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Clement: Ocean which the UK um set up a program in 1856 um where, where uh, uh private ships were voluntarily collecting observations and you could see that the blue shading actually gets broader as you go back in time and that represents both error in the measuring technique and error in the, the network of measurements and the estimate so how many measurements actually go into the global mean temperature. But very clearly there's a trend and this is well, well known now. The second panel is sea level and if you look very carefully, you can see there's a red line towards the end. That's from satellite altimeter data. Um, that's, that is the most comprehensive global estimate of sea level that we have and prior to that there're the estimates are based on, on tide gauges from around the world. Obviously a large trend uh or a very, very clear trend in sea level there. And the third panel is um northern hemisphere snow cover, a slight trend downward um so decruise (sic) decreasing snow cover but a lot of uncertainty related to the fact that we have um that snow cover estimates are sparse and inherently um uncertain.

So, now attribution, next exercise is attribution. We've seen that there's some global climate change. How do we know what is causing it? And the way that the IPC…C approaches this is through, by using global climate models. Um the, the climate models, I won't get into the details but I wanna give you the big picture of what is in these in these models. First of all, there's 23 that are used in the IPCC Report. They're from modeling centers all over the, the, the world. Um, they are coupled ocean atmosphere general circulation model so that they, they simulate the entire um ocean circulation, atmospheric circulation and all the um constituents of the atmosphere also. And uh land surface as well. Um the general circulation of the ocean in the atmosphere is described by well known equations of motion and in that part of the um that part of the models is similar from model to model. However, the other parts of the, um the other elements of the, the models which include radiation, thermodynamics, convection, land surface and, and, and ice um on land are all simulated using parameterizations. And those are done from the in it ways that differ. In some ways pretty significantly from model to model. And so the, un…the uncertainty in many of our climate change projections um comes about from these processes in, in the climate system.

Um so the, the kind of simulations that they do are um, if, if you look back over the 20th century, we know there are well known um radiated forcing which include um carbon dioxide, other green house gases, atmospheric aerosols, some of which are naturally produced um by for example volcanoes, some of which are anthropogenically produced um and solar variability. And if you then take these, these climate models and impose the radiated forcing on them for the 20th century, um you can do an

attribution exercise where if you remove certain forcings then you can see what is, what it, what um which forcings actually lead to a simulation of the observed warming. And I'll show that in the slide next but let me just mention that there is also um the projections also use these same models but using scenarios for $C0_2$ increases in the future over the 21st century.

And then I, I wanna make the point that um the IPCC uses um multi-model averages as a way of trying to extract the robust features of these simulations. Um and you'll see in the slides that I show from the IPCC the measure of robustness or, or spread measure of robustness and spread about the average is done a little bit differently in each quantity but um that's something to keep in mind with when we're looking, when we're using these models, we wanna try to extract the signal that is common in all models and that is our measure of robustness.

So um this is a picture of, of um, of 20th century simulations using um all of the climate the all 23 climate models. And um each of the curves that is located over the continents shows the average surface temperature um for in the black line is observations. The pink, the pink swath is um natural plus anthropogenic forcings. So, if you take the, the models and, and pose all the known forcings, then you get that result. And the swath is wide because there of the, of the, of the uncertainty in, in the different model simulations. Each model does a simulation of for example clouds differently over the 20th century. And then the blue swath is the ma…models but forced only with natural forcings so um volcanic forcing, solar variability, etc. So, what, what this graph shows is that, um that the natural forcings do not, imposed natural forcings do not simulate an increase in temperature over the 20th century and particular the increase that is most pronounced at the, in the second half of the century. But the um by imposing anthropogenic forcing, there is a simulation of the um, of, of the observed warming. And the warming is larger over land if you could see in the bottom panel. Here the land simula…land warming is much more pronounced than the ocean warming which is just related to the, the heat capacity of land is lower than the ocean so it heats up more quickly.

So, having done that, which an attribution exercise saying we, we, we and, and now the statement from the IPCC is that it, it is very likely that this warming is, is due to um human, um human activity. Now we say what is, how, how is, how are anthropogenic greenhouse gases gonna influence the future evolution of the climate? And this is a picture of the temperature projection um out into 2100. It's a simulate…uh it's simulation from 1900 to 2000 which I just showed and then temperature projections out to 2100. Um, the clock here, sorry, I had it, the, it says 1:09. I don't know how much time I have. Can you tell me?

Berry: (inaudible)

Clement: Left?

Berry: Yeah.

Clement: Okay. So um so what you see is that um there're different scenarios. Obviously, we don't know how CO_2 is going to evolve in the future. It depends on technology, policy, etc. So the IPCC produce um generates different scenarios. Some fossil fuel intensive, for example this red line. The other, the, the most conservative is this um constant CO_2 values of at 2000. You see even that there's some projected warming because the ocean is still adjusting to the forcing out several hundred years into the future. And um these, these on the right hand side are our best estimates of the warming at 2100. You can see there's a pretty large range from about um just under 2° up to 4° Celsius so double that for Fahrenheit. And not only are these scenarios, not is only is there some spread related to the fact that there are different possible scenarios for the future but there's also a large spread which uh for each given scenario and that comes about from primarily due to the model simulation of clouds. That's sort of the red herring we've been working on that problem in for several decades. In climate change research, progress is slow but there're a lot of um new satellite observations or satellite um systems which are um will hopefully reduce some of the uncertainty in the future.

Sea level rise is projected to also increase. This is um the red shows the um shows the observations which I showed earlier from 1856 to 2000. Um and then the future projections are shown here with the blue swath um primarily related to um to the range in um in actual warming. So each model has a, produces a certain amount of warming while models that warm more, sea level rises by more. And the estimate by 2100 is about um .2 to half a per to .5 meters. Um, but, and I will come back to this issue um in a moment but I want to um point out that this is text from the Summary for Policy Makers. Models used to date do not include, include the full effects of changes in ice sheet flow, in particular over Greenland, because a basis in the, in the published literature is lacking. The projections include contribution due to increase ice flow from Greenland and Antarctica at rates observed for 1993 to 2003. But these flow rates could increase or decrease in the future and I will present some work that has argued that that flow rate is actually larger uh ha…in recent years and so that these projections are likely to be conservative.

Finally, um there's a, the, the precipa…there's projections about how precipitation will change in the future and this is an inherently um model dependent field or in other words not robust field. But there are some robust signatures that come out. Um the left panel is winter time precip. The, the red colors are decrease in precip and blue are increase and um

right hand panel is summer. Now, this is um a multi-model average and they made an eff…s…effort here to emphasize the um robust features by putting stippling where all the models where 90% of the models agree in sign, not magnitude but sign. And um and then white areas are where there's really no agreement between the models. And one of the things that's been noted in the literature and I will come back to this is that there's a drying in the Caribbean. There's a drying in the generally in the subtropics but there is a fairly pronounced drying in the Caribbean and Southeast US um uh region uh for uh for summer and winter time. I'll come back to that.

Um, there is a, this is a, also from the Summary for Policy Makers. There's this brief statement about um how intense tropical cyclone activity will change in the future and there's, they argue that it, it's likely in some regions, in particular the Atlantic, that there's been an increase in intense tropical storms over the last 30 years. And then they say this, there's a likely, that, there's, that it's likely that there will continue to be an increase in the future and I'll revisit that issue based on more recent findings since then.

So, these, this is a summary of the recent findings. One, um sea level rise may be faster than reported in the, in the IPCC 2007. Secondly, precipitation is projected to decrease and evaporation increase in the subtropics. And finally, the jury is still out on Atlantic storm activity and how that will evolve in the future. So, while the IPCC is arguing that it's likely I think that the current state of affairs um in the science community is that it, it that the jury is out.

So um sea level rise. Uh, this is a, this is a picture from a paper that was published just after the IPCC Report came out in 2007, so it's not cited in there. Um, and this, uh what, what these authors did was they went back and they took the findings from the 2001 IPCC Report that there's been I think full…there have been 4 reports thus for far. So in 2001, they made projections about future warming and future sea level rise. And so those um projections actually were started in 1990. It takes many years for these model simulations to get going so I think some of these model simulations were started in like the mid 90's so a natural place for them to start their simulations was 1990. And so all the data basically since 1990 to today is essentially independent of those um of those simulations. And so we can compare what happened with sea level rise um since, since 1990. Now these lines here, the dash lines, high, medium and low, were three different scenarios from the IPCC 2001 Report. Um high being fossil fuel intensive. Medium uh sort of middle of the road and then low sort of more green uh introduction of green technologies uh scenario. And what you see is that the altimeter data which is shown hard to see but it's shown in gray, superimposed on this station data which is shown in red is

that the sea level has actually been following the high um, the, the high uh warming scenarios for the IPCC Report. Um and so this, this was introduced as, as evidence that, that the IPCC estimates are likely to be conservative. Now why this is happening is not well known. The authors of this study did not, not um make an argument for that. They were just pointing out that there is um sea level does appear to be increasing on the fast side of the range of projections.

Secondly, there was a statement uh made, there was a Miami-Dade Climate Change Task Force which revisited this issue about sea level for obvious reasons in Miami-Dade County is a, is a um issue of great importance. And they came out with a summary statement um on sea level rise in the coming, coming century. This committee was made up of um many scientists, maybe possibly some people in this room um from, from around the region and um some people from the administration, too. Uh, and one of their main findings was that uh as stated here with what is happening in the Artic and Greenland, in other words melt rates from recent years since 2003. There will likely be a sea level rise of at least 1. 5 feet in the coming century or I'm sorry, in the coming 50 years. And a total of at least 3 to 5 feet by the end of the century, po…possibly significant more, signi…significantly more. So, I'll go through and, it and, and back up this with what they, with what they argue but I do wanna point out that this is not published in the peer review literature. Um, it is experts that are assessing this but it has not been reviewed so um there, there um, that's something to keep in mind with this kind of statement.

So one of the points that they make which is interesting and certainly of relevance to this group is that relative sea level rise in South Florida has been going up at a rate of 1.5 inch per century over the last 2500 years. So that's a finding based on geological evidence whereas um in, since 1932, sea level in South Florida has risen by 9 inches so obviously much faster rate than what the um what the pre-industrial sea level rates were.

Uh the IPCC 2000 um 2007, I'm sorry. I should, this is, there's a mistake here. This is IPCC 2001 earlier estimates were um 1 to 3 feet by 2100. But the more recent estimates which are more like .2 to .5 meters do not include contribution from uh recent rates of melt as I mentioned before. Uh, there, the study pointed out that there are key uncertainties and these are related to high latitude ice cover in Greenland and Antarctic both of which if rate, melt rates are faster than um than as, the than the rates used in 2007 Report, then sea level rise is likely to be a lot faster than reported there. Um, and also they point out that artic sea ice is melting much more quickly. Now that doesn't influence sea level directly but it is a big climate feedback so if melt rates are faster, um the albedo of the high latitudes or the reflectivity of the high latitudes goes down and the planet can warm significantly more was what the argument in this, in this um

report. And the committee recommended a detailed documentation of elevation of infrastructure and natural resources for 1, 2, 3, even up to 5 foot benchmarks um of sea level rise. Um that is was an important action to be undertaken immediately by the county.

Um so, secondly, I, I'll um I uh will uh discuss some briefly some um projected precipitation changes. Um this is in a study, this is a picture from a study that is in press right now but it's actually based um is consistent with, with um work that's already been published which has argued that the Hadley cell, or the subsiding part of the, of the um atmosphere which is actually sitting over the subtropics um should expand as the earth warms. And this is a robust signature of global warming in all these models and the subtropics dry. And um so what is shown here is precipitation in the left hand side from the winter half and summer half of the year and then precipitation minus evaporation in the winter and summer half. Again, this is the multi-model average. This is a robust signal in the sense that models get, all models seem to simulate the same sign but the magnitude varies. But what you see is a very clear, drying, now this is, this work has been um gotten a lot of attention because of the uh because of the implications for the western US and drought in the western US but you can see that the uh drying is actually not confined to the west but it's throughout the subtropical belt including South Florida. Uh and I won't, I, I think I'm gonna run out of time so I, I won't go into detail but um this paper um by Seeger, et al., um has argued uh that that you can make an estimate of um Palmer Drought Severity Index for the Southeast US and looking back in time there are drought tree ring uh based drought atlases available that go back to 1000 A.D. and you can see that there's a lot of variability in, in um drought in the, in the Southeast US. This is the first, this is 1000 um this is 500 years and then another 500 years. And one of the things that sort of stands out is that the 20th century looks a little bit wetter compared to the rest of the 20,000 or rest of the last 1000 years.

Finally, the jury is out on Atlantic storm activity. Um so current, current um computing power limits the ability of global climate models to represent hurricanes. This is a picture of Hurricane Rita and a super, a um, a uh, the grid resolution of, of the global climate model superimposed on that storm and you can see that the scale of the storm is not very well represented by the models. Maybe you get a couple grid points. Oops! So um uh models do not simulate these storms very well although there is some approximation of these kind of storms which people have looked at um in the models. Uh, nonetheless, tropical storms are affected by the large scale conditions that today's climate models can represent and so we can ask the question how, what are factors that influence storm development and intensification? One well known factor is warm surface ocean. Um and then this is a study that came out in 2005 in which um it was noted by,

by Carrie Emmanuel that in the last, that, that sea surface temperature which is shown in the solid line tracks very pretty uh pretty well the Atlantic and measure of intensity of Atlanta, Atlantic hurricanes. Now this, this work has been criticized very um uh very heavily because the, the detection of or measures of intensity of storms prior to 1970s is difficult to believe since there was no satellite data but since 1970, still there is a very strong trend in Atlantic hurricane intensity and also warming of the Atlantic sea surface. Um but there are other factors that influence um the inci…intensification, for example, cool upper atmosphere also leads to intensification. Vertical wind shearing low vertical wind shear in order to have a storm intensify. People in South Florida know all these things because we hear about them in the news. Um but so what do the climate models predict will happen to these large scale environments? Well, warm surface ocean warming will continue to um happen in the future which would favor intensification but cool upper atmosphere and vertical wind shear both of the, both of the chan…in the changes in these quantities actually inhibit storm um development. So there's, there, and there's other factors as well which these are the only three that have been most highly, most studied in the literature.

So, how do these factors all add up in terms of intensification of sur…hurricanes? Well, the net effect at present is unknown and um the current state of the art is that um is to take hurricane resolving models and imbed them within global climate models. These are technically challenging for many various regions but it's something that various groups around the country are doing. Some groups at um NOAA Labs in Princeton and at MIT as well. So this is the current state of the art but as, as yet it's un…um it, the, the jury is still out on how the, these things will um uh how tropical storms will evolve in the future.

Finally, just to wrap up, how much time do I have I? 5 minutes?

Berry: Zero.

Clement: Zero, okay. Well, I just, I'll just leave this up. Then um, this is a, an opinion poll that was, that was rel…um conducted last may about Florida, Floridians and their opinion on climate change. Uh it's a some colleagues from uh Rosenstiel School and also from Yale. Um and basically I, I won't go into the details but um Floridians are generally convinced that there's a problem. There's a majority are convinced that there's a problem. Um, they, the majority believe that human activities are causing this problem as opposed to natural cycles. And finally, they are anticipating impacts um in the next 50 years involving hurricanes, water resources and sea level rise and are prepared, according to this study, to support climate change policies at both the state and federal level. Um so this is, I think is consistent with the scientific findings in the sense that we know that there

are these impacts to come and they should um that Floridians are, are prepared to deal with them. Or prepared to, to support policies to deal with those, those impacts. So I'll just leave up. This is the findings and, and leave it there. Thank you very much.

No time for questions?

Berry: One question.

Clement: Okay. Any questions? I think you're supposed to come up to the mike because…

Berry: You need to come up to the…

Clement: They're recording this…

Berry: Look right (inaudible).

Clement: …apparently.

Male: Yeah.

Berry: (inaudible).

Clement: You're gonna be on the web.

Berry: (inaudible)

Male: Uh, Amy, as a modeler, could you just give briefly your opinion of the way that the detection and attribution community uh simulates internal variability which is one of your specialties, in particular, uh decadal and multi-decadal cycles which are so important for this area?

Clement: Uh-hum.

Male: Because uh they treat that in a specific way by I think simulating that variability and that can have the largest impacts on an area like Florida.

Clement: Yeah, thank you. That's a great question. Um the models have their own internal variability which is, is simulated as a, as a result of just the physics there in the model. And some models I, I it's I think currently being assessed um by different groups and some people that work with me too um uh how well they do at simulating those that internal variability. I can't say. I think there's a whole range. Um some, some do something more like, like the world, the real world and others don't, don't do as well. But um right now what there's an interesting emphasis in um a an

emerging emphasis in, in the, in um research community to actually try to predict decadal variations as well. So if you take a climate model and rather than starting it in 1856 and seeing what happens, let's start it with the conditions that we know the climate system, the state of climate system today at than with some, some persistence of the current decadal structures like Atlantic very multi-decadal variability or variability in the Pacific. How did those influence the projections of the future? And there's a paper that come out not to long ago in Nature arguing that, that decadal, natural decadal variability will actually make, make the next 10 or 15 years a little bit cooler than you would expect just based on the anthropogenic forcing. And so, so I, I think that's starting to be addressed and we're, actually it's a very, it's a technically challenging thing to do because you need a lot of data and computer power to be able to do these things but um there are groups and I think NOAA just had a call for proposals on this kind on this topic. So I think some, there'll be more answers forthcoming in the next few years but right now it's still, it's still, there's still a lot of uncertainty associated with that as you point out. Okay. Thanks.