If it seems like there's been a hurricane bullseye over Florida recently, I would say that this is pretty much correct. During the past 10 years, Florida has been struck by 12 hurricanes, which is 48% of the total U.S. landfalling hurricanes during this period. During the devastating 2004 and 2005 seasons, there were $50 Billion dollars in damages and more than 100 deaths.

NEXT [3]

Scientific research on the potential impacts of climate change on hurricane activity has increased dramatically in volume over the past two years in response to the high-impact events of the 2004 and 2005 seasons.
To assess the future risk from hurricanes, we need to understand the impact of global warming on hurricane activity, the natural variability in the Atlantic Ocean, and the nature of local risks.

NEXT [4]

Hurricanes have been of particular significance in the global warming debate, since increased hurricane activity may be the most significant short term impact of global warming on the U.S.
Because of the importance of this issue, there has been substantial controversy surrounding the topic of hurricanes and global warming, and the subject has received substantial media coverage.
Yes, there is a very active ongoing scientific debate on this issue.
However, in many ways, the media has acted to polarize the scientific debate, often confusing the public and policy makers
The scientific process proceeds through the integration of data (which is uncertain), models (which are imperfect) and theory which is incomplete.
The scientific process in many ways is like putting together a puzzle; you are looking to fit together pieces to develop a picture. Even if all the pieces are not yet in place, at some point you can develop confidence in what this picture is going to turn out to be.
Once the picture comes into focus, it becomes much more difficult to cherry pick the science and ignore the large picture.

NEXT [5]

The Intergovernmental Panel on Climate Change has provided a thorough and rigorous assessment of the state of climate change science and impacts as of 2006.
The IPCC 4th Assessment Report assessed and clarified what we do know about hurricanes and global warming and also the associated uncertainties. On the next two slides are the pertinent findings of the IPCC Summary for Policy makers regarding hurricanes.

With regards to Detection of Change
READ

NEXT [6]

With regards to Projections of Future Change
READ.

NEXT [7]

As policy makers grapple with issues related to hurricanes and the broader issue of global climate change, it is a substantial challenge to develop effective and affordable policies in the face of scientific uncertainty. Its really about risk assessment and risk management.

READ

So what I am going to do in my talk this morning is try to put some bounds on the risk we are facing from future North Atlantic hurricanes, and give you a sense of what we think this picture looks like and what the missing pieces are.

NEXT [8]

To assess the impact of global warming on current and future hurricane activity, we need to also understand the impact of decadal scale modes of natural climate variability.

NEXT [9]

This figure shows plots the total number of north atlantic tropical cyclones in blue, and the tropical atlantic sea surface temperature in red.

The data have been smoothed to reveal the decadal scale variations.
I show the period since 1920, which is the period for which we have confidence in the data record.
The data shows some cyclical variations, but there is an overall increasing trend for both the cyclones and sea surface temperature.
How do we sort out what is global warming vs natural variability?
The yellow shading indicates the warm phase of the Atlantic Multidecadal Decadal Oscillation, or AMO, which is associated with increased hurricane activity. We are currently in the warm phase of the AMO, which is expected to continue until at least 2025.
If we look at the year 2025, climate model projections suggest a 1 degree Fahrenheit warming owing to global warming, indicated by the red star.

NEXT [10]

To further aid our efforts at sorting out the natural variability from global warming, lets now add another important mode of natural variability, the Pacific Decadal Oscillation.
During the cool phase of the PDO, represented by light blue, La Ninas are more likely.
The green color reflects the combination of the warm phase of the AMO and the cool phase of the PDO, both of which are conducive to tropical cyclones.
The current green period began just a few years ago and is expected to continue until 2025, and can be compared with the previous green period in the 1950's.

NEXT [11]

Looking at U.S. landfalls, the situation is further illuminated by adding the negative phase of the North Atlantic Oscillation or NAO, which is represented in red and combines with the other colors to produce orange, purple and brown.
The NAO influences the hurricane tracks and hence the number of landfalls.
Of particular interest is the brown period that began in 2004 and is expected to continue for a few more years, before the NAO becomes predominantly positive.

NEXT [12]

If we look at the number of tropical cyclones striking the Florida Peninsula, this analysis is particularly illuminating.
The white period of the 70's, 80's and early 90's was characterized by very few landfalls.
In the yellow and orange period starting in the mid 90's, landfalls increased.
The brown period, reflecting the confluence of all three modes of variability is associated with the very high landfalls that we had in 2004 and 2005.
Once the NAO becomes predominantly positive, Florida should move somewhat out of the bullseye.
While there is a lot of year to year variability within any particular colored regime, this analysis of natural variability provides a background for identifying the signal from global warming.

NEXT [13]

Given our understanding of the Atlantic natural variability and global climate change, what does the hurricane forecast look like for the period 2020-2025?
In terms of natural variability, we expect to be in a green period, associated with the warm phase of the AMO and the cool phase of the PDO.  We also expect there to be a 1 degree Fahrenheit temperature increase from global warming.  By integrating data analysis, model simulations, and theory, we can present a picture, albeit with some missing pieces, that can be used to bound the risk from the future hurricanes.

NEXT [14]

Lets first look at hurricane intensity, where most of the scientific attention has been focused in terms of the impact of global warming.
The upper figure shows plots of the average hurricane intensity as measured by the wind speed, given in blue, and the average tropical sea surface temperature is given in red.
The green bar at the bottom is an indication of the confidence we have in the data quality.  Since 1983, we have high confidence in the intensity data, in the earlier years there is decreasing confidence.  I did not show data before 1970 since we have little confidence in the earlier intensity data.
The data since 1970 indicates a 7% increase in intensity for a 1 degree Fahrenheit temperature increase.
This increase in average intensity is associated with a doubling in the number of category 4 hurricanes.

However, as evidenced by the colored stripes representing the regimes of natural variability, we can't separate out the signal from the global warming given this short data record.

NEXT [15]

We can get some help by looking at what the observations, models and theory have to say about global hurricane intensity
You may be familiar with our paper on hurricane intensity increase, the upper right corner showing the graph from the Webster et al. 2005 Science paper. We found a doubling in the global number of category 4 and 5 hurricanes since 1970, which was associated with an increase of about 1 degree Fahrenheit in global tropical sea surface temperatures. The Webster et al. analysis translates into a 6% increase in average intensity for a 1 degree temperature increase.
Simulations using high resolution climate model simulations scaled to a 1 degree temperature increase give a lower intensity increase, 2%.
Estimates using Potential intensity theory give an increase of 2.3% to 5.7% for Holland's version.
Observations, theory & models all agree that hurricane intensity should increase, they disagree on the magnitude.
Because the intensity data outside the north atlantic is uncertain, the Webster et al. value is probably too large.
So we can put credible bounds on the average intensity increase of between 2 and 5%.
This may not sound like a lot, but insurance companies tell us that damage from landfalling hurricanes goes as the 7$^{th}$ power of the intensity, so the 2-5% increase in intensity translates into a 15 to 40% increase in damage.

NEXT

Now what about the annual *number* of tropical cyclones?
The data is in better shape for the number of tropical cyclones, so we can look at the data record back to 1920.
We can compare the two yellow periods beginning in the 30's and the 90's, that reflect the same regime in terms of natural variability.
Comparing these two periods indicates an increase of 6 tropical cyclones for a one degree warming.
The data prior to the 1950's is associated with some uncertainties, which includes some missed storms and some misclassified storms.

Taking into account the likely undercounting, the actual increase is probably between 3 and 4 tropical cyclones for one degree of warming.
This increase in the number of tropical cyclones is associated with the expansion of the tropical Atlantic warm pool.
In the 1920's, the green region, the warm sea surface temperatures were mostly in the Gulf and the Carribbean.  The current warm pool, in red, extends all the way across the Atlantic to Africa.
The extended warm pool has resulted in more hurricanes forming in the eastern part of the atlantic, and has also increased the season length.
By reducing the east west temperature gradient, this expansion of the warm pool has also reduced the wind shear in the southern part of the main development region.

NEXT

Looking globally, the data tells us that there is no increase in the total number of hurricanes.
Climate models suggest a decrease in the global hurricane number with warming, but possibly a small increase in the number of Atlantic hurricanes.
Why would there be an increase in the number of North Atlantic hurricanes, but a decrease in the other global regions?
Some insight into this is gained by looking at the sea surface temperatures in the other regions, shown in the lower right hand corner since 1970.
The North Atlantic is the coolest ocean basin that hurricanes form in.  In fact, the temperatures around 27 degrees Centigrade are just above the threshold for hurricane formation, which is 26.5 degrees centigrade.  In the south Atlantic, where temperatures are colder, no hurricanes form.
The West Pacific, where 40% of the global hurricanes form, is several degrees warmer than the North Atlantic.
Therefore it seems that the number of North Atlantic hurricanes have not yet saturated because of the relatively cool temperatures.
It is likely that the numbers will increase somewhat with increased warming, but after a certain point the change will start to resemble that for the other warmer regions.
Our understanding of what controls the global number of hurricanes is much less clear than our understanding of global hurricane intensity, and I've represented this by a puzzle where the picture isn't very clear:  we have some pieces in place, we can tell its some sort of landscape, but there are different possibilities for how this could turn out.

NEXT [18]

So lets summarize where we are at.  For the period 2020-2025, associated with a warming of one degree, we are able to put together a reasonable picture and bound the expected activity.
We can expect a hurricane intensity increase, with magnitude between 2 and 5%.
We can also expect an increase in the number of tropical cyclones, but the bounds on this are fairly broad, from 0 to 4 per year.
The landfall distribution is expected to continue with high landfalls on the Gulf coast and Florida
If we try to project out to 2100, when we can expect an additional 5 degrees warming or even more, things are much speculative, and we only have the models to guide us.
Hurricane intensity is expected to increase, the models projecting about a 10% increase
The early increase in North Atlantic frequency would probably stop, and we would expect no further increase.
And we really have no idea of what the landfall distributions might look like, since the modes of natural variability would like change.

NEXT [19]

So what do the future risks to Florida look like?
In addition to the increasing number and intensity of hurricanes, we also have to factor other aspects like sea level rise and increased rainfall.

NEXT [20]

The susceptibility to storm surge increases with increased hurricane intensity.
Two geographical factors determine local storm surge vulnerability: the slope of the continental shelf (shown on the left) and the elevation of the coastal regions on the right.
The three regions that are most vulnerable to storm surges are the West Coast (particularly Tampa), the Gulf portion of south florida, and the Jacksonville/Daytona area.

NEXT [21]

The Army Corps of Engineers has rated the Tampa Bay area as the number 2 storm surge risk, right behind new Orleans. The geography of the bay would act as a funneling effect, and a category 4 hurricane has the potential for a 25 ft storm surge.

NEXT [22]

Arguably the biggest storm surge threat to Florida is from Lake Okeechobee. During 2004, rainfall from the hurricanes brought 6' of water into the lake, nearly exceeding the level for dike stability.
The warm phase of the AMO generally brings more rainfall to south and central Florida. Combine this with more rainfall from more frequent and intense hurricanes, and the probability of breaching the dike is increased.
Breaching the dike would likely result in billions of dollars of property damage, irreversible harm to the Everglades, and contamination of drinking water.

NEXT [23]

A quick summary of the risks to Florida
READ

NEXT [24]

The risk of elevated hurricane activity arguably represents the most devastating potential short-term impact of global warming, at least for the U.S. The combination of the coastal demographics with the increased hurricane activity will continue to escalate the socioeconomic impact of hurricanes. How should policy makers react to this risk?

As a scientist, I do not get involved in advocating for specific policies. I am limiting my comments here to a general assessment of how certain policy strategies might affect the risks associated with increased hurricane activity as global temperatures continue to rise.

Specifically with regards to energy policy. Any conceivable policy for reducing $CO_2$ emissions or sequestering $CO_2$ is unlikely to have a noticeable impact on sea surface temperatures and hurricane characteristics over the next few decades; rather, any such mitigation strategies would only have the potential to impact the longer term effects of global warming including sea level rise and the associated storm surges.

Particularly in the U.S., we are facing a very serious risk in the next few decades, owing to the combination of global warming and the active phase of the Atlantic Multidecadal Oscillation. Decreasing our vulnerability to damage from hurricanes will require a comprehensive evaluation of coastal engineering, building construction practices, insurance, land use, emergency management, and disaster relief policies.  We simply cannot afford to ignore this risk.