David Karoly Interview

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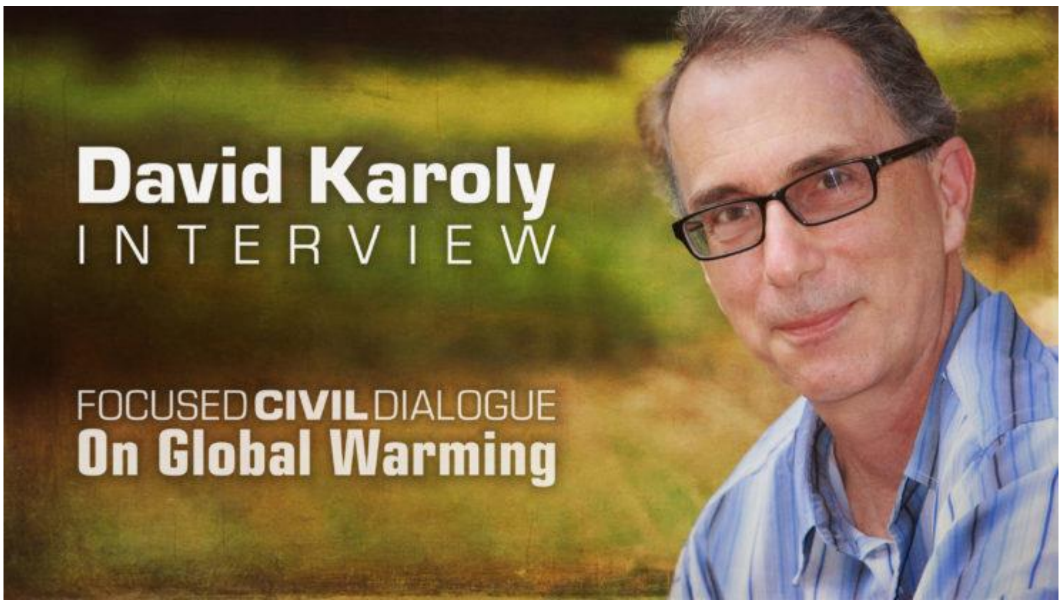

David Karoly is Professor of Atmospheric Science in the School of Earth Sciences at the University of Melbourne, in Australia. Professor Karoly is internationally recognized as an expert in climate change and variability, including greenhouse climate change, stratospheric ozone depletion, and climate variations due to El Niño-Southern Oscillation. One of the articles that grew out of his Ph.D. dissertation research on El Niño-Southern Oscillation has been cited over 1000 times. Professor Karoly was heavily involved, in several different roles, in preparation of the Fourth Assessment Report (2007) by the United Nations Intergovernmental Panel on Climate Change (IPCC). He was also a Review Editor of the Australasia chapter of the IPCC's Fifth Assessment Report (2014).

[Ed. Note: The description above was true at the time of the debate. Currently, Dr. Karoly is the Leader of the Earth Systems and Climate Change Hub for the National Environmental Science Program at CSIRO in Aspendale, Victoria, Australia.]

Information about some of Professor Karoly's many scholarly publications may be accessed on his University of Melbourne ***website.***

[Ed. Note: This website was corrupted. This version is restored from the wayback machine. It has also been converted to a pdf format, the bibliography is expanded, and minor typos and grammatical errors are fixed. Some of the figures were corrupt and recovered from the original sources using the information in the captions and bibliography. The figures have been renumbered. Other additions and corrections are noted with square brackets. Andy May]

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TheBestSchools

Professor Karoly: Thank you very much for agreeing to participate in this interview, as well as in an upcoming Focused Civil Dialogue with Professor William Happer of Princeton University on the subject of global warming (climate change).

You are an internationally known expert on global warming, or climate change, and have been heavily involved over the years in several reports released by the United Nations Intergovernmental Panel on Climate Change (IPCC), which have been the basis for discussion at a series of top-level international meetings of world leaders (the United Nations Conferences on Climate Change), including the one most recently in Paris. While we view the issue of global warming as one requiring further study and debate, we understand that many of your colleagues view the matter as “settled” and for that reason refuse to “give a platform” to critics of the consensus view (namely, that global warming is real, is manmade, is a very bad thing, and requires concerted action by the nations of the world). That is all the more reason why we appreciate your willingness to engage with us and with Professor Happer.

As a conceptual problem, global warming is exceedingly complex, possessing a great many different theoretical and empirical aspects, as well as economic, moral, and political ones. We cannot, of course, hope to achieve anything like comprehensive coverage in this interview. However, we do want to help elevate the level of public discourse on this issue by asking you your views on a fairly wide range of matters.

The following flowchart will give the reader a sense of the overall structure of the interview:

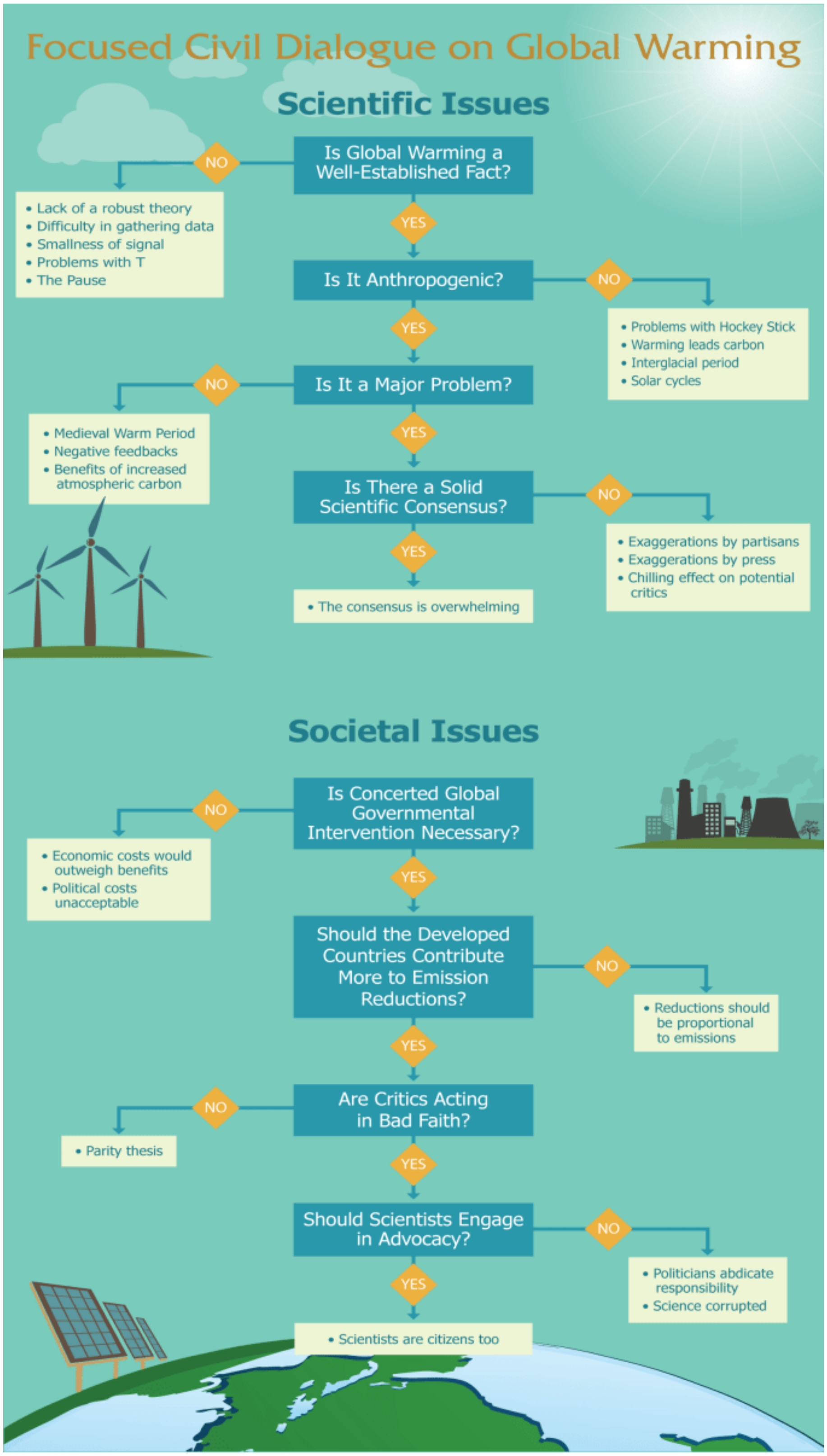

Figure 1. Global Warming Flowchart

Before we get started on the substance of the interview, however, we would like to invite you to tell us a little bit about your personal background. When and where were you born? What did your parents do? How did you first get interested in science? Where did you go to school? Where have you worked? That sort of thing — anything you'd care to share with our readers.

David Karoly's personal story

I was born in Sydney Australia, in 1955, and lived in suburban Sydney for eight years. My father was an electrical engineer and very early computer programmer/engineer, while my mother worked hard as a housewife.

Figure 2. Hungary joined the axis alliance in 1940.

My father migrated to Australia from Hungary as a teenager with his parents in 1939 — a good time to leave eastern Europe! They lived in Melbourne, where my father finished his secondary schooling and graduated in Electrical Engineering from the University of Melbourne. Both my paternal grandparents had university degrees from the University of Budapest, which were not recognized in Australia. I have my grandfather's degree certificate in Civil Engineering from 1921, which my father gave to me, on my office wall. I will come back to my grandfather a little later.

My mother lived in Melbourne with her Australian parents, finished her secondary school, worked in a bank, and met my father through a local tennis club. They married in the early 1950s. I am the middle child, with an older brother and a younger brother. My father and mother initially lived in Melbourne, but moved several times for my father's work, first to Adelaide and then to Sydney, where he worked at the University of New South Wales on one of the very earliest computers in Australia.

Figure 3. The Australian "bush" or forest.

Our house in Sydney was a typical suburban block, with lots of young families nearby. All the neighborhood children played together after school in one house or another, or in the forested area at the end of the street that eventually connected to the Lane Cove River. With a group of boys, I would often play in the bush (the Australian word for our native forests), and these were my first happy experiences in the natural environment.

I started elementary school in Sydney, but when I was eight years old, my father took a new job with an American computer company, Control Data, and the family moved for about half a year to Mountain View, California, an area that would become the center of Silicon Valley. I like to say that I went to elementary school for a while in Silicon Valley, before it was called Silicon Valley.

We moved back to Australia, lived in Canberra for two years and then moved to Melbourne in late 1966, where I started secondary school at Brighton High School in 1967. I liked school a lot, both learning new things and playing different sports. I found math and science subjects easy, and my parents encouraged me to study hard, as all parents do.

We lived close to the beach and a friend taught me how to sail. Another school friend introduced me to the Boy Scouts, and I loved the outdoor activities and camping in the bush.

As I moved into the senior years at high school, although I loved the natural environment, it was obvious that I was fascinated even more by mathematics, physics, and chemistry. I was a nerd, skinny with thick-lensed glasses, and I even had a slide rule! In fact, I had an old slide rule that my grandfather had used before he retired. I decided that when I finished high school, I wanted to be a scientist.

I got very good marks in all my science and math subjects in my final year at high school — good enough to get a scholarship to Monash University, a new university in the eastern suburbs of Melbourne. I decided to go there, rather than to the older and more traditional University of Melbourne (where I work now), because I thought that Monash would have newer and better equipment.

I started at Monash in 1973 in a science degree majoring in Mathematics and Physics. After my first year, I joined the Monash Bushwalking Club and went on many trips to the mountains over the rest of my degree, hiking, climbing, caving, canoeing, and cross-country skiing. I loved it.

An Australian degree was three years long, with an additional Honours year. After completing my first degree, with excellent marks in all my subjects, I was invited to continue and do an Honours year in Physics or in Applied Mathematics. I liked theoretical physics, but I found it abstract and hard to explain to my mother. I wanted to do something that linked my outdoor interests with my science.

Figure 4. Watching clouds convinced Karoly he should study fluid dynamics and the weather.

In my final undergraduate year in Applied Mathematics, I did a subject on geophysical fluid dynamics (GFD), the dynamics of the atmosphere and the ocean. This — together with a hike along a ridge watching clouds form in the lee of the ridge in the eddies in the wind — indicated to me that I could combine my interests in applied mathematics and physics into the study of the weather through GFD. I chose to do an Honours year in Applied Mathematics in GFD, particularly atmospheric dynamics. I loved this extra year and I graduated with first-class honours in applied mathematics at end of 1976.

After Honours, I knew that I wanted to continue in science, and in research if possible, but I wasn't sure what to do. I applied for funding and scholarships for postgraduate study in the USA, the UK, and in Australia. I also applied for an atmospheric physicist position in the Australian Antarctic Division, to winter over at an Australian Antarctic base and be involved in atmospheric monitoring.

I couldn't get funding to study in the US, but I was lucky enough to win a Shell Australia Science and Engineering Postgraduate Scholarship to study in England. Only one of these was offered each year and it funded the winner to study in any science or engineering program at any university in the UK. While most winners choose to study at Oxford, Cambridge, or London, I chose to study in the at-the-time small Meteorology Department at the University of Reading. Oh, and I had to turn down the job in Antarctica for a three-year, all-expenses paid study opportunity in the UK.

Figure 5. Brian Hoskins

I didn’t know exactly what research project I wanted to work on — something to do with atmospheric dynamics — but I contacted a young academic in the Meteorology Department, Brian Hoskins, who had a strong and growing reputation, even half the planet away in Australia. Brian agreed to take me on as his third Ph.D. student and suggested that I work on a project to better understand the theory behind the dispersion of large-scale stationary wave disturbances in the atmosphere. These are key to understanding the causes of the east-west variations in the mean atmospheric winds, as well as the links between forcing factors and atmospheric responses at large distances across the planet. An example is the link between El Niño-related variations in sea surface temperature in the equatorial Pacific Ocean and remote responses, or teleconnections, to variations in weather in the US or in Australia.

I was very lucky to be given this project, inasmuch as the analysis was successful — as the theoretical basis for understanding both the atmospheric teleconnections between the tropics and higher latitudes and the propagation of large-scale waves from the lower atmosphere into the stratosphere. The first research paper I co-authored on this topic, with Brian Hoskins, has been cited more than 1,000 times. Brian is recognized now as one the world’s leading atmospheric scientists and was knighted for his services to science. I was lucky to be in the right place at the right time!

I returned to Australia after completing my Ph.D. at the end of 1980 and started a post-doctoral fellowship in the Australian Numerical Meteorology Research Centre, a joint center run by the Bureau of Meteorology and CSIRO in Melbourne, Australia. I wanted to apply the theoretical insights from my Ph.D. to better understanding the variations of the atmospheric circulation in the Southern Hemisphere, using observations both from the less well-observed Southern Hemisphere and from early global climate model simulations. As I learned in my PhD, there is a lot to be gained from combining theoretical analysis, observational data, and numerical model simulations, and I applied these in the Southern Hemisphere for the first time.

Figure 6. Monash University, Australia.

After two years, I moved back to Monash University and the GFD section in Applied Mathematics, as a new and very wet-behind-the-ears lecturer, teaching introductory calculus, data analysis, and atmospheric dynamics. My research focused on understanding the variability of the Southern Hemisphere atmospheric circulation, both in the lower atmosphere and in the stratosphere. These included topics of great public interest, including the role of El Niño in droughts and floods in Australia, and the causes of the Antarctic ozone hole and its variations from year to year.

This brings me back to my grandfather, who died before I finished my undergraduate degree. While I knew that he had worked in the State Rivers and Water Supply Commission in the state of Victoria, I didn't know what he did. A former Director of the Bureau of Meteorology asked me about my surname at a workshop on drought in the 1980s, and if Alexander Karoly was my father.

I told him he was my grandfather. It turned out he had known the Director of the Bureau and had published research papers on drought and extreme rainfall, as well as on streamflow variations — all as part of his work that I had known nothing about! I look back now and think how interesting it would have been to have a conversation with him on his research and my own.

Should we have confidence in climate models?

TheBestSchools

Wow, that is a really interesting story!

Let's shift gears now and turn to the matter at hand. You have stated that you started out as a global warming skeptic yourself. What changed your mind? In answering this question, could you please address two issues which are often raised by critics of the consensus view, one involving physical theory, the other empirical data.

The first issue is the inherent difficulty of modeling the climate due to the fact that the atmosphere is a fluid-dynamic system, which, like all such systems, is subject to turbulence — which makes its long-term behavior very hard to predict (turbulence being a form of "sensitivity to initial conditions" or "chaos").

In light of this inherent limitation on our ability to predict the long-term behavior of the earth's atmosphere, ought consensus scientists to have such a high degree of confidence in their computer models?

David Karoly

Let me address the first part first, and then tackle the issues of predictability of the weather and the climate.

Figure 7. The Southern Hemisphere.

In the 1980s, a graduate student and I were analyzing variations in the atmospheric circulation and temperature in the Southern Hemisphere to identify the dominant patterns of variability. We found that the temperature data showed long-term trends, both at the surface over the period since about the 1950s and in the lower atmosphere and in the lower stratosphere from weather balloon observations.

I was aware of suggestions on the possible links between increasing greenhouse gases and increases in global average temperature — global warming — and thought that I should test those links. Rather than just looking at the observational data, I used the theoretical responses to changes in radiation associated with increases in sunlight from the sun and from increases in greenhouse gases to define fingerprints of temperature change due to different factors. This has become known as fingerprint detection of climate change and I was a pioneer in this approach in the mid-1980s.

I submitted a paper to an international conference on "Mechanisms of Interannual and Longer-Term Climate Variations" in Melbourne in December 1986, in which I said that I would show that there was no link between increasing greenhouse gases and the observed pattern of temperature change in the Southern Hemisphere. The only problem was that when the analysis was completed, the data showed a clear pattern of warming in the lower atmosphere and cooling in the stratosphere, which could not be explained by natural variability, was not consistent with the expected response to changes in radiation from the sun and was entirely consistent with the expected response to increasing greenhouse gases in the atmosphere.

I published two papers [(Karoly, Southern hemsiphere temperature trends: A possible greenhouse gas effect?, 1987) and (Karoly, 1989)] on this observation analysis, the first on the Southern Hemisphere and the second on the Northern Hemisphere, in the late 1980s, before the Intergovernmental Panel on Climate Change (IPCC) was established in 1988. I continued research on fingerprint detection, refined the approach through collaboration with others, included climate model simulations and other possible forcing factors, including volcanic eruptions, stratospheric ozone depletion, and industrial aerosols in the lower atmosphere.

The more we looked, the stronger was the evidence that human-caused increases in greenhouse gases in the atmosphere were the main cause of the observed warming in the lower atmosphere from the 1960s to the 1990s. This approach was one of the key factors behind the conclusion of the IPCC in 1995 that "The balance of evidence suggests a discernable human influence on climate." [Ed. Note: A key paper on "the human fingerprint" on climate change is (Santer, et al., 1996a), where Karoly is the 6th author.]

Now, for the issue of chaos and the predictability of weather and climate. As you say, the atmosphere is a complex, non-linear, fluid-dynamical system, which means that its specific state and a particular time cannot be predicted accurately for more than a few days to a week. The theory of chaos and the dynamics of non-linear systems were developing rapidly in the second half of the twentieth century. Although the specific trajectory of a non-linear turbulent system, like the atmosphere, in its state space cannot be predicted precisely, we can often determine the attractors and the bounds for these trajectories, which can represent the average behavior of the system and its variations.

If we think of the weather and predicting the maximum temperature at a location, weather forecasts do that reasonably well for a few days, but have no skill more than a week ahead. However, we can make a forecast six months in advance that the average temperature in summer is likely to be hotter than the average temperature in winter, and this will be very skillful most years. The climate of a location is affected by the amount of solar radiation received and other forcing factors, like elevation, proximity to the coast, and prevailing winds. These determine the range of possible temperatures and the average temperature in summer and winter, but not the precise temperature on any day. This is the difference between predicting the weather and the climate.

To model the climate system, we have to represent the fluid dynamics of the atmosphere and ocean using the equations of motion, but we also have to represent the energy losses and gains due to radiation, and all the other important processes: clouds, rain, snow, ice, and all the interactions in the systems. It is changes in the energy losses and gains in the system that determine the changes in the climate, and some of these are predictable if the forcings are known, even though the system is very complex. However, the day-to-day and even the year-to-year variations of this chaotic system are not predictable.

The limits on the predictability of the long-term behavior of the climate system depend on the relative magnitude of the response to any changes in forcing and the internal variability of the system at decadal timescales. The internal variability is much smaller at global scales than at a single location or a small region, smaller at decadal timescales than for a single year, and smaller for some variables, like temperature, than for others, like rainfall.

Scientists have confidence in their models because they test them and evaluate their performance using observations. This has been done using simulations of the climate of the 20th century and comparisons with observed climate variations in many different ways. It is important to understand, when comparing climate models with observations, that both are representing chaotic systems and we shouldn't expect the precise state of the modeled atmosphere to agree with the observations at any one time. However, their average behavior should agree within the bounds associated with internal variability of the chaotic system.

The Accuracy of Climate Observations

TheBestSchools

The second issue has to do with the reliability of the empirical data that we feed into our computer models.

There are a number of inherent difficulties in obtaining reliable data about the past behavior of the atmosphere. Perhaps the most important of these is the weakness of the "signal" (the secular change in temperature measured in tenths of a degree Celsius), which is some three orders of magnitude smaller than the range of the geographic temperature variation, not to mention the normal diurnal and annual temperature variability, over the surface of our planet.

Another issue is the relative difficulty in measuring surface temperatures over the ocean in comparison with the land. Yet another is the sparseness and non-random distribution of the land-based measuring stations where the majority of the data are gathered. For example, whether bias may have crept into the data due to the closing of weather stations in Siberia after the fall of the Soviet Union is one much-discussed problem. Bias due to the skewed placement of stations near urban areas (which are warmer than the surrounding countryside) is another. And so on.

In light of all these difficulties, once again, ought we to place so much confidence in our models, which after all are only as good as the empirical data we feed into them?

David Karoly

It is important to have confidence in the quality and reliability of observational data used for monitoring climate variability and climate change, as well as for evaluating the performance of climate models.

However, this question suggests that the climate models are based on empirical data, like economic models. That is wrong. Climate models are based on the mathematical solutions of the predictive equations representing the physical processes that determine the behavior of the climate system, the atmosphere, the ocean, the land surface and the cryosphere (ice), and the interactions between them. This includes the equations of motion, conservation of energy, conservation of mass, conservation of momentum, and the laws of thermodynamics. These models are used for weather prediction, as well as for simulating the climate. Their performance is evaluated routinely in terms of how well they predict the weather and how well they simulate the mean climate and its variability. Observational data is key to evaluating the performance of the models, but it is not fed into them like empirical models.

Now, let me address these two issues: the weakness of the signal and the difficulty of reliably measuring and combining data from the oceans, and from rural, urban, and remote land areas. It is framed around temperature observations, so I will restrict my answer to them. The answer would be somewhat different for observations of other variables, such as rainfall, or clouds, or wind speed and direction.

As stated already in my answer of the predictability of the climate system, we have to consider the forced response (the signal) to the internal variability (the noise): the variations in space and time. The internal variability is much smaller at global scales than at a single location or a small region and smaller at decadal timescales than for a single year.

While the spatial variations of temperature are large between the tropics and the polar regions and between low elevations and the tops of mountains, it is the variations of these temperatures from their long-term averages or normal that we are interested in when we are estimating the variations of the global average or spatial average temperatures. The spatial scale of the variations of temperature from day to day or year to year is much larger than the spatial scale of the geographic features that can determine the mean climate, like mountain ranges or cities or coastlines. We know that when it is hotter than normal over the ocean, it is hotter than normal over the neighboring land areas and when it is hotter than normal at low elevations, it is also hotter than normal over adjacent mountains. The spatial scale of these variations is also larger when we consider longer-term variations, such as seasonal or annual averages, rather than day-to-day variations.

Hence, to estimate the variations of the average temperature for the globe, it is not the absolute temperatures from different sites that are combined, but the departures of the temperature from normal at many different locations across the globe. This means that the loss of data from Siberia will have minimal impact on estimates of the global temperature variations, because the temperature variations in Siberia are closely related to the temperature variations in surrounding areas.

Several different Centers in the US, the UK, and Japan routinely collect observational data and combine it to estimate global temperature variations. Slightly different methods are used at each of these centers to combine these data and to allow for changes in spatial coverage and areas with limited or no observations.

The World Meteorological Organization (WMO) recently released the latest estimates of the global average temperature for 2015 from three centers — NASA and NOAA in the US, and the UK Met Office, as shown below — and compared it with variations over the period since 1850.

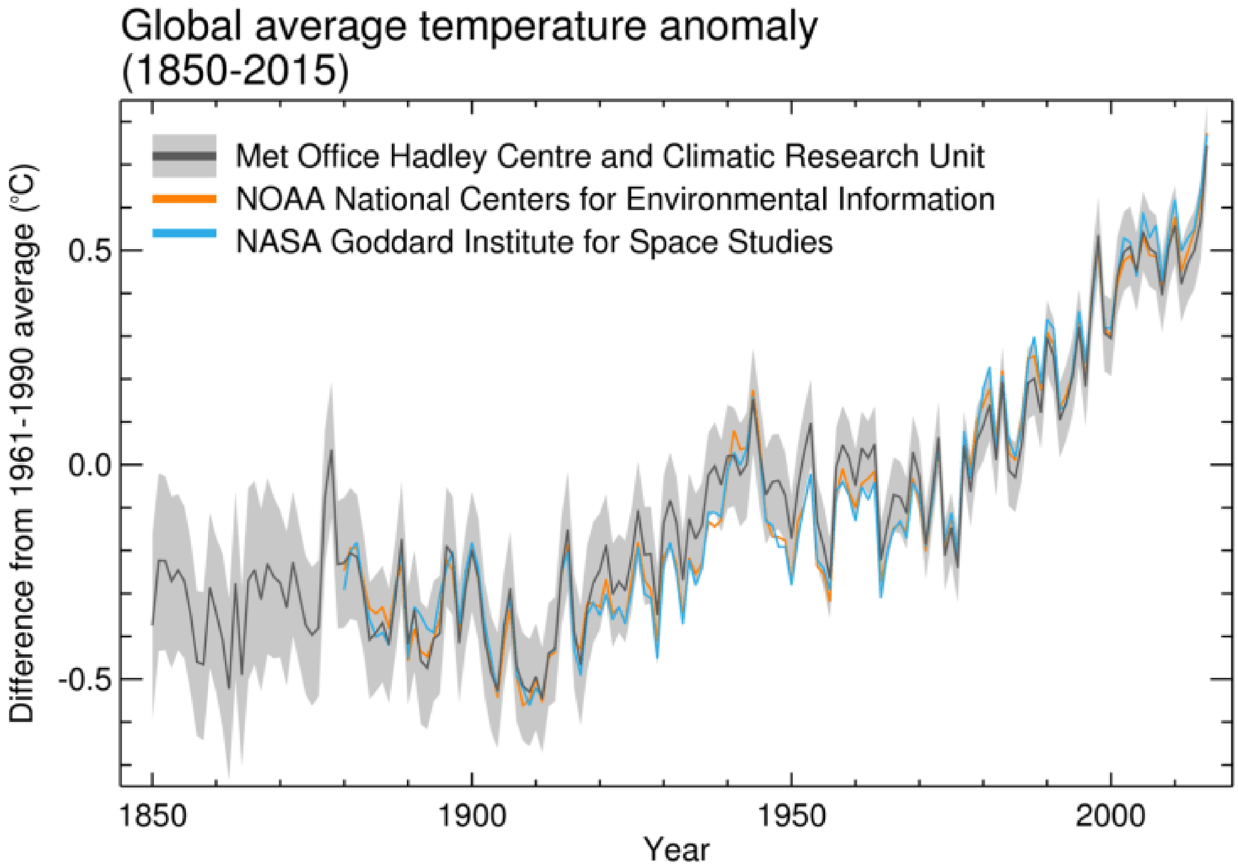

Figure 8. [Source: [World Meteorological Organization Press Release 2](), 25 Jan. 2016.]

The differences of the independent estimates of the global average temperature anomalies from the three centers are smaller than 0.1°C. The uncertainties in the estimates associated with uncertainties in the measurements at each location and the global data coverage, shown in the gray shading, are about 0.1°C in the recent period, but much larger — up to 0.2°C — in the late 19th century, when there was less complete global data coverage.

We can also estimate the signal of the long-term temperature change between the nineteenth century and the twenty-first century from this graph, about 0.9°C. This is much larger than the year-to-year variations of temperature, the noise of up to 0.3°C. Hence, the global warming signal is much larger than the noise of chaotic natural climate variability.

Based on this, scientists have confidence in the quality of the data and the estimates both of variations and longer-term changes in global average temperature over the last 150 years.

The Pause

TheBestSchools

One of the most frustrating things for a layperson about following science news in general, and the global warming debate in particular, is the way in which new data keep coming along that are supposed to supersede what were presented to us as well-established facts only a short time before.

The so-called global warming "pause" or "hiatus" — the claim that temperatures have held steady for the past couple of decades, more or less — is a prime example of this phenomenon. For years, we have been given solemn explanations by consensus scientists as to why the consensus viewpoint on global warming still holds good in spite of the pause. Now, just a few months ago, a new study by the U.S. National Oceanic and Atmospheric Administration (NOAA) was released that supposedly shows that the pause never really existed to begin with!

Where do you stand on the reality of the pause? Can you explain to us why the public should believe today the opposite of what it was told in an equally authoritative tone of voice only yesterday? Wouldn't it be better for the credibility of scientists if they just acknowledged that all of their conclusions are tentative, and let it go at that?

David Karoly

When we look at the global average temperature variations for the period from 1850 to 2015, shown in my answer to the previous question, there is a lot of natural variability from year to year and decade to decade, and a pronounced warming trend from 1910 to 2015. There are periods in the 1950s and 1960s that show a slowdown in the rate of warming and again in the decade of the 2000s.

Most of the year-to-year variability of global average surface temperature is due to the exchange of heat between the ocean and the atmosphere. El Niño — warming of the equatorial Pacific Ocean and release of heat from the ocean into the atmosphere — is associated with higher-than-normal global temperature in the year after the peak of El Niño. La Niña — the opposite phase — has cooler waters in the equatorial Pacific, additional heat uptake into the ocean, and lower-than-normal global average temperature.

The so-called "hiatus" in global warming was a creation of a small number of commentators who usually considered the period from 1998, a very hot year, to around 2012. Nineteen Ninety-Eight was a very hot year associated with the strongest El Niño event in the last 150 years. The years 2011 and 2012 were colder, being associated with back-to-back La Niña events. It is not surprising that if you select a period starting in a hotter year, like 1998, and finishing in a colder year, like 2012 — both associated with natural variability — that there is a reduction in the warming trend in global average temperature due to natural variability.

Does this mean global warming stopped? No — for two reasons. First, global warming is the addition of heat to the climate system, not just the increase in global average temperature. In fact, about 90 percent of the heat added to the climate system due to the increase in greenhouse gases in the atmosphere over the last 100 years has gone into heating up the oceans and only a small fraction has gone into heating the atmosphere and the land surface. The heat content of the ocean, particularly

the deep ocean, has increased more rapidly over the last two decades, even while the global average surface temperature showed a reduced rate of warming due to natural variability from 1998 to 2012.

Second, if we want to focus on the role of global warming in global average temperatures, we need to consider the longer-term average temperature for at least a decade, and the changes from decade to decade. There is a pronounced warming from the decade of the 1990s to the most recent decade — 2006 to 2015 — even including the colder years associated with the strong La Niña of 2010 and 2011.

Hence, global warming did not stop in the early part of the twenty-first century. The slowdown in the rate of increase in global mean temperature only exists if you start in 1998, a very hot year, and is due to natural variability of yearly temperatures. Global warming does not mean that the chaotic variability of global temperature disappears. The year-to-year natural variability is superimposed on longer-term global warming.

The Temperature Record

TheBestSchools

Thank you! That is one of the clearest explanations we have seen of the "hiatus" phenomenon.

Let us ask you about another issue that is often discussed in ways that are confusing for the layperson. We understand that the global average temperature graph you reproduced above from the WMO (it also exists in many slightly different forms) has become so well known that it has come to be referred to affectionately as "T," for temperature. Critics of the consensus view say that T is misleading in several ways.

For one thing, the vertical axis is usually presented in an extremely compressed form, making the modest temperature increases appear much more dramatic. Here is how the *same data* look on a less-compressed vertical scale:

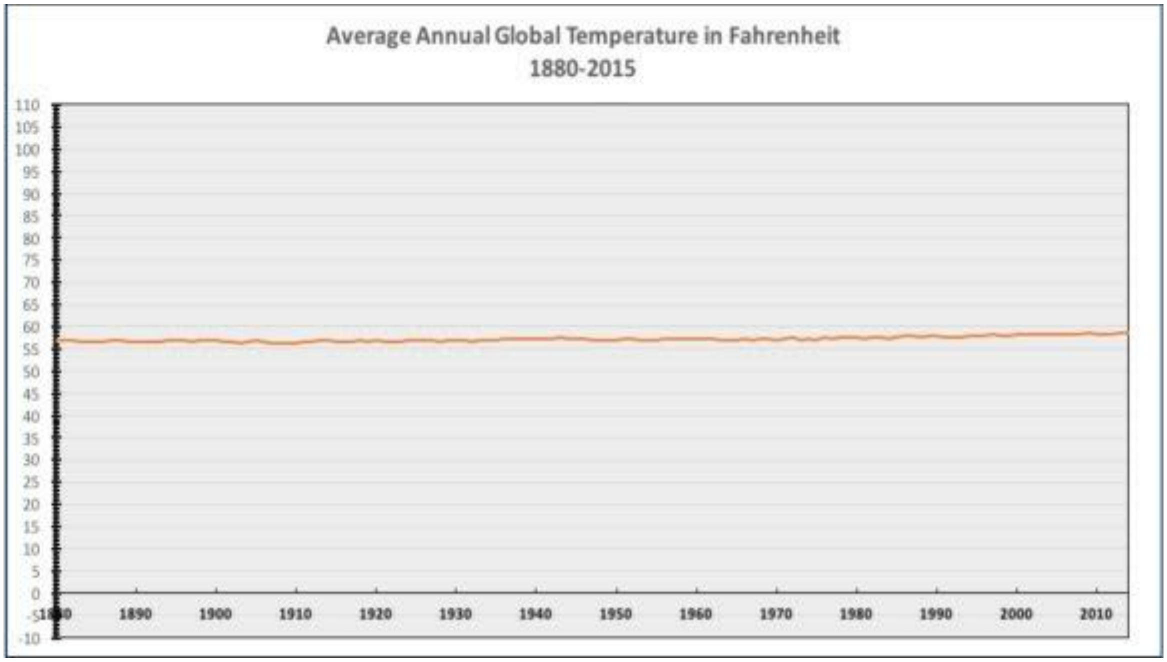

Figure 9. Source: Powerline.

For another thing, T does not represent actual thermometer readings, but rather extrapolated numbers based on various theoretical assumptions about the accuracy of the sparse underlying direct observations (Essex & McKitrick, 2003, p. 138).

How would you respond to these criticisms of T?

David Karoly

I have already commented on the use of the global average temperature to represent global variations of the climate system and why it is used in my answers to several questions above. It is a simple measure of the average temperature of the surface of the planet. The vertical scale that should be used is one that shows the magnitude of the year-to-year variations of the global average temperature due to natural variability, as well as any longer-term trends, such as in the one above or the more recent one that I have shown from WMO.

T does represent actual thermometer readings on land and measurements of ocean temperatures from ships and from satellite data. These data are not extrapolated to estimate the global average temperature but interpolated. As already described, it is the average of the temperature anomalies or departures from normal at each location that are used to estimate the global average temperature, not the absolute temperature. This is done because the spatial scale of variations of the temperature anomalies at monthly and annual time scales is very large, typically a thousand kilometers or more. When it is warmer than normal at a location, it is also warmer than normal in the surrounding large region.

Different methods are used by different Centers to estimate the global average, treating the spatial gaps in data in slightly different ways. The differences between the estimates from the different Centers are small, less than about 0.1°C in the recent period, as shown in the WMO graph above. The

accuracy and reliability of the temperature data have already been discussed in the context of estimating global average temperature and the uncertainties have been quantified and are small.

The Hockey Stick

TheBestSchools

Very well. Let us assume, then, that T reflects reality — that the modest warming trend it shows over the past century or so is well supported. The next question is: What is causing this warming trend?

Now, everybody seems to agree that atmospheric CO_2 levels are much higher today than at any time in recent geological history — which stands to reason given the timing of the Industrial Revolution, beginning in the late eighteenth century and really taking off in the mid-nineteenth century, with a large and ever-growing increase in CO_2 emissions due to the burning of fossil fuels. So, we will just assume that is the case and move on.

Still, the question remains: Is the warming depicted by T the direct result of the rise in atmospheric CO_2? Another graph that has become widely known, especially thanks to its prominence in Al Gore's 2006 film ***An Inconvenient Truth***, is the famous "Hockey Stick."

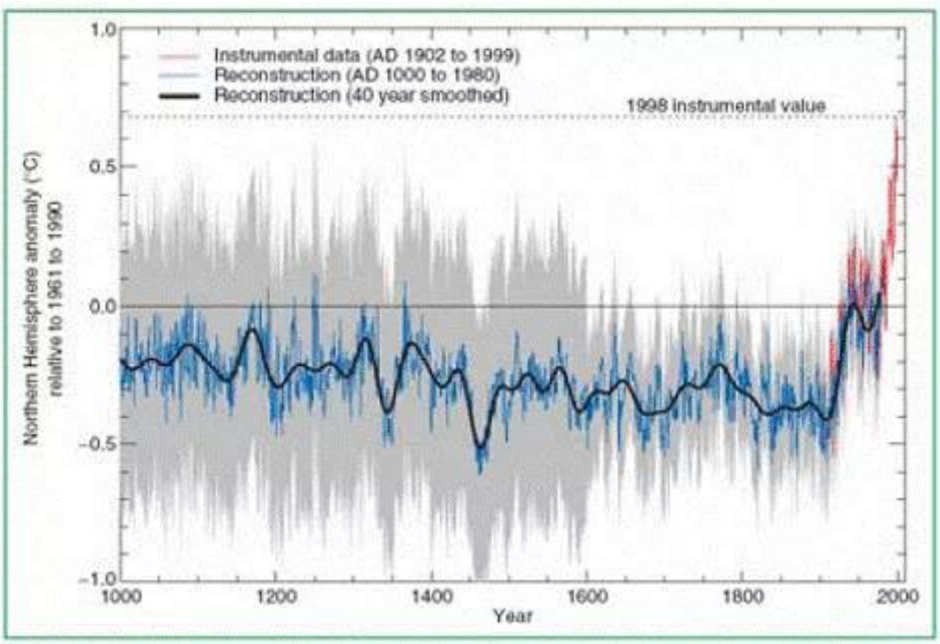

*Figure 10. [Source: **Appinsys.**] also IPCC "TAR" (IPCC, 2001, p. 3).*

Now, like T, the Hockey Stick purports to represent mean global surface temperatures, only this time over a period of 1000 years. What is notable about it is the fact that the warming over the past century (during precisely the period of increase of atmospheric CO_2) appears to be considerably greater than at any time in the past millennium. The Hockey Stick is a very dramatic graph and has

probably done more than anything else to rally the public behind the movement to curtail CO_2 emissions.

Unfortunately, say the critics, the Hockey Stick is also not without problems. Critics note that it is essentially two very different data sets spliced together: thermometer readings for the past century (the “blade” of the hockey stick, depicted in red on the graph) and inherently much less precise estimates (so-called “proxies”) based on tree rings, ice cores, corals, and other sorts of data for the 900 years prior to that (the “handle” of the hockey stick in dark blue, with the uncertainty range in light blue). We know this procedure is misleading because the graph essentially wipes out such well-known climatic phenomena as the “Medieval Warm Period” lasting from approximately 1000 to 1300 A.D., as well as the so-called “Little Ice Age” from about 1550 to 1850. In short, say the critics, the Hockey Stick gives a false impression.

What is your take on the Hockey Stick and related issues?

David Karoly

There are several errors in the question above. First of all, the Hockey Stick represents the variations of Northern Hemisphere average temperatures, not the global average, over the last thousand years. Second, the proxy data extend to late in the twentieth century, typically to the end of the 1980s and show the variability over the millennium and then a pronounced increase over the twentieth century. To provide a temperature scale for the variations of the proxies, their variations are compared with those of observed temperatures at the locations of the proxies and then combined to estimate the Northern Hemisphere average temperature.

There are a number of estimates of the hemispheric average temperature using different methods and different proxy data, not just the one shown above by Michael Mann and his collaborators. They all show that the period around 1000 AD was relatively warm and that the period around 1600 to 1800 was relatively cool, just as the Hockey Stick does. However, they all show that the increase in Northern Hemisphere average temperature over the twentieth century was larger than in any other century over the last millennium and that the last 30 years was likely warmer than any other 30-year period over the last 1000 years averaged over the whole Northern Hemisphere.

The magnitude of the Medieval Warm Period appears to be much greater in the North Atlantic region, in Greenland and western Europe, than in lower latitudes. The Hockey Stick does not wipe out the Medieval Warm Period but reduces its magnitude because it averages over the whole hemisphere.

Recently, there have been improvements in proxy data available for the Southern Hemisphere that allowed reconstructions of Southern Hemisphere average temperature for the last millennium, also. In a study in which I was involved, we showed that many of the decadal and multi-decadal temperature variations in the Northern Hemisphere were out of phase with the Southern Hemisphere, often warmer decades in the north were associated with colder decades in the south. This meant that the global average temperature variations were smaller than the Northern Hemisphere average shown by the Hockey Stick for most of the last 1000 years. The one exception is the pronounced synchronous warming in the Northern Hemisphere and in the Southern Hemisphere in the twentieth century. This synchronous warming in both hemispheres over the twentieth century

indicates that it is not due to natural variability and is likely due to a change in external forcing, such as an increase in greenhouse gases in the atmosphere due to human activity.

Do fossil fuels drive climate change?

TheBestSchools

Now, let's set the whole Hockey Stick issue to one side. Even if the warming has not been as dramatic as that famous graph purports to show, still we have already agreed that there most likely has been some warming over the past century. However, the question remains: If increased atmospheric CO_2 is not responsible, what is?

Critics point to several factors that would need to be excluded before we could identify CO_2 as the main "forcing" (dominant causal factor) with much confidence. These include:

- We are, after all, still recovering from the last ice age (in the true sense of the term), which lasted for about 100,000 years and only ended about 12,000 years ago; therefore, why isn't modest warming simply what we should expect (the null hypothesis) during an interglacial epoch such as ours? Isn't the unspoken assumption by consensus scientists that climate change is abnormal blatantly false?
- Over the geological record taken as a whole, it appears that warming trends regularly precede rising CO_2 levels, not the other way around.
- Some studies show a strong correlation between solar activity cycles and Earth surface temperatures; in fact, it was recently predicted that we may be entering a new Little Ice Age in 20 years or so, given that we are due to experience a "Maunder Minimum" (a period of minimal solar activity) at that time; the last Maunder Minimum is thought by some to have contributed to the Little Ice Age.

Do you believe that these phenomena may be confidently excluded as contributing factors to whatever global warming there has been over the past century or so?

David Karoly

To understand the causes of the increase in carbon dioxide and other long-lived greenhouse gases in the atmosphere, we can look at multiple lines of evidence. Then to identify if there is a link between the increasing greenhouse gases and the observed warming, we can look at other lines of evidence.

The observed concentration of carbon dioxide in the atmosphere is about 400 parts per million. Over the last 800,000 years, during ice ages and warmer interglacial periods, the CO_2 concentration was never above 300 parts per million, as shown by the air extracted from bubbles trapped in ice from Greenland and Antarctica. This shows that the recent large increases in CO_2 can't be explained by natural variability. However, a few scientists suggest other causes, including that the increase is due to CO_2 from underwater volcanoes (Ian Plimer) or to the release of CO_2 from the oceans as they have

warmed over the past century (Murry Salby), which is the reason for the increase of atmospheric CO_2 from an ice age to an interglacial period.

The increase in atmospheric CO_2 matches estimates of the release of carbon into the atmosphere from burning fossil fuels and from deforestation due to land clearing. It is associated with a decline in the isotopic ratio of carbon-13 to carbon-12 in the CO_2, as expected for photosynthetically processed carbon and exactly what would result from the burning of fossil fuels and from land clearing. In addition, there has been an observed small decrease in the oxygen concentration in the atmosphere, exactly as expected from burning fossil fuels. Such a change in isotopic ratios in the atmospheric CO_2 and the decline in atmospheric oxygen cannot be explained by carbon dioxide coming from underwater volcanoes or from the oceans. Hence, human activity since the industrial revolution, associated with burning fossil fuels and with land clearing, is the cause of the increase in atmospheric carbon dioxide.

To determine the likely causes of the observed increase in global average temperatures over the last century or the last 50 years, we have to assess the relative magnitudes of the contributions from natural chaotic variability of the climate system, from increasing greenhouse gases, from changing sunlight from the sun, and other possible factors. As mentioned in the answer to the first question, I have been involved in research on the detection and attribution of climate change for nearly 30 years. The figure below shows the attributable trends in global mean temperature over the period 1951–2010 for a range of different forcing factors, together with the observed trend.

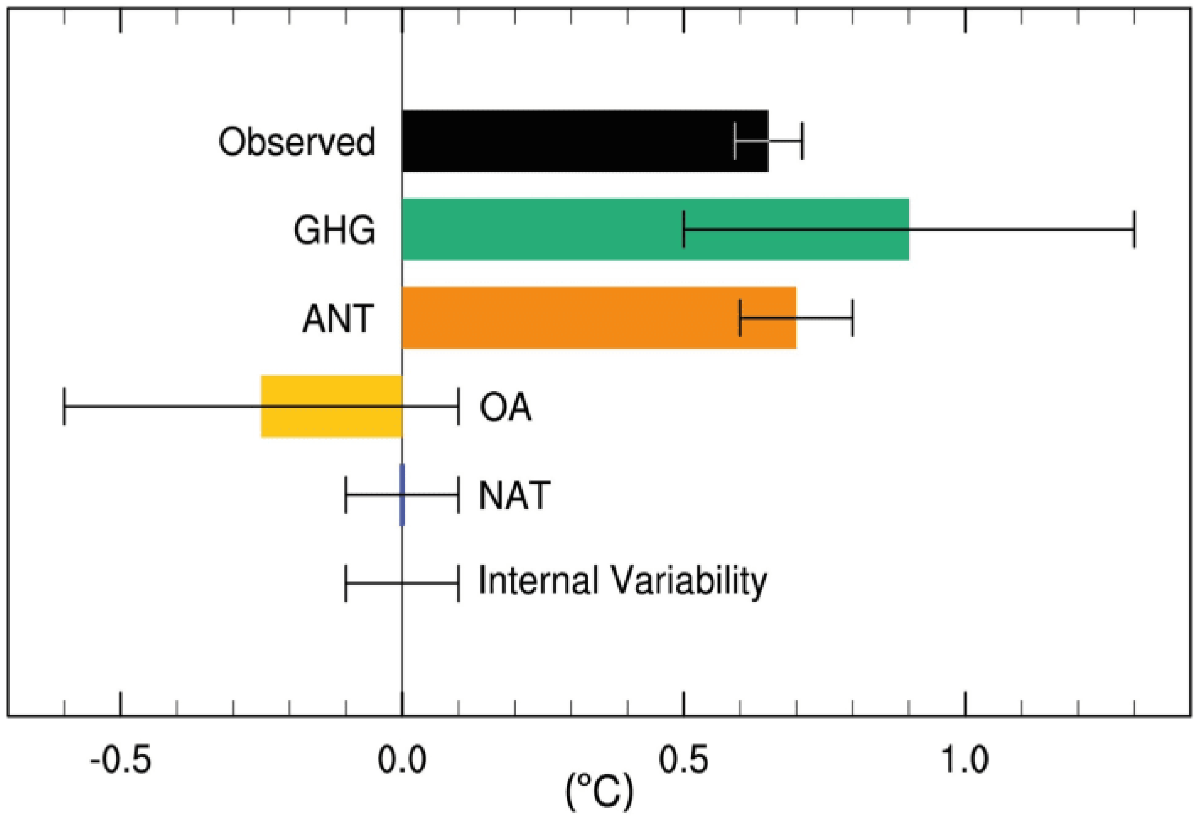

Figure 11. Assessed likely ranges (whiskers) and their mid-points (bars) for attributable warming trends over the 1951–2010 period due to well-mixed greenhouse gases (GHG), other anthropogenic forcings (OA), natural forcings (NAT), combined anthropogenic forcings (ANT), and internal variability. The HadCRUT4 observations are shown in black with the 5–95% uncertainty range due to observational uncertainty in this record. [Source: Figure 10.5 from Bindoff, N.L., P.A. Stott, et al. (2013) "Detection and Attribution of Climate Change: from Global to Regional," in T.F. Stocker, D. Qin, et al. (eds.) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2013.]

In summary, these data show that the increase in greenhouse gases from human activity is the major cause of the observed warming trend. The likely contributions from internal variability and from natural factors, such as changes in volcanoes or changes in sunlight from the sun, are much smaller. In addition, this means that all the phenomena you mention can be excluded as significant contributing factors to climate change over the last 100 years.

Global temperatures are not recovering from the last ice age. The Hockey Stick and other palaeoclimatic evidence show that global temperatures have declined slightly over the last 12,000 years and the last 2,000 years due to reductions in incoming solar radiation associated with variations in the Earth's orbit around the Sun.

Climate scientists are very aware that climate varies naturally across a range of time scales from centuries to hundreds of thousands of years. The climate change over the last 100 years is abnormal because the change in global average temperature is larger than at any time over the last millennium, the change is driven by human-caused increases in carbon dioxide and other long-lived greenhouse

gases, and the carbon dioxide concentration in the atmosphere is now higher than at any time over the last 800,000 years, through multiple ice ages and interglacial periods.

It is true that during the cycles from ice ages to warmer interglacial periods, the warming is initiated by changes in the Earth's orbit around the Sun leading to increases in sunlight at higher latitudes. The rise in CO_2 follows as it is less soluble in warmer water and the oceans release some of the dissolved CO_2 into the atmosphere. However, that does not mean that CO_2 cannot drive climate change or that the current increase in CO_2 is due to the observed warming. Simple radiation physics as well as geological evidence, such as from the Paleocene-Eocene Thermal Maximum, show that increases in CO_2 in the atmosphere have a warming influence on the climate. As discussed already, there are multiple lines of evidence, including changes in the isotopic ratios of carbon and reductions of the concentration of oxygen in the air, that the observed increase in CO_2 since the industrial revolution is due to human activity.

There is certainly a strong correlation between incoming solar radiation and the ice age-interglacial cycle over the last million years. Variations in incoming solar radiation are very important for local climate and for the seasonal cycle. However, over the last 40 years, when we have reliable observations of changes in solar radiation at the top of the atmosphere due to variations in solar activity, the variations in solar radiation are very small and have no correlation with global temperature variations. Over this period, solar radiation has declined slightly, while global temperature has increased significantly.

As shown in the previous figure, the estimated contribution of changes in solar radiation to changes in global temperature over the last 60 years is -0.1 °C to +0.1°C, much smaller than the observed increase of about 0.6°C.

As already mentioned above, we can also confidently exclude changes in solar activity as a contributor to recent observed climate change using the fingerprint of the response to increases of solar radiation in the observed pattern of changes in temperature in the stratosphere and in the lower atmosphere. Increases in solar radiation would lead to warming in the stratosphere due to absorption by oxygen and ozone in the upper atmosphere and warming in the lower atmosphere and at the surface. However, the observed pattern of temperature change over the last 50 years shows cooling in the lower stratosphere and warming in the lower atmosphere and at the surface, exactly as expected from human impacts on the climate.

Is Global Warming a bad thing?

TheBestSchools

Our next question is this: Even assuming that increased atmospheric CO_2 has been the main cause of the recent warming (i.e., that it has been manmade), is there much real reason for concern? Critics give several reasons why there is little reason to be alarmed, notably:

- The Medieval Warm Period demonstrates that global warming by a few degrees is no catastrophe.

- The probable existence of various negative feedbacks indicates that the warming may well be self-limiting; these include:
    - Increased cloud cover, which would reflect more solar energy
    - Increased vegetation, which would absorb more CO_2
- The advantages to agriculture from increased CO_2 concentrations and warmer temperatures may well offset whatever disadvantages there may be.

What say you in response to these ideas?

David Karoly

There are many reasons to be concerned about the adverse impacts of human-caused climate change on society and on natural ecosystems.

There are many reasons to be concerned about the adverse impacts of human-caused climate change on society and on natural ecosystems. While there may be some short-term benefits of higher CO_2 and a slightly warmer climate in some sectors, all comprehensive assessments of the impacts of climate change across many sectors show many reasons for concern.

The Medieval Warm Period is not a good analogue for the impacts of recent climate change because the best estimate of the global average temperature then, rather than the regional temperature in the North Atlantic region, is that it was about the same as the mid-twentieth century. Global average temperatures have already risen by more than half a degree since then and are expected to rise by at least another three degrees or more if no action is taken to slow human-caused climate change.

There are major negative feedbacks in the climate system that will limit the warming of the global climate system. This is demonstrated by the fact that the climate has remained relatively stable over the last 2000 years and global average temperatures have not varied up or down by more than half a degree, while human civilization has developed. The dominant negative feedback is associated with the very rapid increase of outgoing infrared radiation from the surface and the atmosphere as their temperatures increase, governed by the Stefan-Boltzmann equation from radiation physics.

The other negative feedbacks, such as increased cloud cover or increased vegetation, are fully offset by positive feedbacks in the climate system. The most important of these include the increase of water vapor in the atmosphere as it warms, increasing the greenhouse effect; the reductions of snow and ice in higher latitudes in a warming climate, increasing the absorption of solar energy at the surface; and increases of cloud cover reducing the loss of infrared radiation to space, which is particularly obvious on cloudy nights compared with clear nights.

While increases in carbon dioxide are likely to lead to increased plant growth through photosynthesis, benefiting agriculture and forest growth, these benefits are not likely to counteract the impacts of climate change, higher temperature, and changes in rainfall patterns on agriculture, or the many other adverse impacts of climate change.

There are too many adverse impacts of climate change on human and natural systems to list here, so I will only mention a few of the most obvious ones. Increases in global and regional temperatures lead to:

- Major changes in the regions in which plants can grow, affecting agriculture and natural ecosystems. As the climate warms, the growing zones for plants move upward in elevation and poleward to try to maintain the same climate. This will lead to the loss of many natural ecosystems, such as coral reefs and alpine ecosystems in some areas, and dramatic changes in agricultural regions, particularly in already-hot areas like the tropics.

- Increases in hot extremes and heatwaves, affecting human health and leading to crop and animal losses, as well as increases in the occurrence and intensity of wildfires.

- Global sea level rise, flooding coastal areas, causing coastal erosion, and polluting coastal freshwater systems with seawater. Expected sea level rise by the end of this century for even the smallest projected global warming will lead to the annual flooding of many hundreds of millions of people and the complete loss of some low-lying island countries.

The “Consensus”

TheBestSchools

Finally — to wrap up the first part of the interview devoted to scientific questions — as you know there has been a great deal of discussion about the issue of scientific “consensus” on the global warming issue. We have already spoken loosely of the “consensus” as a short-hand way of referring to the official position of the IPCC. However, now we are going to address the broader question of the views of the scientific community at large.

One often hears the claim that the consensus among working atmospheric scientists as a whole in favor of the official IPCC position is “overwhelming”; indeed, one often reads the claim that “97%” of scientists support the mainstream viewpoint. However, some critics question the reality of this consensus on a number of different grounds.

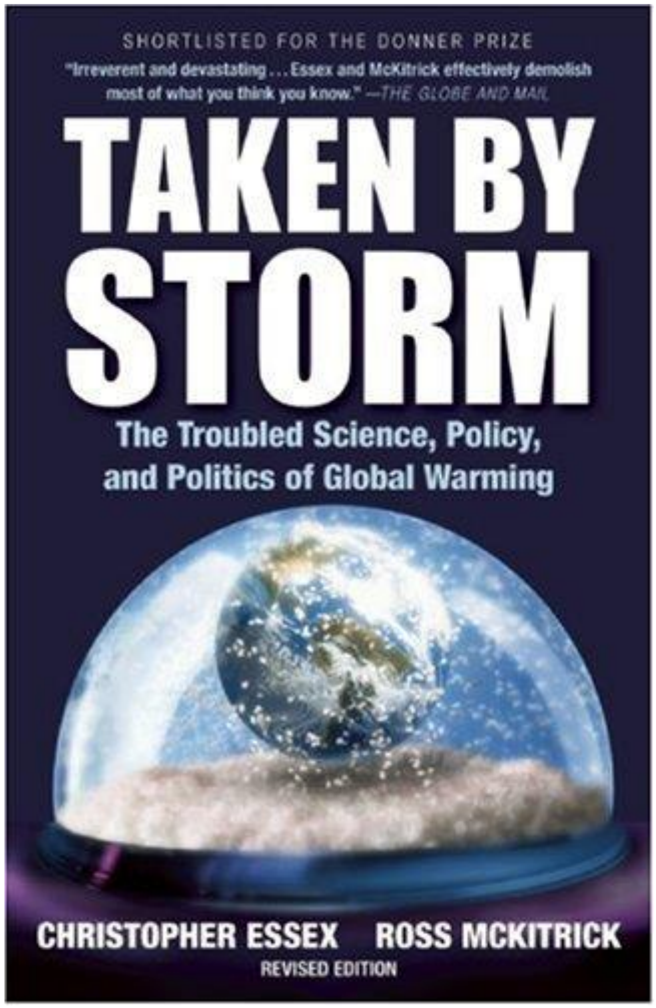

Figure 12. Taken by Storm.

One of the best summaries of the situation from a skeptical perspective, we believe, is the book ***Taken by Storm*** by Christopher Essex and Ross McKitrick (Key Porter Books, revised ed. 2007). Essex is a physicist at the University of Western Ontario, who specializes in complex dynamical systems such as the atmosphere, while McKitrick is an economist at the University of Guelph, who specializes in the economic analysis of environmental policy.

Essex and McKitrick contend that there has been a "perfect storm," in which exaggerations by partisan NGOs and other pressure groups have led to exaggerations in the media, which have in turn created an atmosphere of hysteria to which politicians — who are mostly scientifically illiterate — feel obligated to respond. As examples, the authors point to the news stories a few years back about the supposed plight of the polar bears (in fact, the polar bears are thriving — the ice just shifted to the other side of Hudson's Bay temporarily due to a change in the prevailing winds) and the glaciers (many glaciers are receding, but others are advancing — for example France's Mont Blanc and Alaska's Hubbard Glacier).

Another sort of example occurs when journalists throw around the terms "pollution" and "pollutant" loosely to describe atmospheric CO_2, thus conflating well-substantiated real pollutants which nobody denies — such as sulfur oxide, heavy metals, particulates, etc. — with CO_2 which is produced by all animals and, as a primary plant nutrient, is a vital substance upon which all life on earth ultimately depends.

Even worse than this kind of tendentiousness is when *whatever happens* is automatically interpreted as evidence in favor of one side, in this case, global warming — as was the case with the particularly *cold* winter of 2014. This sets up the sort of "heads I win, tails you lose" situation well known to philosophers of science under the label "unfalsifiable." Such an attitude more closely resembles religious faith than objective science.

Though these and many other news reports sacrifice what used to be considered honorable journalistic skepticism, they do succeed in selling newspapers and attracting readers to blog posts. Unfortunately, they also succeed in creating the aforementioned climate of hysteria, in which politicians feel obliged to *do something, anything,* whether it makes sense or not. Whence the IPCC and the UN Conferences on Climate Change — to which critics of the consensus are generally not invited, making the circle of "consensus" complete.

Finally, Essex and McKitrick point out that the more the supposed "consensus" grows, the more it has a chilling effect on scientists who may disagree, but who prefer to keep their heads down for the sake of their reputations and their careers. In this way, "consensus" is a self-fulfilling prophecy, but one that has little to do with science.

How would you respond to concerns such as these?

David Karoly

There is an overwhelming consensus of climate scientists who agree that human-caused climate change is happening, and that global warming will continue throughout the current century, with many adverse impacts on human and natural systems. This consensus is based on a vast body of scientific evidence and many thousands of peer-reviewed scientific publications. It is the consensus of

Figure 13. The National Academy of Sciences.

the evidence and the peer-reviewed publications that is important, which leads to the consensus of climate scientists.

The US National Academy of Science has carried out independent assessments of the science of climate change under both Republican and Democrat Presidents and supported the consensus scientific conclusions on greenhouse climate change. All major national scientific Academies in different countries around the world support the consensus view, based on their own independent assessments. Governments of all countries around the world have accepted the science at meetings of the IPCC, despite the fact that any individual country could have vetoed the acceptance of the IPCC Assessment Reports.

Many of the statements in the section above and by Essex and McKitrick are either wrong or misleading or both. Scientists cannot control what NGOs say or what the media report. The statements above about the glaciers on Mont Blanc and Hubbard Glacier are wrong, as these glaciers have not advanced over the last hundred years. They are significantly shorter and smaller now than when measured in the late nineteenth century and early twentieth century. It is clear in the US that the media give as much coverage to the small number of skeptical climate scientists as they do to the much larger number of climate scientists who discuss the science accurately. Politicians in the US are mainly split on party lines in terms of their acceptance of the peer-reviewed climate science.

Any scientist or group of scientists who could reliably and convincingly prove that increasing greenhouse gases in the atmosphere have not caused global warming over the last 100 years and will not cause further global warming would be a strong candidate to win a Nobel Prize in Physics. There is no scientific evidence to support this at present.

Is Government Action on Global Warming Necessary

TheBestSchools

Up until now we have mainly been discussing science. However, the global warming issue also has many moral, political, and social ramifications for individual governments and for humanity as a whole. Since, in addition to your scientific research and teaching, you have also been deeply involved in the work of the IPCC, we would like to hear your thoughts on some of these broader societal issues, as well, if you don’t mind.

Let us begin by pointing out that it is logically possible to acknowledge that global warming is a reality, is manmade, and is a very bad thing — and yet to feel that the sort of concerted global governmental intervention that is being proposed by the IPCC and the UN Conferences on Climate Change is a cure worse than the disease.

How one feels about this matter will depend greatly on one’s politics — that is, on how one feels about the proper scope of governmental power in general. On the other hand, even the fiercest political libertarian would presumably acknowledge the need for concerted global governmental action under some circumstances — say, in the case of a large asteroid bearing down upon the earth. And, similarly, we do not suppose that very many friends of Big Government consciously wish for a

single, totalitarian, world dictatorship. So, it is perhaps more a question of people's politics' coloring their assessments of the risks than it is a question of political differences *per se.*

At any rate, we don't ask you to engage in reflection on fundamental political philosophy here (though feel free to do so, if you wish!). However, we would like to know what you would say to those who feel that the economic and political costs which would have to be incurred in order to make a real dent in atmospheric CO_2 reduction would outweigh any possible benefits.

David Karoly

As you say, there are varied opinions on whether any national or international action is needed to address greenhouse climate change in a few countries, often colored by the political beliefs or ideological backgrounds of the opinion-holders. This is particularly true in the United States, where none of the Republican candidates in the current Presidential race have said they accept the scientific conclusions of the US National Academy of Sciences or the IPCC that warming of the climate system is unequivocal, that human activity is the main cause, and that strong action is needed to minimize dangerous climate change. This is opposite for the Democrat candidates, who all accept these scientific conclusions.

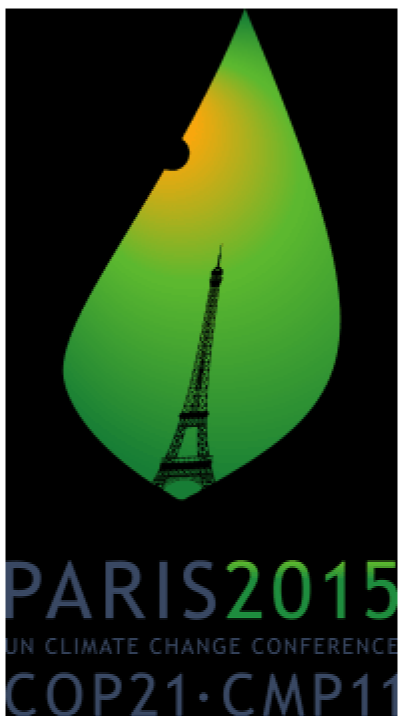

Figure 14. The Paris Agreement.

The governments, liberal, conservative, or socialist, of all countries in the world met in Paris in December 2015 and agreed on nationally determined targets for their national greenhouse gas emission reductions by 2030. All countries agreed that action on climate change is needed, irrespective of their politics.

All countries agreed in 1992 on the fundamental objective of the United Nations Framework Convention on Climate Change (UNFCCC), "stabilization of greenhouse gas concentrations in the atmosphere at a level that would avoid dangerous anthropogenic interference with the climate system." The United States ratified the UNFCCC in 1994 and it has not been revoked by any Democrat or Republican President or Congress in subsequent years. Through the UNFCCC processes, all countries have agreed to limit global warming to 2°C above pre-industrial levels, as this would be associated with smaller impacts from global warming. Hence, political differences between countries have not affected these unanimous decisions.

There are political differences between the levels of action supported by different political parties in a number of countries, including Australia, United Kingdom, and Germany, but there is bipartisan support for action to minimize global warming by reducing greenhouse gas emissions.

It is also important to clear up the misunderstanding that the IPCC makes recommendations and provides policy advice to governments. This is incorrect. The IPCC undertakes comprehensive assessment of the peer-reviewed literature about climate change, including climate change science, projections of future climate change, impacts of climate change, vulnerability and adaptation to those impacts, and approaches to reducing climate change due to human activities. These assessments by the IPCC are also thoroughly reviewed by experts and by governments. The assessment reports contain Summaries for Policymakers that are required to be policy-neutral and to contain no recommendations.

Any decision on how to respond to climate change is an ethical and moral decision for society, and not just an economic decision.

As noted above, any decision on how to respond to climate change — to adapt to the adverse impacts, to reduce the causes by cutting greenhouse gas emissions, or just do nothing and leave it to someone else fix the problem — is an ethical and moral decision for society, and not just an economic decision. In the following, I consider some of the moral perspectives for acting on climate change, and then some perspectives on the difficulties of thorough economic assessments of the costs and benefits of acting to address climate change.

The scientific evidence shows major impacts of global warming on human health, with increased loss of life directly attributable to climate change from heat waves now and much more in the future. Sea level rise is leading to coastal flooding and is likely to lead to the complete loss of land in some low-lying island countries, with the destruction of their traditional lands and cultural heritage. Global warming is having major impacts on natural ecosystems, particularly in the tropics, on coral reefs, and in alpine areas, and will lead to the extinction of growing numbers of species as the magnitude of the warming increases. The moral value of human life, of traditional lands and cultural heritage, and of individual species cannot be measured and differs among people.

The impacts of global warming are also unequally distributed across different people and different regions of the globe. The impacts of warming are likely to be greater in already-hot regions than in colder regions, where they may be some short-term benefits from warming. Poorer people in all countries are likely to be most affected by the impacts of climate change because they are least able to afford protective measures to reduce the impacts or to afford to rebuild and recover from any adverse impacts. People in the least-developed countries have made the smallest contributions to the

causes of climate change, as they have had very small emissions of greenhouse gases in general, yet they are likely to be more affected by climate change because they generally lie in hotter areas and they have lower resources available to adapt to the impacts of climate change. The unequal distribution of the impacts of climate change needs an ethically based response.

There is another aspect of the inequalities of climate change that is hard to assess from a political or economic perspective and requires detailed moral and ethical consideration. Climate change due to human activity is a very long-term problem. Natural processes that remove carbon dioxide from the atmosphere and store it long-term, such as storing carbon in marine sediments, in deep soils, in rocks, or even in fossil fuels, operate over very long-time scales — thousands of years to millions of years. The best scientific evidence is that it will take more than 1000 years and possibly more than 10,000 years for natural processes alone to reduce the current atmospheric concentration of carbon dioxide from 400 parts per million (ppm) to pre-industrial levels below 300 ppm.

The global average temperature change above pre-industrial levels is causally related to the cumulative emissions of carbon dioxide over time, not the emissions at any one time, because of this very slow removal of carbon dioxide due to natural processes and the delay in the warming of the climate system due to the very high heat capacity of the oceans. Hence, any emissions of carbon dioxide from human activity contribute to global warming, irrespective of when they occur. Any delay in reducing emissions associated with continued burning of fossil fuels increases global warming as it adds to the level at which global average temperature will eventually stabilize. Many studies have shown that most of the existing fossil fuel reserves must remain unburned, and in the ground if we are to limit global warming to below two degrees.

Hence, global warming is a very long-term problem that will affect not only the current population, but many future generations, too. Global warming is a direct outcome of human activity since the industrial revolution, but particularly over the last 100 years, that will continue to affect generations over more than the next 1000 years. It is critically important to consider the impacts of global warming on future generations when we consider the costs and benefits of action or inaction on climate change on the current generation.

Figure 15. President Teddy Roosevelt

In 1920, when considering a phrase in the US Bill of Rights, Theodore Roosevelt wrote:

The “greatest good for the greatest number” applies to the number within the womb of time, compared to which those now alive form but an insignificant fraction. Our duty to the whole, including the unborn generations, bids us to restrain an unprincipled present-day minority from wasting the heritage of those unborn generations.[1]

This is particularly relevant when considering the intergenerational aspects of the impacts of climate change and the need for current action.

Politicians and politics often focus on the current and near-term costs and benefits when determining policies. They sometimes focus on the next election. The long-term nature of climate change and particularly its impacts on future generations make it very difficult to address adequately through our current adversarial political systems in most democracies. Perhaps we should make this quote from President Roosevelt required reading for all politicians whenever they debate climate change.

There have been a number of studies of the economic costs of reducing greenhouse gas emissions by converting society to low- and zero-carbon energy sources, with the associated losses of jobs and profits for fossil-fuel based industries and new opportunities for jobs and profits in renewable energy and zero-carbon industries. It is likely to be easier to quantify the losses in existing industries than the possible gains in new industries.

In addition, it is much harder to estimate the economic costs of the adverse impacts of future climate change, including costs across a wide range of sectors, including human health, agriculture, coasts, cities, water resources, forestry, fishing, and tourism. For some impacts, such as the loss of natural ecosystems, like coral reefs and alpine ecosystems, the loss of life, and the loss of land and cultural heritage, quantification of the economic costs is impossible.

Even without including the costs of future impacts due to global warming, most comprehensive studies show that the economic costs are small to avoid dangerous climate change compared to the

expected annual growth in the global economy over the rest of the 21st century. The median estimate is an annual reduction in consumption growth by 0.06%, compared with annual growth in consumption of 1.4% to 3%. In other words, the global economy would still grow if climate change was fully addressed, just a bit slower. This would correspond to the global economy achieving the same growth, but just one to two weeks later each year, and dangerous climate change could be avoided.

Of course, there would be some industries in which the costs would be much higher, particularly those heavily dependent on the use of fossil fuels. The transition to a zero-carbon economy will lead to some winners and some losers, and it is not surprising that the potential losers are using their political influence to slow or avoid this possible change.

Should Western Countries bear the burden

TheBestSchools

Assuming for the moment that concerted global governmental intervention is, on balance, required by the situation we are facing, the next problem that arises is the question of fairness or equity.

Some formula must be found for sharing the economic sacrifices that will be required to halt or even roll back atmospheric CO_2 concentration increases. Should the developed countries (North America and Europe), which have produced the lion's share of emissions in the past, bear the brunt of that sacrifice? Or should the countries of the world bear the burden proportionally to their present-day emissions (in which case, China might be penalized as severely as the U.S.)? Or perhaps in proportion to their ability to absorb the economic hit? Or according to some other formula?

What, in your opinion, would be a fair way for the nations of the world to share the economic burden that will be imposed by any serious effort to reduce CO_2 emissions on a global basis?

David Karoly

As I have described above, we need to address the question of fairness or equity of action on climate change not only from an economic perspective, but also from an ethical perspective, a global perspective, and an intergenerational perspective.

Figure 16. Steel making

I take a rational perspective to assessing fairness in the distribution of international action on climate change, which I hope takes into account the ethical and intergenerational perspectives, too. I think that an economic perspective is key to assessing the relative costs of various national policies but is not appropriate for assessing the fairness of actions between different countries. This is because comparing relative costs between different countries requires the use of a common cost unit. However, different currencies with varying exchange rates, different incomes, different living standards, and different levels of economic activity in different countries mean that there is no agreed way to compare long-term costs between different countries, even if they could be quantified in each country.

Once we have decided the ultimate objective for global action on climate change, then we can assess the fairness of distribution of such action between countries and over time. Through the UNFCCC process, all countries have agreed to limit global warming to less than above pre-industrial levels. Given that the long-term level for stabilization of global temperature is directly related to the cumulative emissions of carbon dioxide and other greenhouse gases from human activities since pre-industrial times, scientists have estimated the global budgets of carbon dioxide emissions consistent with global warming as not exceeding 2°C with a range of probabilities. Hence, there is a finite amount of carbon dioxide emissions from human activities that is consistent with avoiding global warming of 2°C or more and avoiding dangerous climate change. For higher confidence of avoiding warming of two degrees, the carbon budget is smaller.

With any finite resource, the fairest way to distribute it to a group of people is to give the same amount to each person. If we are trying to share a chocolate cake at a children's party, each child is given the same-sized slice. If we are trying to allocate shares of greenhouse gas emissions, the fairest way is to give each person the same amount: equal per-person emissions of greenhouse gases. Given that it is cumulative emissions that determine future temperature change, then the best way might be to determine an individual personal cumulative carbon budget, add this up for all the people in a country, and determine each country's total carbon budget. While it is the total emissions from a country that determine that country's contribution to global warming, the equitable way to consider that contribution, allowing for differences in population, is to look at per-person emissions.

Figure 17. Cooking in the third world.

It is much more complicated than this. Total annual emissions of greenhouse gases from human activity were about 49 billion tons of CO_2 or equivalent (CO_2-e) in 2010, which corresponds to about seven tons per person per year. There are very large differences between different countries in terms of their per capita emissions: 26.6 tons CO_2-e per person per year in Australia, 19.7 tons in the USA, 8.5 tons on average across the European Union, 7.6 tons in China, and only 1.9 tons in India.[2] Hence, there are very large differences between different countries in this equitable measure of their contribution to climate change.

Given these very large differences in per-person emissions, the most equitable approach is for all countries to converge to the same per-person emissions as quickly as possible, by 2050 or before, as well as to reduce the total global emissions. There are practical limits to introducing new technologies to reduce emissions, so an international carbon market could be established to allow some countries to buy emission permits and others to sell them. This international carbon market trading in allowed carbon emission permits would be an effective way to share the economic burden associated with rapid and substantial global emission reductions.

The carbon budget approach also demonstrates the importance of rapid emissions reductions and the intergenerational aspects of equitable climate change mitigation. Any delay in reducing national greenhouse gas emissions would mean that the national carbon budget would be used up more quickly, and larger purchases of emission permits would be needed so the budget did not run out. Similarly, the carbon budget demonstrates clearly that continuing to burn fossil fuels now would prevent future generations from having access to the use of fossil fuels, which is clearly not fair.

This is an overly simplistic discussion of a very complex issue. However, it is important that such discussions take place, that ethical and moral perspectives, as well as scientific perspectives, are included, and that any decisions on equitable distribution of emission reductions are not based on equitable sharing of the economic burden alone.

Bullying of skeptics and Free Speech

TheBestSchools

Although we at TheBestSchools.org are inclined to support the call for further research and discussion, we do not have an official “position” on the global warming debate (after all, we are neither climate scientists nor politicians, and so can afford the luxury of indecision).

However, we do most definitely have a position on the subject of freedom of speech. The aspect of the whole debate that troubles us the most is the very widespread notion that no one who questions the consensus can be doing so in good faith — that all critics of the consensus must be dancing to the tune of their paymasters in industry. It has gotten so bad that U.S. Senator Sheldon Whitehouse (D-RI) has recently called for the RICO Act against racketeering to be used to prosecute critics of the consensus!

But, after all, supporters of the consensus have a strong economic interest, as well — most of them are in the pay of some government bureaucracy! So, given this parity of “interests,” it seems to us that both sides ought to put an end to the *ad hominem* attacks and focus instead on the actual evidence and arguments.

How do you feel about preserving scientists’ and others’ right to disagree on the issue of global warming?

David Karoly

I strongly support the freedom of speech of scientists and of all people. However, freedom of speech should not be used as an argument to support the dissemination of misinformation.

Science is a process of repeatedly assessing evidence by subjecting it to the scrutiny of experts. It is not a popularity contest. Opinions need to be considered as just that, opinions, not evidence or facts. Questioning of evidence and critical assessment of scientific understanding is a core principle of science. But this questioning needs to come from informed experts, not untrained people.

There is a conspiracy among all scientists to try to prevent bad science being made public. That is why scientific papers are peer-reviewed before they are published. But peer review is not perfect. Every

peer-reviewed paper in climate science has assumptions and limitations, some have errors, and some are open to misinterpretation. Extensive efforts have been made to assess the peer-reviewed scientific literature and the data on climate change science in the repeated assessments by the IPCC and by the various national Academies. The vast body of evidence from many thousands of peer-reviewed studies supports the consensus conclusions on global warming and these have grown much stronger over the last 25 years, since the first IPCC Assessment Report in 1990.

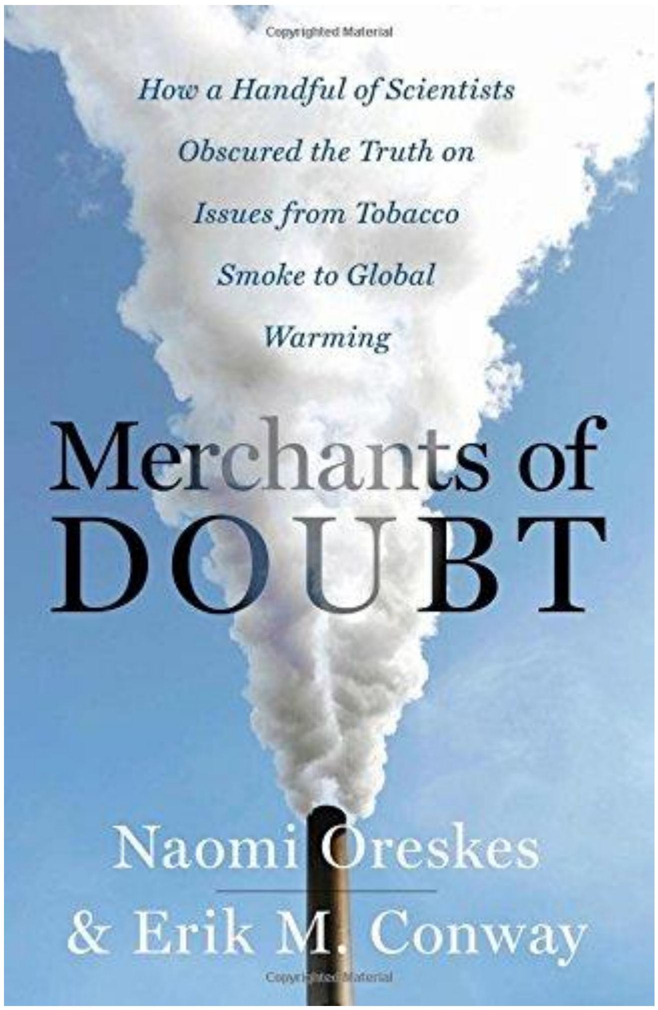

Figure 18. Merchants of Doubt. (Oreskes & Conway, 2010)

Naomi Oreskes and Eric M. Conway, in their book ***Merchants of Doubt*** (Bloomsbury Press, 2010), describe multiple lines of evidence for the coordinated promulgation of scientific misinformation to spread doubt and to slow action to reduce greenhouse gas emissions. These efforts seem to be politically or ideologically motivated.

It is clear that in many jurisdictions, the deliberate spreading of misinformation for financial gain is illegal. Whether the deliberate spreading of misinformation about climate science to support the continued sale of fossil fuels for financial gain is illegal is a question that will need to be determined in the courts.

It is fine for scientists and others to disagree on matters of opinion, but not on matters of the major scientific conclusions in climate science about global warming, which I have described in my answers to the previous questions.

The Balance between Science and Politics

TheBestSchools

There is also the question that is sometimes raised regarding the propriety of scientists' involving themselves to such an extent in political matters in the first place. Many feel that the danger here is twofold:

- Politicians may become lazy and abdicate their responsibility to educate themselves so they can understand the issues themselves.
- Scientists may compromise the integrity of scientific research itself, to the detriment of its proper functioning when controversial matters arise again in the future.

On the other hand, we understand that scientists are citizens and as such have the right — perhaps the duty — to bring their special expertise to bear on matters of great public importance. These competing requirements — as scientists, to remain aloof from politics; as citizens, to become politically engaged — must create a difficult balancing act for conscientious scientists to negotiate, or so it seems to us.

How have you attempted to walk this particular tightrope in your own work?

David Karoly

I think that it is critically important for scientists to communicate the best available scientific evidence and interpretation of that evidence in matters of public interest, not only to scientists but also to the general public, to business and industry, and to government and politicians. Decision-making in all areas should be evidence-based, not based on opinions. Scientific evidence is only one of the many factors that need to be taken into account in decision-making, but it is an important factor when relevant.

I believe that engagement in politics involves standing for election or actively campaigning for one political party. I do not believe that providing advice and information to politicians and all political parties is making science political. I do not believe that publicly pointing out the limitations or advantages, based on scientific evidence, of policy proposals by politicians is being political, as long as it is applied to all political parties.

I have been actively involved in providing evidence and information on climate change science to politicians and to decision-makers in a number of different ways. I was involved in the preparation of the IPCC Assessment Reports released in 2001, in 2007 and in 2014 in a number of different ways, as a Lead Author, as a Coordinating Lead Author and as a Review Editor in different chapters and in different IPCC Working Groups. I have been a member of the Climate Change Authority in Australia since July 2012, which provides advice to the government and to the Australian Parliament on climate change policies. I have made submissions and presented evidence to several Senate Committee

hearings in Australia over the last 20 years and participated in presentations on climate science to parliamentarians in Parliament House, Canberra. I was the Chair of the Premier's Climate Change Reference Group in the State of Victoria in 2008–09. In addition, in a slightly different area, I have been involved in the preparation of the World Meteorological Organization and United Nations Environment Program Scientific Assessments of Ozone Depletion in 2010 and in 2014, first as a Chapter Author and then as a member of the Steering Committee.

Figure 19. Walking the tightrope between Science and Politics.

I think that I have carefully but successfully walked this tightrope to communicate the best available information on climate change science to policy makers. A number of commentators have criticized my engagement in this way, perhaps because they did not want the policy makers to receive the best scientific evidence.

The Strongest and weakest arguments

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Finally, we would like you to tell us — in bulleted list format, if you like — what you consider to be the five strongest arguments in favor of the consensus view, as well as the five weakest arguments that critics commonly advance against the consensus view.

David Karoly

Strongest arguments from climate scientists:

- The observed increases in greenhouse gases in the atmosphere are primarily due to human activity, burning fossil fuels, other industrial activity, deforestation, and land clearing.
- The observed large-scale increase in surface temperature across the globe since the mid-twentieth century is primarily due to human activity, the increase of greenhouse gases in the atmosphere, and other human impacts on the climate system.
- There will continue to be significant global warming over the twenty-first century, with its magnitude depending on the emissions of greenhouse gases from human activity.
- There are substantial adverse impacts on human and natural systems from global warming.

- Rapid, substantial, and sustained reductions in greenhouse gas emissions from human activities are needed to slow global warming and stabilize global temperature at a level that would avoid dangerous human influence on the climate system.

Weakest arguments from critics:

- Observed warming of the climate system over the last century is due to natural variability, including solar variations and recovery from the last ice age, and is not due to human-caused increases in greenhouse gases in the atmosphere.
- Observed increases in greenhouse gases are due to natural variability in natural sources.
- Even if the carbon dioxide increases are due to human activity, increases in carbon dioxide are good for plants and for agriculture.
- Even if the increases of greenhouse gases in the atmosphere cause some global warming, this warming will be mainly beneficial.
- Even if there are some adverse impacts from human-caused global warming, it will cost too much to reduce greenhouse gas emissions and it will be cheaper for modern society to adapt to the impacts of climate change rather than to reduce emissions from burning fossil fuels.

TheBestSchools

Thank you very much for your time — and your frankness and courage — in sharing your views on global warming with our readers.

We look forward to reading the upcoming Focused Civil Dialogue between you and Professor Happer very soon.

Notes

1. Theodore Roosevelt, T. A ***Book-Lover's Holidays in the Open*** (Charles Scribner's Sons, 1916); pp. 300–301.

2. ***Australia's Climate Policy Options, Special Review, Second Draft Report*** (PDF) (Commonwealth of Australia Climate Change Authority. November 2015).

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