Lecture 14: Air-Sea Interactions Pt. 2

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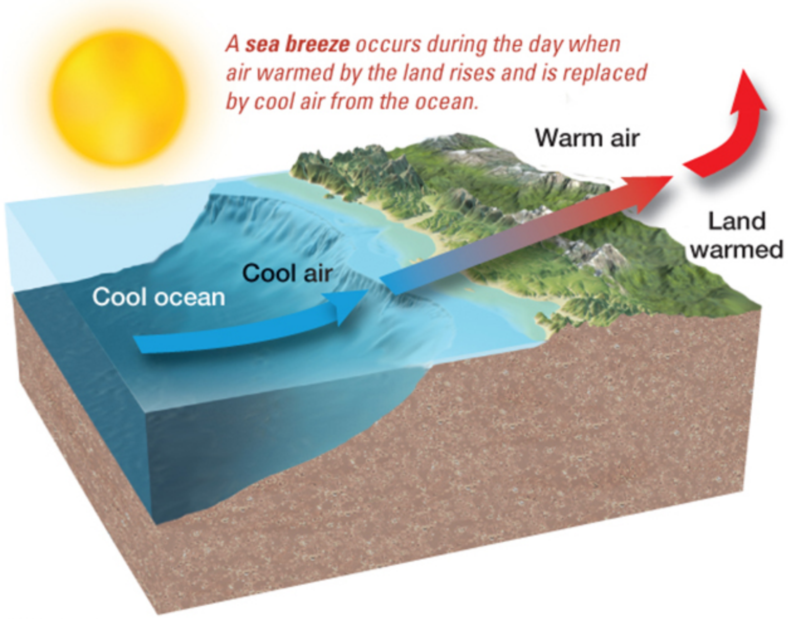
Let’s take a minute to review what we know so far about air-sea interactions.

- Greenhouse gasses in the atmosphere do a great job of trapping radiative heat that is released from the surface of the earth, and warming the atmosphere.
- The ozone layer does a great job of protecting us from damaging ultraviolet radiation. In the atmosphere, air circulation is influenced by both incoming solar energy (heating) and the rotation of the Earth.
- The differences in the amount of solar radiation (heating) between the equator and the poles is important in generating differences in heat surplus or deficit (heat budget) that the ocean and atmosphere can help to equalize.
- Warming and cooling air causes vertical air movement
- Earth’s rotation causes deflection of trajectories of air (to the right in the northern hemisphere; to the left in the southern) – this is called the Coriolis effect.
- Coriolis produces three large circulation cells in each hemisphere.
- These circulation cells produce patterns in surface winds between bands of high and low pressure (can you recall which way these move?)

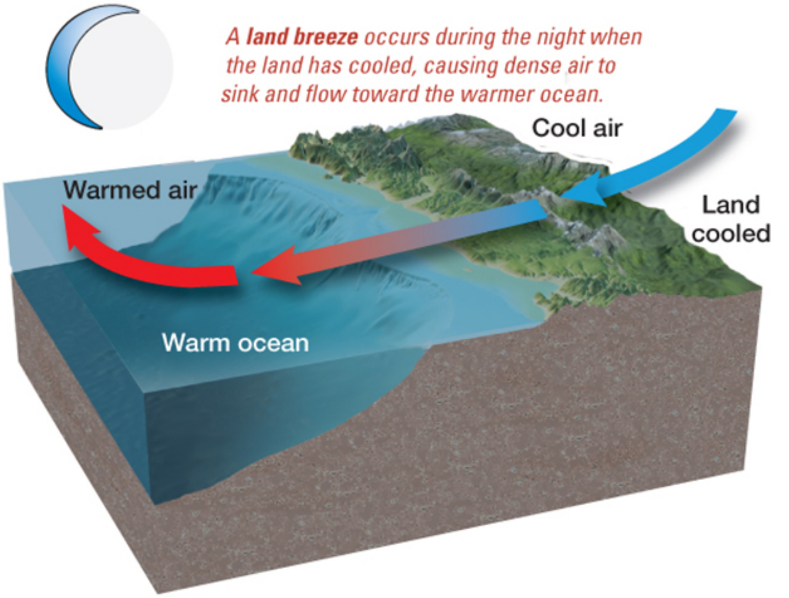
All sound familiar? If so, great! If not, review the previous lecture – there were important concepts in there that today’s lecture build off.

The ocean is huge, and we have already learned about the amazing thermal properties of water. Together, these mean that the ocean has a major influence on global weather and climate. Let’s take a minute to think about the distinction between weather and climate. Weather is the conditions of the atmosphere at a given time and place. You might describe the weather by saying “It is raining and cold today”. Climate is the long term average conditions of weather. In order to understand climate, we must have many years (even decades) of observations of weather that we can use to understand climate at a particular location. If you lived along the New Jersey coast for many many years, you might describe the summer climate at “hot and humid”.

Since you mention the New Jersey shore, let’s talk about sea breezes (well – actually land and sea breezes. These wind patterns are what are considered small scale wind patterns. When solar radiation hits a coastal area, and the same amount of solar radiation is applied to both land and ocean, the land heats up 5 times as much as the water (because it has lower heat capacity – we have discussed this previously). The air above the land therefore heats up more during the day as the sun is beating down. What happens to warm air (hint: we discussed last lecture)? It rises! That creates a zone of low pressure over the land, and you also know from last lecture that air will move from high pressure to low pressure, so the cooler air over the ocean will move onshore creating a breeze that blows from the ocean towards the land. This is why so many people like to ‘beat the heat’ by going to the beach in the summer. Those cool ocean breezes blowing from the ocean are very refreshing on a sweltering summer day. At night, the opposite happens. The land cools much more rapidly than the water (again, water has high heat capacity, so it resists cooling). The cooling land, cools the air above it. The air above the ocean is relatively more warm, so now it rises and the more dense cool air over land blows out to sea. This is known as a land breeze and occurs at night or early morning, whereas sea breezes typically occur in the afternoons. The figure blow shows a diagram of this phenomenon.


*A **sea breeze** occurs during the day when air warmed by the land rises and is replaced by cool air from the ocean.*

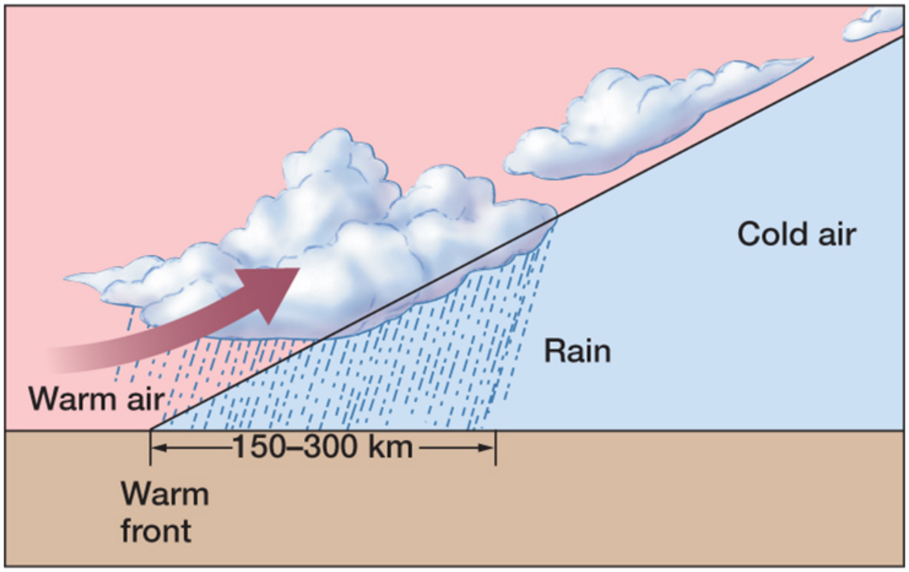
(a) Sea breeze.


*A **land breeze** occurs during the night when the land has cooled, causing dense air to sink and flow toward the warmer ocean.*

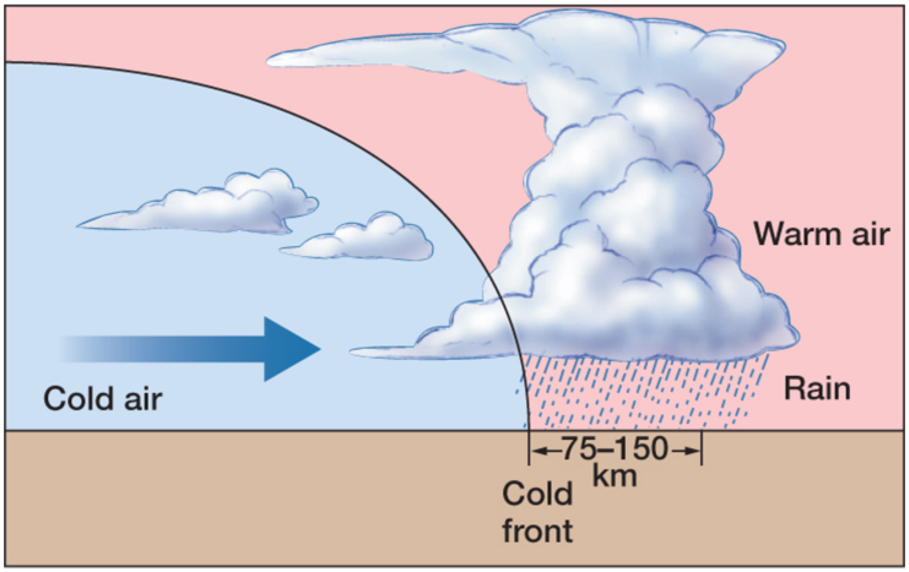
(b) Land breeze.

This same process can be observed seasonally over the continents. In winter in the northern hemisphere, the land masses of the continents tend to be cold, which cools the air above, making high pressure, dense air. These areas of high pressure air pushes towards lower pressure over the ocean. The opposite happens in summer in the northern hemisphere. The land heats up more than the ocean, creating warm, rising, low pressure air over the land which causes winds to blow towards land. These patterns of seasonal winds are important not only to weather and climate, but also to patterns of ocean circulation. We will learn more about that next lecture. These patterns also explain why the Indian ocean is associated with summer monsoon conditions. In winter, cold dry air blows away from land, but in the winter moist air from over the ocean blows towards land creating monsoon rains.

Storms are atmospheric phenomenon that have high winds, precipitation, and often lightning and thunder (probably something you already know – but roll with me here). The seasonal heating and cooling of land masses and the low and high pressure air masses that are associated with that can cause severe storms when those air masses collide. Air masses are large volumes of air that have a defined origin and characteristics. You might have heard of some of these on the weather channel – things like the polar air mass or the tropical air mass. Air masses that originate over land tend to be dry, and the majority of air masses that are generated over the ocean tend to be moist. Air masses generated at the poles are cold, while those in equatorial regions (tropical air masses) tend to be warm. When these air masses interact, we call that region a front. When a warm air mass moves into an area of a cold air mass, we call that a warm front. When a cold air mass moves into a warm area, we call that a cold front. Regardless of whether it is a warm or cold front, when the two air masses meet, the warmer, less dense air rises above the colder more dense air. The warm air cools as it rises and the water vapor it carries condenses as rain. A cold front is typically steeper and the temperature difference greater than a warm front, which means that the rain it generates is usually heavier but shorter than in a warm front. Boom – look at all the amazing weather forecasting you can do now when you want the news!



(a) Profile view of a gradually rising warm front.



(b) Profile view of a steeper cold front.

We already know that air will move from high pressure to low pressure (we call this wind). We also know all about the Coriolis effect. Let's think about what the Coriolis effect does to a rising air mass (one that is heating up) in the northern hemisphere. The air at the surface is moving towards that warm zone (or low pressure zone) to fill it in. That air moving towards the low pressure spot is deflected to the right, which imparts spin on the rising air mass. That spin is counterclockwise, in the meteorology world we call that cyclonic. Look at the figure below and

watch this video (https://youtu.be/rVrNXBioPG4)

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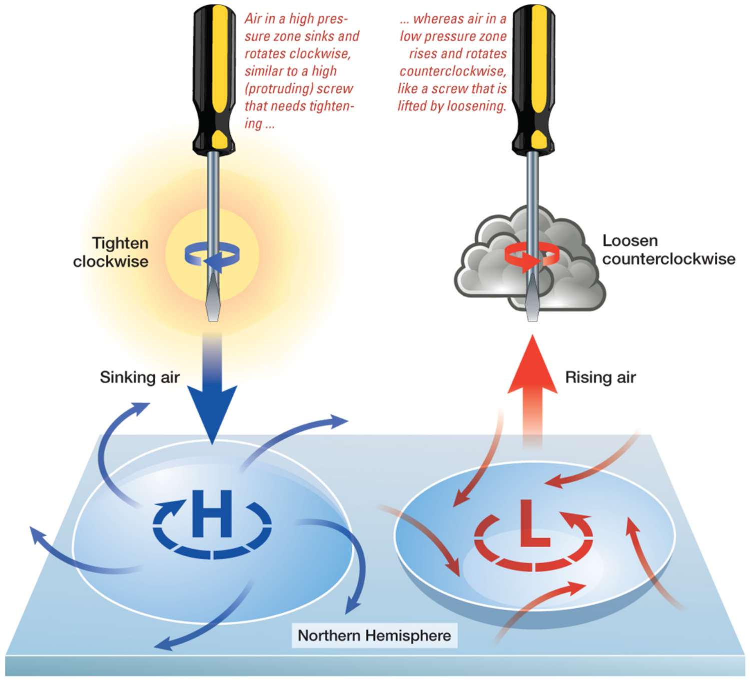
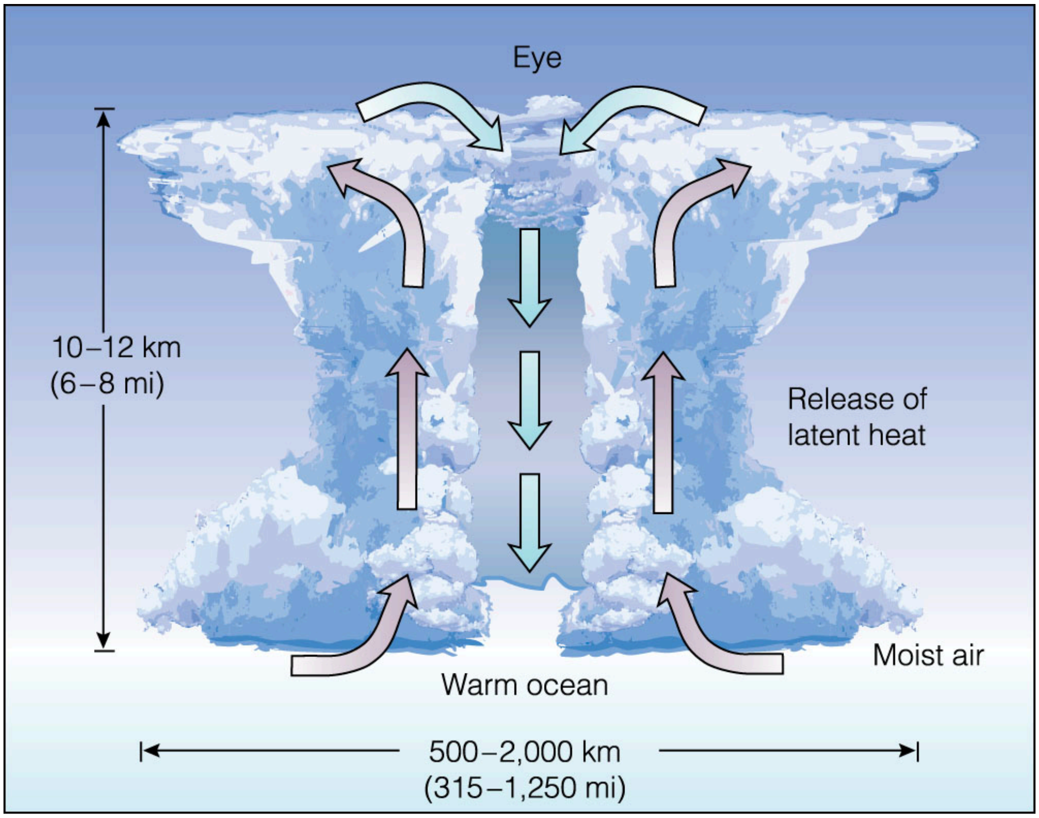
to see how this works. Now think about what happens in the northern hemisphere at a zone of high pressure where dense air is moving downwards and the winds at the surface are moving away from it. You watched the video link, so you already know that in the northern hemisphere those high pressure areas rotate clockwise (we call this anticyclonic).



Now – let's talk about the largest storm systems on Earth! Cyclones! You might be thinking – wait, aren't hurricanes the biggest. Yes! The name for these giant storms changes depending on where you are – just the names differ, not the processes. Here in the U.S., we call them hurricanes, in the western Pacific they are called typhoons, in the Indian ocean they are called tropical cyclones, and in Australia, they are called Willy-Willy (can you think of a key difference between a Willy-Willy and a hurricane? Hint – southern versus northern hemisphere!). For our purposes we will call them hurricanes. These hurricanes are huge masses of warm (low pressure), humid, rotating air. They bring strong winds, torrential rain, and often destruction when they make landfall. The energy contained in a single hurricane is more than all of the energy sources in the U.S. in the past 2 decades! The power source behind all of that energy – latent heat released from warm moist air rapidly cooling and condensing.

Hurricanes need heat and moisture to form. Where do we have a lot of heat and moisture? Tropical ocean, of course. That's where air can ascend the strongest, the lowest pressures can be reached, and hurricanes can be "brewed". Warm moist air rises and starts the whole dynamics we talked about. The more heat there is, the lower the pressure becomes, the stronger the pressure gradient gets, and the more moisture is exported from the ocean surface to the atmosphere. This can create a gigantic vortex of fast moving air, clouds and precipitation that can grow as large as a few thousand miles in diameter. This system then starts to move over water. Since it doesn't face much friction on the ocean its energy is not dissipated that much. It can even grow stronger if it travels over parts of the ocean with higher surface temperature and picks up more "fuel". In a fully developed hurricane, a very low pressure center is formed that sucks down higher pressure cool dry air from above.



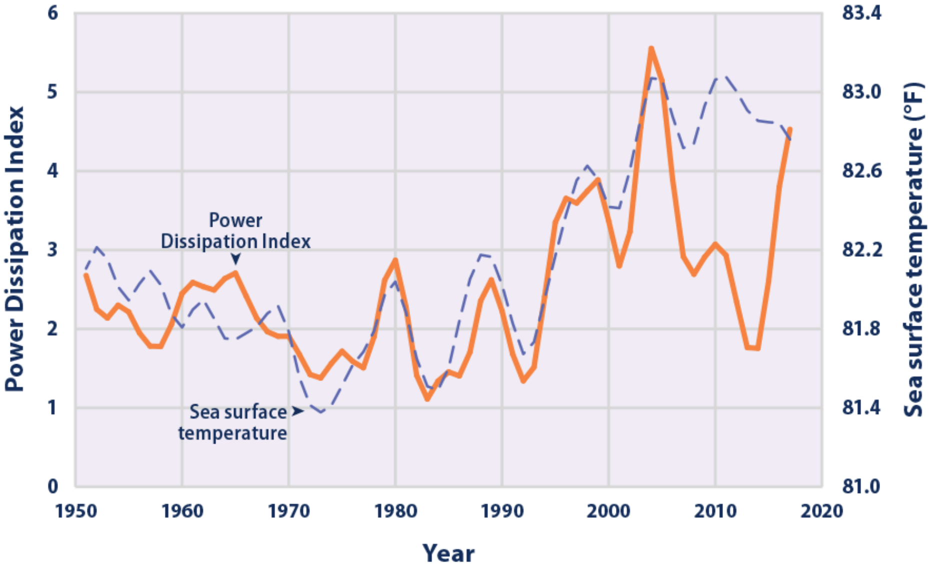
As a convention, if the winds in the rotating storm reach 39 mph, the storm is called a "tropical storm" and when the wind speeds reach 74 mph, the storm is called a "tropical cyclone" or hurricane. The Saffir-Simpson scale is what is used to indicate the intensity of a hurricane. Category 1 is the lowest (74-95 mi/hr winds) and category 5 is the highest (>155 mi/hr winds). When a storm reaches category 1, that storm is then named using human names (fun fact: prior to 1979 only women's names were used, today we are equal opportunity, and the World Meteorlogical Society uses both male and female names). The Met office pre-selects the names in alphabetical order each year – but what happens if they run out of names. Well, that has only happened twice. First in 2005, and then in 2020, when you might recall they had to use 9 greek letters to name the 9 storms that went beyond pre-selected alphabetical names! We believe that this isn't just a weird co-incidence, but rather that there is an increase in frequency of hurricane formation that can be attributed to the increases in the heat content of the ocean-atmosphere system in the past few centuries as a result of human activities. The documented increased heat in the surface ocean means more fuel for the hurricane engines!

If a hurricane hits the land before its huge kinetic energy is dissipated, the change in friction on land can cause massive transfer of momentum to infrastructures (destructive winds), flooding, and erosion. Damage from a hurricane happens because of the high winds, intense rain (remember Hurricane Harvey that dropped over 50 inches of rain in 4 days!), and storm surge. Upon landfall, the worst place of the hurricane for storm surge (which is basically the ocean being blown onto land) is at the right front quadrant of the storm (just ask New York and New Jersey after Hurricane Sandy). Because there is less heat and moisture on land to fuel the hurricanes, they will eventually die out. Another way that the storms might lose energy is if they move over colder water which takes away their fuel source.

Worldwide, about 100 storms develop into hurricanes each year. The specific conditions that can create a hurricane are: ocean water with a temperature of 25°C, warm and moist air, and strong Coriolis effect – these are conditions found in the tropics in late summer and early fall when temperatures are highest which is why all hurricanes originate there at that time (hurricane season!). Hurricanes deflect to the right in the northern hemisphere which pushes them off their trade wind trajectory around the tropics, and into middle latitudes (the opposite is true in the southern hemisphere of course).

The destruction from hurricanes is enormous. In the U.S. Katrina (2005) remains the costliest hurricane ($186.3 Billion). Hurricane Harvey (2017) is in second place ($148.8 billion). Hurricane Sandy (2012) which might be one you remember well, is in fourth place ($81.9 billion). The deadliest hurricane in the U.S. was the Galveston hurricane of 1900 in which over 8,000 lives were lost – tragic! Katrina was the third most deadly hurricane in the U.S. with over 1,200 souls. 202 was the most active hurricane season to date, with over 30 named tropical cyclones, but 2005 (the year of Katrina) remains the year in which the greatest number (15) developed into hurricanes. On average in the U.S. hurricanes in the U.S. that make landfall cost over $20 billion in damage. The graph below shows the ‘power dissipation index’ over time (which is a measure of hurricane strength, duration, and frequency – don’t worry, this isn’t on the exam). It is clear that hurricanes in the U.S. are getting stronger, longer, and more frequent, and if you look at the other line on the graph (the blue dotted line) you will see that this has a lot to do with sea surface temperature. Ah, the power of the ocean!

North Atlantic Tropical Cyclone Activity According to the Power Dissipation Index, 1949–2019



Data source: Emanuel, K.A. 2021 update to data originally published in: Emanuel, K.A. 2007. Environmental factors affecting tropical cyclone power dissipation. J. Climate 20(22):5497–5509.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.