Global Warming:

Could Scientists Be Wrong?

By James Lawrence Powell

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Scientists Have Been Wrong Before.
Could They Be Wrong Today about Global Warming?

Half the American public and a majority of U.S. Congressional Republicans believe scientists are wrong about global warming.[1] But if scientists are right, global warming threatens the future of our grandchildren, generations beyond, and possibly even human civilization itself.

With so much potentially at stake, every parent, every voter, every person of conscience needs to weigh the odds that scientists could be wrong about global warming.

But how to assess those odds? One way is to study cases in which scientists have erred in the past. That will reveal how scientists have gone wrong before and allow us to judge whether they could be wrong today about global warming.

I identify four ways in which scientists collectively have been wrong, as well as a fifth possibility of which some accuse them. I call these:

1. The Surprise
2. The False Assumption
3. The Obsolete Paradigm
4. The Error
5. The Conspiracy

After reviewing these five, we will examine some of the evidence that convinces scientists that they are *not* wrong about global warming. We will test the reliability of the computerized climate models that scientists use to project into the future. Finally we will assess whether, as many people believe, scientists substantially disagree about global warming. If they do, then at least some scientists must be wrong.

1. The Surprise

Sometimes a single unexpected discovery can reveal that the ruling paradigm of a field of science—the prevailing theory that everyone in the field accepts—is wrong. The "surprise" is one way in which scientists could turn out to be wrong about global warming.

One of the most momentous surprises in the history of science occurred in 1895 while German physicist Wilhelm Röntgen was investigating rays emitted when he applied a voltage to the electrodes in an evacuated tube. Röntgen was astonished to find that when he turned off the lights in his laboratory, a nearby paper plate, which he had coated with barium, began to glow eerily. Somehow the invisible rays emanating from the tube were exciting the barium atoms. Röntgen immediately switched his research to these X-rays, as he named them. Soon he had taken an X-ray image of his wife's hand, the very first. When she saw her skeleton, she cried,[2] "I have seen my death!"

In 1896, French chemist Henri Becquerel uncovered a surprise of his own. Following up Röntgen's discovery, he was studying minerals that "phosphoresce": that glow after the

light source is removed, like glow-in-the-dark toys or an old watch dial. Becquerel thought that sunlight might cause the minerals to emit X-rays, which showed up as the phosphorescence. Then he happened to place a phosphorescing mineral and a photographic plate in a laboratory drawer where no light could reach them. When he opened the drawer, to his amazement he found an image of the mineral on the photographic plate. Becquerel realized that phosphorescent minerals must spontaneously emit their own distinctive rays, which had exposed the plate. The phenomenon came to be named radioactivity. From that followed the discovery of the neutron, the proton, nuclear fission, and the chain reaction. These led to the atomic bomb and a world forever changed.

Though some refer to such unexpected discoveries as “accidents,” these two examples show that to be the wrong word. A better one is “serendipity”: a “fortunate happenstance.” Röntgen and Becquerel were not stumbling around, they were conducting controlled experiments. Then each found something unexpected, something that did not seem to fit. Instead of shrugging their shoulders and ignoring the surprising discovery, they began to investigate it, proving Pasteur right when he said, “Chance favors the prepared mind.”

Now let us look in more detail at how the discovery of radioactivity overthrew the ruling paradigm for the age of the earth.

During the second half of the 19th century, nearly all scientists accepted the calculation by the world’s most famous and accomplished physicist, Lord Kelvin, that the Earth is no more than 100 million years old. In arriving at this figure, Kelvin made two assumptions. First, he subscribed to the nebular hypothesis for the origin of the solar system, which held that the Earth was born hot and has been cooling ever since. Second, as he acknowledged, Kelvin assumed that the Earth has no source of heat other than that left over from its fiery beginning. These two assumptions allowed Kelvin to use Joseph Fourier’s mathematical treatment of heat flow to calculate back to the start of the process, which he equated with the age of the Earth.

Becquerel’s PhD student was a Polish chemist named (after her marriage) Marie Curie. She chose radioactivity, a name that she and her husband Pierre coined, as her thesis topic. Soon she and Pierre had discovered two new radioactive elements, polonium and radium. Madame Curie was the first woman to win a Nobel Prize and the first person to win in two different fields of science. All told, the Curie family won five Nobel Prizes.

Pierre Curie discovered that each radioactive decay event releases a tiny amount of heat. But since the Earth has innumerable radioactive atoms, each releasing heat, Kelvin’s second assumption—that the Earth has no internal heat source—was shown to be wrong. His calculation, which he spent most of his long career perfecting, gave a meaningless result. But in another example of serendipity, radioactivity turned out to provide a precise method for calculating the Earth’s age. Today we know it to be 4.5 billion years, 45 times Kelvin’s estimate.

How likely is it that some new effect, some surprise, could turn up to invalidate the science of global warming? No one can say it is impossible, but given all the advances in science since the days of Becquerel and the Curies, the likelihood of some new physical process like radioactivity being discovered is too small to depend on. Instead, if there

were some startling new discovery that would offset or eliminate global warming, it would likely come in the form of a new or enhanced negative climate feedback.

Sunlight passes through the Earth's atmosphere relatively unimpeded to strike the surface, where the energy is absorbed and re-emitted as heat rays. The heat rays rise back into the atmosphere and interact with gases, mainly water vapor and carbon dioxide. The gases absorb the rising radiation and re-emit it in all directions, some of it going downward to warm the surface. This we call the greenhouse effect. The term is not quite right, for the glass in a greenhouse physically blocks the heat from escaping, whereas rising heat rays interact with gas molecules in the atmosphere. But greenhouse effect and greenhouse gases have become useful nicknames.

Today we know that if the amount of carbon dioxide in the atmosphere were to double, the direct result of the greenhouse effect would be to increase surface temperature by about 1°C (1.8°F). But indirect effects, or feedbacks, would also result and here enters the possibility of a surprise.

A feedback loop occurs when something changes, which causes a change in a second something, which causes a corresponding change in the first something. Feedbacks can be positive (amplifying) or negative. To take a mundane example of a negative feedback, consider the float valve in your toilet bowl. As the tank fills with water, the float rises and gradually closes a valve so that less and less water is admitted. When the water gets to the desired level, the float shuts the input valve. This is a negative feedback: the change in the second quantity (water level) reduces the change in the first quantity (water input) until, in this example, it shuts off the first quantity entirely. Understandably, scientists have been looking for negative climate feedbacks that would offset global warming for a long time, but unfortunately for humanity, with little to show for it.

The ice-water feedback is one of the most important positive (amplifying) feedbacks. Ice reflects most incoming sunlight, while ocean water absorbs most of it. As rising temperature melts sea ice, less sunlight is reflected and more is absorbed, causing the temperature of the water to rise further, which melts more ice, and so on. A similar feedback begins when reflective snow melts to expose unreflective, heat-absorbing soil. Thawing permafrost—soil and vegetation below the freezing point of water—also produces a positive feedback. As the temperature rises, permafrost releases not only carbon dioxide, but stored methane, a greenhouse gas 20 times more potent than carbon dioxide. That induces more greenhouse warming, which thaws more permafrost, and so on. These feedbacks are the reason Arctic temperature has risen twice as fast as global temperature overall, with a resulting loss of Arctic sea ice. These three are examples of the so-named slow feedbacks, which operate on a long time scale.

The ice-water feedback is positive, but there is a possibility that melting sea ice might also lead to a negative feedback. As open seawater replaces melting ice, the greater surface area of water could lead to more evaporation and more clouds. If clouds have a net cooling effect, they would tend to offset the warming that led to their formation. This is speculation at the moment, but does suggest what a negative climate feedback could be like.

One of the earliest attempts to locate a significant negative feedback came with the work of a committee of the National Academy of Sciences in 1979, convened to review the results of computer models of the Earth's climate. Known as the Charney Report for its lead author, Jule Charney of MIT, the report concluded, "We have tried but have been unable to find any overlooked or underestimated physical effects that could reduce the currently estimated global warmings [sic] due to a doubling of atmospheric carbon dioxide to negligible proportions or reverse them altogether."

The Charney committee estimated that the overall "climate sensitivity"—the temperature rise that would result from doubling the amount of carbon dioxide in the atmosphere, including all the feedbacks—was about 3.0°C (5.4°F). Since as just mentioned the direct effect without feedbacks is 1°C, the net effect of the feedbacks is to raise climate sensitivity by about +2°C, which means that positive feedbacks dominate.

Another way to gauge the effects of climate feedbacks is to look at the record of actual temperature increases. The chart below shows that global temperature has risen by about 1°C (1.8°F) since the Industrial Revolution. This rise must be the result of all the factors, natural and manmade, positive and negative, that affect global temperature whether scientists can identify those factors or not. This is our reality check. Again we see that whatever negative climate feedbacks exist, they have not been enough to outweigh the positive feedbacks and prevent temperature from rising.

But that might not always remain true. It could be that as the Earth warms, some new feedback will appear that was too weak to matter at lower temperatures. The known feedbacks might strengthen or weaken, or interact with each other in unanticipated ways. But there is no reason to assume that these unpredictable developments would lower global temperature: they might have just the opposite effect and raise it even more.

Thus, while no one can say that a surprising new or strengthened negative feedback is impossible, to pin our hopes on it would be foolish.

2. The False Assumption

As noted, Kelvin's other assumption, shared by nearly every scientist of his day, was that the nebular hypothesis explained the origin of the solar system. The idea originated with philosopher Immanuel Kant and was developed most fully by Pierre-Simon Laplace in a 1796 treatise. They postulated that a colossal cloud of hot cosmic gas and dust, the nebula, had collapsed upon itself due to gravitational forces on its constituent particles. As the nebula shrank, to conserve momentum it had to spin more rapidly, as does a figure skater who gradually pulls in her arms and a leg. As the nebula spun faster and faster, local regions of greater condensation separated and coagulated to become the hot protoplanets. Left over bits became the moons, comets, and asteroids. The assumption of a hot ball gradually cooling was the key that allowed Kelvin to calculate the age of the Earth.

In the nebular hypothesis, a colossal, rapidly spinning Sun will wind up with most of the angular momentum of the solar system—what we might think of as the spin energy—and the tiny-by-comparison planets will have much less. But the Sun turns out to have only 1 percent of the angular momentum and the planets the other 99 percent--exactly

backwards. This fatal flaw required scientists to modify the nebular hypothesis so that it no longer included planets that had originally been hot. The failure of the nebular hypothesis thus on its own invalidated Kelvin's assumptions and his methodology. The discovery of radioactive heat made it a double whammy.

Another famous example of a false assumption was the widespread nineteenth-century belief that an aether, or ether, fills space. In order for gravity and light to propagate, it seemed logical that something must carry them, some invisible medium that occupies space. The famous Michelson-Morley experiment showed that the ether does not exist, putting scientists on the track to discover general relativity and quantum theory.

Could global warming also depend on one or more assumptions that might prove false? To start to answer, look first at the key data that underpin global warming, summarized in *The Chart* below from the Arctic Climate Impact Assessment. Published in 2004, were we to re-plot it today *The Chart* would look the same except that each frame would reach higher. Carbon dioxide emissions from energy consumption rose 20 percent between 2004 and 2012, the last year for which data are available. In March 2015, monthly atmospheric carbon dioxide concentration topped 400 ppm for the first time. In 2014, global temperature set a new record.

The Chart presents the key data for global warming in one view. Anyone who claims to have the answer to whether global warming is true or false must be able to explain it.

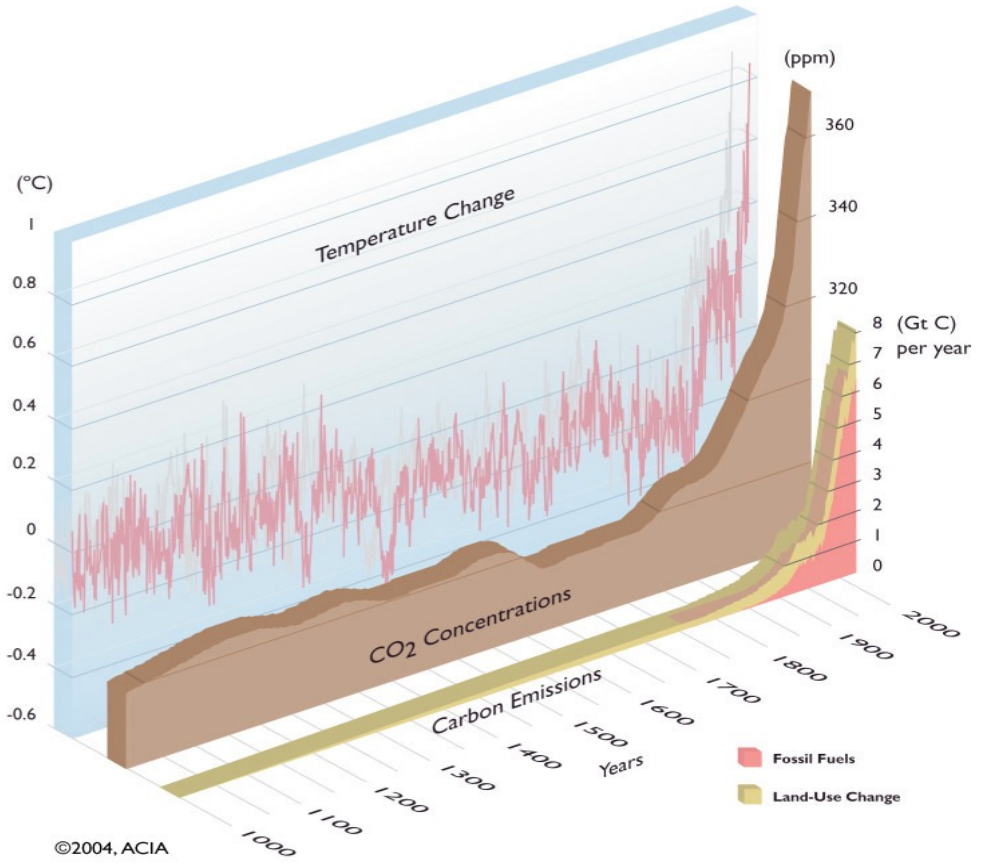


Figure 1: The Chart

The frames show how three quantities have risen roughly in parallel since the year 1000: (1) carbon emissions from fossil fuel combustion and land use changes, (2) atmospheric carbon dioxide concentration, and (3) global temperature.

But how do scientists get their information from hundreds of years in the past, before there were modern instruments like thermometers? We know that global fossil fuel combustion was tiny before the Industrial Revolution and we have increasingly accurate data on how much coal, oil, and natural gas humans have burned as we approach the present. The information on atmospheric carbon dioxide concentration prior to the 1950s comes from air bubbles trapped in ice cores, and after that from direct measurement. The temperature data before the 1870s come from the oxygen isotope thermometer in the same air bubbles, as well as from measurement of the width of tree rings and from other proxies. Since the 1870s, temperatures have been directly measured.

In other words, the three frames, though they are less accurate the farther back you go, represent not assumptions but known facts. If global warming were to depend on assumptions, they would have to reside in the causal connections between the three frames: (1) that the rise in emissions caused the rise in carbon dioxide and (2) that the

rise in carbon dioxide caused the rise in temperature. Are these assumptions, or facts? Let us take them in order.

Carbon Emissions and Carbon Dioxide Concentration

The Chart shows how fossil fuel emissions and carbon dioxide concentration have risen together, suggesting cause and effect. But as scientists like to say, "correlation is not causation." In this case, however, we know that there is an underlying causal connection: that burning a ton of coal or a tankful of gasoline converts the carbon they contain into carbon dioxide, a gas that rises into the atmosphere. So there is a prima facie case that rising fossil fuel emissions caused the rising carbon dioxide concentration. But can we prove it?

Carbon has three varieties, or isotopes: C12, C13, and C14. Plants have a distinctive ratio of C12/C13 that scientists use to fingerprint carbon from a plant source. That is how drug testers catch athletes who dope with synthetic testosterone, which comes from plants and has a different carbon isotope ratio than the carbon normally in our bodies. Fossil fuels like coal, natural gas, and oil also come from plants, so they too have the distinctive carbon isotope ratio of plants. As shown on the chart below, as global carbon emissions from fossil fuels (black line) have risen, the carbon isotope ratio of the atmosphere (red line) has shifted steadily in the direction of plant carbon. Thus the carbon added to the atmosphere has come from plants.

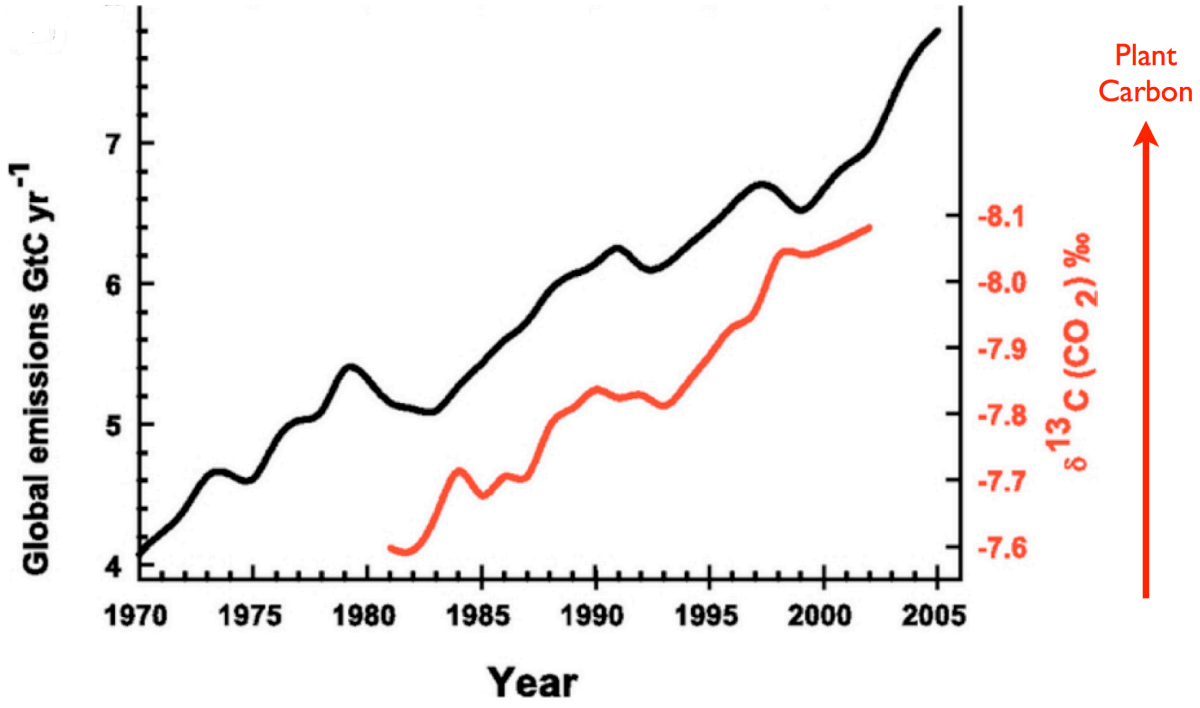


Figure 2. As fossil fuel emissions have risen, so has the proportion of plant carbon.

That does not settle the matter, for there is an abundant source of plant carbon: modern forests. Could the added carbon have come from deforestation, which also releases carbon? To answer we need to consider the third isotope of carbon: C14.

Carbon-14 is radioactive and dies away to undetectable levels in 50,000 years or so. It is the basis for the radiocarbon method of age dating, used to measure the ages of human artifacts, Ice Age mammals, and the like. But being millions of years old, fossil fuels have no C14 left. If the carbon added to the atmosphere has come from ancient plants, the process should have lowered the proportion of C14 in the atmosphere.

This next chart comes from measurements of C14 in tree rings. It shows how the relative abundance of C14 ($\Delta^{14}C$) in the atmosphere was declining with the advance of the Industrial Revolution until about 1950, when it suddenly shot up. The reason is that C14 is a byproduct of atomic bomb explosions.

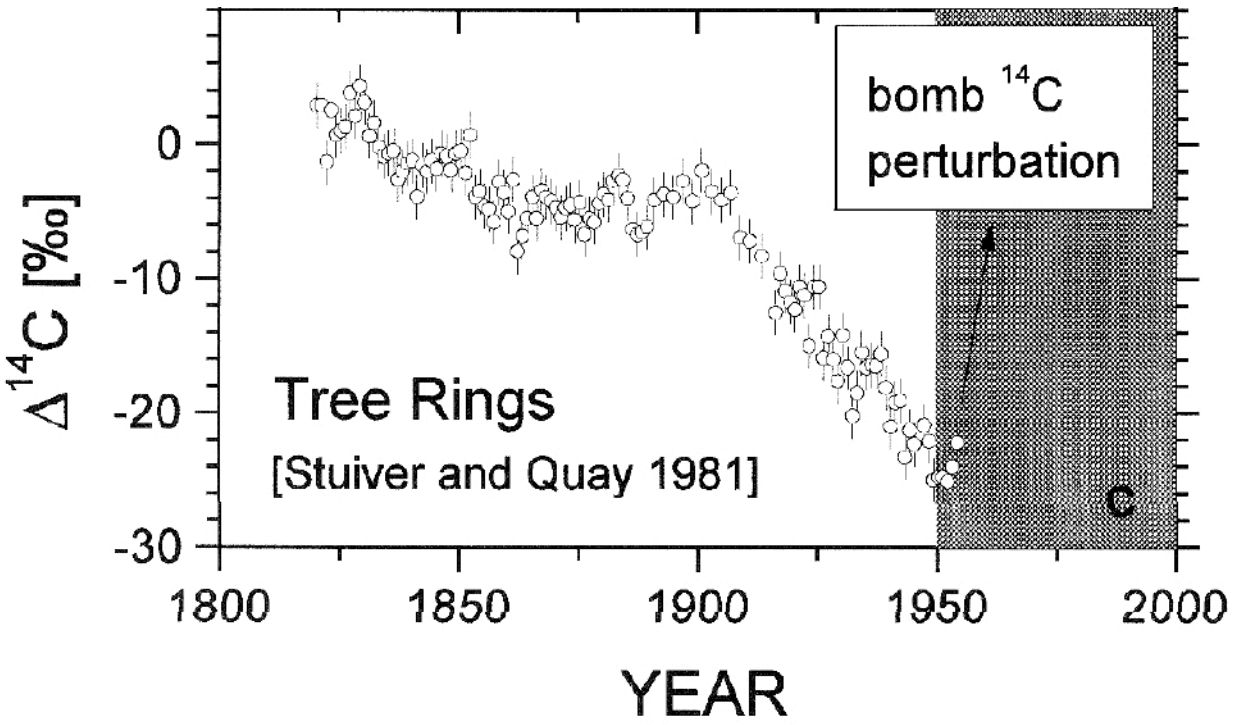


Figure 3. The proportion of C14 in the atmosphere was declining until atomic bomb tests began.

The next chart picks up the story after 1950. C14 continued to build until the ban on above-ground atomic bomb tests went into effect in the 1960s. Then C14 resumed its decline.

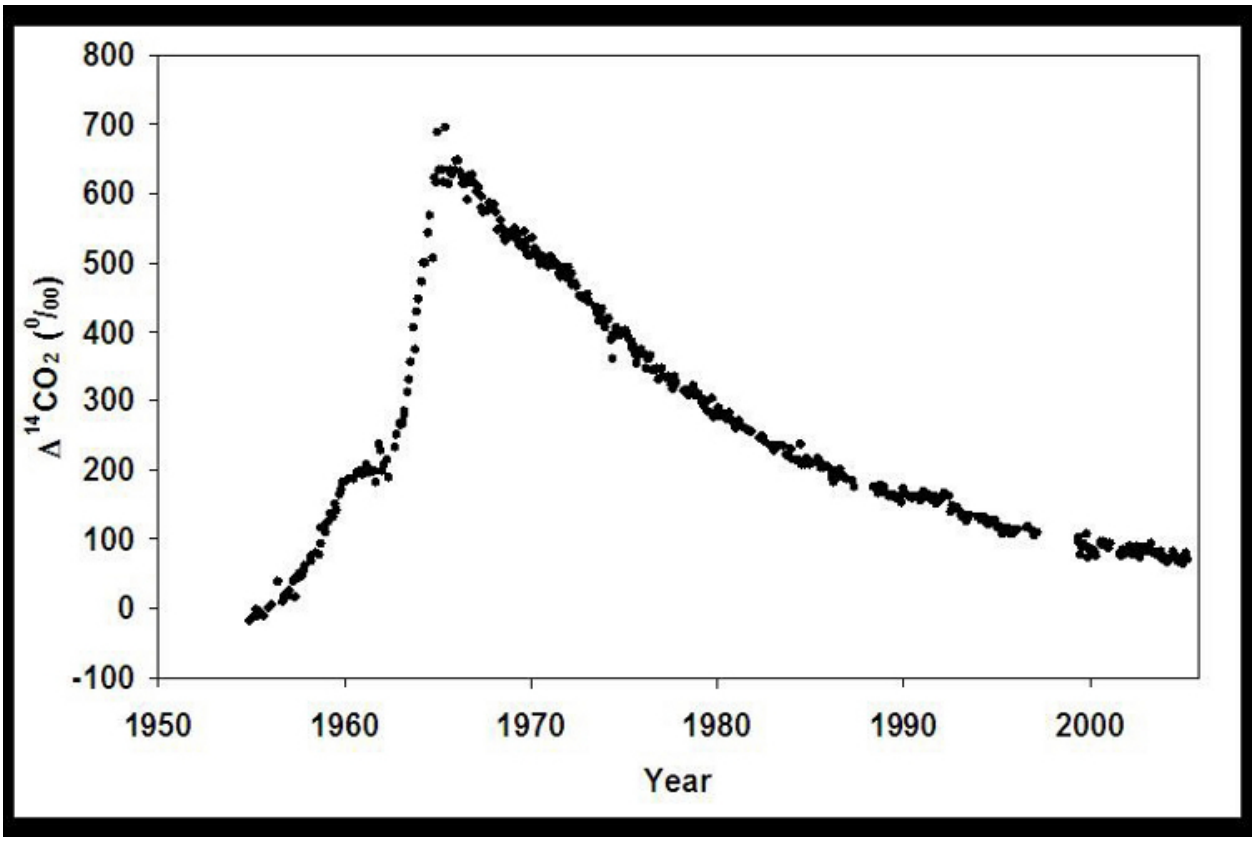


Figure 4. Once bomb testing ended in the 1960s, C14 resumed its decline

When we mentally remove the C14 from bomb tests, we can see that as carbon emissions have risen, the proportion of C14 has fallen. That means that not just plant carbon, but ancient plant carbon, has been added to the atmosphere. The only known source of the vast amounts of ancient plant carbon required is fossil fuel combustion. Thus the carbon isotopes show that the causal connection between fossil fuel combustion and atmospheric carbon dioxide concentration is not an assumption, but a known fact.

Carbon Dioxide and Temperature

Now let us turn to the second potentially faulty assumption: that the carbon dioxide rise caused the temperature rise. Just as we know that burning carbon produces carbon dioxide, so it has been known since the 1860s that carbon dioxide molecules trap heat and redirect some of it back down to the surface. This is the greenhouse effect that we just discussed. A number of studies of radiation show that the greenhouse effect is operating as expected, but can we make a direct connection?

The very idea behind greenhouse warming is that as the amount of carbon dioxide in the atmosphere rises, so will the amount of heat radiation reaching the surface. Using instruments at two Department of Energy facilities, a team of scientists from the Lawrence Berkeley National Laboratory has for the first time directly measured the increase in greenhouse radiation and matched it with the rise in carbon dioxide. The period studied was from 2000 to 2010, during which atmosphere carbon dioxide rose by 22 parts per million (ppm). In the charts below, you can see how as carbon dioxide

concentration (blue) rose and fell at the two sites with the seasonal waxing and waning of photosynthesis and plant growth, the amount of heat radiation reaching the Earth's surface (red) immediately followed, exactly as the greenhouse effect predicts. (You can see a video here.) Therefore that the rise in carbon dioxide caused the temperature rise is not an assumption, but a known fact.3

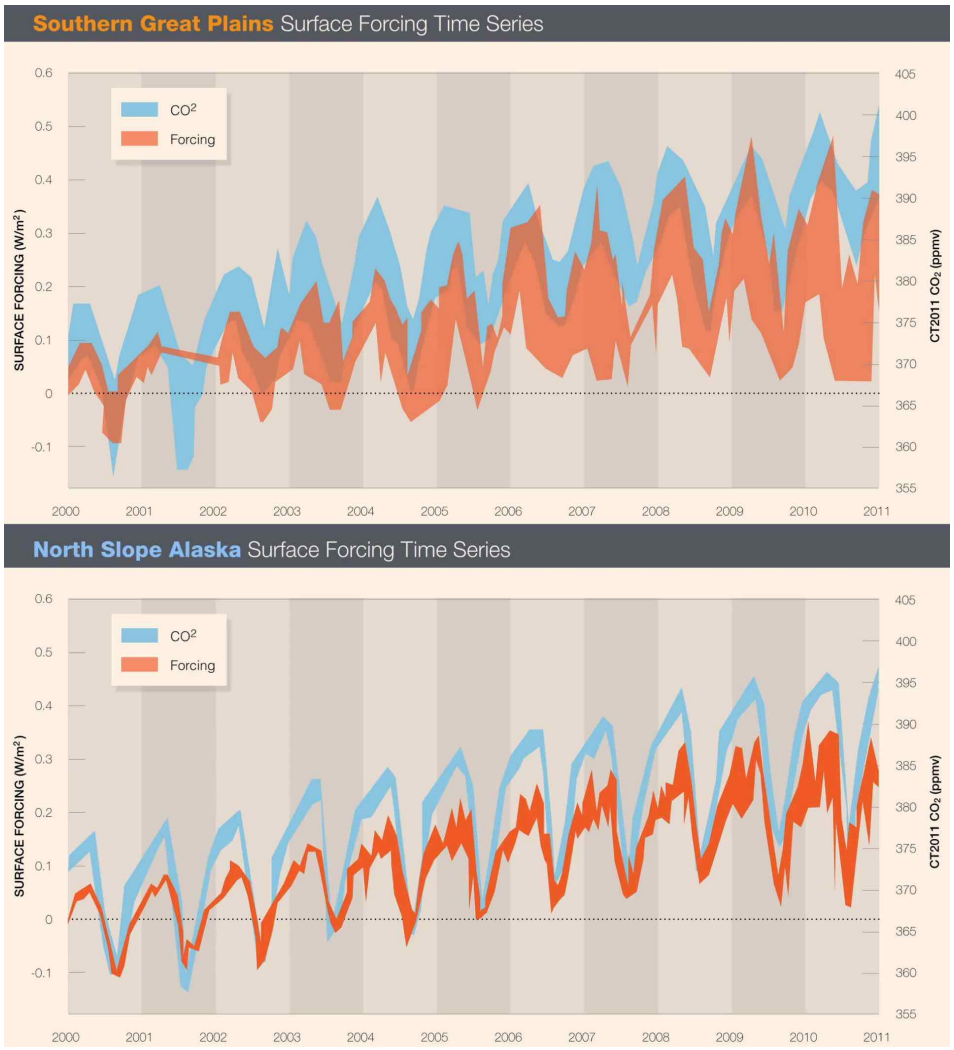


Figure 5. The greenhouse effect in action.

Thus the two connections between the three frames on *The Chart* are rigorous scientific facts. Today we often hear people say that they now accept that global temperature is rising, but they do not believe that humans are the cause. But as the carbon isotopes in particular show, humans *are* the cause. From this settled scientific fact there is no escape.

3. The Obsolete Paradigm

Like the rest of us, scientists have sometimes clung for too long to an outmoded idea. As the great physicist Max Planck observed,

> An important scientific innovation rarely makes its way by gradually winning over and converting its opponents….What does happen is that its opponents gradually die out and that the growing generation is familiar with the idea from the beginning.

During the first half of the twentieth century, geologists were slow to accept continental drift and the idea that meteorite impact caused lunar and terrestrial craters. One reason was that they believed both theories contradicted a founding principle of geology: uniformitarianism. In this view, geologic changes take place not through catastrophes like colliding continents and crashing comets and asteroids, but through the steady, slow processes that we see operating around us every day. Geologists believed that to accept continental drift or meteorite impact was to give up uniformitarianism, which they were unwilling to do. Then in the 1960s came irrefutable evidence for continental drift from paleomagnetism. Photographs from the first successful Ranger mission to the Moon in 1964 showed that virtually all lunar craters are meteoritic. All but a few senior holdouts soon changed their minds about the two theories.

Could climate scientists today be clinging to global warming when they should be rejecting it in favor of some better theory? No. There is no other theory that can explain the observational facts shown in *The Chart*. All the hullaballoo masks the fact that those who say that global warming is false have no better theory, or any theory, to replace it. The one possibility, that changes in the Sun's output have caused global warming, fails because while global temperature has risen, the Sun's output has not.

4. The Error

Global warming is one theory about which scientists were "wrong before they were right." In 1896, Swedish scientist Svante Arrhenius calculated that doubling atmospheric carbon dioxide concentration would cause temperature to rise by several degrees. At first, other scientists acclaimed his discovery. Then in 1900 Kurt Ångström conducted experiments that seemed to show that the carbon dioxide in the atmosphere is already absorbing all the heat radiation that it is capable of absorbing, so that adding more carbon dioxide would not cause more absorption and more warming. The authorities of meteorology embraced Ångström's finding and almost to a person turned against Arrhenius's "carbon dioxide theory." Not until the 1960s did a new generation of climate scientists come to accept it.

Several other factors worked against the acceptance of Arrhenius's theory. At the time he wrote, coal consumption was a minuscule fraction of what it is today and the oil age had not begun. Arrhenius thought it might take as long as three thousand years for coal consumption to cause carbon dioxide to double. Many scientists believed that the oceans would soak up enough of any excess carbon dioxide to keep temperatures from rising. Scientists did not even know how much carbon dioxide the atmosphere held, so they could not tell if it was rising or falling. Moreover, although global temperature did rise from the 1920s until the 1940s, it then began to fall even though fossil fuel emissions climbed.

Two scientists in the 1930s, in separate papers, demonstrated that Ångström's result had been misinterpreted—that the atmosphere cannot be saturated to carbon dioxide absorption. That should have re-opened the door to Arrhenius's theory, but climate scientists had made up their minds and ignored evidence to the contrary.

A new era in climate science dawned in the 1960s with the advent of the digital computer to model climate. The early models confirmed Arrhenius's calculation and also showed that the atmosphere is not saturated to carbon dioxide absorption. Temperature still did not rise much through the 1960s, but then in the 1970s began to take off. Since then, it was risen erratically but inexorably, as shown in Figures 8-10 below.

Scientists of the first half of the twentieth century were wrong to allow Ångström's experiment to cause them to reject global warming. But science itself did not stay wrong, as a later generation corrected the error of their predecessors.

As we will see, today a vast amount of evidence underpins the theory of global warming, making it inconceivable that scientists could simply have made a mistake about it. Tens of thousands of scientists are researching and publishing about global warming, assuring that any mistakes have almost certainly been revealed and corrected.

The role of errors in science by individual scientists is worth an aside. The best always push the boundaries. Arrhenius did so when he took months to calculate the effect of rising carbon dioxide on global temperatures, using data from the absorption of moonlight! Alfred Wegener did so when he proposed continental drift. Arrhenius and Wegener turned out to be right, but many more conjectures in science have turned out to be wrong. One of the best geologists of the twentieth century, Harry Hess, generally credited for the theory of plate tectonics, was forever pushing the current science further than anyone else had the nerve to take it. Hess often turned out to be wrong. But his mistakes exposed research directions that were unlikely to be fruitful and gave new impetus to the right directions. Hess once said, "I take pride in my errors." He was right to do so.

Even the mightiest may have feet of clay. Lord Kelvin not only believed in the ether, he said that a heavier-than-air machine could not fly and that the outer 1500 km of the Earth is rigid as steel.

In *A Journey to the Center of the Earth*, Jules Verne captured the way science benefits from errors[4]:

> Science, my lad, is made up of mistakes, but they are mistakes which it is useful to make, because they lead little by little to the truth.

If we cannot count on a new or strengthened negative feedback to reduce global warming; if the theory is not based on an assumption that could turn out to be false; if it is not accepted out of misplaced allegiance to an older theory; and if it is not simply a mistake; yet global warming is still false, then only one possibility remains: scientists are deliberately wrong. If that too fails, then a fair and reasonable person would have no choice but to conclude that scientists are right about global warming.

5. The Conspiracy

Denialism

The conspiracy theory surely is as old as human society. Whenever people cannot refute on the evidence something they disagree with, they fall back on asserting that a conspiracy has forged that evidence.

Here are a few all-too-familiar modern conspiracy theories: Men did not land on the Moon; NASA faked the whole thing. President Obama was not born in the U.S. and any evidence to the contrary has been cooked up. The Holocaust never happened. Lee Harvey Oswald never fired the fatal shot. Smoking, neither first nor second hand, causes lung cancer. The list goes on.

When we get to science, we find denialist movements claiming that HIV does not cause AIDS, that vaccines trigger autism, that evolution is a conspiracy of godless liberals, that the swine flu epidemic was a hoax mounted by Big Pharma to sell drugs, and, of course, that global warming is a fraud.

A study published in 2012 found that among Americans who strongly doubt or deny global warming, 40% give "conspiracy" as their reason. Second came "flat denial" at 20%, then "doubt science," followed by "hype" and "it's natural."

As science writer Debora MacKenzie summed up in New Scientist, all denialist groups,

> Set themselves up as courageous underdogs fighting a corrupt elite engaged in a conspiracy to suppress the truth or foist a malicious lie on ordinary people. This conspiracy is usually claimed to be promoting a sinister agenda: the nanny state, takeover of the world economy, government power over individuals, financial gain, atheism.

Martin McKee described the six strategies that denialist movements use in some combination:

1. Claim that the science they oppose is the result of a "complex and secretive conspiracy." Say that scientific peer review is used not to ensure that only high-quality articles get published, but to stifle dissent.

2. Use fake experts to counter mainstream scientists. Dr. Fred Singer has opposed action to regulate tobacco smoke, ozone depletion, acid rain, toxic waste, and for the last twenty years, global warming. Each time he has been dead wrong, but at age 90 is still going strong.

3. Cherry-pick to include only facts that appear to support your claim. In 2009, Harrison Schmitt, an Apollo 17 astronaut and U.S. Senator, who has said he is proud to be a "climate denier," sent a paper to NASA in which he claimed that "Arctic sea ice has returned to 1989 levels of coverage." It turned out he was right, but only for the single month of April 1989. In every other month in the period, Arctic sea ice in 2009 was less than in 1989.

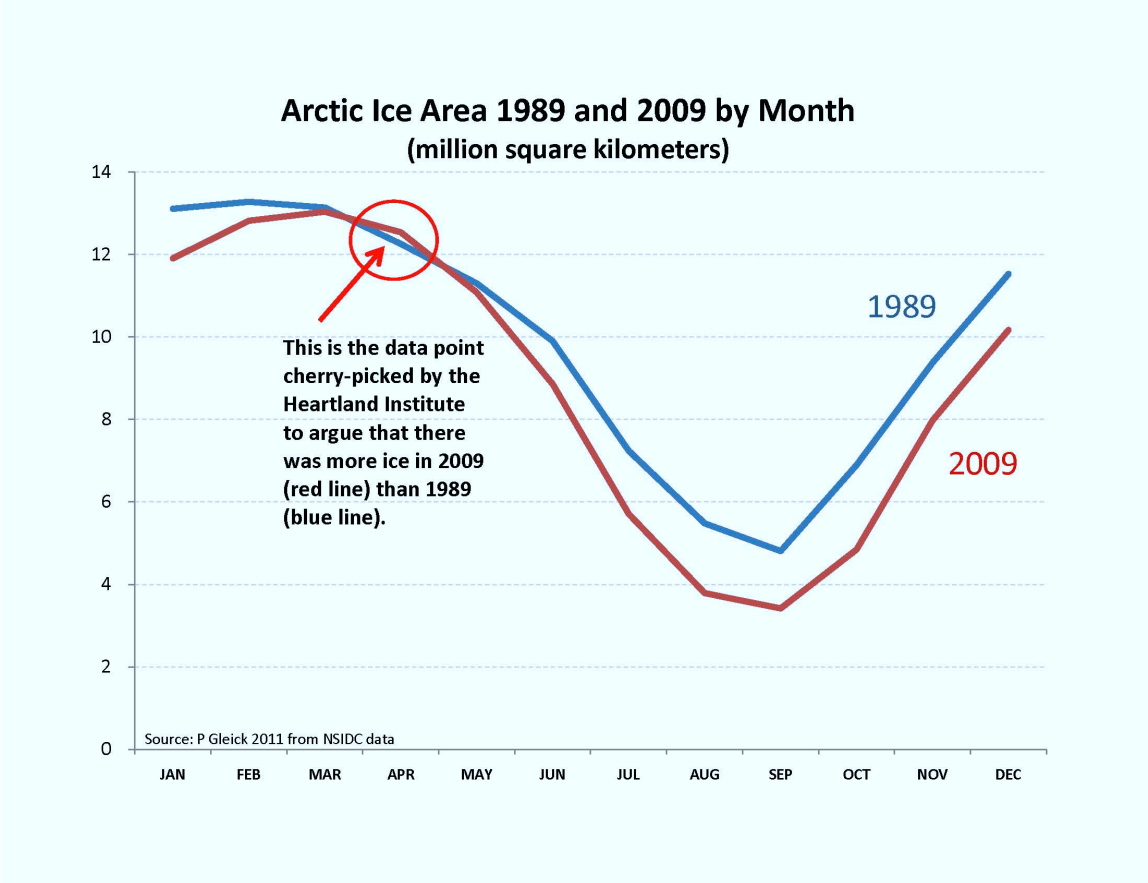


Figure 6: Cherry-picking

Or consider this example from Björn Lomborg, a Dane who has made a career out of downplaying the threat from global warming.

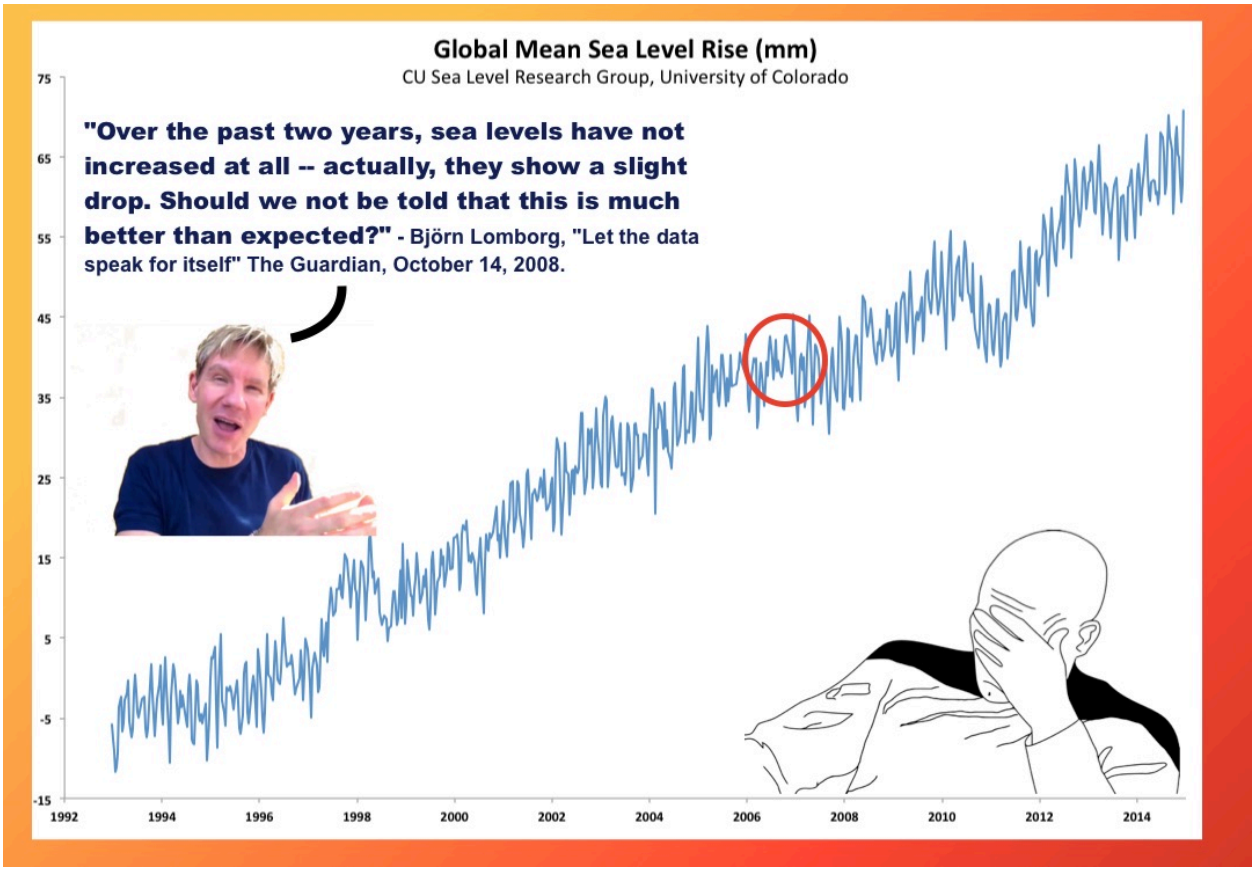


Figure 7. Cherry Danish

A more damaging example has been the assertion that "global warming ended in 1998." Whenever you come across a claim in which a single data point is chosen from a much longer set of data as the starting point of an analysis, there is a good chance you are encountering a case of cherry-picking. The year 1998 had an extreme El Niño, when temperatures tend to be several degrees above the long-term average. Cherry-picking the highest possible starting point minimizes the trend forward. The claim that "global warming ended in 1998" has now been shown to be false (see below), as cherry-pickers eventually turn out to be.

4. Set an impossibly high standard for what scientific research can provide. Move the goalposts, demand absolute proof. For decades, Big Tobacco kept claiming that there was no proof that smoking causes lung cancer, even though their own scientists were telling them that it did.

5. Use logical fallacies like the "straw man," which misrepresents an opponent's position and then knocks it down. A classic example was Richard Nixon's "Checkers Speech." In the 1952 campaign in which he was a candidate for Vice President, Nixon was accused of having illegally used $18,000 of campaign money. In his famous and at the time, rare television response, Nixon set up a straw man: that "they" wanted him to give back his children's new favorite pet:

> It was a little cocker spaniel dog, in a crate he had sent all the way from Texas, black and white, spotted, and our little girl Tricia, six years old, named it Checkers. And, you know, the

> kids, like all kids, loved the dog, and I just want to say this right now, that, regardless of what they say about it, we are going to keep it.

Here's columnist Charles Krauthammer using a straw man argument today on global warming:

> "The debate is settled," asserted propagandist-in-chief Barack Obama in his latest State of the Union address. "Climate change is a fact." Really? There is nothing more anti-scientific than the very idea that science is settled, static, impervious to challenge.

But climate scientists do not say that global warming is settled science in the sense that it is static and impervious to challenge. They are constantly improving it, making changes within the paradigm that human activities are causing global warming.

6. Manufacture doubt. As tobacco company Brown and Williamson put it, "Doubt is our product, since it is the best means of competing with the 'body of fact' that exists in the minds of the general public. It is also the means of establishing a controversy." The media wittingly or unwittingly have colluded in the strategy by bending over backwards to give equal time to the few who deny global warming, as though there were a legitimate scientific debate. Claims that focus on a single discrepancy, like Harrison Schmitt's cherry-picked and false assertion, create doubt that lasts far beyond the time the claim is refuted.

The Greatest Hoax

In 2012, Senator James Inhofe (R-OK) published a book titled: *The Greatest Hoax: How the Global Warming Conspiracy Threatens Your Future*. Far from an outlier, the book joined a shelf-full of conspiracy tomes. If one searches Amazon today for "global warming hoax," these titles show up along with *The Greatest Hoax*:

•*The Deliberate Corruption of Climate Science*
•*The Global Warming / Climate Change Hoax: Fraud, Lies, Deception & Threats*
•*Climategate: A Veteran Meteorologist Exposes the Global Warming Scam*
•*Roosters of the Apocalypse: How the Junk Science of Global Warming is Bankrupting the Western World*
•*Climate of Corruption: Power Behind the Global Warming Hoax*
•*Understanding the Global Warming Hoax*

Could these writers be right? Could global warming be nothing more than a conspiracy? Before anyone accepts such a claim, here are nine questions that need answers.

1. Is a conspiracy over global warming even possible?

The theory that humans are causing global warming depends on data—a mind-boggling amount. *The Chart* summarizes a myriad of individual data points derived from the work of scientists over many decades. In 2013 and 2014, more than 69,000 authors published peer-reviewed articles on global warming and climate change. If global warming is a conspiracy, tens of thousands of scientists must have colluded to fabricate the data in those articles, all without anyone ever having shown that a single item of data has been forged or without a single scientist having been caught.

2. Can one corral a global herd of cats?

To fake all the data that support global warming would require someone with God-like omnipotence to keep everything straight so that none of the faked data would conflict with any other. Scientists from all across the world would have to follow orders. But most scientists have chosen their profession in part because they have no intention of following orders. Anyone who has attended a scientific meeting and listened to scientists debate in the meeting rooms, halls, and bars knows that to try to get them to collude in a criminal conspiracy would be a fool's errand.

3. Why would scientists fake global warming?

When Senator Inhofe was asked in 2009 who was behind the greatest hoax, he replied, "It started in the United Nations and the ones in the United States who really grab ahold of this is the Hollywood elite."

In a 2012 interview promoting his book, Senator Inhofe explained why he rejects global warming:

> Well actually the Genesis 8:22 that I use in [the book] is that "as long as the earth remains there will be springtime and harvest, cold and heat, winter and summer, day and night." My point is, God's still up there. The arrogance of people to think that we, human beings, would be able to change what He is doing in the climate is to me outrageous.

The blurb for *The Deliberate Corruption of Climate Science* tells us that author Dr. Tim Ball "exposes the malicious misuse of climate science by dishonest brokers to advance the agenda of the progressive left." Elsewhere Ball has said that global warming is "the political agenda of a group of people…who believe that industrialization and development and capitalism and the Western way is a terrible system and they want to bring it down."

Climategate: A Veteran Meteorologist Exposes the Global Warming Scam, "Trac[es] the origins of the current climate scare, guid[ing] the reader from the diabolical minds of Marx and Engels in the 1800s, to the global governance machinations of the United Nations today…warning Americans that their future is being undermined by a phony pseudo-science aimed at altering and dominating every aspect of life in the United States and the world."

Climate of Corruption asks and answers, "What true political and financial purposes are served by the vilification of carbon dioxide? How do climate deceptions promote grossly exaggerated claims for non-fossil alternative energy capacities and advance blatant global wealth redistribution goals?"

Harrison Schmitt has said, "Americans should think long and hard before giving up more of their liberties and income to satisfy politicians who just want to 'do something' to satisfy a particular special interest. A long-term political agenda is at work here, gathering power at the expense of liberty."

In 1992, MIT scientist Richard Lindzen wrote that "the need to fight 'global warming' has become part of the dogma of the liberal conscience—a dogma to which scientists are not immune."

In an article in *The Australian* on May 8, 2015, Maurice Newman, chairman of the Prime Minister's business advisory council, said that United Nations is behind the global warming hoax. The real agenda of the UN "is concentrated political authority.

Global warming is the hook," Newman said. "This is not about facts or logic," he added. "It's about a new world order under the control of the UN. It is opposed to capitalism and freedom and has made environmental catastrophism a household topic to achieve its objective."

Does it make sense to blame the alleged global warming conspiracy on anti-capitalism liberals who want to "bring down the Western Way"? A survey by the Pew Foundation found that 52 percent of American scientists identify themselves as liberals. That would leave the other 48% to blow the whistle. Chinese scientists now rank second in the number of global warming publications: are they part of the liberal conspiracy? Even if liberal American scientists would mount a conspiracy, how did they manage to get all those foreigners to cooperate?

But let us return to Senator Inhofe's claim that the "Hollywood Elite" is behind the global warming scam. If he is right, Hollywood is doing one lousy job. As Dr. Joe Romm notes, "The closest to a genuine popular climate movie was the dreadfully unscientific *The Day After Tomorrow*, which is from 2004 (and arguably set back the messaging effort by putting the absurd 'global cooling' notion in people's heads!)"

One recent dystopian movie that had a golden opportunity to fool people into believing that global warming is real was *Interstellar*. Here's what Romm has to say about that film:

> But although it is post-apocalyptic, it is far from obvious that global warming was the cause. And the theme of this movie appears to be "We are not meant to save the world. We are meant to leave it." Not exactly eco-consciousness-raising.

4. Who would have to conspire?

The tens of thousands of data points that support global warming appear in scores of peer-reviewed scientific journals. How do they get there? First, a scientist gets an idea for a research project. Research today requires money. Scientists have to pay for time on a supercomputer, buy expensive research equipment, travel to distant lands, support graduate students, and so on. Universities fund only a small part, if that, of the research of their faculty members. Instead, researchers must apply to organizations like the National Science Foundation for funding. NSF staff review the proposed project and send the proposal out to experts. These specialists ask whether the proposers have done their homework, whether the project will represent state-of-the-art research, whether it has a good likelihood of success, and whether it is important enough to be a worthy use of scarce research funds. If the reviewers answer those questions affirmatively, the proposal then has to compete for NSF dollars with all the other worthy proposals. Only about 25 percent wind up being funded. And once the research is begun, the researchers report periodically to NSF on their progress.

When the research reaches the point at which there are findings to report, the scientist (more likely a team of scientists) writes an article and submits it to a scientific journal. The editors of the journal typically make an initial review to decide whether the article is worthy of publication. They may reject it at that point. If not, they send the article out to a new group of experts who read the paper and respond. These peer reviewers can recommend that the paper not be published, that it be published as is, or that it be published but with significant changes. Few papers appear in print exactly as they were

submitted. In many cases, before publication, the researchers present their results at a scientific meeting to an audience of experts, who are not shy about voicing their criticisms.

Thus by the time a scientific paper appears in print, many people have had a chance to detect fraud and blow the whistle. If global warming were a hoax, not only would thousands of individual researchers be culpable: so would virtually the entire scientific enterprise from top to bottom, from the universities, to the government labs, to the funding agencies, to the journal publishers, to the many science societies, to the United Nations, to the Catholic Church, and so on. Science itself would have to be a vast criminal enterprise to dwarf the Nazis and the Mafia.

5. Who would dare take the chance?

Any scientist contemplating participating in a conspiracy would have to think long and hard about the risk. Universities have elaborate procedures for investigating allegations of scientific fraud. Anyone found guilty would at the very least lose tenure and more likely be drummed out of academe and science.

Funding organizations like NSF have their own careful procedures. Scientists found to have used a government grant to commit fraud would be debarred from ever again receiving federal research funding. They would become scientific pariahs, unable ever to practice their profession.

6. Could they get away with it?

This is not to say that conspiracies never exist. One of the most notorious was the collusion by Big Tobacco to suppress information showing that nicotine is addictive and that smoking causes lung cancer. No one ever went to jail, but the companies did have to pay out hundreds of billions of dollars in a settlement when they began to fear lawsuits on the basis that they had knowingly lied. How was the critical evidence made public? By whistleblower Jeffrey Wigand, well portrayed by actor Russell Crowe in the movie *The Insider*.

Of the tens of thousands of scientists who would have to be part of the global conspiracy over global warming, is there not a single person of conscience like Jeffrey Wigand? Today the whistleblower would not even have to identify himself or herself: just put the damaging information out on WikiLeaks or The Guardian's SecureDrop platform.

7. Why wait until now?

If scientists are bent on bringing down western democracy, why did they wait to use global warming as their vehicle? Why not try something simpler decades ago, like passing secrets to the Russians or Chinese, writing computer malware, sabotaging equipment, or any number of other schemes that clever scientists could come up with?

8. Don't conspirators use email?

One way to prove once and for all that climate scientists are engaged in a global conspiracy would be to gain access to their private e-mails. Tens of thousands of scientists and their co-conspirators around the world, only a few of whom are ever in the same room at the same time, could not possibly collude to fake decades' worth of data without using email. If only we had access to their e-mails!

On November 18, 2009, a few weeks before the Copenhagen Climate Conference, where nations were to agree on a new pact to replace the Kyoto Protocol on carbon emissions, denier websites began to hum. Soon the news was out that an anonymous hacker had stolen more than 1,000 e-mails, comprising over 1 million words, from the Climate Research Unit of the University of East Anglia in the UK (CRU), one of the repositories of global temperature data. Within days the entire set of e-mails, many from leading climate scientists, showed up on the Internet in a searchable database. Naturally, someone dubbed it Climategate. Here at last would be found the incriminating evidence to show that global warming is a conspiracy.

James Delingpole of Britain's Daily Telegraph chortled: "The conspiracy behind the Anthropogenic Global Warming myth has been suddenly, brutally and quite deliciously exposed."

Senator Inhofe fulminated over "The worst scientific scandal of our generation" and accused climate scientists of:

> Obstructing release of damaging data and information; manipulating data and knowingly using flawed climate models to reach preconceived conclusions; colluding to pressure journal editors who published work questioning the climate science "consensus"; and assuming activist roles to influence the political process.

Inhofe's statement listed seven federal statutes that climate scientists named in the stolen e-mails might have violated, including the False Claims Act and Obstruction of Justice and Interference with Federal Proceedings. The Inhofe statement concludes: "The CRU documents and emails reveal, among other things, unethical and potentially illegal behavior by some of the world's preeminent climate scientists." The Inhofe report identified 17 persons, a who's who of climate science, as "key players."

Over the next few years, Pennsylvania State University and government agencies and appointed committees in the U.S. and Britain conducted eight independent investigations into whether the scientists who wrote the e-mails had acted improperly. Some of the investigative reports faulted the scientists for not making their data more openly available and for being slow to honor freedom-of-information requests. Fair enough. Moreover, as would likely happen to any of us if our last 1,000 private e-mails showed up on the Internet, the scientists had written some things that proved embarrassing. But none of the eight reports found a shred of evidence that the scientists had been colluding in a conspiracy.

Of course, to the true denialist, the absence of evidence of a conspiracy merely shows how devious and effective the conspirators have been at covering their tracks.

9. Has any scientist ever been known to collude with funders on global warming?

On Feb. 21, 2015, the New York Times broke a story headlined, "*Deeper Ties to Corporate Cash for Doubtful Climate Researcher.*" The subject was Wei-Hock "Willie" Soon, a PhD scientist with the Harvard-Smithsonian Center for Astrophysics. Soon has written several papers claiming that variations in the Sun's energy largely account for global warming. He is a star of the global warming denialist movement and one of Senator Inhofe's favorite scientists. Physicist Freeman Dyson, himself a prominent global warming denier, said in November 2013, "The whole point of science is to

question accepted dogmas. For that reason, I respect Willie Soon as a good scientist and a courageous citizen."

Since the Smithsonian is part of the U.S. government, it is subject to the Freedom of Information Act. Greenpeace used FOIA to obtain documents pertaining to Soon's funding. They found that since 2008, Soon took more than $800,000 from ExxonMobil, the Charles G. Koch Charitable Foundation, the electric utility Southern Company Services Inc., and Donors Trust Inc., which bundles contributions from donors who wish to remain anonymous.

In at least 11 of his scientific papers, Soon failed to disclose, as journals require, that he had a possible conflict of interest due to the funding of his work. Moreover, in his letters to his funders, Soon referred to his papers as "deliverables:" specific findings that his articles would contain. He allowed funders to review his articles before he submitted them.

The Smithsonian has begun an investigation of Soon's activities and launched a review of its own ethics and disclosure practices.

On March 2, 2015, Soon responded with a statement defending his actions. It was released not by the Harvard-Smithsonian Center for Astrophysics, but by the Heartland Institute.

Whether all this amounts to a conspiracy we will presumably find out as the case unfolds. But one thing to keep in mind is that although Soon's relationship with his funders may be suspect, although he may have violated scientific standards, he could still have published good science. But he has not. From the Times article:

> Gavin A. Schmidt, head of the Goddard Institute for Space Studies in Manhattan, a NASA division that studies climate change, said that the sun had probably accounted for no more than 10 percent of recent global warming and that greenhouse gases produced by human activity explained most of it.
>
> 'The science that Willie Soon does is almost pointless,' Dr. Schmidt said.

Summary

Could scientists turn out to be wrong about global warming? We have reviewed five possibilities and found each wanting:

1. Scientists could discover a new negative climate feedback. But the record of carbon dioxide emissions and the temperature rise from the early twentieth century onward suggest that if an undiscovered negative feedback does exist, it must be small. Plus, any newly found or enhanced feedback is as likely to be positive as negative. Depending on this improbable event is like continuing to smoke because you believe that before it kills you, someone will find a cure for lung cancer.

2. Global warming does not depend on an assumption or assumptions that could turn out to be false. Rising fossil fuel emissions have caused rising carbon dioxide, which in turn has caused rising temperatures. These are not assumptions but known facts.

3. Scientists are not clinging to global warming out of obstinacy, refusing to adopt an obviously better theory. There is no other theory.

4. Scientists were wrong to reject the carbon dioxide theory on the basis of spectroscopic experiments, but they began correcting their mistake 50 years ago. Today a vast amount of evidence supports the theory. To claim that scientists are simply wrong about global warming today is to indict not only climate science, but since it depends on so many different fields of science, science herself. If scientists can be that wrong, nothing would work.

5. Since the four possibilities above have failed, the conspiracy theory is the only option left. But not a single fact supports the claim that global warming is a conspiracy. If it were, surely we would have some incriminating evidence, some death-bed confession, some blown whistle, some leak, some tell-tale e-mail, as tens of thousands of scientists and their multitude of co-conspirators could not possibly keep the conspiracy secret. But we have none of those.

To reject global warming on the grounds that scientists are conspiring to hoax the public is the intellectual equivalent of believing that the Earth is flat or that men did not land on the Moon. It is to choose a blatant absurdity for which there is not a shred of evidence over rigorous scientific fact and for no reason other than that to accept global warming does not happen to suit people. But Nature and the implacable laws of science remain unaffected by what suits us. As Richard Feynman wrote in his report on *The Challenger* spacecraft disaster, “Nature cannot be fooled.”

The Evidence

Scientists are convinced that they are right about global warming because they have uncovered a large amount of evidence supporting the theory and found no compelling evidence against it. Let us look at a sample of that supporting evidence, starting with temperature.

Temperature

Sound theories make predictions that when tested turn out to be true. By definition, the theory of global warming predicts that global temperatures will rise. One frame of *The Chart* showed that this prediction has been met, but let us take a closer look at other kinds of temperature data, starting with the NASA temperature index below.[5] This chart brings the temperature frame of *The Chart* up-to-date and allows us to see the details.

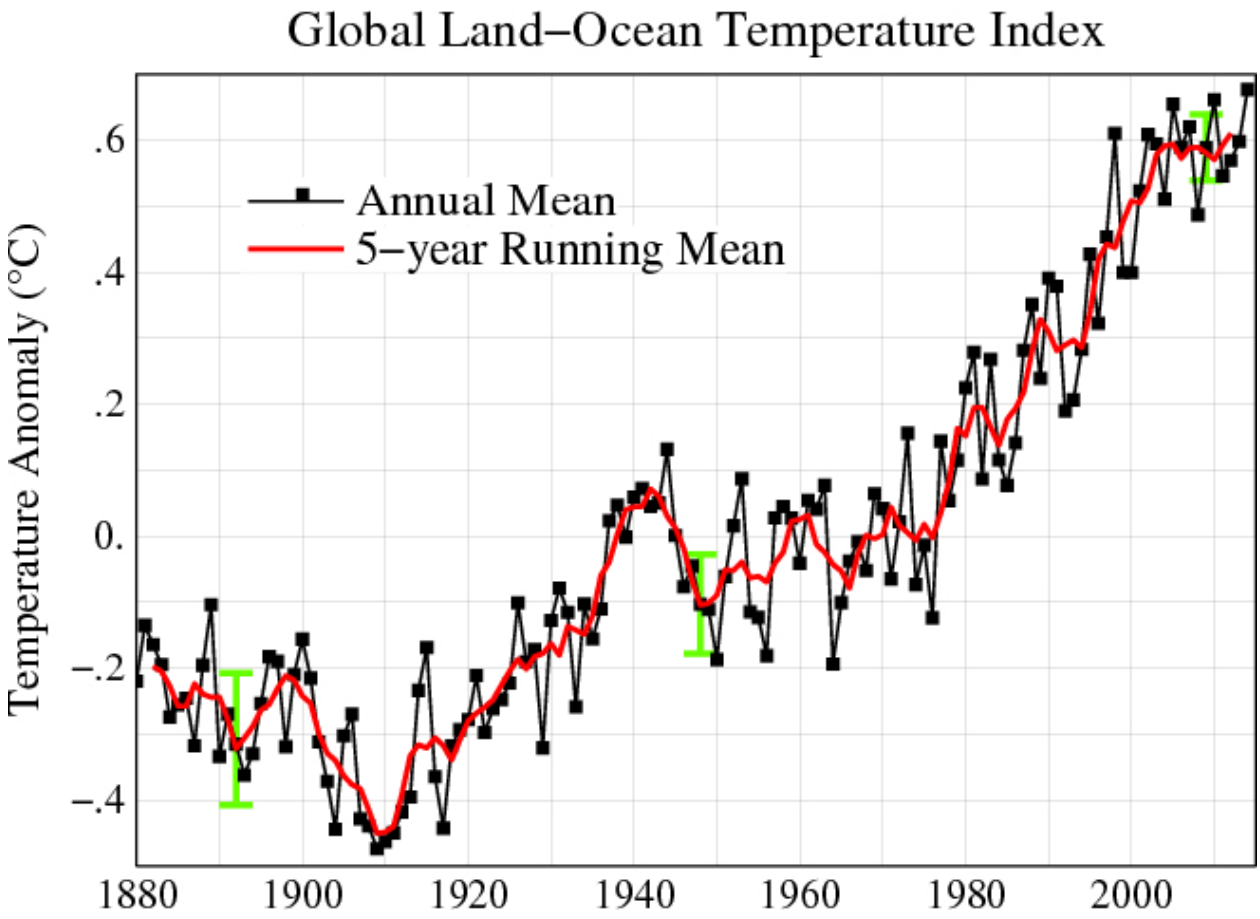


Figure 8. Since the early 1900s, global temperature has risen more than 1°C.

Global temperature has risen by about 1.1°C (2°F) since early in the twentieth century. (Green bars show estimated precision.) But the temperature rise has been erratic compared with the rise in carbon dioxide emissions and atmospheric carbon dioxide concentration. During the 1940s, even though carbon dioxide emissions rose, temperature declined. These facts tell us that factors in addition to the greenhouse effect

play a role in determining global temperature. We know that volcanic eruptions, which put sunlight-reflecting sulfur dioxide into the atmosphere and lower global temperature slightly, are one such factor. Another is ENSO.

ENSO

Anyone paying attention to weather and climate has heard of El Niño, a period of unusual weather that returns every several years. During an El Niño event in the U.S., the jet stream shifts toward the equator and eastward. States across the upper tier are warmer and drier than average, while the Southwest U.S. and Northern Mexico across to the Southeast are cooler and wetter.

El Niño is the warm phase of a dual cycle known as the El Niño Southern Oscillation, or ENSO. During the El Niño phase, the surface temperature of waters in the east-central equatorial Pacific is higher than the long-term average. Off western South America, the warmer waters affect weather, fishing, and agriculture. They usually arrive around Christmas; hence the Spanish name "El Niño," or Christ Child.

The opposite ENSO phase is called La Niña: the girl child. During a La Niña event, sea-surface temperatures in the eastern Pacific are below average and weather effects are opposite. The chart below shows how El Niño years tend to be warmer than average and La Niña years cooler. Scientists cannot predict exactly when the switch from one to the other will occur.

Two El Niño years stand out in the NASA temperature chart as particularly anomalous. One was in 1964, when, contrary to what I have just written, the temperature during an El Niño year fell well below the average. That happened to be the year after the eruption of Mount Agung on Bali, which sent large amounts of sulfur dioxide aerosols into the atmosphere. The other anomalous year was 1998, which as we saw earlier is the cherry-picker's favorite year and the basis for their claim that "global warming ended in 1998." The 1998 El Niño was one of the strongest on record and farther above the average than any year shown in the chart below.

To judge long-term temperature trends, one needs to take at least a decade into account to allow ENSO and the other short-term effects like volcanic eruptions to average out. Note that between 1999 and 2014 inclusive, there were four El Niño years and eight La Niña years. **Even though 2014 was not an El Niño year, it was still the hottest on record.**

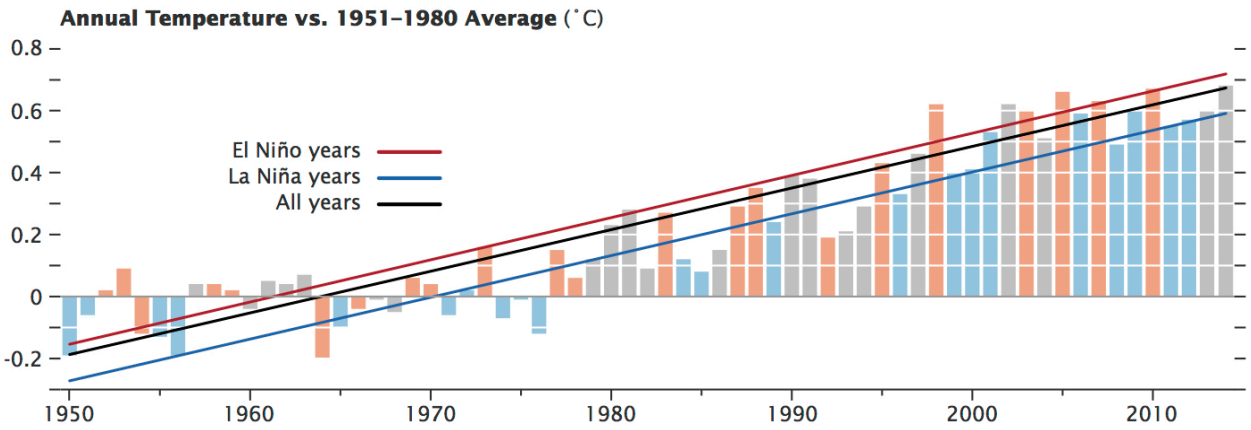


Figure 9: El Niño years have higher temperatures than La Niña years.

January-April 2015 was the warmest four-month start to any year on record. In March 2105 the National Oceanographic and Atmospheric Administration (NOAA) declared that a new El Niño had begun, but a relatively weak one. By mid-May, however, the Australian Bureau of Meteorology said that the 2015 El Niño would be "substantial" and NOAA now said there was "a greater than 80% chance it will last through 2015." This makes it ever more likely that 2015 will set a new global high temperature record.

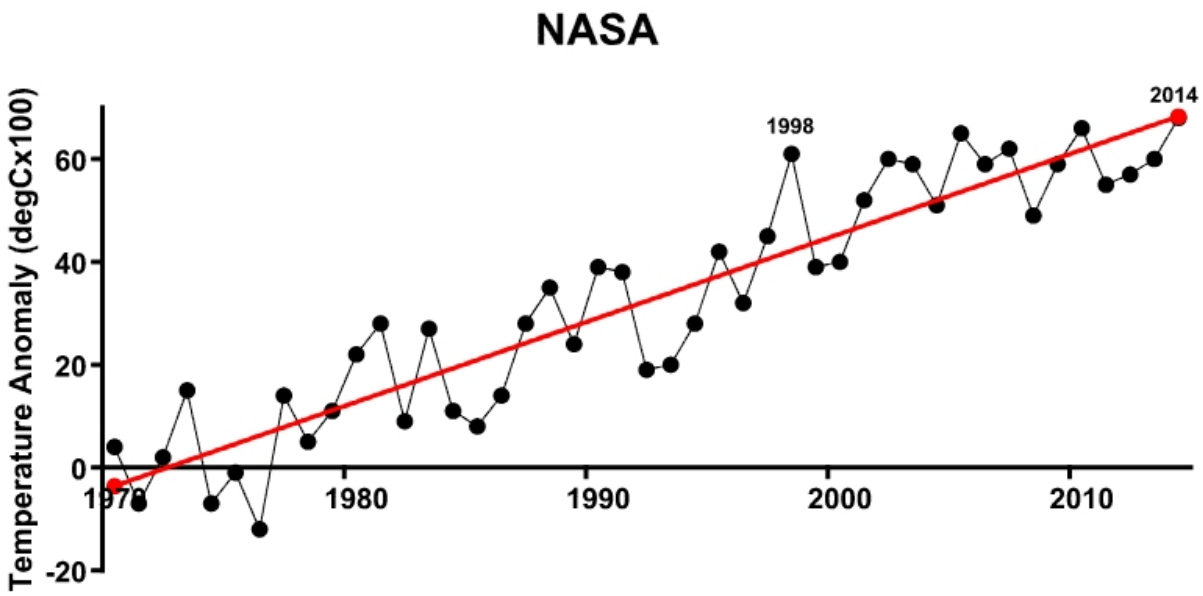
But wait a minute: didn't global warming "end in 1998"?

The Pause that Wasn't

In 2006, Australian scientist Bob Carter wrote an article for the UK Daily Telegraph titled, "There IS a problem with global warming…it stopped in 1998." In 2012, "sixteen concerned scientists" wrote a letter to the *Wall Street Journal* about "The lack of global warming for well over 10 years now." In September 2014, Matt Ridley wrote an opinion piece for the *Journal* titled, "Whatever Happened to Global Warming? Now come climate scientists' implausible explanations for why the 'hiatus' has passed the 15-year mark."

We have already discussed these cherry-picked claims, all of which have in common that they pick 1998 as the starting date. But now we have the data through 2014. Does the pause hold up? No. As statistics expert "Tamino" points out, adding 2014 shows there has been no pause. (See here for an animation of this chart.)

One thing we have learned *not* to expect is that the "sixteen concerned scientists," for example, will now write to the *Wall Street Journal* admitting that they were wrong: that global warming neither paused nor ended. Scientists publishing in peer-reviewed journals have to be able to admit and correct their errors, so as to keep the scientific record as immaculate as possible. Those who write outside science evidently feel no such compunction.



Sic semper cerasus furati

(Thus always cherry pickers)

Figure 10: The data point for 2014 falls exactly on the long-term trend line. The alleged pause disappears.

Record Highs and Lows

Rising temperatures should cause more high temperature records and fewer low temperature ones. As the chart below shows, during the 1960s and 1970s, more low temperature records were broken than high temperature records, consistent with the decline in temperatures during those decades. But in the 1980s the ratio rose above 1:1 and kept rising until by the first decade of the twenty-first century it had risen above 2:1. January 2015 was the second warmest January on record globally and the ratio of U.S. daily high to low temperature records was 4:1.

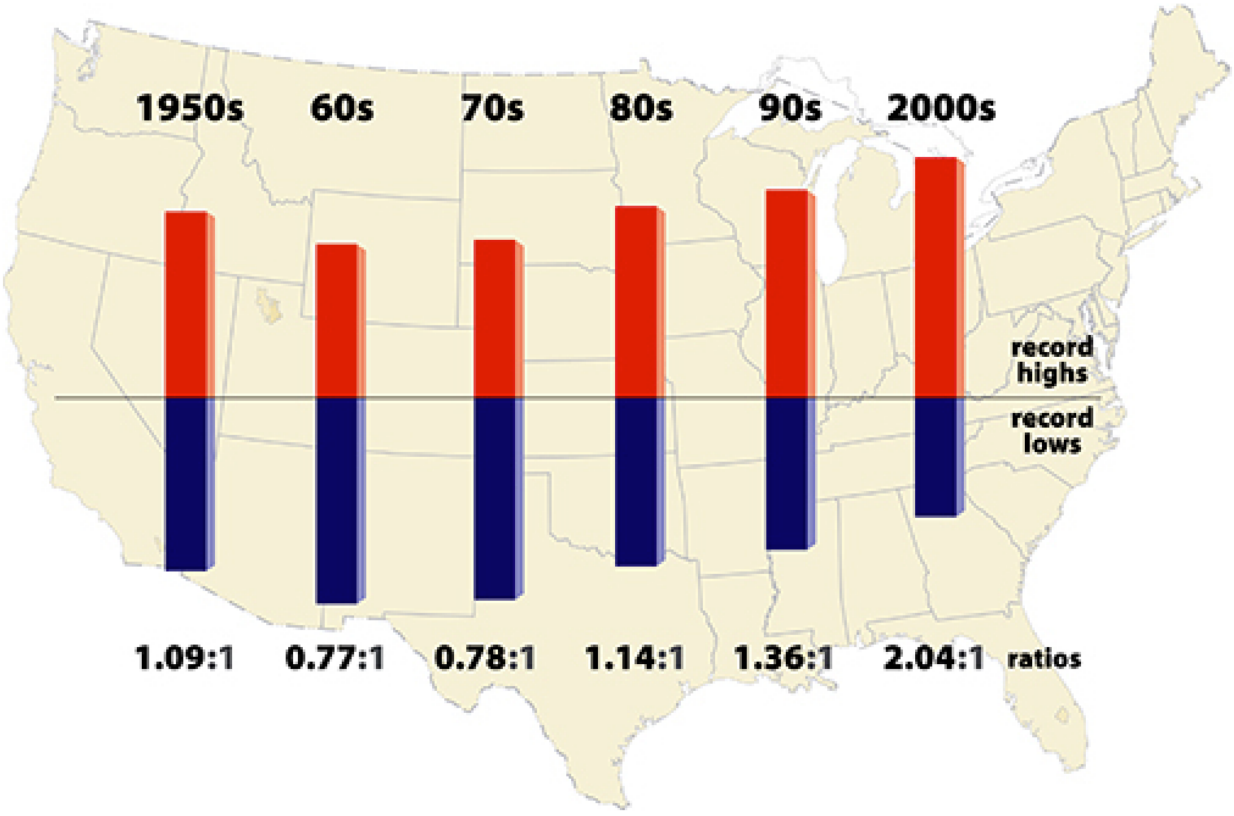


Figure 11. In the 2000s, U.S. record high temperatures have been twice record lows.

Fourteen of the 15 warmest years on record globally have occurred in this century. Of the warmest *months* on record, two occurred in 1998 and the other ten in the twenty-first century. Seven record months have occurred since 2010.

Another revealing statistic is the daily *nighttime* temperature. According to NOAA, between mid-February 2014 and mid-February 2015 in the lower 48 states, 54 weather stations set high nighttime temperature records, but only 2 set low nighttime temperature records.

NOAA reports that between 1998 and 2014 in the U.S., “much above normal” minimum (nighttime) temperatures outweighed the “much below normal” by 29 to 1. Globally, since 1950 the number of cold nights has decreased, while the number of warm nights has increased.

Wherever we look, we find evidence of a warming Earth. And a warmer Earth melts ice.

Melting Ice

Sea-Ice

The Arctic Ocean engulfs the North Pole. The air temperature is so cold that the water freezes, creating a large region of sea ice. The extent, or area of Arctic sea ice provides an indicator of how far global warming has advanced. But because ice reflects most

incoming sunlight while water absorbs most of it, melting sea ice also creates one of the most important positive climate feedbacks. The chart below shows how Arctic temperature was declining until about 1800, as the Earth continued to emerge from the last Ice Age. Then with the Industrial Revolution, Arctic temperature began to rise rapidly.

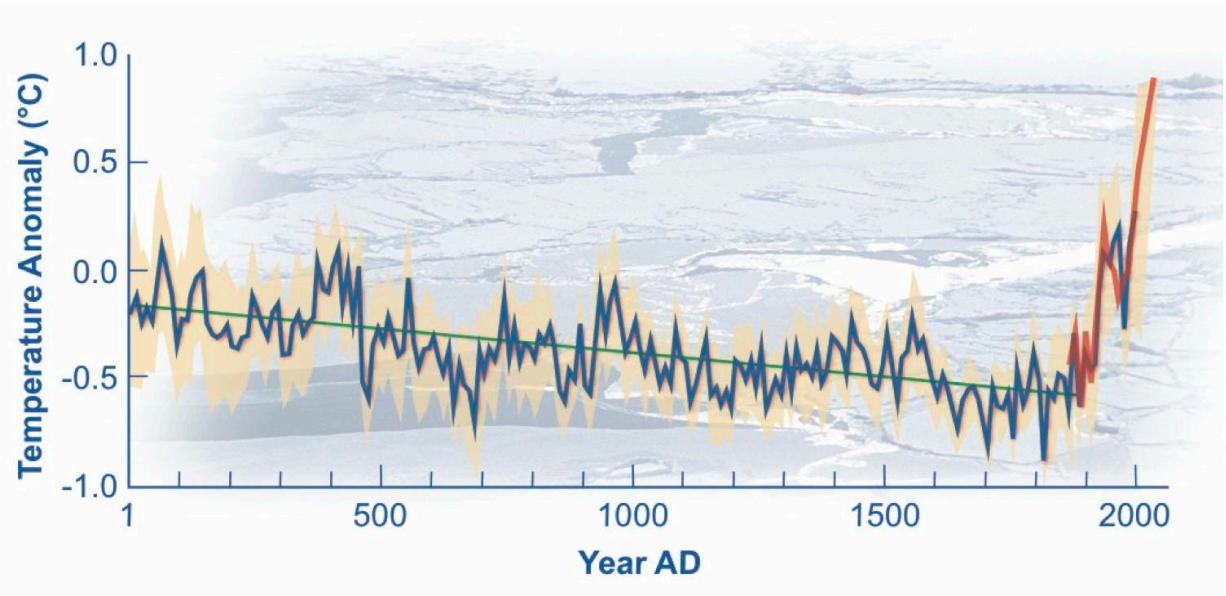


Figure 12. The Arctic "hockey stick."

The chart below, from the National Snow and Ice Data Center, shows satellite measurements of the change in the extent of Arctic sea ice in the month of September, when it reaches its annual minimum.

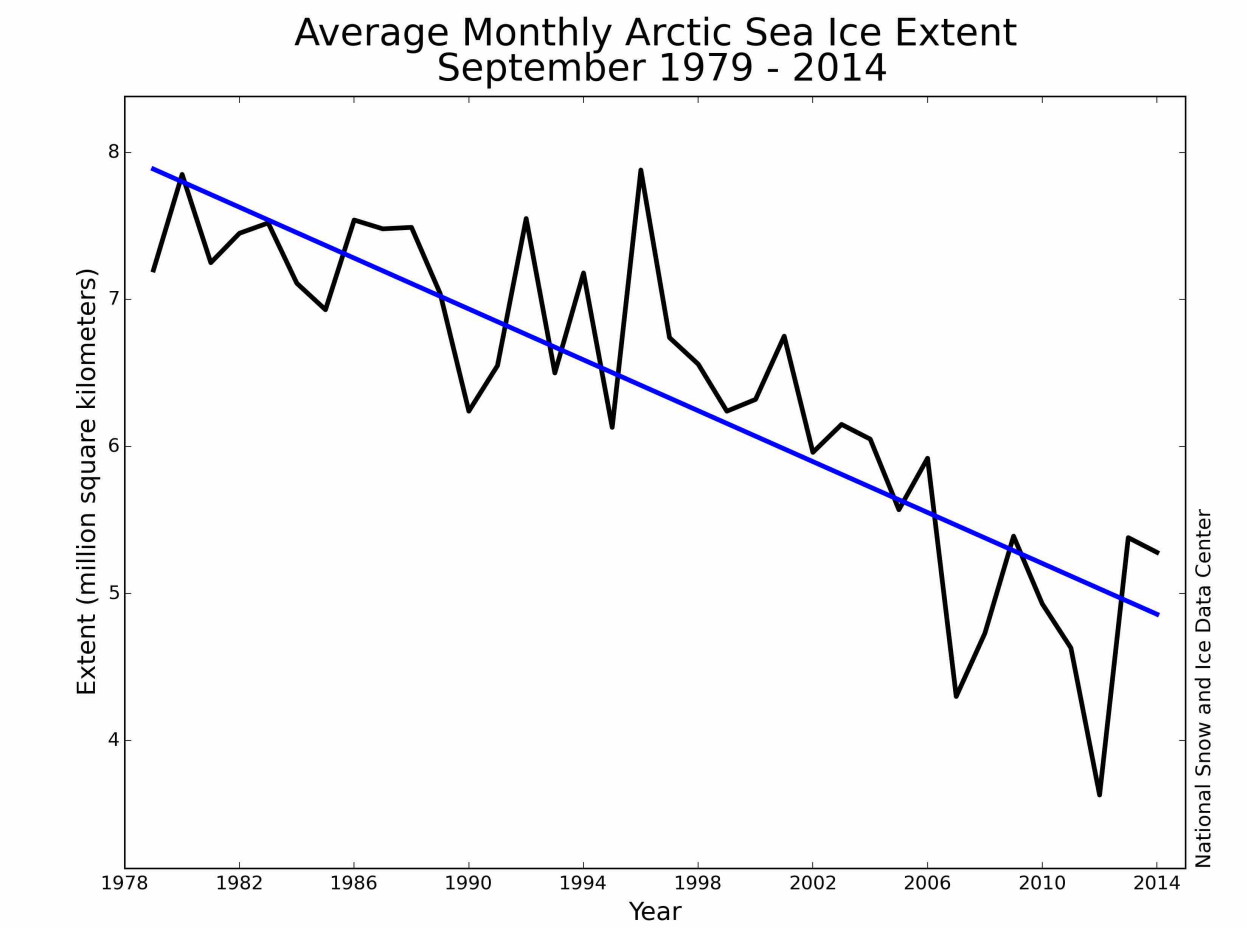


Figure 13. Arctic sea ice extent is declining.

What about the third dimension of sea ice: its thickness? It too has been shrinking, as reflected in the dramatic "Arctic Death Spiral" chart below. The *volume* of Arctic sea ice has declined for each month and the September low (the black line) is spiraling toward zero. At that point, the Arctic Ocean will be ice-free. Estimates of when this will occur vary, but most predict it will happen before 2050.

Because of the ice-water feedback, an ice-free Arctic Ocean would further accelerate global warming. The warmer Arctic would also trigger increased permafrost thawing and methane release. Finally, the Arctic Ocean affects the worldwide system of ocean surface and deep currents, so that the disappearance of Arctic sea ice would have unpredictable and possibly dangerous consequences.

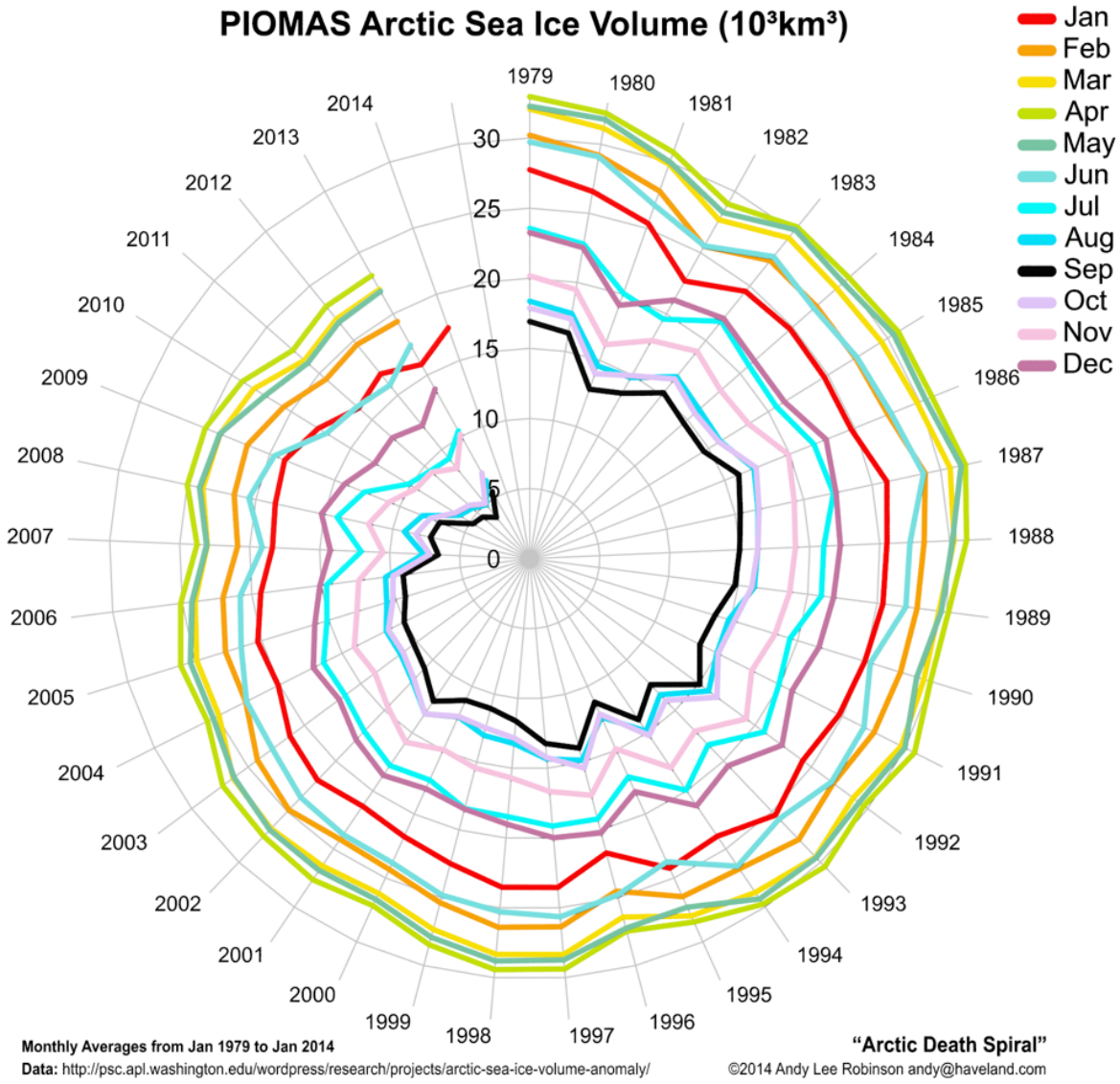


Figure 14. The **volume** of Arctic Sea Ice is spiraling toward zero.

Most of Greenland, the world's largest island, is covered with ice. Satellite measurements presented in the chart below show how Greenland has been losing ice in this century.

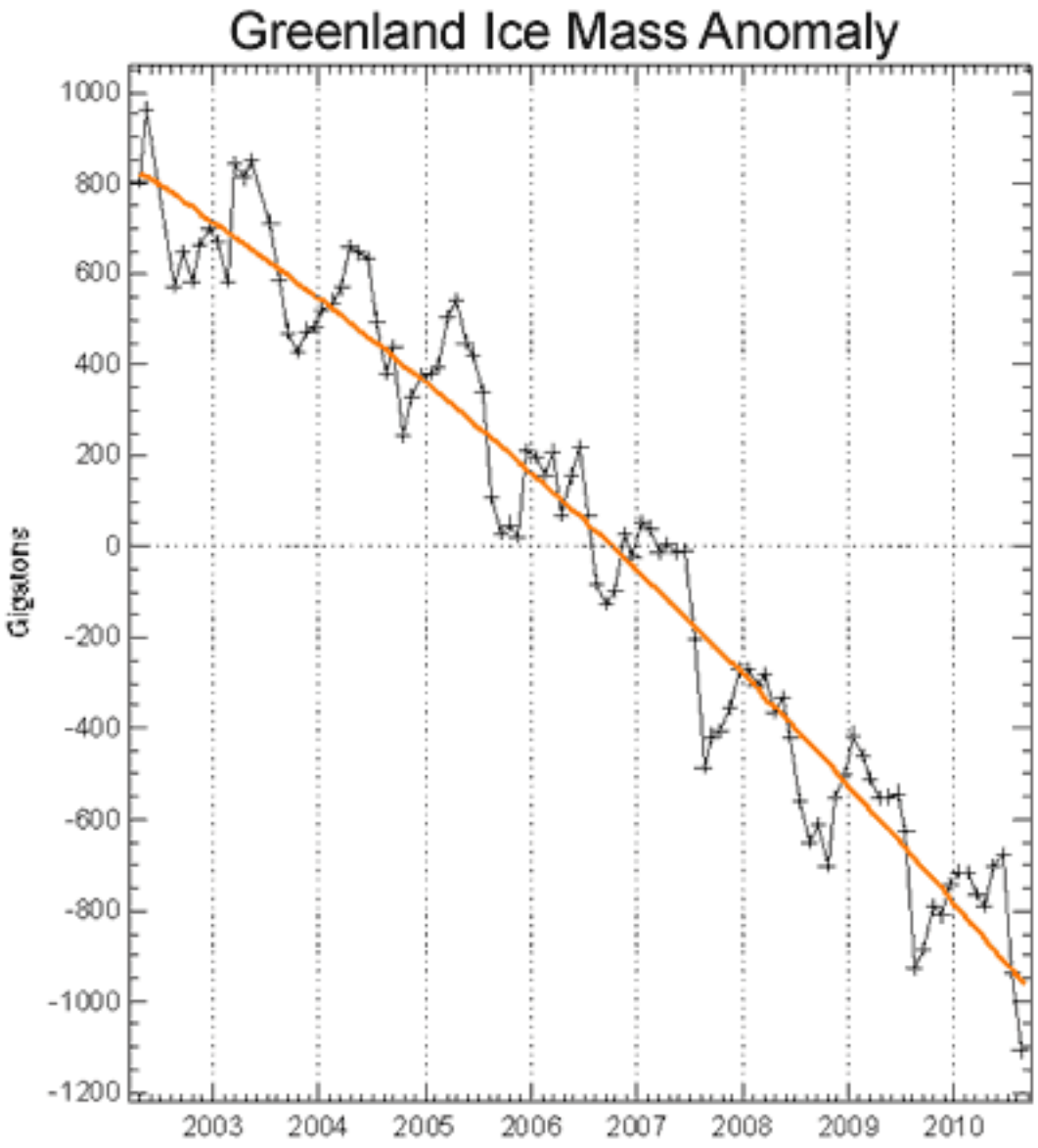


Figure 15. Greenland is losing ice.

Antarctica has been also been losing *land ice*, that is, ice that covers the continent. The average mass loss between 2002 and 2012 was 69 ± 18 gigatons (billion tons) per year.

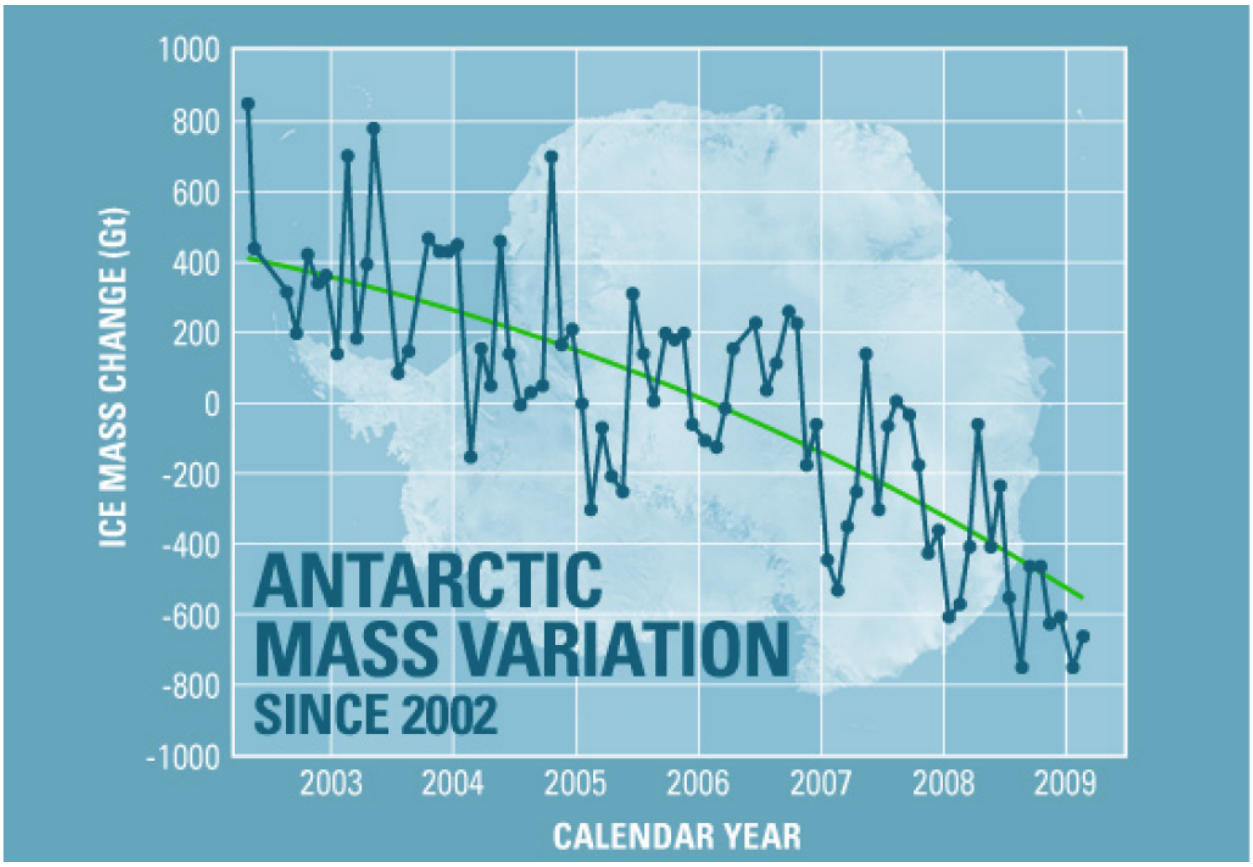


Figure 16. Antarctica is losing land ice

On the other hand, the amount of floating *sea ice* near Antarctica has been increasing, which some point to as evidence that global warming is false. The chart below compares the change in the amount of Arctic and Antarctic sea ice. If you sum the two, since 1978 each month shows an overall decline in polar sea ice.

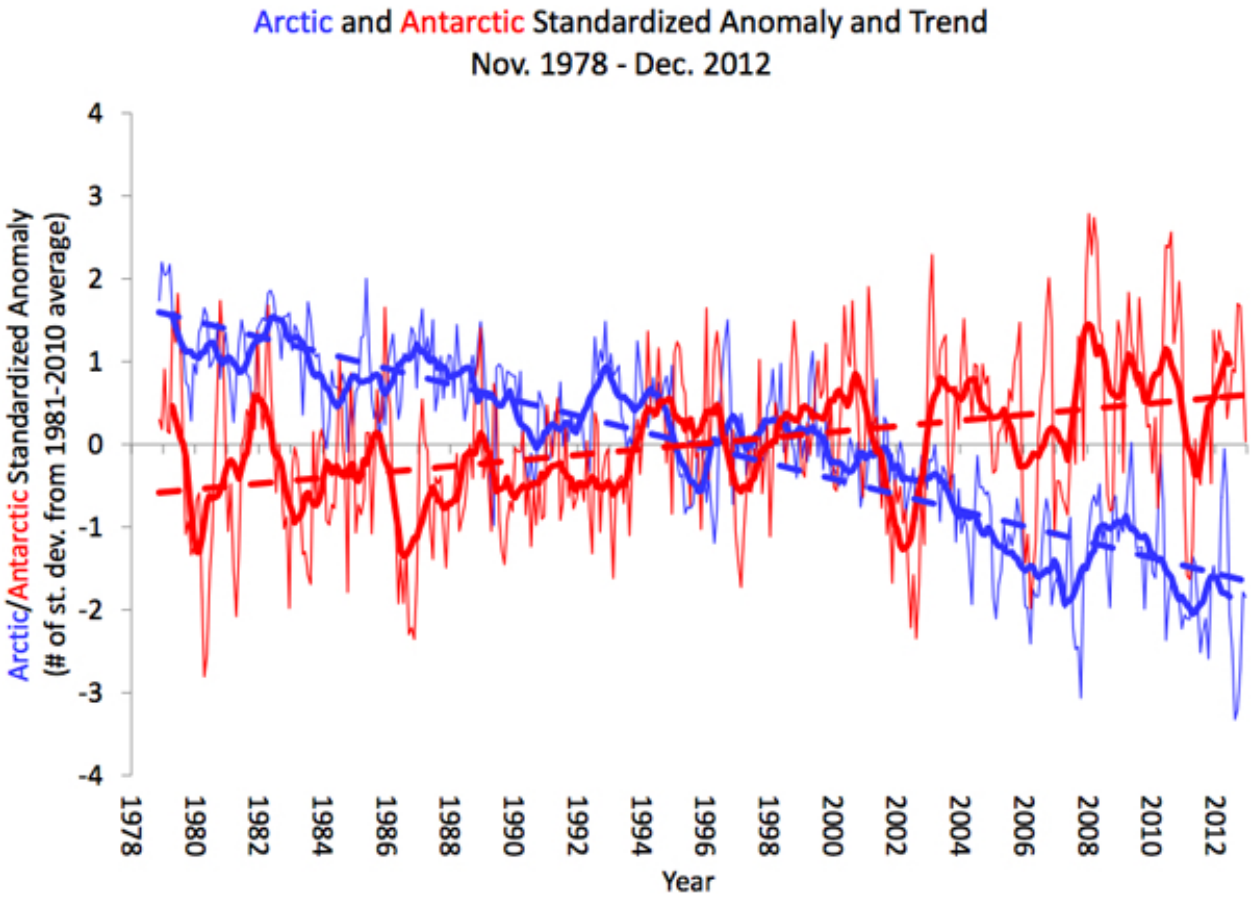


Figure 17. Antarctic sea ice (red) is growing, but less than Arctic sea ice (blue) is shrinking.

But how can Antarctica be gaining sea ice if the planet is warming? Especially considering that the Southern Ocean around Antarctica is itself warming. The National Ice and Data Center has a good discussion of the puzzle. For one thing, we know that as a continent completely surrounded by water, the sea ice around Antarctica is governed by different systems than is the sea ice of the Arctic Ocean, which is enclosed by continents. For example, Antarctic sea ice generally melts from below, rather than into surface meltpools like Arctic sea ice. That makes Antarctic sea ice more vulnerable to under-ice currents. Winds and the large-scale movement of ocean water can bring locally colder water to the surface, increasing the amount of sea ice. Scientists are well on their way to solving the puzzle of growing Antarctic sea ice.

Glaciers

A glacier is a natural illustration of the law of supply and demand. When more snow falls over a year than melts or sublimates, glaciers advance. When the opposite occurs, they retreat. Global warming should cause most individual glaciers to retreat and the total volume of ice held in glaciers to shrink. As shown below, this is what we observe.

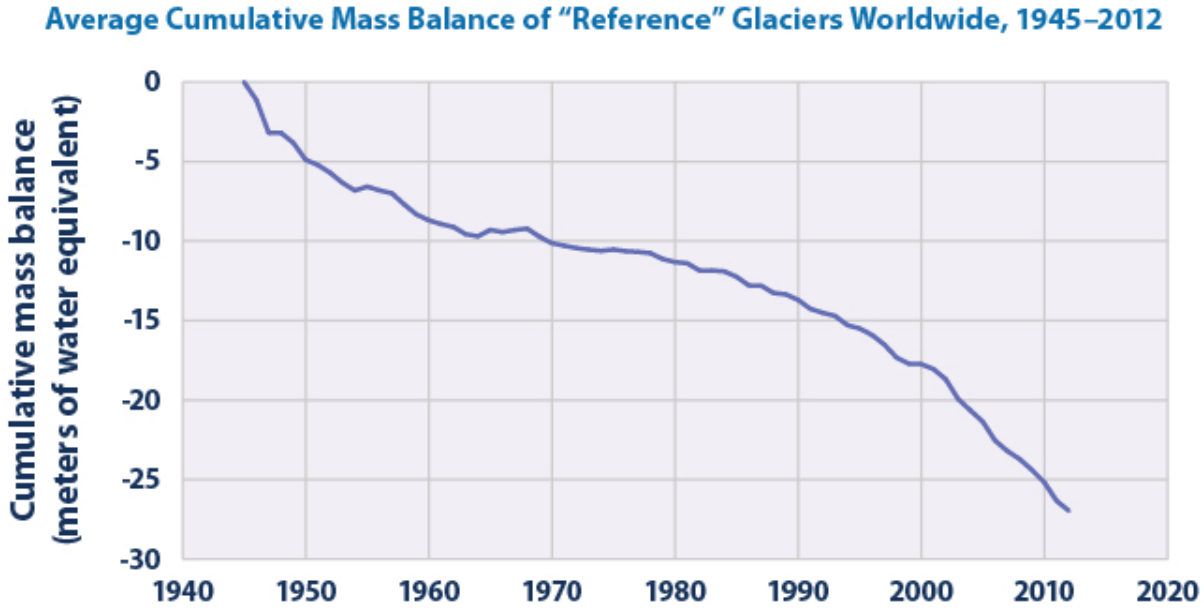


Figure 18. The world's glaciers are losing ice.

Glaciers act as natural reservoirs, reliably storing ice during the cold months and releasing it during the summer, when it is needed for agriculture and human consumption. Regions like those surrounding the Himalayas and those on the western side of the Andes depend on glacial meltwater to feed their rivers. As glaciers melt and more precipitation falls as rain than snow, these frozen storage reservoirs will shrink and eventually disappear.

The Himalayas contain thousands of glaciers that feed nine major rivers, which in turn provide water for 1.3 billion people. Surendra Shrestha, regional director at the United Nations Environment Programme for Asia and the Pacific, says that "If the temperature continues to rise as it is, there will be no snow and ice in the Himalayas in 50 years." He added, "It is a silent tsunami."

Tropical Glaciers: A Fragile Contradiction

Glaciers that lie near the equator are the most vulnerable to rising temperature. A few still exist in East Africa and New Guinea, but most of those left lie in the Andes of Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela. The large cities of these countries tend to lie to the west, in the coastal plain and under the rain shadow of the Andes. These are some of the driest lands on Earth. In some places in the Chilean Atacama Desert, no rain has ever been recorded.

Consider Peru as an example. About 70 percent of its population lives near the coast, which receives only 2 percent of Peru's precipitation. Lima supports 8 million people on less than 1 inch of rainfall per year. How does it manage? By harnessing the water of the Rimac River, which originates in glaciers in the distant Andes to the east.

From 1970 to 2000, Peru's glaciers shrank by nearly one-third. Between 1980 and 2005, the glacier on one of the most famous Peruvian peaks, 5,400-meter [18,000-foot] Pastoruri in Huascarán National Park shrank by 20 meters [66 feet] per year. By the end

of that period, the glacier covered less than one square mile. Selwyn Valverde, with the Huascarán National Park, says, “It's irreversible at this point.” He adds that Pastoruri is no longer technically even a glacier because it does not build up ice in the winter to release in the summer. “It's just loss, loss, loss now. It doesn't accumulate anymore.”

The Quelccaya ice field, the largest body of tropical ice in the world, has lost one-third of its area in the last 35 years, ice that had taken close to 2,000 years to accumulate. At this rate, Quelccaya will disappear sometime in the second half of this century.

Tropical glaciers in other parts of the world also started to melt in the last century. Kilimanjaro lost 80 percent of its ice and seven of Mt. Kenya’s eighteen glaciers disappeared. New Guinea’s tropical glaciers have also declined.

If you want to see a glacier within the lower 48 states, go, naturally, to Glacier National Park. But hurry. At its founding in 1910, 150 glaciers stippled the new park. During the twentieth century, the famous Grinnell Glacier lost 90 percent of its ice. Today only 25 glaciers remain in Glacier National Park and scientists estimate the last will be gone by 2030.

The Oceans

Heat Storage

As expected when the Earth is out of heat balance, ocean heat content has risen since the 1970s. During the alleged pause in surface temperature, the oceans down to 2000 m (6000 ft.) were storing an increasing amount of heat. Sooner or later that heat will emerge to raise global surface temperature even higher.

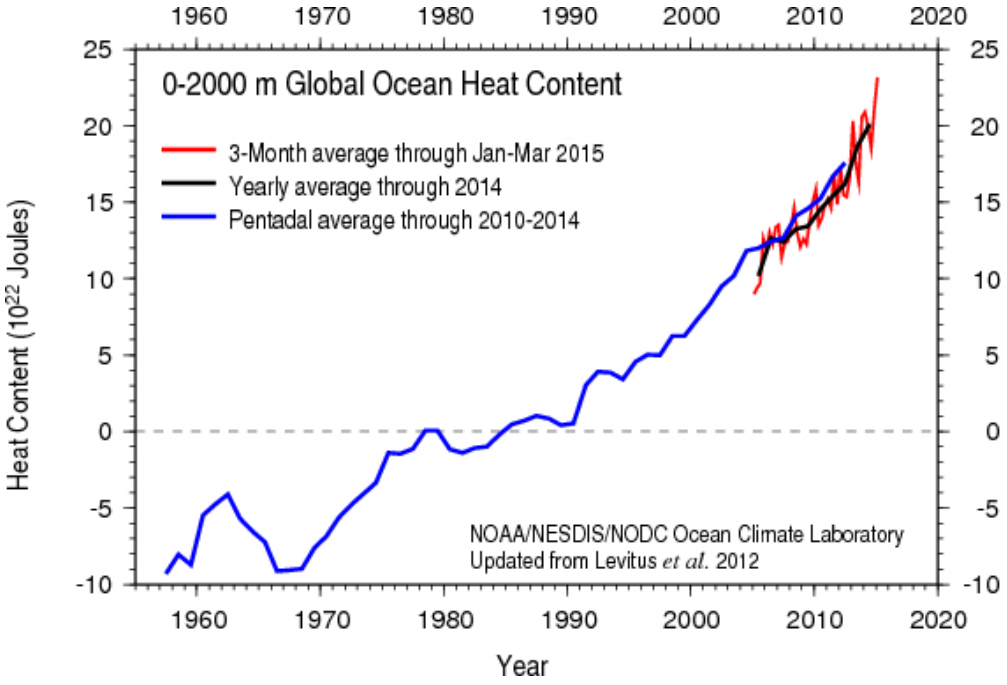


Figure 19. Heat stored in the oceans has risen steadily since the 1970s.

Sea Level

The water from melting ice caps, sea ice, and glaciers winds up in the ocean, where it raises sea level. Sea level also rises because warmer water occupies a greater volume. Rising seas represent both convincing evidence of global warming and one of its greatest threats

The term sea level as commonly used refers to “mean sea level,” the average level of the surface of one or all of the world’s oceans. At a particular location, it is the midpoint between high and low tides. That is a measurement anyone can make at a favorite seacoast. But many factors affect sea level, making it difficult to measure for all the oceans. Wikipedia lists 15 such factors, including the waxing and waning of continental glaciers. Another difficulty is that the land at the seacoast is itself often rising or falling for tectonic reasons. For instance, at the height of the last Ice Age, up to two miles of solid ice lay atop Scandinavia, warping the land surface downward. As the last ice melted and relieved the immense pressure, the land surface of Scandinavia began to rise, causing sea level to appear to fall.

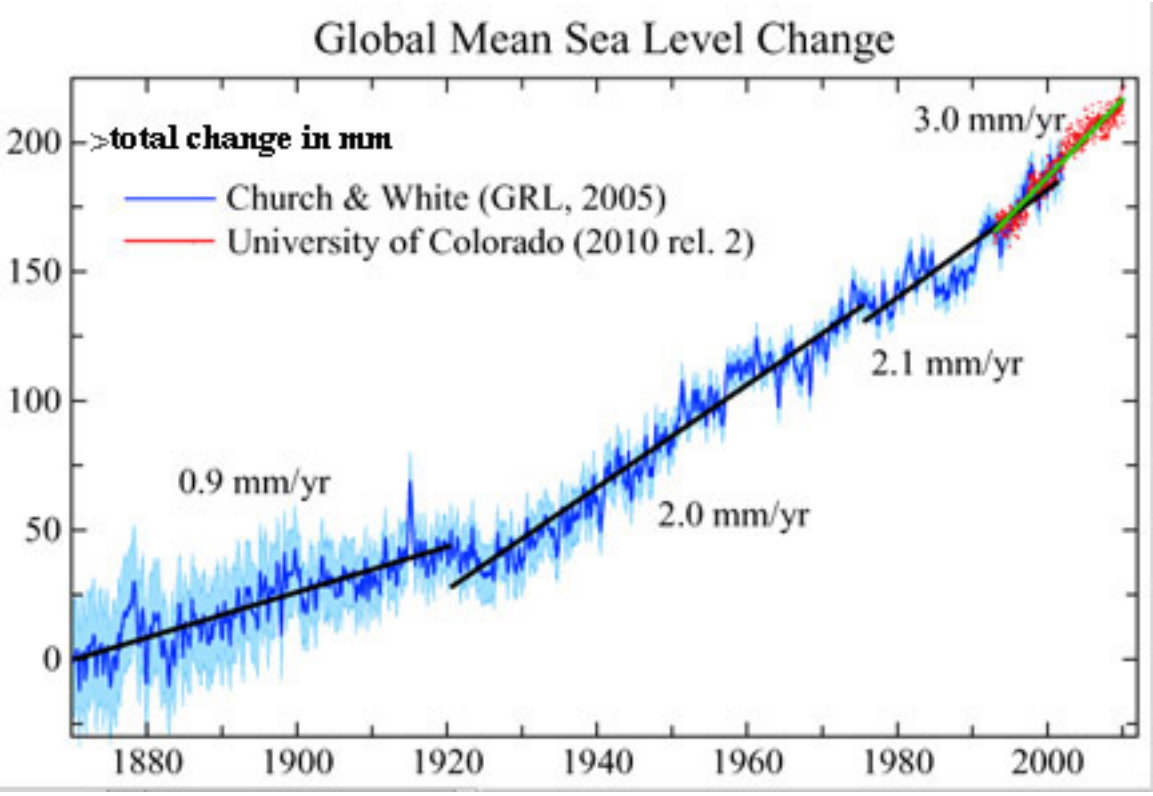


Figure 20. For the last 150 years, sea level has been rising (red=from satellites).

Given all this, we expect estimates of mean sea level to be less accurate the further back we go, as they are on the chart above. Accurate satellite measurements show that sea level today is rising at the fastest rate on record, and may even be accelerating. Elevated seas allow storm surges to ride in on a higher base, causing them to reach much farther

inland. (Note too that during the alleged pause in the rise of surface temperature, sea level kept right on rising.)

Below is a chart of past and possible future changes in sea level from the National Climate Assessment. The proxy data are from corals, peat, and sediment deposits. The orange band (1-4 ft.) comes from climate models, the wider range (0.66-6.6 ft.) from other methods of estimating potential sea level rise.

Note that the highest projected increase by 2100 from the models is 4 feet. If you are standing on a beach with a gentle slope of 1 foot in 100, a 4-foot sea level rise would send sea water 400 feet farther inland and storm surges much farther than that.

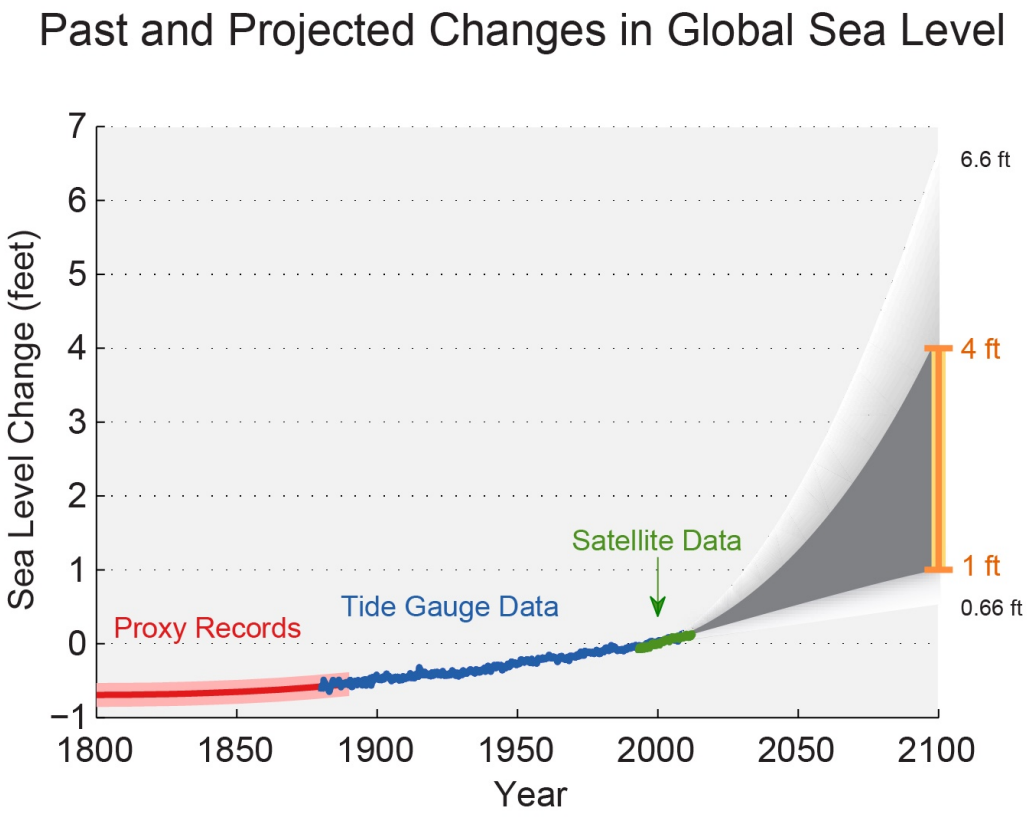


Figure 21. Sea level will rise further, the only question is by how much.

Projections of the rise in temperature and sea level, or in any quantity affected by global warming, typically stop at 2100. It makes sense: 2100 is an obvious target and the further out you project, the more uncertainty in your result. But believe this: if global warming continues on its current trajectory, **however high sea level has risen by 2100, it is going to keep right on rising with no end in sight.** Because the oceans release carbon dioxide on a time scale of centuries and millennia, the long-term effects of global warming, including sea level, will take thousands of years to return to pre-industrial levels. **Global warming may not be forever on a geologic time scale, but on our human one it might as well be.**

By one estimate, more than 200 million people worldwide live along coastlines less than 5 meters above sea level. On the current trajectory of global warming, at some point life near the inexorably rising seas will become untenable.

Acidifying Oceans

Scientists estimate that 30-40 percent of emitted carbon dioxide dissolves in the oceans, where it forms carbonic acid. More acidic oceans bleach and kill corals, while other sea creatures have more difficulty building and maintaining their carbonate shells. This map shows how the oceans have acidified as carbon dioxide levels have increased over the last several centuries. The more carbon dioxide we emit, the worse ocean acidification will become.

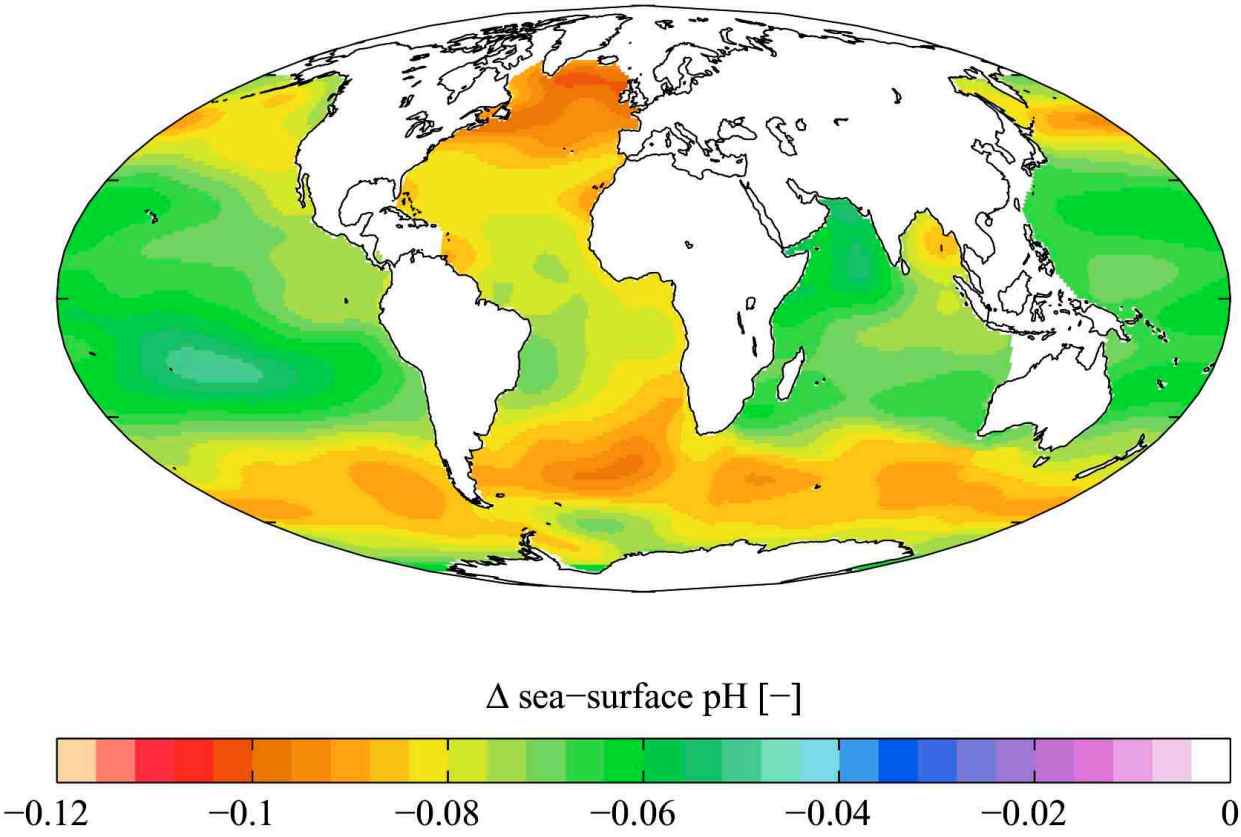


Figure 22. Carbon dioxide emissions have acidified the ocean, threatening marine life.

Biology

Rising global temperatures must affect plants and animals. Spring events, such as first flowering in the spring and the last winter frost, move to earlier calendar dates. Fall events like the first frost shift to later dates, the two together lengthening the summer heat and stressing crops.

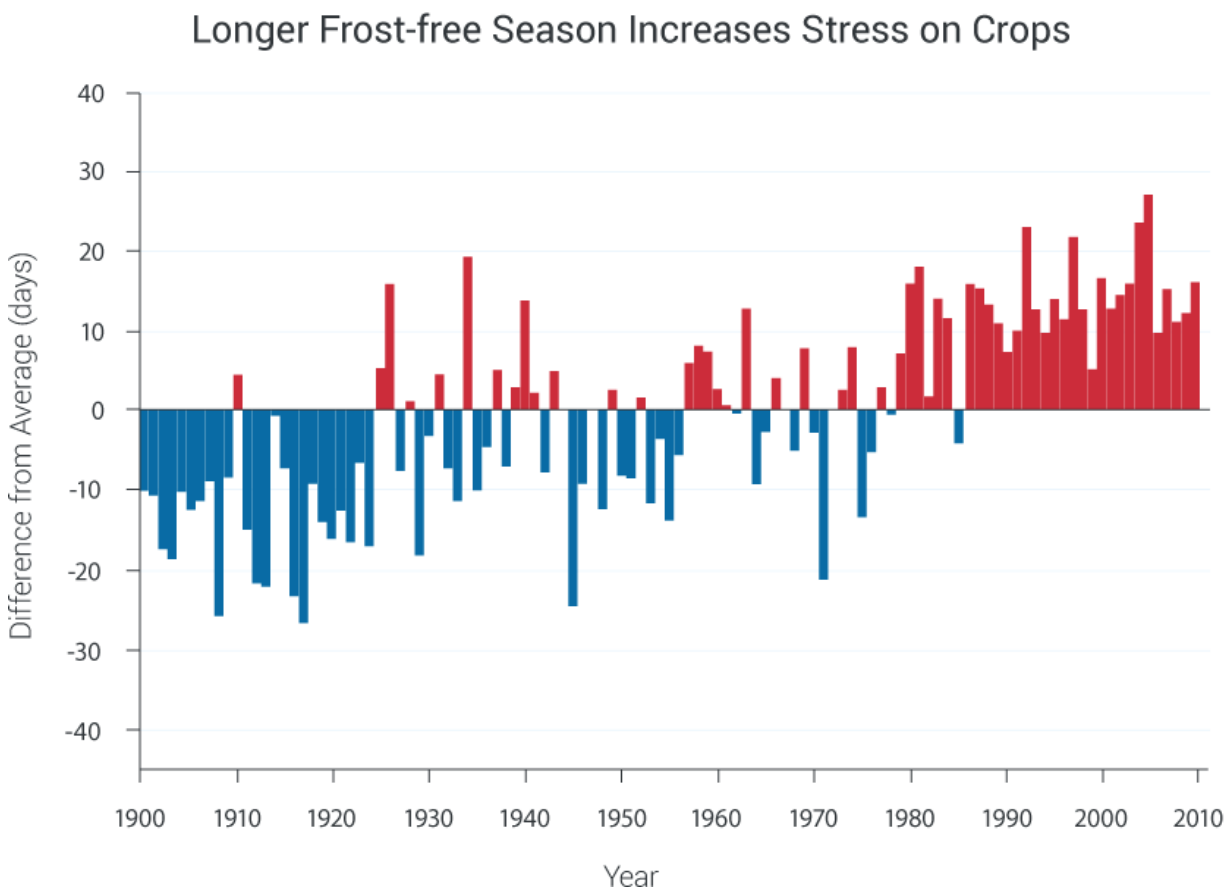


Figure 23. The frost-free season has lengthened.

Warming will cause the climatic zone in which a species has evolved to move toward the poles and up mountainsides, toward cooler temperatures. Some species may be able to shift their ranges to keep up, but many will not. Even species that are able to migrate may find that vital parts of their ecosystem cannot move with them. These species will go extinct and as we emit more carbon dioxide, the more extinctions there will be.

Scientists have begun to look for the effects of rising temperature on the plant and animal world. One study found, "Significant changes in physical and biological systems…on all continents and in most oceans…are in the direction expected with warming temperature. We conclude that anthropogenic climate change is having a significant impact on physical and biological systems globally and in some continents."

Another study used a different data series to conclude that "Global analyses of 1,570 species show highly significant, nonrandom patterns of change in accord with observed climate warming in the twentieth century, indicating a very high confidence (0.95 percent) in a global climate change fingerprint."

Animals, plants, and insects were shifting their ranges toward the pole by an average of nearly 4 miles (6.1 km) per decade; spring events had advanced by 2.3 days per decade. Over the total period studied, ranges shifted poleward from 30-600 miles and the snow line climbed from 300-2,000 feet. A later investigation raised the estimate of spring advancement to 2.8-3.2 days per decade.

The chart below from a 2007 report shows the change in timing of spring events by days per decade for more than 200 species. Almost all the changes are in the direction predicted by global warming. Spring events have advanced by two weeks on average since 1970. Some frog species are breeding a month earlier.

Animals that depend on sea ice are increasingly endangered, including polar bears, ringed seals, and Adelie and Emperor penguins. Species that live on alpine slopes, such as Harlequin frogs, pikas (the favorite animal of many mountaineers), and some butterflies are also threatened. Note that these polar and montane species have nowhere to go: a range shift is not possible when the only way out is poleward or up and no more poleward or up is left.

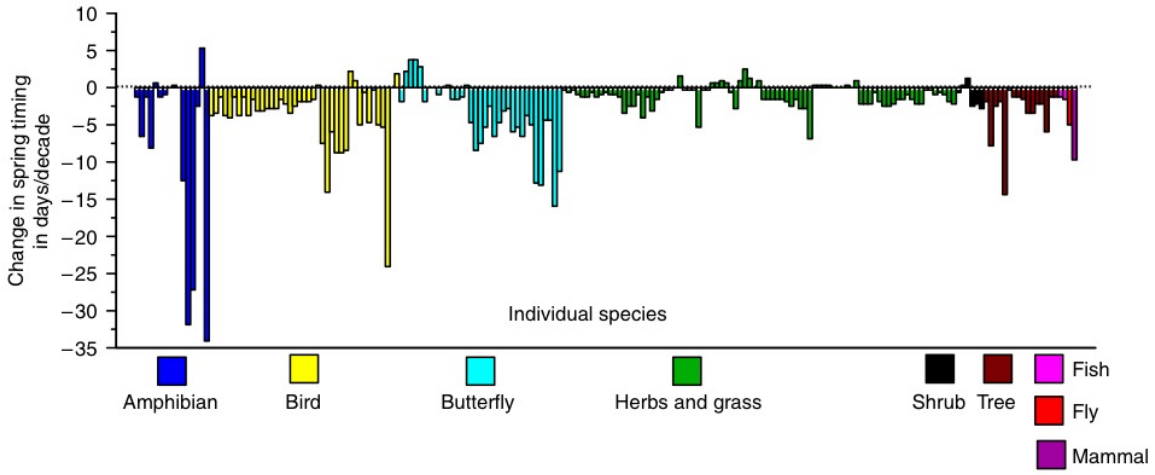


Figure 24. The timing of spring events shows that global warming is affecting many species.

On May 1, 2015, Science Magazine published an article titled, “Accelerating extinction risk from climate change.” The author, Mark Urban of the University of Connecticut, synthesized and reanalyzed the data from 131 carefully selected previously-published studies of extinction risk. His is the most thorough analysis to date. Urban concluded that “If we follow our current, business-as-usual trajectory [which will lead to a 4.3°C rise], climate change threatens one in six species (16%).” But according to the New York Times account of the study, written by science journalist Carl Zimmer, “other experts said the real toll may turn out to be even worse.” John Wiens, an evolutionary biologist at the University of Arizona, for example, said the number could be “two to three times higher” than Urban’s 16 percent. Three times 16% is close to 50%.

The Bark Beetle

Figure 25. Bark beetles nearly destroy a British Columbia forest.

Global warming does not threaten every species—some may even do better for a while, though in at least one case we wish they would not. I write of the mountain pine beetle (*Dendroctonus ponderosae*), which attacks and kills live trees as shown in this photograph of a British Columbia forest. (*Dendroctonus* translates as "tree killer.") The beetle, no larger than a grain of rice, drills through the outer bark of a tree and excavates a cavity into which it lays its eggs. The larvae hatch and devour the cambium layer of wood, which provides nutrients to the tree. These diabolical pipsqueaks then inject a fungus to stop the tree from moving sap to their lair and drowning them. If the tree begins to win the battle, the resourceful beetles emit a pheromone that calls in reinforcements. Often the tree cannot produce enough resin to hold the beetles at bay and it dies. The beetles first attack trees damaged by disease or drought, but when they run out of those, move to healthy trees.

Bark beetles create their own climate feedback: a live tree takes carbon dioxide from the atmosphere during photosynthesis, thereby offsetting the greenhouse effect. A dead tree not only no longer absorbs carbon dioxide, as it decays it releases the gas, changing an entire forest like the one shown in the photograph from a net absorber to a net emitter of carbon dioxide. In 2013, a team of scientists documented this effect, showing that a bark beetle infestation had lowered evaporation and increased the amount of heat escaping to the atmosphere enough to raise surface temperature by 1°C.

Until recently, cold winters killed off enough of the beetles to keep the population in check. But as winters have warmed, more beetles have survived to kill more trees. Dead trees are more likely to burn, raising the risk of forest fires, already higher in the West before the bark beetle pandemic really got going.

In British Columbia alone, bark beetles have killed an estimated one billion trees. Since 2000, the beetles have killed more than 65 million acres of trees in a dozen U.S. states. In Arizona and New Mexico in 2002 and 2003, the beetles killed 20 million ponderosa pines and 50 million piñon pines, destroying up to 90 percent of the trees in a given watershed. In Wyoming and Colorado in 2006, the bark beetle was largely responsible for the death of a million acres of trees. The next year, 1.5 million. In 2008, one U.S. forester estimated that in the next three to five years, "virtually all of Colorado's lodgepole pines will be lost, equivalent to about five million acres."

But here is one piece of good news—or is it:

> According to an annual assessment by the state's forest service, the mountain pine beetle infested 264,000 acres of trees in Colorado at the beginning of 2013. This was much smaller than the 1.15 million acres that were affected in 2008 *because the beetle has already killed off most of the vulnerable trees*. (Italics added.)

Summary

Wherever we look—temperatures, ice in all its forms, sea level, plants and animals—the evidence confirms that the Earth is warming.

Extreme Weather: Has Global Warming Begun?

In the 1830s, French scientist Claude Pouillet pointed out that the Earth must lose as much heat as it gains from the Sun. If our planet gained more heat than it lost, water at the surface would boil off and temperature would rise too high for human civilization. If the Earth lost more heat than it gained, it would cool until all the water at the surface froze, with the same poor result for humanity. Any object floating in space must obey this same requirement. As Pouillet realized, Earth's atmosphere must also remain in heat balance. It accomplishes this mainly through the action of the greenhouse effect.

Without the atmosphere and the greenhouse effect, the temperature at the Earth's surface would be 33°C (59°F) degrees colder on average. Much of human civilization would then be impossible.

Until the Industrial Revolution, the Earth maintained energy balance over geologic timescales of hundreds of thousands of years. For shorter periods, the Earth would fall out of energy balance, but over time return to its equilibrium state. Then about 200 years ago humans began to create a new, fast-track energy imbalance by inserting ever-larger amounts of carbon dioxide and other greenhouse gases into the atmosphere on a time scale of years—perhaps 100,000 times faster than the geologic changes that preceded the industrial age. To imagine we can get away with that indefinitely without paying a price is foolhardy.

Extreme weather events like heat waves, hurricanes, blizzards, downpours, and even droughts require energy, and the warmer the Earth, the more energy is available and the more extreme weather events we expect. Hurricanes, for example, draw their energy from warm seawater. The chart below shows how the temperature of the sea surface has increased, potentially adding energy to tropical storms.

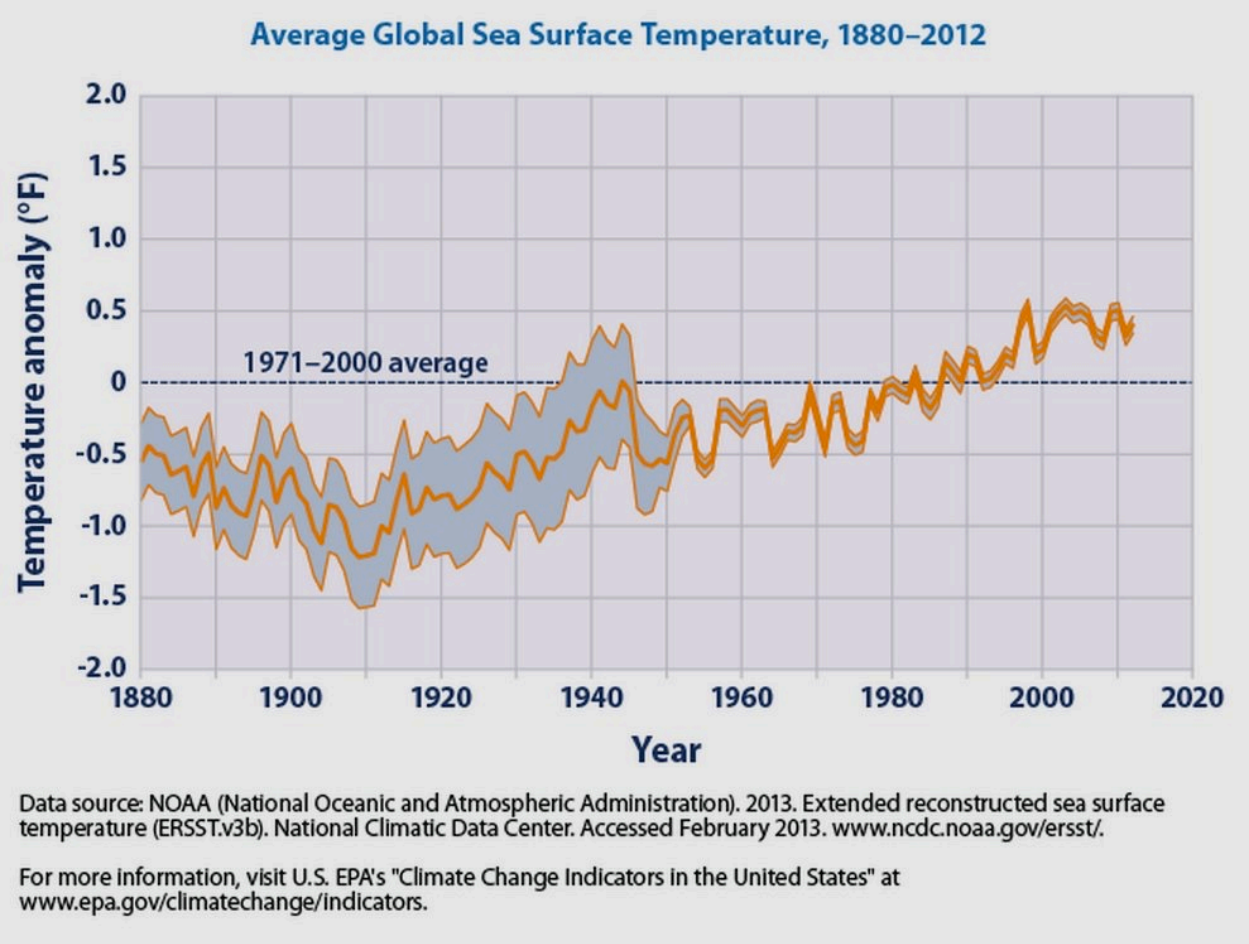


Figure 26. Global sea surface temperature has risen.

Attribution

Until the last few years, when asked whether global warming "caused" a specific extreme weather event like a new high temperature record or a hurricane, a scientist might have been apt to respond, "We cannot attribute any single extreme event to global warming." Many who heard that response no doubt translated it to mean that scientists do not know whether global warming is causing more extreme weather events.

As an excellent article in *The Economist* points out, targeting 2100 as the year by which to gauge the severity of global warming compounds the uncertainty by seeming to put the danger a century ahead. If scientists cannot be sure that global warming has begun and if its worst effects will not be felt for 100 years, why rush to do anything about it? But what if we had strong evidence that global warming not only had begun but was already having harmful effects?

Smoking provides a good analogy. Though not everyone acts on the knowledge, people accept that smoking today is likely to give you lung cancer decades in the future. No one can say for certain that a given smoker will get lung cancer, but the odds are unfavorable to say the least and we know that the more who smoke, the more who will get lung cancer. But how do we know those odds? By using vast health databases to compare the

incidence of lung cancer among smokers and non-smokers. Is it possible to do something similar for global warming?

Not in the same way, for we have only one planet and cannot rerun its history. But we can simulate different histories and futures on Earth using computerized climate models, to be discussed in the next chapter. They have improved enough to predict the likelihood of given extreme weather events with and without greenhouse gas emissions. If global warming has truly begun, these "attribution" studies will show it. We still will not know exactly what caused a single extreme weather event, but we can now say that global warming has made a particular type of event, say, twice or ten times as likely.

European Heat Wave of 2003

One of the first extreme events to be analyzed for the possible contribution of global warming occurred in the summer of 2003, when the deadliest heatwave since at least 1540 struck Europe. France was especially hard-hit, but nearly every nation in western and southern Europe reported far more heat-related deaths than normal.

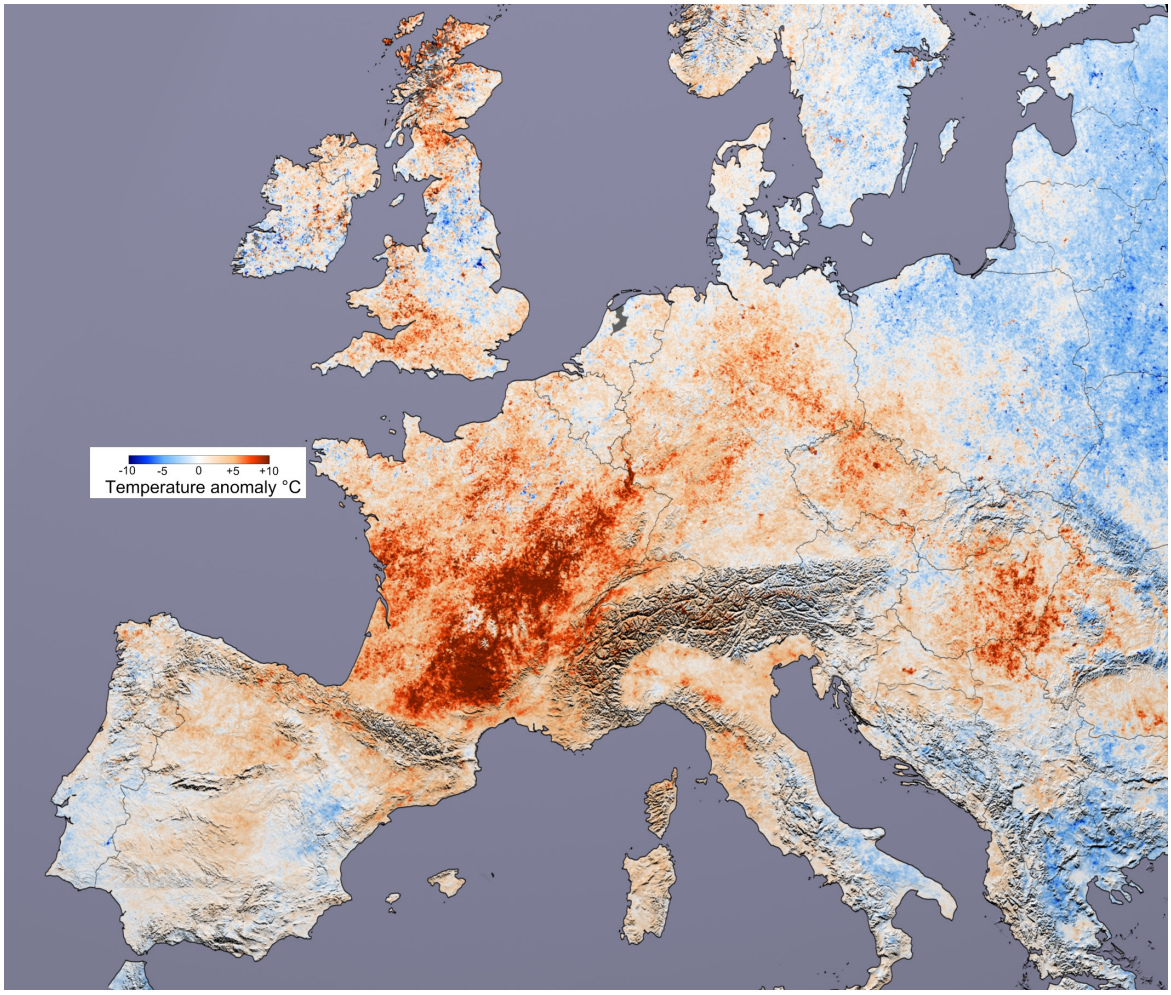


Figure 27. In 2003, a deadly heat wave descended upon Europe. Deaths numbered 70,000.

For the ten preceding years, average August temperatures in France had ranged from 17°C to 22°C (63°F to 72°F.) But in July 2003 temperatures in the south of France rose to 40°C (104°F) and remained high for a week. Other countries also suffered. According to the UN Environmental Program, the all-time maximum temperature recorded in the United Kingdom was broken on August 19 at 38.1°C (101.3°F.) In Switzerland, June was the hottest month ever recorded in 250 years of archives. On August 11, the temperature rose to 41.5°C (106.7°F), a new record.

During the heat wave, nighttime temperatures were often higher than average daytime temperature. The highest nighttime temperature ever recorded in France, 25.5°C (77.9°F), occurred during the night of August 11-12, more than doubling the death rate.

To prevent overheating, nuclear reactors must use cooling water, after which they return the water to its source. In some parts of France that summer, river levels fell too low to allow water for reactors to be withdrawn. Sometimes the water could have been withdrawn but, by the time it left the reactor, would have been too hot to return without violating environmental safety standards. Authorities had to shut down some reactors, cutting electrical power.

Glaciers in the Alps, which have been on the decline since 1980, shrank by a further 5-10 percent. European crops were already suffering from the previous harsh winter; now the high heat added to the toll. Green fodder for livestock declined by 60 percent in France. Potato, wine, and cereal production dropped. High temperatures and low moisture also led to devastating fires that burned nearly six percent of Portugal's forests, an area the size of Luxembourg.

In France, where more than 14,800 died, several factors combined to raise the death toll. Unaccustomed to extreme heat, people were not aware that they needed to drink more water. Most French homes had no air conditioning. Authorities had prepared contingency plans to deal with expected disasters, but they never allowed for temperatures above 100°F (37.7°C). Moreover, August is the month when the French, including French physicians, take their vacations. One result was that the bodies of some who died during the heatwave went uncollected for weeks. Some were never claimed. Most of the victims were elderly, often seniors living alone with no one to turn to for help and advice.

When scientists ask why the heat wave occurred, one thing they note is that the average summer temperature in Europe has been climbing, especially since the 1970s. Obviously, the odds of record-breaking temperatures are greater now than in the mid-twentieth century, as the more recent extremes rise from the higher base.

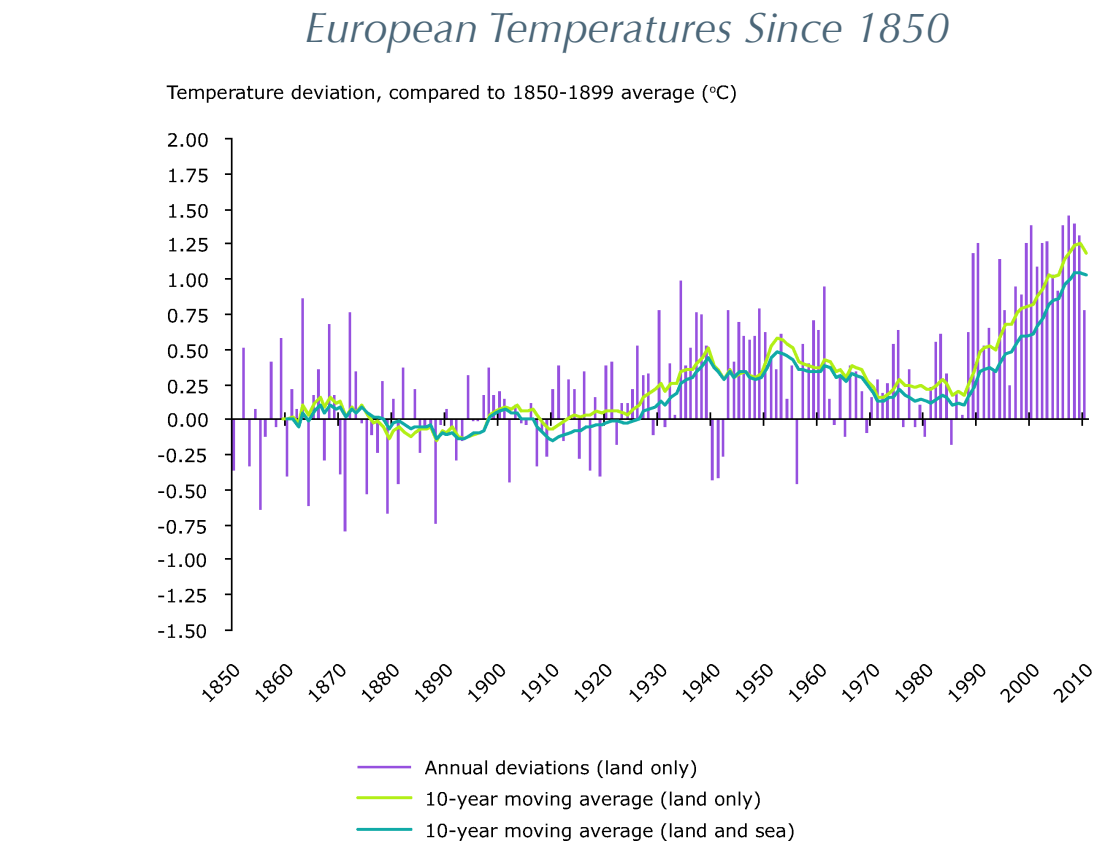


Figure 28. European temperatures now rise from a higher base.

Just how high, statistically speaking, were the European temperatures in the summer of 2003? Scientists reported that the temperature in Switzerland was 5.4 standard deviations above the long-term mean, making it an extremely rare event.

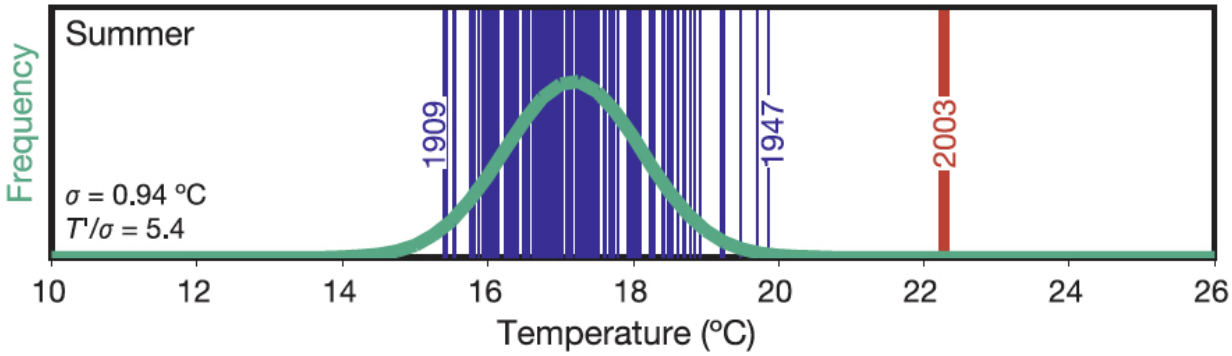


Figure 29. Swiss temperatures in 2003 were 5.4 standard deviations above the average.

In 2004, three climate scientists reported it "very likely (confidence level >90 percent) that human influence has at least doubled the risk of a heatwave exceeding this

threshold magnitude." Their article ended with a truly frightening projection: "By the end of this century…2003 would be classed as an anomalously cold summer relative to the new climate, for the scenario and model under consideration." That's right—anomalously *cold*.

In 2014, one of the three authors of the article, Peter Stott, and two colleagues looked back to ask "how the likelihood of having another extremely hot summer in one of the worst affected parts of Europe has changed ten years after the original study." They found that "events that would occur twice a century in the early 2000s are now expected to occur twice a decade." For a truly extreme event like the 2003 heat wave, "The return time reduces from thousands of years in the late twentieth century to about a hundred years." In other words, ten years of inaction on global warming have increased ten-fold the odds of one of the deadliest heat waves in history.

The American Meteorological Society (AMS) has for a number years published an annual "state of the climate" report. In 2012, the society launched a new annual survey series: "Explaining Extreme Events from a Climate Perspective." These surveys review efforts by scientists to attribute a given extreme weather event to global warming, as Stott and colleagues did for the European Heat Wave of 2003. The report for 2011 considered six individual extreme events, while the one for 2013 presented the results of 20 different research groups exploring the causes of 16 different events. These numbers reflect the increased effort going into attribution studies. Let us consider a few examples.

Texas Heat and Drought of 2011

The U.S. summer of 2011 was by a wide margin both the hottest and driest in a record that began in 1895. During July 2011, 3,552 nighttime high temperature records were broken, but only 770 nighttime low temperature records. If the Sun were the cause of global warming, why would nights warm more than days?

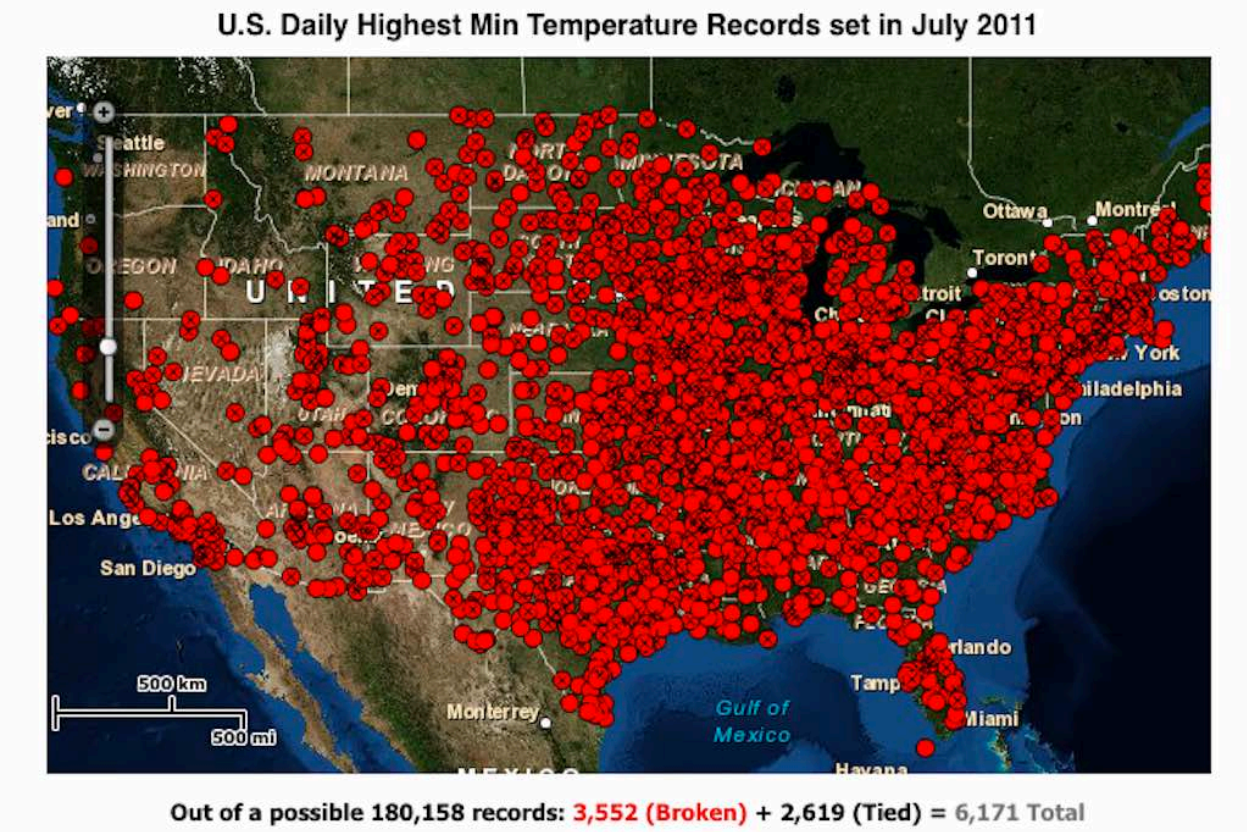


Figure 30. In July 2011, 3,552 U.S. highest nighttime temperature records were set, but only 770 lowest nighttime records.

One article in the AMS review described how the authors used a global climate model to try to determine whether the heat and drought in Texas during the summer of 2011 had become more likely. They acknowledged that the effort "severely stretched the current state of the science." Nevertheless, they were able to conclude that,

> Extreme heat events were roughly 20 times more likely…than in the 1960s. Conditions leading to droughts such as the one that occurred in Texas in 2011 are distinctly more probable than they were 40-50 years ago.

The Warm Spring of 2012 in the Eastern U.S.

As reported by NOAA, 2012 was the warmest on record in the lower 48 states, topping 2011. Climate Central has an interactive chart (static version below) from NOAA showing everything you could want to know about the warmth that year. The year 2012 had the fourth-warmest winter, the warmest spring, the second-warmest summer, and a warmer-than-average fall.[6]

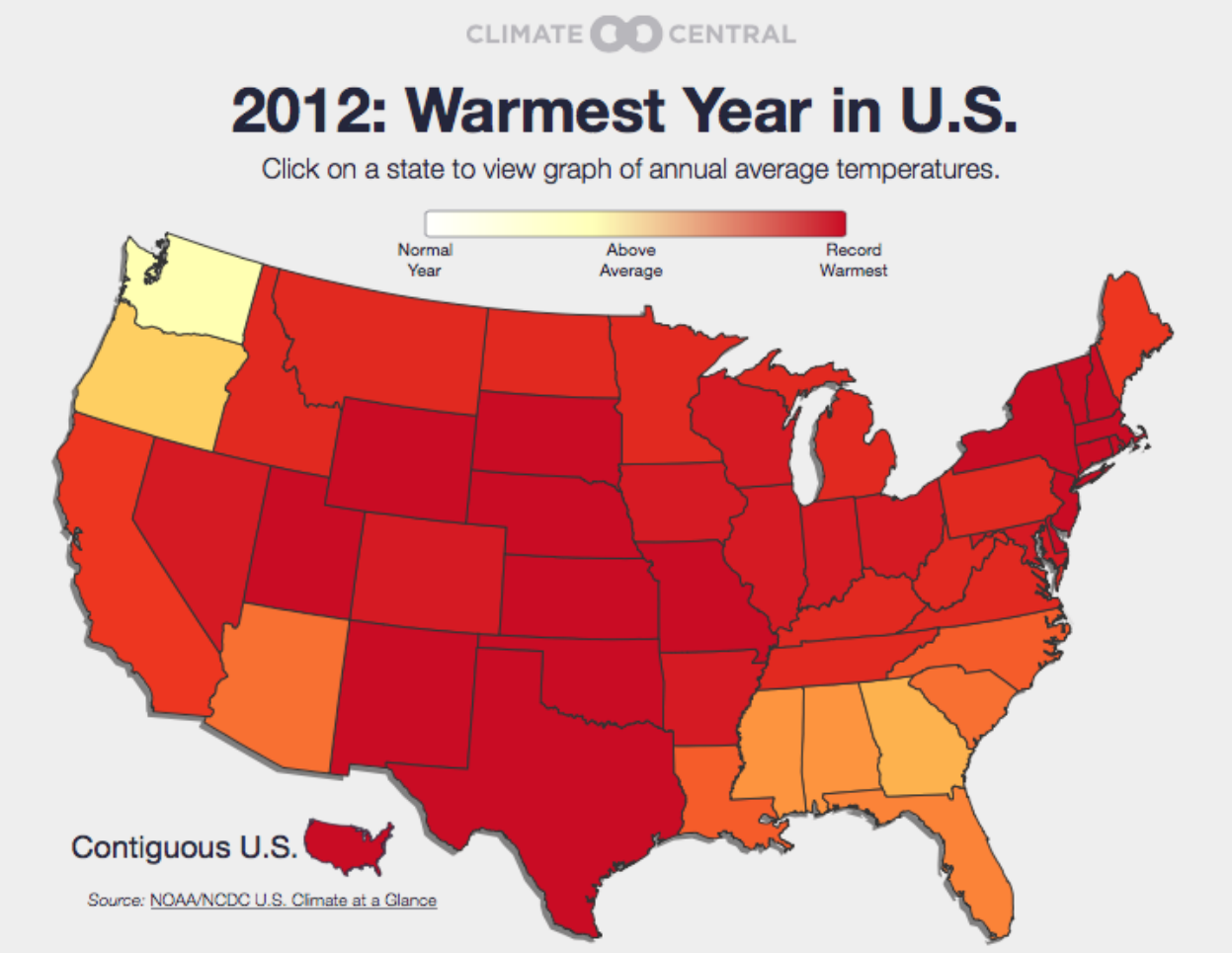


Figure 31. 2012 was the warmest year in U.S. history up to that time.

A team of researchers used climate models to compare the temperatures of 2012 with and without greenhouse gases. Once again, this project stretched the capabilities of the methods. Still, the team concluded that:

> The anthropogenic contribution to the extreme seasonal (March-April-May [2012]) warmth over the eastern United States…leads to a factor of 12 increase in the risk of such an event.

Sandy

Over October 29-30, 2012, Hurricane Sandy ripped into the U.S. mid-Atlantic seaboard, causing an estimated $68 billion of damages. It was the second most-costly U.S. hurricane. To make matters worse, the huge storm surge that Sandy brought to New York harbor occurred at the same time as the peak high tide, raising a storm tide of about 2.7 meters (9 feet). Yet even at its peak, Sandy never exceeded a Category 3 ranking on the 1-5 Saffir-Simpson hurricane wind scale.

Sandy broke 16 tide-gauge levels along the East Coast. What made the storm especially damaging was that, unlike other hurricanes that had made landfall in the same area, Sandy was the only one that tracked westward rather than north-northeastward,

sending it inland rather than out to sea. The researchers estimate that this anomalous trajectory had a probability of occurrence of only once in 700 years.

In the end, the research team concluded that overall a Sandy has a probability of reoccurrence of once in 1570 years at the New York City Battery, showing just how rare the storm was. But in 1950 sea level was enough lower to make the probability of a Sandy at the Battery at that time once in 2230 years. Thus a Sandy-like event, while still rare, is more likely than it was in mid-twentieth century.

The Big Hot and Dry

In January 2013, tennis fans around the world watched players wilting and defaulting as extreme heat descended on the Australian Open. As a press release from the University of New South Wales (UNSW) later reported, in 2013 Australia "had its hottest day on record, its hottest month on record, its hottest summer on record, its hottest spring on record and then rounded it off with the hottest year on record." The average temperature for the year was 1.5°C (2.7°F) above the 1911-1940 average. Four of the papers in the American Meteorological Society survey for 2013 focused on the extreme heat Down Under.

Dr. Lisa Alexander, a researcher at UNSW summed up:

> We often talk about the fingerprint of human-caused climate change when we look at extreme weather patterns. If we were climate detectives then Australia's hottest year on record in 2013 wasn't just a smudged fingerprint at the scene of the crime, it was a clear and unequivocal handprint showing the impact of human caused global warming.

The scientists found that the record year would have been "virtually impossible" without global warming. Global warming had:

•doubled the chance of the most intense heat waves
•tripled the likelihood of heatwave events
•made extreme summer temperature across Australia five time more likely
•increased the chance of hot, dry, drought-like conditions seven times
•made hot spring-temperatures across Australia 30 times more likely

This Hot and Sceptred Isle

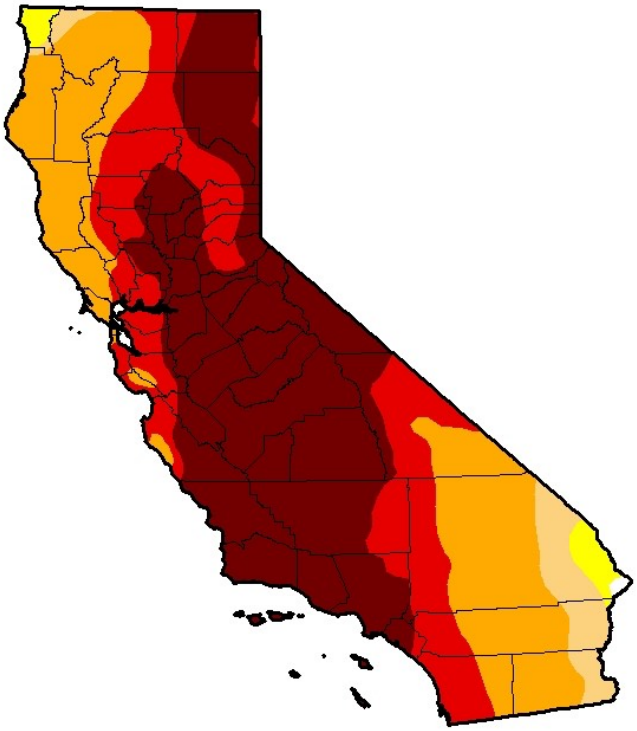
The year 2014 was England's hottest since record-keeping began more than 350 years ago. The Central England Temperature record, covering the area between London, Bristol, and Lancashire, is the longest instrumental record in the world. Researchers used two different methods to study how likely a record year like 2014 has become. First, they ran climate models with and without greenhouse gases. They found that greenhouse gas emissions have made England 13 times more likely to get a year as hot as 2014. Second, they compared the number of very warm years today with those from a century ago. This method found that year like 2014 is 22 times more likely. Thus both methods show that extremely warm years have become much more likely because of human greenhouse gas emissions.

The Great California Drought

On the first of April 2015, California Governor Jerry Brown walked out on a meadow in the Sierra Nevada mountains to participate in the annual measurement of snowpack depth. Instead of skis or snowshoes, the Governor was wearing hiking boots. “We’re standing on dry grass,” he said. “We should be standing on five feet of snow.” Overall the Sierra snowpack, from which California gets a vital part of its water, was only five percent of normal.

By the time of the Governor’s trek, the state was in the midst of the worst drought on record. In April 2014, 23 percent of the state had been in “exceptional drought.” A year later, it was 41 percent. In the spring of 2015, Governor Brown declared the first-ever mandatory water use restriction, requiring water districts to cut water usage by 25 percent. Then on April 29 he upped the ante, calling for $10,000 fines for California residents and businesses who waste the most water. But the governor may not stop there. As reported in USA today, he said:

> "We've done a lot. We have a long way to go," Brown said after meeting with the mayors of 14 cities, including San Diego and Oakland. "So maybe you want to think of this as just another installment on a long enterprise to live with a changing climate and with a drought of uncertain duration."



U.S. Drought Monitor

California

April 7, 2015

(Released Thursday, Apr. 9, 2015)

Valid 7 a.m. EST

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.15	99.85	98.11	93.44	66.60	44.32
Last Week 3/31/2015	0.15	99.85	98.11	93.44	66.60	41.41
3 Months Ago 1/6/2015	0.00	100.00	98.12	94.34	77.94	32.21
Start of Calendar Year 12/30/2014	0.00	100.00	98.12	94.34	77.94	32.21
Start of Water Year 9/30/2014	0.00	100.00	100.00	95.04	81.92	58.41
One Year Ago 4/8/2014	0.00	100.00	99.81	95.21	68.76	23.49

Intensity:

D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Michael Brewer
NCDC/NOAA

http://droughtmonitor.unl.edu/

Figure 32. In spring 2015, 41 percent of California is under exceptional drought

Did global warming "cause" the great California drought? As we have seen, the question is not that simple. Here is what scientists do know, based on an article by Dr. Joe Romm on ThinkProgress.

Researchers at Woods Hole Oceanographic Institute found that

> …the current [California drought] is the most severe drought in the last 1200 years, with single year (2014) and accumulated moisture deficits worse than any previous continuous span of dry years….

Drought is driven by a combination of two factors: reduced precipitation and increased temperatures. In the case of the California drought, the Woods Hole researchers found that the precipitation, though low, was not unprecedented. But temperatures were the highest on record. As Dr. Peter Gleick pointed out, "The last 36 months are the hottest AND driest 36 months in the instrumental record for California."

It would be an oversimplification to say that global warming caused the epic California drought—but global warming did make it worse. Future droughts, occurring at higher temperatures with more evaporation and dryer soils, will be worse still.

Snowmageddon

Before we leave the subject of extreme weather, we need to address one common misconception: that an extreme cold event shows that scientists are wrong about global warming. Global warming does not prevent record cold days. They will still occur, but will be outnumbered by record warm days, as we have seen has been the case recently.

Moreover, we have to keep reminding ourselves that global warming is global. One region may have unusually cool weather at the same time the rest of the planet is unusually warm. This happened in January 2015 when the eastern U.S. was frigid while the entire country had four times as many daily warm records as daily cold records.

Globally, 2015 had the second warmest January on record. This chart from NASA shows that Eastern North America and Mexico were two of the few populated regions with below average temperatures for the month.

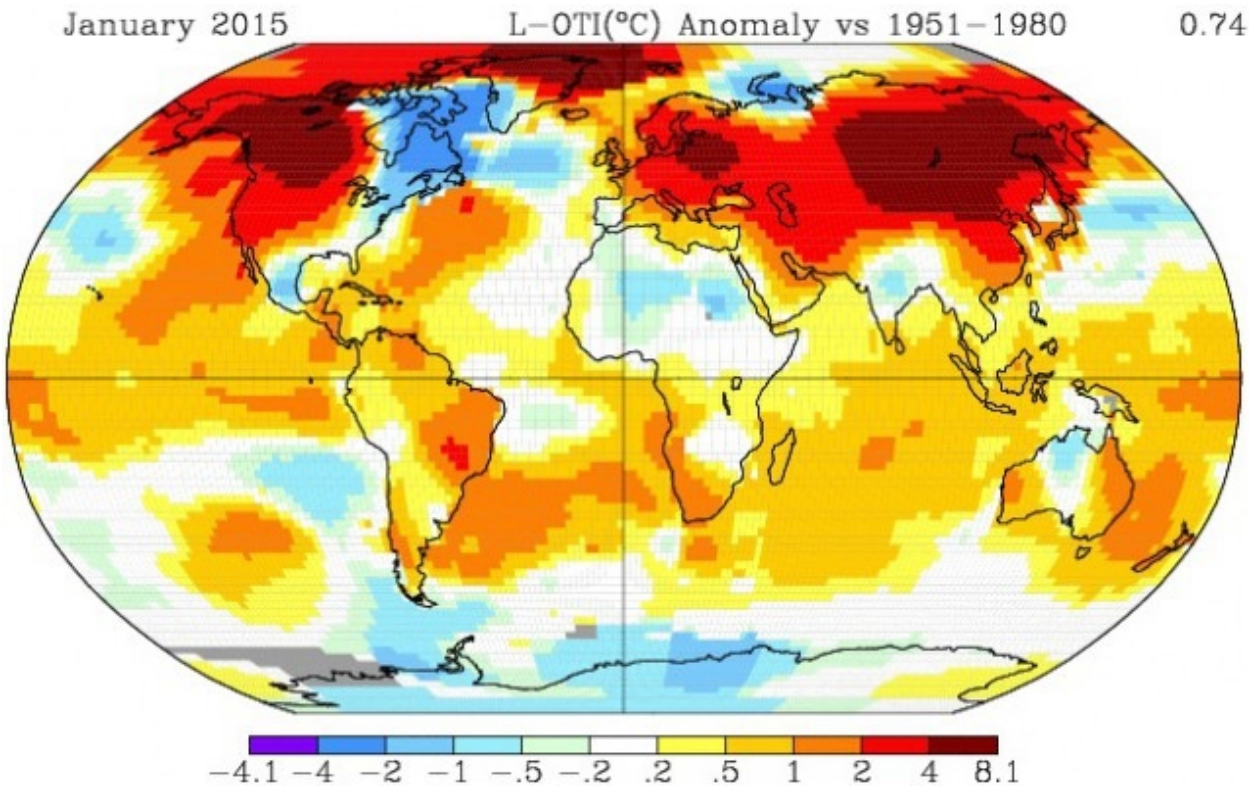


Figure 33. In January 2015, only a few regions, including Eastern North America and Mexico, had temperatures below the long-term average.

One frequently misinterpreted extreme weather event is the blizzard. Snow requires enough water vapor in the atmosphere and low enough temperatures to produce ice crystals. The higher temperatures under global warming will cause more evaporation, which will put more water in the atmosphere and increase the likelihood of rain and snow. But higher temperatures obviously work against snow formation and accumulation. The question is how these two contrary trends balance out. Should we expect fewer blizzards under global warming? Not necessarily.

Climate models project that with global warming we should have a greater proportion of heavy snowstorms, but roughly the same number of average and below-average storms. Two studies found that winter snowstorms have become heavier on average in recent decades.

But what about the last few years? In the northern hemisphere, the winter of 2009-2010 was one of the weirdest. Canada had its warmest and driest winter on record, requiring snow to be hauled in for the Winter Olympics in Vancouver. Yet while the Canadians had too little snow, the eastern U.S. had too much.

In Philadelphia, 23.2 inches of snow fell on December 19-20, 2009 and 28.5 inches fell on February 5-6, 2010, the third and second largest snowstorms, respectively, in the history of the city. Both were “once-in-100-year” storms, yet they occurred within weeks of each other. No pair of storms as large and as close together in time had occurred since modern records began to be kept in 1870.

In Washington D.C., 16.4 inches fell on December 19-20 and 17.8 inches on February 5-6, the eighth and fourth largest snowstorms on record. The winter gave New York City three of its top 10 blizzards since 1869. It proved impossible to resist calling the February blizzard, "Snowmageddon."

The storm provided more than enough snow in Washington for Senator James Inhofe, author of *The Greatest Conspiracy*, and his family to build an igloo and advertise it as "Al Gore's new home," inviting passing motorists to "honk if you love global warming."

Figure 34. The Inhofes build an igloo

Four months later, on June 24, 2010, the temperature in Washington, D.C. reached 99°F, breaking a record that had stood since 1894. The Inhofe Igloo was long gone. It was too hot to honk.

The first few weeks of 2015 saw more snow in our nation's capitol. In late February, Senator Inhofe, now chair of the Senate Environment and Public Works Committee, took the Senate floor with an unusual object in a plastic bag at his side. It was a snowball, which he then tossed to the surprised chair, saying,

> In case we have forgotten, because we keep hearing that 2014 has been the warmest year on record, I ask the chair, you know what this is? It's a snowball. And that's just from outside here. So it's very, very cold out.

Senator Sheldon Whitehouse (D-RI) responded, "You can believe every single major American scientific society, or you can believe the Senator with the snowball."

Some scientists speculate that the spate of blizzards along the East Coast links to disappearing Arctic sea ice. Here's the argument: The Arctic is warming twice as fast as lower latitudes, which lowers the temperature difference between the two regions. That might weaken wind speeds and allow the jet stream to dip farther south. That in turn

might allow winter storms to reach farther down and to remain longer and dump more snow. Scientists have yet to confirm this idea, but it does show that in interpreting extreme weather events, the simple answer, like the Inhofe igloo and snowball, is likely to be wrong.

Summary

Just as this book was wrapping up prior to submission, the New York Times broke a story headlined "New study links weather extremes to global warming." It reported a new peer-reviewed article that had just appeared in *Nature Climate Change* which, according the newspaper account, found that

> The moderate global warming that has already occurred as a result of human emissions is responsible for about 75 percent of daily heat extremes, and about 18 percent of precipitation extremes, scientists reported Monday.

"People can argue that we had these kinds of extremes well before human influence on the climate—we had them centuries ago," said one of the study authors. "And that's correct. But the odds have changed, and we get more of them." His coauthor summed up, "The bottom line is that things are not that complicated. You make the world a degree or two warmer, and there will be more hot days. There will be more moisture in the atmosphere, so that must come down somewhere."

Here's where I think we stand: even though we cannot say that global warming caused a given extreme weather event, there is no longer any doubt that global warming has raised the odds of such events significantly. We don't have to wait for decades to see the effects of global warming: they are evident now, in real time and on the ground, and they are damaging life and property. As *The Economist* aptly concluded its story, "People are routinely told about—and routinely ignore—the bad things they are doing to the climate. The attribution studies show that the climate is doing bad things back."

Do Climate Models Work?

Climate Modeling

How do scientists project temperature and sea level into the future? They model global climate using supercomputers and massive computer programs. Spencer Weart's masterful *The Discovery of Global Warming* gives a non-technical account of the development of global climate models from the 1960s to the present.

The first to show that increasing atmospheric carbon dioxide will raise temperature was Svante Arrhenius in 1896. To calculate how much a given increase in carbon dioxide would cause temperature to rise, Arrhenius spent months making tedious hand calculations. In the early 1950s, Gilbert Plass used an early digital computer for the same purpose. His result agreed with Arrhenius's—doubling carbon dioxide would raise temperature by several degrees—but Plass was able to let the computer do most of the work.

Computerized climate modeling continued in the 1960s as scientists extended the early weather forecasting programs to longer time periods and used steadily more powerful computers. One of the first organizations to take up the work was the U.S. Weather Bureau, which soon renamed its modeling section the Geophysical Fluid Dynamics Laboratory (GFDL).

The earliest models were primitive, able only to divide the atmosphere into a few levels and include simplified ice caps, land, and ocean. The relationships between these regions were written in equations and then in computer code. The computer model was then run forward one step at a time. One of the first took 40 days to settle down to an equilibrium value. But even these earliest models were good enough so that in 1967 the GFDL team could report that doubling atmospheric carbon dioxide would raise temperature "about 2.3°C," confirming that Arrhenius and Plass had not been far off and that the early climate models were not seriously out of whack.

Over the decades, computer power and model sophistication advanced hand in hand. In 1975, the GFDL modelers raised their estimate of climate sensitivity (the temperature rise for doubled atmospheric carbon dioxide) to 2.9°C. Two of the most difficult problems were to model the effects of clouds and of aerosols—tiny droplets and particles in the atmosphere. Both trap heat rising from the surface, warming the Earth, but both also reflect incoming sunlight and thus have a cooling effect. Teasing out their net contribution was hard. Modelers have a good handle today on the effect of aerosols but continue to wrestle with the effect of clouds.

In the 1970s, under the direction of James Hansen, NASA built its own global climate model. It predicted that aerosols would have a net cooling effect. Thus when the next major volcanic eruption injected sulfur dioxide droplets into the atmosphere, temperature should drop for a few years and recover. Mt. Pinatubo in the Philippines erupted in 1991 and had just the effect that the Hansen model had predicted.

The early GFDL models made two specific predictions, one of which seemed counterintuitive. The lowest layer of the atmosphere, between the surface and 11,000 feet on average, is the troposphere. The models predicted that under global warming,

the troposphere would warm but the layer above, the stratosphere, would cool. In 2005, scientists confirmed this prediction. If the Sun were the cause of global warming, why would the atmospheric zone nearer to the Sun cool and the one farther away warm? The other prediction was that because of climate feedbacks the Arctic would warm faster than the planet as a whole. Scientists confirmed that prediction in 1997.

Validation

Models can explain current climate effects like the decline of global temperature in the wake of the Pinatubo eruption, but how can we be sure they are right about the climate decades into the future? One way is to test whether different models, which use dissimilar assumptions and algorithms, give similar results. That the early GFDL and NASA models gave roughly the same result for climate sensitivity was encouraging. Today some two-dozen models are in use and though they differ in the details, all point to higher global temperatures in the future.

Another way to validate the models is to "hindcast": to see whether they can accurately reproduce the known temperature record. *Climate Change 2001,* from the Intergovernmental Panel on Climate Change, showed that they can:

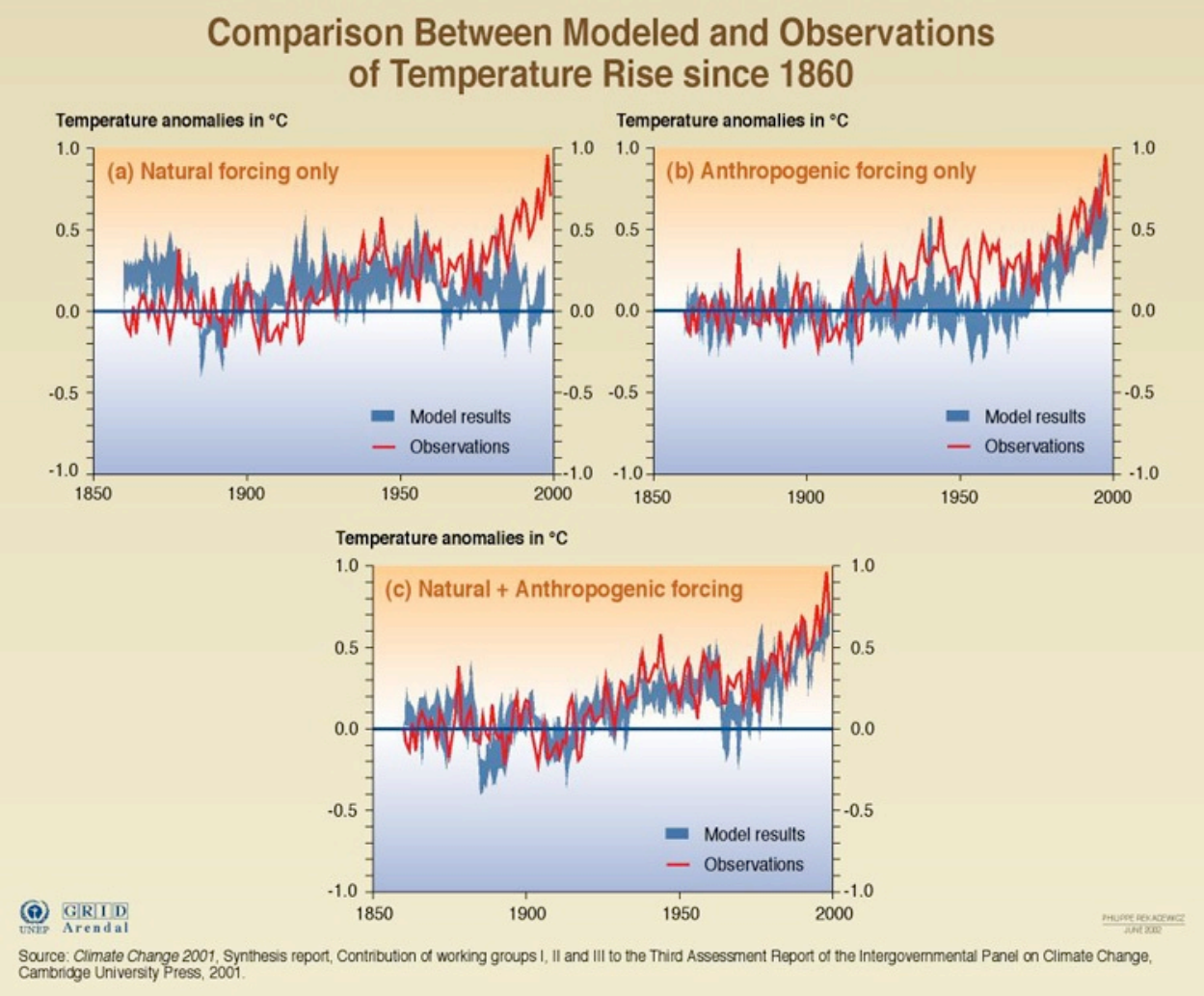


Figure 35. Climate models that use both natural factors and greenhouse gases come closest to replicating observed temperatures.

The frame at the upper left shows that when models use only natural effects—variations in the Sun's output, volcanic eruptions, and the like—they do a poor job of reproducing observed temperatures. The frame at the upper right shows that when the models use only greenhouse gases, again they do a poor job. But when the models include both natural *and* greenhouse gas effects, as shown in the bottom frame, the fit is much better.

An up-to-date test of the climate models would be to see how well they can reproduce observed temperature since 1998—the years of the now-debunked pause. Even though by 2014 temperatures had returned to their long-term trendline, for the period between 1998 and 2014, most climate models predicted higher temperatures than observed.

There are two ways one could respond. The first, the non-scientific way, is to show no interest in why the discrepancy might have occurred and what might be learned from it. Instead, just declare that climate models don't work and that global warming is in doubt. The letter that sixteen scientists wrote to the Wall Street Journal in 2012 exemplifies this approach:

> Perhaps the most inconvenient fact is the lack of global warming for well over 10 years now…But the warming is only missing if one believes computer models where so-called feedbacks involving water vapor and clouds greatly amplify the small effect of carbon dioxide.

The other way to respond, the scientific way, is to treat the discrepancies as opportunities to learn *why* the models do not agree with the observations and to improve the models. This approach will lead either to better models or to the recognition that they are seriously flawed. Following this strategy, climate scientists came to be reminded that not all climate models treat the ENSO cycle in the same way. (Remember that since 1998 there have been 8 cooling La Niña events but only 4 warming El Niños.) Models that do incorporate the phase of the ENSO cycle reproduce not only the post-1998 temperatures, but also each of the observed 15-year temperature trends for the past 50 years. The models work and scientists are continually learning how to make them work better.

Climate Sensitivity

Before we leave the subject of computer modeling, let us return to climate sensitivity. The global climate ("general circulation") models estimate it to be close to 3°C, but scientists have a number of other measures, as shown in the chart below from Scientific American.

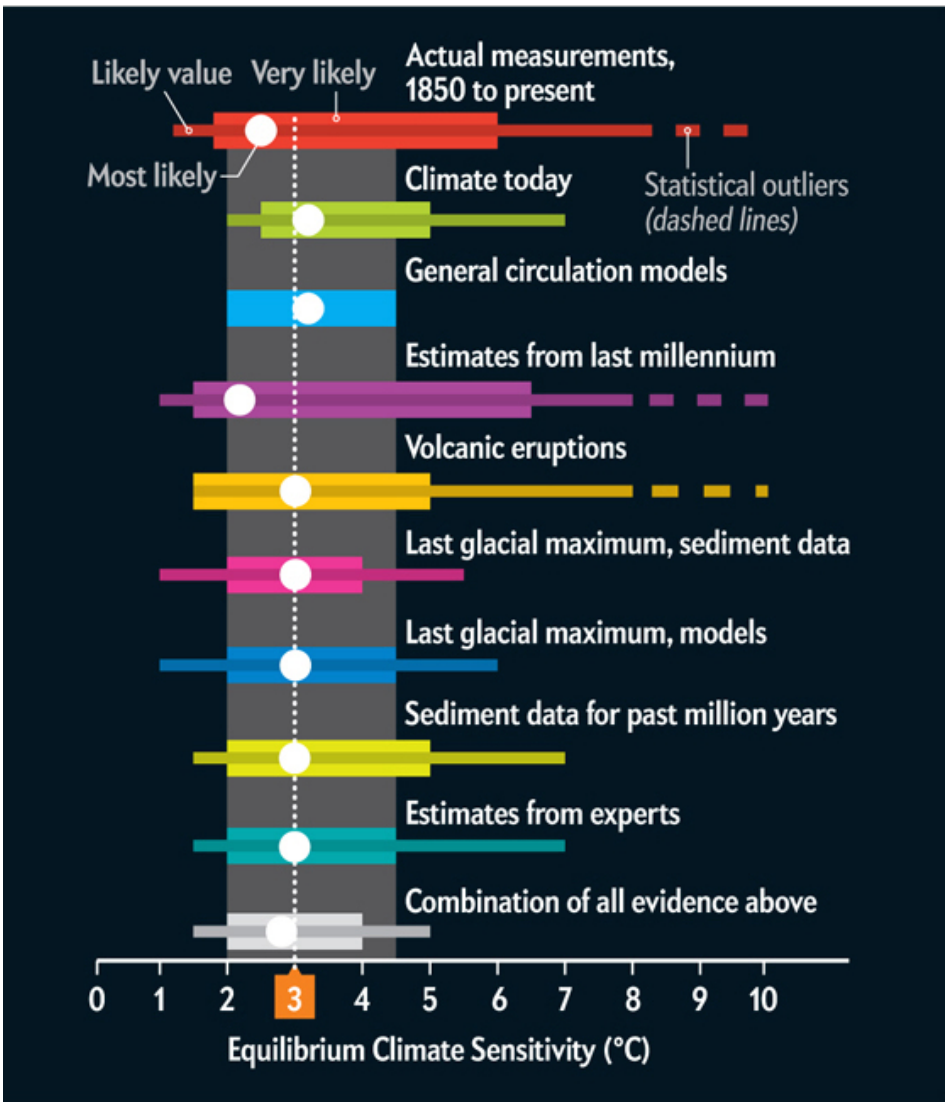


Figure 36. Estimates of climate sensitivity average about 3°C.

Were scientists to discover a new negative feedback, or that one of the few known negative feedbacks would strengthen at higher temperatures (our "Surprise"), the result would be to reduce climate sensitivity below 3°C. Note that one of the measures shown in the chart, "Estimates from last millennium," does give a lower climate sensitivity than the others. How much difference would it make if climate sensitivity turned out to be, say, 2.5°C instead of 3°C?

The pre-industrial level of atmospheric carbon dioxide, known from polar ice cores, was about 280 ppm, so doubling would take it to 560 ppm. The atmosphere presently has 400 ppm of carbon dioxide. As Michael Mann pointed out in an article in Scientific American, on the current trajectory a climate sensitivity of 3°C would raise carbon dioxide concentration to 560 ppm in 2036. If climate sensitivity were instead 2.5°C, carbon dioxide concentration would double by 2046.

The lower climate sensitivity would buy us ten years. If we were lucky enough to get those years, we could use them to reduce carbon emissions and prevent the worst effects

of global warming. But would we? Not if we listen to those who claim global warming is a hoax.

Notice that the broadest bands on the chart above, which show the “very likely” range, are as apt to extend to higher sensitivities as they are to lower. In other words, if climate sensitivity is not 3°C, it is as likely to be higher as lower.

Summary

Scientists have spent half a century improving their climate models. Whenever the models failed to match reality, the modelers got to work and made them better. Climate models are not just the best guides we have to the future, they are the only ones. The models leave no doubt that business-as-usual fossil fuel emissions cause more and stronger extreme weather events, of the kind we have already begun to experience.

Do Scientists Agree?

So far we have reviewed the ways in which scientists could turn out to be wrong about global warming and examined some of the evidence that convinces them they are right. Rather than studying that evidence for ourselves, we could have simply taken scientists' word for it. But first we would have to know what their word is: the extent to which scientists agree about global warming. According to a November 2013 poll by the Pew Research Center, roughly half the American public believe that scientists do not agree. As I will show, that is completely wrong. But it does raise the question of how so many could get such a mistaken impression.

Most people understandably do not read scientific journals. Instead they get their information about science from the media: TV, newspapers, and magazines. There, debate and controversy sell; agreement does not. Whenever there is a media story on global warming, we are apt to find on one side a scientist who accepts global warming and on the other side one who rejects it, as though there are two equally-weighted sides on the question. When Congressional committees hold hearings, those who testify are again roughly balanced between the supposed two sides. This attempt to be "fair and balanced" is reasonable when there *are* two sides, as would be the case if the subject were tax policy, health care, teacher evaluation, or any number of other political and social issues. But science is different: almost never do two roughly balanced groups hold opposite opinions: instead almost all scientists in a field subscribe to the same paradigm.

Take evolution. There is only one side: the overwhelming majority of biologists accept the theory. To stage a media debate between one scientist who accepts evolution and one who does not, or to quote each in a newspaper story, would be completely misleading and irresponsible. **Global warming is no different, for its acceptance by publishing scientists is as strong as that for evolution.**

One way to gauge the extent of agreement over a scientific theory is simply to ask scientists for their opinion, as pollsters do when they query prospective voters. The trouble is, scientific opinion has often turned out to be wrong: otherwise there would have been no scientific revolutions. If one had a time machine and could travel back to 1960 and ask geologists whether they accepted continental drift, nearly 100 percent would say they did not. Ten years later, nearly 100 percent would have said they did.

But if instead of polling scientific opinion, one had relied on the peer-reviewed literature from the 1950s and 1960s, one would have found that it contained no convincing evidence that continental drift is false. The literature proved a much more accurate guide to the state of the science than the opinion of scientists.

When pollsters ask people how they are going to vote a month before an upcoming election, they get the opinion of the respondent at that moment. But a lot can happen in the last month before an election. Once the results are in, how people had *said* they would vote matters only to pollsters. We then have the evidence of how people *did* vote, collectively, and that is all that matters.

In science, a peer-reviewed article is like a vote in an election, except that scientists sign their names. We don't need to ask scientists their opinion, which scientific revolutions

show is unreliable: we can judge what scientists accept as true much more reliably from the evidence they publish.

But tens of thousands of scientific articles are published each year—surely no one could read them all. True, but thanks to the Internet, there is a way to simplify the task to the point that it becomes manageable.

The Web of Science (WoS) is a subscription-based, Internet-hosted reference service of Thompson-Reuters. Most academic libraries subscribe to it. The WoS provides a searchable database of every scientific article published in peer-reviewed journals. If one wants to find out how many articles on the topic "global warming" have been published so far in the twenty-first century, for example, in a few seconds the WoS answers 11,140.[7] The WoS provides an exportable list of those articles with author, date, journal, times cited, etc.

To assess the state of a scientific consensus, a WoS search allows one to review the titles and abstracts (not the text, which would take forever) of articles on global warming to determine how many reject the theory. But why look for rejections rather than endorsements? Because once a theory has become widely accepted—become the ruling paradigm—scientists rarely explicitly endorse it. One can read hundreds of abstracts about plate tectonics, for example, without finding a single one that directly endorses the theory. Acceptance of the ruling paradigm lies in the background of all that scientists in a field do, understood without the need to say so. But if a scientist had evidence that justified rejecting plate tectonics, for example, that would be clear from the article abstract and no doubt even from its title. Searching for rejections is the only practicable and valid way to judge the extent of acceptance of a scientific theory.

Some years ago I began to undertake a review of the peer-reviewed scientific literature on global warming. I reviewed the titles and abstracts of the articles looking for explicit statements of rejection, the kind that those who deny global warming make all the time outside of scientific journals, where anyone can say whatever they like. My first review covered the years 1991-2012 and used the search terms global warming and global climate change. For 2013 and 2014, so as to miss as few articles as possible, I added the search term "climate change." The chart below shows my latest results.

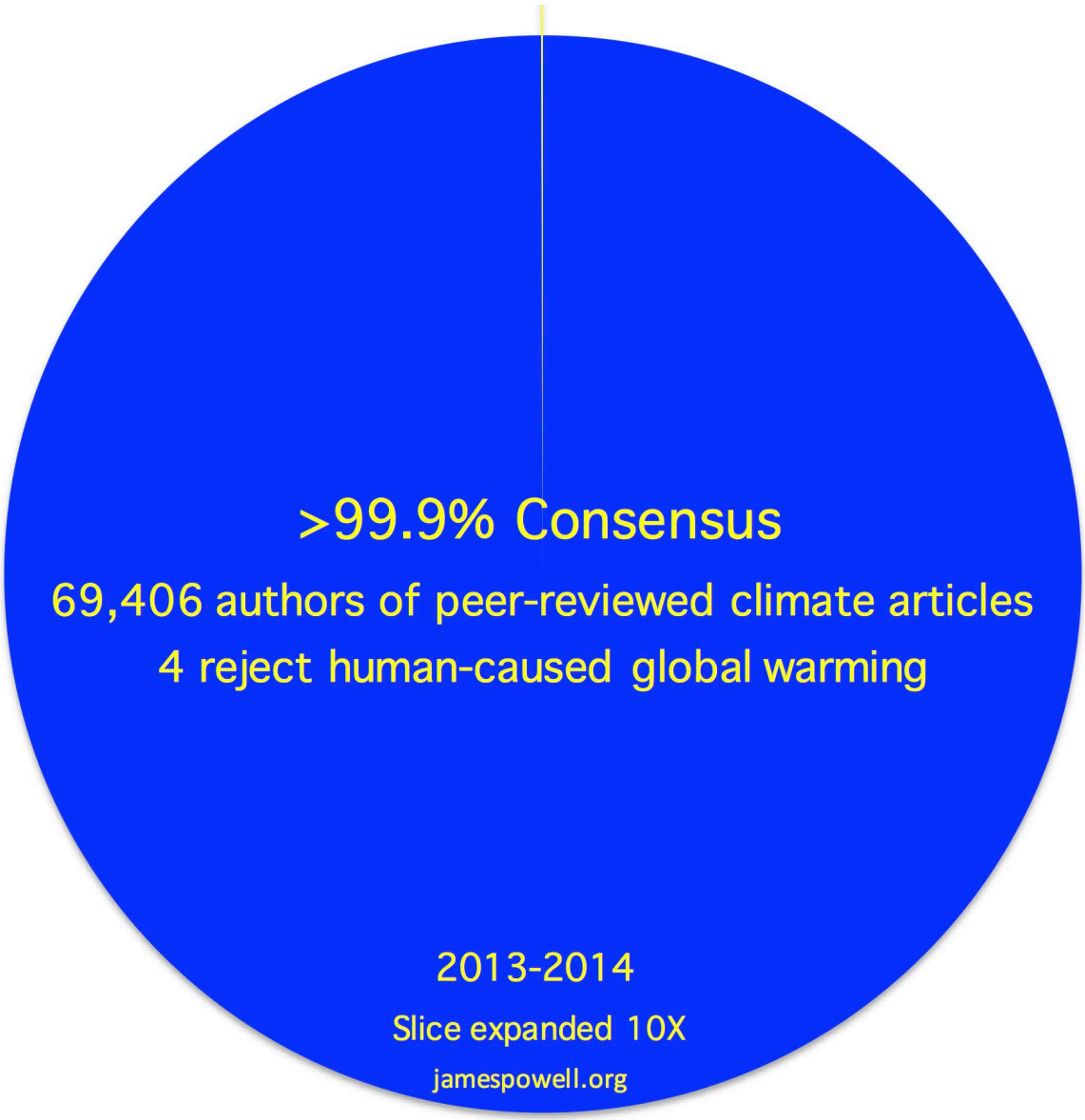


Figure 37. Publishing scientists are close to unanimous: humans are causing global warming.

I found a total of 24,210 articles for 2013 and 2014. They had a total of 69,406 authors. There were five rejecting papers, two of which had the same author, so the number of rejecting authors is four. Thus the ratio of rejecting authors to the total is 4/69406, 1 in 17, 352 or 0.0058%. To be conservative, I conclude that over 99.9% of publishing climate scientists accept that humans are causing global warming. This is as close to unanimous as it gets in science.

Of course, we must not forget that to show that global warming is false might take only a single article—if that one had the facts to back it up. We would not need to conduct a needle-in-the-haystack review of thousands of abstracts to find that article. It would already have made headlines and many other scientists would have cited it in their own articles. But scientists have largely ignored the rejecting articles. Several have never been cited. If an article published in the last 20-plus years had offered compelling

evidence that scientists are wrong about global warming, we would know about that article and we don't. There must be no such evidence, else someone would have published it by now.

Summing Up

We have reviewed the ways scientists have been wrong before and found none that might apply to global warming. That scientists are engaged in a conspiracy over global warming is not just absurd—it is impossible. The scientific evidence for global warming is overwhelming and there is virtually no published evidence against it. Changes in the plant and animal world and the number and strength of extreme weather events offer compelling testimony that the world is warming. Climate models agree that on the present trajectory, warming will get worse with each passing decade, with no end in sight.

Those who reject global warming in spite of these facts are betting the future of the world's grandchildren, as well as the fate of countless species, that a handful of dissident and mostly non-publishing scientists, who have no theory of their own to explain why temperatures are rising, are right and that tens of thousands of publishing scientists are wrong. What are the odds of that being true?

Here's an analogy that may help answer. Imagine that instead of worrying about global warming, you were concerned about your blood pressure, which over your lifetime has risen as shown in the chart below. In your youth, it had been as low as 125/60, but as you have aged, gained weight, and picked up a few bad habits, your blood pressure has climbed to 210/95 and continues to rise.

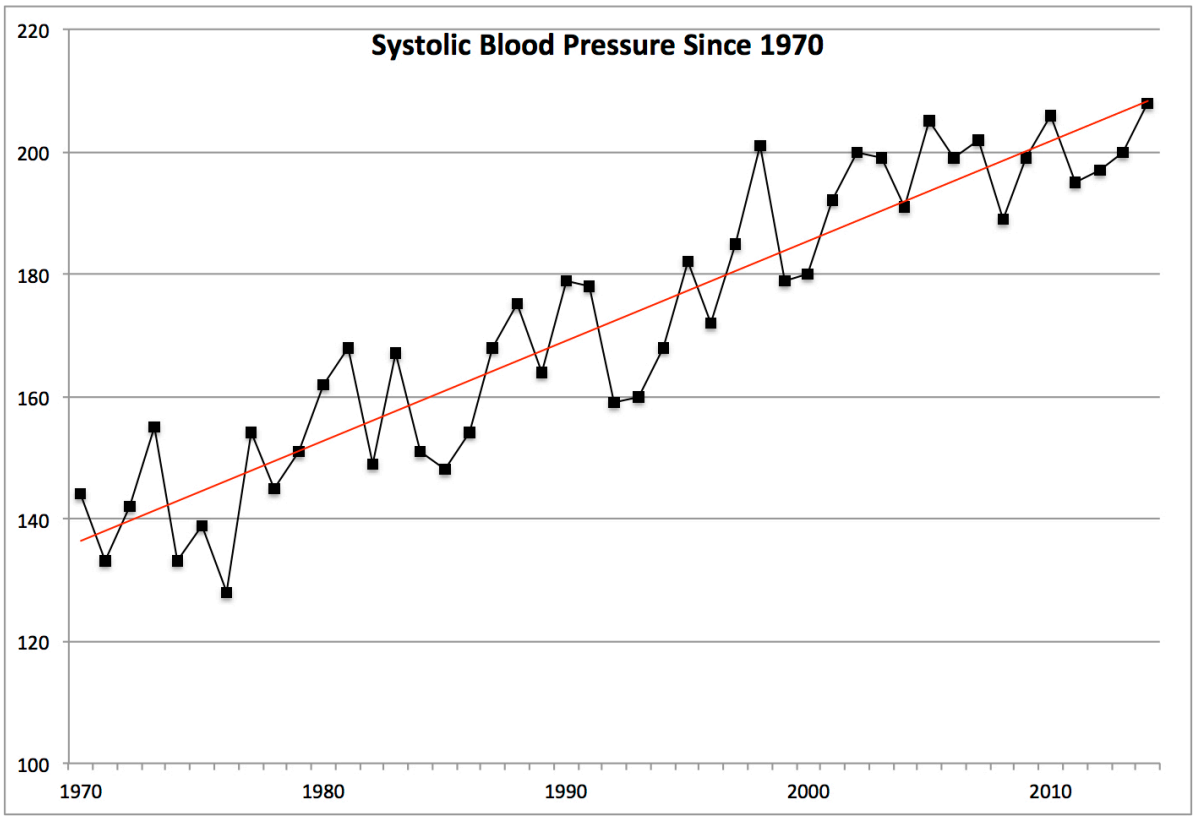


Figure 38. Your Blood Pressure.

You consult your longtime family general practitioner who advises, “I don’t know why your blood pressure has risen so high, but I am confident there is nothing to worry about. You don’t need medication and are not at risk of a stroke. Your blood pressure is bound to come down without your needing to inconvenience yourself and change your lifestyle. Just relax and enjoy life.”

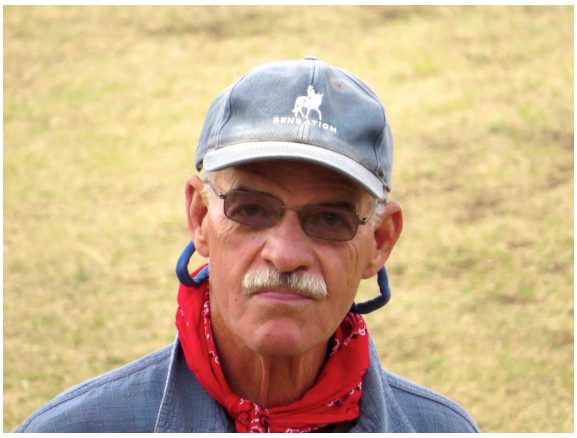
This is music to your ears, but your significant other insists you get a second opinion. Now you go to a specialist, a trained, publishing cardiologist, who conducts a battery of tests and then confers with her team. She tells you: “Your failure to take care of yourself has put you at serious risk of a stroke or heart attack. I am putting you on blood pressure medication immediately. You need to stop smoking, start exercising, restrict your drinking, and lose 30 pounds. Otherwise you do not have long to live.”[8]

Now consider that instead of a pair of physicians giving opposite diagnoses, the ratio of publishing scientists agreeing that global warming is true to the mostly non-scientists who say it is false is thousands to one. Whose advice will you follow?

Acknowledgements

Thanks to Tom Farmer, Joan Hartmann, Dave Morrison, and Joanna Powell for helpful comments on the manuscript.

About the Author



I was born in Berea, Kentucky and graduated from Berea College with a degree in Geology. I have a Ph.D. in Geochemistry from the Massachusetts Institute of Technology and several honorary degrees, including Doctor of Science degrees from Berea College and from Oberlin College. I am not a climate scientist, but I believe that may give me an advantage in a book like this in that I do not have some previous scientific record I need to defend.

I taught Geology at Oberlin College for over 20 years and served as Acting President of Oberlin, President of Franklin and Marshall College, President of Reed College, President of the Franklin Institute Science Museum in Philadelphia, and President and Director of the Los Angeles County Museum of Natural History.

President Reagan and later, President George H. W. Bush, each appointed me to the National Science Board, where I served for 12 years. I am now the Executive Director of the National Physical Science Consortium. Asteroid 1987 SH7 is named for me. For my other books, see my author's page at Amazon. My website is www.jamespowell.org.

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[1] From now on, when I write "global warming" I will mean anthropogenic or human-caused global warming, but leave the modifiers out. When I want to discuss rising temperatures, I will say that.
[2] Links checked May 10, 2015.
[3] Temperature and carbon dioxide emissions are linked through the greenhouse effect and through the climate feedbacks. Not only do (1) rising carbon dioxide emissions raise temperature, (2) in the long run higher temperatures raise carbon dioxide emissions. An example of (2) is thawing permafrost, which releases carbon dioxide, which in turn causes higher temperatures. But feedbacks of this second type operate on a long time scale, whereas the change in heat radiation shown in the two charts immediately followed the carbon dioxide rise. That is how we know that the carbon dioxide increase caused the rise in heat radiation rather the other way round.

[4] Thanks to Joanna L. Powell for this quotation.
[5] For a full discussion of NASA's temperature index, see http://data.giss.nasa.gov/gistemp/. The data plotted come from meteorological stations on land; ocean measurements from buoys, ships and satellites; and Antarctic stations. Other centers that collect and report global temperature data are the Hadley Center of the UK Met Office, the Japanese Meteorological Agency, and Berkeley Earth Surface Temperature.

[6] For information on how NOAA monitors temperature, see http://www.ncdc.noaa.gov/monitoring-references/faq/temperature-monitoring.php
[7] This number will change slightly over time as the WoS adds and revises.
[8] As you may have recognized, the hypothetical blood pressure chart is actually the NASA chart of global temperature since 1970 with the vertical axis and labels changed.