Changing Planet: Past, Present, Future
Lecture 3 ±(DUWK¶V &OLPDWH %DFN WR WKH)XWXU
Daniel P. Schrag, PhD

1. Start of Lecture Three (0:16)

[ANNOUNCER:] From the Howard Hughes Medical Institute...

climate is one of the features of a planet that really determines whether it's habitable. We heard from Andy Knoll about how life has evolved throughout Earth history and he referred to climate change throughout that time period. What I want to do is explore a little bit, what is it that actually controls the climate of a planet and how does it vary over time. Then we'll look at our current predicament and think about how climate is likely to change over our lifetimes and on into the future. So we can start here with a silly picture of an Earth with a little gas burner heating it up. Of course, you know this isn't actually the way the Earth's climate is controlled. But you know, just like the heater in your houses, the Earth's system does have a heater; it's the sun. But it also has a thermostat and that's what we're going to talk about today, and the thermostat is actually the carbon cycle, at all, no ice on Antarctica, no ice on Greenland--a completely different planet. Now there's lots of evidence for that warm world in the Eocene 50 million years ago. There were crocodiles living way up in the Arctic. If you look at the perimeter of Antarctica there's evidence for a pine forest. Palm trees living in Wyoming--pretty cold winters in Wyoming today. Sea level was about 100 meters higher than today, but really a descent into the modern world that is on the cold end of the spectrum. We're living today in a relatively cold climate. It was colder 20,000 years ago but in fact, what was going on 20,000 years ago, if we zoom in just on that upper 2 million years, the last little bit of time, you can see that in fact, those records, there's a lot of detail there. You can see these oscillations back and forth. These are the ice ages waxing and waning, so 20,000 years ago, we were at a glacial maximum, and today we are at, you might call a glacial minimum. We actually call it an interglacial but it's the same idea. We're waxing and waning between these more extreme ice ages and a more mild ice age. Again, though in the context of larger Earth history, we're still in an ice age. So those fluctuations really are between the left hand and the right hand of this slide, a world that has a lot of ice versus a world that has only a little bit of ice.

7. The influence of atmosphere on planetary climates (12:45)

So what I want to do now is step back and say what is it that caused these changes in Earth's climate over Earth history. And how can we explain the difference between Venus and Earth and Mars? And you might think oh, it's really simple. Venus is closer to the sun, it gets more solar radiation so it's hotter. Mars is further from the sun, it gets less radiation so it's colder. And you know that's all true. But here's the interesting thing. A lot of people don't realize that in fact, if Venus had the same atmosphere as the Earth, even though it's closer to the sun and gets about twice as much solar radiation as the Earth, because it's so much brighter than the Earth, you see how it's not dark like the Earth? The Earth has some bright spots too, it has clouds and it has ice sheets, but you see a lot of the Earth is covered with ocean that's quite dark and absorbs a lot of solar energy. Because Venus is so bright and reflects so much light, Venus would actually be colder than the Earth if it had the same atmosphere as the Earth. What actually keeps Venus warm, so hot, 460 degrees Celsius, is that it has an atmosphere 100 times thicker than the Earth, composed almost entirely, 97%, of carbon dioxide, an ultra greenhouse planet. Whereas Mars has a very thin atmosphere, also mostly carbon dioxide, but 100 times thinner than the Earth's atmosphere, and it is further from the sun and therefore it's very, very cold. So the question is, what causes this sort of variation? Why have these planets ended up like this and what has maintained the Earth in this habitable state for 3-1/2 billion years? Why didn't we become like Venus or why didn't we, once we had a snowball Earth and froze over completely like Mars, why didn't we stay that way? And the answer has to do first with the way our energy balance is achieved on the Earth, but it has to do with the carbon cycle.

8. Animation: Greenhouse Effect (14:42)

Let me quickly review for you how this works. So again, the surface of the Earth is heated by the sun. The amount of energy that comes out of the Earth, geothermal energy, is a few thousand times less than what actually comes from the sun. So in certain places it can be important but overall it's the sun that sets the Earth's surface temperature, not the internal temperature of the Earth. And when the sun shines on the Earth, some of it is actually reflected back to space. Again, more of it if it's on an ice-covered part of the Earth or where there's lots of clouds. And some of it is then absorbed by the Earth. When it absorbs solar energy in the visible spectrum, what happens is the Earth heats up in response, because it's absorbing energy, and when objects heat up they emit their own radiation but in a longer wavelength, and so that radiation then heads back towards space. If the Earth had no atmosphere it would be about 30 degrees colder, so we would actually have a frozen planet. We are habitable because of our atmosphere and because our atmosphere has some greenhouse gases, in particular carbon dioxide and methane, the most important of which is actually water vapor. Water vapor is interesting. We don't often talk about it as a greenhouse gas but the reason it's important is it's like an amplifier. It turns over quickly. It lasts in the atmosphere hours to days to weeks and so as a result you can think of the other greenhouse gases, carbon dioxide and methane, as the dial, say, on your stereo, but it's the water vapor that amplifies the effect because it turns over so quickly. And so what happens is these greenhouse gases, they absorb some of the infrared habitable for most of Earth history. It's a very simple reaction, where essentially you have carbon dioxide plus an igneous mineral -- in this case there's a mineral, anorthite -- and water, going to a clay mineral and calcium carbonate. You can see a picture of what a granite looks like, that's... anorthite is the most common mineral in a granite or in a basalt for that matter. And clay on the right, this is the clay kaolinite which is a very common clay. It's a soft mineral that you see on the Earth's surface in mud or other weathered regions. What's interesting about reaction, the reason it works as a thermostat is that it's temperature-dependent. I want to quickly take you guys --

from getting either too warm or too cold. Now it's not a perfect thermostat. It's not like the thermostat in your house where you set the temperature and it fixes it right there. And that's because the time of this takes a little while, so it's a little bit more difficult than that. So when we look back at at other planets, we can actually see what's wrong with the other planets. Venus is hot, has too much carbon dioxide. What is it missing? What does the Earth have that Venus doesn't have? Water. So Venus has rock. It has lots of igneous rock, it has carbon dioxide, it doesn't have water. Earth has everything. What is Mars missing? Now, it has CO_2 in the atmosphere, it has water, it's frozen. It doesn't have volcanism. It doesn't have a source of carbon dioxide that's persistent. And it may an ocean basin called the Tethys. As Africa and India moved north towards Eurasia, ocean crust was subducting beneath the Eurasian continent, and all the volcanoes along that margin were streaming out carbon dioxide because of all the limestone in that region. And then as India and Africa moved north and that basin closed, that subduction stopped, and in the modern Earth, we have a system where most of the subduction is occurring in the Pacific, which has very little limestone. The limestone is mostly buried today in the Atlantic. And so this is probably a long-term cycle. Someday the Atlantic Ocean will subduct again and Europe and North America will come back together and when that happens we'll have another warm climate. We just happen to be in a cold climate today.

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And when we actually look, and this is our same figure of oxygen isotopes on the left, showing the temperature change through Earth history over the last 70 million years, on the right is a set of proxies of carbon dioxide concentration. I don't have time to get into the details of this but they're things like the stomatal density of leaves or chemical proxies that have to do with the amount of boron in shells and a variety of other ways of estimating past CO2, and you can see that, there's a lot of uncertainty but in general we think that the Eocene and this warm period in Earth history was indeed times of higher carbon dioxide concentrations. So it really is the carbon dioxide that's driven this climate change from the warm climates of the Eocene down to the ice age today.

14. The rate of climate change is critical (29:16)

And so finally, when we look at the last little bit of Earth history, these ice ages that have fluctuated over the last couple of million years, we can actually see that carbon dioxide has changed here as well. So this is now carbon dioxide from an ice core over the last 650,000 years and you can see carbon dioxide fluctuating and it matches the temperature changes we've seen perfectly. So during the last glacial maximum 20,000 years ago, carbon dioxide was about 180 parts per million, and in t actually just observe global warming. The Earth is warming up. I think maybe what you mean is, do I believe that humans releasing carbon dioxide from burning fossil fuels is responsible for that global warming, and the answer is yes. And I'll explain why we think that in a little bit. Any other questions? Yeah, in the back.

16. Q&A: How does water vapor amplify the greenhouse effect? (31:09)

500 parts per million. That, I guarantee you. The big question is, will we go much higher than that? Are we going to slow down our use of fossil fuels so that we actually stay around 5 or 600 parts per million, or are we going to shoot through that and go to 800 or 1,000 or 1,200, which really starts to go through the next floor.

19. Some of the emitted CO2 will stay in the atmosphere for a long time (34:43)

Now, in thinking about this, we have to think about what is it that causes this, and we have to learn a little bit about the carbon cycle. I want to give you a sense of what's really going on here. As I said, only about half of the carbon dioxide we put in the air stays there and that's good news. The Earth's system gives us a little bit of a cushion. It takes about half of the pollution we put in the air and removes it. Now one question you might as is well, okay we're putting carbon dioxide into the atmosphere, it turns out today we're emitting about 10 billion tons of carbon, so all of the numbers on here are in units of about billions of tons of carbon so they're very large numbers. And today we're burning in fossil fuels about 10 billion tons of carbon per year. And you can see that's pretty small compared to photosynthesis on land, which is about 110 billion tons of carbon per year, or air/sea gas exchange of carbon dioxide which is almost a hundred gigatons, a hundred billion tons a year. The reason it's so problematic, though, is that the system was basically in balance before. What was coming out from respiration was the same as what was going in photosynthesis. What was going into the ocean through dissolution was the same as what was coming out. And we perturbed that system. Now we're adding, we're taking fossil fuels that were buried, carbon that was buried in the Earth for millions of years, and releasing it very, very quickly and the Earth is trying to soak it up. The Earth is trying to take care of it. And on short timescales, like the timescale of a year, like I said, about a quarter of it goes into the land—plants are growing faster—and about a quarter of it is actually being taken up by the ocean. And eventually the ocean will take up about 80% of it.

as possible and we would end up... On the right it shows what would happen to the carbon dioxide in the atmosphere, modeling the ocean and the land, and you can see that the green left. And Lonnie is really an amazing guy. He looks like a very mild-mannered guy from Columbus, Ohio. If you met him he's a very calm and gentle man, but he actually, he's really Indiana Jones. Seriously. This guy is incredible. What he does is he's a glaciologist but he doesn't study Greenland or Antarctica like any normal glaciologist. He decided he wanted to work on glaciers in the tropics. And so to find glaciers in the tropics you have to go to very high mountains. So he goes up to 22, 24, even 25,000 feet in the tropics and he brings 6 tons of solar powered drilling equipment that he has to carry in by hand and then he spends 2 months at a time camping up on the top of these mountains drilling ice cores through these glaciers. He has spent almost 4 years of his life above 18,000 feet. It's unbelievable what he's accomplished. And so what he does is, he actually has drilled all over the world so, South America, Kilimanjaro and in New Guinea. He also has worked in Tibet. This is a picture of him up 24,000 feet in the Andes looking at core coming out of his solar powered drilling equipment. Here's their sola melted so much that those rivers are flowing at a trickle. This is a really big challenge for agriculture going forward.

25. Climatological data confirms temperatures are rising (46:00)

What about heat waves? Well, we had a really big heat wave this past year. Do people remember the March weather? It was really nice, wasn't it? Early end of winter. It was incredible in the Midwest, actually. This is a map showing the temperature above normal and in the middle of March this was... meteorologists, people who study the atmosphere were scratching their heads. We were talking in the hallways, "Can you believe what we're seeing?" Twenty-five degrees Fahrenheit above normal. In Rochester, Minnesota the overnight low temperature which is usually about 20 or 30 degrees lower than the daytime high actually set the record for the all-time highest temperature. Of course, the daytime was even higher. So, this just doesn't happen. In Chicago you had eight 80-degree days in the middle of March. The previous record was like around 70. And in St. John, New Brunswick, this is up in Canada, March 22nd, I love this, it set the record for any day ever in April. So this was an incredible heat wave. Probably a one in a thousand year event. So if you had to look back at the historical record you'd say, this should happen once ever thousand years. The problem is we've been seeing more and more of these extreme heat waves. You know, the one-in-a-thousand year event is becoming the one-in-fifty year event. Let me give you another example of this. The March heat wave was kind of a nice break for us. Ecologically this was bad for things like maple syrup and a lot of pollination; apples, it was a bad year. But if we look at the heat wave in Europe in the summer of 2003, this was really a big deal. What you see here, this is the distribution of summer temperatures, average summer temperatures for the last hundred years, from 1900 to 2006, and the one on the far right, that's the 2003 summer. I was in Italy that summer. It was scorching hot; really unpleasant. Fifteen thousand people died prematurely in France that summer. It was a really big deal. They lost about 30% of their harvest because crop we're likely to be wrong in the wrong direction, that is, most of the surprises are going to be bad ones.

26. Animation: Dramatic Retreat of Arctic Sea Ice in 2012 (50:05)

Here's a surprise I want to show you. Let's go to the video here. This is a picture of Arctic sea ice. So this is looking at what happened this summer as sea ice began to retreat. Another surprise: in 2007 we were really shocked by the retreat of sea ice and this year by mid-September this is what the sea ice looked like. If you know the history of the Arctic, this is incredible. So here's that same distribution of sea ice in mid-September and you can see the yellow line, that's what the average was from 1979 to today. The two regions I want you to notice: one is the Northwest Passage.

27. Arctic sea lanes are now unfrozen and open (50:28)

If you look at the history of exploration: Amundsen, the great Norwegian explorer who was the first person to the South Pole, he actually took three years to get through the Northwest Passage. He had to spend three winters with the Inuit, stuck in ice. This year we could have gone in a little sailboat in a week or two through the Northwest Passage. The Northeast Passage is even more incredible because that was never open before 2010. You couldn't get from the Atlantic to the Pacific around Russia. And now, not only is it open, it's wide open. In the next two decades we might actually see an ice-free Arctic: really quite incredible. Okay. A lot of other things going on.

28. Melting of Greenland and Anarctica (51:27)

We're seeing melting of ice on Greenland. Here is a picture of Greenland from a satellite and this is actually one of the things

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29. Consequences of dramatically rising oceans (52:58) would be good to switch over to hydrogen cars because you don't have nitrites and sulfur and that kind of stuff going into the atmosphere, would switching to hydrogen really be good for the atmosphere?

[DR. SCHRAG:] So in the next segment we're going to talk about energy technology and solutions, and so we'll get there, but the simple answer is, if hydrogen cars ever actually made it to the market in an economical way, and right now I think they're... that's unlikely, but if they were technologically and economically feasible we don't have to worry about the greenhouse gas effects from putting more water vapor in the atmosphere. The reason is, as I said, water vapor is cycling through the atmosphere all the time. Remember, most of the Earth's surface is covered by water and so water is always evaporating and always precipitating as rain or snow. And so that cycle is happening all the time so adding more... you know, when we boil water and put it in the atmosphere, that doesn't make the atmosphere hotter, putting lots of steam in the atmosphere, even though it's a greenhouse gas, because that steam will precipitate out as the next day or a few days later. And so because water cycles so quickly, we actually don't have to worry about adding water as a cause of climate change. It's responding to the carbon dioxide not driving it.

32. Q&A: How can agriculture adjust to rising temperatures? (57:20)

Let's call on someone, here, in the front row.

[STUDENT:] What are some adaptations that agricultural business will have to make in order to survive the increase in temperature?

[DR. SCHRAG:] That's a really interesting question. I just wrote a big report for President Obama on what agriculture and the U.S. Department of Agriculture will have to do to think about what we call agricultural preparedness. And it's a very difficult challenge because right now there is a huge race going on in biotechnology to try to design crops that can withstand higher summer temperatures and water stress during period of drought. And here's the interesting question, this is a little bit philosophical, but it's a very interesting scientific debate right now: there are geneticists, plant biologists, and in fact, the Howard Hughes Medical Institute is actually for the first time funding a series of investigators in plant biology that's really important, but basically, there's an argument that the geneticists think they can design plants that can grow in very hot or very dry conditions. There are people who study plants, plant physiologists, who think that this is nonsense, that natural selection for 400 million years has tried to make plants that could grow in hot and dry places. So that, you know, there are plants bordering the desert. If plants could figure out a way to grow in hot

Okay, let's take up with where we left off. Here's a picture of Hurricane Sandy. You can still see the devastation in the New Jersey shore. New York City, where I grew up, my brother had to leave his house, his apartment for a while because he was without power. It's going to be a while before New York City is back to normal. And that was just one hurricane. And it really brings up the question of mitigation

Hurricane Katrina in New Orleans. It could have been 100,000 people. I really think it shouldn't be mitigation versus adaptation. I think we have to be talking about mitigation AND adaptation. We need to adapt to climate change. So we're talking about that now in New York City. Mayor Bloomberg is saying, do we want to build sea walls? Do we want to build oyster beds to soften the storm surge? I actually think another type of adaptation is called resilience, which means the ability to recover from damage. So instead of sea walls, you might think of putting a lot of pumps in the subway system.

produce carbon dioxide emissions. Some people have other issues with nuclear, but in terms of reducing CO2 emissions it is certainly on the list. And then the last method is one that's a little more controversial but it turns out that it's going to be essential, and that is burning fossil fuel but taking the carbon dioxide emissions, instead of putting them in the atmosphere, capturing them and injecting them into an underground reservoir, a large underground reservoir where it will actually stay there for millions of years. So it turns out when you analyze carefully possible ways of actually getting to a very low carbon economy, it turns out that we know that we're going to need all three of these. I believe that it's impossible to conceive of a future where all three of these aren't going to be necessary. What we don't know in 2012 is exactly how much of each one we're going to need, but in some ways that's really irrelevant in 2012. This is going to be a very long, hard transition and what we need to do today is work on all three of these. And then let the market decide which is the most economical, which ones do people want the most, and figure it out.

37. Energy use reduction through efficiency (68:29)

Let me show you some quick examples. Hopefully this will give you a little bit of hope that we might actually accomplish this. This is a graph showing the annual electricity use per person in California compared with the rest of the United States. You can see that since about 1970, the United States has continued to use more and more electricity per person, whereas California has been pretty flat. There are a number

This is a study that was done in Salt Lake City in the late eighties. What happened was there was a steel plant outside of Salt Lake City that accounted for about a third of the pollution in the Utah valley. You can see on the left, this is a measure of particles in the air, a measure of air pollution, PM-10, that's 10 micron particles, and you can see them drop in the winter of '86. That's because the workers at this factory went on strike. So they shut the factory down for one winter. It was like a little natural experiment that was done. So they shut off the steel mill and bam, the air cleaned up. On the right what you see is hospital admissions for children from asthma, bronchitis, respiratory diseases. Isn't this incredible? I mean, to me it's amazing that people don't know this. We had politicians talking about shutting down the EPA. It was the EPA that was trying to clean up the air. It always seem control it. But in fact, what if China decided to do this on their own, or India, or some other country in the world? How would we feel about it if we didn't control it at all? These are very big questions that people will discuss more and more and we need to start having public dialogue about this because it's a serious issue. And here's the scary part of this: as scary as geoengineering is it may be better than that alternative which is just letting climate change happen on its own. That's something very serious to think about.

43. Our responsibility is to be educated and to educate others (79:16)

So again, we have to develop new technology but we also have to change our behavior. But let's just conclude by saying that this is a problem that you and your generation is going to continue to face throughout your lifetime. This won't be the last time you hear about climate change. What I'd urge you to do as young educated people, whether you're scientists or non-scientists, human history, and so we have a little bit of a challenge in the short term. In the long run everything will be fine.

45. Q&A: How do warming temperatures increase storm severity? (82:14)

How about another question? Here.