CHAPTER 8

SEAWATER; OCEAN TEMPERATURE; WAVES; CURRENTS; AND THE EL NIÑO/ SOUTHERN OSCILLATION

8. 1. WATER AND SEAWATER

8. 1. 1. Atoms and Molecules

Everything around us consists of certain kinds of *building blocks* like the hollow blocks used to make our concrete houses. From a distance, a concrete house looks different from the way it looks when we are close. When we are close to a house, we are able to see the single blocks and the concrete that make up the house.

The matter that makes up everything around us is similar to a concrete house. All matter consists of separate particles held together in much the same way that cement holds the concrete blocks together in our houses.

However, these particles are too small for us to see without using special microscopes. The particles that make up all matter are known as **molecules.**

Molecules, like the hollow blocks used to build concrete houses, are made of even smaller particles. These smaller particles are called **atoms**. In some kinds of matter, each molecule consists of the same kind of atom. Pure iron or copper metals, or pure oxygen gas are examples of such matter, since they are entirely composed of only one kind of atom.

Two oxygen atoms joined together form an oxygen molecule. Other molecules may be a combination of different atoms. A common table salt molecule consists of one atom of sodium and one atom of chlorine.

8. 1. 2. Elements and Compounds

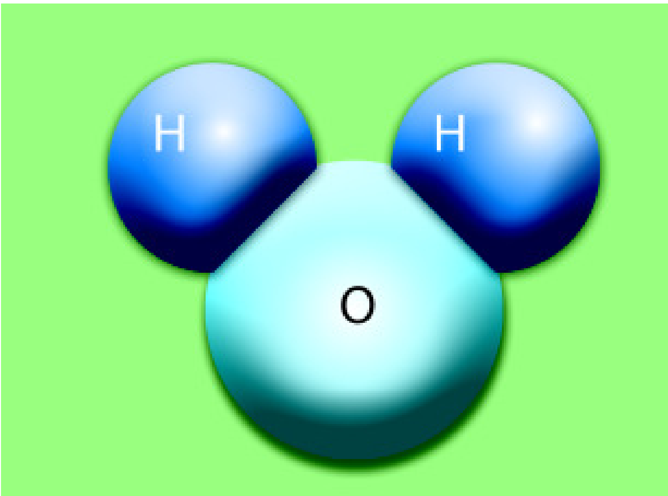
Pure silver, aluminum, mercury, and carbon also serve as examples of matter in which each particle is alike. The particles of these kinds of matter consist of only one kind of atom.

Coins of pure silver only consist of atoms of silver. Matter which has molecules consisting of only one kind of atom is called an **element**. Only a relatively small number of the types of matter on our planet are found as "natural elements".

All seawater is composed of groups of atoms called molecules.

Most matter on earth consists of molecules of two or more different kinds of atoms. Such molecules are called **compounds**. There are thousands of compounds found in or on the earth.

Consider water. By just looking at water, it is impossible to determine whether it is an element or a compound. We now know, however, that water is a compound.



The space-filling model of the water molecule resembles "Mickey Mouse."

8. 1. 3. Composition and Phases of Water

A water molecule is made up of atoms of the elements **hydrogen** and **oxygen**. Hydrogen and oxygen by themselves are normally gases. However, when two atoms of hydrogen combine with one atom of oxygen, they form the chemical compound *water*.

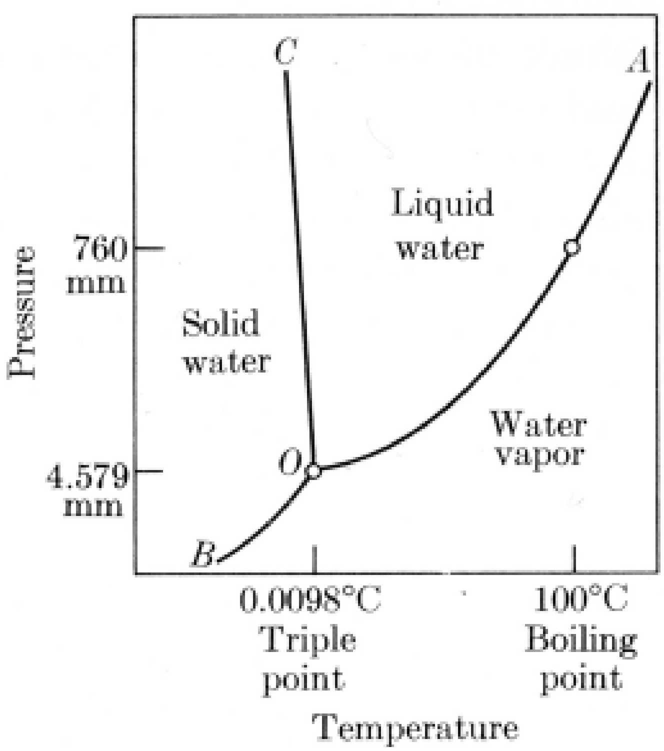
The symbols "**H**" and "**O**" are used to represent these two gases. A molecule of water is represented by the formula "$\mathbf{H_2O}$."

Water is present all around us. In fact, our bodies are 80% water. The water around us does not always look the same. We cannot even see some water around us since much of it is invisible.

Water exists in several phases (see below). Some water is liquid. Some water is solid, in the form of *ice*—as is found in our freezers. Some water is in the form of a gas. Water as a gas is called **water vapor**.

Water vapor cannot usually be seen. We become aware of water vapor as the air containing it begins to cool. As air cools, water vapor forms tiny droplets of liquid water which might form steam or clouds. Clouds and steam are easily seen. Most water vapor, however, is invisible.

The term **phase** refers to the form in which matter occurs. Ice is the solid phase of water. Water, as we know it, is the liquid phase of water. Water vapor is the gaseous phase of water. In each phase, water appears different, but is still made up of water molecules. Each of these are made up of two hydrogen atoms and one oxygen atom.



At any one time, water can be found in a particular location on earth, possibly even occurring in all three phases. This characteristic or property of water is very unusual.

At any one time, water can be found in a particular location on earth, possibly even occurring in all three phases. Take, for example, a person drinking a glass of iced tea here in the tropics. They breathe humid air containing many water vapor molecules. They drink liquid water (tea) and their lips may touch the solid chunks of ice. This characteristic or property of water is very unusual. Of all the matter found on earth, water is the only one with this property of occurring in all three phases simultaneously.

Water also changes from one phase to another. We know that adding heat to ice causes the ice to melt. When ice melts it changes into water – a solid becomes a liquid. Adding more heat may cause it to boil.

The steam produced by boiling shows a change from a liquid phase to a gas. How does water vapor change back to a liquid? (Hint: *adding* heat changed the ice to water, and then into steam; therefore....)

8. 1. 4. Where does Water Come From?

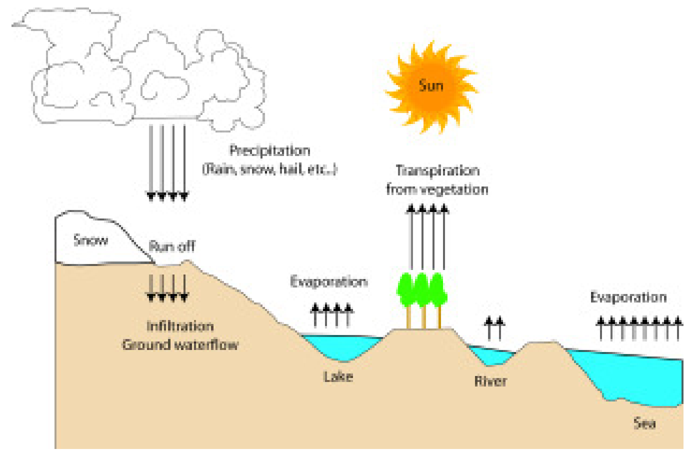
Suppose we were asked, "Where does water come from?" If we said that water comes from a river, we would only be partly correct. This answer only leads to another question. Where did the water in the river come from? If we said that the river water came from rain, we would again be only partly correct.

But, where does the rain come from? A good answer to this question would be the oceans. Clouds form over the ocean as water evaporates (or changes into water vapor). But, where does the water in the oceans come from? Looking at a map suggests that the ocean water comes from rivers, but this obviously cannot be the solution to the question.

Suppose that we tried to draw a picture of where drinking water comes from. Our drawing would show that water molecules come from all over the globe! Our picture would show that water from the ocean rises into the air when it evaporates.

The energy of the sun causes ocean surface water to evaporate (by adding heat to the ocean). This water vapor then condenses around condensation nuclei—usually salt crystals—to form clouds. As clouds gather more and more moisture, they become full of water.

This water eventually falls back to earth as rain or snow. Much of this rain becomes run-off and eventually returns to the oceans. Water flows through such a path repeatedly. The path is called the **water cycle.**



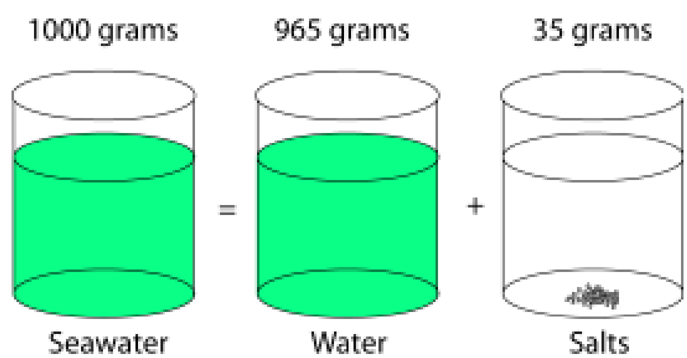
The water cycle

8. 1. 5. Composition of Seawater

We have all tasted ocean water (usually unintentionally) and we all know that it is very salty. However, think about what makes the ocean salty.

Sea water contains many different kinds of salts. About 75% of the total salt content of sea water is sodium chloride (NaCl). Sodium chloride is the name of the salt commonly used as table salt. How much of a one-liter sample of sea water is made up of salts? In every 1,000 grams of seawater, there are about 35 grams of salts. This 35 grams of salt is divided between many different kinds of salts. Sodium chloride makes up approximately 27.2 grams.

Magnesium chloride composes 3.8 grams. Magnesium sulfate and calcium sulfate each amount to approximately 1.5 grams. Potassium sulfate, calcium carbonate and magnesium bromide all are less than 1.0 gram each, in our one liter sample.

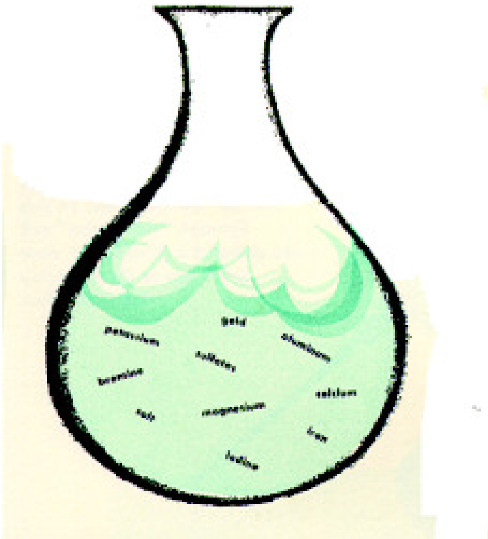


Average total of water and salt grams in seawater.

The total amount of salts in a sample of sea water averages 35 parts per thousand. This is often written as 35 ppt or 35 0/00. The term **salinity** refers to the total amount of salts in a sample of water.

8. 1. 6. Where do Ocean Salts Come From?

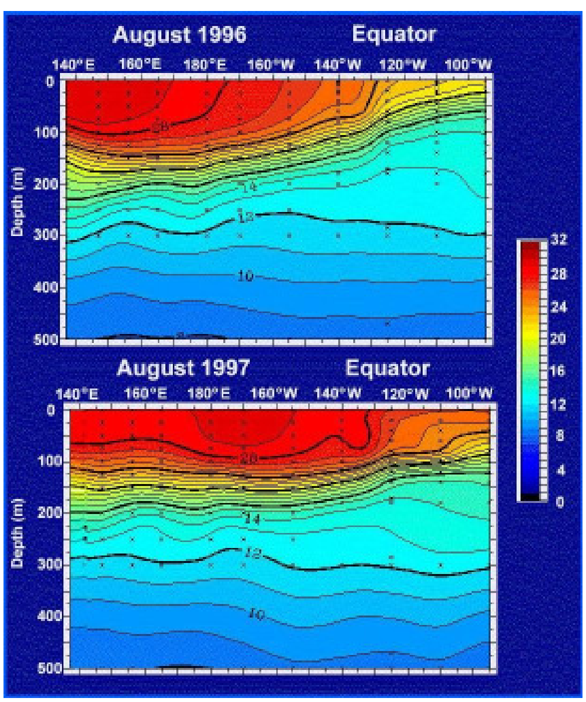
Most of the salts in the ocean come from land masses. These salts come from the soil and rocks on the land. The salts in soils and rocks are slowly washed into the oceans by water runoff, and by groundwater that seeps into the ocean through the earth's surface.



Composition of Solids in Sea Water

Nonmetals	%
Chlorine	55.0
Bromine	0.2
Sulfates (SO_4)	8.0
Carbonates (CO_3)	0.2
Metals	
Sodium	30.0
Potassium	1.1
Calcium	1.2
Magnesium	4.0
Other	0.3
Total	100.0

Composition of solids in seawater



Thermoclines in an El-Nino and non-El Nino year

Year after year, salts are carried into the oceans this way, yet the salinity of ocean water remains fairly constant over time. With salts continually washing into the oceans, how does it remain at a constant salinity? The freshwaters added to the ocean by rivers and rain water help the oceans to retain a constant salinity. Additionally, excess salts are part of the seafloor beds which subduct at deep ocean trenches through plate tectonics. (Remember this from Chapter 4?).

When a salt or other substance is added to a liquid, it may **dissolve**. We say it goes into **solution**. Ocean water has a number of different elements and compounds in solution. Oxygen, carbon dioxide, and nitrogen are dissolved in seawater and are available to most marine life requiring these essential elements and compounds.

Ocean waters are often low in dissolved silica, phosphorous, and sometimes even calcium. This is because marine life forms use these elements in their life processes.

Many marine plants and animals use calcium or silica to form bones and shells. Common examples of these are the diatoms, which are tiny marine plant-like protists; shrimp and other crustaceans; and corals and seashell-forming mollusks.

Diatoms use silica to make external coverings that help them to float and protect them from predators. Crustaceans, corals and shell-forming mollusks use calcium carbonate to make their hard skeletons.

The ocean is a storehouse of dissolved minerals. Some of these are presently being mined from the oceans. Sodium chloride, magnesium, and bromine are some of the common minerals that are currently being extracted from the oceans today. The oceans house other potential mineral resources for future utilization. (See our Chapter 12 for more on open ocean resources.)

8. 2. OCEAN TEMPERATURE

8. 2. 1. Introduction

Temperature plays an important part in the characteristics of each of our world's oceans. Oceanic temperatures are commonly between 0°C [32°F] and 30°C [86°F]. There are, however, areas in which oceanic temperatures are even warmer, and areas in which the temperatures are even colder than these.

We know that the freezing point of freshwater is 0°C [32.0°F]. However, the freezing point of seawater is minus -2°C [28.6°F]. The lowered freezing point is due to the salts present in seawater.

Shallow seas and coastal waters are usually warmer than the middle of the ocean. This is because shallow seas and coastal waters, like the water in Saipan's lagoon, are not very deep. They can be heated much more quickly and easily by the sun than the deep ocean can. Also, the water does not circulate as much in these shallow waters.

8. 2. 2. Temperature Layers and the Thermocline

In parts of the ocean where the water is deep, there are usually invisible temperature *layers*. The first layer is at the surface. It is called the surface layer. This layer may be up to 200 meters thick. The water in this layer is warmed by the sun's rays. Because of surface currents and heat from the sun, the water in this layer is well-mixed.

Below the surface layer is the **thermocline**. This is a relatively thin layer of water, varying in depth at different locations. The temperature of the water drops very quickly as we go below the thermocline. We might think of the thermocline as the boundary between the warm water above and the cold water below.

Below the thermocline layer is the cold water layer. This colder water usually stays below the thermocline. As we might guess, the temperature in the ocean becomes colder the farther down we go. (An exception to this is discussed below in 8. 4. 3.)

8. 2. 3. Effects of Ocean Temperature

As the cold and warm ocean waters move about, they affect the climates all over the earth. This ocean temperature effect will be discussed in more detail later in this chapter.

The cold and warm waters also affect many marine animals. Many marine animals migrate great distances to find the right temperatures for giving birth and protecting their young. For example, many whales migrate to warm tropical seas to give birth to their young calves.

Although coral polyps do not migrate, they can only reproduce in warm water like the water found in the Mariana Islands. The relationship of corals and sea temperature will be discussed in our chapters on Limiting Factors (Ch. 11) and Coral Reefs (Ch. 13).

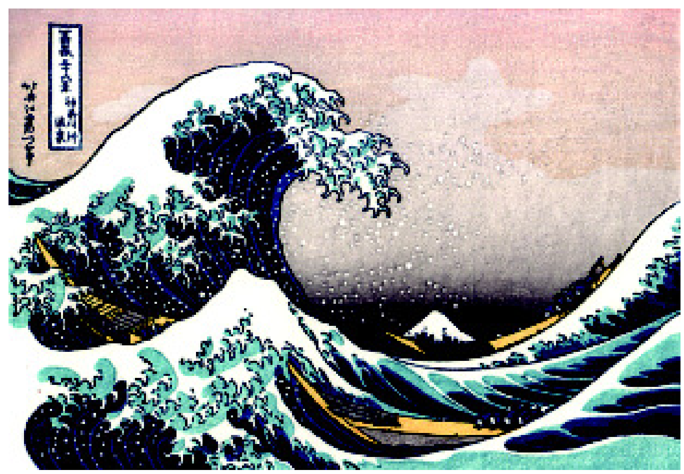
Temperature levels, gravity, and wind are only some of the causes for our moving ocean.

8. 3. WAVES AND TIDES

8. 3. 1. Wind-caused Waves

The ocean is in constant motion. There are many forces working to keep ocean water moving. Temperature levels, gravity, and wind are only some of the causes for our moving ocean.

We have all watched waves break over the reefs and on the beaches of our islands. Most waves are wind-driven. The wind blows across a large body of water, making small ripples at first. Larger ripples may form and begin to grow larger and larger under windy conditions. Soon a wave is born.



An ancient Japanese painting of a tsunami. Tsunami is a Japanese word meaning "harbor wave".

The size of a wave depends on how hard and how long the wind blows. The size of a wave also depends on the distance the wind blows over the water.

For example, waves caused by winds blowing across the immense Pacific Ocean are usually much larger than waves caused by wind blowing across Saipan Lagoon. It follows, then, that the waves caused by wind blowing across a small lake such as Lake Hagoi on Tinian are usually smaller than the waves in Saipan Lagoon.

8. 3. 2. Tsunamis

Although wind-driven waves are the most common waves, there are other forces that drive waves in the ocean. Waves can also be caused by earthquakes, volcanic eruptions, and landslides that take place underwater.

We might think of each earthquake, landslide or eruption as creating a kind of *shock wave* in the water. These waves are similar to the waves created when a rock is thrown into calm water, only much, much larger.

A **tsunami** is a wave that is usually caused by an earthquake from the tectonic movement of the ocean bottom. *Tsunami* is a Japanese word meaning "harbor wave". Harbors and coastal inlets are common places for tsunamis to have their greatest destructive effects. In deep water, a tsunami would have a wavelength from crest to crest of nearly 200 kilometers, but would be less than 1 meter in height. It is extremely fast moving, attaining speeds of as much as 500 miles per hour.

When an earthquake, landslide or volcanic eruption disturbs the ocean floor, a tsunami may form.

When a tsunami strikes a coast, however, a height of 100 feet or more can be quickly reached, as its long wave energy is transformed into rapidly rising water. Tsunamis are often experienced by those ashore as rapidly rising water (similar to a rising tide but much, much faster).

This immense coastal wave bulge is capable of severe destruction. As the tsunami approaches the shore, tidal changes of 18–20 meters may occur within ten minutes. The vertical height that a tsunami reaches is called its *run up*. The horizontal distance inland that a tsunami reaches is called its *inundation*.

The Dec. 26, 2004 tsunami that struck coastlines of the Indian Ocean was widely documented on video. It devastated communities and killed over 250,000 people.

Massive destruction of Hilo, Hawaii by a tsunami.

In 1849, a tsunami devastated many atoll islands of the Western Carolines, and even had a recorded effect on Guam. There is no record of it or any other tsunami affecting the CNMI. You will recall however from our history chapter (Ch. 2) that hardly anyone lived in our islands at that time. Our barrier reefs and steep offshore dropoffs tend to provide us good protection against tsunamis.

Occasionally, very large waves have come ashore unexpectedly. These have caught fisherfolk and hikers unawares, resulting in several deaths. It is unknown if these were actual tsunamis. Several tsunami alerts have been issued in recent years with no visible effects.

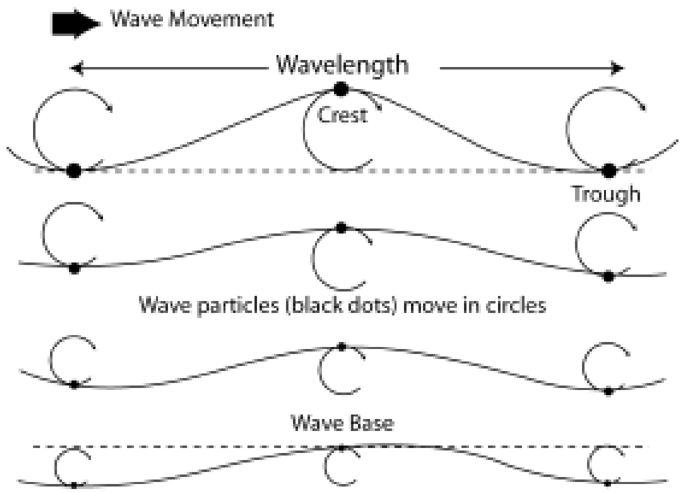
Still, when walking along the coastline, always keep one eye on the ocean and always be prepared for emergencies. Immediately seek high ground if you see that suddenly the water level lowers quickly. It will soon be replaced by a large wave.

Tsunamis are often referred to as "tidal waves". This is a misnomer, however, since the cause of ocean tides is not related to tsunamis. Tides are an effect of a wave, however. In fact, a tide is a very big wave, as we shall soon see.

There have been recent developments in tsunami prediction capabilities. Open ocean sensors are being placed and maintained off the coasts of Hawaii and other tsunami-prone locations.

8. 3. 3. Wave Energetics

As we watch waves move in the middle of the lagoon or ocean, we might think that a large amount of water moves with each passing wave. Actually, very little water moves. If we watch a fisher's float as it moves with a wave, we see it always returns to just about the same place. This is true, of course, unless there is also a current moving in any one direction.



Wave particles (black dots) move in circles.

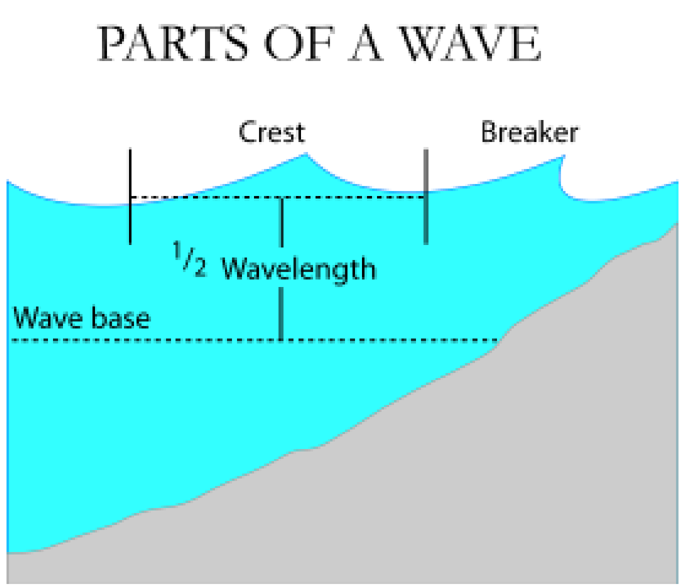
Water in waves moves up-and-forward and down-and backward with each passing wave. In deep water waves, water molecules move in a circle, moving from a high to a low point and back again. Each time these molecules move slightly forward and each time slightly backwards. The diameter of the circle is equal to the **wave height**.

Wave energy is passed from water molecule to water molecule. Wave motion passes forward, but the particles ultimately stay in their same relative positions. Wave energy is also passed downward from particle to particle. As the motion is passed downward, the circles become smaller and smaller.

The figure to the right illustrates the circular motion within waves, and the decrease in the size of the rotations with depth. Finally, at a certain depth, motion stops. The depth at which motion stops is the **wave base**.

8. 3. 4. Wave Dimensions

All waves at the surface have the same general shape as they move. The high point of the wave is the **crest**. The low point is the **trough**. The distance from any crest to the next crest or from any trough to the next crest or trough is called its **wavelength**.



Parts of a wave

8. 3. 5. Wave Frequency and Period

Another word used to describe waves is **frequency**. Frequency is the number of waves that pass a certain point in a certain amount of time. We say that waves have a high frequency when a great number of waves pass a certain point in a given amount of time. Waves have a low frequency when only a few waves pass this point in the same amount of time.

Wave period is the time it takes two successive crests to pass a given point.

Frequency relates to the number of waves whereas wave period relates to the time between each wave.

8. 3. 6. Wave Energy and the Breaking of Waves at Our Shorelines

As ocean waves move, they have a certain amount of energy. This amount of energy depends on the height of the waves, the frequency of the waves, and their wavelengths.

As waves enter shallow water, their frequency becomes lower as they adjust to the shoreline. No matter from which direction a wave arrives, it always adjusts itself and breaks along the shore more or less parallel to the shoreline.

The part of the wave closest to the direction the wave comes from begins the breaking, and once started it is carried continuously along the shoreline.

The condition of many waves breaking along a shore is called surf.

Waves break partly because the lower part of the wave (the wave base) touches the ocean bottom, so that the wave loses some of its energy. Actually the wave is transferring its energy to the shoreline. Sand particles move, coastal rocks shake, and the solid mass of the coast absorbs some of the wave's energy.

Also, water returning from the shore (as counterwaves) interferes with incoming waves, causing them to lose more energy. When this happens, the crest of the wave overtakes the trough, and the wave breaks. Such a wave is called a **breaker**. The condition of many waves breaking along a shore is called **surf**.

8. 3. 7. Tides: Two Constant Global Waves

All along most coasts of the one great world ocean, water levels rise and fall, usually twice each day. Each rise in the water level is called **high tide**. Each fall in the water level is called **low tide**. The moving water of a tide is sometimes called a **tidal current**.

In order for the tides to take place, large amounts of water must be moved. This movement of water is caused chiefly by the gravitational forces of the moon and sun pulling on the water of the ocean.

The moving water of a tide is sometimes called a tidal current. A tidal gauge, Guam.

At this point we should recall the two basics of Newton's Universal Law of Gravity, *"(1) Mass attracts mass; the greater the mass, the greater the attraction, and (2) the greater the distance between the masses, the lesser the attraction."*

When we throw a ball into the air, instead of flying off to the moon it returns back to earth because the gravitational attraction of the earth is greater than that of the moon and the ball is closer to the earth. The moon does, however, have a gravitational pull on our planet. So does the sun.

Because of the moon's **gravitational field**, a bulge of the ocean's water always faces the moon. A second lesser bulge, caused by **centrifugal force**, forms on that side of the earth opposite from the moon. Centrifugal force is the force that causes moving objects—in this case the ocean water turning with the earth's rotation—to move away from the center of rotation, the earth. Water to fill these bulges is drawn from the area of ocean between the bulges. Water is also drawn towards the equator from the poles.

The **rotation of the earth** forces all coastal locations on our planet to pass in sequence through these two bulges. These coasts also pass through the lower between-bulge troughs—two highs, and two lows every 24 hours. In this special sense, the bulges and their troughs, with the earth's turning, form two big global waves.

Tides, then, are the observed effects of two constant global ocean waves—caused by the gravitational attraction among the earth, the moon, and the sun, as well as the earth's rotation. The sun is important because it is so massive, although relatively distant.

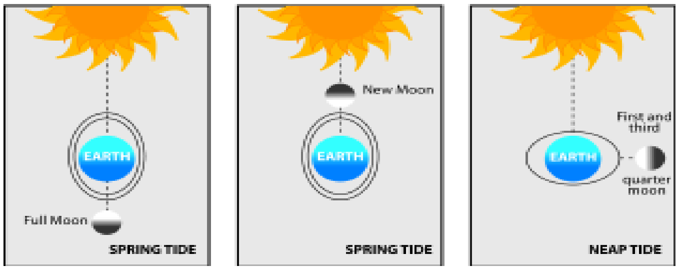
The moon, however, is even more important (influential) because relatively it is so close, even though it is also relatively very small.

In most coastal areas there are two high tides and two low tides each day. In some places there may only be a small change in the water level. However, in other places, such as narrow bays, the difference between high and low tides may be quite large.

In the Bay of Fundy, a large inlet along the northeastern Atlantic coast, between Nova Scotia and Maine, the difference between daily high and low tides may be more than 20 meters (60 feet). Here in the Mariana Islands, the daily **tidal range** is usually about 1 meter, (3 feet).

8. 3. 8. Tidal Cycles

Tidal bulges remain in nearly the same position in relation to the earth, moon, and sun. As mentioned, during one 24-hour period, different locations on earth pass through the high and low positions. A complete tidal cycle takes about 24 hours. During the 24 hours of the earth's rotation, the moon moves slightly past the position from when the rotation started. For this reason the times of our tides vary slightly from day-to-day.



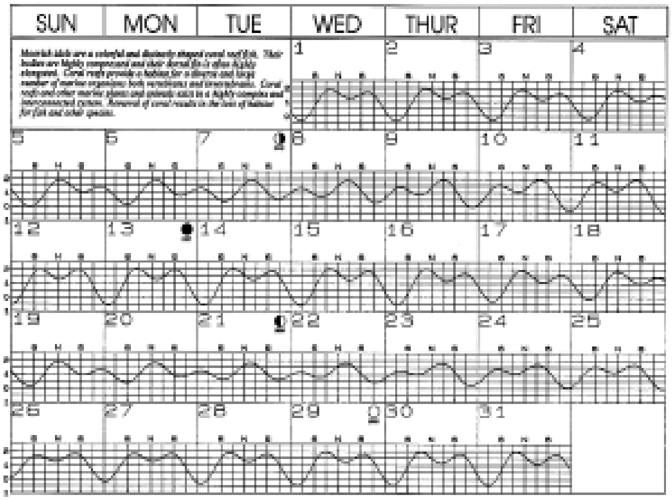
Spring tides and neap tides.

Spring Tides

The sun's gravity has a lesser effect than the moon's because the sun is farther from the earth. Remember that attraction between two bodies lessens as they move farther apart.

During each lunar month's full moon and new moon, the moon is oriented in line with the sun and the earth. When this happens, the sun's attraction adds to the moon's. Since the sun's attraction adds to the moon's attraction, the tides are especially high and especially low.

This is because the bulges of the oceans' water facing directly towards and away from the moon are extra big and the between-bulge troughs are extra thin.



A month's depiction of tides.

These maximum, semi-monthly extra high and extra low tides are called **spring tides**. Do not confuse these with the solar season of spring. The word "spring" is the same, but, in this regard, it has two very different meanings. Remember that the spring tides occur twice each month during the full moon and new moon positions.

Neap tides

Neap tides, or minimum tides, also occur twice each lunar month. Neap tides happen when the sun and moon are at right angles to each other. Their forces of gravity are then pulling in different directions and the tidal range is at its smallest.

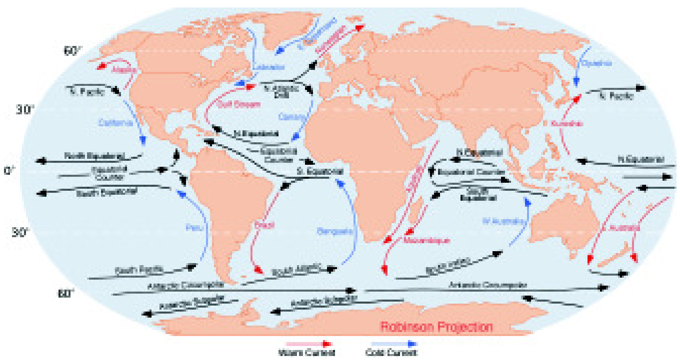
The two bulges of ocean water are less pronounced and the between-bulge troughs have higher water levels. Neap tides occur during the two monthly half moon positions.

8. 4. CURRENTS

The term **current** refers to any large-scale sustained movement in a body of water. There are several different forces driving the large-scale oceanic currents. Try to identify these forces as you read each section below.

8. 4. 1. Surface Currents

One kind of current that moves in surface waters is caused by the wind. This current is known (naturally!!) as a **surface current**. Because winds cause surface currents, these currents have circulation patterns similar to those of the atmosphere.



Because winds cause surface currents, these currents have circulation patterns similar to those of the atmosphere.

Thus, when our east-to-west trade winds blow across the CNMI, the general direction of the surface currents around our islands is also from east to west.

The kinds of winds that have the greatest effect in creating surface currents are **prevailing winds**. Prevailing winds from the east towards the west are found at latitudes 10°-30° north and south of the equator.

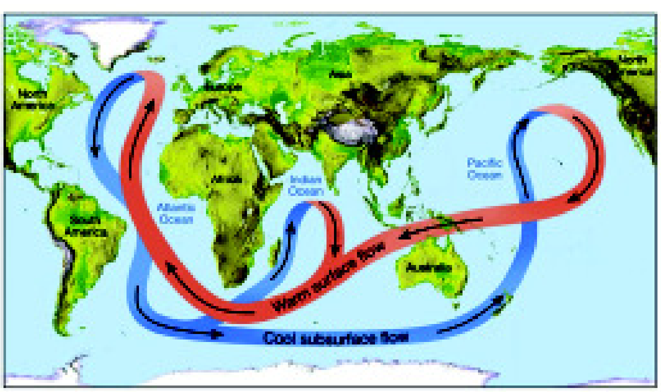
Our Region's Three Major Surface Currents

These winds also help create the **North Pacific Equatorial Current**. This current moves in a westerly direction across the northern tropical Pacific region. This current affects the southernmost Mariana Islands.

It then curves northward off the coast of Eastern Asia becoming the **Kuroshio Current**. West-to-east winds occur at our northernmost islands of Uracas and Maug. There, a surface current, the **North Pacific Counter Current**, moves in the same direction as the winds, from west to east.

8. 4. 2. Deep Ocean Currents

A certain volume of cold water weighs a little more than an equal volume of warm water. We say that cold water has greater **density** than warm water. Because cold water has greater density, it sinks. Warm water, being relatively light (less dense), rises.



Close to the ocean bottom, the deep water movement is from areas of higher density to lower ones. Thus, the movement is from the cooler polar zones to the warmer tropical ones. Depicted here is the world's largest density current, the great ocean conveyor.

In the ocean, water is heated near the equator. As water heats, it becomes less dense, takes up more space, and rises to the surface. This lighter, warmed water, following the prevailing winds, can eventually travel polewards from the tropical regions. This is because the east to west equatorial currents eventually run into continents.

On the other hand, water from areas like the Antarctic and Greenland is extremely cold and dense; thus, it sinks. Deep ocean currents return cold, dense water from polar regions to the tropics.

Gravity drives the deep cold water, and tends to pull the dense water masses downwards, into deep oceanic canyons which lead away from the poles.

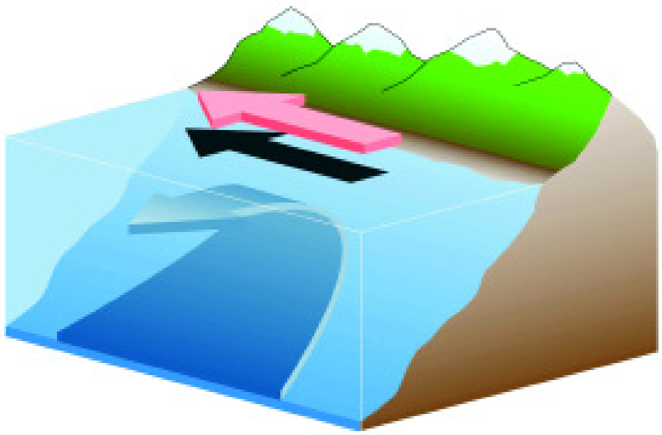
Close to the ocean bottom, the deep water movement is from areas of higher density to lower ones. Thus, the movement is from the cooler polar zones to the warmer tropical ones. *A mass balance* is kept, since the poleward-moving surface currents make up for the deepwater loss at the poles.

This cold, deep water movement is generally referred to as a **density current**. Density currents tend to move below, and in the opposite direction of, surface currents. Density currents flow at a rate of about 20 kilometers a year, whereas surface currents flow at an average rate of 2 kilometers per hour. Water from the poles sinking to the ocean depths might not resurface for perhaps 500 to 2000 years. The largest density current is the **Great Ocean Conveyor**.

8. 4. 3. Upwellings

Some water from these slow moving currents may surface along coastal regions under certain conditions.

Along the west coasts of several continents, trade winds blow surface waters away from the coastline. When this happens, these *blown-away* surface waters are replaced by *upwelled* deeper waters. These rise from depths up to 300 meters below.



Upwelling occurs when trade winds blow surface waters away from the coastline. These blown-away surface waters are replaced by upwelled deeper waters.

The **upwellings** of cold water carry abundant nutrients needed for life, and dense biological activity is generally associated with upwelling regions. One of the most famous upwelling regions occurs off the coast of Peru, and it supports many fisheries.

The upwelling off Peru is not always constant. As discussed below, its variation is the reason for the world climate-affecting El Niño, normal, and La Niña periods.

A somewhat artificial upwelling occurs through the intake pipes of ocean thermal energy conversion (OTEC) plants like the one at Kona, Hawaii. Here the deep cold ocean water is brought to the surface for energy conversion purposes. The nutrient-rich cold water is used in special aquaculture and mariculture projects.

8. 4. 4. Local Density Currents

There are also several different local density currents. These currents may be created by heavy rainfall onto the ocean's surface, by streams and groundwater seeps discharging freshwater into the ocean, and even by sewage treatment plant outfalls.

Because freshwater is less dense (contains fewer salts), it will flow across the ocean's surface. Eventually it will mix into the saltwater, but, for a long time, it remains a separate current flow of its own.

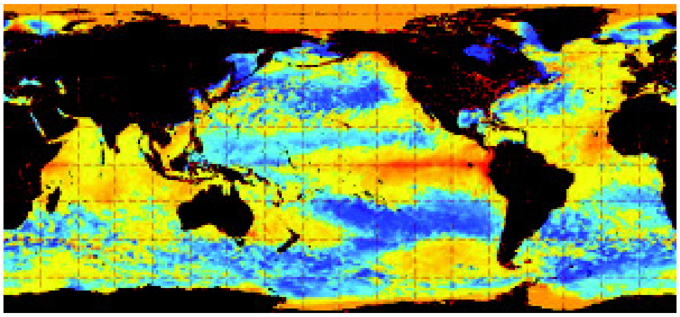
Another type of local density current can be caused when ocean water in a lagoon reaches a higher temperature than water in the surrounding ocean. At high tide, when this warm water is returned to the sea, many small density currents can be created.

Evaporation also causes dissolved salts to be concentrated in a smaller volume of sea water. Some of the ocean water, trapped on a reef flat and in coastal tide pools during low tide, is evaporated by the hot sun. Without additions of fresh rainwater or oceanic water, this trapped water becomes increasingly more dense.

Eventually, the ocean water brought in by the rising tides will flush this denser saline water out, causing another type of density current. These local density currents are often felt (if colder or warmer) and seen by recreational snorklers, scuba divers, and subsistence spear fishers. Coastal water moving in a density current distorts and diffracts light waves, causing a general blurring of visibility.

8. 4. 5. Turbidity Currents

Another type of current is the **turbidity current**. A turbidity current is a muddy slurry of water and sediment that flows downward due to its greater density. Many originate in the head of a submarine canyon and flow down through the canyon and out onto the ocean bottom. Rivers also carry large amounts of sediment during their flood stages. When rivers empty into the ocean, the sediment may continue to flow as rivers of mud, across coastal shelves and down their slopes. These currents have cut many gorges on continental shelves, down the continental slopes, and on the slopes of many submerged volcanoes.



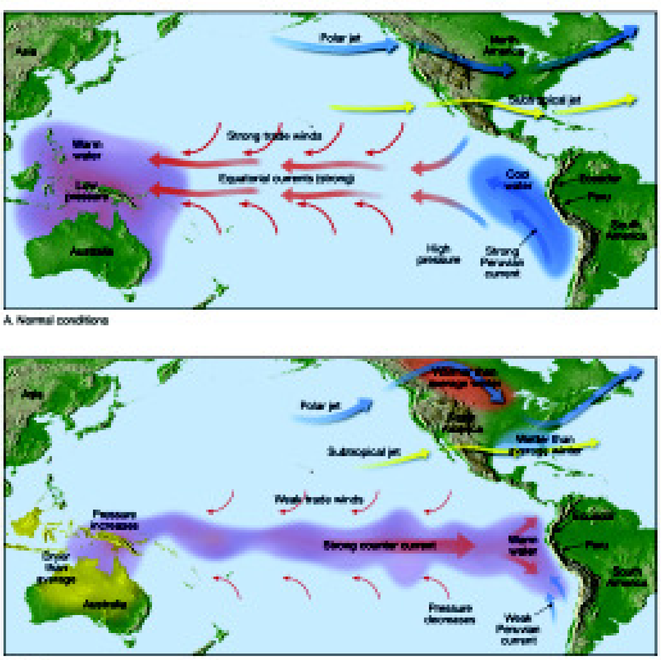
The 1998 El Nino event

8. 5. ENSO; "EL NIÑO"; AND "LA NIÑA"

A special current system that affects upwelling, wind patterns and weather is one in the Pacific, off the western coast of South America. In the 19th century, Peruvian fishermen noticed a warm current that periodically changed fishing conditions in the region around Christmas time. They named this phenomena **El Niño** (Spanish for "little boy" or "Christ child").

An opposite condition, or an abnormally cold current is named **La Niña** (Spanish for "little girl"), the *opposite* of El Niño. Normal temperature years are referred to as "normal periods".

Scientists have found that El Niño events are associated with an "oscillation" (swinging regularly back and forth) of trade wind flow patterns. This is referred to as the **Southern Oscillation**. Most of the time the trade winds blow in one direction, but at other times they oscillate and instead blow in the other direction. Together, the global temperature-affecting winds, currents, and water temperature network is referred to as **El Niño/Southern Oscillation** or, more briefly, as **ENSO**.



Ocean currents are dramatically impacted by ENSO.

8. 5. 1. Importance of ENSO

Much remains to be learned concerning this special system of currents. We do know that many phenomena in the Pacific region and the world are affected by it. In late 1997 and early 1998, the media was full of stories concerning the effects of what was described as an unusually strong El Niño.

Floods and storms in California, drought in Micronesia, including our Marianas, and predictions of poor fishing in the CNMI were forecast for 1998. While the effects of ENSO can be exaggerated, scientists have found that this system can have an influence far from the coast of South America. It turned out that we experienced an unusually good fishing season in the summer of 1998. The extra warm water caused large schools of tuna to stay for a longer period here.

La Niña events in the fall of 1998 and during 1999 led to a relatively early rainy season and fewer typhoons. Those typhoons which formed tended to do so towards our west and posed no threat to us. [Ed. note: 'knock on wood"!]

The whole Pacific Ocean region seems to be tied together in one large system, with ENSO having many effects. The saying "no man is an island, entire of itself" could refer to all humans in the region affected socially and ecologically by ENSO.

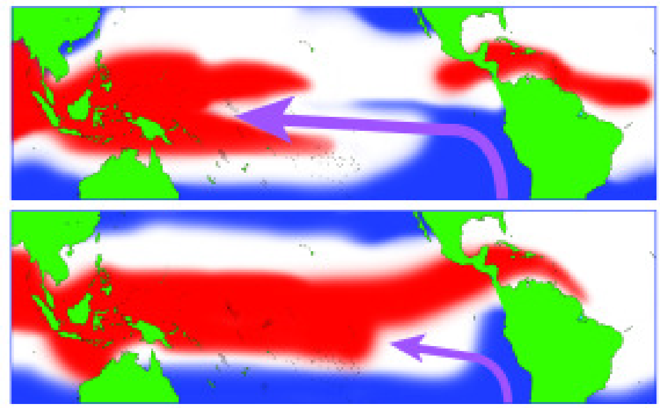
8. 5. 2. Trade Winds and Current Patterns

Winds, currents and upwelling patterns influence one another. In the Pacific Ocean, prevailing winds, called the “trade winds”, blow in a generally east-to-west direction. As they blow, ocean water is moved. This creates currents and regions of upwelling.

Temperature differences in the ocean cause winds and produce patterns of rainfall. All of these factors interact with one another as shown in the diagram to the right, which is a simplified model.

However, the strength of trade winds and the pattern of currents can change. During years when trade winds are strong, surface water is blown away from the South American coast. As surface water is blown away, deeper cold water rises as an upwelling.

This rising water brings dissolved nutrients from deep ocean layers to the surface, producing highly productive conditions and good fishing. Along the coast of Peru, these were considered to be the *normal* conditions.



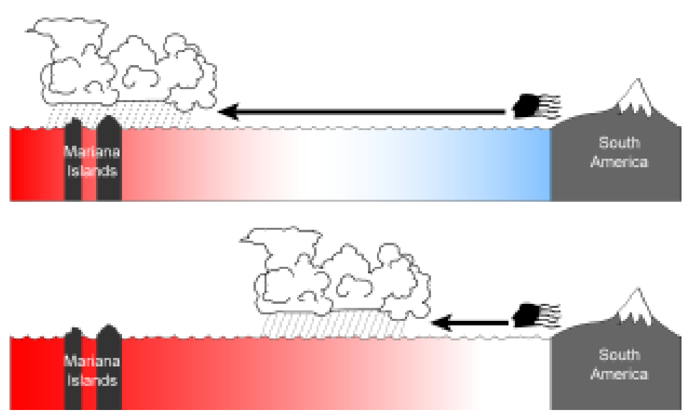
Varying rainfall patterns due to temperature changes

As mentioned and for unknown reasons, the trade winds blowing from east to west sometimes weaken and on occasion, even reverse themselves. When the trade winds weaken, surface water is not blown away, and upwelling becomes less strong. With less upwelling, surface temperatures are not as cool, and fewer nutrients move to the surface.

Plankton productivity then decreases, so fishing becomes poor. The warm surface water and poor fishing were recognized by South American fishermen. As mentioned, the name El Niño came about because these conditions were seen every several years, around Christmas time.

8. 5. 3. Rainfall Patterns and ENSO

As trade winds become either stronger or weaker, rainfall patterns also change in the Pacific. The diagram to the right is a simplified model of this pattern and how it might affect some of the Pacific island regions.



Trade winds affect rainfall patterns.

When there are strong trade winds, rainfall in the western Pacific is relatively high—these are the “normal” years. Because our Marianas Islands are in the western Pacific, the normal years are a time of abundant rainfall for crops.

On the other hand, the El Niño pattern has weak trade winds and rainfall is relatively low in the western Pacific. These are expected to be years of drought in much of Micronesia. Crops might fail and water rationing might be needed. The El Niño pattern repeated itself in 1997, and drought was experienced in many parts of Micronesia during 1998.

The effects of an El Niño period along the west coast of South America are quite different. Near Peru, an El Niño period will mean that warmer weather pushes aside the usually cold Humboldt Current near the coast. Rainfall patterns also change, so that usually dry desert regions receive large amounts of rainfall.

Farmers in desert regions of South America, for the most part, welcome the additional rainfall brought by an El Niño period. However, the increased rainfall can also bring flooding and increased soil erosion.

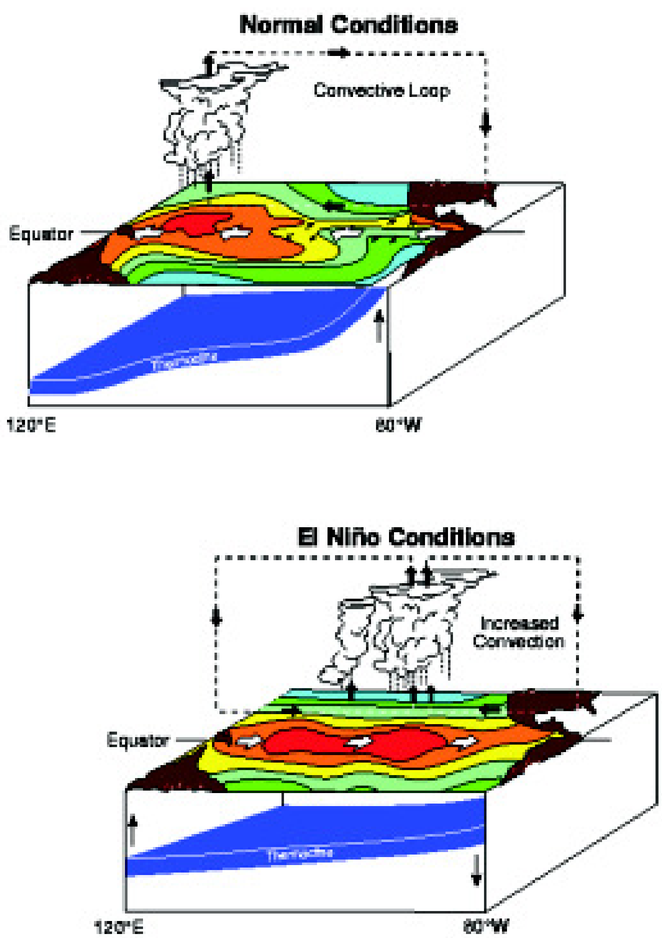
8. 5. 4. Upwelling and Ocean Temperature Changes

During an El Niño period, weakened easterly winds do not push surface water into the western Pacific as much as usual. Instead warm water and their resulting rising air currents stay farther east. This produces more rainfall in the central Pacific and less rainfall in western Pacific.

Warm water also moves into the eastern Pacific, changing the usual upwelling pattern so that fewer nutrients move to the surface. As mentioned fisheries are affected by this, so that South American fishing catches are reduced. Those in Peru who live off the resources of the sea might not welcome the changes brought by El Niño in the Pacific.

Wind pattern changes can cause ocean surface temperature changes, but changes in ocean surface temperature can also cause changes in wind patterns. Oceanographers use **sea surface temperature** (SST) measurements to detect the possible development of an El Niño or La Niña event.

Weather satellites and a series of ocean buoys can detect movement of warm water out of its normal position. As warm water moves towards the eastern Pacific, an El Niño pattern may develop. If it is unusually cold, it could signify a La Niña year.



During an El Niño period, easterly winds are weakened and warm water moves into the eastern Pacific, changing the usual upwelling pattern.

8. 5. 5. Micronesia and El Niño

What are the effects of an El Niño pattern on Micronesia? The models are still incomplete, and predictions are uncertain. At the time we first began writing this book, some meteorologists had predicted poor fishing, lower rainfall, and lower sea levels in many parts of Micronesia.

Using updated models, UOG meteorologists Charles Guard and Dr. Mark Lander of the Water and Environment Research Institute very accurately predicted Micronesian rainfall totals for the 1997-98 El Niño. This led to good public warnings and strict water conservation measures.

In 1997, public utilities in the CNMI began to monitor water use and to warn households that they must repair pipes and stop leaks. Farmers were cautioned to prepare for drought by planting crops that require less water. The atoll Micronesian islands to our south suffered a severe drought; however, leaders were alerted, preparations were made, and relief agencies were called upon to provide emergency services. The period of 1982-83 had a strong El Niño event; but 1997-98 had an even stronger one.

While humans cannot change the conditions that cause El Niño events, research scientists have developed models and gathered data that allow us to know they are coming. This then allows us to prepare for possible crises.