Eric Holcomb's statement on the reality of climate change

Eric's credentials:

Eric has a B.S. in Fluids and Thermal Engineering from Case Western Reserve University, and an M.S. in aerospace engineering from Iowa State University. Eric's work over about a 20-year span at The Boeing Company included aerodynamics and computational fluid dynamics (CFD), which is closely related to computational climate modeling. Eric is now semi-retired and serves as a volunteer telescope operator and astronomy educator at the University of Oregon's Pine Mountain Observatory.

The following is Eric's own personal explanation of climate change and why the most common arguments against anthropogenic (human-caused) "global warming" (AGW) aren't valid, now broken down into several major topics. Before we begin, we should note that frequent use of the term "climate change" by scientists does *not* mean that warming is no longer happening; it's merely a more general term that includes changes in precipitation and other forms of weather besides just temperatures.

Note: The next page contains updates for the years 2014, 2015 and 2016; followed by what I had originally written before then.

December 2016 update:

Although an amazing 16-month streak of record warmth (globally) ended in September with the end of El Niño conditions, the globe remains on track to be one of the warmest years, if not the warmest, in the 122-year record, according to NOAA scientists. The World Meteorological Organization agrees, noting that 2016 will very likely be a new high for the third year in a row, and that "human-induced global warming has contributed to at least half the extreme weather events studied in recent years." The average U.S. temperature in autumn was 57.6 degrees F (4.1 degrees above average) and surpassed last fall as the warmest on record, according to NOAA. But don't expect winters to go away … new research shows that warmer Arctic temperatures are causing the polar vortex to shift, leading to a harsher winter for some of us here in the U.S. As for the arctic itself, "a new NOAA-sponsored report shows that unprecedented warming air temperature in 2016 over the Arctic contributed to a record-breaking delay in the fall sea ice freeze-up, leading to extensive melting of the Greenland ice sheet and land-based snow cover."

December 2015 update:

2015 is now certain to be the year that scientists were expecting … a record-smashing warm year for the global average temperature, thanks to a combination of global warming and a strong El Niño. As reported by NOAA for data through November, "The year-to-date temperature across global land and ocean surfaces was 1.57°F (0.87°C) above the 20th century average. This was the highest for January–November in the 1880-2015 record, surpassing the previous record set in 2014 by 0.25°F (0.14°C). Nine of the first eleven months in 2015 have been record warm for their respective months." The global average temperature has also risen a full 1.0°C since 1880, and 0.24°C since the previous strong El Niño in 1998. Any remaining doubts about continued global warming should now be gone!

December 2014 update:

2014 also broke all previous high temperature records, albeit by a smaller margin … 0.69°C (above the 20th Century average) versus 0.66°C in 2010.

"Fourteen of the 15 warmest years on record have all occurred in the 21st century," said the World Meteorological Organization's (WMO's) secretary-general Michel Jarraud. "What we saw in 2014 is consistent with what we expect from a changing climate."

"Record-breaking heat combined with torrential rainfall and floods destroyed livelihoods and ruined lives. What is particularly unusual and alarming this year are the high temperatures of vast areas of the ocean surface, including in the northern hemisphere," he said.

Greenhouse Gases and the Greenhouse (Warming) Effect

According to quantum physics, atoms and molecules have energy levels associated with the electron "orbits," as well as the ways that molecules vibrate and rotate, for example. Transitions between energy levels result in the absorption or emission of electromagnetic radiation, which can include visible light, infrared (heat) radiation and ultraviolet radiation. [Quantum physics is probably the most extensively tested and verified theory in the history of science; it underlies human understanding of everything in the microscopic world, from gas molecules to DNA molecules, computer chips, and much more.] For the present discussion, what's important is the emission of heat radiation by the Earth's warm surface (both land and water), and the absorption of heat radiation by "greenhouse gases" in the atmosphere such as carbon dioxide (CO_2), water vapor (H_2O) and methane (CH_4).

Surface radiation – The Earth's surface is made up of dense substances such as rock and water. Individual atoms and molecules interact so strongly that there is essentially a continuous range of energy levels, resulting in heat radiation over a wide range of wavelengths of infrared light. The total energy emitted varies with temperature in a way first described by physicists Stefan and Boltzmann in the time period from 1879 to 1884. The Stefan-Boltzmann equation has been used successfully in science and technology for over 100 years.

Gas radiation – Gases are typically at much lower densities than solids or liquids, and thus tend to have discrete quantum energy levels resulting in narrow "absorption bands." However, gases in the lower atmosphere have broader absorption bands due to collisions between molecules, resulting in a greater ability to absorb the continuous spectrum of energy emitted by the Earth's surface.

It only takes a hand calculator, the Stefan-Boltzmann equation, the solar constant and some simple geometry to show that the average temperature of the Earth's surface would be about 0°F without greenhouse gases (a fact that isn't well known). This may seem very surprising at first, but consider how much it can cool off on a clear night, and then consider the geometry of a sphere … there's four times as much surface area radiating heat to space as the cross-sectional area perpendicular to the oncoming sunlight. [That's the "simple geometry" part.] Furthermore, the Earth reflects about 30% of sunlight directly back into space … energy that isn't available for warming. [It's necessary to include the reflectance, technical known as the *albedo*, when doing the calculation.]

Adding greenhouse gases at the natural pre-industrial level raises the average surface temperature to 59°F at sea level (or about 57°F overall). If this first "blanket" is so important, how can we expect a second "blanket" (the added greenhouse gases due to human activity) to have negligible effect? The detailed radiation heat transfer calculations are not simple, but they're at a level comparable to the equations used to send men to the moon in the 1960's – and were first performed on 1950's and 1960's era computers using experimental data gathered by the U.S. military. The military was more interested in things like heat-seeking missiles than climate, but the data were of high enough quality that physicists were able to reliably calculate the effect of CO_2 levels on air temperature for the first time. [Today military planners take climate change and its potential impacts on human society very seriously.]

A couple of key points that are often the subject of confusion:

<u>Water vapor</u> – this is the most important greenhouse house in the Earth's atmosphere, responsible for about ¾ (75%) of the natural greenhouse warming, when clouds are also included. However, there is plenty of capacity for CO_2 to cause additional warming, both at wavelengths of infrared light where water vapor doesn't absorb strongly, and in the upper atmosphere, which is very cold and dry. Water vapor is considered a "feedback" in climate models because as the air warms, it can hold more water vapor (humidity), which in turn absorbs more heat. According to some recent estimates, water vapor feedback could *double* the warming effect of CO_2 alone.

<u>Upper atmosphere</u> – what happens in the upper atmosphere (mostly the stratosphere) is critical to the greenhouse effect because heat radiation emitted there can escape easily into space. [Remember that gas molecules both absorb and emit heat radiation.] Because the upper atmosphere is cold (air expands and cools as it rises), less heat escapes to space than would be the case if there were no atmosphere (or no greenhouse gases), which would allow the Earth's warm surface to radiate directly to space with nothing "in the way." This was first well-understood in the 1950s.

Computer Models and Feedbacks

One of the most common arguments of the climate change skeptics is that modern computer models of climate are too complex to be reliable, sometimes together with the argument that "we can't even predict the weather accurately, so how we can predict future climate changes?"

However, it's a basic law of thermodynamics that adding heat to a system will cause it to get warmer (and/or cause a "phase change" like melting ice), unless heat in removed somewhere else in the system. No ability to predict weather is needed to make that statement. As discussed above, physicists knew by the late 1950s that adding CO_2 would add heat to the "system" (mostly the atmosphere and oceans), enough to cause about 3°C (5°F) of warming if CO_2 levels doubled from 280 ppm (the pre-industrial level) to 560 ppm while nothing else changed. [The atmospheric CO_2 concentration is currently about 400 ppm, and rising by about 2 ppm per year.] An extremely important point is that the heat absorbed by CO_2 is essentially an input to modern computer models (calculated using the methods first employed in the 1950s), not an output of some complex and unreliable calculation. Much of the excess heat is radiated back to the oceans and shows up directly in ocean heat measurements.

What the basic thermodynamics don't say is where the extra heat will go (for example, motions of individual air masses), what the secondary effects (such as cloud cover) will be, or how climatic patterns such as patterns of precipitation will be affected. That's where the modern computer models come into play. These models require large amounts of computer resources because they need to resolve details reasonably well in both time and space (the three-dimensional space on and above the Earth's surface). Weather models are similar to climate models, but run with greater resolution for a much shorter period of simulated time (days or weeks as opposed to years or decades).

The models are getting better, but there are still considerable uncertainties. With respect to global warming, it is important to note that these uncertainties are in the secondary effects on global temperature (also known as "feedbacks") and in the consequences of warming (such as drought and flooding). A feedback is anything that can make warming better (less warming, known as a negative feedback) or worse (more warming, known as a positive feedback). Examples of negative feedbacks include increased cloud cover and increased atmospheric aerosols (although aerosols can also be an independent mechanism). Important positive feedbacks include the ice-albedo effect (melting ice leaves behind darker soil that absorbs more sunlight), the water vapor effect discussed above, and the release of methane from thawing arctic permafrost. All-in-all, there's a significant likelihood that the positive feedbacks will be stronger than the negative feedbacks, thus making the situation worse.

An important point about feedbacks is that at least some warming must occur before a feedback "kicks in." It is simply not possible for there to be no warming unless some *independent* mechanism was to counteract the greenhouse effect. All credible climate models predict at least some significant warming with increasing atmospheric greenhouse gas levels. This is true even when uncertain parameters (such as those affecting cloud cover) are varied over a wide range in the models.

The Accumulation of Greenhouse Gases in the Atmosphere

Scientists know the size of the atmosphere, the amount of CO_2 released by burning carbon fuels, and the amounts of such fuels consumed (to reasonably accuracy). When you do the math, you find that only about half of the CO_2 released from fuels actually stays in the atmosphere; the rest is absorbed by the ocean or by plants. Unfortunately, there is little evidence that plant growth will get much faster, and the ability of the ocean to absorb CO_2 is diminishing. Scientists also use carbon dating techniques (using radioactive isotopes of carbon) to show that much of the CO_2 in the air comes from "old" sources – namely fossil fuels formed millions of years ago.

For a long time, many scientists assumed that the oceans would absorb almost all excess CO_2, not unreasonable considering how much CO_2 can be dissolved in water (in carbonated beverages, for example). However, the oceans are deep and transfer of CO_2 from surface layers to the deep ocean is a very slow process. Furthermore, surface layers can quickly release some of their CO_2 back into the atmosphere, especially as they warm.

Skeptics sometimes point out, correctly, that CO_2 from fossil fuels is only a small percentage (3 to 5%) of the total carbon cycle, which includes natural burning, respiration by animals, photosynthesis by plants, the ocean, and a variety of geological processes. However, CO_2 accumulates in the atmosphere, and a small excess sustained for many years is enough to explain the current concentration of 400 ppm. It's a bit like eating an extra piece of candy each day; keep doing it and you'll eventually get fat.

CO_2 is not the only important greenhouse gas whose atmospheric concentration is increasing. Methane, the primary constituent of natural gas, is also released by some human activities, and may be released in greater amounts in this century due to decay of organic material in thawing arctic permafrost. Although methane eventually chemically reacts to form CO_2, its contribution to the greenhouse effect is rather large, over 20 times that of CO_2 (on a molecule-by-molecule basis) until that happens.

The Global Temperature Record and Recent Weather Events

<u>Temperature Record</u> – skeptics often claim that global warming either hasn't happened, or stopped after 1998, a very warm year. However, 1998 was warm (and 2008 and 2011 cool) partly because of

oceanic phenomena such as the well-known El Niño and La Niña events in the Pacific. If you discard the high and the low (sort of like judging in sports), the continued warming trend of the past 30 to 40 years is obvious. Recent studies that attempt to correct for other influences (such as El Niño and solar variability) make this extremely clear, as does the record-smashing 2015 temperatures. The rate of warming is about 0.17°C (0.30°F) per decade, and is probably not slowing down.

2010 tied for the warmest near on record (globally) according to the National Oceanic and Atmospheric Administration (NOAA). Here's the exact quote: "According to NOAA scientists, 2010 tied with 2005 as the warmest year of the global surface temperature record, beginning in 1880. This was the 34th consecutive year with global temperatures above the 20th century average. For the contiguous United States alone, the 2010 average annual temperature was above normal, resulting in the 23rd warmest year on record." 2011 and 2012 were slightly cooler, but were the warmest La Niña years on record.

Winter storms, etc. – So what about the cold and snow experienced on the U.S. east coast/Midwest and in Europe during the winters of 2010 and 2011? First of all, it only affected a few percent of the Earth's surface area for a month or two. Second, the "arctic oscillation" in the jet stream that brought cold air farther south in some areas also brought warm air father north in other areas. In the author's hometown of Bend, OR, there were several 50°F days, at 3,500 ft above sea level in the middle of January, although the subsequent spring was cool and wet, after the jet stream shifted. In 2010, it was unusually warm during the Olympics in Vancouver, BC, and throughout the Pacific Northwest. Of course a few scientists do look rather foolish for not anticipating that "arctic oscillations" could happen; but then again the author has never claimed that scientists are perfect!

No one should expect an end to winter snowfall anytime soon; the arctic is still going to be extremely cold in December and January because high latitudes receive little or no sunlight during that time period. If that cold air travels south and encounters warmer, moister air, a great deal of snowfall can be (and obviously was) generated. Similar encounters of warm and cold air masses create conditions ideal for spring tornadoes. Although the tragic outbreak of these storms in 2011 may have more to do with a La Niña event than global warming, it is possible that warmer temperatures may increase the severity of storms of various kinds, including hurricanes, tornadoes, rainstorms and snowstorms.

In summary, the couple of degrees of warming that's happened so far will not prevent winter storms from happening. Only long-term averages of atmospheric and oceanic temperatures are really meaningful to determine if global warming is happening, and this trend is clearly upward. The 2009 global averages were almost back to the upward trend line, and the 2010, 2014 and 2015 averages all broke records (2015 by a large margin).

Other Possible Explanations for Global Warming

Despite comments from skeptics that there are "too many variables" to understand climate change, there are in reality only a small number of variables that can significantly affect global average temperature. All of these variables have been studied extensively, and only greenhouse gases can adequately account for recent global warming. Examples of the alternative possibilities:

Solar activity – Everyone knows that the sun is responsible for almost all the Earth's heat, at least at and above the surface. [Interior heat is sustained over billions of years by radioactive decay.] Fortunately, astrophysicists know that middle-aged "main sequence" stars like the sun don't vary much in brightness over short periods of time. The sun undergoes cycles of magnetic and sunspot activity that slightly increase the sun's energy output when there are a lot of sunspots, even though the dark sunspots are relatively cool. [Areas of the sun's surface surrounding sunspots become brighter, more than making up the difference.] An absence of sunspots during the Maunder Minimum from 1645 to 1715 is often associated with the "Little Ice Age," when average temperatures may have dropped by as much as 1°C, at least in the northern hemisphere. Solar astrophysicists recently announced that such as event (as the Maunder Minimum) may happen again beginning in the next decade or so.

However, before concluding that the warming problem is solved, consider these points:

- The sun's energy output has been measured accurately from space since 1979 and found to vary by no more than about 0.1%. This cannot explain the rapid warming of the past 35 years.
- Scientists now believe that solar variability cannot account for more than about 10% of the warming recorded during the 20th Century.
- Even if a new Maunder Minimum does occur (which is very uncertain), it may only offset about 10% of the warming effect of the accumulated greenhouse gases by the late 21st Century, and for an unknown length of time, possibly shorter than the 70 years of the historical event.
- There was almost no sunspot activity in 2008 or 2009, and yet temperatures remained warm, especially after accounting for a La Niña event.

Earth orbit and axis tilt – Since the 1960s, scientists have believed that past ice ages were caused by slow cycles, known as Milankovitch cycles, in the shape of the Earth's orbit and the direction and tilt angle of the Earth's axis of rotation. ["Slow" meaning tens to hundreds of thousands of years.] However, scientists have also uncovered extensive evidence (for example, in Antarctic ice sheets) that CO_2 plays a major "positive feedback" role in the process. For example, when an ice age is ending, ocean warming may release stored CO_2, which in turn causes further warming. In any event, the Milankovitch cycles are much too slow to explain the rapid warming of the 20th and early 21st Centuries.

Reflected sunlight – As noted above, the Earth reflects about 30% of sunlight directly back into space. If the Earth were to reflect less sunlight, for example because of reflective ice melting, this could produce some warming. However, this effect, known as the "ice-albedo" effect, is considered a feedback that makes warming worse, not the primary cause of warming. In other words, something else (in this case greenhouse gases) had to start the warming process before the ice could melt.

Volcanoes – As spectacular examples of the Earth's internal heat, these events can influence climate in several ways. Initially, a volcanic eruption will release ash and other particulates into the air, which can block the sun and cause temporary cooling. [The actual heat released in the eruption would be too small to have a global impact.] Volcanoes also outgas CO_2, which has a warming effect for many years after the ash settles out of the atmosphere. However, there simply hasn't been enough volcanic activity since the Industrial Revolution to explain the CO_2 imbalance in the atmosphere; only the burning of fossil fuels can explain it. [Even during the PETM event described below that took place 56 million years ago, when there was extensive volcanism, scientists now estimate that the release of carbon into the atmosphere was at least 10 times slower than it is today. According to the U.S. Geological Survey, volcanoes in today's world only release about 1% as much CO_2 as human activity.]

Ocean currents and phenomena – The Earth's oceans store a vast amount of heat, and ocean currents transport some of that heat thousands of miles, greatly influencing local climate in a number of geographic locations including northern Europe, warmed by the Gulf Stream current. Ocean currents may have been responsible for the "Medieval Warm Period" when the Vikings colonized parts of Greenland. The periodic El Niño events in the Pacific can raise air temperatures by a significant fraction of a degree. [An El Niño is caused by warm water, driven by prevailing winds, piling up in the western Pacific until eventually an eastward "wave" releases the stored energy.] However, stored ocean heat is unlikely to produce an air temperature increase sustained for years or decades. Furthermore, measurements of ocean temperature show that the oceans are also warming, which is exactly what is expected from increased greenhouse gas levels. [There are some oceanic oscillations that last for decades (longer than El Niño), but if they warmed the air in the absence of any other warming mechanism, then the oceans would need to cool at least somewhat as the air warmed.]

Cosmic rays – A few skeptics have proposed hypotheses of warming that depend on an interaction between cosmic rays and cloud cover. However, there is little evidence for the changes in cosmic ray influx and cloud cover that would be required to explain recent warming.

Natural Variation and Past Climates

Natural variation is perhaps the favorite argument of the climate change skeptics. No one denies that there have been natural variations in the Earth's climate, for many reasons, over time scales ranging from a year to millions of years. The "many reasons" include those discussed above under "Other Possible Explanations of Global Warming," as well as other causes.

However, unless it can be shown which specific variation is causing the current rapid warming trend, what happened in the past is largely irrelevant. (After all, there has never been a rapid increase in atmospheric greenhouse gases due to human activity before.) Scientists can't find a natural variation to explain what's happened since the 1970s, or a natural variation that's likely to stop further warming in this century, aside from the relatively modest effect that a new sunspot minimum might have.

Perhaps even more importantly, it is now very clear that atmospheric CO_2 levels have a positive correlation with past (natural) climate change events. As noted above, there is evidence of the feedback role of CO_2 in ice ages of the past million years. Going back further, an article in the July 2011 *Scientific American* discusses research linking CO_2 and CH_4 levels to the Paleocene-Eocene Thermal Maximum (PETM), which happened 56 million years ago. Causes of the greenhouse gas emissions at that prehistoric time included volcanoes, methane bubbling up from the ocean bottom, peat and coal fires, and thawing permafrost. The overall warming of 5°C was judged to have happened "moderately fast" over thousands of years, but much slower than the "fast" modern warming.

Because increased atmospheric CO_2 can sometimes be a feedback (as noted above for ice ages), it can lag behind the start of warming by hundreds of years, which skeptics often cite as evidence against

AGW. However, there is no logical reason why CO_2 can't act in both ways, sometimes as the primary cause of warming, and sometimes as a feedback.

The Effects of Global Warming

Some skeptics admit to at least some level of human-caused (anthropogenic) global warming, but claim it's too small to be significant, or that it might actually be beneficial.

1. Too small – Some models predict warming in this century of 10°F if CO_2 emissions aren't curtailed, which could have catastrophic effects including sea level rise, more intense severe weather events, reduction in agricultural crop yields, spread of disease and species extinctions. The relatively small amount of warming so far (now 1.0°C or 1.8°F since 1880 according to NASA and NOAA) can give a false sense of security. There are good technical reasons (such as the absorption of heat by the ocean) why the warming isn't already worse, and these are fully accounted for in the models of future warming. (Also see the section added below on "the false sense of security.")
2. Might be beneficial – This is partially correct! Some plants and animals benefit from warming and higher CO_2 levels, and some regions that are now very cold much of the year could benefit. However, the level of atmospheric CO_2 (about 350 ppm) that scientists tell us is "safe" in the long run has already been exceeded. The negative consequences of further increases will likely far outweigh any benefits. In the distant future, humans might want to put more CO_2 back into the air to prevent an ice age, but that time isn't now!

Conspiracy Theories

Especially since the stolen e-mail "scandal" of 2009 (and a few more e-mails released in 2011), skeptics love to make accusations of scientific conspiracies. However, an impartial press review of the thousands of e-mails shows nothing that undermines the basic science. How could a conspiracy involving hundreds or thousands of scientists happen in a world where information is leaked by unnamed sources every day, and people do TV interviews with their identity hidden to expose the truth? Furthermore, most scientists are really quite moderate on political and environmental issues, and generally respect the evidence unless under great pressure to do otherwise. And while some research funding is directly related to warming and its consequences, there are plenty of scientists (for example, at NASA and NOAA) who would still be studying the Earth and its climate even without global warming.

It's also worth reiterating that physicists had worked out the net effect of atmospheric CO_2 on warming in the 1950s based on experimental data gathered for military purposes. That was before the modern environmental movement, and certainly before Al Gore popularized the subject of global warming. The 1950s calculations didn't include "feedbacks," but those may make the situation worse, not better. [To be fair, it actually did take about three decades after the 1950s to be certain that the radiation heat input from CO_2 would cause overall global warming, but now that conclusion is beyond any serious scientific doubt. See the AIP website (listed below) for more details on the history.]

So there you have it! This isn't comprehensive, and doesn't begin to address the issue of solutions to the global warming problem, but it should make it abundantly clear what my viewpoint is!

The False Sense of Security

The atmospheric CO_2 level has risen by 40%, whereas temperatures so far have only risen by 1.5°F (prior to 2015), about 0.3% on the absolute temperature scale used by physicists. Why? …

1. According to the Stefan-Boltzmann equation, radiation is proportional to the *fourth power* of temperature. Even if the Earth's surface needed to radiate 40% more heat to restore a balance, only about a 10% temperature increase would be needed. [The natural greenhouse effect warms the Earth by 57°F, or about 12% on the absolute scale. About 1/4 of that (3%) is due to CO_2. And 40% of that would be 1.2% more, if things were really that simple. (They aren't.)]
2. CO_2, while very important, is nonetheless an imperfect "thermal blanket." It doesn't absorb all wavelengths of infrared light, and its "absorption bands" partially overlap those of water vapor. Also, there is a sort of "law of diminishing returns" – it takes roughly a doubling of CO_2 to produce a 1% rise in temperature. A 40% increase is only about half of one doubling (1.4 x 1.4 = 1.96). The doubling rule obviously breaks down at CO_2 concentrations too low to have any significant effect at all, but is approximately valid within the range of interest.
3. The oceans serve as a vast thermal buffer, taking over a century to fully respond to changes in atmospheric greenhouse gas levels. It's estimated that there could be another 1.5°F in warming even if the CO_2 concentration stopped increasing, remaining at about 400 ppm.

Once again, all of these things and more are accounted for in the models that predict serious warming in the 21st Century. It would be foolish to be lulled into a false sense of security by the small changes so far.

Comparing Planets … Venus, Earth and Mars

Many people have heard that the planet Venus has a thick CO_2 atmosphere with a "runaway" greenhouse (surface temperature about 850°F), whereas the planet Mars has a thin CO_2 atmosphere and is rather cold (surface temperature about -60°F on average). Comparing Venus, Earth and Mars can be a very useful exercise.

Venus reflects so much sunlight that its temperature would be similar to Earth without a greenhouse effect, despite the closeness of Venus to the sun (about 70% the Earth's distance). However, the thick atmosphere of Venus (atmospheric pressure about 90 times higher than on Earth) allows the CO_2 to approach 100% of the theoretical maximum effectiveness (similar to a solid object) in absorbing and emitting thermal radiation. The net result is like having multiple blankets, each a little warmer than the one above it, and the bottom blanket (just above the surface) being very hot.

Mars, on the other hand, has an atmospheric pressure over 100 times less than on Earth. At such low pressures, the thermal effectiveness of CO_2 is much lower, on the order of a few percent, versus about 20% in Earth's lower atmosphere. Therefore, even though Mars has more atmospheric CO_2 than Earth (because the atmosphere is 95% CO_2), the greenhouse warming is less, about 9°F.

This comparison can only be made for the terrestrial planets with atmospheres (excluding Mercury). The "gas giant" planets are vastly different in structure and gas composition, may lack a solid surface, and generate some heat by slow gravitational contraction over billions of years.

References

Eric recommends the following websites for a detailed scientific discussion of climate change and the history of human understanding of the greenhouse effect.

American Institute of Physics

www.aip.org. (See especially the history section, http://www.aip.org/history/climate/index.htm. This is by far the best overall history of the subject that I've seen.)

NASA

www.nasa.gov

http://climate.nasa.gov/

NOAA (National Oceanic and Atmospheric Administration)

www.noaa.gov

http://www.noaa.gov/climate.html

RealClimate (the most technical of the websites listed here)

RealClimate.org

Science Daily ("Earth & Climate" section summarizes a lot of recent research)

http://www.sciencedaily.com/

Skeptical Science

http://www.skepticalscience.com/