

Global warming, and ice sheets*

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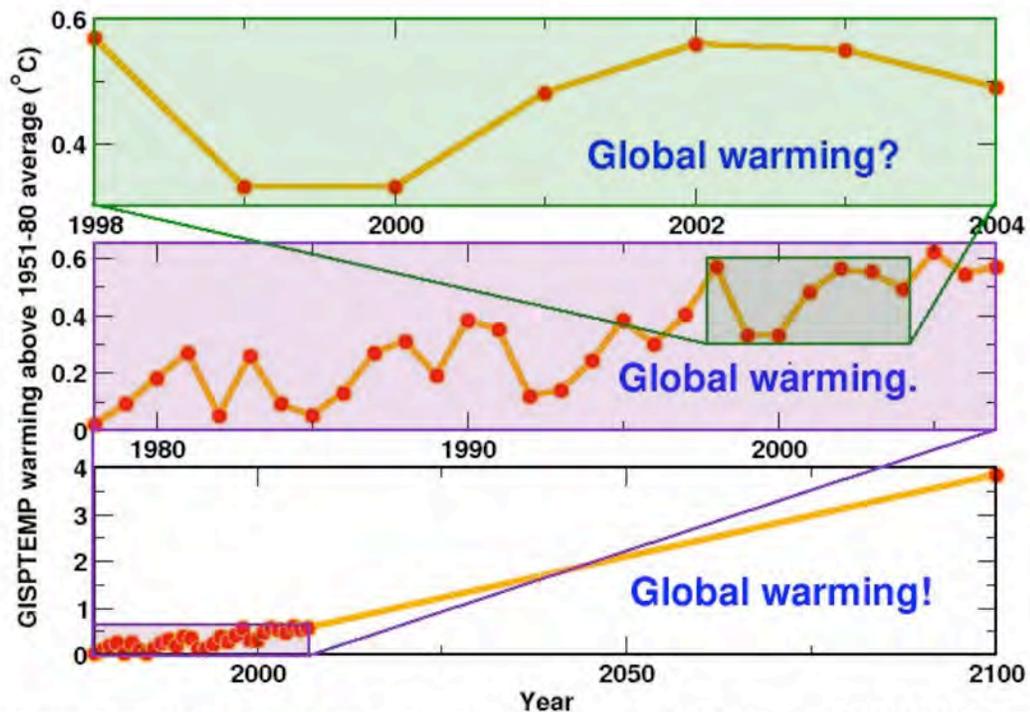
The United States National Academy of Sciences, the United Nations Intergovernmental Panel on Climate Change, and numerous leading professional societies such as the American Geophysical Union and the American Association for the Advancement of Science Board of Directors, have attested to the strong scientific evidence that human activities (especially burning of fossil fuels) are changing the composition of the atmosphere, that this is contributing to warming and other climate changes, that the changes so far are small compared to those expected under business as usual, that impacts of the climate changes on economies and ecosystems will be notable, and that mitigation and adaptation options exist. Here, in question-and-answer format, is a synopsis of some of the relevant science, with special attention to ice sheets.

*Any opinions, findings, conclusions, or recommendations expressed in this document are those of the author and do not necessarily reflect those of the Pennsylvania State University, the Intergovernmental Panel on Climate Change, the National Research Council, or other organizations. My remarks neither prejudice nor presage the contents of Synthesis and Assessment Product 1.2 of the U.S. Climate Change Science Program, now in preparation and for which I am one of the lead authors. Some of the figures attached may be subject to copyright protection.

GLOBAL WARMING

Q1: Is climate changing?

A: Yes. Warming is shown by thermometers in the air, including those far from cities, thermometers taken aloft by balloons or looking down from space, thermometers placed in the ocean and in boreholes in rock, and by changes in where and when biological events happen and ice thaws. Note that weather still exists—chilly days and weeks do happen, and a La Nina event in the Pacific or other natural events can make a whole year colder than the previous one. But if you take any of the major measures of global temperature, and any time long enough to smooth out the bumps from weather, you find that warming is occurring.



You may see the claim that global warming stopped in 1998. The 1998-2004 data (top) may look that way. But, we know weather still exists. A thirty-year view (center), long enough to smooth out the weather, clearly shows warming. The A2 projection for the year 2100 (bottom) provides an interesting comparison. Data from NASA GISS GISTEMP, <http://data.giss.nasa.gov/gistemp/graphs/Fig.A2.txt>, projection from IPCC WG1 AR4 SPM, www.ipcc.ch

Figure 1. History of globally averaged surface temperature, showing a six-year interval (top) that is too short to average over the weather, a thirty-year interval (center) that reveals the recent warming, and a comparison of these recent changes to changes that may occur this century.

Q2: Climate has always changed. What's the big deal now?

A: Indeed, natural changes have happened, with continental drift altering atmospheric CO₂ over tens of millions of years, wiggles in the orbit causing ice ages and CO₂ changes over tens of thousands of years, and other natural changes. Earth and life are still here. If we didn't have a special concern for humans, and for the other species that we know, climate change might not be a big deal.

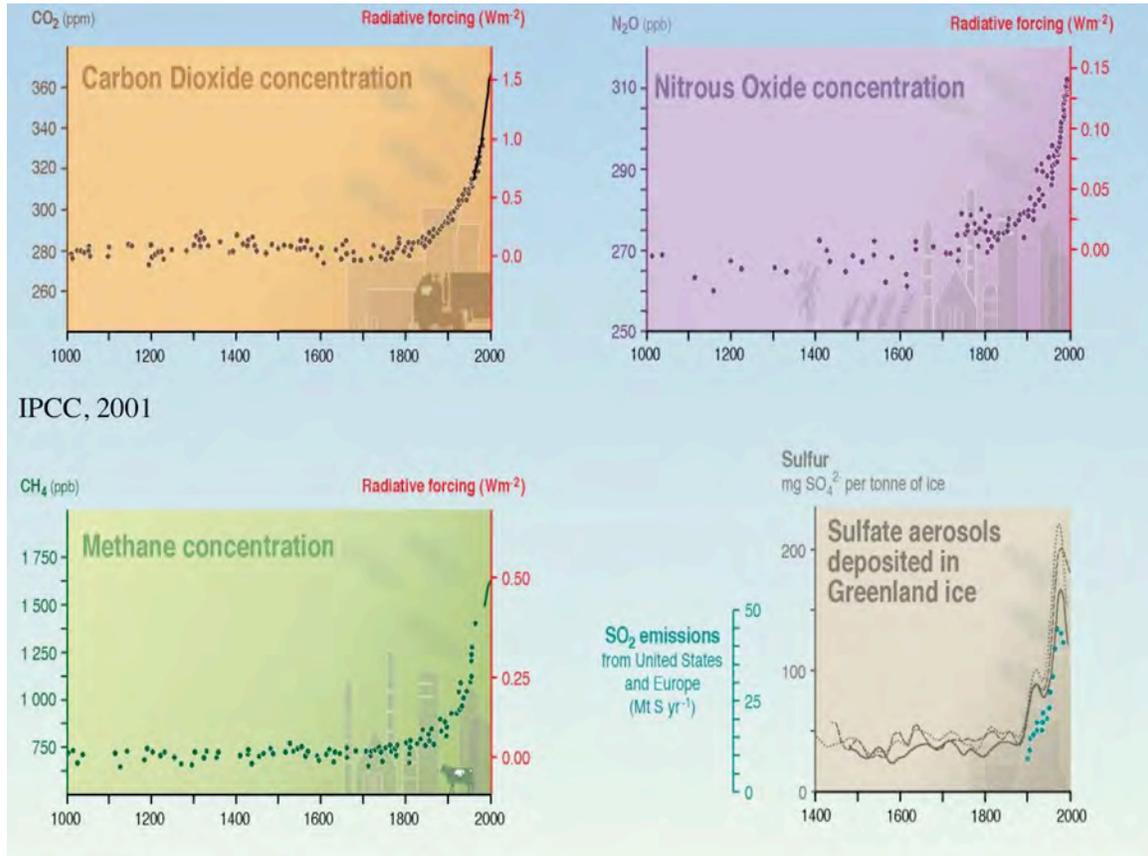


Figure 2. Shown here is the history of three trace gases that warm the planet (carbon dioxide or CO₂, nitrous oxide and methane) over the last thousand years, together with “acid rain” that cools the planet, from the IPCC WG1 Third Assessment Report in 2003. Further back in time, natural changes have occurred in these, and in the climate, but the recent changes are mostly due to us. Water vapor is not shown, although it is an important greenhouse gas. Water vapor put into the air rains or snows out quickly, in just over a week on average, so we cannot put it up fast enough to make much difference. The only way we know to change water vapor a lot is to change the temperature, because warmer air picks up more water vapor from the ocean.

Q3: So why blame the recent changes on us?

A: The human cause of rising CO₂ is very clear—we know from oil-tanker shipments and coal trains how much fossil fuel is being burned, burning uses oxygen and the drop in atmospheric oxygen is of the size expected to explain the burning (but with plenty of oxygen left to breathe), and other isotopic indicators agree that we are responsible for the rising CO₂. The warming effect of CO₂ has been known for over a century, and was clarified especially well by military research linked to World War II—the hot exhaust makes a target of a high-altitude bomber but must be viewed through the “haze” of CO₂ and other greenhouse gases in the atmosphere, so the US military did a really good job of studying the interactions of gases and heat radiation. And, the warming now has the “fingerprint” of CO₂—where and when the climate changed was following a natural pattern in the early part of the 20th century, but switched to a mostly human pattern more recently.

Record since 1958 of atmospheric CO₂ (the Keeling curve, below) and the shorter record of atmospheric O₂ (the new Keeling curve, right). These are related--oxygen is being used to burn fossil fuels to make the CO₂. We'll be able to breathe, but CO₂ is from burning plants, not from ocean or volcanoes. The changing carbon isotopic ratio ¹³C:¹²C in CO₂ also shows that plants rather than volcanoes or oceans are controlling, and the changing ¹⁴C:¹²C shows that the plants have been dead a LONG time--fossil fuels.

Scripps Institution of Oceanography

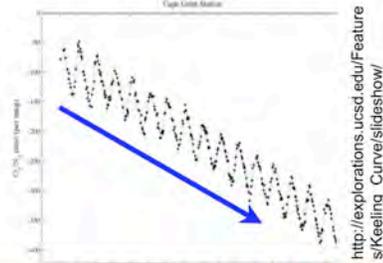


Figure 3A. The bottom of this figure shows the recent rise in CO₂. If the CO₂ comes from burning, rather than from volcanoes or the ocean, then O₂ in the atmosphere should be dropping to supply the O₂ in the CO₂. The upper panel shows the dropping oxygen. Charles David Keeling (CO₂), and Ralph Keeling (O₂), both of the Scripps Institution of Oceanography, generated the curves.

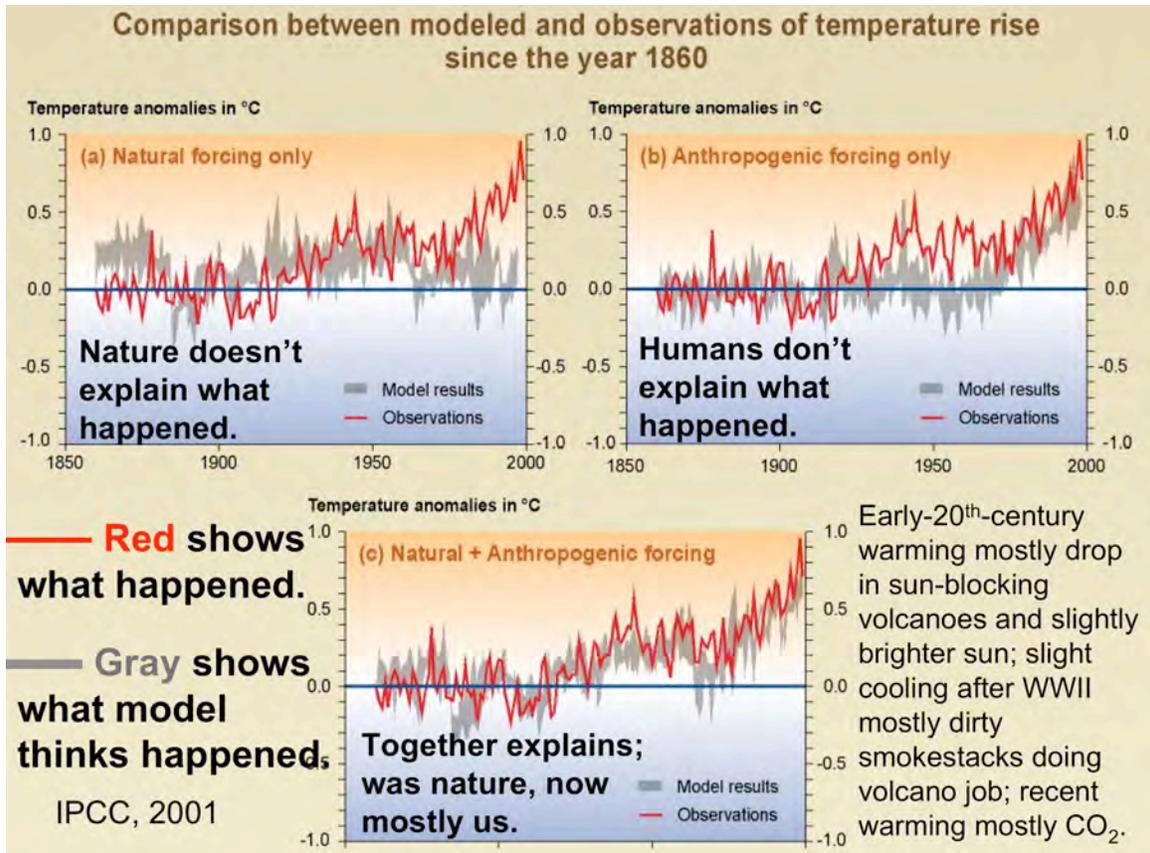


Figure 3B. The “fingerprint” of changing climate in time and space looks like that expected from human influence recently, but from natural influence further back in time before there were so many humans doing so much. This figure from the IPCC WG1 Third Assessment Report, 2001, summarizes part of the “attribution” exercise. The red in each panel is the history of global average surface temperature from 1860 to 2000. The gray is model output. For the upper left, the model was told only about the natural causes of climate change. The latter part of the cool Little Ice Age in the late 1800s had a lot of sun-blocking volcanic action and a slightly dim sun, with warming in the early 20th century as these returned to normal. These do not explain the more-recent changes, but the sun-blocking effect of our post-WWII dirty smokestacks doing the volcano job, and the warming effect of our CO₂, together explain the more-recent changes (upper right), so that nature and humans are sufficient to explain the whole history (bottom). Similar fingerprinting exercises look at the pattern of climate change across the surface of the planet, and going up in the atmosphere, and similarly find that humans are now primarily responsible, with high scientific confidence.

Q4: But isn't the claim about human causes based on untested computer models?

A: No. Very simple, fundamental physics principles point to the human influence at least since the latter part of the 20th century—temperature has been rising as expected for CO₂, at a time when satellites show that the sun has not been getting brighter, and other likely causes of climate change are similarly not contributing to warming. Computer models are used to provide additional support for the role of CO₂ in warming, but those models are tested extensively, with the model-builders checking themselves many, many times and finding much skill. (“Do our models agree with fundamental physical law? When given simple problems for which we already know the answer, do our models get it correct? Do our models reproduce climate changes of the past, for times hotter and colder than the present, without “cheating” by “tuning” the model to give the right answer?”)

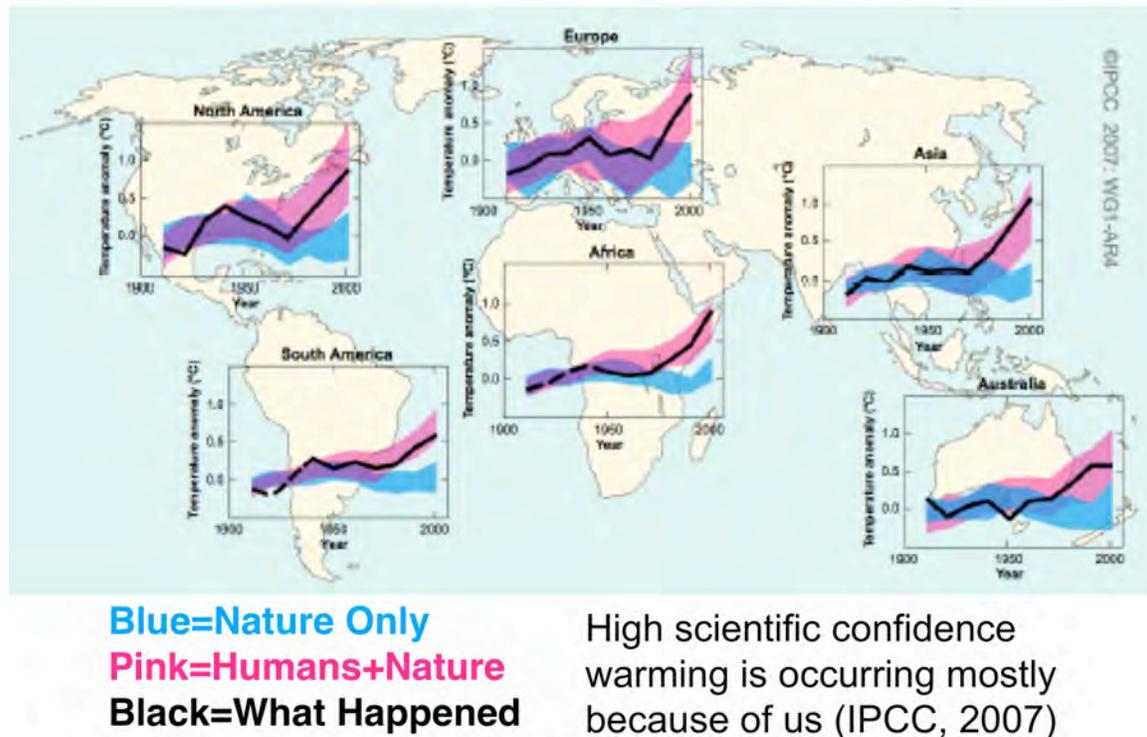


Figure 4. Our understanding of the climate system is now rather good, and the models show a lot of skill, reconstructing the history of climate change if given information on human and natural causes of change, but failing to reconstruct the history of climate change from natural causes alone. This is the updated version of the previous figure, from the IPCC WG1 AR4 SPM, in 2007. The models have NOT been “tuned” to match the history of climate change. Instead, any model tuning that is required is focused on matching the climate for one time interval. One of the tests of the models is whether they can then match the changing climate over time. As shown here, the models are now skillful not only for the globe, but also for smaller regions. Modeling has been going on long enough to show that earlier projections have been skillful (e.g., Rahmstorf et al., Science, 2007).

Q5: But aren't the human-caused changes in climate small?

A: Yes. Although the recent warming is scientifically unequivocal, and has caused other changes in the Earth system noticed by many people, other people who are not paying close attention may not have noticed, and not every point on the planet has warmed. But, the planet is still warming from what we have done already (the ocean takes a while to heat up), and there is enough fossil fuel left to make a much bigger perturbation to the planet than what we have done so far, with much bigger warming expected as a result. We have just started down this path.

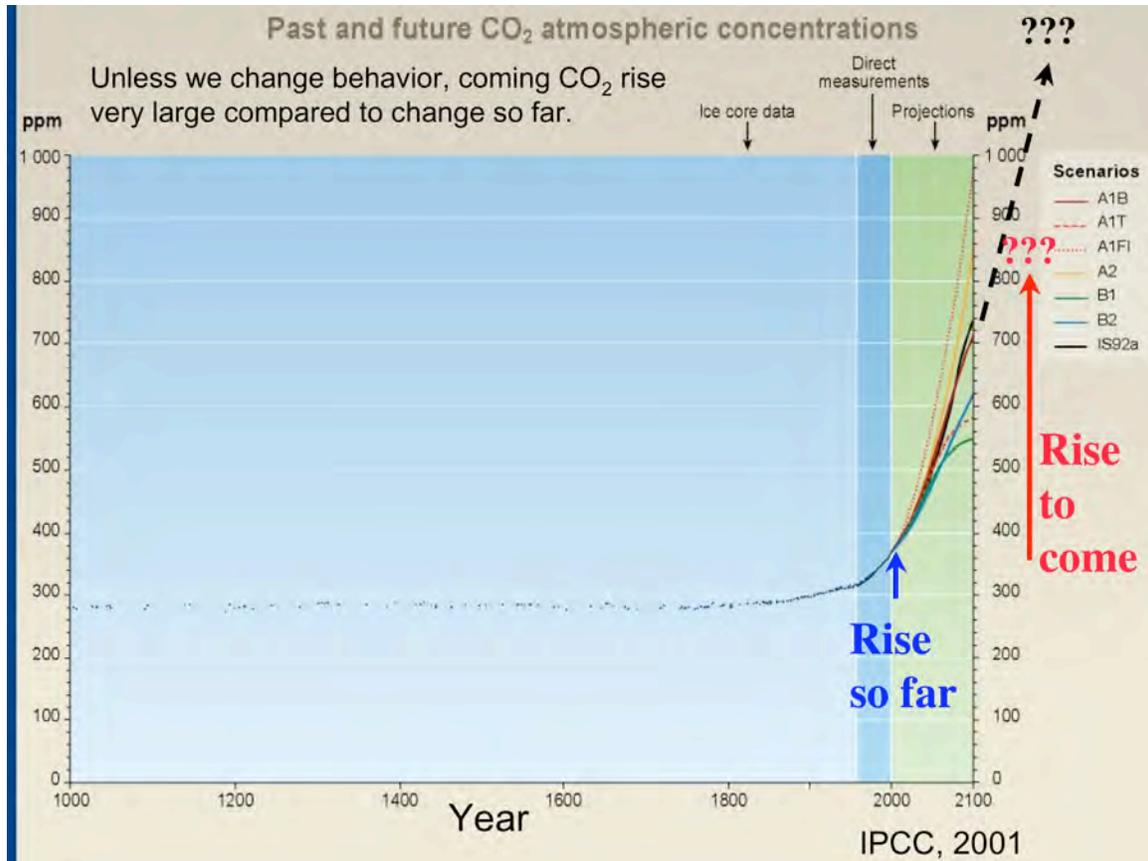
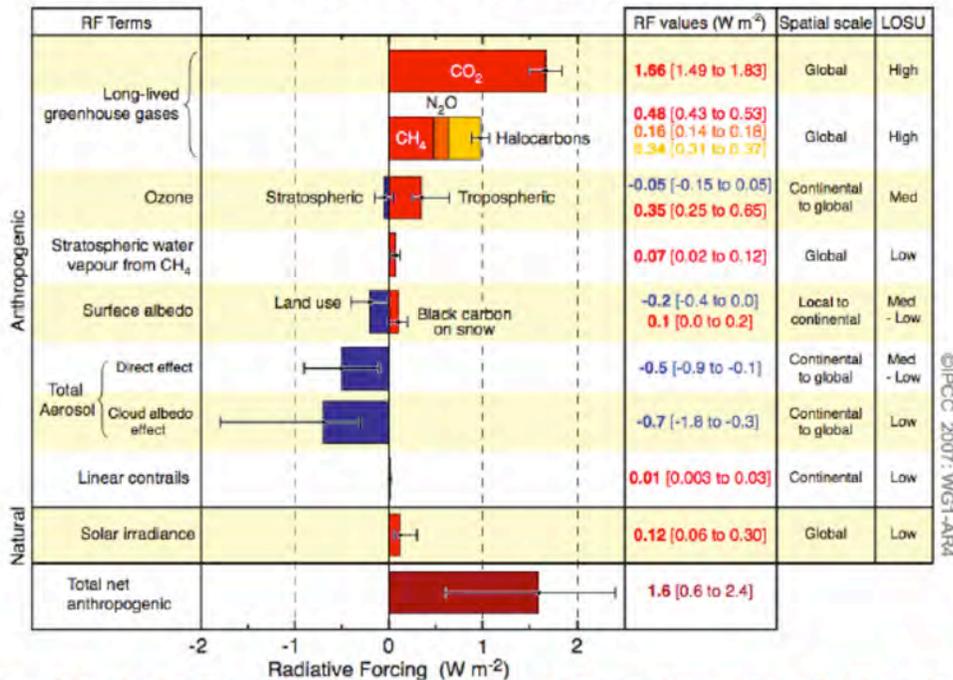


Figure 5A. Plotted properly, the recent rise in CO₂ looks very impressive, because it is far larger and faster than the changes of the previous millennium, and far larger than our uncertainties in estimating that history. But if we continue working hard to find and burn fossil fuels, the coming changes could be much, much larger than those that have occurred so far. We're not sure how high CO₂ might go; this graph goes up to 1000 ppmv, but something above 2000 ppmv is not impossible. The effect of CO₂ is such that each doubling has roughly the same influence on temperature, so moving from the pre-human level of ~280 ppmv to 560 ppmv will cause some warming (probably 5-6°F at equilibrium), with an additional doubling (to 1120 ppmv) needed to get another 5-6°F, and one more doubling (to 2240 ppmv) not impossible, to give another 5-6°F warming. If CO₂ comes down really rapidly, the full warming won't be realized.

Radiative Forcing Components



Five-year olds playing soccer. Red is warming, blue cooling. Lots of things have been kicking the climate, and it took much effort to learn with confidence that CO₂ kicks harder. Under business as usual, CO₂ will come to dominate by far.

Figure 5B. Particles (aerosols) or water vapor put into the lower part of the atmosphere stay for a week or two before falling out, methane may last a decade or so, contrails an afternoon, but much of the CO₂ will stay up for centuries or longer. If we continue to raise CO₂, it will come to dominate over the other causes of climate change. The human contributions so far (plus the very small solar contribution) are shown here, in a figure from the IPCC WG1 AR4 SPM.

Multi-model Averages and Assessed Ranges for Surface Warming

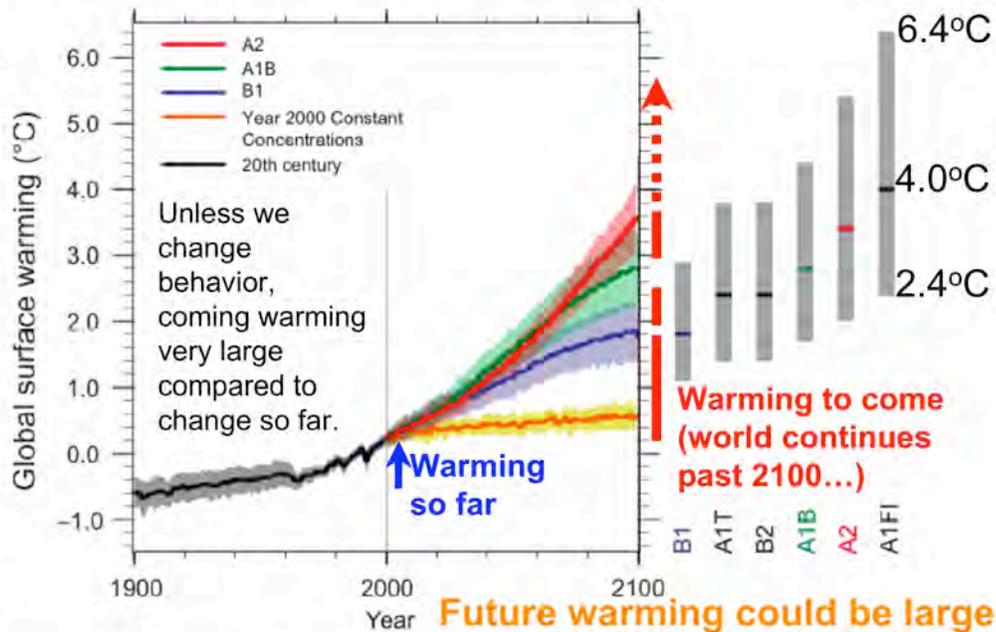


FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. (Figures 10.4 and 10.29) IPCC WG1 AR4 SPM, 2007

Figure 5C. The warming so far, while scientifically unequivocal, has not been noticed by everyone everywhere, and cold days do still occur. If we continue business as usual, the warming is expected to become much larger. The lower orange curve is the warming “in the pipeline” if the atmospheric composition were stabilized now. The other curves are the warming for various scenarios of future emissions. Uncertainties arise from what we don’t know about nature, and what we don’t know about human behavior, with human behavior more important than nature now. As noted in the figure, the world does not end in the year 2100, and all of the curves are rising as they cross 2100. Also notice that the uncertainties are mostly on the more-warming side of the central estimates.

Q6: But what if you're wrong, and the warming is natural?

A: If nature is causing warming, is that a reason to turn up the thermostat? The climate over the last century has moved a bit like a soccer ball in a game of five-year-olds as noted with Figure 5B, and while CO₂ has been the most forceful kicker, sun and volcanoes and particles from smokestacks and other players have also moved the ball around the field, so it has taken a while for the scientists watching to gain confidence that CO₂ is the prime mover. But under business as usual, CO₂ is expected to grow in strength without a coupled increase in the strength of the other players. Let one of the five-year-olds grow to become a member of the US national soccer team while the rest of the kids stay the same size and strength, and you have much more confidence which way the ball will go. Let CO₂ grow unchecked into the future, without beefing up any of the other players, and the influence of the CO₂ will similarly grow.

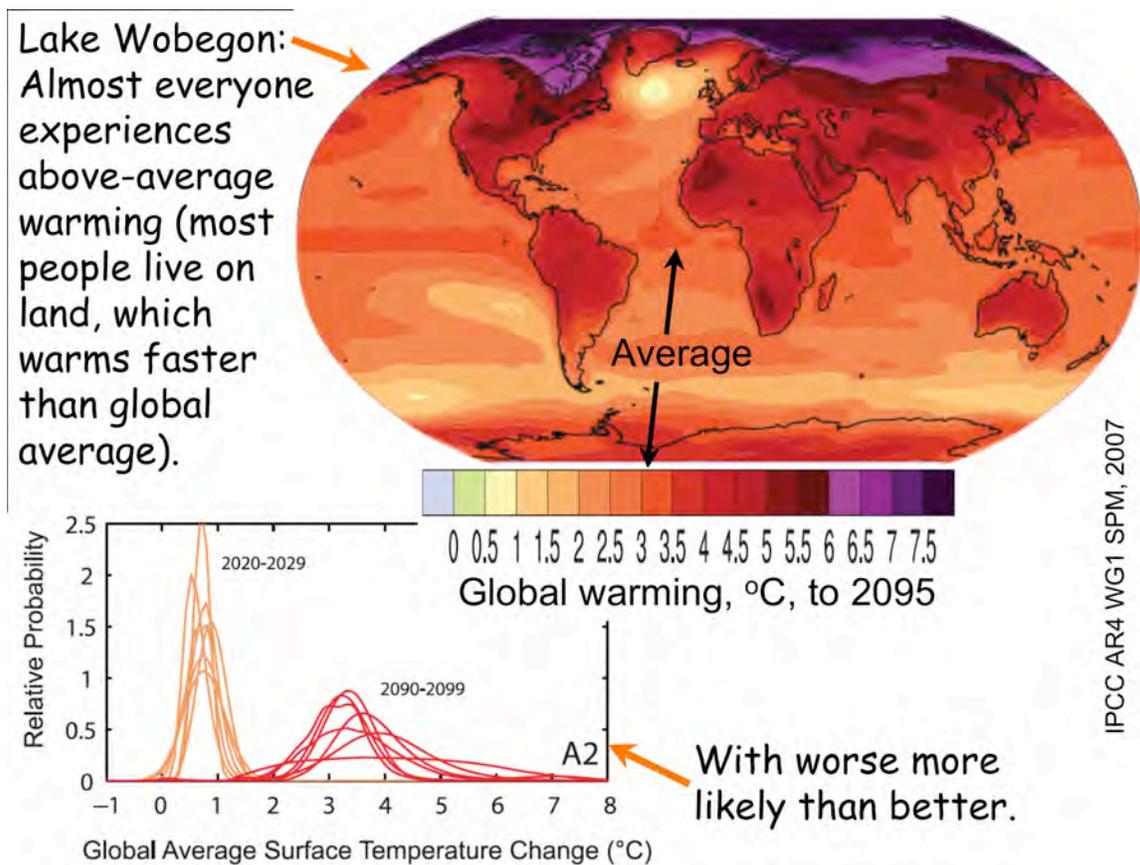


Figure 6. The globally averaged surface temperature rise is often reported, but that may be misleading, because the land is expected to warm more than the ocean, and we mostly live on the land. The uncertainties are also such that the warming may be less than indicated here, but there is more possibility of a larger warming than of a smaller warming.

ICE SHEETS.

Q7: Why all this excitement about the Antarctic and Greenland Ice Sheets, when they are changing only a little bit?

A: Sea level has been rising just over an inch per decade recently, primarily because the recent warming is causing ocean water to expand, and mountain glaciers in Alaska, Patagonia, the Alps and elsewhere to melt. Although measurements show that the big ice sheets of Greenland and Antarctica are contributing to the sea-level rise, they are still not the major players. But, the ice sheets grossly dominate possible sea-level rise because they are so big. The little warming that has happened so far seems to have caused a little melting of the big ice sheets, so if more warming occurs, many people would like to know whether more sea-level rise will result.

Q8: Haven't the ice sheets survived warming in the past?

A: Yes. The ice sheets have grown when the climate cooled, and shrunk when the climate warmed. For a little warming, the shrinkage seems to have been small; for too much warming, the Greenland ice sheet seems to have largely or completely disappeared, and even more warming seems to have done the same to parts or all of the Antarctic ice sheet. Unfortunately, just how much warming is "too much" remains unclear. We might reach a temperature this century that, if maintained, would melt the Greenland ice sheet and important parts of the Antarctic ice.

Q9: But won't that melting take a long time?

A: Yes, although we don't know how long. Drop an ice cube in a glass of tea, and unless you put the glass in the freezer, the ice cube is doomed, after a while. Too much warming, and Greenland's ice will melt, but such a large "ice cube" will not melt quickly. However, Greenland and coastal Antarctica have also exhibited flow instabilities. At places including the Larsen B Ice Shelf along the Antarctic Peninsula, Pine Island Bay in West Antarctica, and Jakobshavn Glacier in Greenland, warming has caused shrinkage or break-up of floating extensions of the ice sheet called ice shelves, "unplugging" the not-yet-floating ice behind to flow faster (as much as eight-fold) to the sea to make icebergs. Although loss of the floating ice shelves did not raise sea level, the delivery of additional icebergs from the flow acceleration did raise sea level. In Greenland, additional meltwater has reached the bed of the ice sheet to lubricate faster flow that lowers more of the ice into warmer air. In considering these processes, the UN IPCC in 2007 wrote "understanding of these effects is too limited to... provide a best estimate or an upper bound for sea level rise". (So, the IPCC did not somehow reduce their estimate of total sea-level rise.) Even so, losing an ice sheet is not expected in decades, although whether centuries or millennia, and how many of each, we just don't know. Notice that the ongoing sea-level rise of just over an inch per decade contributes to coastal retreat (as do other processes), and that about three-quarters of the US coastline is estimated to be retreating. If Greenland were to melt in a millennium, it would add about 3 inches per decade on average, dominating the current sources of sea-level rise; were the larger Antarctic ice sheet to contribute as well, much larger rates are possible.

Q10: Are there tipping points for ice sheets?

A: Quite possibly. Transferring an ice cube from your freezer to your glass of iced tea is surely a tipping point for the ice cube; even if you take it out of the tea and put it back in the freezer, you won't immediately have the whole ice cube again. Too warm, and an ice sheet melts unless you can get it back in the "freezer" in a hurry, and if the faster flow lowers the ice sheet, the cold central region will become warmer, favoring melting. Many times in the past, ice sheets have been well-behaved, changing slowly in response to changing climate, but sometimes large and rapid ice-sheet changes have occurred and huge ice sheets have disappeared completely.

Q11: What about all the uncertainties?

A: This is science, not revealed Truth, so there are uncertainties. But, that often provides little comfort to people worried about large future changes. In many ways, the scientific evidence indicates that there is a central estimate of what will happen, that things could be a little better or a little worse than the central estimate, or things could be a lot worse. We don't expect an ice sheet to fall apart really rapidly, or for the meltwaters to greatly change the currents in the north Atlantic and bring drought to huge regions as happened during the warming from the last ice age, but while such events may be highly unlikely, they are not impossible. We wish we could find "a whole lot better" to offset the "whole lot worse" possibility, but that usually does not appear. The estimates of how much warming we will get from a given amount of CO₂ usually have a similar pattern—a central estimate, and the possibility of a little less, or a little more, or a lot more.

Q12: So where does that leave us?

A: The best available scientific evidence shows that human fossil-fuel burning and other activities are altering the composition of the air, causing warming, sea-level rise, and other climatic changes, and that human decisions will determine whether or not future changes are much larger than those that have already occurred.

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