This satellite photograph shows the typical pinwheel structure of a hurricane (Hurricane Lili over the Gulf of Mexico, October 2002).

Hurricanes are oceanic storms. They form over tropical oceans when huge amounts of warm water evaporates into the atmosphere. When that vapor condenses and falls as torrential rains, heat is released into the atmosphere, creating a region of rapidly rising air and low atmospheric pressure. Air spirals rapidly into the area of low pressure, creating tremendous winds. Damage from wind, rain, and flooding follows the path of a hurricane.
In this lesson we consider the following topics related to coastal ocean processes:

- Wave processes and shore erosion
- Estuaries
- Hurricanes
- ENSO (El Nino - Southern Oscillation)

**WAVES & SHORE EROSION**

- Most ocean waves are caused by wind. Wave size increases with increasing wind speed, duration, and fetch -- the distance of ocean surface over which the wind blows.

- Waves hitting the shore at an angle cause a longshore current - flow of water along the shore in the direction of the waves. The longshore current and waves together cause littoral drift - the movement of sand along the shore in the direction of the waves. When human structures stop sand carried by littoral drift, shore erosion results.
Summary of Important Concepts, continued

- Two coastal regions subject to particularly severe erosion are **barrier islands** (common on the U.S. east coast) and **sea cliffs** (common on the U.S. west coast).

- Human activities contribute to shore erosion.
  1. **River dams** trap sand that would otherwise be carried down rivers to the shoreline. This cuts off one of the main supplies of new sand to beaches.
  2. **Jetties, groins, and breakwaters** stick out from the shoreline and block sand moving by littoral drift. The result is shore erosion on the downstream side of the structures.
  3. **Seawalls and revetments** cause breaking waves to bounce hard back toward the sea, carrying sand with them.

- **Mitigation** of shore erosion may be accomplished by:
  - **beach replenishment**: adding sand to eroded beaches
  - setting structures (houses, roads) far back from sea cliffs
  - designing groins, jetties, and breakwaters so that they allow sand carried by littoral drift to pass through

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Summary of Important Concepts, continued

ESTUARIES

- Estuaries are semi-enclosed basins, protected from the open ocean, where fresh river water and salty ocean water mix. Estuaries are important habitats for many forms of life.
- Many estuaries have either been destroyed or are threatened by human impacts. The main impacts are filling in to create new land; pollution; and fishing and transportation.

HURRICANES

- Hurricanes are storms that form over warm tropical oceans. Air spirals rapidly into an area of low pressure and rises, condenses to rain, and releases heat, causing more air to rise and further strengthening the storm.
- Damage from hurricanes is caused by high winds, flooding due to heavy rains, and flooding due to storm surges: high sea levels caused by converging winds and low atmospheric pressures.
ENS0

- **ENS0** (short for “El Nino - Southern Oscillation”) conditions occur every four to seven years when warm water that normally remains on the western side of the tropical Pacific Ocean flows east across the Pacific and spreads out near South and Central America.
- ENSO causes increased amounts of rainfall, flooding and mass wasting from North America to South America, and droughts in southeastern Asia.
- ENSO can be predicted months in advance by monitoring water temperatures in the tropical Pacific Ocean.
WAVE PROCESSES & SHORE EROSION

Waves form as wind blows over the ocean surface. Waves increase in size with the following factors:
- greater wind velocity
- greater amounts of time that the wind blows
- greater fetch: the distance of water over which the wind blows
In waves far out at sea, in deep water, the motion of water in the waves is circular. As waves move by, the water moves in a circle. You can observe this by watching the way an object (like the seagull in this figure) moves as the wave passes. Such waves are called waves of oscillation. The wave form itself moves, but the water does not have net forward motion -- instead the water travels in circles.
We measure the sizes of waves by:

- **wave height** -- the vertical distance from low point (trough) to high point (crest)

- **wavelength** -- the horizontal distance from one crest to the next crest

Note in this figure the circular motion of the water, and notice that the motion becomes less with depth. At a water depth equal to **half the wavelength**, you can see that there is no more water motion.
Wherever they form out at sea, waves eventually will come into shore. When this occurs some important changes take place. At a water depth equal to half the wave length, the waves begin to \textit{slow down} due to friction with the sea floor. (Recall from the previous slide that water motion in a wave occurs down to a depth equal to half the wavelength. Therefore waves feel friction with the bottom and slow down when the depth becomes half the wavelength.)
The shallower the water, the slower the waves move. This causes the waves to bunch up (wavelengths decrease) and grow taller (wave heights increase). Eventually the waves move slower than the water orbiting within them, causing the waves to tumble toward the shore, or break. Breaking waves are called waves of translation because the water in them moves landward (rather than in a circle), hitting the shore with great force.
Wherever waves approach the shore at an angle, they bend in toward the shore somewhat, because the part of the wave closer to shore, in shallower water, moves slower than the part farther from shore, in deeper water. This bending of waves is called refraction.
When waves strike the shore at an angle, it causes a current of water to flow along the shore in the direction of the waves. This is called a longshore current.

The longshore current, along with the waves breaking on the beach at an angle, cause littoral drift: the movement of large amounts of sand along the shore in the direction of the waves.
The longshore current is like a river running parallel to the shore, in the surf zone. And like a river, if too much water builds up there, the water needs to find an outlet. Excess water often flows out to sea in narrow but powerful currents called rip currents that flow rapidly away from shore.

Rip currents may be hazardous to swimmers who get caught in them and swept out to sea. But rip currents are not too dangerous if you keep your head. Don’t try to swim against the current. Swim parallel to shore and you will soon exit the narrow current and be able to swim back!
This photograph shows the waves hitting the beach at an angle. Therefore the direction of the **longshore current** (the movement of water) and the **littoral drift** (the movement of sand) is along the beach toward the viewer. We measure littoral drift by the volume of sand moved in cubic meters per year or cubic yards per year.

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Littoral drift builds up very large features over time. In this photograph of San Diego, you can see the large sand spit (about 10 miles long) called Coronado Island, that encloses San Diego Bay. The sand spit formed by northward (to the left in the picture) littoral drift of sand from the Tijuana River in Mexico to the south (out of view to the right). San Diego Bay forms an excellent natural harbor as a result, and is the main reason why this area is a major U.S. Navy base.
Human structures may interfere with the movement sand by littoral drift. In this figure, the rock jetties built to create an open inlet block the movement of sand moving by littoral drift. The sand builds up on one side of the jetties, and gets eroded on the other side because no sand comes along to replace the sand that moves away. The result: severe shore erosion on the “downstream” side of the jetties.
This photograph shows how littoral drift was interrupted by the rock groins that stick out into the water. Sand accumulates on one side and erodes on the other. What is the direction of littoral drift here? (Answer: toward you.)

Shore erosion in this area of coastal New Jersey has caused damage to roads and private property.

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The effect of jetties on littoral drift is dramatically illustrated in this figure. In the 1930s jetties were built at Ocean City, Maryland, to maintain a channel connection to the ocean. The direction of littoral drift here is from north to south (top to bottom in the figure). By stopping the sand from coming south, the jetties deprived Assateague Island of the sand it would normally have received. As a result, the island has eroded and shifted landward by more than half a kilometer in places. (The red line shows the former location of the island.)
**Barrier islands** are some the most unstable and rapidly eroding shoreline areas in the world. Barrier islands are particularly common on the eastern shore of the U.S.. The photograph shows the barrier islands off of Long Island, NY (top) and New Jersey. These islands extend almost continuously south to Georgia. They have been heavily populated in most areas, since they are prime beach-front vacation property! But barrier islands are just piles of sand, and wave erosion tends to cause them to erode and shift toward the mainland over time.
Waves and storms, particularly the hurricanes which commonly batter the southeastern U.S. coast, cause dramatic changes in barrier islands.

This figure shows how Hog Island, Virginia, has changed over the past 150 years, as a result of hurricanes and wave erosion. The dashed lines show the former shorelines of the island. Entire towns, such as the once-thriving community of Broadwater, have disappeared into the ocean as the barrier has shifted toward the mainland.

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Some shorelines, particularly on the western coast of the U.S., are dominated by sea cliffs rather than beaches. The tops of these cliffs form prime real estate. But sea cliffs are subject to erosion by both wave undercutting and mass wasting. How long is that nice ocean view shown here going to last ?!
Sea cliffs that are being actively eroded by waves (top figure at the right) typically have steep slopes due to wave undercutting, with small or no piles of boulders at the base, and the boulders are rounded. This shows that waves regularly crash against the base of the cliff, rounding off the angular edges of the boulders, and eventually eroding them away.
In contrast, sea cliffs that are NOT being actively eroded by waves (bottom figure at the right) typically have less steep slopes, larger piles of boulders at the base, and the boulders are angular (have corners and edges). Since waves are not hitting the base of the cliff, boulders that fall pile up and are not rounded off by wave erosion.
Mitigation of Shore Erosion

Human activities contribute to shore erosion in the following ways.

1. **River dams** trap sand that would otherwise be carried down rivers to the shoreline. This cuts off one of the main supplies of new sand to beaches.

2. **Jetties, groins, and breakwaters** stick out from the shoreline and block sand moving by littoral drift. The result is shore erosion on the down-drift side of the structures.

3. **Seawalls** or revetments cause breaking waves to bounce hard back toward the sea, carrying away sand and eroding the beach.

- **Mitigation** of shore erosion may be accomplished by:
  - beach replenishment: adding sand to eroded beaches; generally an expensive and short-term solution, since the sand often erodes away within a few years
  - setting structures (houses, roads) far back from the edges of eroding sea cliffs
  - designing groins, jetties, and breakwaters so that they allow sand carried by littoral drift to pass through
Estuaries are semi-enclosed basins, protected from the open ocean, where fresh river water and salty ocean water mix. Estuaries are important habitats for many species. Chesapeake Bay, Maryland, is one of the largest estuaries in the U.S.. Notice on this figure how the salinity (the salt content of the water) increases from the northern end, where the biggest rivers come in, to the southern end, which connects with the Atlantic Ocean.
Estuaries are important habitats that support many forms of life. The water in estuaries has high amounts nutrients, and that plus the shallow water (allowing for sunlight to penetrate) means plant life flourishes. Many types of marine animals spend all or part of their life cycle in estuaries. For example, many species of fish spend their juvenile years in the protected waters of estuaries, venturing out to sea once they are older. Estuaries provide important sources of food for people.

However, due to their location in protected shoreline areas, estuaries are often negatively affected by human activities. Many acres of estuaries have been filled in to create new land for urban growth. Life in estuaries is impacted by sewage, pollution, and runoff from farms carrying pesticides and fertilizers. The quiet waters of estuaries do not flush toxic materials very quickly. Fishing and boat transportation in estuaries puts further stresses on these ecosystems.
HURRICANES
Hurricanes (also called typhoons or cyclones) are storms that form out at sea over warm tropical ocean waters, generally 80 F degrees or warmer. Prime hurricane season tends to be in the late summer and early fall, when surface waters are the warmest.

The warm ocean water evaporates easily, creating vast amounts of warm, humid air. When this air rises, it expands and cools, causing the water vapor to condense to rain. This process releases heat to the atmosphere, causing more air to rise, feeding a cycle of faster and faster rising air and rain formation. Air is sucked into the area of rising air, spiraling faster and faster into the center region of rising air. Spiraling winds exceeding 74 mph define a storm as a “hurricane”.

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This figure shows a cross-section of typical hurricane. Warm, humid air (red arrows) spirals in from the sides and rises, dumping vast amounts of rain and releasing heat in the process. The heated, rising air creates very low atmospheric pressures; so low that the pressure in the upper atmosphere above the storm is actually higher than in the lower atmosphere in the center of the storm. This causes a downward flow of air in the center of the storm, forming the “eye” of the hurricane.
Satellite photograph of the tropical Atlantic north of the equator, showing a series of tropical storms and hurricanes with their classic counter-clockwise spiral structure. The prevailing winds in the tropics push all storms to the west, toward the Caribbean, Central America, Mexico, and the southeastern U.S.
Once hurricanes form, they are pushed west with the prevailing west-blowing winds in tropics. The Coriolis force causes storms north of the equator to travel in right-curving paths, and storms south of the equator to travel in left-curving paths. Note that storms forming in the Atlantic north of the equator are carried toward the Caribbean and southeastern U.S..
A hurricane heading toward the U.S. typically follows a right-curving path and moves along at about 10 to 40 mph.

The winds are fastest on the side of the storm where the forward movement of the storm adds to the direction of spiraling wind. Because storms north of the equator spiral counterclockwise and travel west, the strongest winds are always on the north side of the storm (the area labeled “Strong side” in the figure here).
Damage from hurricanes relates to high winds, flooding due to heavy rains, and flooding due to storm surges.

Storm surges are like a “hill” of ocean water pushed up by a hurricane. Storm surges are caused by two factors: low atmospheric pressure that pulls the ocean surface up, and the spiraling, converging winds that push the ocean water in toward the center of the storm. Storm surges cause far more death and destruction than the high winds in a hurricane. Large hurricanes may create storm surges that rise more than 20 feet above average sea level! If coastal residents are unlucky enough to have a storm surge coincide with a high tide, then the flooding is that much worse.

Hurricane prediction: Hurricanes can be predicted to some degree. Wind directions, sea surface temperatures, and behavior of past storms can be used to issue warnings about storm development, possible landfall location, and storm size. However the storms can unpredictably weaken, strengthen, or change direction.
ENSO

ENSO (short for “El Nino / Southern Oscillation”) refers to a set of perturbations that occur in the tropical Pacific ocean about every four to seven years. These perturbations cause major changes in climate in many parts of the world, and several types of human hazards.

Normally in the tropical Pacific Ocean, persistent west-blowing winds push ocean water west toward southeast Asia, where it accumulates. Deep cold water rises upward on the east side of the Pacific near South America to replace the surface water moving west.

However, for reasons that are still poorly understood, periodically these persistent tropical winds become weak or even blow the other direction. As a result the warm water on the west side of the Pacific, near southeast Asia, flows eastward across the Pacific and accumulates near South and Central America.
This figure shows what happens as when ENSO situation develops. Warm water near Asia and Australia gradually flows east across the tropical Pacific, hits Central and South America, and spreads out to the north and south.
This figure shows the abnormally high water temperatures (red and yellow) that occur in the eastern tropical Pacific during ENSO conditions.
How does ENSO affect climate and people? The main connection to understand is that rainfall and storms are related to warm ocean water. Areas near warm ocean water have high rain and storms, because warm water evaporates easily, putting lots of water vapor in the atmosphere. Therefore, during ENSO conditions:

1. Southeast Asia, normally a region of high rainfall due to the warm water that normally builds up in the western tropical Pacific, experiences droughts and crop failures.

2. South, Central, and North America experience heavy rains and frequent storms, leading to widespread flooding and mass wasting (slumps, slides, and debris flows).

3. Marine life in the tropical regions of South and Central America suffers massive mortality, because the warm water shuts off the upwelling of deep, cold, nutrient-rich water that normally rises off the coast of South America. People in these areas who depend on harvesting the ocean for food suffer accordingly.
Although its effects are widespread and severe, ENSO conditions can now be predicted months in advance. The graph above shows that ENSO conditions (shown on the red side of the graph) occur fairly regularly; generally above every four to seven years. Presently there are dozens of ocean buoys deployed throughout the tropical Pacific Ocean. These buoys measure air and water temperatures, wind speed and direction, and other parameters. These measurements tell scientists when the oceanic and atmospheric changes that signal a developing ENSO are beginning.