Good evening. Welcome to sustainable environments lecture. This is a series of lectures that are intended to raise awareness of current environmental events and issues around sustainability and how they impact our social stability and economic vitality. This is really to prosper, open conversation and really engage in dialogues that we all understand the issues that are in front of us. And ultimately my goal here is to provide you, the public, with access to experts in fields so that we can all gain an insight. Tonight's lecture is being sponsored by Rawlins Professorship, the Institute for Sustainable Development, and the Gateway Science Museum and I'd like to further publically thank all faculty and staff of those organization for helping me put this together. In May of this year Yale and George Mason University put out the Six Americas report and it was a large scale survey that looked at how the American public viewed the issues of climate change. They separated these into six categories, but I'm going to break it down into three. Of the several thousand people that they interviewed, they found that 39 percent of the American public was alarmed or concerned about issues of planet change. 35 percent were conscious and disengaged. Another 25 percent were doubtful or really not concerned about it at this point. So, as I read the report and look through the lay out, one thing came out of it and it was one of their final questions. If given a chance to talk to experts on the issues of climate change, 90 percent of all respondents ask the similar question. Do scientists really know that global warming is caused by human activity rather than financial changes in the environment?
So tonight, we have an opportunity to hear from Dr. Ben Santer. He will give a talk, "The causes of recent climate change: Separating fact from fiction." Ben has quite a resume. I was really astounded as I've read through it. I can give you the brief synopsis. He's a Doctorate in Climatology from East Anglia University in United Kingdom. In 1995, he was a lead author for the Climate Change Detection and Attributions chapter of the IPCC report. He has been a contributor to all of the Intergovernmental Panel on Climate Change reports. In 1998, he got a Norbert Gerbier-MUMM International Award from the World Meteorological Society; 2002, the E.O. Lawrence Award for scholarship from the Department of Energy; 2005, Distinguished Scientist Fellow from DOE, from the Office of Biological and Environmental Research; and 2007, he was one of the co-recipients of the Nobel Peace Prize that was awarded from the Intergovernmental Panel on Climate Change; 2011, he was a fellow at the American Geophysical Society. Also, in 2011, he was admitted as a member to the National Academy of Sciences. He has published 39 peer-reviewed articles, written 12 books, and had given over 270 lectures on climate change. So with that, Ben Santer.

Ben Santer: Thank you Jim. Good evening ladies and gentlemen and thank you for giving me the opportunity to speak to you. I love this picture. This is the amount of water vapor in the atmosphere on the day Katrina made landfall. This little blob that you can see here is actually Katrina. And it's not just a pretty picture. It illustrates that since the late 1970's, we've had the ability to monitor global scale changes in climate from space and as I'll try and tell you later, we've actually looked at this satellite measurements of water vapor change and tried to determine whether they have some human fingerprint in them.
Jim mentioned the Intergovernmental Panel on Climate Change or IPCC. I'm sure many of you have heard that organization. They were set up in the late 1980s to advise the nations of the world what we know and what we don't know about the nature and causes of climate change, likely impacts of climate change on many things we care about and possible mitigation and adaptation strategies. They've issued four reports. The most recent one was in 2007. And as Jim mentioned, I was conveniently the author of Chapter 8 of the Second Assessment Report and that chapter dealt with cause and effect relationships in the climate system. After years of work, we came to this conclusion, the balance of evidence suggest a discernible human influence on global climate. I spent roughly two years of my scientific career defending that conclusion and the process by which it had been reached. It's kind of funny to think that for the rest of your life, you will be associated with one sentence. No matter what I do for the rest of my life, that one sentence will always be something that follows me around. Well, "Extraordinary claims do demand extraordinary proof" as Carl Sagan and others have said. That claim back then in 1995 was extraordinary. We were not saying, "Eureka, there's order in the bathtub. We understand everything."
But we were saying while we look at the totality of the scientific evidence, most of it points in one direction. Subsequently, other groups of scientist in 2001 and in 2007 came to much stronger statements regarding the reality of the human effect on climate. They actually tried to quantify the size of that human fingerprint. And again, most recently, the bottom line statement was most of the observed increase in globally average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Very likely had a specific probabilistic meaning greater than 90 percent probability of occurrence. So, one of my jobs here tonight is to give you some sense of the scientific underpinning for these conclusions. Where do they come from? Why has there been this evolution of the scientific evidence. How did we get to this point in time where we think that humans are not just innocent bystanders in the climate system but active participants?
So first of all, I'm going to tell you a little bit about the drivers of climate change both natural and human, the things that can cause change in the climate system. Then, I'm going to give you a brief climate 101 looking at observations of climate change. Not just surface temperature measurements but a variety of different measurements. Then, I'll tell you how we put it together, how do we put it together, how do we look at both the drivers, the observed climate change, and figure out how much of the change that we see that we observe is due to human actions, how much is purely natural. Our tools of the trade for doing that disentangling are complex numerical models of the climate system. The climate models, we call them. How good are they? How do we compare them with observations? How do we use them to do climate fingerprinting to try and unlock cause and effect relationships.

I'll tell you a little bit about that. I also want to tell you that there's still a lot of uncertainty in our science particularly with regard to projections out to the end of the 21st century. How large are the changes in temperature in sea level and precipitation going to be? What is there seasonal and regional distribution? These are critically important questions and yet the uncertainties in these projections out to 2100 are very large. Are there clever ways that we might be able to shrink those projection uncertainties to relate things that we can measure and monitor in today's world to those projections of future change. The answer, I hope to convince you is maybe. There may be clever transfer functions that relate present day observables to those projection uncertainties. I've spent a lot of my career trying to addressing myths about climate change and to do the science necessary to address the criticism and I'll give you one example of this sort of debunking that I've done recently and finally some conclusions.
Okay, one take home message is that climate change is not an "either/or" proposition. It's not either all natural or all human. The climate changes that we've experienced over the last 150 years due to some combination of natural influences and human influences. The natural influences include things like changes in the sun's energy output.

The sun is a variable star. We've measured, as I'll show you later, its energy output roughly over the last 33 years or so. Further back in time, we look at things like sun's spots so called cosmogenic isotopes like 10 beryllium things whose abundance depends on changes in solar activity overtime. And we've made inferences about long-term changes in solar output. We know the sun varies on time scales of 11 years and longer than that. In addition to purely natural changes in the sun, there are changes in the amount of volcanic destiny atmosphere. This is satellite imagery of the eruption of Mt. Pinatubo in the Philippines in June 1991. This big pancake-type thing here is the dust cloud from Pinatubo. Pinatubo actually injected dust up into the stratosphere and when dust from volcanic eruptions gets up there, it intercepts some of the incoming sunlight and actually some of the outgoing long wave radiation from the earth's surface. It heats the upper atmosphere and cools the lower atmosphere. And for a very large volcanic eruption, temperature on earth's surface can be reduced four years at that time, sometimes even longer.
Then there are things that are completely unrelated to changes in the sun and changes in the amount of volcanic dust in the atmosphere and we know and loved many of them here in California. El Ninos, La Ninas, things like the Pacific decadal oscillations, these are internal modes of oscillation of the climate system. Think of a bell. When you ring it, it rings in preferred ways depending on the composition of the bell, shape, the size of the bell, the climate system likes to ring in certain preferred ways. El Ninos and La Ninas are one way in which the climate system oscillates. And what you see here are ocean surface temperatures during one of the largest El Ninas of the 20th Century and we’ll get back to that later. It’s basically the slashing of water along the tropical and equatorial Pacific. And the effects of the El Nino’s are manifested not only locally where those temperature changes occur, they affect atmospheric circulation, they affect pressure patterns, they affect rainfall patterns all over the world. This is all natural.
In addition to these purely natural drivers of climate change, there are things that we've done to the climate system. We know that beyond the shadow of the doubt, what you see here in the top panel are estimates of changes in three powerful greenhouse gases, carbon dioxide, methane, and nitrous oxide. These large spikes here, this large increase that we've seen over the period of the industrial Revolution, we know that in the case of carbon dioxide, most of the increase probably about 4/5 of it is due to our activities. How do we know that? Well, it turns out that you can actually do isotopic fingerprinting. You can look at ratios of carbon 14 and carbon 12 and figure out how much of this increase is due to human cause, burning of fossil fuels. And again, the very clear answer is about 75 to 80 percent of that increase is due to us. So from my perspective, the debate in our field has not been have human activities changed the chemistry of earth's atmosphere. We know they have. The debate has always been how much climate change will that human cause change in atmospheric chemistry lead to. In addition to changing the levels of greenhouse gases in the atmosphere, we've also changed the composition of and the loadings of so-called aerosol particles. Aerosols come in different flavors if you will. Some aerosol like sulfate aerosols primarily reflect incoming sunlight and cool locally. Others like soot aerosols, darker aerosols primarily absorb incoming sunlight and heat locally. Again, these aerosol particles are not just a figment of some mad scientist's imagination. You can see them from space.
This satellite imagery here is smoke from biomass burning from fires in Guatemala in Mexico in 1998. And again, at least locally and even regionally these aerosols can have profound effects on climate. Additionally, humans have transformed surface of the land. This is also satellite imagery of Rondonia in the Brazilian rainforest and this herringbone like pattern here, these are logging roads. When you perturb the surface of the earth in such a massive way, you influence what we call the albedo, the reflectivity of the surface. You influence the fluxes of moisture from the soil into the atmosphere and just like in the case of aerosols, locally and perhaps even regionally, you have the potential to influence climate. So the challenge is how do we separate the natural drivers of climate change and their impacts on climate from these human influences on climate.
Well, let's take a step back and look at observations of climate change, much discussion about observations, their credibility, and their quality.
Much of that discussion has focused on the integrity and reliability of surface temperature records. There are now four groups around the world that have taken on the difficult job of trying to assimilate information from many, many different thousands of surface measurement stations, ship measurements, buoys, satellite measurements and splice together some coherent picture of global scale changes in our planet. This is one such estimate from the Natural Climatic Data Center in Nashville in North Carolina. Their estimate really is quite similar to what the three other groups have obtained. Those three other groups being the Goddard Institute for Space Studies in New York, the UK Met Office Hadley Center in the UK and the Climatic Research Unit in the UK, and most recently, a group of Berkeley, the so called Berkeley Earth Surface temperature project. Again, this is pretty similar to what the other three groups obtain. There’s an overall increase of roughly 1.3 degrees Fahrenheit over the last 100 plus years, 130 years or so with a lot of wiggles, a lot of noise. And we’ll get back to these concepts of signal and noise later. Now, many people have criticized surface temperature records and who argued that they’re not reliable. They’re contaminated by urbanization effects. So what do we do in science as we look at independent measurements?
These are independent satellite measurements of the temperature of the lower atmosphere. Roughly, the lowest 5 miles of the atmosphere, these had been made primarily by two groups, one group at the University of Alabama and one group at Remote Sensing Systems in Santa Rosa in California. For a long time, the Alabama group actually estimated that there was global scale cooling of the lower atmosphere. It turned out that they had made a sign error in accounting for the effects of satellite orbital drift on the sampling of earth's daily temperature cycle. Now, however, the two groups really produce very similar estimates of global scale temperature change and the warming over the full 32 to 33-year period of the satellite record is roughly a half a degree Celsius, nearly 1 degree Fahrenheit. And again, these measurements are completely independent of the surface thermometer measurements we saw in the previous panel.
Well, is there other corroborative evidence to support these surface temperature measurements and the satellite-based measurements of temperature change of the lowest 5 miles of the atmosphere? The answer is yes. People have looked at things like not only the abstract temperature measurements which I just mentioned, the satellite measurements. They've looked at sea level measurements. They've looked at surface humidity. They've looked at the total amount of water vapor in the atmosphere. They've looked at the heat content of the upper 300 or 700 meters of the ocean temperature over oceans and over land. People have used multiple observation estimates of these things. And the bottom line is that they're all going up. So everything that we expect to show increase in response to those changes in atmospheric chemistry levels of greenhouse gases in the atmosphere is actually increasing.
And things that we expect to be seeing a decrease in Northern Hemisphere's snow cover, glacial mass balance. Sea ice extent in the Arctic are decreasing as we've changed atmospheric chemistry. So the bottom line here is that there's an internal and physical consistency to the changes that we see in many different aspects of the climate system. This is not a house of cards built on one observational data set alone.
So we've studied some of the natural and human drivers of climate change, we've learned a little bit about the observations of climate change. How do we put it together? How do we study cause and effect relationships?
This is a very famous figure from the Fourth Assessment Report of the IPCC. And what it shows you, first of all the black line is a smooth version of the red curve I've showed you earlier. It's an observational estimate of surface temperature change of the plant over the last century plus or so. And it shows, you know, this complex behavior with some peak in the warming which I'm sure we'll get back to here in the 1940s, sensation of warming and more recent rapid warming. Now, Einstein loved what he called "Gedankenexperiment," the thought experiments, experiments that you can't really do in the real world. One of the advantages of computer models of the climate system is that you can do these Gedankenexperiment. You can do this thought experiments and that's what you see here. So the blue envelope is when you take two dozen of the world's computer models of the climate system developed at over a dozen institutes around the world and you run those models purely with natural factors. So our best estimates of changes in the sun's energy output over the 20th Century and our best estimates of changes in volcanic activity over the 20th Century. I like to call this an undisturbed earth experiment. Essentially, you're trying to simulate how might the climate of the planet have evolved in the absence of any human intervention. And again, you get an envelope of solutions here because you're using many models that produce different results. They have different resolution, different physics, different parameterization, so different ways of representing things that they can't explicitly simulate. But the bottom line is that the undisturbed earth experiments can't capture the rapid warming that we observe over the second half of the 20th Century.
Now, when you run the same models not only with natural factors but also with human cause changes and greenhouse gases, aerosols, stratospheric ozone depletion, you get this red envelope here, and at least qualitatively, the black line is contained in the red envelope. So there's some similarity between the model solution when you include natural and human factors in the observations. Now this isn't compelling statistical evidence by any stretch of the imagination. The global mean temperature can change for many different reasons. It's a sort of necessary consistency test. But it's pretty weak evidence. So can we go further? We can.
Back in the 1970's, Klaus Hasselmann, the director of the Max Planck Institute for Meteorology in Hamburg recognize that the problem of trying to identify some human caused climate change signal embedded in noise of natural climate variability was the signal to noise problem. And that one could borrow techniques that were standard in electrical engineering to try and do that separation of the signal from the noise. And what he recognized was you got to look at patterns. If you're just looking what global mean information alone, there's not a lot of specificity there. But if you look at complex geographical patterns of climate change or if you take slices through the earth's atmosphere, you have much better hope of being able to discriminate between different things that cause change. And that's what you see here. So these are all computer models simulations. No observations yet. This is from a particular model developed at the National Center for Atmospheric Research in Boulder in Colorado. And these are slices through the atmosphere from the North Pole to the South Pole and from the surface right up to about 20 miles, right up into the stratosphere. And in each case this model was run with changes in one thing only. According to our best understanding of how that factor actually changed over the 20th century. So here, this model was run only with changes in carbon dioxide, methane, nitrous oxide, chlorofluorocarbons over the 20th Century. Here, the same model was run only with changes in the sulfate aerosol particles which actually scatter incoming sunlight back into space. Here, the model was run only with stratospheric ozone changes and with tropospheric ozone changes. Here, it was run only with natural changes in volcanic dust over the 20th century and here only with natural changes in the sun's energy output over the 20th century. And in this experiment which we like to call everything in the kitchen sink, the model was run with all five of these factors simultaneously.
Now, let's focus on two of these fingerprints if you will and just to go back, you know, the key point without getting into the details is they're different. They're not the same. And let's focus on two of these that have received so much attention. Now, we've known since the 1960's when the first people like Suki Manabe and Jim Henson and Warren Washington performed experiments with climate models and they doubled the atmospheric carbon dioxide levels and they looked at the response to that perturbation and this is what they've got. They found that when you increase atmospheric CO2, you more effectively trap heat lower in the atmosphere and the upper atmosphere actually cooled. Now, people always say that computer models are not full suppliable. They don't make projections that you can actually compare with observations and falsify the model. That's not true. Back in the 1960's, when Suki Manabe and Jim Henson and Warren Washington were doing this kind of thing, we really didn't have the observational data to determine what was happening particularly in the stratosphere. Satellite measurements kicked in in the late 70's. Weather balloon measurements of temperature change were sparse back in the 1960s. These guys could've been wrong but as I'll show later, they were not. This is actually what we've observed. Warming of the lower atmosphere and cooling of the upper atmosphere. Now, the fingerprint of changes in the sun's energy output as you slice through the atmosphere is completely different. And again, here just let me explain for people who can't see the color bar here. So yellow to red means warming, and blue means cooling. And these changes are estimated over roughly the second half of the 20th Century. Again, these are only climate model simulations.
Now, why do they look so different? Well our best estimate from a variety of sources is that there has been some small increase in the sun's energy output over the 20th century. Essentially, more sunlight arriving at the top of the atmosphere and you have heating throughout the entire atmospheric column. So, this is shown not only by this model but by virtually every climate model that's been used to perform sun only experiments. So, what do the observations look like?
That’s what you see here. You see another slice through the atmosphere from the North Pole to the South Pole. This is a climate model calculation again from the surface right up into the stratosphere and this is based on weather balloon measurements of temperature change over roughly the last 40 years or so. And while there are some noticeable differences between the model calculation, this is sort of everything in the kitchen sink calculation again and between the observations notably here in the tropical upper troposphere as we call it. The basic pattern of cooling of the stratosphere, warming of the troposphere is common to both the model calculation and the observations and is fundamentally different from the sun explains everything fingerprint.
Now, people still pose it that the sun explains everything in addition to the fingerprint difficulty which I've just showed you. There's another difficulty. These are our best estimates from satellites from space of changes in the sun's energy output since we started directly measuring those energy output changes in the last 70s and you can see nicely the 11-year solar cycle in the sun's energy output. But, the key thing to know here is that over the period that we've actually monitored the sun, there's been no overall increase in solar energy output. But, our best understanding is that global mean temperature has increased over the period that we've been monitoring the sun. So, the sun explains everything. Hypothesis does not fit the available observations either in terms of the pattern of change or in terms of the lack of change in solar energy output over the last 32 years.

Now, people have done this when the first fingerprint studies like this were done in the early to mid 90s. They were criticized quite rightly. People said, "Dr. Santer, if there really is some human-caused climate change signal lurking in observations, you should see it in many different aspects of the climate system, not just in surface temperature, not just in atmospheric temperature."
Go look beyond temperature and that was a valid criticism and the community responded by doing this kind of pattern comparison between simulation output and observations from many different things, for the total amount of water vapor in the atmosphere, for surface pressure patterns, for rainfall patterns, for the vertical structure of ocean warming, so how a warming signal was penetrating into the world's ocean basins for continental scale runoff. Now the number of things that people, the number of different climate variables for which this type of work has been performed is probably several dozen. And in each case, the bottom line message is natural causes alone can't explain the observed changes that we see in many independently monitored variables.
Okay, one integral component of fingerprinting is climate models. We use them to simulate the fingerprint that we search for in observations. We also use them to simulate the noise of internal climate variability things like El Ninos and La Ninas. And some have claimed these models are garbage, garbage in and garbage out. You folks never compared them with observations. You never scrutinized them. That's not true. Let's all hope to convince you.
The group that I've worked at Livermore is called the Program for Climate Model Diagnosis and Intercomparison. We are not climate model developers. Back in the late 80s, the department of energy decided that it was useful to separate the endeavor of developing computer models of the climate system from the job that evaluating them comparing them with observations. Our job is to evaluate all the world's climate models to compare them with observations in a variety of different ways and this are test that we routinely perform. We asked how well they simulate today's average climate, the daily cycle of temperature clouds and rainfall, the march of the seasons, the changes that we see in transition from winter to summer. We asked how well they simulate the cooling that occurred after massive eruptions like the Pinatubo eruption. We even asked how well they take up things like bomb tritium. The tritium that was produced as a result of atmospheric testing in the 1950s that provides you with some information about how rapidly heat is penetrating into the ocean and you can use those bomb tritium measurements to make inferences about how successfully models transport even to the ocean. My own interest is in confronting models with observations over the satellite era, the last 30 plus years or so and over the full instrumental record comparing things like surface temperature changes. We even subject these models to ice age conditions. We think we know something about the configuration of ice sheets at the time of the last ice age.
The orbital parameters that we're on operation at the time of the last ice age and given these orbital conditions, given this ice sheets we asked, "Okay, climate model, what kind of simulation of the atmospheric circulation and the ocean circulation do you produced when confronted with ice age conditions?? And then we compare with paleoclimate data in order to see whether the model gets for example, the monsoonal changes that we think happened at the time of the last ice age. We even at Livermore and elsewhere attempt to diagnose these models by running them in weather forecast mode. Well, how would you do that? Well, the idea there is that when you take a climate model and you actually make whether forecast, hours or days into the future, you can immediately confront the model with high quality observations and you can quickly see errors that set up and learn something about the causes of those areas in a very variable technique for putting your finger on the cause of model errors. And we've also ask not only how well models simulate the response to forcing factors like the ones I've discussed but how well they simulate internal climate variability, things like El Ninos, La Ninas, the pacific decade of isolation.
I’m going to show you two examples of climate model evaluation studies that we performed at Livermore. This is called a performance portrait and the beauty here is that you can evaluate all the world's climate models and do statistics across them. This is transformational. Even 15 years ago, we really couldn't do this kind thing, now we can. At Livermore, we house the simulation output from all the roughly two dozen models that were run in support of the IPCC's fourth assessment report. And what we did here is, we compared each of these models with observations and we asked, "Okay model, we're going to look at a bunch of different climate variables, things that you recognized like total cloud cover, rainfall, water vapor, surface pressure, some other more esoteric things", and here are the roughly two dozen models, their identities had been skillfully disguised using letters here. And in each case what we do is we asked how well does model A or B or C for this particular field here capture the observed changes in that variable over the seasonal cycle, from winter through the summer. And we're actually looking at the patterns how well the model gets the observed patterns right. Now, people can calculate different measures of model skill, relative or absolute measures of skill. I don't want to get into the technical details suffice it to say that this is a relative measure of skill. So what you’re looking at now is how well each model is doing relative to its peers and if you have red colors here then you're doing poorly. For example, dark red means that you're doing 50 percent worse than the average model and blue to purple means that you're doing well relative to your peers.
So you look at model L here, across the board, across all of these variables, it's really not doing very well relative to its peers.
Another model, model G, lots of blues, its doing pretty well relative to its peers.
And one of the curious things is that when you take the results from this collection of nearly two dozen models and average them and compare the model average with observation, the model average actually outperforms pretty much any individual model. And we know that too, the wisdom of the masses. We know that too from numerical weather forecasting. Many operational weather forecast centers actually use multiple models, combine forecast and often show higher skill when they use multiple models to make forecast. And we've seen this superiority of the model average and many different things. Not only in terms of what I'm showing you here but also in terms of complex patterns of variability. We don't fully understand why we get these results. It seems like there's almost some random component to model error structures that you smooth out when you averaged over a large enough collection of models.
Back in 2007, my colleagues and I published a paper in proceedings of the National Academy of Sciences where we claimed to have identified some human-caused climate change signal in satellite measurements of water vapor change, the same measurements that I showed you on the very first slide. In doing that climate fingerprint work, we used all of these models.
All of these two dozen models that I showed you previously.
And we were criticized quite rightly. I think people said, "Well, some of these models are better than other's Dr. Santer, so you ought to do a Letterman here and identify the top 10 models and then repeat your 2007 analysis and see whether you can still identify human effect on climate if you identify the top 10 models." So we tried to do that. And the bottom line here is, isn't it a democracy, one model, one vote? Or should you pay more attention to demonstrably better models. And if so, how do you identify demonstrably better models.
So we revisited this in 2009 in a follow up paper and what we did is we look at 70 different measures of model performance and we just look at two things. We look at water vapor and we look at ocean surface temperature and we look at how well these two dozen models simulated, observed, averaged water vapor, and average SST, and how well they captured more difficult things like the variability of water vapor in ocean surface temperature. And we looked in a bunch of different regions, in El Nino regions, we looked in Pacific Decadal Oscillation regions, we looked in the tropics.

And we also looked at different time scales. When we confronted the model variability with observed variability, we looked at year to year variability. We looked at variability on time scales of decades and we looked at variability in terms of month to month changes. Now, here are the identities had been disguised using national flags, so not quite a successfully as in the performance portrait but the key thing here is that we're looking at this two dozen models and we're looking here in this first panel how well they captured the average climate. And we're using 20 different measures of model performance and then we ranked the models. And there are different ways of ranking them. I won't get into the details here. I'd be happy to explain later but the key thing is you want to be in this gray box. If you're in the great box, you're in the top 10. Now, then we repeated this exercise and we did it looking at variability. We looked at the size and the patterns of variability and again we looked on different time scales and different areas. This is a much tougher test, a much more challenging test than getting the mean state or the seasonal cycle, right? And what I want to show you here is the top four models.
So if you look at this test of how well do you capture the mean and the transition from winter to summer, here with the top four performers and they were US model, a Japanese model, a British model, and German model.
But in terms of these more challenging test of the variability, the structure and the size of it, none of the top four models in this first series of test was in the top 10. So what this tells you is that even for a relatively simple case where you're only looking at two things not a whole slew of variables, only water vapor, only ocean surface temperature, it's very difficult to identify the best models. Model errors are complex. They're complex geographically, they're complex in time. It's not easy to answer the questions which are the best. What we did answer was did it matter for what we did? Did it matter for our claim to have detected a human influence on the water vapor and the answer was, "No." We did the fingerprint analysis, a 144 different ways using different combinations of top 10 and bottom 10 models, didn't make a difference. In each case, we could identify some human effect on water vapor, why? Because the physics governing the water vapor changes is very simple. You get the largest increases of water vapor over the warmest areas of the ocean and increases in water vapor were everywhere all over the globe. But the natural variability pattern of water vapor didn't look anything like the signal which is why model quality for that particular problem didn't matter. And I think that's the stage where we're at. When you do this kind of climate fingerprinting work, you have a responsibility to see whether your conclusions depend on which models you select, which statistical methods you use, and to really look at this question of the robustness of your results. We did and in this case didn't matter. But this is clearly an important question because for the next report of the IPCC which will come out in 2014, we're going to be dealing probably with three dozen different models, a variable quality, and you'll inevitably get into this question, "is it the democracy?" Or should we wait better models, should we wait the projections of better models more highly. That will be a very charged political issue.
Can we reduce uncertainties and projections of future climate change?
This again is from the fourth assessment report of the IPCC. One of the most famous figures in that 2007 report and what it shows are projections of surface temperature change.
Again, from this roughly two dozen different models and the red, the green, and the blue envelopes are different story lines if you will about population growth, mix of energy use, whether we go down a business as usual type road in terms of emissions which is pretty much what the red envelope shows you here, or whether we decide to reduce emissions over time. So these are projected surface temperature changes out to 2100 and you can see here in this part that there is a substantial uncertainty associated with which emissions pathway we’re going to follow. But for anyone of these things, there is also a large uncertainty that arises from basic uncertainties in the model.
So this red line for example, this is the average surface temperature change projected by this two dozen models and this envelope here is the one standard deviation uncertainty in that projection but this red bar here is the full range of model uncertainly in the A2 sort of business as usual scenario. And that uncertainly is huge from two degrees to over five degrees. Now, that has tremendous implications, the prime of policy maker and we're near two degrees, well that suggest that possibly we can get by with relatively modest mitigation mostly through adaptation. But if I'm up above five degrees, adaptation alone isn't going to do it. So, is there some scientifically credible way of reducing those projection uncertainties. Can we shrink them? Can we collapse them? Now we know that the drivers of these uncertainties are primarily associated with uncertainties in so called feedback mechanisms. These are things that amplify the warming caused by human caused increases in greenhouse gasses. And there are really four primary feedbacks. One is associated with clouds, their behavior. Where do you get more of them? What the altitude of clouds will be when you start warming and moistening the planet’s atmosphere? There is a feedback associated with the amount of water vapor in the atmosphere so as you warm the atmosphere by increasing carbon dioxide, you increase the concentration of water vapor in the atmosphere. Water vapor is a greenhouse gas that amplifies the warming. There are also feedbacks associated with snow and sea ice. Now, let's look at the snow feedback.
This is from a beautiful paper published by Alex Hole and a colleague at UCLA in 2006. And what they did is they looked at this snow feedback. First, let me explain what a snow feedback is. So when you start increasing carbon dioxide, warming up the planet, you melt back snow and sea ice that typically exposes darker, less reflective surfaces underneath. You absorb more incoming sunlight. You amplify the warming. It’s a positive amplifying feedback effect. And what Alex Hole did is he looked at these roughly two dozen models which I’ve already discussed and first of all, he looked at the seasonal cycle. So he looked at April to May temperature changes in the northern hemisphere. And he looked at April to May snow cover changes which he could get at from satellites. And then in the models, he looked at the relationship between 21st century changes in temperature in snow cover. He found this beautiful linear relationship between the changes in temperature and snow cover over the seasonal cycle and this on the Y axis which is what were really interested in. And what he could do of course, since we have good measurements of temperature and snow cover changes over the seasonal cycle, we can pin down the observations very well here. That's, this gray bar and the inferences that these models that lie within are close to the gray bar give you more reasonable estimates of the true relationship between temperatures changes and snow cover change. So it suggests that there may be some way of relating things we can observe in today's world. So the seasonal changes in snow cover and temperature to this feedback uncertainty, to this projection uncertainty. And many people are now all around the world doing this kind of stuff for clouds, for water vapor, in order to try and search for that Holy Grail relating present day observables to these projection uncertainties.
I want to tackle one particular myth and I'm sure you've all heard about this. This claim which is surfaced quite a lot in the last couple of years that there's been no warming since 1998 and that computer models of the climate system are incapable of replicating this kind of behavior. I testify that this hearing together with the late Steve Schneider in May 2010 and this particular claim, this is verbatim, was made by Professor Will Happer. We decided to do the science to look at this claim. I think it's important in the case of all these kind of issues to do the science and see whether the claim has validity or not.
So what you see here are observations of the temperature change of the lower troposphere again, the lowest five miles of earth's atmosphere. This is from remote sensing systems in California and you can see is pretty noisy. Again, at the start of the satellite record of atmospheric temperature change is the late 1970s this goes through to the end of 2010 here. And you can see the period that Professor Happer focused on and many others have focused on, is this period after this big spike here? The spike is the big 97, 98 El Nino event. El Nino is on average tend to warm the so essentially what Professor Happer was saying was, there's been no warming over this period here and climate models are incapable of replicating this kind of behavior. Well the first thing to note is what are these brown lines? I fitted 10 year trends to overlapping segments of this 32-year time series and they're noisy. They bounce around a lot. You can see that statistically, the most negative trend is actually near the beginning of the record and not near the end of the record. And not surprisingly, the largest warming trend is the one that has an end point that stops near the big warm event. So this illustrates, you know, a key issue in climate science signal and noise. There's a lot of noise on year to year time scales there and typically when we're trying to identify human effects on climate, we looked at long swipes of time, that's how we beat down the noise. You know particularly if you choose the end points of the period that you looked at, so you're starting near a high point and ending near a low point with La Ninas which caused cooling, how informative is that.
So if you do the same exercise but you look at overlapping 20-year trends, you see that they are positive, nothing negative here and you’ve beaten down the range of trends by about a factor of four just by looking at a longer swipe of time. The analogy I liked to use is, if you looked at the minute by minute record of day trading on the Dow, you couldn’t use that to make reliable inferences about the long term behavior of the Dow. In the same way, you can’t really look at month to month or even year to year climate variability or even one cool decade where you, you know, judiciously or injudiciously pick the points to start near an El Nino and end near La Nina’s, you can’t really use that to make strong inferences about whether there is or is not a human effect on climate.
So what we did then is we looked at the same models that I've talked about up to now and we calculated synthetic satellite temperatures from them so we essentially tried to calculate the temperature that was directly comparable with observed satellite temperatures to sample the model atmosphere and model temperature, the way a real world satellite sees the Earth's atmosphere. And here are the temperature changes from 1979 through the end of 2010, so the same period we're looking at in the observations. And I can do exactly the same thing that I did in the previous figure. I can fit overlapping 10-year trends and build up a big distribution of trends from the climate models to test Professor Happer's assertion that models can't produce 10-year periods with little or no warming when those models are run with human-caused changes in greenhouse gases.
So this distribution of model trends, we call it a PDF, Probability Density Function, and you can see that first of all it has a negative tail. So in other words, these models can produce 10-year periods by chance that show little or no warming or even cooling.
You can also see that when you average all of the observed 10-year trends, you beat down the noise and you get a positive trend. These are for the two different observed satellite data sets and their average 10-year trend when you look at all possible overlapping 10-year segments is positive and it's not very different from the average of this collection of two dozen models. So Professor Happer was wrong. Models clearly can replicate observed temperature changes over the post 1998 period and a 10-year chunk selected to start near a high point and an end near a low point does not constitute evidence of absence of the human effect on climate.
I hope I've showed you that we've done this kind of fingerprinting confronting models and observations by looking at complex patterns of climate change for many different aspects of the climate system, not just for surface temperature. And in each case, the stories internally and physically consistent. Natural causation alone can't explain the observed changes that we've seen and monitored independently in many different aspects of the climate system. People criticized climate models and say they are not useful for this kind of purpose. You never confront them with observations. That's not true. I've given you a couple of examples of how our community routinely evaluates models in a variety of different innovative ways. But there are still important uncertainties. For me one of the key uncertainties is in projections of future climate change, shrinking those projection uncertainties, finding those transfer functions that might, just might enable us to relate present day observables to the behavior of these feedbacks and to this large uncertainties and projections of future climate change. So, there are plenty of interesting problems for all you students in the room that science has not done and dusted.
There's been a lot of discussion about trust and accountability in climate science. I'd like to make a few comments about that. First of all some folks have argued that climate modeling is some shadowy back room endeavor where people don't share simulation output. It's done in the darkness, not in full public scrutiny. That's not true. The simulation output that I've showed you here today are currently used by 4,500 scientists around the world. It's freely available to anyone. You can download it without charge. You can do research with it. We routinely share not only simulation output and observation data, we also share analysis software, visualization software, there's something called the earth system grid which are community uses to facilitate the sharing of information. Basically now modeling groups make their simulation output available to the whole world to look at. I'm sure you've all heard about the climate gate. I was personally affected by that. Some of my emails were in the roughly thousand emails that were illegally purloined from the University of East Anglia from the climatic research unit, that's where I did my PhD. Climate gate does not call into question, IPCC and National Academy of Sciences conclusions that the Earth is warming and that humans are major contributor to that warming. The allegations had been shown to be baseless. These are good men and women who have spent much of their scientific careers, devoted to the difficult job of trying to understand the nature and causes of climate change. They deserve our thanks in my opinion. Unfortunately, even some of our elected representatives use words like scam, hoax, and conspiracy to describe everything that I've presented you today, that does all of us to do service. I firmly believe that in order to take wise decisions on what to do about climate change; we need the best available scientific information and not miss information, not disinformation, not wishful thinking. My job is I see it is to do the best science I possibly can and also to try and explain that
science in plain English, what we did, what we learned, what it means. We can't afford to embrace ignorance.
I’m a climber. I spent a lot of my life in high alpine environments around the world.
In addition to the scientific imperative to understand the nature and causes of climate change and likely outcomes, I also believe that there is a moral and ethical imperative.
Over my lifetime, I've seen important changes in some of the regions that I've climbed in, in the Alps, in the Himalayas, in the Rockies.
These are fragile beautiful places and it's of concern to me that the future generations will not experience these places in the same way that I did.
So I think I'll leave it there. Thank you very much for inviting me here and giving me the opportunity to speak to you.