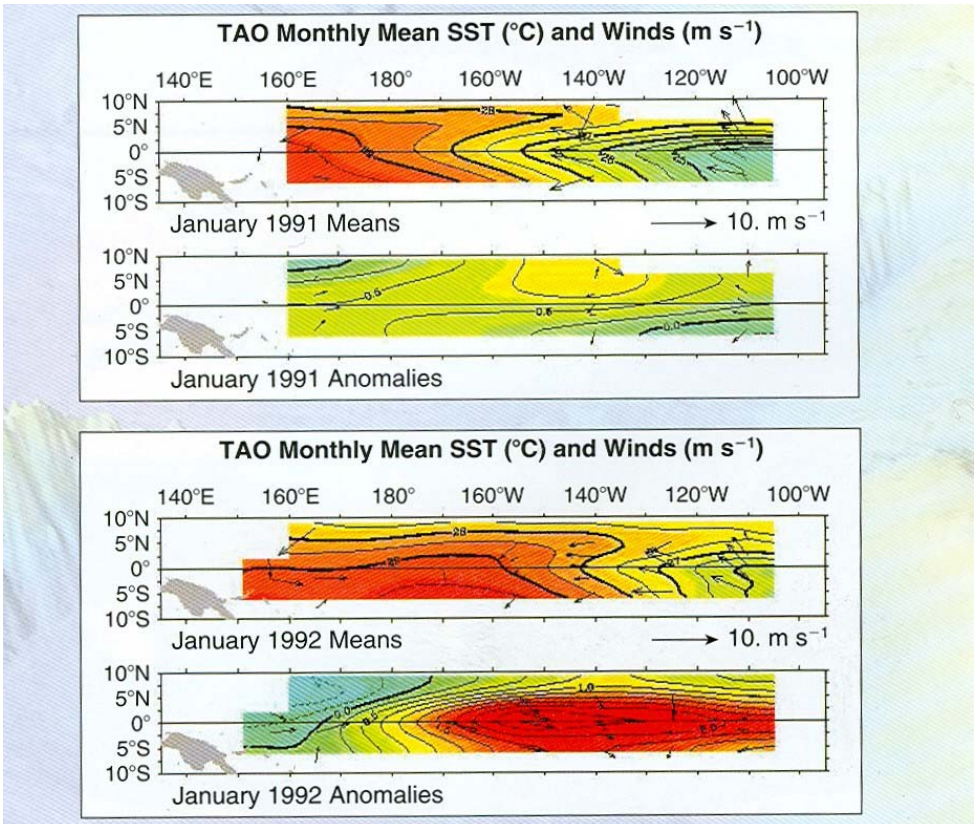


Figure 10-3 The Tropical Atmospheric Ocean Array (TAO) of oceanographic sensor buoys and moored current meters in the Nino-4 region of central Pacific Ocean (between 160^{0}E and 150^{0}W, and from 5^{0}S to 5°N). Data obtained from these sensors is used by NOAA to monitor oceanic conditions that might mark the onset of EI Nino events.

One means of tracking EI Nino is by monitoring sea-surface temperatures (SST). Under normal conditions, surface waters in the eastern Pacific are cooler (SSTs around 22°C) than SSTs in the western Pacific (SSTs around 30°C). When temperatures in the eastern Pacific become *warmer* than usual, this SST departure is defined as a positive SST anomaly. Conversely, negative SST anomalies mark times when surface waters there are *cooler* than usual. EI Nino events may be seen in SST data collected by the TAO array (Color plate 6). During EI Nino, higher than usual temperatures displace the typical "cold

tongue" of water that normally extends westward across the equatorial Pacific Ocean. Shifts atmospheric pressure that accompany El Nino are also periodic and can be detected by orbiting weather satellites.



Color plate 6 Monthly mean sea-surface temperature data for the Niño-4 region, compiled by the Tropical Atmospheric Ocean Array (TAO) of the NOAA Pacific Marine Environmental Laboratory. January, 1991 is a normal (non-El Niño) year, while January, 1992 shows data for an El Niño event. [*Courtesy of NOAA.*]

Effects of El Nino

The El Nino-Southern Oscillation can cause global shifts in weather patterns, as well as latitudinal changes in the position of jet stream winds that reside in the stratosphere along frontal boundaries between air masses. (Jet Stream winds "steer" tropospheric high- and low-pressure cells, and thus weather fronts). In particular, El-Nino accompanies the deflection of the subtropical jet stream (so-called the "Pineapple Express" that flows near Hawaii) to the north. This deflection may be significant enough to allow tropical storms to flow northward, causing flooding as far north as Washington and Oregon (Figure 10-4). The 1982-83 ENSO was responsible for flooding and droughts in 12 countries, thousands of deaths, and billions of dollars in property damage. In southern California, the rainfall nearly tripled, and the coast was battered by destructive winds and high waves.

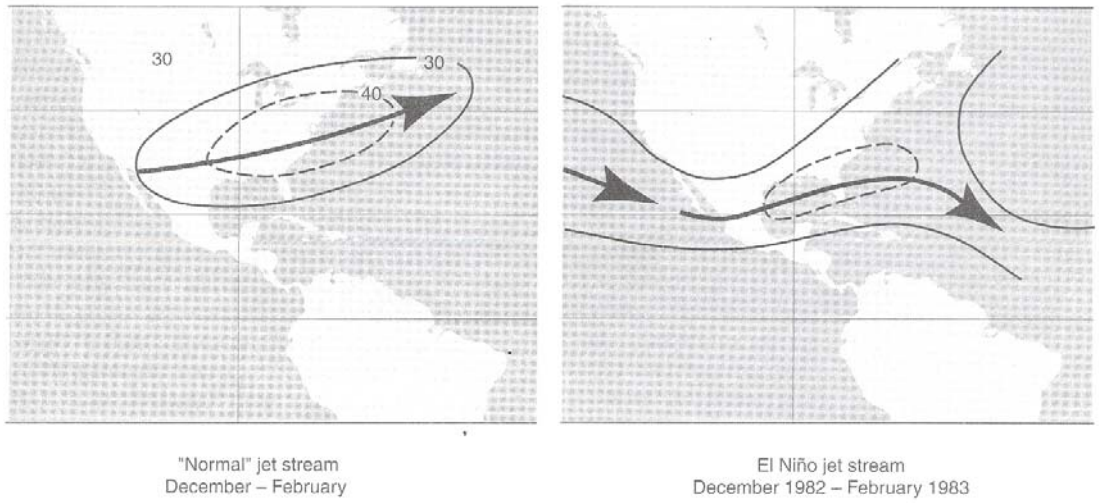


Figure 10-4 Typical December-February location of the subtropical jet stream (left) and northward deflection of the subtropical jet stream during the EI Nino of 1982-83 *(right).* [After Eugene M. Rasmusson, "EI Nino: The Ocean/Atmosphere Connection." *Oceanus,* Vol. 27, no. 2, 1984, pp. 5-13].

During El Nino years, the presence of high pressure cells in the western equatorial Pacific disrupts the rainfall regime of the tropical Pacific. Normally, heavy rainfall occurs over the North Australian-Indonesian region and along the South Pacific convergence zone from New Guinea eastward to the International Date Line. The 1982-83 El Nino was marked by severe droughts in Australia, Indonesia, and the western equatorial Pacific. It was also associated with dust storms and brush fires in Australia. Drought during the 1997 -98 El Nino caused forest fires of such severity that aircraft were unable to land at Indonesian airports because of impenetrable smoke.

El Nino events may also affect the Atlantic Ocean, as the northward shift of the subtropical jet stream allows warmer, moister air to flow eastward into the Gulf of Mexico and the Caribbean Sea. The invasion of this air from the Pacific tends to slow down the development of tropical storms and hurricanes in the Atlantic basin. This is because Atlantic tropical storms increase in strength and can evolve into hurricanes as they move northward into regions of cooler, drier air at higher latitudes. Only seven named storms formed during the Atlantic hurricane season of 1997, and only three of these developed into hurricanes.

ENSO events are aperiodic, with a return interval typically varying from 3 to 7 years (Figure 10-5). Because of this short return period, predicting these events is important to government preparedness agencies and the general public. Pacific equatorial sea-surface temperatures determined by the TAO buoy network are shown in Figure 10-5. Averaging temperatures over this region allows oceanographers to identify positive (warmer) temperature anomalies that may signal the onset of an ENSO event. Pronounced events may last for an entire year before conditions return to normal, but most events persist for only 3-4 months. La Nina events are seen as negative temperature anomalies; that is, cooler than usual surface waters move eastward across the equatorial Pacific Ocean.

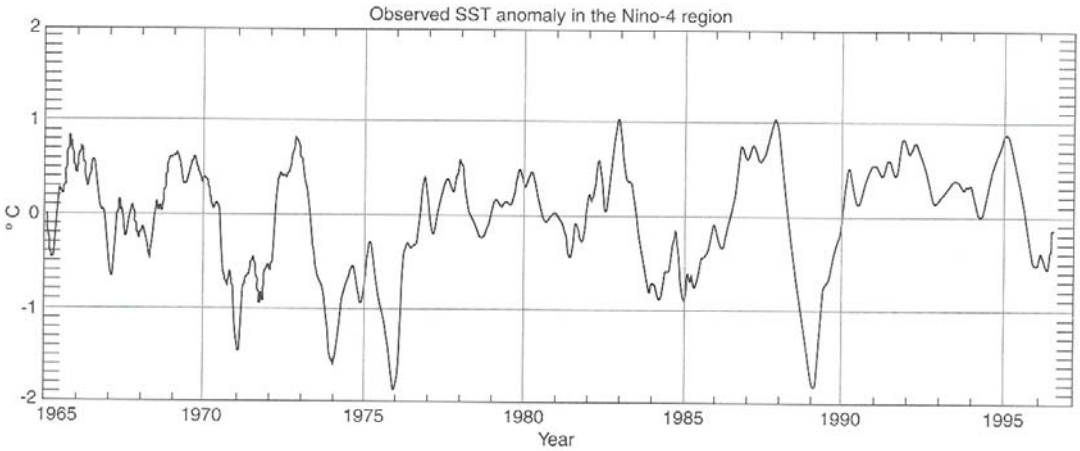


Figure 10-5 The periodicity of EI Nino is demonstrated by the sea-surface temperature anomalies observed over time in the Pacific Ocean near 180^0 latitude at the equator. Positive anomalies are temperatures higher than average, and mark the warm surface waters of EI Nino events.

How do El Nino events end? The accumulation of warm surface waters in the eastern Pacific causes a weakening of the westward-flowing trade winds, leading to the further strengthening of ENSO events by *positive feedback*. However, sea-surface height in the western Pacific eventually decreases as surface waters "slosh" across the equatorial Pacific as eastward propagating *Kelvin waves*. (Kelvin waves are similar to seiches, having an up-down motion similar to that of the wave that develops in a bathtub as the bather moves, causing water to slosh back and forth in the tub). These long-period waves eventually slosh back to the eastern Pacific, leading to the reestablishment of the normal east-to-west motion of surface currents. As the surface currents are restored, the eastern equatorial Pacific cools, and the pole-to-equator motion of the Peru Current restores the normal upwelling regime of the Peru Coastal Current.

Web Sites

Current information on sea-surface temperatures, El Nino, and La Nina, with animations and interactive questions and answers, may be found at the following sites:

http://www.elnino.noaa.gov/lanina.html NOAA site

http://www.ogp.noaa.gov/enso/ More NOAA

http://www.pmel.noaa.gov/toga-tao/ la-nina-story-nas.html NOAA and TAO Buoy array

http://www.pmel.noaa.gov/toga-tao/ el-nino/home.html with animations of SST in the he Pacific

http://www.pbs.orglnova/elnino Public Broadcasting System (PBS) *Nova*

http://www.nws.noaa.gov National Weather Service

http://observe.ivy.nasa.gov/nasa/ earth/el nino/elninol.html NASA's site

MAR110 Homework 10: ENSO

EXERCIZE-1

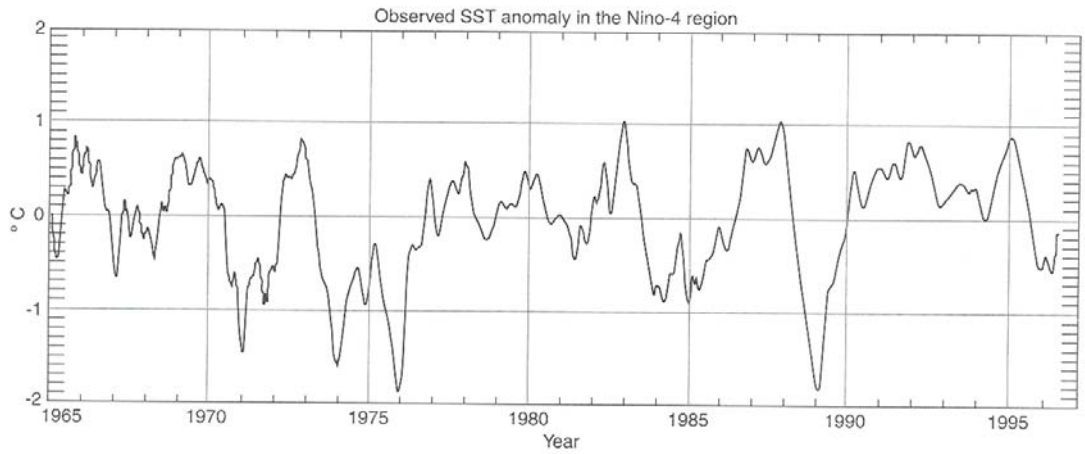
1. In Figure 10.5 to determine the periodicity of El Nino.
   a) How many El Nino events do you recognize in this figure? _____
   (Keep in mind that "an event" may last for more than a year.)

   b) How many years elapse between El Nino events? _____

   c) How many La Nina events do you recognize in this figure? _____
   (Recall that La Nina events are cooler than normal.)

   d) How many years elapse between La Nina events? _____

   e) Are the periodicities of El Nino and La Nina events the same? _____
   Explain.



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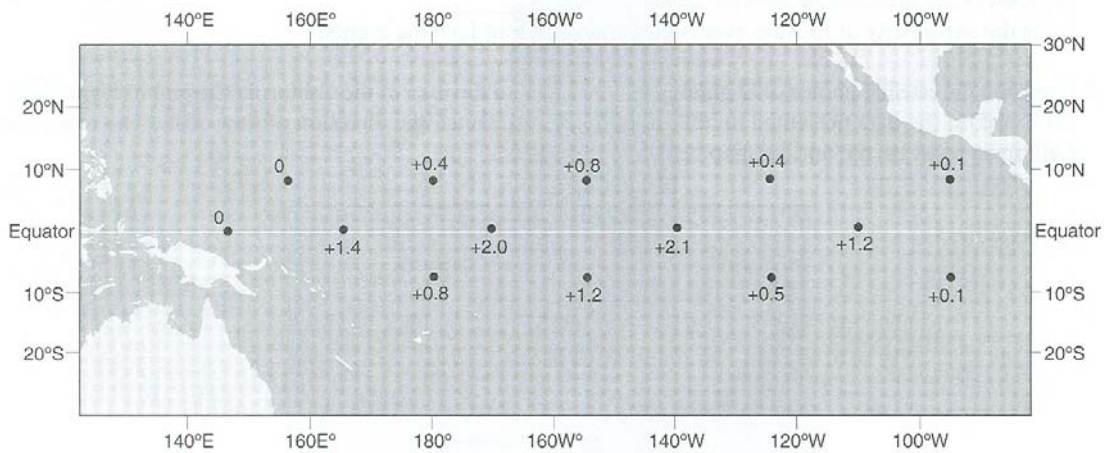

Figure 10-6 Selected NOAA TAO buoy sites in the central equatorial Pacific, with *average* sea surface temperature (SST) anomaly data for a selected time period.

2. Figure 10-6 (above) shows the locations of selected NOAA TAO buoys from the central equatorial Pacific, with average sea surface temperature (SST) anomaly data from a selected time period.

    a) Contour these data with a 0.5ºC interval

    b) Do these data indicate either an El Nino or a La Nina event? <u>*Yes or No*</u> *Justify your answer* by comparing these data with SST anomaly data in Figure 10.5.

3. Figure 10-7 (below) shows the locations of selected NOAA TAO buoys from the central equatorial Pacific, with average sea surface temperature (SST) anomaly data from a different time period than in Figure 10-6.

    a) Contour these Figure 10-7 data with a 0.5ºC interval.

    b) Compare these results with those in question 2. Based on your analysis of these data, is there anything that you might predict about the future climatic conditions in the west coast of South America?

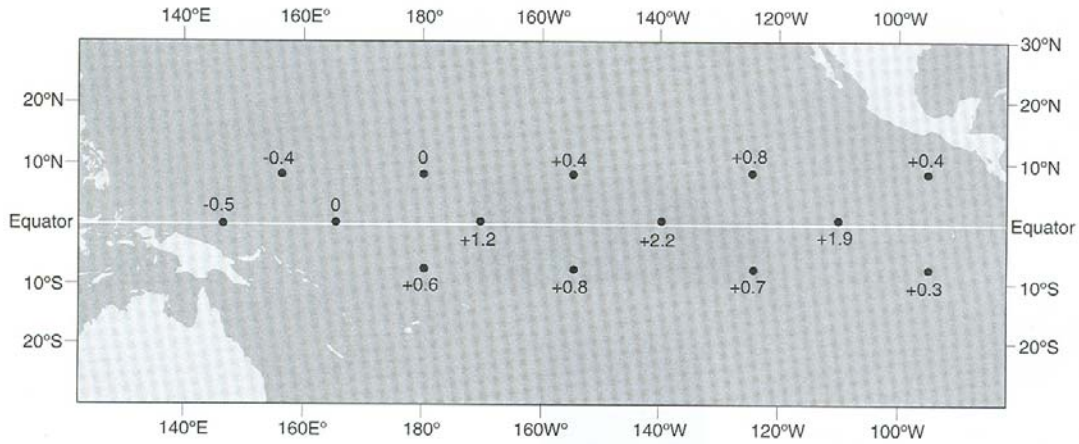

Figure 10-7 Selected NOAA TAO buoy sites in the central equatorial Pacific, but with the *average* sea surface temperature (SST) anomaly data from a different time period than in Figure 10-6.

c) Do these data indicate either an El Nino or a La Nina event? Yes or No
If yes, which type of event? _____.

d) Assuming one-month time difference between these data and those in question 2, when might the climatic conditions change in Guayaquil, Ecuador (3ºS, 82oW)? _____