**9UNP0101SD\_Howard\_Berger**

(applause)

- Thank you. It's a pleasure to be here tonight. When I did this two years ago I think it was snowing outside. So, the thunderstorms and things we may get later tonight seems a little bit more appropriate to the topic at hand. I'm an associate researcher at the Cooperative Institute for Meteorological Satellite Studies. We're a cooperating institute between NOAA, NASA and the university. So, a lot of our work is geared toward operations. We do research mostly with designs to kind of transition that research to a forecaster. I'll be talking a little bit about that in the context of hurricanes.

This is just the names of the Tropical Cyclone Research Team. Almost everything I'm going to present to you tonight is other people's work. And they definitely get the kudos for putting a lot of this together. I get the privilege of presenting a lot of their work. We also collaborate with some people at the Naval Research Lab in Monterey, and the Hurricane Research Division in Miami. We have lots of collaborations around the country and around the world. Because weather is a world phenomenon, it's definitely something that you need-- You need that versatility to get good science. Just a brief outline. I'll begin with some definitions so we can clarify some of the hurricane and tropical cyclone words. The bulk of my talk will be on satellites and tropical cyclones.

I'll talk about how we use satellites to study them, what things we can detect from satellites and what kind of research we can do, and will be doing in the next few years. And then, I want to conclude by touching on this issue of global climate change and tropical cyclones. It's definitely been in the news for a long time, and it's another kind of hot area of research. There is a scientist in our group that has published some work in it, so it's quite relevant to our group. This is our Web page. We've just updated it for this hurricane season. So, if you've been on it before, it's a little bit different, you've probably noticed. Please go to the link and check it out. It's very useful. Particularly when there is a storm, you can get all kinds of information about the hurricanes.

And a lot of what I'll show you tonight is on our Web site. Though some of the stuff, particularly the older storms may not be directly on there. But if for some reason you want an animation, please contact me and I'd be happy to show you where some of those animations are. So, basic definitions. The term "tropical cyclone" tends to be used a bit loosely. But typically, it's sort of used to describe an organized cluster of storms. Essentially, it's used from anything from an organized cluster of storms, which might make a tropical depression, to something as intense as a hurricane. And usually, the qualifier of these different distinctions are made by the speed of the winds. So, a tropical depression is a tropical cyclone with winds less than 39 miles per hour. There has to be some organization, some structure, which I'll show you in a minute.

A tropical storm is when the winds are a little bit faster. In the North Atlantic and the North-East Pacific, we use the term "hurricane" for anything with winds greater than 74 miles per hour. A tropical cyclone, I want to make a contrast with the storms we would get over Wisconsin, which meteorologists would call an extra-tropical cyclone or a mid-latitude cyclone. They're very different in terms of sort of the energy involved, and the way they form, and how strong they are, etc. They tend to have cold fronts and warm fronts. These are features that you do not see in tropical cyclones. So what are the hurricane threats? I'll touch on this a little bit. You may be quite familiar with these, particularly after the past few years. Storm surge is the primary threat to life.

The storm surge is an elevated water level, above the mean tide. And what causes storm surge is that we've got this giant storm with lots of wind, and it's just pushing all of the ocean water onto the coast. As it makes landfall, this water kind of piles up and raises the water level. And then on top of that elevated storm surge, you would get increased waves. So that would be an additional damage on top of the storm surge. When the United States makes evacuation decisions, it's based on this threat of storm surge, We don't evacuate for winds. They evacuate because they believe that people are in danger of the storm surge. The winds are, of course, a particularly dangerous threat. And ironically, if you evacuate people and they evacuate too late, the winds can be even more dangerous. Because if you have a bunch of cars on the highway and the winds are very bad, then it's not a very good scene.

The other threat that many people don't even consider is fresh water flooding from rain. Hurricanes have a lot of rain in them. And the even more dangerous thing about the fresh water flooding is it can happen from very, very weak storms. Tropical storms or tropical depressions can make landfall. And if they move very, very slowly, they can pour lots of rain in an area and cause all sorts of damage and all sorts of casualties. So it's definitely something that needs to be considered. And then, to make matters worse, when hurricanes make landfall, they often spawn tornadoes, so you have both threats to worry about. But tornadoes is for a different talk. When we talk about hurricane intensity, we often hear reference to the Saffir-Simpson scale. That scale is based on the wind speed of the hurricane.

You have everything from a tropical storm, as I mentioned, which has winds from 39-74 miles per hour. What you're looking at is a montage of a satellite image of Hurricane Dean. We'll be seeing quite a bit from Hurricane Dean. These are satellite images taken at various different times, put on the same image. You can see, for example, the tropical depression and tropical storm. You get some sort of clustering in the clouds, but it's not particularly symmetric. It's not particularly well organized. As it gains in strength, in this particular case, it gets a little bit bigger. That's not really directly related to the intensity. But it gets a little bit more structure.

You're starting to see some of these kind of rain bands, these kind of wedges of cloud out here. Then, right before Hurricane Dean made landfall, when it was a Category 5, you really get to see the tight circulation. And if the red line weren't there, you'd see the clear eye that forms within the hurricane. This just kind of gives you a sense of what these storms look like in a satellite image. I'll go into that in a little bit more detail. Again, we've kind of had a taste of satellites and tropical cyclones. That's kind of the briefest picture of how they're useful. How do we use satellites? What do they do? You get a chance to see my brilliant attempts at drawing in Power Point here.

Satellites detect radiation. And this radiation comes in various forms. But all satellite images that you see are radiation that's been interpreted by scientists. So just a few examples, and a lot of what we'll see tonight, is you have solar radiation that hits clouds, scatters off of the clouds and is beamed back to the satellite. That's a visible radiation. So that would be what the clouds look like if you were to stand in the space shuttle and see it from space. Clouds also emit radiation. They tend to emit primarily in the infrared. So you'll often see infrared images. You'll see several of those tonight.

Infrared is sensitive to the temperature of the clouds, so high clouds that are much, much colder-- As the cloud gets higher, it's much, much colder, so you can detect cloud height from satellite images. You also have atmospheric emission. When we talk about the greenhouse effect or global warming, it's because you have carbon dioxide, for example, in the atmosphere. That's emitting radiation. You can use satellites to figure out how much carbon dioxide there is, or how much water vapor there is in the atmosphere. And of course, you have land emission and sea surface emission. Many of you have probably seen maps of Wisconsin or of the planet, and a lot of them are satellite-derived images, where they looked at the visible light coming off the ground. So, anything that you see is someone's algorithm or someone's clever trick for converting this radiation into something that we can understand and conceptually use. Now, why do we use satellites for tropical cyclones? Why is this kind of an obvious pair?

Well, this is a plot of sort of conventional observations that would go into a forecast model. And I'll talk a little bit about that. But most of the observations are cluster. Each blue mark represents one observation. So it would be clustered over the continents. These little streaks that you see here are airplanes. So every time you get up in an airplane, they're sending observations of temperature and moisture. They're going into forecast models and they're used by weather forecasters. You also have some buoys over the ocean, and there are some ship reports as well. But hurricanes form here or in the western pacific, and there's not a lot of observations there.

If we include what we can get from satellites, the coverage is much, much better. This is isn't even accurate. The blank spots are because this particular modeling center doesn't use some observations. But you get the basic picture. You get global coverage of the planet from satellites. And you get that very, very frequently. You can get it as frequently as every 30 minutes with some types of satellites. So it's a natural fit to look at something that happens in the middle of the ocean with satellites, because basically there's no other way to do it. I wanted to talk a little bit about an application of satellites. This is data that I use, and members of my group use quite often.

I'll show you several things that we derive from this. There are cloud track winds or atmospheric motion vectors. I'll try to keep the acronyms to a minimum, but AMV is one that may come up a few times. What these are, conceptually they're quite simple. If you look at the way a cloud moves over a given period of time, you can back out what the wind is doing. So for example, if you have a cloud, you have three images that are 30 minutes apart. So you have three satellite images of clouds. Let's say that the cloud is here at 11:30. And then at noon, the cloud is here. And at 12:30, the cloud is here.

And you know the distance between each of these points, you can calculate what the wind is. You've got a change in distance over a change in time. And you have, from these three images, you have two measures of the wind, where the cloud is. Conceptually, it's actually quite simple. And many, many years ago, it was done by hand, by people looking at screens and calculating this. Now fortunately, it's done by computers. But the very, very difficult part is figuring out the height assignment, figuring out where in the atmosphere that cloud is. That's quite tricky in a lot of circumstances, and is in fact sort of a very active area of research, is trying to prove that height assignment. There's also a quality control issue, which is some of the work that I do. That's figuring out once you have this wind, how good is it?

Is there a computer problem that's caused this wind to be bad, or are we doing something wrong conceptually. It's something that you have to figure out. And it's research that we do every day. So what does this give you? It gives you a picture. This is a picture of sort of one day's worth of these atmospheric motion vectors from satellites all over the planet. Now, the satellites that are primarily used for this data type are what we call geo-stationary satellites. They're satellites that are rotating at the same speed as the earth. That allows you to basically take a video camera of the clouds. You see the clouds moving because the satellite is in the same position relative to the earth.

The second primary type of satellite is the polar orbiting satellite. That satellite moves up along, would often stay parallel a longitude line and cross over the poles. And we've actually fairly recently been deriving these atmospheric motion vectors from polar orbiting satellites. So that's just not contained in this plot here.

(inaudible)

 There's quite a few. And I wouldn't have an accurate count. These are the primary geo-stationary satellites that you see up here. And then there are probably a dozen or so, at least, polar orbiting satellites. There's probably more than that.

That's just weather satellites. There are probably thousands of communication satellites. I don't know if anybody has a number. But quite a few. And they're from many different countries. There's a very, very active international collaboration between the United States, Europe, China, Japan. It's pretty exciting stuff. So now we've talked a little bit about the satellite data. We have to look into how hurricanes are forecasted, and in fact, how anything is forecasted in the weather. You have to start out with observations.

If you don't know what's going on now, you're never going to be able to figure out what's going to happen in the future. For hurricanes, the primary types of observations are, of course, satellite observations. And in the Atlantic and in the Gulf of Mexico, we have aircraft. And when a hurricane is close to landfall, scientists fly into the storms very regularly and get very, very accurate measurements of the storm's intensity, it's size, it's position. That's sort of the primary tool if you've got a landfalling hurricane. But if the hurricane is far off into the ocean, or if it's way out into the Pacific, where there are no aircraft reconnaissance, then satellites are basically the only thing you have, unless the storm happens to pass over a buoy. Of course, there are ship observations, but ships generally try to avoid the storms, so they're certainly not a primary tool. So once we have the observations, what do we do with them? Well they go sort of in two ways. One, they go to big, powerful computer models, which is something I'll talk about in a little more detail later.

And they go to the big, powerful forecaster brain. The forecasters in the National Hurricane Center, that probably is an understatement. They are the best in the world at what they do, and have lots of experience studying hurricanes. They look at the observations and get a sense of, you know, based on their experience, what's going on and what it's going to do. And then of course, they look at these computer models and have the very difficult task of figuring out which computer model is doing a good job and which one to believe. And particularly for figuring out track forecasting, the computer model is their primary tool. If you're trying to make a two or three day forecast, the computer model is really all you have. But there are many, many computer models that are running, so they have to figure out which one to use, what to believe. Then of course, with all this information, they produce the forecast. So what are forecasters interested in?

Of course, they're interested in... These are perhaps obvious questions, but they make kind of a nice organizational structure to talk about the products that we do. None of the scientists at the University here in our group make forecasts themselves. But as I was saying, we provide products and guidance for scientists, for the forecasters to make their own decisions. Where is the storm? This is kind of the most basic question that you have. And before satellites were invented, this was definitely not a trivial problem. People were surprised by hurricanes, unless a ship happen to have found it, or that sort of thing. There was not a lot of information as to where they were. But because of satellites, we aren't surprised by a storm's existence.

Now, figuring out the exact position of the hurricane can be tricky, even with the imagery, because sometimes the clouds kind of obscure where the storm center is, and you need to use other tools to figure it out. But the imagery is definitely the primary tool. This is a high resolution image of Hurricane Katrina. And you get a very, very clear sense of the storm. You can see the very, very tight circulation, the counterclockwise motion of these clouds, and of course the very, very menacing eye. You can see some of the cloud structure, even inside the eye. It's an incredible image. But from this image, you get, you know, the center of the storm is probably there. And that problem, at least, is solved from this particular image. What I'm going to show you now is an animation of Hurricane Katrina.

This is a combination of visible and infrared. It's kind of blended together, because the visible images are not very useful at night. The infrared is the primary tool. So it blends this together. What you'll see is Katrina will move into the gulf. And as it strengthens, the eye will clear out and you'll see it develop a strong eye and make landfall. It's kind of a quick animation, so I'll replay it. So from the satellite image, you can get a sense of the lifecycle of the storm, how it's strengthening, how it's weakening, and of course, where it is, how it's moving. That's kind of the most basic, fundamental question that we can answer with satellites. And it's very powerful.

The next question is how strong is it. Again, the primary tool for forecasters would be sending an airplane into the storm to actually measure its wind speed, measure its central pressure. But if you can't do that, these two satellite techniques are fairly well-established and give you an estimate of storm intensity. The first one I'm going to talk about is the AMSU. The AMSU instrument is a microwave instrument. Microwave is nice because it is not sensitive to clouds. What it's sensitive to is a lot of the structure inside the hurricane. In this particular application, it's sensitive to the sinking motion inside the eye. In the eye, you have this clear region. And if you have sinking air, that tends to produce clear, clear skies.

And it also is a warming process. When you have air that sinks, it warms. And that's what a satellite is measuring. It turns out that that sinking is directly related to how intense the storm is. So the more sinking, the more warming you have, the stronger the storm. This is just kind of schematic in some ways, of Hurricane Rita. These contours here represent sort of the warming that you can see from the satellite. When it's fairly meek at 40 miles an hour, you're not seeing very much warming. There's kind of a single contour of temperature. At its most intense, you get a lot of the warm air.

And it's a fairly linear relationship. There's a lot of complications and details to get it right, but conceptually it's not that complicated. The other technique that we've done here at Wisconsin is the Advanced Dvorak Technique. The slide is a little bit busy. The Dvorak Technique itself is again, quite simple. What Dvorak did, I believe in the late '70s, was he looked at hundreds and hundreds of satellite images, and looked at the intensity of those storms from the satellite images. He basically did pattern matching. He said a storm that looks like this, that's this strong. And a storm that looks like this, that's this strong. So the technique is a fairly complicated look-up table.

Right now, it's being practiced and used operationally at many centers around the world. They have a scientist whose task it is to look at those images and make an assessment on its intensity based on the Dvorak Technique. It's very, very low tech, and I think that's what's really neat about it. What we've done at Wisconsin is of course made it higher tech, and we've automated it. This is work that Tim Olander has been doing for a long time. He's taken that subjectivity out of the process. So he looks at this satellite image, and from that satellite image, through a fairly lengthy process, detects what the intensity is. This particular storm has 921 millibars. I'm trying to see which storm he has here. It's not -- But what he's plotted here is sort of a timeline of Hurricane Keith.

This is mean sea level pressure along here. So the lower the pressure, the stronger the storm. And you can see how they can assign an intensity estimate at essentially every time we have a satellite image, so every 30 minutes. Aircraft recon goes in maybe every three hours. So while the aircraft is much more accurate, we get much more frequent measurements of the air. Here is just some, the ADT is statistics based on its performance. You can see it's not-- The errors are a little bit-- In this particular case, they're actually a little bit lower than the official forecast, but we don't need to get into that detail. The next question is where is it going and when will it get there. This is essentially the track forecast. How do you figure out the track?

I'm going to talk a little bit about it directly, the satellite steering flow, which is a direct product that we produce. And then I want to talk a little bit about satellite data assimilation, which is this process of getting data into computer models. Because track forecasting is primarily done through computer models. It's worth talking about. This is a satellite derived steering current. If you remember, we talked about the atmospheric motion vectors earlier. What we've done is take those atmospheric motion vectors and looked at how they change vertically in the atmosphere, and average them over a depth of the atmosphere. If you could imagine that a hurricane is a quirk in the stream, and the stream is the atmosphere, if you kind of average what the wind is doing vertically, you get a sense of what direction the hurricane will move. Keep in mind, this is a snapshot. It's sort of an instantaneous measurement of the steering current at a given time.

So the flow could very much change. And the hurricane itself can actually change the flow itself. So it's complicated, but in terms of a quick picture, this gives you a very nice picture of what the flow is doing. The arrows you see here, the streamline show the wind direction of the steering current. And the reds and some of the whites that you can see are fast winds. The yellows and blues are quite slow winds. So what I'm going to do is animate this. What you'll notice is that reasonably, Dean kind of follows the direction of the flow throughout the time period. And you also get a nice sense of the atmosphere changing and what it looks like, what the flow is looking like around the continental United States. You can see the clockwise circulation here that's pushing the storm westward.

So it's a very, very useful tool. I like looking at this a lot, particularly when I'm looking at say, the National Hurricane Center, when they put out their forecast discussion, they're describing what the atmosphere is. They talk about ridges and troughs, and things like that. I can throw this up here and go, okay, yeah. I can see this is a trough here. This is a ridge. And here is, you know, you've got a high pressure center here. You get a very quick picture of what the atmosphere is doing. I find this very, very helpful. So back to this flow chart here.

As I mentioned, this process of data assimilation comes in right here, where we bring observations into these computer models. And doing it is definitely not a trivial process. What I want to try to do is give you some conceptual idea of what's going on. And I do this for a couple reasons. One of them, as I mentioned, is it's fundamental to understanding track forecasting. The other reason is this is a lot of the work that I've been involved with, and I've always wanted to find ways to explain this to my parents. So I'm going to try it out on you guys, and please let me know whether the explanation is confusing or clear, and we'll see how it goes. Let's pose a question. Your friend leaves to Madison from Chicago at 12:00. The question that we're trying to figure out is when does that friend arrive.

So the forecast variable. What we're trying to predict in this particular problem is the arrival time in Madison. The forecast model, I'll call it the Google model, for the obvious image. And this model says that your friend will drive the 146 miles at 60 miles an hour. Okay, that's the estimate. It's a very simple model. That makes the math work out easier. So based on the Google model, the prediction is at 2:26pm, you'll be eating Michael's Frozen Custard with your friend. Distance, speed of travel, fairly simple. Now, at 12:30pm, 30 minutes into our forecast, the Google model would predict that your friend has traveled 30 miles.

But your friend calls. Fortunately we have cell phones, or I'd have to think of an entirely different example. He tells you that he was stuck in traffic and has actually only traveled 15 miles. This is much more than likely than him actually getting the 60 miles an hour. So you have to adjust your model prediction. If you assume that he will drive 60 miles per hour from the point that he called you on, then you have a new arrival time, at 2:41, which is 15 minutes later than your original prediction. And that, in its essence, is what data assimilation is. You have a forecast, you set that forecast forward, and then you correct the forecast with new information. Then you come up with a new forecast.

(inaudible)

 Yes, but this is a very simple model. Yes, you're right. But let's say from now on, it goes away. You're right. You could adjust your model. There's one other sort of subtlety that I want to try to introduce. At 1:00pm, your friend calls again. This time he tells you he's traveled 20 miles, but he's previously forgotten to tell you that his odometer isn't very accurate. Now you've got an additional problem. You have to account for an uncertainty in your observation.

We'll call this observation error for perhaps obvious reasons. So now the question is, you've been given an observation that he's traveled 20 miles. Your question is, is your model more accurate than your observation? This in fact goes into your point. If you fully trust your model, okay, if you say he's going to be driving at 60 miles an hour, then you have to assume that he has already traveled 30 miles in 30 minutes. And the only conclusion is that the odometer is wrong. So your observation error is solely the reason why he tells you he only traveled 20 miles and not 30. If you fully trust your observation, then you know, the odometer is perfect, then obviously the only explanation is that he didn't go 60 miles an hour and your model is wrong. And of course, the truth is probably somewhere in between those two extremes. And this is essentially the problems that you deal with when you're doing data assimilation in terms of the weather, which is what I want to talk about very briefly here.

So, in the atmospheric case, the model is very complex, mathematical equations that represent the physical processes of the atmosphere. It's much more complicated than the simple distance equals rate times time sort of question. The model variables, the things you're trying to predict are things like temperature, pressure, moisture and wind around the globe. So you've got a lot more models and you've got to do it three and four dimensionally. The problem is much, much more complex. But this question of error is still very, very crucial. And again, another area of active research is estimating these errors. How good is your model? How good is your individual observation? You have to do that for every single observation that you have.

You have to make this decision. I mean, it's done automatically, but that's conceptually what's going on. If you fully trust your model, and your observation differs, then you eject the observation. Vice versa if your observation is perfect. Then if you go back to the image that I showed you with the types of observations that we have, you can see how satellite data assimilation is crucial to this problem. It gives us, again, nearly global coverage of the atmosphere. So how does this work in practice? Typically, when you have these global numerical weather depiction models, they run every six hours or so. So, a model that started 7:00pm Central Daylight Time, would produce a ten-day forecast. Six hours into that forecast, they would take in new observations and they would correct that six-hour forecast and produce a new model that would do another ten-day run.

And you would continue this cycle over and over again. So you get ten-day forecasts, but each one is, in principle, a little bit better than the previous one. That's in principle how data assimilation works. Of course, the details are very, very messy. But conceptually you can understand that. So we do this data assimilation process. We run these models out and we get track forecasts. How good are the track forecasts? These are track errors from the actual forecasters. This is sort of the value added of the forecaster looking at the models and making their own decisions.

What we have here, along the black, this is the track error in nautical miles. This is the year of the forecasts. And these values here are the average errors for 72 hours, a 48-hour forecast, and 24-hour forecasts. You can see that the short-term forecasts are generally better than the long-term forecasts. But what the trend lines here show is that in general, the forecasts have been improving. The trend continues past 2002. This is just the latest image that they had from the Web site. In terms of track forecasting, we've definitely been getting better. I'd say the primary reason for that improvement is that our computer models and our use of satellite data and other observations has gotten better. That's the good news.

This is the intensity error. This is the error in wind speed forecasts, again in year. You notice that the trend is pretty much flat. It's gotten a little bit better. But in general, not so good. It's a much, much more difficult forecast to make. And it's certainly where lots of active research goes into. Which leads to sort of the final question in our forecast. How strong will it be? Again, we don't provide intensity forecasts, but we do, this is one particular tool that I know is used by hurricane forecasters to figure out intensity.

Then I'm going to show something from a MIMIC plot, which I'll explain. It's more of a research tool, something that will give us more information into the structure of a hurricane. It's also probably the coolest animation that we have. So I have to show you that. First of all, what is wind shear? This is a plot of wind shear. Wind shear is the change in wind in the atmosphere with height. If you take the wind at the upper levels of the atmosphere, take the wind at the lower levels and subtract the two, that's how you calculate wind shear. So we go back to the atmospheric motion vectors that I talked about and we produce these plots from that data. It turns out that hurricanes are very, very sensitive to wind shear.

They don't like strong wind shear. So a forecaster will look at this and say the hurricane is moving into a region of low wind shear so it's likely to strengthen. And that's what they would use a plot like this for. Again, the color scheme is very similar. The reds and whites show very, very strong wind shear. The dark colors show very, very weak shear. And the arrows show the direction of the shear itself. This is Hurricane Dean, again. We're going to watch. If you remember, Hurricane Dean strengthened as it moved into the gulf and against the Yucatan.

As you'll watch, it will strengthen in an environment of low shear in this animation. It pretty much stays in the blues almost the entire time. This particular case. I know I've been told this is a very, very useful tool, and something the forecasters look at all the time to make some of these forecast decisions. Yes?

(inaudible)

 In this case, what you're interested in is the environment around it. And in fact, I believe what they do here is they try to remove the wind caused by the hurricane from these plots. But yeah, the hurricane is definitely interacting with the environment, so that is relevant. I think that it's the environment that they care about, not the actual storm.

Yes?

(inaudible)

 Yeah, definitely. Some of that may be the removal that I talked about. But yeah, it definitely seems to have flown that way. I'm not familiar enough with what was going on weather-wise to explain why. But it definitely seemed to be in a very favorable environment. It's also in an area of very, very warm sea surface temperatures, so there's more to it than the shear. The shear is a primary issue. The final satellite product that I'm going to be showing here is the MIMIC product.

This is unique in lots of different ways. What the MIMIC product uses is microwave imagery. If you remember, the microwave instrument is only available on polar orbiting satellites. So you only get an image if the satellite happens to pass over the storm. If you have even a few satellites, you might get a pass every hour and a half, every three hours. You may not get a full pass. You may get the satellite passing over at the side of the storm. So you get these little snapshots. It makes it very, very difficult to analyze what's going on. So what Tony Wimmers has done is he's found a very clever technique to blend the successive images and create an animation.

How he described it in a talk a few weeks ago is that with a little bit of work, he makes polar orbiting satellites look like geo-stationary satellites. And as you'll see, that's pretty much what it looks like. It's not quite as accurate. He's doing some mathematical calculations and some assumptions, but it's a fairly powerful technique. That's the technique behind what you're going to see. What are you looking at with the microwave? As I said, the microwave is sensitive to the thunderstorms and some of the ice particles inside the storm, these things that are present in very, very deep, intense thunderstorms. So it gives you a very good sense of the strength of the storm and the structure of that strength, where in the storm is it strong. The yellows and the reds are these regions of very, very intense thunderstorms. I'm going to play this once and let you look at it.

Then we'll talk a little bit about what you've seen and I'll run it again. It's kind of a complicated image. One thing to keep in mind is that this image is following the storm. So it can be a little disconcerting to see the land moving and the storm isn't. So it's a storm-centered image, so it's a little strange. Okay, now I can ask you. Anybody notice anything interesting in that animation? Anything? I can talk a little bit. Let me back up a little bit.

So, hurricanes tend to have these very, very strong thunderstorms just outside of the eye of the storm. That's what you're basically looking at here, these very, very strong thunderstorms surrounding the eye. What did you notice? What happened to the eye as that animation went through? I'll play it once more. What happened to its sides? Well, lots of things happened, I guess is the question. What I've seen is that, you see there's kind of this inner eye. And very, very weakly at this point, there's sort of an outer eye. Watch as I run it again, watch the way that outer eye kind of develops and strengthens.

Then watch what happens to the eye inside it. Often, not always, but often when storms get very, very intense, they develop this secondary eye wall, this second band of thunderstorms. When that happens, the inner eye tends to collapse. Then the outer eye wall becomes the eye wall. When this happens, the intensity of the storm tends to change. It often weakens. I'll show it once more so you can see it. Again, it develops very strongly, and then the inner eye wall slowly collapses. In this case, it actually intensifies a bit in this particular case. This is Hurricane Ivan from 2004.

Why is this significant? Well, if forecasters can find a way to understand this process, which they don't understand very well right now, then they get some sense of, at the very least, when it may change. Often, when the secondary eye wall formation process happens, the storm weakens. So if they have some understanding of why this happens, then they might be able to predict an intensity change from it. There's lots of other things you can get from these images. In fact, my colleague was involved in a lawsuit with Hurricane Katrina because his images could give information about intensity that other instruments could not. It's a very, very powerful tool. He's just published it a few months ago. It's definitely a cutting edge product that he's produced. Now I want to move away from the short-term forecasting realm and talk very briefly about global climate change and tropical cyclones.

What's behind global climate change? Well, the earth is warmed by the sun and the atmosphere. If we didn't have an atmosphere, it would be unbearably cold on the planet. The oxygen, the nitrogen-- More importantly, the carbon dioxide and the water vapor in the atmosphere emit radiation to keep up warm. If we increase the atmospheric CO2, you would increase this atmospheric component of warming, and hence the theory behind global warming. Now, the big question. What will warming do to the planet? It's a bit uncertain. There's been lots of active research. And there are very, very intelligent people making very, very educated guesses.

But nobody is really certain. The system is just very, very complex. Why would this affect tropical cyclones? Tropical cyclones can be thought of as engines. The warm, moist air from these tropical oceans fuels them. Water vapor, when it condenses into liquid water, releases energy. It's a very, very powerful energy source. That's the fuel that drives hurricanes, which is why when they move on land, they weaken. They don't have that really, really rich water vapor air. And they give off cool, dry air aloft as exhaust.

That sort of follows the engine model of a hurricane. Our tropical sea surface temperatures have warmed by about 0.2 degrees Celsius. This is from a paper by Bister and Emanuel. I'm sure there are other numbers floating around. But they've been warming by a little bit over the past 50 years. If you increase the temperature of the ocean surface, you'll increase the storm's potential fuel. If you warm the ocean, you're going to increase the amount of evaporation that you have. And you get more of that water vapor into the atmosphere, more fuel for the storms. That's the theory. You increase the storm's potential fuel.

This is just a plot of the number of Atlantic hurricanes and major hurricanes from 1945-2005. I could add 2006 and 2007, and it would drop down significantly from 2005. But the point is still the same. First of all, you notice that in both of these plots, it's very, very noisy. There are some years where there are a lot of storms and some years where there's a few storms. But you can play some tricks. This is just an average, a smoothing technique. I just took a little bit of an average. You can see, when you smooth it out a little bit, that there are some trends. It looks like there was a minimum in the '70s, and an increase in the '90s and 2000.

So these trends are something you can look at in the Atlantic. Several scientists have. The question is, is this increased frequency in the Atlantic part of natural variability, is it a sign of global warming, or is it both? Well, the answer is really is that it's uncertain. Globally, there has been little change in tropical cyclone frequency. So just looking at the Atlantic, you get one story. Looking at the globe, it's a much more mixed picture. Climate modeling studies have been ambiguous. They've done lots of studies where they've run climate models and sort of counted the number of hurricanes that is produced. Some studies have shown an increase.

Some have not. And sort of the fundamental problem is there's a short historical record. We've only been studying hurricanes, looking at them, really, for maybe 100 years, and really well with satellites for even shorter than that, 20-30 years. There's a big data problem. Peter Webster was one of the primary scientists in his 2005 paper in "Science." He showed a global increase in Category 4 and 5, the very, very intense storms, between 1970-2004. But he did not find an increase in the global storm total. So, the total number of storms, he didn't find an increase, just with the very, very intense ones. Emanuel published in his 2005 paper in "Nature," he found a relationship between a quantity of power dissipation. Essentially, he looked at the maximum winds of the hurricanes and cubed that wind.

He found a relationship between that quantity over the lifetime of the storm and increased sea surface temperatures. He looked at both the Atlantic and the Pacific. So he found this relationship. Both of these studies kind of suffered from the same problem. They relied on the National Hurricane Center's Best Track dataset. This is historical dataset. You can go online and download it yourself. And it's a great dataset, but it's not very well suited to the task of detecting trends. Why? The observation network has changed throughout the dataset.

When they created it, they chose the best possible estimate of the hurricane's intensity and position at the time. So of course, that estimate, and the skill of that estimate, is much, much different. Hopefully, much, much better now that it was 20, 30 or 40 years ago. You could be detecting a trend in the data that isn't physical, but rather is a symptom of the way we measure hurricanes. What's the solution? Well, in part, satellites. Jim Kossin, who's a colleague, produced or did some research with some colleagues at the National Climatic Data Center. He published this in "Geophysical Research Letters." What he did was he derived a globally consistent dataset, using reprocessed satellite data from 1983-2005. His paper really only addresses the problem in a limited basis, but he basically degraded the 2005 satellite data to be the same quality as the 1983 data.

Then he came up with a very simple method for estimating hurricane intensity from the satellite data. So he sacrificed accuracy for consistency. His research came up with two conclusions. He calculated that there was a significant intensity increase in tropical cyclones in the Atlantic basin. In that particular result, he agreed essentially with Emanuel and Webster. But he calculated no significant trend in the global dataset. So looking at the globe, he said there was no statistical trend from the algorithm that he produced. If you have a statistics background, or you know, it's worth taking a look at the paper. It's quite interesting. My favorite part is he basically throws that last sentence in as almost an afterthought, even though it really is quite a big deal.

It's an interesting study. Of course, this doesn't end the search for the answer, but it's definitely one approach. There have been other scientists that are trying other things, looking at ship data and trying to simulate today what it was like if we only had ships today, and trying to see if they could detect a trend that way. But there's various other tricks that scientists are trying to address this problem. But it's something that definitely has to be addressed. I want to conclude by quoting the Inter-Governmental Panel on Climate Change, the Nobel Prize winning group that have studied the state-of-the-art of climate science. I'll read some of this to you. "There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures." So, it agrees fairly well with what we've talked about. "There's also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater."

It's a very politicized statement. You can sort of see them trying not to offend anybody. It's kind of interesting. "Multi-decadal variability and the quality of tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual number of tropical cyclones." So it very much fits this research that's been going on. I think it says it with lots of big words, but in kind of a nice way. That's basically the conclusion of my talk. For more information, please see our Web site. I also very much recommend the NOAA's Hurricane Research Division FAQ list.

The easiest way to find it is just Google "HRD FAQ". That's how I do it. I can never remember it. It should bring you right there. And of course, feel free to contact me if you have any information. Of course, I forgot to bring business cards. Thank you very much.

(applause)

 Yes?

(inaudible)

 Yes, he asked if there is a trend in the Atlantic, a positive trend in the Atlantic and no significant global trend, then is there, say, a negative trend globally. That's a good question. I suppose that's a possibility. It's also possible that just-- You have a lot more storms, say, in the west Pacific than you do in the Atlantic, so maybe that just, sort of the signal to noise has just increased so much when you add more neutral cases. I don't remember. I'm sure Jim Kossin's work dealt with that, but I don't remember the actual answer. So it could be either one. Yes?

(inaudible)

 That's a fabulous question that I wish I knew.

It's changed a lot in the past ten or 15 years. Certainly, like the microwave for example, which-- I should know my satellite history better. The microwave instruments that, if we had them, were very, very low resolution, so that's one thing. And I believe the geo-stationary satellites were also no where near the quality they are today. So even if the numbers had stayed the same, which they haven't, we definitely have more of them, the quality and our understanding of them have improved.

(inaudible)

 Right. No, that's exactly what, sort of what Jim Kossin's work tried to address. And the criticism of Emanuel's and Webster's work. That's exactly.

If you don't have as good a detection system, and you don't-- We also didn't send airplanes in as frequently as we do now. So it's likely that we missed the very, very intense storms that we had. All of those issues that you mentioned are significant. Yes?

(inaudible)

 Well, this is not our government. This is a worldwide body of scientists and politicians.

(inaudible)

 Sure.

(inaudible)

 I would say that, I don't know this for certain, but I would say the Bush administration had very, very little, or did not have a great impact. There may be some people who know the process, but this is completely independent of, I'm sure there were government scientists there, but this is independent of the Bush administration. This is a worldwide body of the best scientists, probably a lot of university scientists, which I don't believe had particular pressure. Most of the news stories have been NOAA, NASA scientists directly speaking out. I would think there may be some sort of international political pressure in some of the statements here, but I would guess that it's not all that significant. Someone may correct me.

(inaudible)

 I would say the IPCC is the best, is the state of the art. Their report is the state of the art climate science in the world today. Yes?

(inaudible)

 It would certainly be, 2006 and 2007 were both, I think, slightly below average years, in terms of numbers. I mean, 2005 was extraordinary. In terms of the 30-year trends that people are calculating, I'm not entirely sure. Most of this activity happened in 2005, for sort of obvious reasons. Whether two extra data points will change some of these results, I don't know. Yes?

(inaudible)

 Yes.

(inaudible)

 That's a great question. I don't know the answer. I certainly don't know enough about how the climate changes. There is evidence that the sea surface temperatures are also increasing. They may be increasing less than the air temperature. They're definitely connected and related. I don't know. Yeah?

(inaudible)

 Yes.

(inaudible)

 In terms of?

(inaudible)

 Mm-hmm.

(inaudible)

 Well, I think there's...

(inaudible)

 I'm not an expert in the feedbacks, but I know, sort of the simplest I've heard is that if you have ice melt. For example, if the icecaps melt, then certainly in Antarctica, for example, if the ice melts, then you get less solar radiation that's scattered back to the earth. So you get a feedback in terms of the solar radiation that would've been reflected back into space is now absorbed by the ground and heats the planet in that sense.

If you're looking at the changes in the mid-latitudes, it gets fairly complicated as to these feedbacks. Which I'm not an expert in climate science at all. Yeah, they're quite complicated. It's actually worth finding the Web site and looking. They've got a fairly consistent report. I think they're various levels of complexity of the IPCC report. That's the place to go if you have questions about sort of the state of the art climate. They've got a lot of numbers and they talk about all these issues. It's not an area that I'm an expert in. Yes?

(inaudible)

 Are you talking about the intensity estimate? It doesn't directly measure it. What it... Okay.

(inaudible)

 For that, it measures lots of different things. That's a good question. For the AMSU intensity, what I believe it's measuring is it's measuring oxygen molecules that are warming in the upper levels. So that as this air sinks in the eye it warms.

And what the satellite is sensitive to is the oxygen in the upper levels that's warming. That's what it's detecting. It's taking that radiation and statistically relating it to wind speed. In the MIMIC algorithms, which are also microwave, I believe what it's sensitive to are the ice crystals and the ice particles that are very prevalent in the intense thunderstorms of the hurricane. So it's the same sort of instrument, but used in very different ways. Yes?

(inaudible)

 Yes.

(inaudible)

 I don't think it's that sophisticated.

It looks at-- It find the center of the storm. It can measure whether there's a clear eye, or whether you've got sort of a curved band. And Dvorak himself had very specific intensity estimates for all these various shapes of the storm. And it also has a lot of different rules, like it looks at the history of the storm and says, well you can only change it by this much from the previous estimate. So it's relatively simple. I think it's a bunch of sort of yes/no questions. There's some complexity in figuring out those features. But yeah, it's nothing more complicated. Yes?

(inaudible)

 I absolutely wish I had seen it. I'm embarrassed to say that I haven't. But from what I've heard, he did sort of overstate some of the impacts of hurricanes. Off-base may be too strong a word. I would say you have to be very, very careful when you make, particularly somebody in the public eye, and they make conclusions of science that may not be scientifically sound. Because it then hurts your other arguments that are probably very scientifically sound. So I would say, you know, he definitely commands a very large audience and has a lot of impact. So if he made statements that weren't true, maybe off-base is not too strong a word. I would say, you know, you always have to judge between getting too complicated and being obviously truthful and not misleading. And I think there are ways to do that without exaggeration.

He probably could've found a cleaner way, but I have not seen the movie, so I shouldn't entirely speak on it. Yes?

(inaudible)

 Yes. I believe when you go-- The geo-stationary satellites are very, very far out in the atmosphere, something like 36,000 kilometers up. In order to use the microwave, you need a very, very large antenna. So it's essentially an engineering problem. There was a meeting, I think this spring of people trying to, proposing to put microwave satellites on geo-stationary. It would be a fabulous instrument to have, but I think it's an engineering problem.

(applause)