TRANSCRIPTS OF SEPTEMBER 10, 2008

List of Presenters:
1. *Charles Cole: Water Harvesting*
2. *Julio Betancourt: Climate Related Resource Uncertainties – Part 1*
3. *Kathy Jacobs: Climate Related Resource Uncertainties – Part 2*

Presenter #2:
Dr. Julio Betancourt, Senior Scientist, USGS: "CLIMATE-RELATED RESOURCE UNCERTAINTIES – Part 1"

Introduction to next presenters from Chairman Jim Barry

CHAIRMAN JIM BARRY: Okay. Let's move on to presentations on Climate-Related Resource Uncertainties… I just wanted to remind us of some slides that we've already seen 'cause, in large part, we're talking about climate and climate variability and how it's going to affect the Colorado River Basin. And you can see that we get 144,000 acre-feet per year out of the Colorado River and, if you add in the Groundwater Replenishment District, another 12.5, so it's about 157,000 acre-feet via the CAP. So, it's important, but it's also part of a larger context. It's not just Pima County, it's those seven states that make up the Colorado River Basin.

Next slide, please. So, in 2020, we're talking about Tucson Water, that looks like about what -Eighty percent Colorado River Water? So, our stake in the Colorado River Water and the reliability of it as a source is enormous and it's important that we keep that in mind when we listen to Julio and Kathy talk today.

And the final slide is we do have this tiered Shortage-Sharing Agreement and there is hope that that is going to go some considerable length to protecting the municipal supplies but we need to, perhaps, revisit that at some time. So, I just wanted to remind us of these slides, because we have an enormous stake in the Colorado River, and so we have a great stake in what we hear about it today.

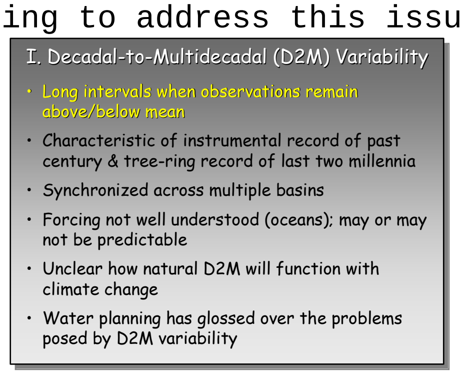
Our first presenter is Dr. Julio Betancourt, who is a Senior Scientist with the U.S. Geological Survey, and an Adjunct Professor at the University of Arizona in Tucson. He got his Master’s and Doctoral Degrees from U of A. He’s probably (inaudible) over 130 technical papers and a wide variety of scientific journals. He focuses on climate variability and climate change and how that affects floods and fires and droughts in ecosystems; conducted field studies in the western U.S. and throughout the world. And, over the past four years, he has helped educate and organize our community to stem the spread of African Buffelgrass. I also would mention I have known Julio for a long time, and the last time we ran across each other we were trying to save Tumamock Hill using the County’s 1997 Open Space Bonds. So, with that in mind, Julio.

DR. BETANCOURT: Thanks.

CHAIRMAN JIM BARRY: And I will remind you, you’ve got 30 minutes.

DR. BETANCOURT: Okay. Thanks, Jim, and thanks for the opportunity to address you this morning. So, what I want to talk about is actually the sensitivity of the water supply, both climate variability and climate change in the Colorado River Basin. And remind you that what we’ve done in switching from groundwater to the surface water of the Colorado River is that we’ve now changed over to water supply that is actually more subject not just to climate variability, but also to the climate change.

So, I’m going to have a couple of little tutorials here about climate variability -- globally and relative to the Colorado River. I’m going to talk about climate change, and then I’m going to give you an example of a study by a close colleague of mine, Greg McCabe that actually takes some of the Colorado River supply through a water-balance model, and some of the projected changes in temperature, along with some of the possible climate variability. Most of these exercises actually come up with very similar results, so I’m just going to show you one as an example, so you can see what it is that people are doing to address this issue, and then I want to finish with a couple of comments about the projection now from the Intergovernmental Panel and climate change for less precipitation and not just higher temperature



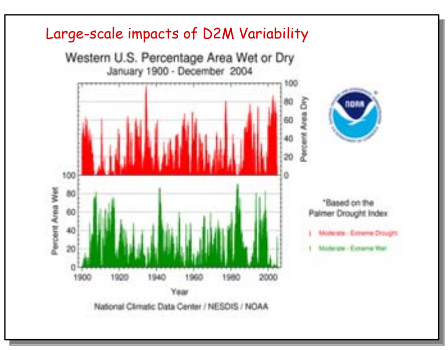
So, first, I want to talk about an issue that we refer to as "Decadal to Multidecadal Climate Variability," and it’s defined as long intervals when the precipitation or the stream flow observations remain either above or below the mean from a few years to a few decades. This is very important. It's actually very characteristic of the instrumental record of the past 100 years, and also of the tree ring record of the last two millennia, a lot of it that has been generated at the University of Arizona.

The thing that's interesting, and perhaps troublesome, about this kind of climate variability is that it's synchronized across multiples basins. So, when we have problems in the Colorado River Basin, more than likely we're also having problems in the Mississippi River Basin, we're having problems in the Rio Grande Basin, maybe even in the Columbia Basin. This kind of variability tends to be broad-scale, subcontinental in scale. The forcing is not well-understood. We generally think that the hydroclimatology on land has a lot to do with variability in the oceans. We don't really understand the forcing all that well, you know. Where's it coming from? It's operating through the ocean, but we don't understand whether it's internal variability, or externally driven variability, like solar, or volcanic forcing, for example.

It may or may not be predictable. And I think some of the new evidence having to do with variability in the North Atlantic Ocean in which there is actually a system of currents, a conveyor belt that takes a long time to play through that has kind of intrinsic quality to it that may actually give some predictability to hydroclimatology on land based on what it is that the North Atlantic is doing in terms of its kind of slow operation.

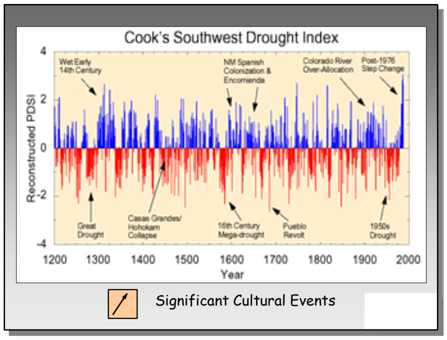
It's unclear how this kind of variability will function with climate change, and I'll argue - and I think most of us would argue - that water planning has generally glossed over the problems posed by Decadal to Multidecadal Climate Variability. If we haven't adapted to this kind of natural variability, that's going to make it that much harder to adapt to climate change.

So, by Decadal to Multidecadal Variability, I mean this kind of pattern in the red is actually the percent area experiencing dry conditions based on the Palmer Drought Severity Index, which shows these slow oscillations. In fact, at the beginning of the century, you can see the early period in the early 1900s, and in the wet areas down below in the green, that was actually probably the wettest period in the



last century. In the red, you can see the 1930s and the 1950s throughout, and then picking up again since about 1999. And below you can see these relatively wet periods in the ‘80s and the ‘90s when our populations grew really, really fast; it’s been abnormally wet until the last few years. So, this is what I mean by Decadal to Multidecadal Variability, and you can pick this up in the tree ring record.

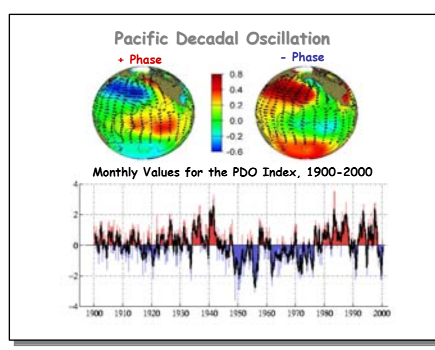
Ed Cook’s Southwest Drought Index is based on many, many chronologies, and you can see this kind of fluctuation between relatively dry conditions and relatively wet conditions. So, there’s not an equal chance in any given year of getting a wet year or a dry year. Wet years tend to be clustered and dry years tend to be clustered as well.



And you can see some correspondence in these notable cultural events: The Great Drought that ended up in abandonment of the Colorado Plateau by the Anasazi. The Casas Grandes Hohokam Collapse in the 1400s. This big 16th Century Mega-Drought from 1575 to 1595 that was basically coast to coast. The Pueblo Revolt in 1681 came at the tail-end of a major drought from 1673, roughly, to 1681. And then you can pick out the Colorado River over-allocation in the beginning of the century,a relatively dry period from 1930-1960, followed by this big step change in climate where it got relatively wet.

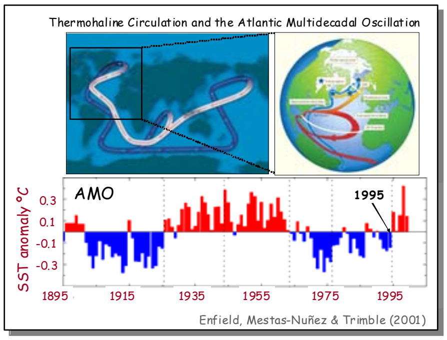
So, this is not only what modulates our water supply; it’s also what modulates ecosystem response to climate variability. So, we get these big die-offs of the pinyon and the ponderosa and other things when you have droughts and, in the wake of that disturbance, you end up getting recovery once things get wet again.

So, there are lots of ideas about how this variability is forced- what the reasons and the causes for it are. Most of them have actually to do with the oceans. You’ve heard about El Niño Southern Oscillation and the Tropical Pacific; this is inner-annual variability that also has kind of a decadal signal to it. It is a physical mechanism; you can actually model it, although not really well in the general circulation models, but you can actually model it; it’s physical. We



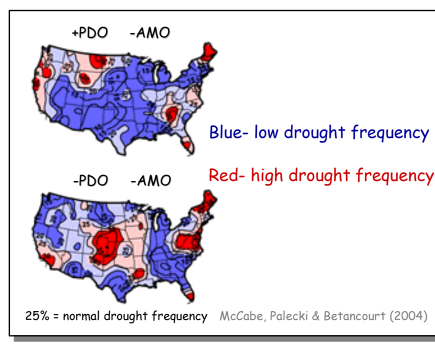
know a lot about it.

And then there are these other oscillations that you're going to be hearing about: The Pacific Decadal Oscillation, or the PDO, and the Atlantic Multidecadal Oscillation, or the AMO. And I'll show you in a minute what they look like. But, we don't know whether the PDO is actually a physical mechanism; it may be a statistical artifact; whereas, the AMO, we know that it is a physical mechanism tied to what is called the "Thermohaline Circulation."

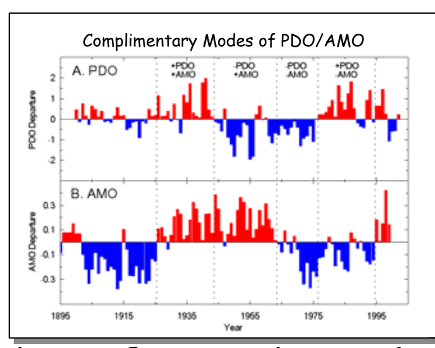


It is possible that the Atlantic Multidecadal Oscillation, through exchanges of latent heat flux from the Carribean over to the Tropical Pacific may actually force decadal-scale variations in El Niño and Niña.

This is the Pacific Decadal Oscillation; it kind of looks like El Niño and La Niña in terms of sea surface temperatures at the top, with the positive phase giving us a lot more precipitation in the southwest; the negative phase, less precipitation. The time series is down below and you can pick out this relatively dry period that we got into from 1946 to, roughly, 1976 when the PDO was actually in its positive phase. And then, once it goes positive, generally we have more precipitation in the southwest.

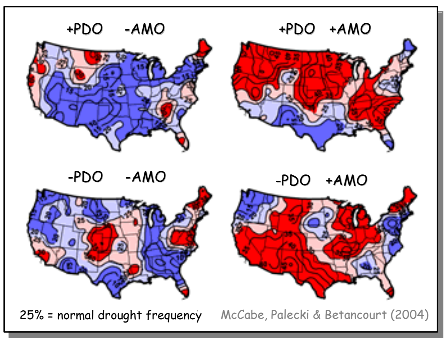


Here is the Atlantic Multidecadal Oscillation, the time series is actually down below; it's basically average temperature from zero to 70 degrees latitude in the North Atlantic; it is actually the surface expression of something called the "Thermohaline Circulation," this conveyor belt that takes water from the tropics, takes it north into the North Atlantic where it becomes denser, as it becomes saltier and colder, it then sinks at depth and then returns back towards the equator. It's part of a larger, global circulation of heat and water. A packet of water takes about 1,000 years to make its way around. The inflection points in the time series are actually 1930 and 1960 and, in general, when the North Atlantic is warm, when it's in the red in the time series, there's a tendency for North America



to experience widespread drought; and, when it’s in its cool phase, there’s a tendency for most of North America to experience relatively wet conditions. And you can see the change that happened around 1995 where the North Atlantic turned warm. And so this is an interesting comment that I’ll make and that is: That whenever - whenever we see more intense or frequent Atlantic hurricane activity, we also see drought across most of North America, and there is a link.

So, you have to look at these things (e.g., PDO and AMO) in complementary modes so you can see these sort of scenarios that I’ve put together with the two times series where the PDO and the AMO are either in their positive or negative phases. And so, in general, when the PDO is in its negative phase and the AMO is in its positive phase is when we get the most intense droughts in western North America and, particularly, in the southwest.

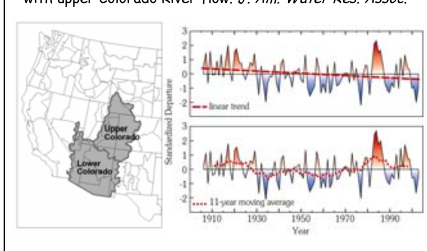


So, I’ll show you what this looks like mapped out. Don’t bother too much about the numbers, just remember that blue means low drought frequency, and red means high drought frequency. So, let’s take the AMO, map out when the North Atlantic is cool and change the PDO from positive to negative to see what happens. So, on the top you see that what happens is that when the AMO is cool in both instances (both positive and negative PDO), North America is overall wetter than normal; whereas, what you end up doing when you change the PDO from its positive to the negative phase is you actually shift the areas of drought, for example, to the Pacific Northwest when the PDO is in its positive phase, and then back to the southwest when it’s in its negative phase. In respect to the PDO, as well as El Niño/La Niña, the Southwest and the Pacific Northwest tend to behave in opposite fashion.

When the North Atlantic is actually in its warm phase, we have exactly the opposite, where we have continental-scale drought over the U.S. Again, when you change the PDO from negative to positive, you shift the areas that are either wet or dry from the Pacific northwest to the southwest.

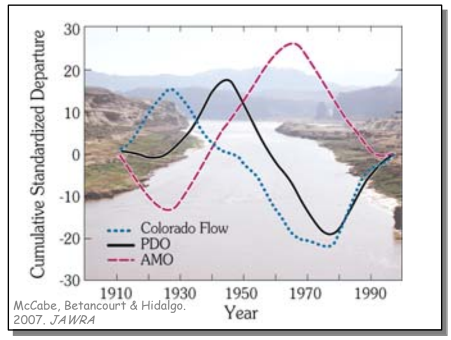
So, let’s look at the Colorado River real quick. This is from a paper where we looked at these kinds of things last year with Greg McCabe (USGS hydrologist) and I and

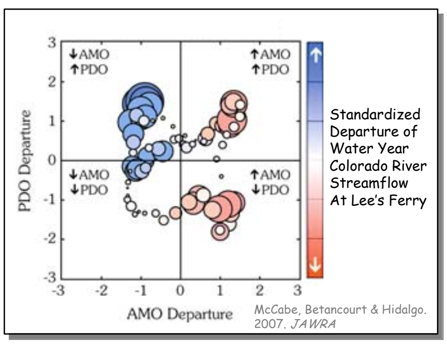
McCabe, G.J., Betancourt, J.L. and Hidalgo, H. 2007. Associations of D2M sea-surface temperature variability with upper Colorado River flow. *J. Am. Water Res. Assoc.*



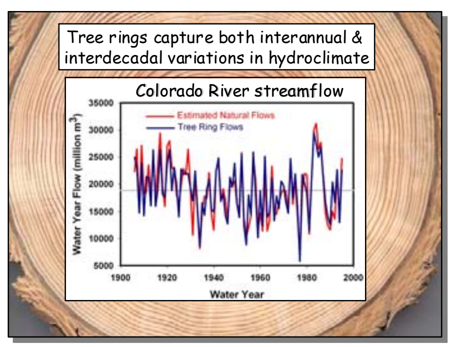
Hugo Hildago at Scripps Institution of Oceanography , and so what you have here are two times series of Colorado River stream flow of natural - naturalized Colorado River stream flow, and you see this sort of general trend downwards, and then we take that trend out and we just look at the variability over time, and you see these periods of relatively low flows, and these periods of relatively high flow. And I want to sort of put those into context relative to some of these climatic indices that I’ve been referring to.

So, I’m not going to go into a lot of detail. You’ll get the picture here pretty quickly. This is cumulative standardized departures of Colorado River stream flow, plotted up in the blue dotted line against the PDO in the dark line the AMO in the dotted red line. You can see this inverse relationship between the stream flow and the AMO, and less so with the PDO. So, taking this at face value, the Pacific is surprisingly less important in Colorado River stream flow than the North Atlantic.





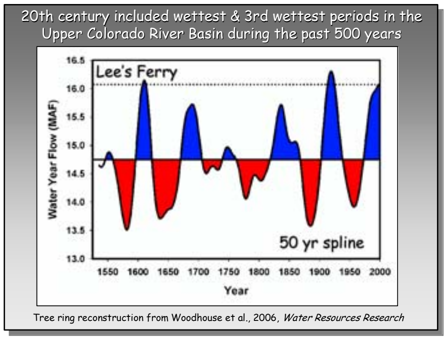
Now, we’ve looked at these patterns frontwards and backwards and we’ve also looked at them back in time, and now I want to introduce the tree ring record. I’m sure most of you are familiar with the fact that annual rings, particularly in conifers, are indicative of climate during the season that the ring was produced. And particularly averaged over relatively large areas, there’s a tendency for the tree ring widths to actually capture not just the inner-annual variability in precipitation and stream flow, but also the decadal scale variability. So, here you see by decadal scale I mean this kind of slow variation over time in tree-ring growth vs. Colorado River streamflow during the 20th century.

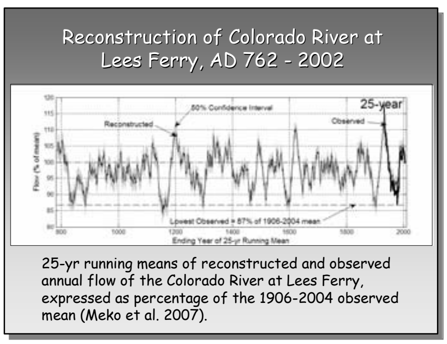


CHAIRMAN JIM BARRY: Fifteen minutes, Julio.

DR. BETANCOURT: Okay.

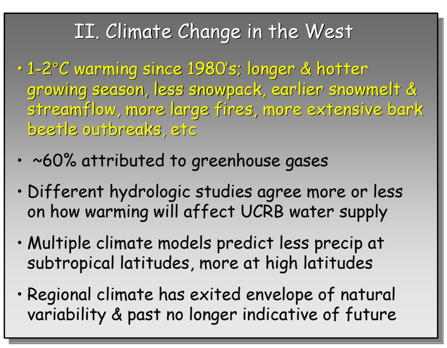
So, let’s take back in time some of this data for Colorado River stream flow reconstruction that just happened and was published first in 2005, and then again in 2007 by Connie Woodhouse and Davie Meko and Steve Gray. And this is a 500-yr reconstruction that was published three years ago, and now they've actually taken it back more than 1,000 years. And there's some really interesting aspects of this chronology. Here we are in the 20th Century, with this big, huge wet period from about 1905 to 1921, and then here's the dry period in between, and then the wet period that returned. You can look back further in time and compare the magnitude and frequency of such periods back in time. And take a look at this 1130 to 1150 drought, there's absolutely no reason why that drought could not occur today, by the way, in terms of the boundary conditions, the earth's boundary conditions. So, you know, it's pretty obvious that the last 100 years doesn't really capture the variability that's occurred over the last 1,000 years.



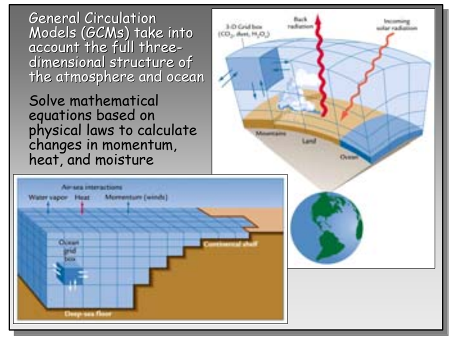


Here's another example of this now smoothed out with a 50-year line - and the story here is the 20th Century included both the wettest and third-wettest periods in the upper Colorado River Basin during the last 500 years. So, there's a little bit of an illusion of surplus from the 20th Century instrumental record that does not actually match in the tree ring record.

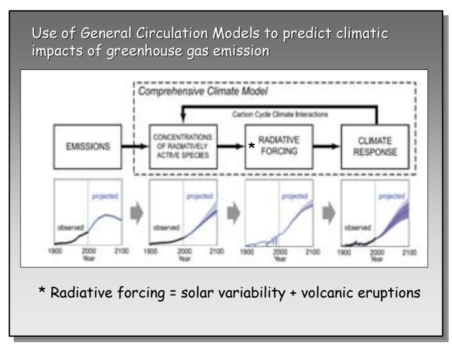
Okay. Climate change in the West. You've been hearing and reading about this in the newspapers. There's been a one to two degrees Celsius, depending on the elevation, warming since the 1980s, longer and hotter growing seasons, less snow pack, earlier snow melt and stream flow, more large fires, more extensive bark beetle outbreaks, et cetera. All these things are tied together to this this advance in the onset of spring and a longer growing season, including things like we're getting a greater proportion of precipitation as rain rather than snow higher up all of these mountains which are, basically, the water towers that we depend on.



There’s a recent study by people at Scripps and USGS where they’ve actually taken general circulation models and downscaled them into both regional climate models and hydrological models, and 60% of these patterns that we’re seeing are now attributed through this modeling to the buildup in greenhouse gases. Again, most hydrologic studies agree, more or less, on how the warming will affect the water supply in the Colorado River. There’s a new development now, particularly with the last Intergovernmental Panel on Climate Change (IPCC) report, that are now almost unanimously predicting less precipitation at subtropical latitudes, more at high latitudes. I’ll have a slide at the end that refers to this, where the southwest is actually in the crosshairs.



The last point that I’ll make is that the regional climate has exited the envelope of natural variability, and the past no longer is indicative of the future. So, we use these general circulation models that take into account the full three-dimensional structure of the atmosphere and the ocean to solve mathematical equations that are based on physical laws to calculate changes in momentum, heat and moisture. I ’m old enough to remember when this first started, I didn’t have a lot of confidence in what I saw, and now I have a tremendous amount of confidence. These models have really improved. These are heroes in the scientific community. These guys have done a marvelous job. So, one of the things they do is they take these models, they plug in the emissions and then, through a series of steps, they’ll look at the impact of the concentrations of those radioactively active species of compounds, they’ll look at the radiative forcing. By "radiative forcing" I mean solar variability or volcanic eruptions which can, in fact, modulate the climate, and then they look at the climate response. So, this allows them to actually take any of these steps and look at it separately and together, and this is what has been done with the IPCC, and the answer to questions about the uncertainty of climate changes that follow. And that is that, when you take the natural forcing and you force the models just with the natural forcing, they can’t reproduce the actual



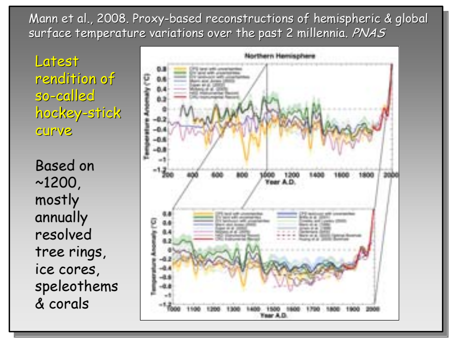
observed temperature trend, but when you take the two together they reproduce it fairly well.

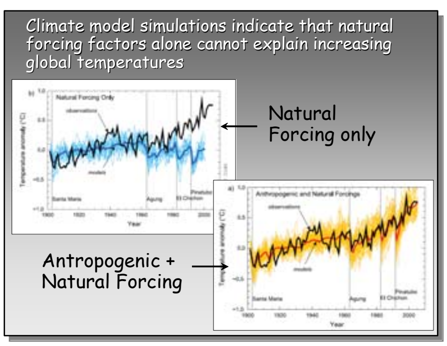
CHAIRMAN JIM BARRY: Let me ask a quick question. Can you explain what you mean by "forcing?"

DR. BETANCOURT: By forcing I mean what is the initial reason for why the climate is changing? It could be that you had a volcanic eruption that puts a lot of particulates up in the air and blocks the sun, or it could be solar variability.

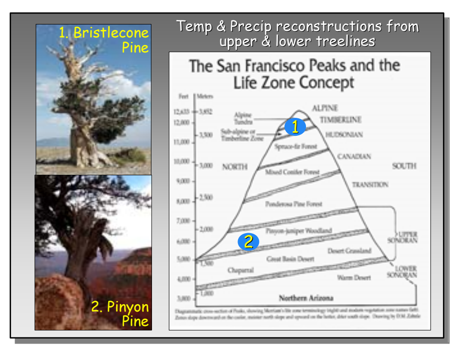
CHAIRMAN JIM BARRY: Okay. I gotcha.

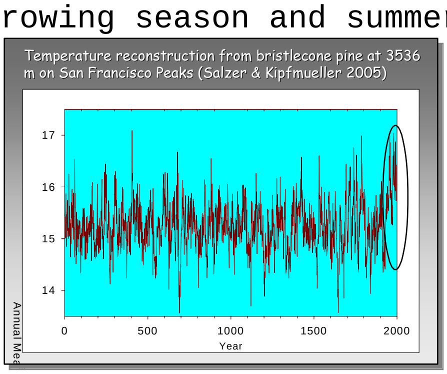
DR. BETANCOURT: So, people have actually taken great pains to collect proxy data for instrumental data, and these are tree rings (inaudible) and corals, and then developed something that you've heard about, I'm sure, before, which is this hockey stick curve with this big change over at the end. So, this is the latest and greatest, this is a paper that just came out in the proceedings of the National Academy of Sciences by Michael Mann at Penn State and others. It shows that over the last 1,000 years, clearly, the last century has an anomalous rise in temperature throughout the northern hemisphere and, actually, globally. Now they've taken it back another 1,000 years and you could argue the same for the last 2,000 years that the recent increase in temperatures is unique.





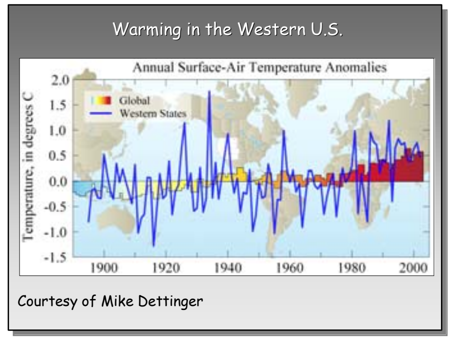
And you can actually see this in our own data. I'm going to take you to the upper tree line at San Francisco Peaks where Bristlecone Pine actually responds to the length of the growing season and summertime temperatures, and there's a wonderful reconstruction that spans the last 1,500 years from upper tree line just north of Flagstaff and San Francisco Peaks, and here it is and at the end here's this big rise. So, these Bristlecone Pines at upper tree line that respond primarily to

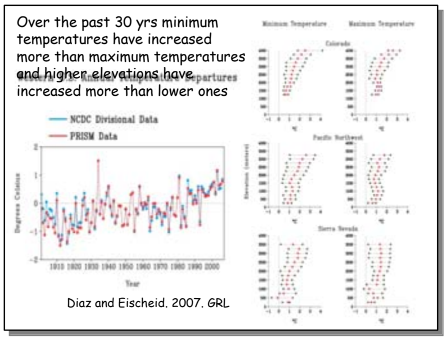


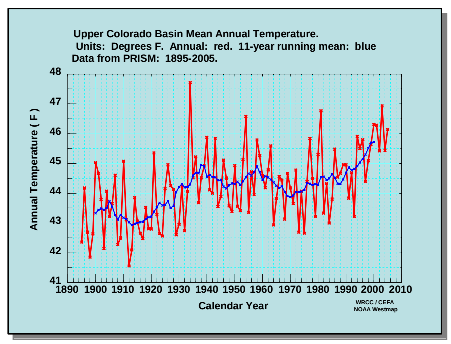


temperature variations are now adding an unprecedented amount of wood every year.

If you look at the temperature trends over the last 100 years throughout the west, that is that blue line, you can see the rise over there at the end, it almost appears like in step fashion. You can see that around 1984, or in the 1970s, and certainly by 1984, there's this big shift to higher temperatures, and underneath it is actually the global temperature curve. There are two observations to make about these temperature changes in the west, and one is that minimum temperatures have increased more than maximum temperatures, and then that higher elevations have increased more than lower ones which, of course, affects snow packs. So, at lower elevations there's been about a 1 degree C increase and, at higher elevations, there's been about a two-degree C change in temperature.



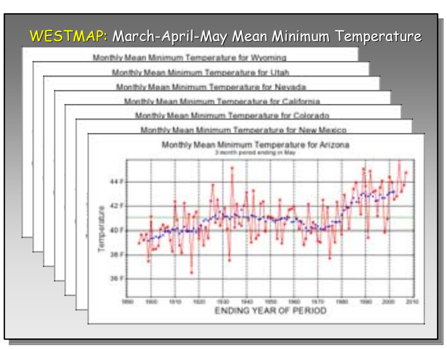


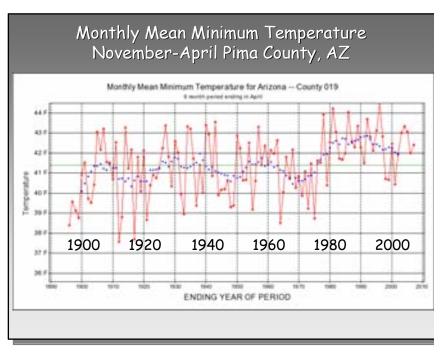


CHAIRMAN JIM BARRY: Ten minutes, Julio.

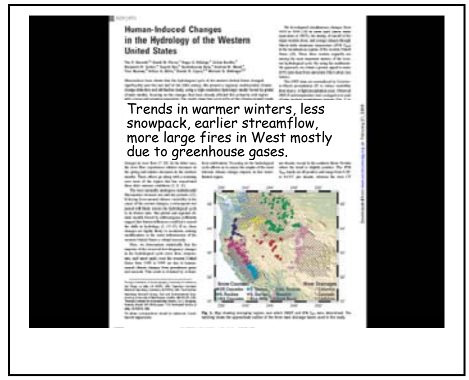
DR. BETANCOURT: Okay. You look at temperature averaged over the upper Colorado River, here's the trend and you see that rise there towards the end.

And then what I want to do is show you all of these Colorado River states. This is not just the tyranny of averages over a region; each one of these regions has pretty much the same change, and this is a change that's occurred relatively recently and you look at Arizona and you can see this big change after about 1984, but relatively flatlined below

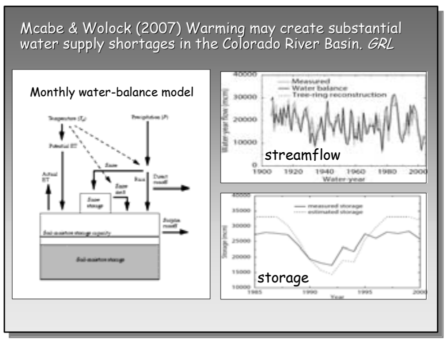


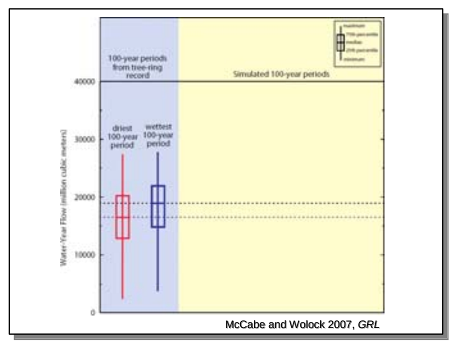


until you get to the beginning of the century. You want to look at Pima County, it's exactly the same thing. This is something that is being seen everywhere; it's not just a matter, again, of the tyranny of averaging over large areas. So, there's been this study by Tim Barnett, et al., that I mentioned and that is that the trends in warmer winters, less snow pack, earlier stream flow, more large fires in the west are mostly due to greenhouse gases.



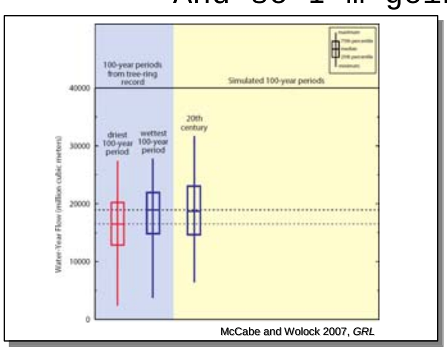
Now, what people have done with the Colorado River, they're taking all of these trends and actually starting to plug them in to hydrologic models. These next slides come from a study by Greg McCabe, who's a USGS scientist and actually Dave Walock, another USGS scientist, and they've taken a water-balance model where they can partition precipitation into different components and they can basically back out stream flow and, also, storage out of these models and then play different games, increasing the temperature by a degree or two degrees C, and then actually using past droughts as the scenario to see what would happen.

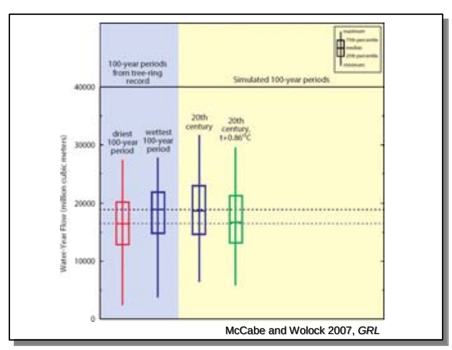




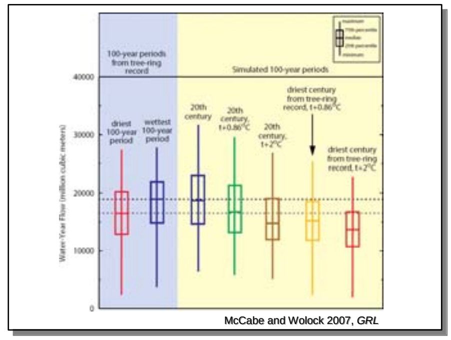
And so I'm going to take you through this really quickly.

So, this is water year flow in million-cubic meters per year, and so the first thing I'm going to show you is the driest 100-year period from the tree ring period and the wettest 100-year period, sort of defining the envelope of variability, that's where the 20th Century is, when you add 0.86 degrees C, even if you don't change the

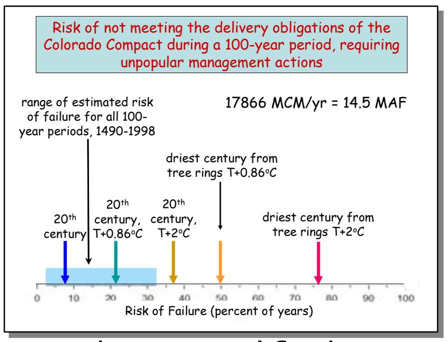




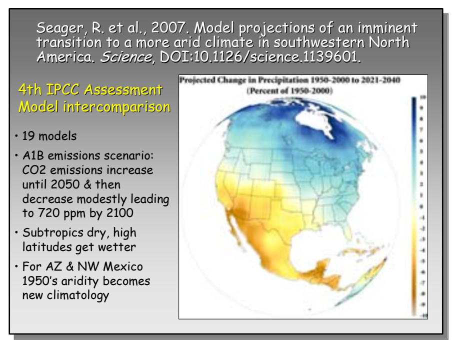
precipitation, you end up looking like the driest 100-year period in the last 500 years. When you add two degrees, you actually go below the envelope of natural variability. And then if you take the driest century from the tree ring record and you add 0.86 degrees C, which is what we've experienced in the upper Colorado River in the last 100 years, this is what you get. And, with two degrees, the driest century would produce something like this.



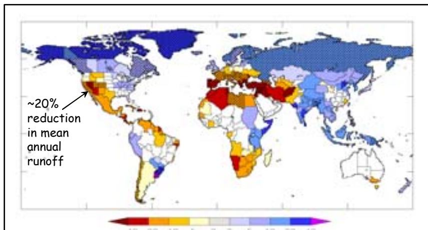
And the bottom line is the following: This is the risk of not meeting delivery obligations in the Colorado River Compact during 100-year period requiring unpopular management actions. And so you can see that the risk ranges from 10% or so, maybe 20% if we add just a degree C without really changing the precipitation, all the way out to more than 75% if what we look at are two degrees warmer and we apply that to the driest century from tree rings.



I want to move on real quick. I just want to say that for most of these scenarios, increasing reservoir storage capacity will not mitigate the effects of increased temperatures at all.

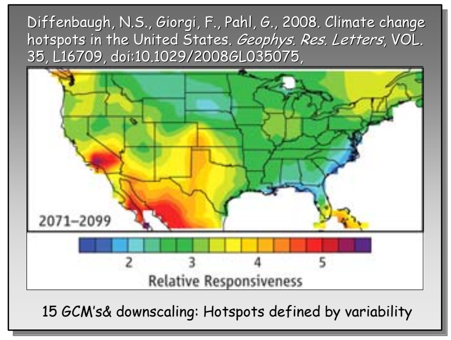


So, what's happening now is the IPCC has run 19 different models, and 18 agree that what's going to happen is the high latitudes are going to get wetter and the low latitudes are going to get drier, and you can see this bull's-eye painted over the southwest. The argument here is that in the 21st Century, the mean climatology is going to look more like the 1950s drought.



Model-projected % change in mean annual runoff volume from 1900-1970 to 2041-2060 under IPCC 2007 A1B scenario. Color is defined by the median of values from the 12 climate models analyzed by Milly et al. (2005). Any color indicates that 8 or more of the 12 models agreed on the direction of change. Diagonal stippling indicates agreement between 11 or 12 of the models agreed on the direction of change (Milly et al., 2008).

So, that's what they're saying and - and, actually, the scientists that work on this are pretty insistent that this is the case. I still think there are some questions, but I think this is troublesome for us. And, of course, the devil's always in the details. That white area in between the yellows and the blues raises the question of how big is that white area, that neutral area? That neutral area seems to be centered over the Colorado River, so are we just going to see stationarity, where the precipitation is not going to change much over the Colorado River, but we're going to be impacted further south? And so there's some real questions here. And people are now running downscaled regional models to try to get a better handle on what's going to happen exactly in the southwest. For example, Noah Diffenbaugh and others have now taken 15 general circulation models and they've looked at the regional sensitivity to changes in different climatic parameters, including their means, extremes, and variance. A map of relative changes in climatic variance shows the Southwest as a hotspot for climatic change.



So, I want to make one final comment and then I'm done. We had a paper come out in science earlier this year - the title was "Stationarity is Dead, Whither Water Management." Stationarity is actually the assumption that the future is going to look like the past, and I think we've now exited the envelope of natural variability in a directional but, yet, uncertain direction. And so now projected changes in runoff during the multidecadal lifetime of major infrastructure projects are large enough to push the hydroclimate beyond the range of historical behavior, and much of the fundamental assumptions that we've used in water planning and water management worldwide are now violated by this particular phenomenon. So, I'll leave it at that. Thank you very much.

(Applause.)

CHAIRMAN JIM BARRY: Julio, thank you. Can we hold questions until both of the presenters are… okay Dan - go ahead.

MEMBER DAN SULLIVAN: - if I could. Well, our science has started basically (inaudible; not speaking into a microphone). There's no doubt that global warming has generated intense (inaudible) on both sides of - the other side is (inaudible) seen here today, this is the question, so you can correct me where I'm wrong, is that there has been an enormous variability in the past concerning (inaudible), without greenhouse emissions being (inaudible) the cause of those enormous changes and fluctuations, but certain scientists seem to be saying now that we have the same manner of variability in the future, it must be greenhouse emissions -

DR. BETANCOURT: No, that’s not what we’re saying.

MEMBER DAN SULLIVAN: Well, the only cause (inaudible; not speaking into microphone) between what is happening now and the past is the (inaudible) of how temperature changed. Other than that is there any other reason?

DR. BETANCOURT: Let me back up a second and say that when you run these models, you take into account the so-called forcing, the natural forcing, whether it’s solar variability, which we can actually compute or -

MEMBER DAN SULLIVAN: And then some scientists say today is the cause for recent (inaudible).

DR. BETANCOURT: By "some" you’re talking about a fraction of a fraction.

MEMBER DAN SULLIVAN: (Inaudible; not speaking into a microphone) that doesn’t mean that necessarily more; that they’re a fraction of a fraction.

DR. BETANCOURT: No, but I guess what I’m telling you is that variability is actually taken into account; that natural variability and the forcing, whether it’s solar variability or whether it’s volcanic forcing is actually taken into account in the models, and when you do that you actually can’t reproduce the actual observed global warming or regional warming or length of the growing season; that these are not things that have changed in the same way within the recent past.

MEMBER DAN SULLIVAN: (Inaudible; not speaking into a microphone).

DR. BETANCOURT: Oh, no, there’s no question that these things have happened before in the past. They haven’t happened this quickly, and they haven’t happened in the context of the kind of demands that we have on natural resources, including water.

CHAIRMAN JIM BARRY: Okay. Let’s -

MEMBER DAN SULLIVAN: (Inaudible; not speaking into a microphone) -

CHAIRMAN JIM BARRY: Let’s revisit this.

MEMBER DAN SULLIVAN: - (inaudible; not speaking into a microphone).

DR. BETANCOURT: I’d be more than happy to have this conversation with you after.