Science, Politics, and Public Perceptions of Climate Change

Richard C. J. Somerville

Abstract

Recent research has demonstrated that climate change continues to occur, and in several aspects, the magnitude and rapidity of observed changes frequently exceed the estimates of earlier projections, such as those published in 2007 by the Intergovernmental Panel on Climate Change in its Fourth Assessment Report. Measurements show that the Greenland and Antarctic ice sheets are losing mass and contributing to sea-level rise. Arctic sea ice has melted more rapidly than climate models had predicted. Global sea-level rise may exceed 1 m by 2100, with a rise of up to 2 m considered possible. Global carbon dioxide emissions from fossil fuels are increasing rather than decreasing. This chapter summarizes recent research findings and notes that many countries have agreed on the aspirational goal of limiting global warming to 2°C above nineteenth-century "preindustrial" temperatures, in order to have a reasonable chance for avoiding dangerous human-caused climate change. Setting such a goal is a political decision. However, science shows that achieving this goal requires that global greenhouse gas emissions must peak within the next decade and then decline rapidly. Although the expert scientific community is in wide agreement on the basic results of climate change science, much confusion persists among the general public and politicians in many countries. To date, little progress has been made toward reducing global emissions.

Introduction

The comprehensive Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), published in 2007, authoritatively evaluates climate change science published in the peer-reviewed research literature up to about mid-2006. Viewed from the perspective of what is known in late 2010, the report is thus inevitably somewhat out of date.

In 2007, at the time of the publication of AR4, climate scientists already understood from the most recent research that "observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change" (Rahmstorf et al. 2007).

Now, in 2011, more recent research has demonstrated that climate change continues to occur, and in several

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aspects, the magnitude and rapidity of observed changes frequently exceed the estimates of earlier projections, including those of AR4. In addition, the case for attributing much observed recent climate change to human activities is even stronger now than at the time of AR4.

Several recent examples, drawn from many aspects of climate science, but especially emphasizing atmospheric phenomena, support this conclusion. These include temperature, atmospheric moisture content, precipitation, and other aspects of the hydrological cycle.

Motivated by the rapid progress in research, a recent scientific synthesis, *The Copenhagen Diagnosis* (Allison et al. 2009), has assessed recent climate research findings, including:

- Measurements show that the Greenland and Antarctic ice sheets are losing mass and contributing to sea-level rise.
- Arctic sea ice has melted far beyond the expectations of climate models.
- Global sea-level rise may attain or exceed 1 m by 2100, with a rise of up to 2 m considered possible.
- In 2008, global carbon dioxide emissions from fossil fuels were about 40% higher than those in 1990.
- At today's emissions rates, after just 20 more years, the world will no longer have a reasonable chance of limiting warming to less than 2°C.

The Copenhagen Diagnosis also cites research supporting the position that, in order to avoid dangerous climate disruption, global emissions must peak and then start to decline rapidly within the next 5–10 years, reaching near-zero well within this century.

The Copenhagen Diagnosis is available at http://www.copenhagendiagnosis.org. A somewhat updated version has been formally published recently (Allison et al. 2011).

This chapter summarizes the rapid recent progress in climate change research and relates it to recent developments in the politics and public perceptions of climate change.

The Intergovernmental Panel on Climate Change and Its 2007 Report

We can begin by looking back at the last IPCC report and asking some key questions:

1. What is the Intergovernmental Panel on Climate Change and how does it work?
2. Were the main conclusions in the IPCC Fourth Assessment Report (AR4), published in 2007, correct?
3. How has climate science changed since the scientific papers that were assessed in AR4?

IPCC was founded in 1988. The history of IPCC has been documented by Bolin (2007). To date, IPCC has produced four major Assessment Reports (ARs). The average interval between reports is about 6 years:

1990: First AR (FAR)
1995: Second AR (SAR)
2001: Third AR (TAR)
2007: Fourth AR (AR4)

In 2013, the Fifth AR (AR5) is expected. During the 20 years since the publication of the First Assessment Report, great progress has been made in climate change science. As an example, much more observational data have become available, and computer simulations of the climate system have made great advances in physical comprehensiveness and realism and also in computational resolution.

The Working Group I (physical science) part of AR4 was written by 152 scientists called "Lead Authors." Twenty-two of the 152 are called "Coordinating Lead Authors." These are the scientists who led the writing teams for each of the 11 chapters. I was a Coordinating Lead Author for AR4. In this discussion, however, I am speaking as an individual scientist, not on behalf of IPCC or any other organization. In this chapter, I shall refer to the Working Group I (WGI) portion of the IPCC report only, and I shall not consider the reports of IPCC Working Groups II and III, which deal with adaptation, impacts, mitigation, and other issues.

There were several diversity criteria in choosing the 152 Lead Authors in WGI of AR4:

The Lead Authors included younger as well as older scientists. At the time of their appointment, 25% of the Lead Authors had earned a Ph.D. within the last 10 years.

The Lead Authors were not a clique composed of authors of earlier IPCC reports. In fact, 75% of them had not been previous IPCC authors.

The Lead Authors were not overwhelmingly representatives of a few developed countries. Fully 35% of them were from developing countries and countries with economies in transition.

The 152 Lead Authors were chosen by IPCC from about 700 nominations by governments.

The WGI portion of the 2007 IPCC report (AR4) is about 1,000 pages long and took 3 years to write. During the writing, more than 30,000 review comments, from both governments and individuals, were received on three separate drafts. The authors' written responses to every review comment are in the public record. The open and transparent nature of the IPCC process, the multiple stages of peer review, and the credentials of the authors all contribute to the stature of the report.

We can start with the iconic figure depicting the atmospheric CO_2 concentration as a function of time, as measured since 1958 (Fig. 1). This is the famous "Keeling curve." This graph shows that the relentless upward trend in the amount of CO_2 in the atmosphere continues. In fact, the concentration now is increasing more rapidly than before. Charles David Keeling, who began these observations in 1958, died in 2005. However, the meticulous measurements that he undertook, initially made with an instrument that he invented, are now being continued by others at several stations in an international network.

The International Scientific Congress in Copenhagen in March, 2009

There were two noteworthy climate meetings in Copenhagen in 2009. The more famous one, the United Nations Framework Convention on Climate Change (UNFCCC) meeting, was held in Copenhagen in December 2009. This was the 15th Conference of the Parties (COP15). The UNFCCC was the document to which the countries that had ratified it were parties. The primary scientific input to the COP15 negotiations was, of course, AR4, the Fourth Assessment Report of

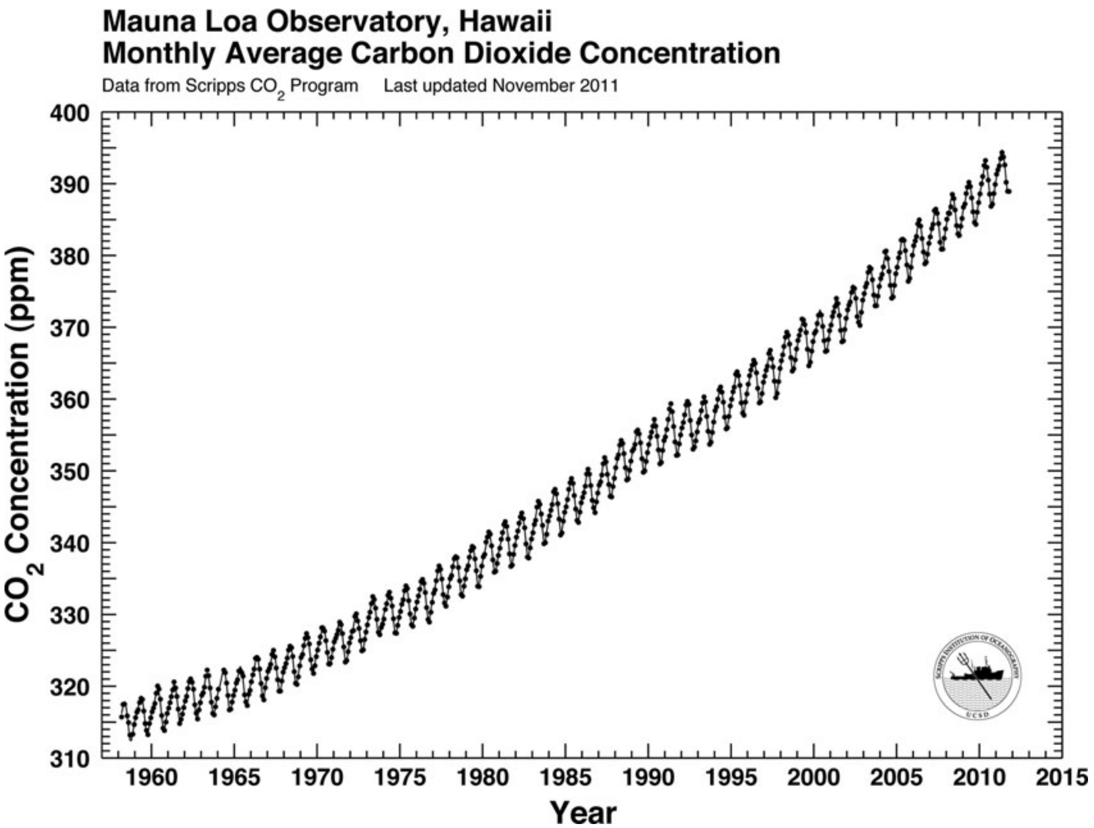


Fig. 1 The Keeling curve, showing atmospheric carbon dioxide amounts as a function of time since 1958 (credit: Scripps Institution of Oceanography CO_2 Program)

the Intergovernmental Panel on Climate Change (IPCC), published in 2007. This report and many other recent IPCC documents are available at http://www.ipcc.ch and are also published by Cambridge University Press.

However, new scientific developments occur continually. Since the publication of the AR4 IPCC report, new knowledge has emerged that furthers our understanding of climate change, including the impacts of human influence on the climate. To bring this new knowledge together, about 9 months before COP15, an international scientific congress, called Climate Change: Global Risks, Challenges and Decisions, was held, also in Copenhagen, from 10 to 12 March 2009. One must keep in mind that the AR4 IPCC report was published in 2007 and the most recent papers that it assesses were published in 2006.

The Copenhagen congress in March 2009 covered more recent research results, but the conclusions of this meeting did not go through any procedure resembling the long IPCC process of multiple drafts and extensive review. Nor did the March 2009 Copenhagen meeting report have the full participation of many expert authors, as did the IPCC. This fact illustrates the inevitable trade-off between the slow and painstaking IPCC process and faster but less thorough summaries and assessments of recent science.

We now consider some of the key results presented at the March 2009 Copenhagen meeting. Temperature is the single most important climate variable. Let us first consider recent temperature trends. IPCC in 2007 concluded, "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

The 2007 IPCC Fourth Assessment Report (AR4) described "an unambiguous picture of the ongoing warming of the climate system." This trend is continuing. Small year-to-year differences in global average temperatures are unimportant in evaluating long-term trends. During a warming trend, a given year is not always warmer than all the previous years, because the ongoing warming is sometimes temporarily masked by internal climate variability, a normal and natural phenomenon. For example, 2008 was slightly cooler globally than 2007, in part, because a La Niña occurred in 2008 (NASA Goddard Institute for Space Studies 2009). Such natural events can lead to slight temporary cooling. Solar output was also at its lowest level of the satellite era, another temporary cooling influence.

Quantitatively, the global average temperature in 2008 was only about 0.1°C less than in the years immediately preceding it. Such a small difference over such a short time is not statistically significant in evaluating trends. It is noteworthy that 2008, while at the time it may have been the coolest year since 2000, remains one of the ten warmest years since instrumental records began in mid-nineteenth century and the most recent 10-year period is still warmer than the previous 10-year period. The long-term trend is clearly still a warming trend (NASA Goddard Institute for Space Studies 2009).

Our knowledge of the causes of this trend has also improved. IPCC said in 2007, "Most of the observed increase in globally averaged temperatures since the mid-twentieth century is 'very likely' due to the observed increase in anthropogenic greenhouse gas concentrations." Science never provides absolute certainty. Here, "very likely" is calibrated language used by IPCC to express the degree of scientific uncertainty or the possible range of given scientific findings. In this terminology, used consistently in AR4, "very likely" means at least 90% probable.

Thanks to recent research, we have learned that by far the greatest part of the observed century-scale warming is due to human rather than natural factors (Lean and Rind 2008). These scientists analyzed the role of natural factors (e.g., solar variability and volcanoes) vs. human influences (e.g., added man-made greenhouse gases and aerosols) on temperatures since 1889. They found, for example, that the sun contributed only about 10% of surface warming in the last century and a negligible amount in the last quarter century, thus contributing far less than had been estimated in earlier assessments.

Recent research has also clarified our understanding of a warming trend in the atmosphere above the lowest layers near the Earth's surface. By reducing errors in temperature measurements, a warming in the tropical upper troposphere, 10–15 km above the surface, is now apparent in observations, thus reconciling different measurement data and model simulations (Thorne 2008). A new method based on wind observations (Allen and Sherwood 2008) shows a similar warming trend in the upper troposphere, consistent with model results.

The climatic roles of clouds, and of small liquid or solid particles ("aerosols") in the atmosphere, are among the subjects where intensive research is occurring and progress is being made, but only the results of future research can settle several interesting and important scientific questions. AR4 affirmed this conclusion, and it is still true.

In the 2007 IPCC Fourth Assessment Report (AR4), projections were made that future climates would generally have more precipitation at high latitudes and less in the subtropics, where many major deserts exist. However, at that time, no observational studies could be cited defining precipitation trends on a 50-year time scale. Now, such trends have been identified in measurements. For example, Zhang et al. (2007) found that precipitation has been reduced in the subtropics but has increased in middle latitudes, consistent with model projections of human-caused global warming.

Recent research and new observations have decisively settled the question of whether a warming climate will lead to an atmosphere containing more water vapor and, if so, whether the additional water vapor will add to the greenhouse effect, augmenting the warming. The answers to both these questions are yes. Water vapor does become more plentiful in a warmer atmosphere (Dessler et al. 2008). Satellite data show that atmospheric moisture content over the oceans has increased since 1998, with human causes being responsible (Santer et al. 2007).

Recent research has also found that precipitation tends to increase as atmospheric water-vapor content increases (Wentz et al. 2007; Allan and Soden 2008). These conclusions strengthen those of earlier studies.

In the remainder of this section, I briefly summarize several important findings from recent research. Further details, and citations of many of the original papers in the peer-reviewed literature, on which these summary statements are based, may be found in *The Copenhagen Diagnosis* (Allison et al. 2009, 2011).

Only a small fraction of the heat gained by the planet in recent decades is stored in the atmosphere. By far, the largest portion of heat stored is to be found in the ocean. Recently developed observational advances, such as the deployment of a widespread fleet of thousands of autonomous instrumented floats, have greatly improved our knowledge of ocean heat content. Current estimates indicate that ocean warming is about 50% greater than had been previously reported by the IPCC.

Increased melting of the large polar ice sheets contributes to the observed increase in sea level. Observations of the area of the Greenland ice sheet that has been at the melting point temperature for at least 1 day during the summer period shows a 50% increase during the period 1979–2008. The Greenland region experienced an extremely warm summer in 2007. The whole area of south Greenland reached the melting temperatures during that summer, and the melt season began 10–20 days earlier and lasted up to 60 days longer in south Greenland.

In addition to melting, the large polar ice sheets lose mass by ice discharge, which also depends on regional temperature changes. Satellite measurements of very small changes in gravity have revolutionized the ability to estimate loss of mass from these processes. The Greenland ice sheet has been losing mass at a rate of about 179 Gt/year since 2003.

One of the most dramatic developments since the last IPCC report is the rapid reduction in the area of Arctic sea ice in summer. A new minimum in Arctic sea ice was observed only a few months after the publication of AR4. In summer 2007, the minimum area covered by sea ice in the Arctic decreased by about 2 million square kilometers as compared to previous years. In 2008, the decrease was almost as dramatic, as it is at the time of the final submission of this manuscript in September of 2011. This decreasing ice coverage is important for climate on a larger scale for several reasons, including that an ice-free ocean is far less reflective and so absorbs more heat than an ice-covered ocean. Thus, the loss of Arctic sea ice triggers a strong feedback that amplifies the warming.

The global carbon cycle is in strong disequilibrium because of the input of CO_2 into the atmosphere from fossil fuel combustion and land-use change. Fossil fuels presently account for about 85% of total emissions, and land-use change, for about 15%. Total emissions have grown at about 2% per year since 1800. However, fossil fuel emissions have accelerated since 2000 to grow at about 3.4% per year, an observed growth rate that is at or even somewhat beyond the upper edge of the range of growth rates in IPCC scenarios. Total CO_2 emissions are responsible for two-thirds of the growth of all greenhouse gas radiative forcing.

The IPCC in the TAR (2001) attempted to assess scientific evidence available at the time in terms of "reasons for concern." The resulting visual representation of that synthesis, the so-called burning embers diagram, shows the increasing risk of various types of climate impacts with an increase in global average temperature. Using the same methodology, the same diagram of reasons for concern has been updated by several authors (Smith et al. 2009). Although there inevitably is some subjectivity in any such exercise, the results are provocative and disquieting.

Several conclusions follow from the updated "burning embers diagram" and associated recent findings. First, the risks of climate change impacts now tend to appear at lower global average temperature increases. Second, a 2°C limit of warming relative to preindustrial temperatures, which was widely thought in 2001 to be sufficient to avoid serious risks, now appears to be less adequate. Third, the risks of large-scale discontinuities are now considered to be greater than previously thought.

In summary, although a 2°C rise in temperature above preindustrial remains the most commonly quoted limit for avoiding dangerous climate change, there is now a serious case to be made that this level of warming nevertheless carries significant risks of harmful impacts for society and for the environment.

According to the IPCC analysis in AR4, atmospheric CO_2 concentration should not exceed 400 ppm CO_2 if the global temperature rise is to be kept within 2.0–2.4°C. Today, the mean CO_2 concentration is above 385 ppm and is rising by 2 ppm/year. The 2007 concentration of all greenhouse gases, both CO_2 and non-CO_2 gases, was about 463 ppm CO_2 equivalents. Adjusting this concentration for the cooling effects of aerosols yields a CO_2-equivalent concentration of 396 ppm. A recent study estimates that a concentration of 450 ppm CO_2 equivalents (including the cooling effect of aerosols) would give only a 50–50 chance of limiting the temperature rise to 2°C or less.

Thus, atmospheric CO_2 concentrations are already at levels predicted to lead to global warming of between 2.0 and 2.4°C. The conclusion from both the IPCC and subsequent analyses is blunt and stark—immediate and dramatic emission reductions of all greenhouse gases are urgently needed if the 2°C limit is to be respected.

Humanity is now committing future generations to a strongly altered climate. Even beyond the current century, there are major implications for longer-term climate change. Higher temperatures and changes in precipitation caused by CO_2 emissions from human activity are largely irreversible on human time scales. Atmospheric temperatures are not expected to decrease for many centuries to millennia, even after human-induced greenhouse gas emissions stop completely (Matthews and Caldeira 2008; Solomon et al. 2009; Eby et al. 2009).

An analysis of several decades of data in the western United States suggests that as much as 60% of the hydrological changes in this region are due to human activities. This trend, if sustained, has profound consequences for the future water supply of this already water-stressed part of the world (Barnett et al. 2008).

One complex climate model that had been modified to include recent advances in understanding of the carbon cycle, natural climate factors, and other elements then produced twice as large a global average temperature increase at the end of the twenty-first century as it had before the model was modified: 5.2°C in the new model run compared to 2.4°C for the older version of the model (Sokolov et al. 2009).

Many recent aspects of observed climate change reveal a more rapid pace than had been foreseen by recent model projections. Thus, recent revisions of projected climate change exceed earlier estimates, and it is increasingly clear that the projections reported in the IPCC Fourth Assessment Report in 2007 may well have underestimated the pace of current climate change. This conclusion of Rahmstorf et al. (2007), which appeared after AR4 was published, could stand as a conclusion for this entire survey of the results of climate change science:

> Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change, in particular for sea level.

How *The Copenhagen Diagnosis* Came to Be Written

The Copenhagen Diagnosis (Allison et al. 2009) is a report published online in November 2009. It is available for download at http://www.copenhagendiagnosis.com and http://www.copenhagendiagnosis.org. A group of 26 climate scientists wrote *The Copenhagen Diagnosis*. All are active researchers. They come from eight countries and include three women and several younger scientists. I am one of the 26 scientists who wrote this report. Our group is private, independent, and unaffiliated with any organization. We speak only for ourselves, not for the Intergovernmental Panel on Climate Change (IPCC) or anyone else. We are self-selected and self-organized. We have no official leader or formal structure. About half of us are IPCC authors, so we know firsthand what preparing such an assessment entails and what scientific standards it should meet. Our report is firmly based on the more than 200 peer-reviewed papers we cite.

Our aim was to write a readable, short, authoritative report summarizing relevant peer-reviewed climate change research appearing since the cutoff publication date (about mid-2006) for papers assessed in the most recent (2007) IPCC assessment. Like IPCC, we insisted on being policy relevant but policy neutral. We thought that such an update was needed to inform the UN climate negotiations in Copenhagen in December 2009, because there has been so much important recent research. It seemed obvious to us that somebody ought to prepare such an update, so we simply decided to accept this responsibility ourselves. The veracity and value of this report thus rests entirely on the scientific credibility of its authors as well as that of the peer-reviewed publications we cite. Any errors or shortcomings in our report are also the sole responsibility of the 26 named authors.

We worked on this document for about a year. Many of us met in Copenhagen in March 2009, at the time of the congress described above, to organize the work and to agree on deadlines, topics, chapter lengths, etc. In deciding who would be in the group of authors, our primary criterion was scientific expertise on one or more of the various topics that we thought needed to be covered. We sought scientists with excellent research reputations, willing and able to work to deadlines, fluent in English, and able to function as part of a writing team. Typically, one author would draft a given chapter, then several others of the group would review and revise it, and finally, the entire group would consider the revised draft and reach consensus.

The Climate Change Research Centre at the University of New South Wales in Sydney, Australia, contributed some staff support, for example, for developing the web site. A grant paid essential costs such as printing and travel to our meeting in Copenhagen. Nobody had any influence whatever on the contents of the report other than the 26 authors. We, the authors of *The Copenhagen Diagnosis*, all freely contributed our time and expertise. None of us were paid anything from any source to write this report.

In *The Copenhagen Diagnosis*, the reader is hearing directly from the 26 scientists who wrote it. We made all our own editorial decisions, such as to include "boxes" dealing with common misconceptions. We also decided what each of our chapters would be about and how long they would be. In short, we authors enjoyed complete autonomy to design and write our report as we wished.

The Copenhagen Diagnosis is emphatically not an attack on IPCC or a repudiation of the IPCC process or the 2007 IPCC assessment report. We simply considered that the significance of very recent research, and of many climate observations made after the AR4 IPCC assessment was written, together with novel and important improvements in several areas of scientific tools and technology, all deserved to be brought to the attention of the Copenhagen negotiators, the media, governments, corporations, and the global public. Our goal has been to make our report accessible to all.

The Copenhagen Diagnosis is about climate change science, not policy. For example, we summarize recent research underpinning the scientific rationale for large and rapid reductions in global greenhouse gas emissions, in order to reduce the likelihood of dangerous man-made climate change. However, we have no political or policy agenda, and we do not speak to the issue of formulating policies to achieve such reductions in emissions. As scientists, when climate change research is relevant to public policy, we consider it important to bring that research to the attention of the wider world. We are convinced that sound science can and should inform wise policy. This conviction led us to write *The Copenhagen Diagnosis*.

Main Findings of *The Copenhagen Diagnosis*

According to *The Copenhagen Diagnosis* (Allison et al. 2009), the most significant recent climate change findings are:

Surging greenhouse gas emissions: Global carbon dioxide emissions from fossil fuels in 2008 were nearly 40% higher than those in 1990 (Fig. 2). Even if global emission rates are stabilized at present-day

Fig. 2 Global fossil fuel CO_2 emissions as a function of time (credit: Allison et al. 2009, *The Copenhagen Diagnosis*)

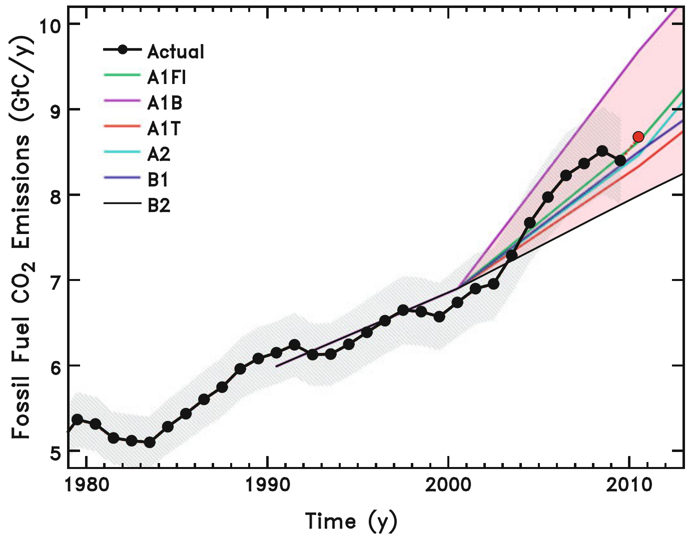
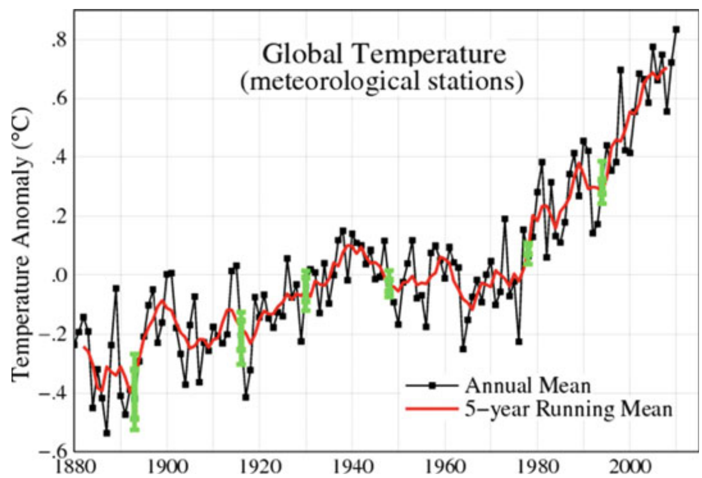


Fig. 3 Global annual-mean surface air temperature change since 1880, with the base period 1951–1980, derived from the meteorological station network [an update of Fig. 6b in Hansen et al. (2001)]. Uncertainty bars (95% confidence limits), shown for both the annual and 5-year means, account only for incomplete spatial sampling of data (credit: NASA, GISS, available online at http://data.giss.nasa.gov/gistemp/graphs/)



levels, just 20 more years of emissions would give a 25% probability that warming exceeds 2°C, even with zero emissions after 2030. Every year of delayed action increases the chances of exceeding 2°C warming.

Recent global temperatures demonstrate human-induced warming: Over the past 25 years, temperatures have increased at a rate of 0.19°C per decade, in very good agreement with predictions based on greenhouse gas increases (Fig. 3). Even over the past 10 years, despite a decrease in solar forcing, the trend continues to be one of warming. Natural, short-term fluctuations are occurring as usual, but there have been no significant changes in the underlying warming trend.

Acceleration of melting of ice sheets, glaciers, and ice caps: A wide array of satellite and ice measurements now demonstrate beyond doubt that both the Greenland and Antarctic ice sheets are losing mass at an increasing rate. Melting of glaciers and ice caps in other parts of the world has also accelerated since 1990.

Rapid Arctic sea-ice decline: Summer melting of Arctic sea ice (Fig. 4) has accelerated far beyond the expectations of climate models (Fig. 5). The area of sea-ice melt during 2007–2010 (Fig. 5) was about 40% greater than the average prediction from IPCC AR4 climate models. The minimum for 2011, about to be attained at the time of the final submission of this manuscript, seems on track to be about the same as the lowest minimum on record so far, for 2007 (see http://nsidc.org/data/seaice_index/images/daily_images/N_stddev_timeseries.png).

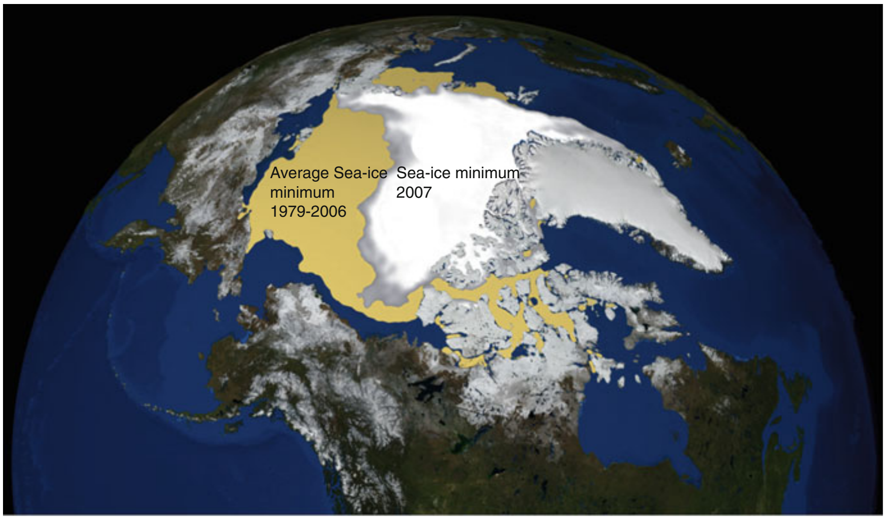


Fig. 4 Minimum Arctic sea-ice extent from 1979 to 2007 (credit: Allison et al. 2009, *The Copenhagen Diagnosis*)

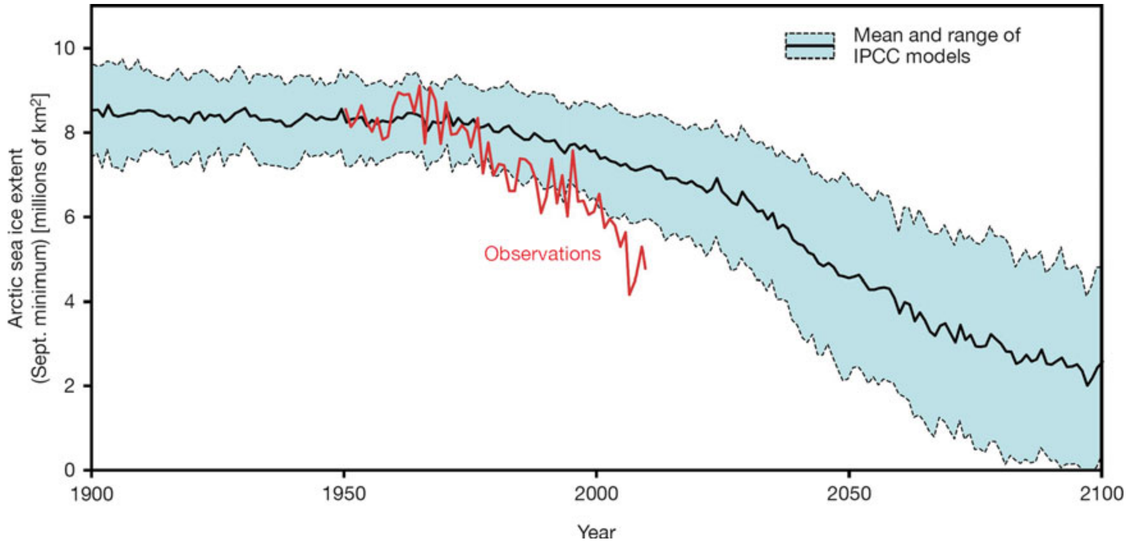


Fig. 5 Observed and modeled Arctic sea-ice extent (credit: Allison et al. 2011, *The Copenhagen Diagnosis*)

Current sea-level rise underestimated: Satellites show recent global average sea-level rise (3.4 mm/year over the past 15 years) to be ~80% above past IPCC predictions (Fig. 6). This acceleration in sea-level rise is consistent with a doubling in contribution from melting of glaciers, ice caps, and the Greenland and west Antarctic ice sheets.

Sea-level predictions revised: By 2100, global sea level is likely to rise at least twice as much as projected by Working Group I of the IPCC AR4; for unmitigated emissions, it may well exceed 1 m. The upper limit has been estimated as ~2-m sea-level rise by 2100. Sea level will continue to rise for centuries after global temperatures have been stabilized, and several meters of sea-level rise must be expected over the next few centuries.

Delay in action risks irreversible damage: Several vulnerable elements in the climate system (e.g., continental ice sheets, Amazon rainforest, West African monsoon, and others) could be pushed toward abrupt

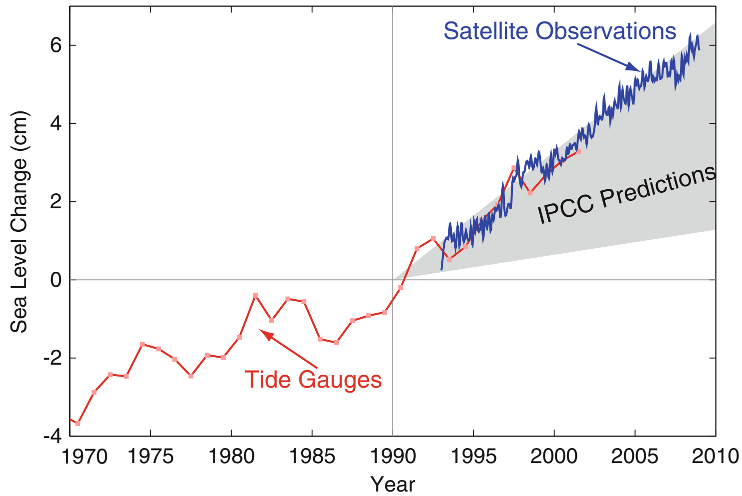


Fig. 6 Sea-level change from 1970 to 2010 (credit: Allison et al. 2009, *The Copenhagen Diagnosis*)

or irreversible change if warming continues in a business-as-usual way throughout this century. The risk of transgressing critical thresholds ("tipping points") increases strongly with ongoing climate change. Thus, waiting for higher levels of scientific certainty could mean that some tipping points will be crossed before they are recognized.

The turning point must come soon: If global warming is to be limited to a maximum of 2°C above preindustrial values, global emissions need to peak between 2015 and 2020 and then decline rapidly. To stabilize climate, a decarbonized global society—with near-zero emissions of CO_2 and other long-lived greenhouse gases—needs to be reached well within this century (Fig. 7). More specifically, the average annual per-capita emissions will have to shrink to well below 1-metric ton CO_2 by 2050. This is 80–95% below the per-capita emissions in developed nations in 2000.

In this chapter, we give only the above brief summary of *The Copenhagen Diagnosis*. Figures 2, 4, 5, and 6 in this chapter are from *The Copenhagen Diagnosis* and are used with permission. The full report is available at http://www.copenhagendiagnosis.com and in updated form as Allison et al. (2011).

COP15 in Copenhagen, December 2009

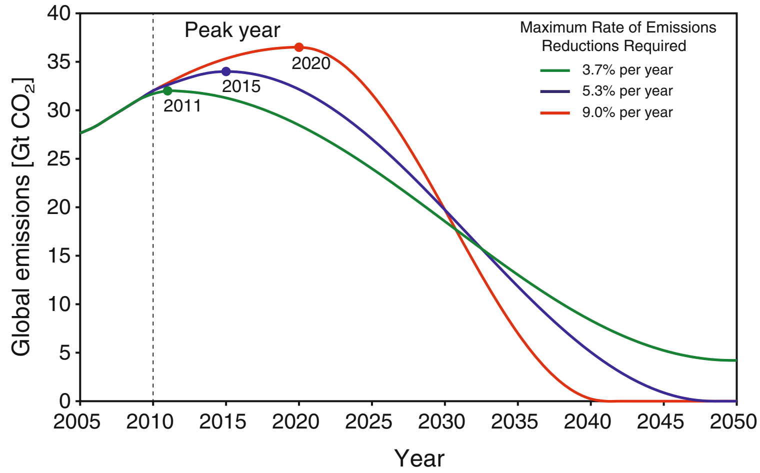
At the beginning of December 2009, one might have naively anticipated that the increasingly somber and compelling results of climate change science would have led the governments of the world to produce an agreement to rapidly reduce global emissions of greenhouse gases. Indeed, such an agreement at COP15 in Copenhagen in 2009 had been widely expected after COP13 in Bali 2 years earlier. Many observers had predicted that a binding treaty, with clear and firm targets and timetables and enforcement mechanisms, was achievable. Furthermore, as we have seen, the passage of time had seen a strengthening of the scientific rationale for such an agreement. This is apparent in the conclusions of AR4 as strengthened by subsequent research summarized in *The Copenhagen Diagnosis*.

However, the outcome of the COP15 climate negotiations in Copenhagen in December 2009 disappointed almost everybody. The final "agreement" among a few countries, known as the Copenhagen Accord (http://en.wikipedia.org/wiki/Copenhagen_Accord), was brokered by the USA and China at the last minute. This document has no legally binding status and is simply an aspirational statement. It is better than nothing, and one must hope for further progress in the future. However, there is no sign, in this minimal diplomatic result, of the clear need for urgency based on solid climate change science.

Yet, many countries have already agreed on the firm aspirational goal of limiting global warming to 2°C above nineteenth-century "preindustrial" temperatures, in order to have a reasonable chance for avoiding dangerous human-caused climate change.

Setting such a goal is a political decision. Now that the goal is set, however, science can say with confidence that meeting the goal requires that *global*

Fig. 7 Emissions pathways to give 67% chance of limiting global warming to 2°C (credit: Allison et al. 2009, *The Copenhagen Diagnosis*)



greenhouse gas emissions must peak within the next decade and then decline rapidly. We say that emphatically in the 2009 report *The Copenhagen Diagnosis*, where we also cite the peer-reviewed research on which this statement is firmly based, such as Meinshausen et al. (2009).

We scientists have been aware of this urgency for more than 30 years. The authoritative IPCC report in 2007 emphasized it. My book *The Forgiving Air: Understanding Environmental Change* (Somerville 2008) cited, "the need to act soon if sensible targets are to be met, the fact that the needed reductions in greenhouse gas emissions will be large, and the fact that both developed and developing countries must be involved."

These results are sensitive to assumptions, of course. Meinshausen et al. (2009) conclude that "the probability of exceeding 2°C rises to 75% if 2020 emissions are not lower than 50 Gt CO2 equiv. (25% above 2000)."

We relied on this chapter and others in reaching our conclusion in *The Copenhagen Diagnosis* that "the required decline in emissions coupled with a growing population will mean that by 2050, annual per capita CO2 emissions very likely will need to be below 1 ton." Obviously, that is very tough to achieve. See our Fig. 7 in this chapter, which is Fig. 22 on page 51 in *The Copenhagen Diagnosis*.

When I say that we scientists have known about the urgency for more than 30 years, there, I have one particular paper in mind, among others. That paper is Siegenthaler and Oeschger (1978). Here is the conclusion taken from its summary (page 389):

> For a prescribed maximum increase of 50 percent above the preindustrial carbon dioxide level, the production could grow by about 50 percent until the beginning of the next century, but should then decrease rapidly.

So "production" (meaning emissions) has to peak and then quickly decline early in the current century. This 1978 result came from simple models and the limited data available in the 1970s. We know much more today about the numbers and the caveats and other details. However, the essential scientific foundation was already clear more than 30 years ago, at least to two insightful Swiss scientists. That is the message of Fig. 7 in the present paper: the urgency is scientific, not political.

Mother Nature herself thus imposes a timescale on when emissions need to peak and then begin to decline rapidly. This urgency is therefore not ideological, but rather is due to the physics and biogeochemistry of the climate system itself. Diplomats are powerless to alter laws of nature and must face scientific facts.

Thus, it is profoundly regrettable that the dithering and procrastination at COP15 in Copenhagen continued a year later in December 2010 at COP16 in Cancun, Mexico. The Cancun negotiations are just concluding as these lines are being written. The enduring failure to achieve meaningful science-based international agreements will inevitably have serious consequences for the degree of climate disruption that the Earth will undergo.

Public Perceptions and the Politics of Climate Change

In late November 2009, at about the same time that *The Copenhagen Diagnosis* was released, a crime was committed in which thousands of e-mails of prominent climate scientists were illegally obtained from a server at the University of East Anglia in the United

Kingdom. These e-mails, which appear to be authentic, were published online and extensively discussed in the press and the blogosphere.

Extremely serious questions were immediately raised. Is the science of global warming valid, or has it been proven wrong by this episode of e-mails stolen from a climate research center in England? The short answer is that the hacked e-mails do not undermine the science in any way.

There is no doubt that the e-mails have embarrassed several scientists. Writing what they thought were private messages to their close colleagues, they expressed themselves in intemperate language. Angered by what they regarded as intolerable harassment by repeated and unreasonable demands, they lashed out in frustration in e-mails to one another.

Edited excerpts from the e-mails do read poorly, especially out of context, and they might lead some people to conclude that climate research must involve biased, power hungry, and unprincipled scientists. Following the release of the e-mails, many in the blogosphere and media immediately appointed themselves prosecutor, judge, and jury. There was little chance to mount a defense in this rush to judgment.

During the year following the release of the e-mails, several independent investigations were carried out and the outcome of all of them has been to exonerate the scientists from accusations of fraud, incompetence, and dishonesty. Many of the specific charges made against the scientists have been shown to be false. Cherry-picked words like "trick" turn out to be innocent jargon. In science, a "trick" is not an underhanded tactic to conceal the truth. It is just a clever way to solve a technical problem, like finding solutions to certain equations. "Trick" means one thing to scientists, something else to bridge players, and something altogether different to dog trainers. Context matters.

Much has also been made of unsuccessful demands for temperature data to be released from the center at East Anglia. In fact, the scientists did resist such demands. Not all the legal issues have yet been completely resolved. They involve freedom of information laws as well as the proprietary restrictions attached to some data by the organizations that originally supplied the data. Nearly all the data in question, however, is freely available from several sources. Several other centers worldwide independently monitor and analyze global temperatures, and their findings closely confirm the ones from the English center. The notion that the central scientific results of modern climate change research might be upset by the release of additional data is not credible.

In my opinion, the most serious charge by far against the e-mailing group of scientists is that they blocked publication by other scientists with whom they disagreed and that they prevented the IPCC, the Intergovernmental Panel on Climate Change, from considering the findings of those scientists in its 2007 assessment report, AR4. Work by Soon and Baliunas and by McIntyre and McKitrick was alleged to be in that category.

The facts, however, are that in these cases, scientific practice worked exactly as it should. The papers by these authors were indeed published. Other scientists considered them and did further research and published it too. The IPCC cited and discussed all this in its landmark Fourth Assessment Report, published in 2007. This is the relevant passage from page 466 of that report:

> The 'hockey stick' reconstruction of Mann et al. (1998) has been the subject of several critical studies. Soon and Baliunas (2003) challenged the conclusion that the 20th century was the warmest at a hemispheric average scale. They surveyed regionally diverse proxy climate data, noting evidence for relatively warm (or cold), or alternatively dry (or wet) conditions occurring at any time within pre-defined periods assumed to bracket the so-called 'Medieval Warm Period' (and 'Little Ice Age'). Their qualitative approach precluded any quantitative summary of the evidence at precise times, limiting the value of their review as a basis for comparison of the relative magnitude of mean hemispheric 20th-century warmth (Mann and Jones, 2003; Osborn and Briffa, 2006). Box 6.4 provides more information on the 'Medieval Warm Period'.
>
> McIntyre and McKitrick (2003) reported that they were unable to replicate the results of Mann et al. (1998). Wahl and Ammann (2007) showed that this was a consequence of differences in the way McIntyre and McKitrick (2003) had implemented the method of Mann et al. (1998) and that the original reconstruction could be closely duplicated using the original proxy data. McIntyre and McKitrick (2005a,b) raised further concerns about the details of the Mann et al. (1998) method, principally relating to the independent verification of the reconstruction against 19th-century instrumental temperature data and to the extraction of the dominant modes of variability present in a network of western North American tree ring chronologies, using Principal Components Analysis. The latter may have some theoretical foundation, but Wahl and Amman (2006) also show that the impact on the amplitude of the final reconstruction is very small (~0.05°C; for further discussion of these issues see also Huybers, 2005; McIntyre and McKitrick, 2005c, d; von Storch and Zorita, 2005).

It is a standard tactic of many climate skeptics or contrarians to try to frame the issue in terms of the whole edifice of modern climate science hanging from some slender thread. Thus, if a given scientist uses intemperate language, or a particular measurement is missing from an archive, or a published paper has a minor mistake in it, the whole structure comes tumbling down, or so the skeptics would have people believe.

In fact, climate change science is not fragile or vulnerable, and there are multiple lines of evidence in support of all its main conclusions. That is what the 2007 IPCC report says. It remains definitive.

Historians of science tell us that the overwhelming degree of scientific agreement on climate change is rare for such a complex issue. A Galileo does come along every few hundred years to reveal fundamental errors in the prevailing understanding and thus to revolutionize a branch of science. However, almost all the people who think they are a Galileo are simply wrong. Facts matter.

Minor errors have been found in the IPCC reports, though not in the WGI (physical science) portion of AR4, and IPCC has acknowledged these errors and taken steps to reduce the likelihood of such errors in future reports. It is noteworthy, however, that since the WGI AR4 report was published in 2007, no reputable scientist has yet been able to point to a major conclusion of this IPCC report and then point to a persuasive body of peer-reviewed published research that proves that conclusion wrong. *The Copenhagen Diagnosis* has similarly not been challenged successfully. Science can never provide absolute certainty, and any scientific finding is always subject to review and revision on the basis of further research. However, it is highly unlikely that the bedrock conclusions of modern climate science will be proven wrong. Indeed, the most recent research further supports and underscores the fundamental scientific result that man-made climate change is real and serious.

A Scientific Response to Climate Skeptics

Although the expert community is in wide agreement on the basic results of climate change science, as assessed in AR4 and *The Copenhagen Diagnosis*, much confusion exists among the general public and politicians in many countries, as polling data convincingly shows.

In my opinion, many people need to learn more about the nature of junk or fake science, so they will be better equipped to recognize and reject it. There are a number of warning signs that can help identify suspicious claims. One is failure to rely on and cite published research results from peer-reviewed journals. Trustworthy science is not something that appears first on television or the Internet. Reputable scientists first announce the results of their research by peer-reviewed publication in well-regarded scientific journals. Peer review is not a guarantee of excellent science, but the lack of it is a red flag. Peer review is a necessary rather than a sufficient criterion.

Another warning sign is a lack of relevant credentials on the part of the person making assertions, especially education and research experience in the specialized field in question. For example, it is not essential to have earned a Ph.D. degree or to hold a university professorship. It is important, however, that the person be qualified, not in some general broad scientific area, such as physics or chemistry, but in the relevant specialty. Accomplishments and even great distinction in one area of science do not qualify anybody to speak authoritatively in a very different area. We would not ask even an expert cardiologist for advice on dentistry. One should inquire whether the person claiming expertise in climate science has done first-person research on the topic under consideration and published it in reputable peer-reviewed journals. Is the person actively participating in the research area under question, or simply criticizing it from the vantage point of an outsider? One should be suspicious of a lack of detailed familiarity with the specific scientific topic and its research literature. Good science takes account of what is already known and acknowledges and builds on earlier research by others.

Other warning signs include a blatant failure to be objective and to consider all relevant research results, both pro and con a given position. Scientific honesty and integrity require wide-ranging and thorough consideration of all the evidence that might bear on a particular question. Choosing to make selective choices among competing evidence so as to emphasize those results that support a given position, while ignoring or dismissing any findings that do not support it, is a hallmark of pseudoscience.

Mixing science with ideology or policy or personalities is never justified in research. Scientific validity has nothing to do with political viewpoints. Whether a given politician agrees or disagrees with a research finding is absolutely unimportant scientifically. Science can usefully inform the making of policy, but only if policy considerations have not infected the science. Similarly, one should always be alert to the risk of bias due to political viewpoints, ideological preferences, or connections with interested parties. All sources of funding, financial interests, and other potential reasons for bias should be openly disclosed.

Finally, we must always be alert for any hint of delusions of grandeur on the part of those who would insist that they themselves are correct, while nearly everyone else in the entire field of climate science is badly mistaken. Scientific progress is nearly always incremental, with very few exceptions. Occasionally, an unknown lone genius in a humble position, such as the young Einstein doing theoretical physics while working as a clerk in a patent office, does indeed revolutionize a scientific field, dramatically overthrowing conventional wisdom. However, such events are exceedingly rare, and claims to be such a lone genius deserve the most severe scrutiny. For every authentic Einstein, there must be thousands of outright charlatans, as well as many more ordinary mortals who are simply very badly mistaken.

I have attempted to summarize a number of key points and scientific results in a recently published essay in *Climatic Change* (Somerville 2010), which I paraphrase here:

1. The essential findings of mainstream climate change science are firm. The world is warming. There are many kinds of evidence: air temperatures, ocean temperatures, melting ice, rising sea levels, and much more. Human activities are the main cause. The warming is not natural. It is not due to the sun, for example. We know this because we can measure the effect on the Earth's energy balance of man-made carbon dioxide, and it is much stronger than that of changes in the sun, which we also measure.
2. The greenhouse effect is well understood. It is as real as gravity. The foundations of the science are more than 150 years old. Carbon dioxide in the atmosphere traps heat. We know carbon dioxide is increasing because we measure it. We know the increase is due to human activities like burning fossil fuels because we can analyze the chemical evidence for that.
3. Our climate predictions are coming true. Many observed climate changes, like rising sea level, are occurring at the high end of the predicted changes. Some changes, like melting sea ice, are happening faster than the anticipated worst case. Unless mankind takes strong steps to halt and reverse the rapid global increase of fossil fuel use and the other activities that cause climate change, and does so in a very few years, severe climate change is inevitable. Urgent action is needed if global warming is to be limited to moderate levels.
4. The standard skeptical arguments have been refuted many times over in technical papers published in the peer-reviewed scientific research literature. The refutations are now summarized on many web sites and in many books. For example, natural climate change like ice ages is irrelevant to the current warming. We know why ice ages come and go. That is due to changes in the Earth's orbit around the sun, changes that take thousands of years. The warming that is occurring now, over just a few decades, cannot possibly be caused by such slow-acting processes. But it can be caused by man-made changes in the greenhouse effect.
5. Science has its own high standards. It does not work by unqualified people making claims on television or the Internet. It works by scientists doing research and publishing it in carefully reviewed research journals. Other scientists examine the research and repeat it and extend it. Valid results are confirmed, and wrong ones are exposed and abandoned. Science is self-correcting. People who are not experts, who are not trained and experienced in this field, and who do not do research and publish it following standard scientific practice are not doing science. When they claim that they are the real experts, they are just plain wrong.
6. The leading scientific organizations of the world, like national academies of science and professional scientific societies, have carefully examined the results of climate science and endorsed these results. It is silly to imagine that thousands of climate scientists worldwide are engaged in a massive conspiracy to fool everybody. The first thing that the world needs to do if it is going to confront the challenge of climate change wisely is to learn about what science has discovered and accept it.

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