Slide # 1: You know it from the waves on a beach, from a trip on a boat, or a message in a bottle – the ocean is always in motion. From tiny ripples to tidal waves, the liquid ocean never stops as differences in wind, water temperature, and salt all keep the water moving both at the surface and below the waves. If you're curious about how the motion of the ocean can make it too cold to swim along the New Jersey beaches in July, and warm enough for palm trees to grow along the coast of Ireland, then follow along…

Slide # 2: Although weather events like storms can temporarily change the ocean, there are also some general forces that create patterns in how large areas of the ocean move. But before we can understand HOW the ocean moves, we'll need to understand WHY the ocean moves. Let's start with something known as the Coriolis force, since this force has an effect on the motion of the water and wind all around the planet.

Slide # 3: The Coriolis force was first recognized in 1835 by Gustave-Gaspard Coriolis, a French engineer and mathematician. He determined that fluids, such as air and water, will not flow in straight lines on the earth's surface, but instead bend to either the left or the right. This happens for two reasons: first, the earth is round, and second, the earth is spinning on its axis. The combination of these two conditions causes differences in how fast an object moves depending on its distance north or south the equator. Because the diameter of the earth is greatest at the equator and smallest at the poles, an object at the equator has to travel farther and faster to complete one rotation of the earth in the same amount of time as an object at the poles. Let's continue and look at this concept in motion.

Slide # 4: Once again, here are two views of the earth: one looking down from the top, and another from the side. As you can see, an object at the equator will travel almost 24,000 miles in one rotation of the earth, or one day. At the same time, an object near the North Pole at 85 degrees latitude would only travel a little over 2,000 miles in one rotation, or one day, because the diameter of the earth is much smaller at that point. So, even though we can't "feel" the difference, an object or person at the equator is rotating with the earth at 990 miles per hour, while someone at 85 degrees latitude is rotating with the earth at only 34 miles per hour. Still confused…let's continue for another example.

Slide # 5: Let's pretend that we plan to fire a missile from the equator directly north. When it's launched, we know that the missile is also rotating to the east with the earth at 990 miles per hour at the equator. But as the missile travels north and the diameter of the earth decreases, the ground the missile is traveling over is moving relatively slower and slower. By the time the missile reaches the yellow dot on the image, the earth underneath is only moving at about 600 miles per hour to the east. So, the missile is now not only moving north, but also moving east at 1000-600, or 400 miles per hour. The movement of the missile to the north and east make it look like it is curving to the right. The important thing to remember is that the same effect happens to wind and water on the surface of the planet - the Coriolis force curves the motion of wind and water to the right in the northern hemisphere, and to the left in the southern hemisphere.

Slide # 6: In the early 1900's, the Swedish oceanographer Walfrid Ekman realized that the motion of wind and water on the planet was a bit more complicated than our missile example. He used observations from a Norwegian explorer named Fridtjof Nansen who had been in a boat frozen in the ice near the North Pole for 2 years. Nansen had measured the wind speed and direction and noticed that he, and the ice he was frozen in, moved at about 45 degrees to the right of the wind direction. He determined that this movement was due to the Coriolis force.

Slide # 7: About 50 years later, Ekman combined the observations of Coriolis and Nansen and realized that as water at the surface of the ocean was moved 45 degrees to the right, the water just below the surface water moves slightly even more to the right. This deflection of water to the right continues down through the layers of water until it reaches the depth where wind no longer influences the currents, known as the Ekman layer. If you combine all the layers of water below the surface that move to the right because of the wind, it adds up that the surface water ultimately moves 90 degrees to the right of the wind direction. For example, if a wind is blowing directly to the north in the northern hemisphere, the surface water will move 90 degrees to the right, or to the east. The opposite is true for the southern hemisphere. The Ekman layer can be anywhere from 6-20 meters deep off the coast of New Jersey, and up to 100 meters deep in the open ocean.

Slide # 8: This animation gives you a visualization of the Ekman layer. The red arrow represents the water closest to the surface, and the other arrows represent other layers of water that each move slightly more to the right, creating a gentle spiral. The current is strongest closest to the surface and gets weaker as it gets deeper. The water in the Ekman layer moves 90 degrees to the right of the wind direction.

Slide # 9: The Coriolis force has an effect on the entire global ocean. Let's take a look at how the Coriolis force plays a role in the movement of water in the northern Atlantic Ocean.

Slide # 10: This is an image taken from a satellite that shows the water temperatures at the surface of the ocean. Warm water is indicated by red, and cold water by purple and gray. The two moving arrows show the dominant direction of the surface currents in the North Atlantic. The current gets very narrow and fast along the eastern coast of the United States, where it is known as the Gulf Stream. The current then gets slower and wider as it moves south along Europe and Africa, where it is known as the Canary Current. Why does the North Atlantic surface current rotate in a clockwise direction? If you guessed it has something to do with the Coriolis force, you're right…let's find out how.

Slide # 11: As this image shows, the dominant surface currents in the North Atlantic move in the same clockwise direction as the dominant winds. That sounds simple, doesn't it? However, if you remember how the Coriolis force works in the northern hemisphere, you know that the surface water moves 90 degrees to the right of the wind direction. So, that means that the water being moved by the clockwise winds is actually moving to the right of the wind direction from all sides, and piling up in the middle of the North Atlantic. This causes the water in the middle of the North Atlantic to be almost 4 feet higher than along the coast. Since the water in the middle is higher, it sets up what is known as a pressure gradient. Just like water running down a hill, water at the center of the North Atlantic runs "downhill" towards the coastlines. As it moves towards the coastline, the water is once again turned to the right because of the Coriolis force, causing the surface current to move in a clockwise direction. This is shown using the purple arrows.

Slide # 12: Now we can see how the movement of the North Atlantic surface currents affects the climate along the coasts. Points A and B on the map are both the same distance north of the equator, but the water temperature at point B along Africa is much cooler than at point A off the eastern coast of the United States. This may not make sense until you realize that the clockwise currents of the North Atlantic pull cold water from areas like Iceland down along the coasts of Europe and Africa. At the same time, warm water from the coast of South America is pulled north along the coast of North America. Notice that the water temperatures along Cape Cod, Massachusetts are the same as those along Scotland, which is much farther north. This is a result of the warm Gulf Stream carrying water away from the eastern coast of the United States and toward northern Europe. This warm water actually keeps the climate on the coast of Ireland warm enough for palm trees to grow all year long!

Slide # 13: Let's zoom in now and take a closer look at an interesting feature in the Atlantic Ocean called the Gulf Stream. This ribbon of fast-moving warm water starts in the Gulf of Mexico, and twists and bends like a river as it moves north. The water of the Gulf Stream is much warmer, and therefore lighter, than the water surrounding it, which can cause a difference of up to three and a half feet in the height of the ocean over a distance of only a few miles.

Slide # 14: Because the Gulf Stream curves like a river in the ocean, it can sometimes bend so much that it cuts off a piece of itself. These pieces are called rings because they rotate to create a spinning circle of water. When a ring is formed on the north side of the Gulf Stream it is called a warm ring because it traps warm water as it rotates clockwise. When a ring is formed on the south side of the Gulf Stream it is called a cold ring because it traps cold water as it rotates counter-clockwise.

Slide # 15: In these images you can see a cross-section of the ocean from top to bottom from point A to point B. You can see that the Gulf Stream separates the cold water along the continental shelf from the warmer water to the south. You can also see that the warm and cold rings are deeper than the continental shelf, and therefore can't get too close to the shelf or the coast – they just won't fit! Warm and cold rings can last up to several months before being reabsorbed by the Gulf Stream or slowly losing strength and disappearing.

Slide # 16: This is a real image of the Gulf Stream taken from a satellite. The color red shows warm water temperatures and clearly shows the path of the Gulf Stream as it heads out into the ocean. The arrows show the movement of the Gulf Stream and the rings that it creates. Notice that the water inside the rings is either warmer or colder than the water surrounding them. The white spots on the image are clouds seen by the satellite.

Slide # 17: Now lets look at an animation of the Gulf Stream. This animation shows how the Gulf Stream and its rings might move over a two-month period. At the top right corner you can see a how a warm ring forms and rotates clockwise, and in the middle you can see how a cold ring forms and rotates counter-clockwise. As the rings form, they spin towards the west, while the Gulf Stream continues to move toward the east. The rings that are furthest east are typically the newest ones, and usually have the coldest or warmest water inside. Good examples of this are the warm and cold rings that are furthest east if you jump back to the previous slide.

Slide # 18: Have you ever been to a beach on the Mid-Atlantic coast on a really hot summer day and jumped into the surf for a swim, only to run right back out because the water is really cold? That doesn't seem to make sense, does it? Well, there's a very good explanation, and it has everything to do with an important event that happens in different areas of the ocean called coastal upwelling. Let's find out how.

Slide # 19: Before we find out exactly what coastal upwelling is, we need to explore some interesting facts about water, and we'll use a hot air balloon as an example. As you probably know, as the air inside the balloon is heated, the molecules move further away from one another and the air becomes lighter, allowing the balloon to rise. When the air in the balloon is allowed to cool, it gets heavier and the balloon sinks back to the ground. Well, the same thing happens with water. As water gets warmer the molecules spread out, making it lighter and allowing it to float on top of heavier cold water.

Slide # 20: Let's continue to use our balloon example to show how salt can affect water. If you add weight to a floating balloon, it will make the balloon heavier and cause it to sink towards the ground. The same is true for water. When you add salt to water, it makes it heavier and causes it to sink below water that is less salty. If you add salt water to a glass of fresh water, the heavier salt water will sink to the bottom.

Slide # 21: Now we can use your new knowledge of water to understand how a coastal upwelling happens. During the summer, the water along the coast of New Jersey is typically divided into two layers. The layer at the surface of the ocean is lighter because it's less salty and is warmer from the heat from the sun, and the layer at the bottom is heavier because it's more salty and colder. These two layers don't mix very well, and the area between these layers where the temperature changes rapidly is called the thermocline.

Slide # 22: Let's look at an upwelling in motion to see how it actually happens. In the summertime, the winds along the coast of New Jersey often blow along the coast from the southwest to the northeast. But if you remember the Coriolis effect, you know that the surface water moves 90 degrees to the right of the wind direction, so the water along the coast is being pushed towards the southeast, or away from the coast. When the warm surface water is moved offshore the colder bottom water below it upwells, or rises to the surface. This cold water has plenty of nutrients that act as fertilizer for microscopic plants called phytoplankton, which multiply quickly and serve as an important food source for many animals in the ocean.

Slide # 23: These two images show how scientists can see an upwelling along the coast of New Jersey using sensors on a satellite that can detect the temperature of the water at the surface of the ocean. In the image on the left there is warm surface water all along the coast on July 14th. Bust just a week later, on July 21st, lots of green, blue and purple along the coast show that much colder water has come up to the surface as a result of an upwelling. This same cold water is what can make it too cold to take a dip in the ocean on a hot July day!

Slide # 24: Now that you know a little bit about how the ocean moves, let's discover how scientists are learning even more about the ocean. As you know, the ocean is not an easy place for humans to study – it can be cold, deep, dark, rough, and is always in motion. One of the newest ways to study the ocean is through coastal ocean observatories, which are like laboratories in the ocean where scientists have equipment that can collect lots of information over long periods of time. Let's take a look at the Long-term Ecosystem Observatory, or LEO, here in New Jersey as an example.

Slide # 25: LEO, the first coastal ocean observatory in the world, is located about 4 miles off the coast of southern New Jersey in about 50 feet of water. An underground cable runs from the Rutgers University Marine Field Station on land out to two nodes at the LEO site. The cable provides electricity to power the equipment at the site, and allows scientists to collect data and know instantly what is happening in that area of the ocean. Scientists can collect information over long periods of time at LEO because their equipment can be plugged into the nodes and doesn't have to be powered by batteries, which eventually lose power.

Slide # 26: This image gives an example of the different equipment that has been used at the LEO site over the past several years. Scientists can look at the ocean from both the "top down" and the "bottom up" by using information from satellites, airplanes, boats, weather and radar stations on land, and robots under the water. This information can be used to make forecasts about the conditions in the ocean, just like the weather forecast we get everyday about conditions in the atmosphere.

Slide # 27: Although the LEO site began as a small area off the coast of New Jersey, it has now expanded to cover much of the coastal ocean off of New Jersey and beyond. Other scientists are beginning to develop other coastal observatories around the world, and in the future a network of these observatories will provide us with much more information about the inner space right here on our own planet – the ocean!