CLIMATE CENTRAL

Statement of

Heidi M. Cullen, PhD
CEO and Director of Communications
Climate Central

Before the

Subcommittee on Energy and Environment
U.S. House of Representatives

"A Rational Discussion of Climate Change: the Science, the Evidence, the Response"

Washington, DC
November 17, 2010

One Palmer Square • Suite 330 • Princeton • New Jersey • 08542
T 609.924.3800 F 609.924.3882 E info@climatecentral.org W www.climatecentral.org

Chairman Baird and Members of the Subcommittee, thank you for this opportunity to engage in a rational discussion of the science of climate change. My testimony will focus on the basic science and physics of climate change, the causes and production of anthropogenic greenhouse gases and the expected impacts on the climate.

Introduction

I am a climate scientist by training, but I have spent the last several years as a climate science educator – producing reports for outlets like PBS NewsHour and The Weather Channel. When I first started at The Weather Channel in 2003 people assumed that if I worked at a 24/7 weather network, I must be a meteorologist. The question I was asked most often was "What's the forecast?" I was always happy to provide the local weather forecast. But these experiences made me realize that many people do not truly understand the difference between climate and weather, between climatologists and meteorologists. Here's a rough answer: climatologists pick up where meteorologists leave off. We focus on timescales beyond the memory of the atmosphere, which is only about one week. Climatologists look at patterns that range from months to hundreds, thousands, and even millions of years. The single most important and obvious example of climate is the seasonal cycle, otherwise known as the four seasons. Summer, the result of the Earth being tilted closer to the sun, is warmer. And winter, the result of the Earth being tilted away from the sun, is colder. The forecast follows the physics. Which is why, if in January, I issued a forecast that said it would be significantly warmer in six months, you might not think I was a genius, but you'd believe it.

There are countless others patterns on our planet that influence the weather. Take El Niño, for example. El Niño can bring drought to northern Australia, Indonesia, the Philippines, southeastern Africa and northern Brazil. Heavier rainfall is often seen along coastal Ecuador, northwestern Peru, southern Brazil, central Argentina, and equatorial eastern Africa. There are many ways in which climate can work itself into the weather.

Meteorologists focus on the atmosphere, whereas climatologists focus on everything that *influences* the atmosphere. The atmosphere may be where the weather lives, but it speaks to the ocean, the land, and sea ice on a regular basis. The hope is that if scientists can untangle all the messy relationships at work within our climate system, we should be better able to keep people out of harm's way. The further we can extend our forecasts, the longer out in time a society can see, the better prepared we'll be for what's in the pipeline.

And this is where global warming enters the equation. If the four seasons are *Mother Nature's* most powerful signature within the climate system, then global warming, the term that refers to Earth's increasing temperature due to a build-up of greenhouse gases in the atmosphere, is *humanity's* most powerful signature.

The Basic Science and Physics of Climate Change

We tend to think of man-made global warming as a purely modern concept, something that has come into vogue in the last 20 or so years, but in reality this idea is more than 100 years old. The notion that the global climate could be affected by human activities was first put forth by Svante Arrhenius in 1895, who based his proposal on his prediction that emissions of carbon dioxide from the burning of fossil fuels (i.e., coal, petroleum, and natural gas) and other combustion processes would alter atmospheric composition in ways that would lead to global warming. Arrhenius calculated the temperature increase to be expected from a doubling of CO_2 in the atmosphere--a rise of about 8°F.

More than a century later, the estimates from state-of-the-art climate models doing the same calculations to determine the increase in temperature due to a doubling of the CO_2 concentration show that the calculation by Arrhenius was in the right ballpark. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) synthesized the results from 18 different climate models used by groups around the world to estimate the climate sensitivity and its uncertainty. They estimated that a CO_2 doubling would lead to an increase in global average temperature of about 5.4°F with an uncertainty spanning the range from about 3.6°F to 8.1°F. It's pretty amazing that Arrhenius, doing his calculations by hand and with very little data, came so close to the much more detailed calculations that can be done today.

In the following section, I aim to provide a brief history of climate change that will explain the basic physics and chemistry of global warming and important climate discoveries that serve as the groundwork of our current scientific understanding of this life-threatening issue.

- The discovery of the greenhouse effect

The French mathematician and physicist Joseph Fourier in 1824 helped discover the greenhouse effect. Specifically, Fourier was looking to use the principles of physics to understand what sets the average temperature of Earth. Fourier was interested in understanding some basic principles about the flow of heat around the planet. It made perfect sense that the sun's rays warmed the surface of the Earth, but this left a nagging question: when light from the sun reaches the surface of the Earth and heats it up, why doesn't the Earth keep warming up until it's as hot as the sun? Why is the Earth's temperature set at roughly 59°F--the average temperature at the Earth's surface?

Fourier reasoned that there must be some type of balance between what the sun sends in and what the Earth sends back out, so he coined the term *planetary energy balance*, which is simply a fancy way of saying that there is a balance between energy coming in from the sun and going back out to outer space. If the Earth continually receives heat from the sun yet always hovers around an average temperature of 59°F, then the Earth must be sending an equal amount of heat back to space. Fourier suggested that the Earth's surface must emit invisible infrared radiation that carries the extra heat back into space. Infrared radiation (IR), like sunlight, is a form of light. But it's a wavelength that our eyes can't see.

It was a great idea, but when he actually tried to calculate the planet's temperature using this effect, he got a temperature well below freezing. So, he knew he must be missing something. To arrive at 59°F, the Earth's average temperature, Fourier realized that he needed the atmosphere to pick up the slack. And in the process, he discovered a phenomenon he called the *greenhouse effect*. The greenhouse effect is a process whereby the gases in the Earth's atmosphere trap certain wavelengths of sunlight, not allowing them to escape back out to space. Like the glass in a greenhouse, these *greenhouse gases* let sunlight through on their way in from space, but intercept infrared light on their way back out.

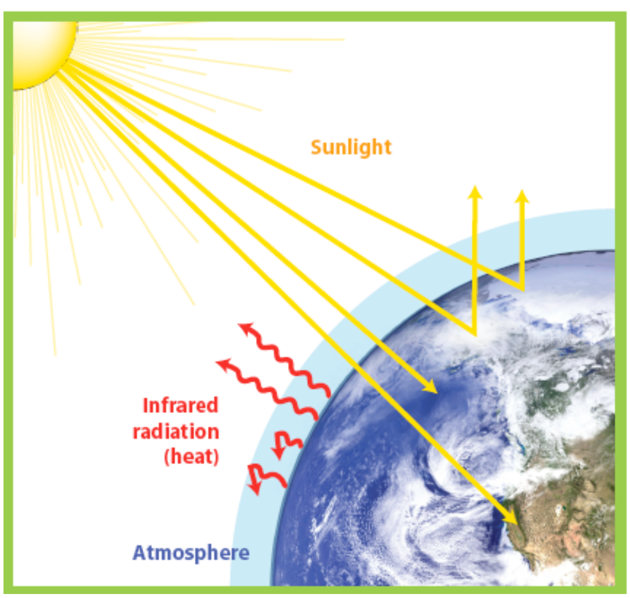

Figure 1: The Greenhouse Effect

In 1849, an Irish scientist named John Tyndall was able to build on this idea after he became obsessed with the glaciers he was climbing while visiting the Alps on vacation. Like so many other scientists at the time, Tyndall wanted to understand how these massive sheets of ice formed and grew. He brought his personal observations of glaciers into the laboratory with him in 1859, when at the age of 39, he began a series of groundbreaking experiments.

Tyndall was intrigued by the concept of a *thermostat*. We know them today as devices that regulate the temperature of a room by heating or cooling it. So Tyndall devised an experiment that tested whether the Earth's atmosphere might act like a thermostat, helping to control the planet's temperature. Tyndall reasoned that it might help explain how ice ages had blanketed parts of the Earth in the past.

For his experiment, Tyndall built a device, called a spectrophotometer, which he used to measure the amount of radiated heat (like the heat radiated from a stove) that gases like water vapor, carbon dioxide, or ozone could absorb. His experiment showed that different gases in the atmosphere had different abilities to absorb and transmit heat. While some of the gases in the atmosphere--oxygen, nitrogen and hydrogen--were essentially transparent to both sunlight and IR, other gases were in fact opaque, in that they actually absorbed the IR, as if they were bricks in an oven. Those gases include CO_2, but also methane, nitrous oxide and even water vapor. These "greenhouse gases" are very good at absorbing infrared light. They spread heat back to the land and the oceans. They let sunlight through on its way in from space, but intercept infrared light on its way back out. Tyndall knew he was on to something. The fact that certain gases in the atmosphere could absorb infrared radiation had the makings of a very clever natural thermostat, just as he suspected. His top three thermostat picks were water vapor, without which he said the Earth's surface would be "held fast in the iron grip of frost", methane, ozone, and of course, carbon dioxide. Bingo, a natural thermostat right inside our atmosphere.

Tyndall's experiments proved that Fourier's greenhouse effect was indeed real. His experiment proved that nitrogen (78%) and oxygen (21%), the two main gases in the atmosphere, are not greenhouse gases because these molecules only have two atoms, so they cannot absorb or radiate energy at infrared wavelengths. However, water vapor, methane and carbon dioxide, which each have three or more atoms, are excellent at trapping infrared radiation. They absorb 95% of the long-wave or infrared radiation emitted from the surface. So, even though there are only trace amounts of CO_2 in the atmosphere, a little goes a long way to making it really tough for all the heat to escape back into space. In other words, greenhouse gases in the atmosphere act as a secondary source of heat in addition to the sun. And it's the greenhouse gases that provide the additional warming that Fourier needed to explain that average temperature of 59°F.

Thanks to Tyndall it is now accepted that visible light from the sun passes through the Earth's atmosphere without being blocked by CO_2. Only about 50% of incoming solar energy reaches the Earth's surface, with about 30% being reflected by clouds and the Earth's surface (especially in icy regions), and about 15% absorbed by water vapor. The sunlight that makes it to the Earth's surface is absorbed and re-emitted at a longer wavelength known as infrared radiation that we cannot see, like heat from an oven. Carbon dioxide (and other heat-trapping gases such as methane and water vapor) absorbs the infrared radiation and warms the air, which also warms the land and water below it. More carbon dioxide translates to more warming. And this is where the concept of a natural thermostat becomes very powerful - mess with the amount of CO_2 in the atmosphere and you're resetting the thermostat of the planet.

- The discovery of global warming

Svante Arrhenius (1859-1927), a Swedish physicist and chemist, began his research on global warming by trying to understand the cause of ice ages. He took Tyndall's thermostat mechanism and explored whether the amount of CO_2 in the atmosphere could raise or lower the Earth's temperature.

We refer to events or processes that result in changes to the climate as *forcings*. A volcano eruption is an example of a natural forcing. A forcing can often result in an amplification (positive) or a reduction (negative) in the amount of change and often comes hand in hand with something known as a *feedback* - a situation where some effect causes more of itself. A negative feedback tends to reduce or stabilize a process, while a positive feedback tends to grow or magnify it.

Arrhenius believed some type of positive feedback mechanism was responsible for plunging the planet into an ice age. For example, a drop in carbon dioxide would lead to a drop in temperature creating more snow and ice. When snow and ice cover a region, such as the Arctic or Antarctica, their white, light-reflecting surface tends to bounce sunlight back out to space, helping to further reduce temperature. If snow and ice covered regions expanded over more of North America and Europe, the climate would further cool while also leading to growing ice sheets.

Arrhenius thought his theory was pretty solid, but he wanted to prove it mathematically. So he set about doing a series of grueling calculations that attempted to estimate the temperature response of changing levels of carbon dioxide in the atmosphere. It was a classic 'back of the envelope' calculation, but he was confident enough that he published the work in 1896 for his colleagues to read. The end result of all that work was one simple number: 8°F. That number represented roughly how much Arrhenius thought the Earth's average temperature would drop if the amount of CO_2 in the atmosphere fell by half.

But back in the time of Arrhenius, global warming impacts were mainly left to future investigation—at the time, the majority of scientists still needed to be convinced that the concentration of CO_2 in the atmosphere could vary, even over very long timescales, and that this could affect the climate. Scientists at the time were focused more on trying to understand the gradual shifts that took place over periods a thousand times longer than Arrhenius' estimate, those that accounted for alternating ice ages and warm periods, and in distant times (more than 65 million years ago), the presence of dinosaurs. They couldn't even begin to wrap their minds around climate change on a human time scale, like decades or centuries. Nobody thought there was any reason to worry about Arrhenius's hypothetical future warming that he suggested would be caused by humans and their fossil fuel burning. It was an idea that most experts at the time universally dismissed. Simply put, most scientists of the era believed that humanity was too small and insignificant to influence the climate.

- the chemical fingerprint of human activity

Fast-forward to the mid-1950's and enter Charles David Keeling, a brilliant and passionate scientist who was just beginning his research career at Cal Tech. Keeling had become obsessed with carbon dioxide and wanted to understand what processes affected fluctuations in the amount of CO_2 in the atmosphere. Answering a question like that literally required an instrument that didn't exist, the equivalent of an ultra-accurate 'atmospheric breathalyzer'. So Keeling built his own instrument and then spent months tinkering with it until it was as close to perfect as he could get at measuring the concentration in canisters with a range of values of known concentration. Keeling tried his instrument out by measuring CO_2 concentrations in various locations around California and then comparing these samples in the lab against calibration gases. He began to notice that the samples he took in very pristine locations (i.e., spots where air came in off the Pacific Ocean) all yielded the same number. He suspected that he had identified the baseline concentration of CO_2 in the atmosphere; a clear signal that wasn't being contaminated by emissions from factories or farms or uptake by forests and crops. With this instrument, formally called a *gas chromatograph*, Keeling headed to the Scripps Institution of Oceanography to begin what is perhaps the single most important scientific contribution to the discovery of global warming. Keeling was on a mission to find out, once and for all, if CO_2 levels in the atmosphere were increasing. He would spend the next 50 years carefully tracking CO_2 and building, data point by data point, the finest instrumental record of the CO_2 concentration in the atmosphere, generating a time history that is now known to scientists simply as *the Keeling Curve*.

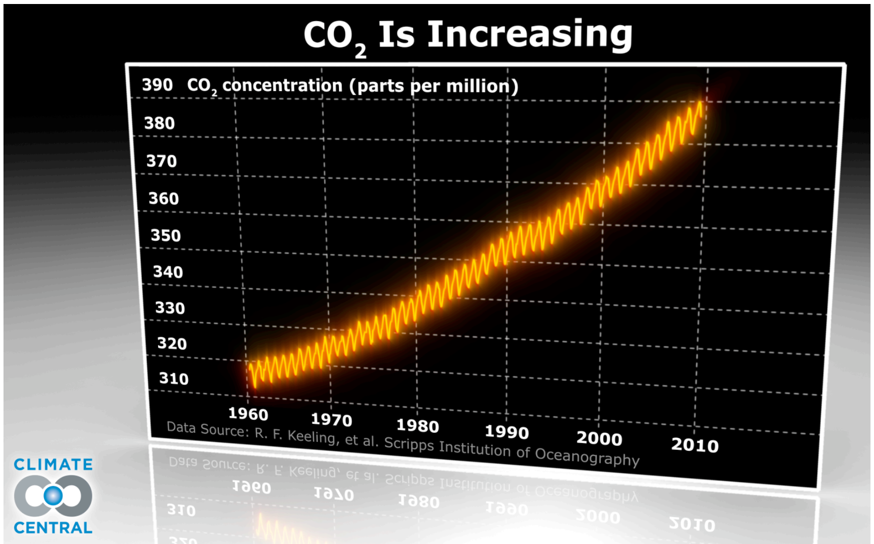

Figure 2: The Keeling Curve

The Keeling Curve refers to a monthly record of atmospheric carbon dioxide levels that begins in 1958 and continues to today. The instrument Keeling built, the gas chromatograph, works by passing infrared light through a sample of air and measuring the amount of infrared light absorbed by the air. Because carbon dioxide is a greenhouse gas, Keeling knew that the more infrared light absorbed by the air, the higher the concentration of CO_2 in the air. Because CO_2 is found in very small concentrations, the gas chromatograph doesn't measure in terms of per cent, which means out of a hundred, but in terms of parts per million (ppm). What he found was both disturbing and fascinating. Keeling, using his Mauna Loa measurements, could see that with each passing year CO_2 levels were steadily moving upward. In 2010, more than fifty years after Keeling began his observations, the concentration at Mauna Loa is 390 ppm. Keeling's measurements thus provided solid evidence that the atmospheric CO_2 concentration was increasing. If anything proved Arrhenius was on to something, it was these data. Keeling's record was the icing on the cake and he rightly stands with Fourier, Tyndall, and Arrhenius as one of the giants of climate science. He helped prove the importance of the greenhouse effect and the reality of global warming. He provided the data upon which the groundbreaking theories of Tyndall and Arrhenius firmly rest. As is the case in research science, Keeling's painstaking measurements have been verified and supplemented by many others. Measurements at about 100 other sites have confirmed the long-term trend shown by the Keeling Curve.

Keeling established that carbon dioxide was rising in the atmosphere. The next step was to find the smoking gun, and see what or who was causing the increase. In order to put Arrhenius's theory to rest once and for all, scientists were looking to identify the source of all that additional carbon dioxide. And they came up with some very clever ways to identify this smoking gun.

Just as we come into this world with our own unique set of fingerprints, so too does carbon. Carbon enters the atmosphere from a lot of different places, places that stamp each molecule of carbon dioxide and send it off into the atmosphere with a unique fingerprint. Volcanoes emit CO_2 into the atmosphere when they erupt, the soil and oceans release CO_2 into the atmosphere, and plants and trees give off carbon dioxide when they are cut or burned. Burning coal, oil and natural gas are all sources that release carbon into the atmosphere to forms carbon dioxide. The average person, in fact, breathes out about two pounds of carbon dioxide every day. When you have the right tools, distinguishing where an individual molecule of CO_2 comes from is not that hard. As with many other important advances in the fields of climate and weather, this fingerprint device was an outgrowth of military activity.

Carbon, like virtually all of the chemical elements, come in different varieties known as isotopes, distinguished by the number of neutrons in their atomic cores. Carbon dioxide can be made from all of the isotopes of carbon — but not all sources of CO_2 have the same types of carbon atoms in them. In addition to carbon-14, there is carbon-12, which is the most common form of carbon, as well as carbon-13, which makes up only about 1 in every 100 carbon atoms. Carbon-14, the radioactive one, is even more rare, with only one carbon-14 isotope for every trillion carbon atoms in the atmosphere. Scientists can use these isotopes to fingerprint the origin of the carbon. You can literally trace where the CO_2 in the atmosphere originated by measuring the amount of different carbon isotopes. It's like a tracing a bullet back to the gun from which it was shot.

All living organisms are built out of carbon atoms. Coal, oil and natural gas are ancient. In fact, they are called 'fossil fuels' because coal, oil and natural gas come from plants and marine organisms that lived roughly 200-300 million years ago. Fossil fuels such as coal, oil and natural gas, for example, have no carbon-14, and neither does the CO_2 that comes from burning them. A small fraction of the CO_2 molecules that enter the atmosphere through natural means such as the decay of plants, on the other hand, does contain carbon-14. Because they have extra neutrons, atoms of carbon-14 are more massive than atoms of carbon-12, and so are the CO_2 molecules they are made of. Instruments called mass spectrometers measure that difference. Based on how much of the heavier CO_2 they measure in samples of atmosphere, scientists calculate that about a quarter of the CO_2 present today must come from fossil fuels. From the perspective of a molecule of carbon dioxide, that means roughly one out of every four CO_2 molecules in the atmosphere today, was put there by us. That conclusion is confirmed by the fact that this fraction amounts to most of the growth in CO_2 over the last 250 years, when fossil-fuel burning has really taken off. It is this increase in CO_2 concentrations that is primarily responsible for the increase in global average temperatures over the past century, and especially in recent decades. So while it's true that most of the carbon dioxide in the atmosphere today comes from natural sources, most of the *additional* CO_2 that's been placed in the atmosphere over the last 250 years comes from us.

- the causes and production of anthropogenic greenhouse gases

From 1000 A.D. to about 1750 AD, carbon dioxide levels in the atmosphere hovered between 275 and 285 parts per million (ppm), and then began to increase. Initially, the increase was largely due to the burning of coal, which was the primary energy source for the Industrial Revolution, and whose exhaust products when burned include CO_2. Since then, the other major fossil fuels, oil and natural gas, have also become sources of growth in CO_2 levels. The latest IPCC report presents statistics over the years since 1970, which are indicative of the historical proportion that fossil fuel burning occupies in the sources of CO_2. The percentage of emissions from solid, liquid and gas fuels represents about a 70% fraction of CO_2 emissions and has seen its share increasing during this period.

But other factors contribute as well. For example, the widespread cutting down of forests can add CO_2 to the atmosphere if the trees are burned; like fossil fuels, they release this greenhouse gas as well. If the trees are left to rot, that too releases CO_2, albeit more slowly. And because living trees absorb CO_2 in the process of photosynthesis, the cutting of forests eliminates a source of CO_2 removal, so the gas builds up more quickly than it otherwise might. The same estimates from the IPCC quantify deforestation and land-use change emissions as about 22% of CO_2 emissions.

Some manufacturing processes add CO_2 to the atmosphere as well. The manufacture of cement is one; it does not just require energy, which often comes from fossil-fuels, but the chemical reactions involved in its manufacture release large amounts of the gas as well. All in all cement production has occupied a 3% share of CO_2 emissions. All this said, fossil fuel burning remains the predominant source of the historical increase in atmospheric CO_2 concentrations that added about 100 ppm (36%) over the last 250 years to the CO_2 levels of the pre-industrial era.

- the expected impacts on the climate

Data collected over the past 50 years point to the fact that our weather is getting more extreme. But trying to isolate the fingerprint of global warming within the weather is much harder than isolating the fingerprint of global warming within the climate system. That doesn't mean it's not there; it just means seeing climate change in the weather is a much noisier, more chaotic and more complicated process. Statistical analyses can help us see the story buried beneath the noise. And climate scientists have come up with some very clever variations on using a slow motion instant replay of the weather to help them see how the statistics of extreme events are changing.

It turns out that you can use climate models as an "instant replay" to recreate a specific weather event. Think of it like doing an autopsy, except it's being performed on a specific extreme weather event. The European heat wave of 2003, an extreme weather event that killed over 35,000 people, offers the best example of how climate models can help us see the global warming embedded within our weather.

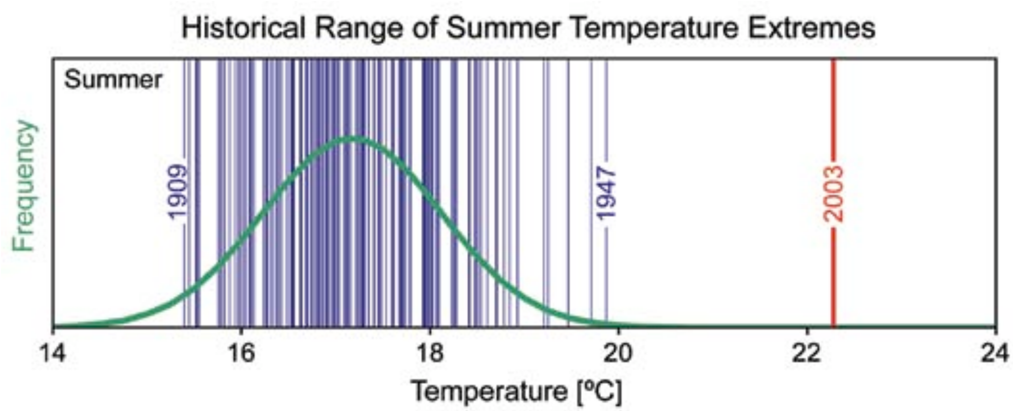

Figure 3: Each vertical line represents the mean summer temperature for a single year from the average of four stations in Switzerland over the period 1864 through 2003. Extreme values from the years 1909, 1947, and 2003 identified. Source: From Schär *et al.*, 2004.

When you step back and compare the summer of 2003 with summers past, it becomes even more obvious. As you can see in Figure 3, there are a series of vertical lines that almost look like a bar code. Each vertical line represents the mean summer temperature for a single year from the average of four stations in Switzerland over the period 1864 through 2003. Until the summer of 2003, the years 1909 and 1947 stood out at the edges as the most extreme temperatures in terms of hot and cold summers. Climate scientists estimate the summer of 2003 was probably the hottest in Europe since at least AD 1500.

If climate is what you expect and weather is what you get, then the summer of 2003 in Europe was way outside the envelope of what anyone would have expected. Statistically speaking, in a natural climate system with no man-made CO_2 emissions, the chance of getting a summer as hot as 2003 would have been around once every thousand years or one in a thousand.

The point of this weather autopsy isn't so much whether the 2003 heat wave was caused solely by global warming. Indeed, almost any weather event can occur on its own by chance in an unmodified climate. But using climate models, it is possible to work out how much human activities may have increased the risk of the occurrence of such a heat wave. It's like smoking and lung cancer. People who don't smoke can still get the disease, but smoking one pack of cigarettes a day for 20 years increases your chances of developing lung cancer 20-fold. Thanks to some sophisticated climate models and well-honed statistical techniques, scientists can identify the push that global warming is giving the weather.

This weather autopsy showed that human influences had at least doubled the very rare chance of summers as hot as the one Europe experienced in 2003. More specifically, climate models showed that greenhouse gas emissions had contributed to an increase in 2003-style summers–moving from a one in a thousand years to at least once in every 500 years and possibly as high as once in every 250 years. What is perhaps the most shocking is what happens when you run the models in forecast mode instead of autopsy mode. If the summer of 2003 had been a freak event of nature, we could just chalk it up to the luck of the draw. But according to the model predictions, by the 2040's, the 2003-type summers will be happening every other year. And by the end of this century, people will look back wistfully upon the summer of 2003 as a time when summers were much colder.

Figure 4: Land Vulnerability to Rising Sea Level.

Scientists now believe that the Earth could warm up by more 7ºF, on average, by the end of the century, if emissions of greenhouse gases continue to grow at current rates. That's significant enough to trigger all sorts of big changes in the environment. To start with, scientists expect sea level to rise by three feet or more—partly because water expands as it warms, partly due to melting ice in Greenland and other places. Low-lying areas—including significant parts of states like Florida, and entire countries like Bangladesh and the Maldive Islands will be much more prone to erosion and to catastrophic flooding from storm surges. The warming could also make the most powerful of tropical storms even more powerful. And rainstorms in general are likely to become more intense, with more of them causing damaging floods.

As mountain glaciers melt, they'll cause even more flooding—at first. But if they shrink enough, the fresh water they provide will become scarce. Billions of people in India and China, for example, depend on water that comes off glaciers in the Himalayas and the Tibetan Plateau. In the U.S., warmer winters and spring will induce earlier snowmelt in the Rocky and Sierra Nevada mountains. That means less meltwater for a thirsty California, especially during the summer when water is really needed.

In already arid regions (Australia and the American West are just two examples) droughts are likely to come more often and be more severe, and they could last longer. That's likely to lead to more wildfires. Heat waves will be more frequent too, not just in deserts but in temperate zones, including most of the continental U.S.

All of these changes will have an impact on people, our physical safety and our ability to grow food and get water. But climate change could have an even greater impact on the survival of some species. Plants and animals thrive in certain specific climate conditions. They cannot easily adapt to the changes that have already begun. The trees that produce Vermont maple syrup, for example, may have trouble surviving in Vermont as the New England climate changes, and Georgia may lose its population of Brown Thrashers—the state bird. Not all of the changes will happen on land. The warming of the oceans has already contributed to a worldwide die-off in coral reefs, which is expected to accelerate as temperatures continue to rise. Corals are home to a wide variety of sea-dwelling creatures, so when they go, many other species could be in big trouble.

	+ 1–2° F	+ 3–5° F	+ 6–7° F
Coral Reef Bleaching	Coral bleaching events in about 1/6 of the world's reefs	Most coral reefs bleached world wide	Widespread coral mortality
Biological Extinctions	Amphibian extinctions 	20–30% of species extinct 	Extinction of up to 40% of species 
Coastal Impacts	Increased damage from floods and storms	Millions more people could experience coastal flooding each year	Greater than 30% of global coastal wetlands lost
	2010	2030–2060	2070–2100

Figure 5: As temperatures increase, so will the damage.

Conclusion

When I worked at The Weather Channel, I was constantly awestruck by the extent to which people rallied around a weather forecast. Whether it was sandbagging in advance of the Red River flood, or evacuating in advance of Hurricane Gustav. There's something so inspiring about the way communities can pull together under these extremely challenging circumstances. We're clearly pretty good at processing the risks associated with extreme weather, which is why it's so important for people to understand that their weather is their climate. As such climate and global warming need to be built into our daily weather forecasts because by connecting climate and weather we can begin to work on our long-term memory and relate it to what's outside our window today. If climate is cold statistics, weather is personal experience. We need to reconnect them.

The weather forecast is so engrained in our existence that we know very well how to make it actionable. If we hear on the radio in the morning that it's going to rain, we bring an umbrella. If we hear that the temperature is going to be unseasonably cool, then we pack a sweater. By definition, weather is a timescale we can't stop. With a weather forecast, we're strictly working on our defense. However, with the climate forecast, the necessary actions are not as straightforward, and this highlights some of the basic philosophical differences between weather and climate. I've come to view long-range climate projections as an "anti-forecast" in the sense that it's a forecast you want to prevent from happening. Until now, we've been able to view extreme weather like flooding as an act of God. But the science tells us that due to climate change these floods will happen more often and we need to be prepared for them. I say that a climate forecast is an "anti-forecast" because it is in our power to prevent it from happening. It represents only a *possible* future, if we continue to burn fossil fuels *business as usual*. The future is ultimately in our hands. And the urgency is that the longer we wait, the further down the pipeline climate travels and works its way into weather, and once it's in the weather, it's there for good.

We are currently in a race against our own ability to intuitively trust what the science is telling us, assess the risks of global warming, and predict future impacts. So when we look at a climate forecast out to 2100 and see significantly warmer temperatures (both average and extreme) and sea level three feet higher, we need to assess the risk as well as the different solutions necessary to prevent it from happening. The challenge is to reduce greenhouse gas emissions, replace our energy infrastructure and adapt to the warming already in the pipeline.

Thank you for affording me this opportunity to share with you this brief history of climate change. I would be pleased to address any questions you might wish to raise.