Ocean Circulation
- On the map below, draw the major surface currents of the world's oceans. Use the figure in your book if you need help.

- Label the following currents and gyres on your map:

<table>
<thead>
<tr>
<th>Currents</th>
<th>Gyres</th>
</tr>
</thead>
<tbody>
<tr>
<td>The California Current</td>
<td>North Pacific</td>
</tr>
<tr>
<td>The Kurashiro Current</td>
<td>South Pacific</td>
</tr>
<tr>
<td>The Gulf Stream</td>
<td>North Atlantic</td>
</tr>
<tr>
<td>The Canary Current</td>
<td>South Atlantic</td>
</tr>
<tr>
<td>West Wind Drift</td>
<td>Indian</td>
</tr>
<tr>
<td>The Peru Current</td>
<td>(Note: All of these are also called subtropical gyres)</td>
</tr>
<tr>
<td>The North Equatorial Current</td>
<td></td>
</tr>
<tr>
<td>The South Equatorial Current</td>
<td></td>
</tr>
</tbody>
</table>

The coriolis effect causes water to pile up in the middle of these gyres. The “hills of water” are small, only 2-3 meters high, so you’d never see or feel them. Nevertheless, they do influence oceanic circulation. The center of the gyres are also not in the center of the ocean basins. Instead, because of the eastward rotation of the Earth, they are displaced westwards (the Earth rotates out from under them, so to speak).

So, given a westward displaced gyre, which currents flow fastest and strongest, the eastern boundary currents or the western boundary currents?

The western boundary currents are strongest.

Explain your answer. The center of the gyres are displaced westward creating less space for the water to flow through on the west side of the gyres. Since the same amount of water flows through the western and eastern boundary currents, the flow must be stronger and faster through the western boundary currents.

Look at a sea-level elevation map.
Back to Salinity variations. The difference between annual precipitation and evaporation can explain the longitudinal (N-S) variation in salinity, but explains less of the latitudinal (E-W) variations. How might surface water circulation patterns influence surface salinity values as shown to the right? Specifically, why isn’t the surface water off the coast of California as salty as in the middle of the north Pacific at 30ºN? Cold, less salty water flows south from Alaska with the California Current.

Upwelling and Downwelling

These diagrams show the various ways that upwelling and downwelling can be created. Note that the situation in “A” could also be produced by winds moving towards you out of the paper, as we discussed in class. These images will form the basis for the answers to the following questions.

The diagram below shows a map on the left and a cross section on the right. Assuming a north wind as shown on the map, draw in the direction of surface currents and deeper water currents on the cross section.

Does your diagram show evidence for upwelling here? Would you expect the upwelled water to be warm or cold? Yes, the diagram should show evidence for upwelling. The upwelled water would be cold.

The diagram to the left shows SSTs for the Monterey Bay Region. Note that upwelling, as denoted by the cold regions, occurs at specific areas along the coast. Note, the upwelling does not coincide with the location of canyons. Based on the shape of the coast line, why does upwelling principally occur along these certain stretches of coastline? Upwelling is concentrated where the southward flowing California Current must flow around a left bend. These occur where the trend of the coastline turns east and the coastline has a southerly exposure. This occurs near Half Moon Bay, between Ano Nuevo and Santa Cruz, and near Pt Sur. Upwelling does not occur between Santa Cruz and Capitola because deep water does not exist there.
Ocean Circulation and Biologic Productivity.

Organisms need nutrients to live. Thus the availability of nutrients determines the location and abundance of organisms, especially those at the base of the food web such as plankton. The location of plankton blooms in the oceans can be identified by satellite because the plankton contains chlorophyll and appear as different colors to sensitive satellite instruments such as the Sea-viewing Wide Field-of-View Sensor (SeaWiFS). In general, high concentrations of nutrients, and thus plankton, correspond to areas of upwelling and high productivity.

Why do high concentrations of nutrients and plankton at the surface correspond to zones of upwelling? Because nutrient concentrations are low in surface waters and higher in deeper waters. Only in upwelling zones can the deeper water reach shallower levels.

Examine the map of global chlorophyll concentrations (which corresponds to plankton concentrations and thus nutrient concentrations and biologic productivity). As usual, reds and yellows are high values, whereas blues and purples are low values. The polar regions generally have high plankton concentrations because of the 24-hour light during summer months in high latitudes.

Examine the coasts of the continents. In general, which coasts of continents have higher biologic productivity: the east coast or west coast? The west coasts.

The centers of the subtropical gyres have the lowest biologic productivity values. Why? The centers of the subtropical gyres are areas of downwelling. They are areas of downwelling because water is piled up there (the “hills of seawater”) due to Coriolis and Eckman effects in the gyres. See the diagram above.

Why do the equatorial regions have productivity values that are higher than the centers of the gyres? Because upwelling does occur along the equator as the water moves away from the equator towards the gyres. See diagram above.

El Niño

El Niño is defined as the warming of the eastern equatorial Pacific. Under typical conditions, the waters off the west coast of equatorial South America is relatively cool (fig to left), high pressure dominates in the western equatorial Pacific (see figs at beginning of exercise), and the trade winds blow strongly to the west.

During El Niño conditions (fig to right) the eastern equatorial Pacific is abnormally warm, the low pressure system moves eastward, and the trade winds weaken.
Whereas the previous figures showed actual sea surface temperatures (SST), these figures show sea-level height anomalies, from which SST anomalies may be inferred. Anomalies are the difference between the observed sea-level height or temperature and the normal (average) sea-level height or temperature. The white areas indicate sea level 13-30 cm (5-10 inches) above normal. These figures show the development of the 1997-98 El Niño, which is one of the strongest on record.

Why would warmer water produce a sea-level height anomaly?

Warm seawater has a lower density than cooler seawater. Because the mass of the seawater doesn’t change, the volume increase.

Considering the above figures, are there any signs of an El Niño event in the inferred SSTs in March of 1997?

Very little

As the El Niño event developed in October of 1997, what happened to the SSTs in the western Equatorial Pacific?

The SSTs in the western Equatorial Pacific got cooler. During an El Niño event, as the eastern Equatorial Pacific gets warmer, the western Equatorial Pacific gets correspondingly cooler.

To investigate some of the causes and effects of El Niño, it is useful to get a 3-dimensional view of the oceans by looking at temperature-depth profiles in the equatorial Pacific.
**Historical Records of El Niño events**

The diagram at bottom is from MBARI. It shows temperature and salinity profiles contoured against time from a Monterey Bay location very close to where we took our second CTD cast. The lowermost diagram is a measure of density, which is calculated from temperature and salinity.

Draw arrows that show upwelling events on these diagrams. Your arrows should be wherever cold salty water reaches shallower depths.

During what time of year does upwelling occur in Monterey Bay? Is it the same as in Peru?
**Difficult to tell exact months, but in general the Spring time, perhaps February-July. Not the same as Peru.**

Does upwelling bring higher salinity or lower salinity water to the surface?
**Higher salinity water.**

Can you find the 1997-98 El Niño event on the Monterey Bay record?
**Yes, it is a big event where warm water extends to deep levels.**

Can you find the 1991-92 El Niño event on the Monterey Bay record?
**It shows up much more strongly at the end of 1992, especially in the salinity data.**

During what time of year is biologic productivity likely to be highest in the Monterey Bay area?
**During upwelling events; the Spring time—Feb-July.**

One question that remains is why deep Monterey Bay water is saltier than surface Monterey Bay water. There are at least two possibilities:

1) Evaporation during the summer creates salty water at the surface that then sinks.
2) The southerly flowing California Current introduces low salinity over the higher salinity water.

Which one of these possibilities is more likely to be correct? Please explain why.
**Southerly flowing California Current introducing low salinity water is more likely. If evaporation in the summer created saltier water, we would see warm salty water at the surface. Instead, we see warm, low salinity water at the surface, which counters predictions of the summer evaporation hypothesis.**