THE ENDLESS VOYAGE

"Something in the Air" Episode 110

The ocean and atmosphere are interacting in many ways. It's sort of a David and Goliath or Mutt and Jeff or something—some kind of argument or dance between ocean and atmosphere that determines climate.

I think the most important thing to understand is that the climate system really is a function of three parts of the whole Earth system. There's the ocean, the atmosphere and the land.

It's not a linear system. It's not a simple system. And the interaction of all the parts of the climate system can give us surprises, and these surprises—and we have some hints at what they might be—could be the things that are devastating.

NARRATOR:
FOR THE MOST PART, THE DAILY WEATHER IS A MANAGEABLE, IF OCCASIONALLY CHALLENGING, FACT OF LIFE. BUT THERE ARE TIMES WHEN EARTH'S CLIMATE SYSTEM IMPRESSES US WITH ITS EXTRAORDINARY POWER. AND THE RESULT IS ANYTHING BUT MODERATE. ONE SUCH EPISODE OCCURRED IN LATE OCTOBER, 1998, WHEN A CHAIN OF ROLLING THUNDERCLOUDS BEGAN DRIFTING WESTWARD ACROSS THE COAST OF CENTRAL AFRICA. BY THE MORNING OF OCTOBER 22, THE CLOUDS HAD BECOME ORGANIZED INTO A TROPICAL DEPRESSION. SLOWLY, THE STORM GREW. AND BY THE TIME ITS LEADING EDGE TOUCHED THE CENTRAL AMERICAN SHORE AT SPEED OF 170 MILES PER HOUR, THIS TOWERING BLACK MOUNTAIN OF WIND AND RAIN WAS A RARE CATEGORY-5 STORM. IT WAS ABOUT TO BECOME THE MOST LETHAL ATLANTIC HURRICANE OF MODERN TIMES. ITS NAME WAS HURRICANE MITCH.

TIMOTHY SPANGLER, Ph.D., National Center for Atmospheric Research (NCAR):
It was so powerful, its central pressure was the fourth lowest pressure we've ever measure we've ever measured in the Caribbean. It was 905 millibars. And it was so powerful that we believe that it was lifting the ocean 20 feet underneath it. Imagine this huge dome of water—20 feet—just being sucked up by the storm. It then moved further to the west to Honduras, and Nicaragua. There it collapsed and, as it was dying, it dropped tremendous amounts of rain. Some 9,000 people died in Honduras. I think that's incredible. Mostly from mudslides and heavy rain. Many of them were located in villages that were in floodplains where we wouldn't really think you should be locating—lodging in villages. It eventually dissipated after sitting there for almost four days, pouring six, eight, 10 inches of rain a day on Honduras. Then it exited to the northeast and went over Florida, where it caused some damage, a lot of heavy rain, and eventually left, out over the East Coast.

NARRATOR:
IN ADDITION TO THE 9,000 PEOPLE WHO DIED, 570,000 OTHERS WERE MADE HOMELESS. THE ECONOMIC DAMAGE WAS LIKEWISE CATASTROPHIC. OFFICIALS IN HONDURAS SAY THE HURRICANE SET THEIR COUNTRY'S INFRASTRUCTURE BACK 50 YEARS. THE COST FOR NICARAGUA HAS BEEN ESTIMATED AT $1.36 BILLION, OR 67% OF THAT COUNTRY'S GROSS DOMESTIC PRODUCT. THE COST OF A NATURAL DISASTER CLAIMING 67% OF THE U.S. GROSS DOMESTIC PRODUCT WOULD BE A STAGGERING $4.3 TRILLION.

We don't know exactly what made Hurricane Mitch such a severe storm. We know that the water was quite warm. Hurricanes get their energy from water. As they condense the water, they evaporate it, bring up a storm—condense it. And we know that the air aloft 30,000 feet over the storm, was a bit divergent, meaning that it was spreading out. And this allows the storm to rise rapidly. So we know that these conditions were in place for Hurricane Mitch to be very, very powerful, but we don't know why those conditions were there.

NARRATOR:
HURRICANE MITCH MAY BE A UNIQUELY DRAMATIC EXAMPLE, BUT THE INTERPLAY BETWEEN ATMOSPHERE AND OCEAN IS COMMON TO NEARLY ALL WEATHER EVENTS.

LEE-LEUNG FU, Ph.D., Jet Propulsion Laboratory:
The circulation of the atmosphere is certainly coupled with the ocean and vice-versa. It's mutually influential. The ocean is forced by winds in the first place, as well as the freshwater exchange and the heat exchange with the atmosphere. And the sea surface temperature influences the position of jet stream, for instance. So when the ocean's hot, air rises. When the ocean's cold, the air descends. So, it creates a lot of disturbance of the atmosphere. A good example is the oceanographic phenomenon called El Niño, which brings the tremendous warming of the equatorial Pacific and a change of the jet stream, and heavily influenced on the rainfall patterns and storm-tracks in wintertime of United States and even around the world.

PETER RHINES, Ph.D., University of Washington:
The ocean is a very dense medium, water is 800 times denser than air. And it contains so much of the heat storage and so much of the carbon and most of the mass of the coupled climate system—the atmosphere/ocean system—that the ocean is sort of like a big flywheel or a big inertia that's always talking to the atmosphere through it's moisture and heat fields. And yet the atmosphere is racing along above with more kinetic energy than the oceans, about the same amount of sort of momentum, but more kinetic energy, and it's mercurial, I guess you'd say. It's such a fast-responding system. The atmosphere is what everyone thinks of in terms of weather and climate yet there are definite interactions in both directions.

DAVID PIERCE, Ph.D., Scripps Institution of Oceanography, UCSD:
And the way that the ocean and the atmosphere work together is generally by carrying heat from the equator where the sun shines the most, to the Polar Regions, where heat is lost to the atmosphere.

PETER NIILER, Ph.D., Scripps Institution of Oceanography, UCSD:
The relationship between the ocean and the atmosphere is really—they're totally synergetic. They're—now, understand, both of them are fluids. The atmosphere is a transparent fluid, and the ocean is basically an opaque fluid. But they obey the same physical laws of movement, and they both can be described by this very similar—what we call equations of motion or physical laws.

RAYMOND W. SCHMITT JR., Ph.D., Woods Hole Oceanographic Institution:
The ocean and the atmosphere interact in a very fundamental way, in that the atmosphere is driven by solar heating. The motions in the atmosphere are driven by solar heating, and that wind that develops due to those differences in density from one part of the world to another drive motions in the ocean.

The atmosphere has a mass that is very much smaller than that of the ocean—or the heat capacity, for that matter. And so the atmosphere tends to establish patterns of climate that are short term in the atmospheric flow. It also establishes patterns of climate that have to do with the constituents of the atmosphere which are like the gas content and the various kinds of ionospheric properties of the atmosphere.

PETER WEBSTER, Ph.D., University of Colorado, Boulder:
The atmosphere is made out of gas, of course. And most of the components of the atmosphere are very inert, they don't do very much except they provide mass which is the pressure we feel at the surface of the Earth. But there are some constituents in the atmosphere which, of course, are very, very important. And one of which is water vapor, perhaps the most important of all, because that gives us clouds, it gives us rain. It also gives us clouds which act as an umbrella to keep out the sun. So that's a regulator of the climate.

And water vapor varies between zero and 4% of the atmosphere. And this is important because it sustains life. It helps cause weather, if you will. And water vapor transports heat—latent heat.

NARRATOR:
THE MOVEMENT OF HEAT AROUND THE GLOBE IS ONE OF THE MOST CRITICAL COMPONENTS OF EARTH'S CLIMATE SYSTEM. THE DRIVING FORCE BEHIND THIS PROCESS IS THE SUN.

SPANGLER:
You know the equators are warm. At the equator, you get more heat than the Earth can absorb, and at the poles, you get less heat than it is capable of absorbing. So you have an

excess of heat at the equator, a deficit at the poles, and the atmosphere is constantly trying to get rid of that difference. This leads to atmospheric circulations.

NARRATOR:
THE CIRCUITS OF AIR THAT MOVE AS PART OF THE CIRCULATION PROCESS ARE KNOWN AS CELLS.

An atmospheric circulation cell—and there are many of them—is generally an overturning.

TIMOTHY SPANGLER, Ph.D., National Center for Atmospheric Research (NCAR):
An atmospheric circulation cell is where you have air rising in one place, and to replace that air that's rising, air has to come from someplace else. If you imagine a room, you have a radiator on one side of the room and windows on the other, the warm air by the radiator is rising, cool air is sinking by the window, and it comes across the room and rises back through the radiator and you get an atmospheric cell.

The most basic of all of the cells is the Hadley cell. And the Hadley cell is a sort of universal flowing of air towards the equator and rising and flowing back towards higher latitudes.

And the Hadley cell is the idea that you would have rising air at the equator and sinking air at the poles and that you'd get this circulation that would move warm air toward the poles and cool air from the poles back to the equator.

NARRATOR:
WHILE THE INITIAL MOTION OF THESE CELLS MAY BE DRIVEN FIRST BY TEMPERATURE AND THEN BY PRESSURE GRADIENTS, THEIR PRECISE MOVEMENT IS ALSO INFLUENCED BY THE ROTATION OF EARTH ITSELF. IT IS THIS ROTATION WHICH DEFLECTS THE PATH OF ANY MOVING OBJECT, INCLUDING AIR OR WATER, FROM ITS INITIAL COURSE. THIS DEFLECTION WAS EXAMINED IN DETAIL IN THE 1830'S BY A FRENCH SCIENTIST NAMED GASPARD-GUSTAVE DE CORIOLIS.

The Coriolis force is perhaps the most feared concept in weather forecasting. All of us who teach always shake our heads about trying to explain this, and it's not simple. It is the issue that when you see air flowing on the surface of the Earth on the Northern Hemisphere, it appears to turn to the right. So this is called the Coriolis Effect. We talk about a Coriolis force which—there must be a force present making that happen, but it is an apparent force, an apparent force because we simply have to put it in mathematically to make this turning happen. Now, in simple terms, imagine you're in an airplane in Chicago and you're going to fly due south to Dallas. You fly due south for three hours to Dallas, but when you get there, Dallas isn't there anymore. Dallas has moved to the east one eighth of the way around the Earth, if we rotate every 24 hours. And so, if you look at the path of the airplane relative to the Earth, it appears as if it has been deflected to the right.

LIBE WASHBURN, Ph.D., University of California, Santa Barbara:
The Coriolis Effect is an apparent force that arises when an object that is moving is viewed in a reference frame that is rotating. And a good example of this occurs on a merry-go-round, which is a rotating reference frame.

SPANGLER:
If you are on a merry-go-round and you're sitting on one side and your brother's sitting on the other side, you try and throw the ball to your brother, you'll miss him to his left, because the ball will be deflected to the right. The reason is that you're angular momentum on this rotating sphere is moving the ball to the right and your brother's going to the left and when you throw it at him, the ball appears to be deflected to the right.

The tennis ball you were playing catch with would go in a beautiful arc of a circle. It wouldn't go straight. And, of course, that tennis ball is going straight for an observer who's not on the merry-go-round, but you don't know that.

I think the one thing one should do is think of a planet where there was no rotation. Then, except for inhomogeneities, mountain ranges or oceans and so on, all the flows will be between the equator directly to the pole. They'd be all north-south. Very, very boring. And so what we have—and as the equator would heat up, say, during the summertime or some stage, this Hadley Circulation would just get faster and faster and transport all the heat.

If there were no Coriolis force, it would descend by the pole. But instead, it rises by the equator, it starts toward the pole and then it is deflected to the right. And eventually, it never gets to the pole, it only gets to about 30 degrees north, where it begins to descend because it's cooled. And, eventually it returns near the surface where it is also deflected to the right, and this causes the tradewinds that blow in the Caribbean and over islands in the Pacific, and across Africa. And they, of course, were the winds that allowed the early traders to sail along the equator and move to different continents. So, without the Coriolis force, we would not have the circular weather that we get today and the patterns that we're used to seeing would not exist.

NARRATOR:
OF THESE PATTERNS, THE HADLEY CELL IS GENERALLY CONSIDERED TO BE THE MOST BASIC. BUT THERE ARE OTHER ATMOSPHERIC CIRCULATION PATTERNS AS WELL.

You also get cells in the east-west direction, which are called Walker cells, named after Sir Gilbert Walker, who was the person who first started—did some seminal work in the El Niño southern oscillation, I think, 70 or 80 years ago. And this is the overturning along the equator between regions of very warm sea surface temperature like the western

Pacific Ocean and cooler regions in the eastern Pacific Ocean where one gets overturnings again. And so, these atmospheric cells are extremely important.

SPANGLER:
Our prevailing winds in the United States are typically from west to east. Now, that descending air then runs into air coming from the pole that is trying to get to the equator because of the difference between the cold air at the pole and the warm air at the equator and it begins to rise. So, in the middle of the Earth between 30 degrees north and 60 degrees north, you have what's called the Ferrel cell—descending air about 30 degrees north, ascending air at about 60 degrees north, and then you have the polar cell, which is air descending over the pole and rising at about 60 degrees north.

NARRATOR:
ONE OF THE CIRCULATION ZONES THAT SCIENTISTS ARE ESPECIALLY INTRIGUED BY IS LOCATED NEAR THE EQUATOR. IT'S KNOWN AS THE I.T.C.Z.

PETER WEBSTER, Ph.D., University of Colorado, Boulder:
I.T.C.Z. means Inter-Tropical Convergence Zone. When one looks at a satellite picture where all the cloudiness is averaged over a long period of time, you tend to see around the equator, just to the north or just to the south, depending on the season, a band of cloudiness. And this is referred to as the I.T.C.Z. And it's generally thought to be the confluence region or the region where the trade winds from the northern hemisphere meet the trade winds from the southern hemisphere. And the simplest sense one can think of that is that's the rising part of the Hadley circulation. Now, these trade winds have been traveling over very, very warm air and as they come together and are forced to rise, one gets the release of latent heat. And this, of course, heats the atmosphere and tends to draw more air into that region. So you finish up with a very strong circulation cell. So, the I.T.C.Z. is a very turbulent part of the atmosphere, a very, very important part of the atmosphere.

If you're sailing, you can see it very clearly. Recently I flew from Atlanta to South Africa, and I could immediately tell when I was over the I.T.C.Z.. And this zone causes rain, very persistent rain, and it is the feature that saves so many countries who need rain and have dry periods and wet periods. The I.T.C.Z. moves northward in our summer and southward in our winter. And, for example, Kenya, Niger in Africa have their rainy season from May through September or October, as the I.T.C.Z. is over them and causing all of this convection.

NARRATOR:
THE PRECISE LOCATION OF THE I.T.C.Z. DETERMINES THE LOCATION AND INTENSITY OF SEASONAL PATTERNS OF WIND CIRCULATION KNOWN AS MONSOONS.

The monsoon climates of the world exist in Africa, Asia, Northern Australia and, to some extent, in the Americas. They also include about 65% of the population of the world.

And there's a good reason for that, because associated with the monsoons are very wet summers, warm summers, lots of rainfall and generally, very, very good agriculturally.

TIMOTHY SPANGLER, Ph.D., National Center for Atmospheric Research (NCAR):
When the monsoon fails, it's bad. Now, why would it fail? Well, not everybody knows exactly why it fails, except we know that if the ocean temperature's warmer than normal, it takes longer for the monsoon to set in. Or if the land is cooker than normal, it takes longer for the monsoon to set in and sometimes it fails entirely. We do have a monsoon in other locations. For example, we have a monsoon in North America, where we have air moving from the Gulf of Mexico into the central United States every August, and you get a lot of severe thunderstorms, a lot of rainfall. Even here in Colorado, it comes from what we call the American monsoon.

WEBSTER:
So, what you find within a monsoon season which lasts say, from, over India, for example, from June all the way through September, are periods of where you get very large amounts of precipitation for two or three weeks, and then mini-droughts for two or three weeks, then large amounts of precipitation once again. Within those periods of very large precipitation are storms which are moving through.

NARRATOR:
STORMS CAN RANGE FROM A TROPICAL CYCLONE ON THE ORDER OF HURRICANE MITCH, TO AN EXTRA-TROPICAL WINTER STORM, LIKE A BLIZZARD OR MAJOR RAINSTORM. OFTEN, A STORM BEGINS AS A RESULT OF AIR MASSES THAT HAVE COLLIDED.

SPANGLER:
We have many different kinds of storms. You can have rainstorms. You can have snowstorms. You can have dust storms. You can have tornadoes, thunderstorms. And the thing that determines is, I think, the temperature and the winds. When you have cold temperatures, you get snow. When you get warmer temperatures, you get rain. In the United States, most of our precipitation begins as snow, as ice, but it melts and becomes rain as it falls into the warmer air near the surface. In the tropics, you can go through a different process of forming rain, and it can be water the whole time.

And there are reasons that are not very well understood why certain storms are stronger than others. The sea surface temperature tends to be warmer, perhaps. In the upper troposphere, 10, 15 kilometers high, the circulation is such as to be more conducive to the formation of strong updrafts rather than tending to slow them down. And so there are many reasons. Precisely, if one were to say six days in advance, "Will this be a strong hurricane or a weak hurricane?" it's difficult to know. But just sometimes there's a confluence of influences which are such as to allow a storm to grow. For example, generally the storms in the northwest Pacific Ocean, the typhoons sometimes become what are called super typhoons, and they seem to be stronger there than, say, in the

Atlantic. I think the issue with Mitch is that things were right for its formation. Things were wrong in terms of where it finished up.

The National Weather Service in Shreveport has issued a tornado warning effective until 3:00 p.m.

NARRATOR:
FEW WOULD DISAGREE THAT THERE REMAINS A GREAT DEAL YET TO BE LEARNED ABOUT CLIMATE IN GENERAL, AND ATMOSPHERIC CIRCULATION IN PARTICULAR. YET METEOROLOGISTS ARE MAKING GREAT STRIDES IN THEIR EFFORTS TO INCREASE THE ACCURACY AND UTILITY OF THEIR FORECASTS.

SPANGLER:
There are many advances in weather forecasting. The National Weather Service in the United States has been significantly modernized in the last 12 years, and the effects have been, I think, dramatic. For example, the new Doppler Radars that you see sometimes on TV all over the United States, have improved the forecasting and the detection of tornadoes, so that 10 years ago, the average lead time for a tornado warning was a negative eight minutes, meaning that a tornado would have been on the ground eight minutes before someone would have observed it and reported it and a warning would have gotten out. Today the average lead time for a tornado warning is a positive 12 minutes and I believe that that will go to 20 and 25 minutes very soon.

WEBSTER:
Generally, we do very, very well now in forecasting out to about six days in weather forecasting. We can forecast over relatively small areas. We can forecast the weather in Denver versus the weather in Kansas City four or five days in advance. And we can differentiate between those two.

SPANGLER:
The real advances in weather forecasting come from computer modeling. Computer models calculate the weather at certain discrete locations. They used to be about 50 miles apart. Today we use models that have accuracies, and these discrete points are only 10 miles apart, and so they see the Rocky Mountains, they see the Great Salt Lake, they know features there that are on the ground. We can run these models so much faster on the faster computers. They need a lot of data to be accurate, and we're getting new data from new satellites that are being launched. I think the data from satellites is very, very impressive.

NARRATOR:
SOME OF THE MOST IMPORTANT RESEARCH WORK CURRENTLY BEING DONE IN THE FIELD OF METEOROLOGY INVOLVES HURRICANES.

ERIC TERRILL, Ph.D., Scripps Institution of Oceanography, UCSD:
We're, in fact, conducting research to better understand hurricanes and how hurricanes interact with the ocean. Numerical forecast models which tracks the hurricanes reasonably well don't do such a good job of predicting the strengths of the hurricanes and the rapid changes in strengths of the hurricane. So, what we do is we develop new sensors, new technology, bring them to sea and take measurements, bring that data back and analyze it to provide new insight. What's unique about the hurricane program is that you obviously don't want to be at sea doing measurements within a hurricane if you can help it. So, in fact, we're developing autonomous instruments packages that can be placed out of airplanes where we'll be flying through hurricanes, dropping these into the hurricane itself, and then allow these sensors to bring—in fact, talk by satellites back to us. So, after they're deployed, they'll stay in the ocean for a number of months, and we'll measure the various hurricanes that pass over them and understand the ocean physics hopefully better, based on the information we get out of the sensor packages.

NARRATOR:
CLEARLY THE PROGRESS BEING MADE IN METEOROLOGICAL RESEARCH IS IMPRESSIVE. BUT THERE REMAINS A GREAT DEAL OF WORK YET TO BE DONE.

PETER WEBSTER, Ph.D., University of Colorado, Boulder:
I'd say there are three major challenges facing us in the future. And the first one is to decide if we thoroughly understand the building blocks of climate. And by that I mean, are there certain features that we've neglected to look at? The second thing is with global warming climate change. How is that going to be manifested? I don't think we know that.

ANTHONY MICHAELS, Ph.D., Wrigley Institute of Environmental Studies, University of Southern California:
The real issue is that by changing the heat dynamics of the atmosphere, you're going to change all kinds of other things—patterns of weather, patterns of storminess, where it's wet, where it's dry. And those will have regional impacts. The real fear with global warming is not that this average is going to cause a problem. It's really that there are uncertainties in this system.

WEBSTER:
And the third thing we have going is the impact on population. Our population is growing enormously. In some countries, 4 or 5% a year. And that's 17-, 18-year doubling timescales. So the reaction of those populations to climate change, we don't understand. So what I'm painting a picture of is of a complex system of climate variability, of global warming, of population and human reaction that is such a complex system that we—I don't think can predict the outcome of these—so it's an unpredictable system, perhaps.

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