Jonathan Overpeck, Arizona Inn, April 25, 2008
Columbia University Alumni of Southern Arizona

Introduction: Last winter at, I guess a convention or workshop for the North American Association of American Environmental Education, I introduced myself to one of the speakers, and I quickly learned that I was talking to a special person. The speaker comes to us ... from the United Nations via the University of Arizona. He was the lead signer on the report which won the Nobel Peace Prize. When I met him, he introduced himself as "Peck" but he said, "My friends call me Peck. You can call me anything you want." My tendency is to call him "Jon" because in my opinion, Peck doesn't win the Nobel Peace Prize. Jon wins the Nobel Peace Prize. So without further comment..., we'll turn it over to Professor Overpeck.

Overpeck:

It's wonderful to join you guys today. What I would like to do is give you an overview of the climate change issue. And what I really want to do is spend more time talking about the Southwest and the challenges that climate change poses to the Southwest but...it's always good to think about how you can turn bad things into good. There are I think real ways that we can turn this to good both in Arizona but also in our nation. But before I get to that, I want to talk about global climate change and update you on what the U.N. Intergovernmental Panel on Climate Change [IPCC] said.... And then we will focus in a little on sea level because I'd like to highlight that, [it is one of the biggies that is challenging the United States.] And then we'll talk about the Southwest United States in more detail. The Southwest, and the West more generally including California, Arizona, and Texas constitute the biggest near-term challenge.

We need to learn to adapt to the change that's already occurring.... We need to consider what we might do to reduce the big changes that could come. If we don't reduce greenhouse gas emissions, we might miss the boat.... Now we might decide as people, as citizens, to wait and not worry about it, but the important thing is that we have that conversation. I'm here as a scientist to say, here's what the science says. At the very end of course I'll be talking a little bit about solutions because we tend to get a little upset or depressed about the story and it's nice to know that there are solutions. We caused the problem; we can stop the problem. Okay, the slide please. Thanks.

Okay, I was actually one of many who were involved in this Intergovernmental Panel on Climate Change report, that won the Nobel Prize with Vice President Gore. I lucky to be one of the leaders in what occurred at the end of the meeting with diplomats from 113 nations around the world, in Paris, where thirty scientists, myself included, interacted with these diplomats from all these countries (there were multiple ones from multiple countries) to agree on the wording, word by word, of our summary for [policymakers].

The report of the science was 1,000 pages thick. You can get it through the University Press or you can get it free on the web. I'm sure you're all going to run out and do that (laughter). But we actually had to make a couple different summaries. We made a technical summary and shortened it down to just 100 pages,...and then made one for policymakers so it was only like 15 pages long.

[Governments had] requested this very short summary so that their leaders, premiers, presidents, ministers of the environment, and such would read this thing and get a sense of what the biggest issues are. But in order to get the wording connected with those policymakers most efficiently we had to agree on every single word. We didn't change the science or anything, but it was quite a week, believe me, trying to work with these diplomats. It was really remarkable at this meeting, having to do that. We had representatives from China and Saudi Arabia, who were really trying to play down this issue of global warming. We couldn't change the science, but they sure could try to dilute the language. And we had other countries like Germany and Great Britain which were trying to really keep it really big and bold on the radar screen of policymakers around the world. The U.S., interestingly enough, was in the middle. I think the U.S. delegation was quite unbiased. And I was very happy to see scientists in that delegation who I knew and worked with in the community. So there wasn't any bias on the part of the United States.

In the language of the 1,000-page report we tried really hard to focus on very precise language that identified with how well we knew everything we knew. So we had this language that corresponded to language of uncertainty in very specific, quantitative terms. But in the summary for policymakers we wanted to say it in ways that would connect with our policymakers. So for example, we said that current concentrations of greenhouse gases in the atmosphere, CO_2, methane, nitrous oxide, and others, are now far, far above [past levels]. We know that for hundreds of thousands of years because we can look at them in little bubbles in ice cores from Antarctica. We can do that in multiple ice cores, and we know pretty well that we know what the atmosphere looked like before we came along. We can also look at the chemistry of the gases that are in the atmosphere and we know that these are produced by predominantly fossil fuel burning and a few other human activities. But you know again we have used the term "far far above."

Then we said global warming is unequivocal. In other words, in our science-speak, we know to a high degree of certainty, 95% confidence, that global warming is occurring. The scientists who came up with the statement, we hope that the nations of the world would accept it and this word got accepted without any debate. Global warming is *unequivocal*. And the reason the nations of the world *all* agree that this is unequivocal is not only is the atmosphere warming, surface air temperatures, this is what we hear about in the news all the time, but we're seeing more extreme high temperatures, we're seeing more heat waves, statistically significant trends in the world. We're also seeing the atmosphere warming up not just on the surface, but well up into the lower atmosphere layers where the ozone is getting destroyed, that's where we're getting cooling, as predicted. But we're also seeing the ocean warm everywhere, just about. And we're seeing not only warming at the surface of the ocean, we're seeing warming now over a kilometer, 3,000 feet into the ocean.

We're seeing warming. So the earth is warming in many different ways, in everything, and as it warms the atmosphere should hold more water vapor, that's what it's doing, because it adds more water vapor, we should see it intensify the hydrologic cycle which translates to more extra-tropical precipitation, rainfall, and snowfall, more rainfall intensity. Now our storms even here seem to be getting, instead of having rainfall or less rainfall, rain when it seems to be coming is coming in heavier events. We're also seeing more drought. Dry places are getting drier. Wet places are getting wetter. This will come back to later. We're also seeing more hurricanes,

particularly in the Atlantic where we have reasonable data. They're getting more intense, stronger. We're also seeing global sea-level rises as the ocean warms up. It expands, and the sea level is going up just as you'd expect from the temperature increases in the surface of the ocean and in the depths of the ocean. We are seeing other things happen that are consistent with global warming. We're seeing less Northern Hemisphere snow. We're seeing a lot less summer ice in the Arctic, even in the winter sea ice. The ice that floats on the ocean. Glaciers just about everywhere now around the world are retreating, in many places dramatically, and we are seeing a decrease in cold temperatures. My friends in Wisconsin are happy with that, except they did not notice it this year because of course we don't want to confuse climate with weather. We can have any given year in a place that would be exceptionally cool and it doesn't have anything to do with the debate on global climate change.

I'm going to talk more on this later but there's a cover article from the University of Arizona article in *Science* magazine, one of our most prestigious journals about how we're getting more fire in the West because of global warming. Next slide please.

Okay. Hit to the bottom twice, please. What we see here is the record of global temperature going back as far as we have thermometer records and what you're seeing as black dots are year-by-year changes in temperature and the blue line is a smooth line through that with confidence intervals. And what you can see is that over this period of time since the industrial revolution, when have a fairly decent global network of thermometers is temperatures going up and down but there has been, since the middle part of the century, particularly since the 1960s, a fairly inexorable warming. And the warming has gotten steeper, more warming per unit of time in the last couple decades. And we have this natural variability superimposed on what humans are doing to the climate system. So this is also another reason why if you have a string of cold years relative to say, you know, mid-nineties or something, it's not a big deal to the climate scientist. What really matters is the trend. What's happening over decades. And what happening over decades the earth is getting warmer. Next slide please.

Here's a map showing around the world of where we have thermometers back to 1901, the trend up to 2005. So these areas in gray, the poles and also parts of the interior parts of Africa and South America. Those are places where we don't have thermometers going back that far. Some of these places ships weren't visiting very often in the ocean as well. Wherever we have data going back 105 years, we have colored in this map, the trend in temperature. And you can see overall these yellow and red that signify warming, and there's also some places such as in the southeastern U.S. where there has been cooling over those intervals. But almost everywhere, around the globe, it has been warming. And that's why it's called global warming. So this big debate about why not call it something else, let's just call it what it is. It's global warming.

But there's some interesting patterns here that one should note. One is that we're getting warming over the oceans and also land so there's the scientists who do this kind of work have taken out any biases, say due to the urban heat island effect. And there can be other anthropogenic factors that could be biasing it. But if you look at the map, you know those biases don't exist out over the middle of the ocean. Nonetheless the warming is greater over land and in higher latitudes in particular in the Northern Hemisphere than anywhere else. This was predicted twenty-five years

ago when I was in grad school, and it's happening. Little details like what's happening in the southeast or this really anomalous heating that we're getting here, two to three degrees Fahrenheit in Arizona. It's above the average for the United States but we're not sure what part of that is due to humans and what part of that is due to just being in the wrong place at the wrong time. But outside of Alaska we're warming up just as fast as anywhere in the United States. Remember that map, because you're going to see when we get to the projected climate of the future that the pattern is quite similar.

We believe with 90% confidence that humans are causing global warming. This is for multiple reasons. One of which is this very diagnostic pattern that we see and that no other known climate forcing can be causing it. So there's not a lot of uncertainty, this is what I like to point out, that there are things we know and things we don't know. Things we know in the science community, with very little doubt, is that the earth is getting warmer and that the warming is global and that humans are causing it. And it is predominantly caused by fossil fuel burning, but there are other things as well. It's world burning of fossil fuel that's causing the global warming that has occurred.

When we start to talk about what we don't know, it's still a lot. And most of it really focuses on the future. What's going to happen in the future? There are many reasons why we don't know with any precision or accuracy what's going to happen in the future. A couple of the biggest issues are we don't know how much greenhouse gas that humans are going to put up in the atmosphere in the future. For example, when we started out this process, we had to agree as nations in an intergovernmental process, on what emissions we would look at going into the future. We agreed on a few scenarios of emissions. We don't know exactly what humans are going to do in the future and how much greenhouse gas is going to put out. We had to come up with different scenarios.

[Here's just a subset of the ones we looked at.] We agreed to look at some in greater detail. One of the problems is, if you're going to do climate modeling, climate simulations into the future for these areas, you can't do them all because it just takes too much computer time. These models are trying to simulate the earth in a very realistic fashion, which they can do, but it takes up a lot of computer CPU. So we agreed that this red one, A2, with the maximum emissions, would be the one all the groups would consider. And we picked that one because at the time we were putting up CO_2 and other gases at a rate that a little slower than this red line. Since that time India and China have come on line and since that time we are putting up greenhouse gases much faster than even that scenario. In fact we're putting them up even faster than this one labeled A1/FI (fossil intensity). Wonderful. So none of the scenarios we set up seven years ago were for emissions as great as what we're actually doing. So it's a little scary. So I'm going to show you here today it is by no means an extreme case. I'm going to be showing you how a middle-of-the-road assessment of the kind of climate change we will get for a given climate scenario.

Q: [inaudible]. Yes. Business as usual right now is close to NASCAR at full tilt. [laughter] Next slide, please.

So what I am going to show you, and this is the red line, is the average of about 20 models. The

shaded area is one standard deviation or two standard deviations around that, no, one standard deviation, so its kind of the uncertainty at the 95% level [*sic*]. And then we have the green line and the blue line. I am going to show results for the red one and the green one and if you look at the global warming associated by 2100 A.D. with the red A2 scenario, it's about three and a half degrees C warming. Note that these over here are done a little differently. It actually shows the range of all the models that are simulated in those different scenarios. And there are a few models running this A1/ FI, but nevertheless, even from the A2, we're seeing some models nearly double than what the average is. For this A1/FI, more than double. So we're going to be looking at some areas down in this range. But keep in mind that some of these models the certainty includes much more warming. Okay, next slide please.

Here we are looking at the A2 scenario and we're looking at an average temperature change between the end of this century and the end of last century, so it's a hundred years of climate change into the future, roughly, and this is just a couple decades into the future. Let's just look at this model by the end of the century. What we see is warming, and remember this is about three and a half degrees of global warming and look at the pattern. You see more warming over land on average than you see over the oceans and you see more over the higher latitudes. In fact, you even see that one little bull's-eye in the North Atlantic that has been cooling. It shows less warming in the future. It's nothing like in that movie *The Day After Tomorrow* where you're going to cool the North Atlantic and turn it into a new Ice Age or anything like that. But only less warming out there. So this pattern looks a lot like what we're actually seeing in Mother Nature only with more confidence. But it also tells us that global warming of three and a half degrees is more like five or six degrees warming here in the West. That's degrees C, we'll look at degrees F. I also want to highlight that we'll have the most warming up here in the poles.

You always hear in the news that there'll be winners, and there'll be losers. For us it will be far more losers than winners when it comes to climate change. Let me give you some examples. Next slide.

All right. I'm not going to go into details of how we communicated climate change but there has been some science that has come out since our report where we couldn't come to a consensus about what kind of sea-level rise we might get due to warming by the end of the century. And the reason for that is we as scientists don't yet know how the great ice sheets, Greenland and Antarctica, will be affected by this warming. They seem to be falling apart much faster than we thought possible and much faster than our models can accommodate. So that is giving an estimate that had very high uncertainty estimates, we decided to say we just don't know. But I would say that by the time the next report comes out, this will be more like what the report will be saying. Maybe a meter sea-level rise, three feet, by the end of the century, this is a good estimate of what the sea-level rise could be. You can see here different color lines. Those are the different scenarios that we talked to you about. But still we haven't done this with a process model that simulates the actual mechanisms within these ice sheets. Next slide please.

One of the reasons I actually believe that the amount of sea-level rise that we could get is dramatically larger than most other scientists think is that I studied paleoclimate, ancient climates going back hundreds, thousands, even millions of years. The last time the Arctic was warmer than

today was over 16,000 years ago. The last interglacial we call it. Due to changes in the earth's orbit, the Arctic was warmer than today. We did some work here at the University of Arizona with colleagues in many other places that showed, using data and models, that the Arctic was three to four degrees warmer at that time than today. And because there are many coral reefs of that age that we can date, now above current sea level. We can attach this amount of global warming to the amount of sea-level rise that occurred at that time. Next slide please.

Four to nine meters above the present day. So in our work we show that 125,000 years ago we probably lost a good part of Greenland. And we had taken out a decent part of West Antarctica as well and those big ice sheets were transformed into sea-level rise, giving us what is now is the Florida Keys, right? The Florida Keys are these islands that are made out of coral rock that were under water at this time. And you see that around the world. I'm not saying we had this amount of sea-level rise by the end of this century, but it says that these ice sheets which might melt at a rate of a meter of sea level per year, three feet, given enough time, we'll see a lot more sea-level rise. And we're not talking about a lot of warming here. We're not seeing as much warming in here as we will see by the end of the century if we keep the pedal to the metal. And sad thing, or the nice thing, depending on how you look at it, is that CO_2, once in the atmosphere, stays a long time. And that's why if we put it up there it will keep warming the earth and probably destroy these ice sheets.

You all know why that really matters. Probably in your head you're seeing New Orleans with one meter of sea-level rise shown in the areas that are red where land is submerged by a three-feet sea-level rise. You can go on our website and see anywhere in the world how this might affect it. The next slide please.

This shows Florida with six meters or twenty feet of sea-level rise and the areas of Miami and all the way up here to Cape Canaveral, these are all submerged, long before we get to six meters of sea-level rise. We'll end up with a Florida that has a much smaller size and smaller electoral influence. [laughter] Next slide.

See, we've got winners and losers, right? It's very interesting that even now insurance companies are leaving Florida. They're not willing to insure coastal properties there the way they used to. Is that because of sea-level rise? Hurricanes. Right. Next slide please.

Another thing we feel very confident about is that we're likely going to get more intense hurricanes in the future. There's a lot of debate in the newspapers now. The scientific community is not sure if we have seen more intense hurricanes. We thought with 66% confidence that we have, based on literature and the science. But what scientists all seem to agree with is that we will have more intense ones. It is just a matter of time before these hotter sea surface temperatures will fuel stronger hurricanes.... So when you combine this with the sea-level rise, that means it could be rough on the east coast, the Gulf coast, and the United States. We of course will get some of these remnants. For us that means more flooding in October. That's not a big problem for us. Next slide please.

What I'd like to talk about the rest of the time here is a little more about what is a problem in the

West, and I would probably argue that sea-level rise is really something that is next generation. It's going to be in our great great-grandchildren who are going to look back and have some very, very strong feelings about us, one way or the other. Either we were heroes, or we weren't. In the West, I think the problem is something that we and our children will have to deal with. It's much more proximate. Next slide please.

Just to get it started, I'd like to show you our drought that I think we're still in and there's still some debate about this in the scientific community. Has this drought gone away or not? Depending on how you look at it, you can have an opinion but basically I don't think it has. Here we are. The drought starts in 1999. In 2002 and 2004 we had this kind of a pattern in summer where it went well in New Mexico and up into Canada and across

the rest of the United States. It was in these patterns including exceptional, extreme drought. This is the worst drought that we've had since we started taking records here in the West. And it continues to the present day. Next slide please.

Here we are going into this winter and you can see that as of yet and last summer, we still have pretty substantial drought even though down here in Arizona we had a lot of snow this winter. Next slide please.

Not just here in Arizona but up here in most of the West had an above-normal snow pack. So right now it looks like the drought has been beat back by a good snow year and it will be very interesting to see if the drought disappears or if it comes back with a vengeance. You know, I was in New Mexico quite a bit this winter and they looked pretty good in the winter but since then out there the drought has been reintensified. Next slide.

This drought is anomalous. Not only is it probably the worst drought we've had since we started taking records in terms of precipitation deficit but it's also quite unique in a sense that it has been the hottest drought we've ever had. And that says it's a transition probably, from the old kind—natural drought, to the global warming type drought. And this is why. Up here we're looking at the degrees Fahrenheit. We're looking at the Western United States average for just these years, so this is a little different than I showed you before. This is more updated. In 2000 and 2007 minus or relative to the 20th century. You can see the West, especially where we live, has really warmed up, a couple degrees or more. And that's what's making this drought have a much larger effect than a drought prior to global warming. Next slide please.

What do I mean by that? Well, my colleague David Breashears here at the University of Arizona and a lot of other folks from around the West had a paper in the *Proceedings of the National Academy of Science* and got a lot of attention, and in this paper he had a sage thought and called it a global-change-type drought. He's the first guy who highlighted it, and his team, that this is really a different drought. Here's what I mean. Next slide please.

So it's a normal drought perhaps, but it's coupled with this extreme warmth and it isn't all that extreme compared to where we're going, of course. This is a picture of the northwest New Mexico. It's pinyon junipers west of Santa Fe and you can see in brown all the pinyon pine trees

in October 2002. You go back a little over a year ago and those brown trees are now, next slide please, thoroughly dead and have lost their needles. And all that's left are a few of these juniper trees. And there are still some good junipers here and there, right around the Four Corners area, but there is a 12,000 square kilometers of forest hit like this. You're seeing it in other types of forest too, like the ponderosa pine up in Colorado. And what's happened is this drought; these trees survived in the 1950s drought. They survived the Dust Bowl droughts of the 1930s. They didn't survive this drought because it was so darn hot. Next slide please.

And here's what I mean. This is a time series going back to the middle of the century and we are looking in the blue line at precipitation, and in the red we're looking at temperature. And you can see during the 1950's now, which was the worst drought before the current one, and we had a couple years of lower increased precipitation in blue and a couple years it was a little hot, particularly during one of the years. That drought did not kill the pinyon pine because the other problems were not present. Now we've had this year after year of low precipitation but we've also had year-by-year of hotter and hotter temperatures. This is a different kind of drought. This is the kind of drought that we will have more of in the future and of course as things get hotter and hotter, which scientists, unless they have a real bias for one reason or another, heh, heh, will all agree it's going to get warmer. We might have some cool years, we might even have a cool decade, there might be a big volcanic eruption, but averaged over the century, the temperature is only going up, so it's going to cause this problem over and over. And it's going to be worse each time. Next slide please.

And of course when you have a lot of dead or dried up vegetation, what do you get? Forest fires. This is the reason we're getting, not only in Arizona, unprecedented wildfire, but across the entire West. Next slide please.

All right. [I'd like to focus on temperature.] Because temperature, like I said before, is something we know, scientists know, is going to continue to warm. It's the robust aspect of the science. And what we're looking at here is global record. Here's North America, Eurasia, and here's your Greenland... It's like looking down at the North Pole. Here is a map showing changes in March and April snow coverage. Why did I pick March or April? This is the time of year when we're basically relying on snow up here in natural reservoirs for our water systems. It's also the time of year when snow is basically moistening the soil and getting the soil across the West and across Eurasia ready for the drier season that comes in the summer, so that the vegetation can do all right because it has the moisture trapped in the soil. What we've been seeing over this recent period, and I think we're looking at a couple recent decades versus a couple decades before that, is that everywhere we look we see brown colors except for these spots. And that just says is that due to temperature increases, we're getting a reduction in spring snow coverage. And we really think it's connected to these really hot temperatures because if you look at these temperatures isotherms, this is five degrees C (you can't see what this one is, is it zero?), but this area has warmed dramatically, so in spring, all these areas that are melting, the snow is melting, in areas where it's above freezing now and it wasn't before. These isotherms are in degrees C, and the colors are in percents. So we're talking fairly large, thirty percent in some cases, twenty percent, these are big numbers. Next slide please.

Great. Since the IPCC report, some colleagues have written a report that just came out and in this they highlighted that these increased temperatures, reduction of snow pattern in spring, and related change in river flow, i.e. the Colorado River, these are all connected. They make a point that up to 60% of that regional climate change is due to humans. This is a big advance for us, because up to now, we've been talking mostly about the hemisphere, the continental scale, we can nail that down as being due to humans, and now we're starting to be able to see statistical evidence, even on this regional scale, that we're causing it. So while many of us in the room have got the common sense to see that what we're seeing in the West is due to global warming, it's been hard to say this with statistical confidence. It's now been done, and obviously that has big implications. Next slide please.

Let's talk about the future. Here we are in a more comfortable, familiar units, degrees Fahrenheit. This is an A2 scenario so it's average across the whole model, so it's not the extreme case by any means. It's emissions averaging less than what we're doing right now—some models simulate almost double the warming than is shown here. But we're not looking at on the annual average, we're looking at JJA, which is June/July/August, which is summertime average at the end of this century minus the end of last century. And you can see pretty much what we saw on the global map, only blown up. We're using here the NOAA climate boundaries,... where you can see the greater warming in the interior and less warming along the coast where the heat when it warms the ocean is mixed down in the ocean, ... So the coast always has that moderating effect, which many of us know when we go to the beach. That will continue in the future. This is the part the world is going to warm the most. And the warming is going to be greatest in summer. Which is too bad for people like us. Next slide please.

If you look at precipitation estimates, what's going to happen to annual precipitation versus the last century, by the end of this century, what you see here is apparent drying out of the Southwest and moistening of the Midwest. You see a gradient from dry to wet, where the dry places get drier, and the wetter places get wetter. You see this on a global scale. I think I said we have a higher confidence in temperature and lower in precipitation. What's scary is that almost all the models, save one, agree that we are going to see drying out in winter. Here we get most of our rainfall during the winter, some in the summer, these models stink when it comes to summertime rainfall, monsoon rainfall, but they're good at winter apparently. They all agree with the same mechanism that appears to be happening in Mother Nature. Since 1999 what's given us our droughts is the storm tracks have moved north, so instead of getting as many storms that bring rain down in our neck of the woods they just keep going up north. That's what's happening in these models with increasing frequency in the future. So that's pretty scary to me. As a scientist, to see agreement between all the models and Mother Nature. That doesn't happen very often with precipitation. Next slide please.

Okay. We've already seen a big drop in snowpack. This is looking by mid-century, not end of century, how much reduction in snowpack that you could have in spring. These are in percentages and you can see the numbers are in the 50% to 100% range for snow in the lower southern Rockies. Our head waters, the Colorado River. We're not going to have that snow anymore. What does that mean? Let's go to the next slide.

There are two big things that we should be worried about. Here's a map showing the A2 scenario, how stream flow, no not stream flow but how soil moisture, is going to change. These are percentage units, and you can see the red colors—where there are no colors, very few places, on this map the models don't agree, no where there's stippling the models agree, and there's stippling in here. And the red colors say it's basically drying out of the soil on average, not every year. Other parts of the world we see a slight moistening. And these arid regions, or semiarid regions here and here, you've heard about the big drought in Australia. There's probably a Peck down there giving the same talk I'm giving you guys. What's happening down there is very consistent as well with what we predicted should happen and will happen. Drying out of the subtropics. And that means moisture in the soil, and that means the vegetation is going to suffer. Next slide.

They also means our ... Colorado River, our Central Arizona Project, is going to suffer. This is a prediction by mid-century showing percentage changes in river flow, stream flow. Where you have white it means the models don't agree, where you have blue it means they agree there's going to be an increase, where you have reds and oranges, they agree there's going to be a decrease. In this analysis that just came out, from a group of scientists from our geophysical fluid dynamics lab in Princeton, New Jersey, they estimated that in this part of the world we are going to see up to 40% decrease in river flow. To be fair, other studies have been done on the same issue. Some say it's only going to be 10% reduction. They all say reduction. This is the fastest growing part of the country. All the models are saying reduction in river flow is likely by mid-century.

[Audience question: If you were to pick one number what would you pick?] I tend to think that these lower numbers are biased. And the reason I think they're biased is because the models that they use to get the low numbers are not good at getting the low-flow years that we have observed in the past. And we're not sure what it is, I actually have a study going with colleagues all over the West, to try and figure out why we have this big range, and what might be wrong with these lower estimates. But what I think is happening up in the Rockies, when you get a lot of snow it's obviously going to do the job because of the warm temperatures in spring some of it is sublimating, going directly from frozen snow to a vapor in the atmosphere. Some of it is evaporating. It is melting and then going into the atmosphere. You're getting rain now on that snow. And anyone that skis knows what happens when you get rain on snow. It goes fast, and then it evaporates because it's hotter than it has been. And that's what I think is going on. The other thing since it's more arid and there is less soil moisture, if there's a bunch of dry years the soil under the snow is pretty darned dried out, so it's like a sponge. It can soak up a lot more water that won't, that coming year, flow into the river system. And I'm not sure if it's those things or some other things and we have to discover but for whatever reason these models are getting such low numbers, seem to overestimate the flow in low-flow years and they don't the magnitude of the full reduction correct. Next slide please.

This is my last slide before I conclude.... It integrates temperature effects and precipitation effects. It makes a very important point. Okay. What we're looking at here is something called the Palmer Drought Severity Index, PDSI. It is commonly used to measure a drought. And this is what it looked like during our two biggest droughts here in the Southwest. During the 1950s, the

previous record of drought and the worst drought previous to this one, these orangish-yellow-red colors show drought conditions. The redder it is, the droughtier it is.... If white it's average conditions, if green or blue it is wetter than normal. So this is 1950s drought. You can see the thing wasn't all the way up into Canada on average, but it really affected our part of the world. This is the current drought, at least the first part of it. It doesn't include 2004, which is one of the worst years, but it does include 2002. You can see it was a pretty bad drought and was a little more extensive. What my colleagues at NOAA did was to put the future model A2 precipitation and temperature projections into the Palmer Drought Severity Index to see what it would result in terms off average conditions in the West. Next slide please.

By 2050 here, averaged over a couple decades, and sooner than that. On one you can see that is already, according to the models, we should be getting a drying out of the West, it looks a lot like that, doesn't it? This is what was projected, and this is what's happening. It gets a little worse than projected, and remember this is averaged across a lot of models and then by mid-century, though, even those average models, not an extreme scenario, show a very droughty looking West, and these are not conditions during a drought per se; these are average conditions. Now it is a little test to see who has really been paying attention. What does this map look like? Does it look like projections in temperature that I showed you or projections of precipitation? Temperature. You bet. That's a very interesting thing. I highlighted again and again that we have better confidence in temperature. By the end of the century unless we do something, temperatures are going up. And I wouldn't do the same thing. I wouldn't bet nearly as much on precipitation change. This map looks like a temperature map. It doesn't show a gradient from down here to up here. So this is really being driven by temperature. I think that's what people lose track of is that in droughts the temperature increase is just as important, perhaps more important, than the precipitation decrease. And that's why we're having a drought now that's killing forests that previous droughts didn't kill. That's why Lake Mead and Lake Powell are 50% full, and when the drought started 8 years ago they were full. Next slide please.

Don't forget, of course, ...there is a likelihood of increasing drought in the future too. The next slide just shows you what I mean, there were mega-droughts that occurred during medieval times. Most of us have gone up and seen Mesa Verde and Choco Canyon, so many parts in the West where we have this flourishing ancient pueblo culture, often called Anasazi. This is the drought that we think is associated with, though not necessarily the ultimate or only cause or source of their demise. It went on for 170 years. We know this from tree-ring records across this region. This is the Palmer Drought Severity Index again and look at that pattern. It looks a lot like what we're expecting in the future, but this is a period of reduced rainfall, or snowfall, whereas in the future, it's being driven more by temperature. So what happens if we get all of those things together? We don't know what caused this. Although I think it's related to work we're doing here, and Richard Seager, we're having this big debate with him, the guy we're hoping to get from Columbia, it could be because of the Atlantic Ocean warming up, which is again exactly what's happening now. So is it possible that we could fit into this period of extended drought which is not just decades but hundreds of years made a lot worse by hot temperatures. Unprecedented hot temperatures. Right now, the last 50 years, temperatures have been warmer than any temperatures we've had in the last 1,300 years. That's due to humans.

Okay. So conclusions. I hope I'm leaving you all with the firm sense that scientists, at least the scientists who study climate, agree that global warming is a very real phenomenon. That there's no doubt about that, and there's very little doubt that humans are causing the problem and that the warming in the West is quite symptomatic if not one and the same as global warming and ... that at least 60% of that is due to humans. Humans are causing the problem, there's little doubt, I've said that, and more global climate change is going to come no matter what we do. This is because, and it was inferred in my slides, the climate system is like a huge supertanker. You can't change it on a dime. And this is because of a lot of things. One is that the CO_2 stays in the atmosphere, some of it for centuries, even millennia. Another reason is that the ocean is like a giant flywheel in the system. And right now the ocean is taking up heat but over time, and it will continue taking it up for some time but then eventually it will start to give that heat back off. So this warming will go on and on for centuries. And that's why we're worried about ice sheets. Even now. Okay? We're going to have to adapt to some degree future climate change no matter what we do. And that's a very important thing for us in the Southwest, where hotter conditions mean drier, more arid conditions.

And what's the opportunity in that? Well, I think there's big opportunity in that. One is that semiarid-to-arid conditions are the dominant type of land cover on the earth. More than any other type of land cover. So that people, just like they're moving here in droves, they're moving into these other places around the earth as we go from six billion people to nine billion people or whatever we end up with in 20 or 30 years. So the problems we have here are the problems everyone is going to be having around the globe. It's going to cause a massive conflict, and that's perhaps why the Peace Prize was awarded certainly. Hardship. And we're in a position here—wealthy, we have a problem of our own, we can provide solutions that work here that might actually find a market everywhere. How do you save water? How do you deal with hotter temperatures? How do you get cleaner energy? Talk about investment opportunity! All right, next slide please.

And this is just to highlight how much population growth is currently projected by the U.S. census. We'll double by 2030 here in Arizona; Colorado won't double but it will go up by almost half as much again. California will double, and they're not going to have to double to increase by a lot more people than in Arizona. These are the seven basin states that share the Colorado River water. Water is going down, people are going up, what are we going to do about that? We're going to have to do something. But the next slide highlights that we're also starting to get these major landscape transformations. What's it going to be in the Sonoran Desert? It actually is complicated by this thing called buffle grass that you have probably been reading about. And other invasive species, plants that come from other parts of the world that are going to cause our ecosystems to function different than they are functioning naturally. And in the Sonoran Desert we're not used to fire. These plants, the saguaros, and other succulents, are not used to fire. The other species that we're introducing because we want to improve our range for cattle and that do well in extremely hot temperatures. But these grasses dry out too, and they burn, and they burn hot. This is beginning to happen and could cause real problems in the Sonoran Desert. The woody species that come in from the south could make our desert much more fire prone. But we've already seen what happens to forests, we don't need to dwell more on that. It's happening around the world.

So I would like to leave with everyone thinking that we have to think about adapting to climate change. I think it we can do it. I think we can manage economic growth and maintain our quality of life ...as long as we don't let the situation get too out of control. I really worry if we let it go unchecked. It could be really hard to sustain things as we know them here in Arizona. Fortunately, I think our governor has been pretty clear on this issue. She just this last week announced her new initiative, the Western Climate Initiative, to reduce the amount of greenhouse gas emissions, and that's not just governors around the U.S.; some are in Canada, and some in Mexico. And she is now also working with us here in Tucson at the University of Arizona on a climate change adaptation initiative. You see the same thing obviously in California with Schwarzenegger and his crew. They're leading. You see it in New Mexico. You see it in Colorado. You see it in Utah, and you see it everywhere across the West because it is starting to sink home that people will no longer want to come here, and our economy depends on that, or at least if we're going to have economic vitality we have to deal with this.

But the biggest changes are avoidable. We've caused this problem. We have turned up the global thermostat. Since 1970 arguably, we have taken over the earth's climate system. We dominate it. We can reduce those just as effectively. It's going to cost. And the question is, is that cost worth it? That's a policy, that's a value, that's a voter decision, not a scientist's decision. Next slide please.

Okay. I would like to highlight what's being done in the scientific community and the policy community coalescing around this idea of reducing greenhouse gas emissions to 80% below 1990 levels, which were 20% less than now, by 2050. I don't know, we were talking before this lunch, whether that's enough. That isn't the big point. This is huge. If we did this, it's a big job and it will have a big benefit. And the science will get better and better and quickly over the next few years, if we all of a sudden say well this isn't enough, we will be hopefully that much closer to doing better than this. But it's unlikely that we are going to say we have to do less than this.

How are we going to do this? This is my last slide. I don't spend a lot of time talking about this because I'm a climate scientist. I'm not an engineer. But I try to read up on this stuff and keep abreast of what solutions are out there, and I think the messages are coupled. One is that there is no silver bullet here. We haven't figured out a cost-effective way to take the CO_2 out of the atmosphere. Someday we might figure that out. In the meantime, what we really need to do is conserve and become more efficient. That will provide us with say, 20-30% perhaps part of the solution, but we also have to go to these carbon-free sources of energy. Coal can be burned, but we have to put the CO_2 underground. We have a plant in the United States that does this already; another one is being built in California. We just have to make them work economically and competitively. We also of course have read how people are taking advantage of our real estate market to buy lots of land for solar. The next five years we are going to see major solar build-out around Arizona. Wind??, hydropower, not here of course, and geothermal. Not the old kind of geothermal where you go to Yellowstone and poke a hole in Old Faithful, but geothermal taking advantage of the fact that the whole West has an anomalously warm crust. That can be used to generate energy. This same electricity can fuel hybrid vehicles, electric vehicles, and produce hydrogen, and there are lots of ways we can fuel vehicles with carbon-free fuels. Biofuels, if you

want to talk about it, I would be happy to, are really under a big cloud now. And there are other options we can talk about if you want. The big point here, though, is I think I went to Congress last year, and I think I briefed parts of Congress and staff members six times. The biggest thing I try to impress upon everybody, and I'm going up there again in May, is that if I was President of the United States, or if I was the Speaker of the House, I would make damn sure that this country puts a lot of money. Manhattan Project scale money, Apollo Project scale money,... into technology solutions. So that if the American people get hit with enough hurricanes, or the drought out there gets bad enough, we will be ready to take action. So that when we demand action, we'll be ready to take action. That's like a no-regrets strategy. Because we're going to have a lot of these problems due to natural variability in any case and sooner or later we'll have to start deploying these types of technology. So thank you. [Applause]

Q: building New Orleans on higher ground.

Yeah, I don't think that things look good for New Orleans. You know, I think we're going to get a meter or two of sea-level rise no matter what we do. Options (1) build pretty far inland; (2) give up; (3) kind of like the Netherlands does and that will work only as long as we don't allow the climate change to get totally out of control and melt the ice sheets, in which case you probably can't save New Orleans short of jack-up rigs.

Q: [inaudible]

Yeah, New Orleans, Miami, Charleston, New York, Boston, Providence where I went to grad school. These places all are going to see increased threat. I think that our map should show the major airports of all those cities that I just mentioned are all within one meter of sea-level rise. There's been a study done, which I haven't read yet, about transportation, which is how many of our roads between the east coast and southeast are within this danger zone. You know, huge infrastructure let alone fancy houses.

Q & A: Colorado River flow; water sources in general

...

Lake Mead won't go dry. But who has the highest priority on the water? California—giving California those rights was the price Arizona paid for the Central Arizona Project....

...I don't want to talk about this at the Arizona Inn, but I was talking to a group of doctors one time, and one asked me, "What about condoms? What about world population? Isn't that the problem?" And I think it's interesting. We all know how popular a topic that is, but I think the real problem with world population isn't the number of people; it's the fact that we're living in a world now where many of these people are starting to move on up in terms of their affluence. And they're starting to live like us. ...Instead of eating rice and grains, they want to eat meat. And you know the amount of extra energy that goes into that meat is a lot. And so in a way, we may have to be global leaders in many more ways than we mentioned.

I think she had her hand up the longest, I'll go there:

Q: Do you have any comments on the Oregon Petition Project? You know that there are about 30,000 American scientists who disagree with you about the importance of atmospheric carbon dioxide as causing anything like these catastrophic consequences?

Yeah, I wonder about that. You know they've asked me to sign it. (laughter from audience) I read it; it's a bunch of bull. And I would say if you have the time to parse it and see how many of those scientists are actually climate scientists, you'll find out of whatever number you said, the number of climate scientists is going to be very, very low. Umm, you know, so, there's a difference in would you like, if you go to the doctor and let's say you have a fairly serious problem that requires an operation, would you like me to operate on you? I took AP biology in high school (laughter). I know all about that kind of medical stuff. (laughter) You gotta go to the expert. You know, you wouldn't bring your car to me to get it fixed even though I was a car junkie in high school. You take your car to someone who actually knows something about it. It's the same thing with climate. Those guys don't know what they're talking about.

Q: inaudible. Oh boy. There's all sorts of ecological impacts that are very murky in terms of our competence. [Our Working Group 1 IPCC report] had a thousand pages on just the physical basis of climate change. We really didn't get into the ecological, which was Working Group 2.... I am now working with the National Academy on a committee on the ecological consequences of climate change in report for the public. We're actually writing up a report for the public rather than for our peers, which is different. I'm just really scared when I read about what's going to happen to our ecosystems and species and biodiversity and things. We're seeing this happen. We're see a lot of this happen already with even the small amount of climate change we've already had. You know ...the timing of biological process in getting out of sync, say between say the flowers and the pollinators and between prey and predators. It will be interesting to see if Mother Nature can actually deal with it. What makes me worry is that the rate of climate change that we are going to see for the next hundred years is likely to exceed by maybe a rate of ten anything that occurred naturally on the scale of the globe during the time that all the species on earth evolved. The other thing that worries me is that in the past they didn't have to deal with ground water table lowering, stream flow reductions, all these houses and fragmentation of ecosystems, air pollution, water pollution, invasive species,.... We're making it a lot harder for these organisms to deal with the environmental change, which of course they've done all through revolutionary history. We're going to hit them harder and faster than ever before, and in some cases it will be warmer than they've ever seen before, and we're also going to do it with all these other balls and chains around them. And I think we are.... We're going to see some real major impacts in the earth's biota. And I think ultimately no matter what we do, our great-great grandkids will look back at us and just wonder what the heck was going through our brains. Because we do know now these things were going to happen. Scientists know these things were going to happen, and yet the public could decide not to do anything about it.

Q: largely inaudible, concerning need for government to deal with it because of being only entity huge enough, yet government is incompetent—the engine for change is not government, but the people themselves.]

I couldn't agree with you more. But there are a couple of points that I think I are instructive. A good analogy to what we're faced with here, of course on a much bigger scale, is the ozone hole problem.... It's a problem that was clearly substantial: if we allow the ozone in the stratosphere to be destroyed we get so much UV coming through that it destroys life as we know it. The scientists went through a process very similar to this Intergovernmental Panel on Climate Change, in fact the IPCC was modeled on the ozone assessments, which continue to this very day, identified the problem and it made not only the governments of the world to realize the problem, it got the companies that were really important, Dupont, and it happened during Bush I's term in office, and I can't remember the exact details, but you know, the detractors that were saying to him don't do anything were out of town, heh heh, when he made the pronouncement that the United States was going to act on this issue and be a leader in the world. And it's just like with climate change, if the United States does it alone it won't be enough, it won't be worth it probably, and if it doesn't do it, it won't be enough for the rest of the world to do it. It'll have to be done together. But President Bush got the companies that were making the chemicals that were destroying the ozone layer to say we recognize this as a problem and we will come up with new chemicals. There are a lot of lessons in that. One is that these companies are doing great now because they get to sell these chemicals all over the place, and they and continue to make money. The other thing is that, just like I said, I do not think the problem is solved until the United States leads it. So somehow I think the U.S. government has to be involved and ... the people have to make him do it. But if we decide we want this solved, and it's not me to tell you when it's solved, then government has to act and lead the country. Because China will not go do anything until the U.S. does. The guys who signed Kyoto are not meeting their Kyoto obligations. Why should they when China and the U.S. are out-competing them; they have a lower overhead.

The last thing is my idea and others share, is to have this Manhattan Project-scale thing, which is a scale of money, "easy money" I guess, that only government has. You know, Iraq shows that we can have that kind of sustained investment in something and not necessarily destroy our country. That's what we need to do here. I would love to get Exxon Mobil to do it, but I think we have a better chance of getting the U.S. government to do it than Exxon Mobil.

Q: inaudible. I wish you success. The big story here is don't leave a single rock unturned. If you think this is a problem and we need to deal with it, the main thing is we are having this discussion in an open way and that we are not leaving any options closed, we're looking for any solutions wherever they lie. It will not be easy. [Applause.]