Lecture Twenty
Ocean Influences on Weather and Climate

Scope: Oceans are important to both weather and climate. They represent a huge volume of water, and thus, serve as the atmosphere's principal reservoir. Further, oceans serve as a vast reservoir of heat energy. The surface and deep oceans are connected through circulation, in which the atmosphere is also a major player.

Outline

I. In the ocean, pressure increases with depth very quickly, owing to liquid water's great density.

- **A.** You'll experience 1000 millibars of pressure just due to the liquid water mass by going down only 33 feet meters into the ocean.
- **B.** With the atmospheric pressure, the total pressure being exerted at the point 33 feet underneath the sea surface is 2000 millibars, or 2 atmospheres.

II. Let's look at the vertical variation of temperature in the ocean.

- **A.** We start with a roughly constant temperature layer immediately below the surface. Then, there's a zone of rapid temperature decrease called the thermocline. Farther beneath that is the deep ocean, with relatively small temperature variation.
- **B.** Mixed layer and thermocline depths vary markedly with latitude, longitude, and season, as well as on interannual timescales.
- **C.** Latitude is a fairly good proxy for sea surface temperature (SST), but it is also influenced by the ocean's circulation.

III. Just as winds do, ocean currents accomplish heat transport.

- **A.** A rough map of the principal surface ocean currents of the North Pacific shows the North Equatorial Current, which carries warm water across the tropical Pacific.
- **B.** This circulation then turns north-northeast along Asia's east coast and, further along, south, becoming the cold California Current.
- **C.** Closer to the equator, the flow is west to east. This is called a countercurrent.

IV. One of the main jobs of oceans is to moderate tempe

- **A.** Looking at a map of average surface air temper note that colder temperatures extend farther sou over the ocean.
- **B.** In summer, we see a larger difference between coasts in land temperatures.
- **C.** The ocean's coolest and warmest months are als to corresponding continental locations.

V. The picture of winds pushing surface currents is mo we might expect.

- **A.** The northeast trade winds of the tropical North ocean's surface current southwestward, but the the right of the wind.
- **B.** The primary forcing for the wind is PGF, but th deviates to the right of that forcing because of t
- **C.** The surface layer current drags the water under the primary forcing for the next layer down. Th also tries to make that water turn to the right of
- **D.** By about 100 meters down, the water is flowing opposite direction to the surface wind. This mot Ekman transport.
- **E.** If the surface wind is blowing toward the south, upper part of the ocean is moving to the west. T transport is perpendicular to the surface wind.
- **F.** Ocean/land differences are also central to mons referring to the seasonal reversal of winds.

VI. An important circulation in the tropics is the east/w Walker circulation.

- **A.** The tropical Pacific has persistent trade winds, equator. The Ekman transport pushes water mas westward across the Pacific.
- **B.** The flow of water away from the coastlines in t creates upwelling, decreasing sea surface tempe bringing the thermocline closer to the surface.
- **C.** Meanwhile, the water being carried across the P the Sun, creating a deep layer of warm water in

IV. One of the main jobs of oceans is to moderate temperatures.

A. Looking at a map of average surface air temperature in winter, we note that colder temperatures extend farther south over land than over the ocean.

B. In summer, we see a larger difference between the west and east coasts in land temperatures.

C. The ocean's coolest and warmest months are also delayed relative to corresponding continental locations.

V. The picture of winds pushing surface currents is more complicated than we might expect.

A. The northeast trade winds of the tropical North Pacific push the ocean's surface current southwestward, but the current moves to the right of the wind.

B. The primary forcing for the wind is PGF, but the surface wind deviates to the right of that forcing because of the Coriolis effect.

C. The surface layer current drags the water underneath, representing the primary forcing for the next layer down. The Coriolis force also tries to make that water turn to the right of this forcing.

D. By about 100 meters down, the water is flowing in the opposite direction to the surface wind. This motion is called the Ekman transport.

E. If the surface wind is blowing toward the south, the mass in the upper part of the ocean is moving to the west. The *average* transport is perpendicular to the surface wind.

F. Ocean/land differences are also central to monsoon circulation, referring to the seasonal reversal of winds.

VI. An important circulation in the tropics is the east/west Walker circulation.

A. The tropical Pacific has persistent trade winds, angling toward the equator. The Ekman transport pushes water mass generally westward across the Pacific.

B. The flow of water away from the coastlines in the east Pacific creates upwelling, decreasing sea surface temperatures and bringing the thermocline closer to the surface.

C. Meanwhile, the water being carried across the Pacific is heated by the Sun, creating a deep layer of warm water in the west.

D. This layer provides a huge reservoir of energy that drives deep convection and strong ascent and causes surface pressure to drop.

E. The ascending air in the west Pacific spreads eastward, sinking over the east Pacific and closing the circulation loop.

VII. The Pacific circulation cell tends to oscillate in strength and shift around in space over a period of about 2 to 5 years. This is called the Southern Oscillation.

A. The Southern Oscillation results in the warming of the waters off Peru and Ecuador, a phase known as El Niño. The period in which sea surface temperatures are colder than usual is called La Niñas.

B. In recent years, scientists have realized that the El Niño/La Niña and the Southern Oscillation are intimately related.

VIII. The thermohaline circulation involves 2 properties that determine how dense liquid water is: its temperature and its salinity.

A. The Gulf Stream carries warm water poleward. As the originally tropical current gives up heat and water to the atmosphere, what remains behind in the ocean is colder and saltier.

B. Because this water is denser, it sinks to the bottom of the ocean and starts spreading southward.

C. Much of this cold, salty water flows all the way to the South Pole, where it is upwelled and returned to the surface. This is the thermohaline circulation.

Suggested Reading:

There is no suggested reading for this lecture.

Questions to Consider:

1. Consider winds, forces, and ocean currents in the following question: How would the climates of the west and east coasts of North America be different if the Earth rotated in the opposite direction?
2. Someone claims that icebergs tend to move to the right of the mean atmospheric surface wind. Is that statement correct?

Lecture Twenty-One
Tropical Cyclones

Scope: In this lecture, we turn to tropical cyclones (TCs), the generic term for hurricanes and typhoons. As their name suggests, TCs are born in the tropical areas of the Earth, but no tropical region is favorable to tropical cyclones at all times, and some never see tropical cyclone development. But once formed, many tropical cyclones don't see fit to stay in the tropics.

Outline

I. Tropical cyclones (TCs) have both similarities and differences with their mid-latitude extratropical cousins.

A. Like extratropical cyclones, TCs are circular regions of low pressure with counterclockwise winds in the northern hemisphere.

B. However, TCs don't have fronts and they don't form in places with horizontal temperature gradients, which means that the TC environment typically doesn't have much vertical wind shear.

II. Let's see when, where, and how tropical cyclones form.

A. Hurricane formation requires sea surface temperatures of at least 79°C, which make the tropical atmosphere moist and unstable.

B. In the northern hemisphere, hurricanes generally move northwestward at first, away from the equator, then turn eastward.

C. While tracks often originate close to the equator, they don't form on it or cross it because Coriolis vanishes at the equator. However, Coriolis determines the sense of tropical cyclone rotation.

III. Two more ingredients in the hurricane recipe are weak vertical wind shear and a preexisting source of cyclonic relative vorticity.

A. A cluster of thunderstorms in an initially calm environment will push air upward, fueled by latent heat release. The combination of latent heating and upper-level divergence causes a decrease in pressure beneath the storms; this low pressure, in turn, draws warm, moist air up from below.

B. The large-scale wind creates a cyclonic surface circulation. Looking at the isobars in the vertical plane, we note calm winds in the center and wind speeds decreasing with height.

C. Looking farther aloft, the isobars are bowing upward instead of downward. This means that the pressure gradient and the wind direction have reversed.

D. Vertical shear distorts this process, tilting the storm downshear with height and stretching horizontally the heating and upper-level divergence that helped create the surface low to begin with.

IV. The most dramatic hurricanes are noted for the incredible clouds that form the eye wall. For landfalling storms, the worst damage is often to the right of the eye.

V. Hurricane winds represent gradient wind balance with a little bit of friction. After landfall, increased friction increases low-level convergence into the eye.

A. Surface friction promotes ascent from below and brings mass into the cyclone. It also works to raise sea leve pressure.

B. Even extratropical cyclones won't survive this frictional infilling without other supporting ascent mechanisms, such as positive vorticity advection and warm advection. Those mechanisms disappear when the extratropical cyclone becomes vertically stacked, with the surface cyclone beneath its own trough.

C. Hurricanes are already vertically stacked, so they cannot handle the degree of frictional infill that takes place once they pass over land. At that point, too, the tropical cyclone has lost contact with its primary source of instability, the warm sea surface.

VI. How does the eye form?

A. Consider again a deep convective cloud complex in the tropics, its latent heating and ascent encouraging low sea level pressure, which induces surface convergence.

B. Over time, the Coriolis force will guide the winds into gradient wind balance, with counterclockwise flow around this thunderstorm complex. As the spin increases, the eye forms.

C. The eye wall is the donut-shaped cloud around the hole. Under it, the strongest winds will be found, but note that there is downward motion in the center of the eye, which is one of the reasons that it's largely cloud-free.

D. The eye wall is warm, especially in the upper troposphere because of adiabatic compression. This is called a warm core structure. Farther beyond the eye, the rainbands form.

VII. A numerical simulation shows the development of a hurricane-like vortex, starting with individual thunderstorms.

A. The process starts with a large bubble of warm, moist air over an ocean with a surface temperature of 84°C. The bubble is positively buoyant and soon rises, creating storms.

B. Early on, horizontal convergence into the central area of ascent is obvious, but that eases as the Coriolis effect gets started. Soon, we have counterclockwise rotation and a hurricane.

C. Descending motion in the eye causes compression warming, which makes the surface pressure drop further.

VIII. Let's look at a vertical cross-section of the center of a mature hurricane.

A. In this depiction, the hurricane is about 12 kilometers deep and 300 kilometers across. The eye is about 50 kilometers in diameter.

B. Farther out are the rainbands. Most of the flow is going around in circles cyclonically in the lower troposphere, but some air is able to enter the storm at low levels. This is called the radial inflow.

C. Note that the eye wall is slanting outward with height. The explanation for the slant involves the fact that hurricane winds decrease with altitude to conserve angular momentum (radius × spin velocity).

IX. Tropical cyclone formation benefits from preexisting vertical vorticity and thunderstorms. One major source of both is the ITCZ, which has numerous thunderstorms and horizontal shear that represents vertical vorticity.

Suggested Reading:

Emanuel, *Divine Wind.*

Stewart, *Storm.*

Questions to Consider:

1. Why are sea-surface temperatures often cooler in the wake of a tropical cyclone?
2. After landfall, a hurricane does not weaken as quickly as usual. What factors might be present to help the hurricane maintain more of its original intensity?

Lecture Twenty-Two
Light and Lightning

Scope: This lecture is dedicated to light and lightning and incorporates much of the knowledge we've gained so far. We'll find out why the clear daytime sky appears blue and the setting Sun turns red and orange. We'll also look at the light made by the atmosphere: lightning. The key here is charge separation, but as we'll see, questions remain about how clouds become charge-separated.

Outline

I. The colors we see are certain wavelengths of electromagnetic radiation, but color is also partly perception. It is what we perceive it to be.

II. Sunlight entering the Earth's atmosphere can be absorbed, scattered, or refracted.

- **A.** Differential scattering is what makes the clear daylight sky blue. Differential refraction gives us the rainbow.
- **B.** The color of the blue sky is the result of Rayleigh scattering, which occurs when the wavelength of electromagnetic radiation encounters an object that is smaller than its own wavelength.

III. Refraction also plays a role in the color of the sky.

- **A.** Light is refracted (bent) by passing through the atmosphere.
- **B.** Isaac Newton showed that white light is actually a combination of the familiar rainbow colors.
- **C.** Differential refraction is responsible for the dramatic phenomenon of the green flash sometimes seen above the setting Sun.

IV. The colorful atmospheric rainbow involves refraction and reflection, and both occur as sunlight encounters liquid water drops.

- **A.** When white sunlight enters a drop of liquid water, there's a density change and the light bends.
- **B.** Some of the light then reflects off the backside of the drop and exits the front side again, bending the light yet again.

V. *At twilight, a small amount of light illuminates the upper atmosphere.*

A. *The sky's color becomes deep blue or even a bit violet. But* Rayleigh scattering predicts that the twilight sky should be yellow.

B. There is little absorption of visible light radiation between 0.4 and 0.7 microns. The absorption that does take place is the result of stratospheric ozone and tends to filter out the longer wavelength colors—orange and red.

C. At twilight, the optical path length is longer, and the ozone has a greater opportunity to filter out the warmer colors.

VI. Lightning creates thunder by superheating air.

A. When a lightning stroke occurs, air in a narrow channel around the stroke is heated to 54,000°F very suddenly.

B. Enormous pressure gradients are created, pushing air away from the bolt at more than 800 mph and creating a sonic boom.

VII. As we know, lightning is an electrical phenomenon.

A. To have lightning, we need a charge separation. Lightning tries to bridge the gap between positive and negative charges.

B. Even in clear weather, there is a general charge separation called the fair weather electric field. Under typical circumstances, there is an excess of positive ions in the free atmosphere and an excess of negative ions in the ground.

C. This electric field is about 100 volts per meter, and it's a residue of thunderstorm activity.

VIII. How does charge separation in a cloud occur?

A. The negatively charged ground can induce positive charges in ice crystals or hailstones in the base of a deep cloud.

B. The small ice crystals are transported upward by the updraft, but the hailstones tend to gravitate toward the cloud base.

C. Collisions between the 2 particles may transfer negative charges from the ice crystals to the hailstones, resulting in a surplus of positive charges at the cloud top and negative charges at the base.

D. The negative charge at the cloud base repels the negative charge in the ground, inducing positive charge in the ground and resulting in charge separation.

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IX. A lightning stroke has 4 parts: 2 strokes down and 2 up.

- **A.** In the first part of the stroke sequence, the stepped leader is created, a stream of negative ions looking for a path to the ground.
- **B.** The stepped leader ionizes the air, smoothing the path for the return stroke, a rush of positive charges from the ground to the cloud base.
- **C.** Many lightning sequences involve 2 strikes in rapid succession. This may occur because the air channel established by the stepped leader and the return stroke has been ionized and creates a favorable environment for the transmission of current.
- **D.** The second pair of strokes starts with the dart leader, which is similar to the stepped leader.

X. Here are a few lightning facts.

- **A.** CG lightning is most frequent on the Gulf Coast near Florida but rare along the West Coast.
- **B.** Types of lightning other than CG also exist, including cloud-to-cloud lightning, so-called heat lightning, and dry lightning.
- **C.** By putting more aerosol particles into the air, human beings may have increased the incidence of lightning.

Suggested Reading:

Hoeppe, *Why the Sky is Blue*.

Questions to Consider:

1. You are stationary, looking at a distant traffic signal. When the green lamp is lit, you can barely see it. The yellow light is brighter, and the red light is unmistakable. Why can you see the red light so much better than the green one? Hint: The red lamp has the same candlepower as the others.
2. There's nothing special about visible light, other than the fact that we can see it. But, we've seen that the Earth and all of its objects also emit radiation, albeit at longer wavelengths in the far infrared. Why didn't we evolve eyes to take advantage of this ubiquitous radiation?