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.

Although it may be hard to believe from the common references in broadcast and print media, before the winter of 1997-98, only oceanographers and Pacific fishermen were familiar with El Nino. This oceanographic phenomenon in the Pacific Ocean was originally noticed by fishermen along the Pacific coast of Peru and Ecuador, when periodic appearances of warm, nutrient-poor ocean waters led to 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, the term *El Nino* was proposed for the oceanographic and meteorological events that occurred across the Pacific Ocean during December of that year, and persisted for several months before the restoration of "normal" ocean currents and surface-water temperatures. In 1972, oceanographers and meteorologists used the term *El Nino-Southern Oscillation* (ENSO), broadening the definition of these events to include periodic climate-related shifts in weather patterns in the equatorial Pacific and Indian oceans. To complicate matters, during the 1990s, the news media began to refer to times when anomalously cold surface-water masses appeared in the eastern equatorial Pacific Ocean as *La Nina* events.

The Generation of El Nino Events

Occurrences of unusually warm surface water in the Pacific Ocean are episodic, and eight severe El Nino events have 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, which was the strongest event of the twentieth century, affecting the entire Pacific Rim and the Indian Ocean.

To understand the El Nino-Southern Oscillation, it is first necessary to understand the "normal" circulation of the equatorial Pacific Ocean (*Figure 10-1*). During normal times, the coastal current along the Pacific margin of South America is the Peru Current (also previously known as the Humboldt Current), which moves cold waters northward from Antarctic regions. Southeast trade winds in the equatorial Pacific Ocean, combined with Coriolis deflection to the left in the Southern Hemisphere, push the water in the northward-flowing Peru Current offshore, causing surface waters to be replaced by 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 El 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).

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 disappearance of fish species that depend on the upwelling of cool, nutrient-rich water, 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 El Nino**

The onset of El 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 El Nino events. The NOAA Pacific Marine Environmental Laboratory maintains the **Tropical Atmospheric Ocean Array** (TAO), an array of 70 buoys moored in the central Pacific, between 160°E and 150°W and from 5°S to 5°N, in an area termed the Nino-4 Region (Figure 10-3). NOAATAO 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](image)

*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°E and 150°W, and from 5°S to 5°N). Data obtained from these sensors is used by NOAA to monitor oceanic conditions that might mark the onset of El Nino events.

One means of tracking El Nino is by monitoring sea-surface temperatures. Under normal conditions, surface waters in the eastern Pacific are cooler (around 22°C) than those in the western Pacific (around 30°C). If temperatures in the eastern Pacific are *warmer* than usual, this is a positive SST anomaly. Conversely, negative SST anomalies mark times when surface waters there are *cooler* than usual. El Nino events may be seen in SST data collected by the TAO array (Color Plate 6). During El Nino, higher than usual temperatures displace the typical "cold tongue" of water that normally extends westward across the equatorial Pacific Ocean. The atmospheric pressure shifts that trigger El Nino are also periodic and can be detected by orbiting weather satellites.
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 the jet streams (stratospheric winds that affect weather patterns by "steering" high- and low-pressure cells, and thus weather fronts). In particular, deflection of the subtropical jet stream (often called the "Pineapple Express" because it flows near Hawaii) to the north may allow tropical storms to flow northward, causing flooding as far north as Washington and Oregon (Figure 17-4). 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 17-4 Typical December-February location of the subtropical jet stream (left) and northward deflection of the subtropical jet stream during the El Nino of 1982-83 (right). [After Eugene M. Rasmusson, "El 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 periodic, with a return interval of 3-7 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.

![Observed SST anomaly in the Nino-4 region](image)

*Figure 10-5* The periodicity of El Nino is demonstrated by the sea-surface temperature anomalies observed over time in the Pacific Ocean near 180° latitude at the equator. Positive anomalies are temperatures higher than average, and mark the warm surface waters of El 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 in eastward-flowing 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 slow-moving 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](http://www.elnino.noaa.gov/lanina.html)  NOAA site
- [http://www.pmel.noaa.gov/toga-tao/el-nino/home.html](http://www.pmel.noaa.gov/toga-tao/el-nino/home.html)  with animations of SST in the he Pacific
- [http://www.pbs.org/wnova/elnino](http://www.pbs.org/wnova/elnino)  Public Broadcasting System Nova
- [http://observe.ivy.nasa.gov/nasa/earth/el_nino/elninol.html](http://observe.ivy.nasa.gov/nasa/earth/el_nino/elninol.html)  NASA's site
QUESTION 1. (LEiO)

1. Use the information in Figure 17.5 to determine the periodicity of El Niño.
   (a) How many El Niño events can be recognized in this figure? (Keep in mind that a single event may last more than one year.) __________
   (b) How many years elapse between El Niño events? __________
   (c) How many La Niña events (cooler than usual conditions) can be recognized? __________
   (d) How many years elapse between these events? __________
   (e) Is the periodicity of El Niño events the same as that of La Niña events? __________
QUESTION 4 (LEiO)

4. The figure below shows the locations of selected oceanographic buoys from the NOAA-TAO array in the central equatorial Pacific, with mean sea-surface temperature (SST) anomaly data indicated for each buoy. Contour these data, using 0.5° intervals.

(a) Do these data indicate normal conditions, an El Niño event, or La Niña? Justify your answer by comparing to the SST anomaly data plotted in Figure 17-5.
QUESTION 5 (LEiO)

5. The figure below shows SST anomaly data for the same buoys as in Question 4, but from a different time period. Once again, contour these data, using 0.5° intervals.

(a) Compare these data to those in Question 4. Is there anything you might predict for future climatic conditions on the west coast of South America, based on these data? 

(b) If these data indicate an event, which type? 

(c) Assuming a time difference of one month between these data and those in Question 4, when might climatic conditions change in Guayaquil, Ecuador (3°S, 82°W)? 