Global climate change and the scientific consensus

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The public may want to know what scientists believe about climate warming. Strictly speaking, we believe almost nothing, at least when we are being scientists. As scientists, our job is to present the data on climate change and to propose plausible explanations for these observations. It is most important that these explanations be testable through predictions that can be verified. The concept of human caused climate warming is based on an enormous body of observations that is consistent with the idea that we are making the atmosphere hotter through our use of fossil fuels. This idea dates from the late 19th century, and it has been tested in numerous ways. The case for human caused climate warming represents the observations of generations of scientists and is one of the most compelling scientific stories ever written.

The evidence

The Earth's surface has undergone unprecedented warming over the last century, particularly over the last 25 years. Every year since 1992 is in the list of the 20 warmest years on record. The physics of how greenhouse gases can absorb and radiate heat is indisputable. The question has always been whether or not human emissions of greenhouse gases, such as carbon dioxide, are a primary factor in the observed warming. There are three striking fingerprints of human generated greenhouse gases on the Earth's temperature.

1. The world's oceans have absorbed 20 times as much heat as the atmosphere over the last century, and ocean warming over the last 25 years is now apparent down to 9,000 ft.
2. The atmospheric boundary between the troposphere near Earth and the overlying stratosphere has shifted upward over the last two decades by more than 900 ft.
3. The global average temperature has increased 1.4 degrees Fahrenheit in the last 100 years, with most of this shift happening within the last three decades.

Additional evidence of recent warming comes from observations of the melting of Arctic sea ice and worldwide massive retreat of glaciers, both predicted by climate warming scenarios. Within the last two decades we have seen an acceleration of sea level rise to a rate that is faster than the rate of rise in any 20-year period in the preceding 115 years.

Scientists cannot recreate the Earth's climate in a laboratory bottle and change its composition to see what happens. Instead, teams of climate scientists have used global climate models to simulate the globally averaged temperature of the atmosphere. These mathematical models are able to simulate the observed warming only when human generated greenhouse gases are included along with natural forces affecting atmospheric temperature. It is especially compelling that the models accurately predicted the global cooling measured following from the eruption of Mount Pinatubo, which pumped aerosols into the stratosphere thus reducing heating from the sun. Given their ability to closely simulate the observed warming since 1900, it is prudent to take seriously the models' projections for future warming.

The scientific consensus

In February 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (greater than 90 percent probability) due to the observed increase in anthropogenic greenhouse gas concentrations." The IPCC's report, the fourth in a series since 1990, was the work of 150 lead and 450 contributing authors, representing 113 nations. These researchers, most of whom were unpaid and newly recruited to this effort, concluded that the warming of the climate is "unequivocal" and that human activities are behind the unprecedented speed of change.

The authors stated that future warming is "very unlikely" to be inconsequential. This echoes the consensus of 11 of the world's leading national academies of science, which stated in 2005 that we should mitigate the causes of climate change and prepare to adapt to the consequences. As John Holdren, the president of the American Association for the Advancement of Science, stated, "We have three choices – mitigation, adaptation, and suffering." What we do in the near term will determine the mix of these.

The IPCC's latest report is sobering for some scientists because of what is left out. Because the rate of increased ice flow from glaciers in Greenland and Antarctica had not been measured sufficiently for inclusion in the models, the scientists limited their assessment of sea level rise primarily to factors affecting ocean expansion caused by heat. Similarly, they left out the thawing of the Arctic permafrost, which many scientists agree is accelerating, resulting in significant emissions of carbon dioxide and methane. Accordingly, the estimate of sea level rise is conservative. Several scientists have argued that it could be much higher than the predicted 7 to 23 inches by 2100. Stefan Rahmstorf and colleagues recently reported in *Science* that the observed rises in temperature and sea level over the last 6 years have been at the upper limit of the IPCC's previous predictions.

Scientific credibility

What is most remarkable about the scientific consensus is that there is one. Scientists build their careers by challenging paradigms and reframing conventional wisdom in the light of new data. Scientists are skeptical by habit, but skepticism means rationally evaluating rather than mindlessly doubting. Science is the discipline of careful

evaluation of all available evidence, leading to judgment of the current state of reliable knowledge, and current judgment is always falsifiable by new evidence. The work behind the IPCC reports and the joint academies statement is of the highest scientific standard and represents the views of the world's best experts.

There is general consensus on the following:

- The climate is undergoing a pronounced warming trend beyond the range of natural variability.
- The major cause of most of the observed warming is rising levels of the greenhouse gases, primarily carbon dioxide.
- The rise in carbon dioxide is the result of burning fossil fuels.
- As carbon dioxide continues to rise over the next century, the warming will continue.
- A climate change of the projected magnitude over this time frame represents potential danger to human welfare and the environment.

The IPCC and the joint academies of science statement agree on these points. A more complete list of endorsing societies and institutions includes the following:

- Academia Brasiliera de Ciências (Bazil)
- Royal Society of Canada
- Chinese Academy of Sciences
- Academié des Sciences (France)
- Deutsche Akademie der Naturforscher Leopoldina (Germany)
- Indian National Science Academy
- Accademia dei Lincei (Italy)
- Science Council of Japan
- Russian Academy of Sciences
- Royal Society (United Kingdom)
- National Academy of Sciences (United States of America)
- Australian Academy of Sciences
- Royal Flemish Academy of Belgium for Sciences and the Arts
- Caribbean Academy of Sciences
- Indonesian Academy of Sciences
- Royal Irish Academy
- Academy of Sciences Malaysia
- Academy Council of the Royal Society of New Zealand
- Royal Swedish Academy of Sciences
- NASA's Goddard Institute of Space Studies (GISS)
- National Oceanic and Atmospheric Administration (NOAA)
- National Academy of Sciences (NAS)
- State of the Canadian Cryosphere (SOCC)
- Environmental Protection Agency (EPA)
- Royal Society of the United Kingdom (RS)
- American Geophysical Union (AGU)

- American Institute of Physics (AIP)
- National Center for Atmospheric Research (NCAR)
- American Meteorological Society (AMS)
- Canadian Meteorological and Oceanographic Society (CMOS)

The organizations listed above do not give their endorsement without lengthy and careful consideration. More importantly, all of the work leading up to the IPCC reports has gone through the peer review process. This process of critical review helps insure that only carefully constructed science is published, and when errors do appear, the system is self-correcting as additional data come to light. The IPCC assessments are arguably the most peer reviewed scientific studies ever produced. The American Association for the Advancement of Science, the world's largest and possibly most prestigious scientific organization, endorses the general tenants of climate change outlined above.

The skeptics and their concerns

A small number of scientists have taken issue with the above consensus. With few exceptions, their concerns have not been published in the peer reviewed scientific literature. Substantial evidence leading to conclusions contrary to the consensus discussed above would be rapidly published by the best science journals. In fact, over the last decade the climate literature has hosted several papers showing the limitations of the global climate models, including some theoretical treatments suggesting that they are flawed. Most of the skeptics' concerns, however, have played out in the popular press, usually in the form of assertion without validating data or critical review.

The best approach to all of these disagreements is to focus on the data and the science. Under close inspection, each of the skeptics' charges represents only a small or incomplete piece of the climate puzzle, and none of them present a serious scientific challenge to the evidence showing human caused climate change. Here are a few of the most important:

1. Antarctica has not warmed, and in fact shows evidence of cooling.

    Antarctica is predicted to warm very slowly during the first half of this century. We do not know the net balance of ice across the entire continent, but it appears to be gaining some mass in the interior, and losing mass along the coasts, especially the Antarctic Peninsula, which is warming five times the global average. There is nothing happening in Antarctica that is inconsistent with global climate model predictions.

2. Solar forcing from the sun has caused the observed warming.

    Human greenhouse gas forcing is at least 5 times more powerful than solar forcing in accounting for the observed warming.

3. Cosmic rays have caused the warming through their interaction with cloud cover.

The relationship between cloud dynamics and cosmic rays was recently demonstrated in a paper published in the scientific literature. The linkage between this and the observed warming requires two more essential mechanistic steps, and neither of these has been demonstrated. The variation of cosmic rays since the early 1950's when we began measuring them does not correlate with the observed warming.

4. Satellite measured temperatures of the near Earth atmosphere are lower than the terrestrial measures. This suggests the terrestrial measures documented the heat island effect of human development on the land, rather than overall atmospheric warming.

Satellite measured temperatures were in error because they were incorrectly interpreted relative to the level of the atmosphere sampled. Corrected data from satellites closely match the ground-based measures. This was probably the most significant scientific challenge to the IPCC and national academies' position. The observed inconsistency was quickly published and then laid to rest as the community of scientists vetted it.

5. Scientists predicted the onset of an ice age in the 1970's and were wrong. Why should we believe them this time?

It is true that a few scientists noted a cooling trend and suggested that since we were experiencing the second longest known interglacial period, we were due for another glacial advance. The press reported at the time that an ice age was imminent, but this was clearly injudicious speculation by the scientists involved. There were no daily headlines, and no deluge of scholarly publications. There was no widespread scientific consensus. Climate science has made tremendous strides since the 1970's and today the consensus about warming is essentially universal. The global climate models have predicted several observed phenomena, thus validating this approach.

6. Although ice cores show good correspondence between high levels of greenhouse gases and warmer temperatures over the last 650,000 years, correlation does not prove causation.

This argument suggests that higher greenhouse gas levels are a result of higher temperatures, rather than vice versa. Instead, temperature and greenhouse gases can be mutually reinforcing and interact in a dynamic fashion. It is true that carbon dioxide levels in the atmosphere increase because at higher temperatures biological respiration increases and the oceans release more of this gas. But, increases in greenhouse gases can also force atmospheric temperatures to higher levels. Warming and cooling cycles in paleohistory have been initiated by other factors such as Earth's orbit and relationship to solar radiation, volcanism, and the Earth's system of thermal transfer via ocean currents, but the greenhouse gases can reinforce these cycles. This is why we are concerned that thawing of the permafrost will amplify climate warming through release of carbon dioxide and methane. The atmosphere is

a dynamic system and greenhouse gases are one determinant of the near Earth atmospheric temperature. At their present very high levels they are having a major impact.

7. Climate warming is not really so bad. Climate change is part of the natural process of the planet, and it is likely that many species will benefit from such a change, just as they have in the past.

The speed of the current warming is the main reason why we should be concerned. Plants and animals have adapted through natural selection to the particular climatic zone where they currently exist. Human caused rapid climate change will vastly outpace the process of natural selection, and it is likely that there will be many more losers than winners. Moreover, future projections show that there will be more frequent intense heat waves and more violent storms. This extreme climatic variability will have negative consequences for most organisms, including humans. Other consequences that cannot be taken so lightly include sea level rise and likely increased hurricane intensity.

Ongoing research

Climate change science continues to evolve and develop. The scientific literature blossoms with new papers and analyses on several issues related to the global climate models. Here are a few of the areas of active research:

1. Global climate models are not good at resolving fine scale regional and local climate variability. While more stable and globally predictive than meteorological models, which are sensitive to small errors in starting conditions, global climate models cannot predict weather for a given location. This is a significant shortcoming because people experience climate locally rather than globally. Work is ongoing at institutions such as the National Center for Atmospheric Research and the UK Hadley Center to develop regional climate models with predictive power.

2. Land use change is relatively unexplored as a climate-forcing factor. Changes in human uses of land can have big impacts on the energy reflected back into space from the land, and can dramatically influence wind flow, heat convection, and precipitation on a regional basis. Moreover, plans to use vegetation to capture carbon dioxide must reflect the impact of this strategy via land use as a forcing factor. Predicting the effect of future land uses will be a large part of future climate assessments.

3. Research on atmospheric circulation in the tropics is a rapidly developing science. Factors such as the El Niño/La Niña oscillation, the flow of the trade winds, and the form and function of tropical clouds are areas of active research. While this represents a source of uncertainty in the global climate models, the consensus view is that this work will not alter the importance of the greenhouse gases as primary forcing factors for global atmospheric temperature.

The recent IPCC fourth assessment is explicit about the high degree of certainty for the role of human generated greenhouse gases in recent climate warming, while noting that projections of future climate also depend on a variety of forcing factors. Greenhouse gases are a dominant factor in these projections, and the report is candid about the need for additional understanding of factors such as aerosols. As climate change science progresses, we will further reduce the uncertainty associated with climate projections. Meanwhile, it is essential that we weigh the cost of error associated with waiting until all scientific issues are settled before action is taken to reduce emissions of greenhouse gases. John Holdren, president of the American Association for the Advancement of Science, sums up the scientific uncertainty related to climate change with the metaphor of driving a car towards a cliff in a fog. While we might not know exactly where the cliff is, we are virtually certain that there is one down the road, and it is time to apply the brakes.

So, what can we do?

The long emergency of climate change is far from hopeless. Reduction of greenhouse gases requires leadership and concerted action on a planet wide basis, and I believe that this is possible. There is immense economic potential in the development of renewable energy, energy conservation, and efficient transportation. Because of the business opportunities emanating from climate change, I am more hopeful than I have been in 15 years that we can significantly reduce carbon emissions. Just as in the Great Depression, those who capitalize on the opportunities inherent in this challenge can create wealth. In a recent survey of 31 major companies for a Pew report on climate strategies, 90 percent said they believe that government regulation of emissions is imminent.

The effects of climate change will unfold over the next two centuries. While strategies such as emissions cap-and-trade and new energy technologies are brought to the market, we must also prepare to adapt to climate change. Carbon dioxide remains in the atmosphere for over 200 years, and thus if we were to cease all emissions tomorrow, we would continue to warm gradually through 2100 and beyond due to past emissions. This rate of warming is far better than what it will be if we continue with business as usual. Clearly, we must prepare for some consequences of climate change, while reducing emissions in order to avoid the worst consequences.