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Article

The Nature of Science and the Public Debate over Anthropogenic Global Warming

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Misconceptions about the nature of science, and a lack of understanding of how the scientific community evaluates evidence and reaches consensus, distorts the public evaluation of anthropogenic global warming.

There are several popular misconceptions about the nature of science that underlie the resistance of much of the public to climate change science. These misconceptions also underlie the public response to other conclusions of the scientific community, such as biological evolution.[1] Common misconceptions include the following: (1) an emphasis on "facts" and a demand for "proof"; (2) a view of theories that equates them with unsubstantiated guesses; (3) a strong discomfort with uncertainty and unresolved questions; (4) a failure to recognize the importance of scale and context in recognizing trends and formulating explanations; and (5) a rejection of scientific consensus because it is perceived as politically or philosophically motivated. It is critical that these problems be explicitly addressed when communicating climate science. Otherwise, the public debate will be framed not by the evidence, but by faulty views of science itself.

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Fact and Theory in Science

A common public misconception is that science is a search for unchanging scientific "facts." However, if "fact" means an objective statement of the true nature of the physical universe, there are very few "facts" in science. The closest thing to "facts" in science are the observations upon which our understanding of the natural world is built. However, our observations are themselves subject to bias and error. More importantly, our observations are always limited. Our descriptions cannot be exhaustive—we must choose what to observe. Observations are driven by the questions being asked, and are made in a particular context. They are also dependent on expectations and the available tools. The limits of individual observation explain why science demands repeated and independent confirmation of observational results (whether direct or experimental). This also explains why the diversity of the scientific community—across disciplines, cultures, and worldviews—is critical to its success.

Science is not the encyclopedic accumulation of "facts." Observations (data) by themselves have little meaning or utility. Meaning and explanation require the recognition of the consistent patterns in our observations. We can understand our natural world only to the extent that it behaves in regular, predictable ways. Much of the doing of science involves discovering these patterns. It is these regularities in the natural world that suggest underlying consistent causes, and constructing causal explanations for patterns of observations is generating a scientific theory.

Scientists and nonscientists typically use the word "theory" in very different ways and in different contexts. In common parlance, "theory" often means an unsubstantiated guess. However, scientific "theories" are not guesses, but are natural cause-and-effect explanations for the regularities we observe in the natural world around us. Theories integrate diverse independent observations by recognizing patterns and trends within the data that give those observations meaning. The construction of theories is the essence of science, and its power as a methodology.[2]

A prominent source cited by climate skeptics illustrates the misconstrued role of observations and theories in science. *The Skeptics Handbook* states:

> [Computer models are] sophisticated, put together by experts, and getting better all the time. But even if they could predict the climate correctly (they can't), even if they were based on solid proven theories (they aren't), they still wouldn't count as evidence. Models of complex systems are based on scores of assumptions and estimates piled on dozens of theories.
>
> …
>
> Science depends on observations, made by people at some time and place. Things you can see, hold, hear, and record.[3]

Notice that theories and models are not perceived as providing a basis for supporting, or refuting, our current understanding of climate processes. Only "observations" seem to qualify as evidence. But this ignores the fact that observations in isolation are without meaning. The denigrated "theories" and "models" are simply the expression of the patterns that are seen in the observational data, combined with our current understanding of physical processes. Theories are the only way to understand the observations, and they provide the basis for prediction and testing. It is the ability of theories to predict future observations that makes them such powerful tools. Testing our theoretical understanding against new observations is also the only way to find errors and advance our knowledge of the natural world. Theories extend our reach beyond what is currently known and generate expectations for future discoveries. They are how we gain new insights into nature. Without theories, we have nothing.

It is also significant that the quote above stresses that the theories are not "proven." This again fails to understand the nature of explanatory theories. Even the most powerful and unquestioned theories are not "proven" in any absolute sense. Theories are held with varying degrees of confidence based on their explanatory and predictive power. The common demand for proof is related to a failure to understand the role of uncertainty in science.

Misunderstanding Uncertainty

There are several different types of uncertainty in science. There is the uncertainty that results just from the limits of precision with which we are capable of measuring things. This is expressed in terms of significant figures or ranges of error in numerical values. Then there is the uncertainty that results from inherently random (or stochastic) processes that are described in terms of probability. One of the common misconceptions of random processes is that they are haphazard and without any coherent pattern. However, as with the flipping of a coin, or the rolling of dice, the behavior of a system can be predicted quite accurately after many trials even when the outcome of an individual event cannot be predicted. Lastly, there is the uncertainty that results from the inherently incomplete understanding of physical reality that is present in any theory. Because our knowledge is always incomplete, scientific theories will always be accompanied by some degree of uncertainty. This means that conclusions in science are always held tentatively.

A problem in communicating the conclusions of science is that many people are very uncomfortable with uncertainty. The language of science, with talk of probabilities and likelihoods, conflicts with the desire for confident assurance and certainty. Furthermore, when scientific conclusions require fundamental shifts in previous views or imply a costly response, people typically demand a level of certainty, or "proof," that science cannot provide.

Certain scientific theories are widely held, not because they are "proven," but because they are able to provide testable explanations for a wide range of observations. They bring many seemingly unrelated observations under a unified explanatory umbrella. It is the weight of the total body of available evidence, not the agreement of every individual observation, that causes a theory to be accepted or rejected. Scientific consensus (though never unanimity) can only be obtained when the available evidence overwhelmingly supports a particular interpretation.

The following statement from *A Cool Look at Global Warming* argues for a rejection of action to reduce CO_2 emissions because of a perceived possibility of error in the scientific conclusions.

> The earth's atmosphere may be warming, but if so, not by much and not in an alarming or unprecedented way. It is possible that the warming has a "significant human influence," to use the IPCC's term, and I do not dismiss the possibility. But there are other powerful possible causes that have nothing to do with us. If this were simply an example of scientists arguing among themselves we might recognize that this is how science proceeds, and move on. But if there is no true causal link between CO_2 and rising temperatures, then all the talk about carbon caps and carbon trading is simply futile. But it is worse than futile, because one consequence of developing policies in this area will be to reduce not only our own standard of living but the standard of living of the world's poorest countries.[4]

Contrary to the doubts expressed above, there is a demonstrable causal link between increasing CO_2 and increased surface temperatures. However, there is uncertainty in the rate and magnitude of the temperature rise, and its regional and global effects. The quotation above is really reacting to two kinds of uncertainty in climate science. One is the uncertainty that results from our incomplete knowledge of all relevant climate feedbacks, and the other results from the inherent randomness of the atmospheric system that requires forecasts to be made in terms of probability. The latter uncertainty would still be present even if we had complete knowledge of all of the relevant physics.

The argument made above is that if a scientific theory cannot be proven (or if it cannot predict certain outcomes with certainty), then it is unwise to act on its implications. This not only fails to recognize that no theory in science is absolute, but also that every one of us regularly makes decisions in the absence of certainty. In fact, we regularly make life-and-death decisions in the absence of certainty. The emphasis should not be on waiting for the scientific community to reach some unattainable standard of proof, but to act on the best current understanding of the available evidence. Also, it must be recognized that to fail to act is itself an action with potential consequences. We are acting on incomplete knowledge regardless.

Importance of Scale and Context

Any processes will act only within a particular range of time scales. Thus, any observed trend can only be understood by reference to the processes that are important on time scale represented by the trend. The importance of a time scale can be illustrated by reference to a familiar set of data—the stock market. Trends in stock market prices can be analyzed over a range of time scales from a single day to weeks, months, and years. The observed trends in the data would have different explanations at different time scales. Different market forces act at different time scales. The explanation for a trend on one time scale is unlikely to be applicable at another. Processes of the earth/climate system similarly act over different time scales.

The recognized patterns and trends in observations that undergird scientific theories are nearly always scale dependent. Trends can be recognized and understood only in the context of a particular temporal and spatial scale. The causal agents involved at different temporal and spatial scales will almost always be different—at least in importance if not in kind. It is thus critical that the scales being discussed be made explicit. Public discussions of both evolution and climate change are often made without any reference to the relevant scale. In the case of climate change, this often expresses itself in the confusion of human and geological time scales.

Some of the major drivers of climate change, and important feedback mechanisms, are listed in table 1.

The time scales over which these driving and feedback mechanisms act are also shown. What is critical for the current discussion is that the plausible mechanisms for climate change vary with the time scales under consideration. The discussion of potential causes for climate change must always be undertaken within the context of a particular temporal scale.

The misapplication and misunderstanding of the role of scale is common in the public discussion of climate change. A few years back there was very frequent mention that there had been no global warming for a decade, or even that global average temperatures had declined. A typical example of such a claim is quoted below:

> Global-warming activists insist that we can't take an assumption from a single year. However, if the CWS forecast turns out to be correct, we will have gone *eleven* years without any warming at all—eleven years in which carbon emissions did not decline in any significant manner. How does one begin to explain that? And how will Kerry and Boxer and the rest of their Democratic colleagues try to sell cap-and-trade as a scientific necessity while people spend a fortune heating their homes in the coldest winter in a decade?[5]

The decade-long interval mentioned above is part of a century-long trend of increasing global temperatures. The long-term trend is a consequence of a multitude of driving forces and feedback processes, each acting at different time scales. Any multidecadal trend is going to be "noisy." Short-term trends will not necessarily reflect long-term ones. Furthermore, the years in question represent a time of declining solar irradiance occurring as part of a cyclical change in solar activity. Despite low solar irradiance, nine of those eleven years were still among the ten warmest years in the modern instrumental record up to that time (see fig. 1). That long-term trend has continued in subsequent years with nine of the ten warmest years occurring since 2001.[6]

	Solar Radiation	**Plate Tectonics**	**Ocean Circulation**	**Atmospheric Composition**	**Albedo**	**Anthropogenic Causes**
Billions of Years	Increase in solar radiation during lifetime of Sun.			Oxidation of the oceans and atmosphere.		
Tens to Hundreds of Millions of Years		Change in continental positions.	Changing shape and connections of ocean basins.			
Millions to Tens of Millions of Years		Change in continental positions and uplift of mountains.	Changing shape and connections of ocean basins. Disruption of thermohaline circulation, and ocean stratification.	Carbon storage in organic deposits (e.g., coal, shale) and in limestones. Removal of CO_2 during accelerated rates of chemical weathering.		
Tens to Hundreds of Thousands of Years	Milankovitch orbital variations in intensity and seasonal distribution of solar radiation.		Disruption of thermohaline circulation and ocean stratification.	Generation of CO_2 during formation of major volcanic provinces. Absorption and release of CO_2 from ocean. Terrestrial and ocean sediment carbon storage and release.	Growth and retreat of large continental ice sheets.	
Tens to Hundreds of Years			Large freshwater outflows into North Atlantic. Rapid disintegration of ice shelves (Heinrich events).	Melting of permafrost and ocean floor methane ices.	Change in seasonal extent of sea ice.	Release of CO_2 from burning of stored carbon ("fossil fuels") and deforestation.
Years	Sun spot cycles		El Nino and La Nina oscillations. North Atlantic oscillation.	Individual volcanic eruptions (release of H_2S or CO_2).		

Table 1. This table summarizes some of the major forcing and feedback mechanisms that determine global climate. These mechanisms act to cause changes in the global climate at different time scales. The columns of the table group climate mechanisms by type, and the rows represent the different temporal scales over which the mechanisms act, from years to billions of years.

The quote above also mentions the unusually cold winter of 2009–2010. Aside from the error of using single data points to refute a long-term trend, there is also the problem of spatial scale. Those cold winter temperatures occurred in North America, northern Europe, and central Asia. However, at the same time, the arctic was well above average in temperature, and much of the rest of the world was warm as well. Despite the regional cold during the northern hemisphere winter, 2010 was globally the warmest year in the instrumental record according to the Goddard Institute for Space Studies. Particular extreme weather events, or records, are much more likely to be noticed and remembered than long-term trends.[7]

The tendency to emphasize individual data points at the expense of long-term trends is also illustrated in the quotation below:

> On a global basis, world sea ice in April 2008 reached levels that were "unprecedented" for the month of April in over 25 years. Levels are the third highest (for April) since the commencement of records in 1979, exceeded only by levels in 1979 and 1982. This continues a pattern established earlier in 2008, as global sea ice in March 2008 was also the third highest March on record, while January 2008 sea ice was the second highest January on record. It was also the second highest single month in the past 20 years (second only to Sept 1996).[8]

Citing of such single-month "records" seems to assume that for anthropogenic global warming to be true, all climate-related observations must proceed according to invariant trends. Thus any deviation from a consistent trend is viewed as evidence against global warming. But because the global climate at any point in time is the result of many processes acting over a wide range of temporal and spatial scales, trends will always be statistical patterns averaged over many years. The actual global ice extent data (including both Arctic and Antarctic sea ice) that was the basis of the quotation above is shown in figure 2. In the Arctic, where sea ice loss has been most dramatic, maximum sea ice extent in 2008 did not even approach the long-term 1972–2008 average. Figure 3 shows the long-term trend in Arctic sea ice extent since the 1950s.

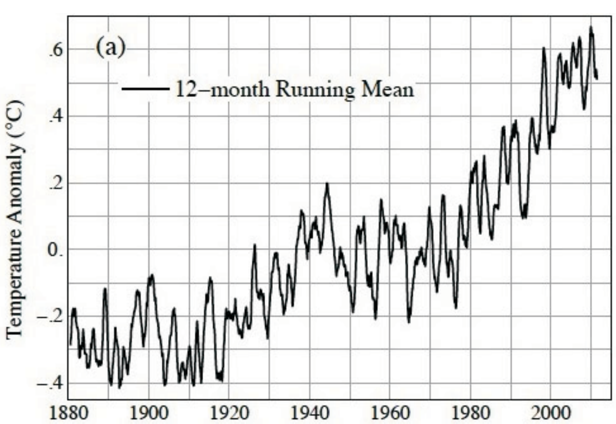

Figure 1. Global surface temperature anomalies over 120 years using data from four different sources. Image credit: Robert Simmon, NASA Earth Observatory. ("Despite subtle differences, global temperature records in close agreement," posted January 13, 2011, http://www.giss.nasa.gov/research/news/20110113/).

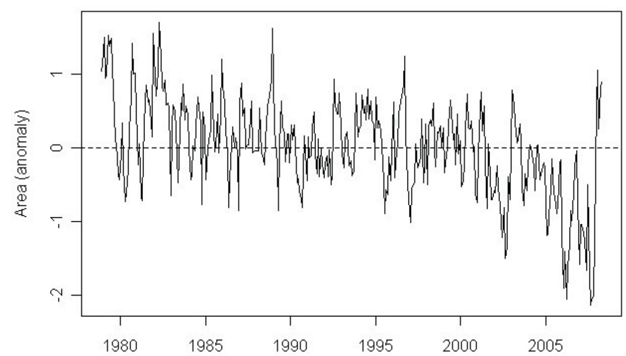

Figure 2. Global ice extent including both Arctic and Antarctic sea ice. (Steve McIntyre, "Southern Hemisphere Sea Ice Reaches 'Unprecedented' Levels" [May 4, 2008], http://climateaudit.org/2008/05/04/world-sea-ice-reaches-levels-unprecedented-in-25-years/).

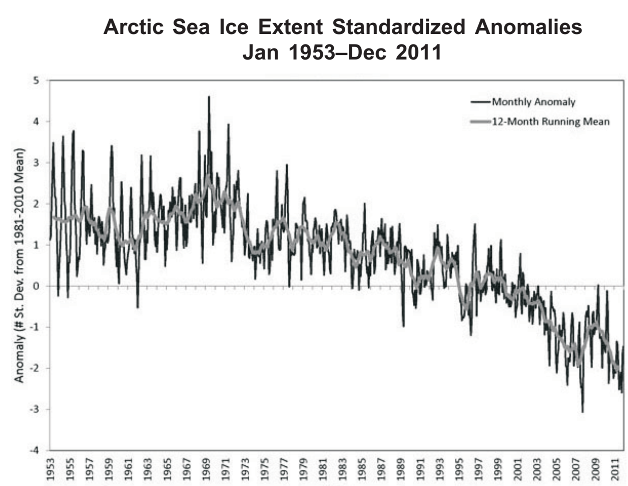

Figure 3. Arctic sea ice extent showing monthly anomalies and yearly running means. Reproduced from the National Snow and Ice Data Center. Image by Walt Meier and Julienne Stroeve, National Snow and Ice Data Center, University of Colorado, Boulder. (http://nsidc.org/cryosphere/sotc/sea_ice.html).

Not only must temporal scales be kept in mind, but also spatial scales. Regional or local events may not follow global trends. In fact, as we have seen with the example of the cold North American winter of 2009–2010, global climate change does not mean globally uniform or invariable change. Nonetheless, people often cite specific local changes as overturning long-term global trends. As an example,

> Glaciers are growing in the Himalayan Mountains, confounding global warming alarmists who have recently claimed the glaciers were shrinking and that global warming was to blame. A new study of the Karakoram, Hindu Kush, and Western Himalaya mountain ranges by researchers at England's Newcastle University shows consistent recent growth among the region's glaciers.[9]

Determining the behavior of mountain glaciers is very difficult without direct observation and mass balance calculations (determining the difference between snow accumulation and snow/ice melt). Such work has been done for many glaciers in North America, Europe, and the former Soviet Union. Analysis of this mass balance data shows that the global trend for mountain glaciers is one of accelerated ice loss despite increases in annual snow accumulation.[10] Figure 4 shows average annual glacial thickness changes from this data. In the Himalayas, where mass balance data is largely not available, most reports on glacier fluctuations are based on satellite- and ground-based observations of terminus location. On the basis of current data, there are some glaciers in the Himalayas that appear to be advancing, but most are retreating.[11] Whatever the final conclusions for the Himalayan region, all glaciers would not be expected to behave the same way given the many local and regional factors that can control snow accumulation and melt rates. Again, it is the global average patterns that are significant.

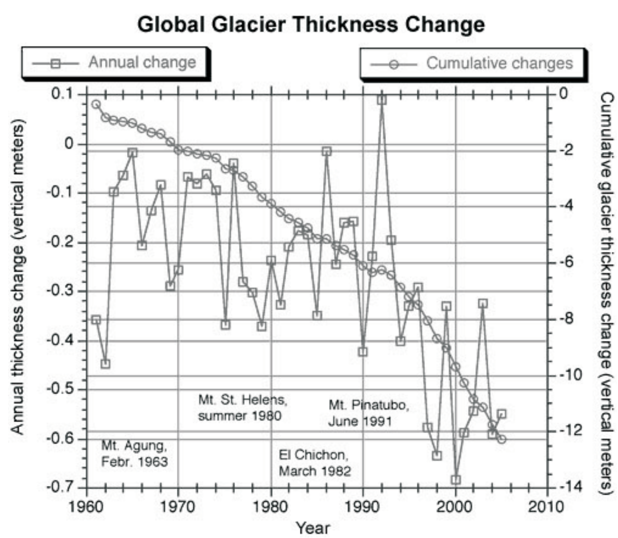

Figure 4. Average annual and cumulative change in glacier thickness for the period 1961–2005. Based on mass balance data from subpolar and mountain glaciers primarily from Europe, North America and the former Soviet Union. Graph reproduced from the National Snow and Ice Data Center. Image courtesy of Mark Dyurgerov, Institute of Arctic and Alpine Research, University of Colorado, Boulder (http://nsidc.org/sotc/glacier_balance.html).

Even beyond the issue of scale is one of appropriate context. The question of the likely extent of anthropogenic climate change, and the debate over appropriate societal responses, must be addressed within the context of our modern industrialized society. The following statement attempts to consider future global warming completely divorced from consideration of its impact on modern societies—in fact, divorced from the consideration of the existence of humanity at all.

> Atmospheric carbon dioxide is at higher levels than at any time in the past 650,000 years. Yes, but if we go back 500 million years, carbon levels were not just 10–20 percent higher, they were 10–20 *times* higher. The earth has thoroughly tested the runaway greenhouse effect, and *nothing* happened.[12]

This argument is surprisingly quite common. The general point seems to be that global temperatures (and CO_2 levels) have been much higher in the geologic past, and therefore modern climate change need not be viewed as extraordinary, or of special concern. The earth has indeed been much warmer than today at several periods during its past history. There have been times in the geologic past when no permanent glacial ice was present at the poles, and forests extended above the Arctic and Antarctic circles. However, the world at these times was also inhabited by very different plants and animals adapted to these very different climatic and environmental conditions. The warming now occurring is taking place during one of the coolest periods in earth history, when our ecosystems and human societies have been adapted to a cooler global climate. Modern climate change must be considered in the context of the current climate sensitivities of Earth's biota and the potential impacts on human society (including agricultural production, water availability, frequency of extreme events, etc.).

Also ignored, when citing climates of the geological past, is that the rate at which climate changes is critically important. When climate changes faster than terrestrial and marine organisms can respond, it can result in major disruption to the world's ecosystems and widespread species extinction. The greatest extinction in Earth history occurred at the end of the Permian Period, when up to 95% of known fossil marine species and 70% of terrestrial vertebrate species became extinct. There is now strong evidence that this extinction was at least in part the consequence of a runaway greenhouse effect initiated by the extensive release of CO_2 from the eruption of enormous lava flows in Siberia.[13] The resulting warming was likely amplified by decreased albedo from melting polar ice, and the release of methane from thawing permafrost and the melting of methane ices from warming ocean bottom waters. The impact of this runaway greenhouse effect contributed to one of the greatest reorganizations of life on Earth. Far from providing reassurance in the face of modern climate change, the earth's climatic history provides a very sobering cautionary tale.

Claims about the extent, causes, and consequences of climate change must always be understood and evaluated within the proper context. Climate change is not about particular weather events or regional observations, but it is a summary of long-term global trends that extend over decades and centuries. In responding to the evidence of climate change, we must also think in terms of future decades and centuries. Our decisions now will have long-term consequences for our children and grandchildren.

Rejection of Scientific Consensus

Developing a scientific consensus over a set of questions is a major goal of the scientific community. The reason is that when agreement is achieved on a particular issue, it enables science to move on to new questions and thus advance our understanding. Much of the doing of science is the applying of accepted theories to new problems and new observations.

Because the scientific community is very diverse, consensus conclusions carry a lot of weight. Consensus views, while never unanimous, represent the conclusions of scientists based on the overwhelming congruence of evidence from multiple independent sources. Such consensus conclusions are not easily obtained, and they are also not easily overturned—and they should not be. Science is inherently conservative and resistant to change. Otherwise, there would be no theoretically stable foundation from which to work. Thus, when a new consensus is reached, it represents the result of the accumulation of a very large and persuasive body of evidence.

In contrast with consensus as understood by the scientific community, the public often has a very different perspective. Because of the lack of understanding of uncertainty in science, an overwhelming consensus of the scientific community may be rejected because of the critical arguments of a few individuals. When scientific conclusions are perceived as absolute statements, an entire theoretical framework may be seen as being overturned by a single contrary observation or critical study. The existence of uncertainty may also result in the public perceiving all views as equally valid since no theory is "proven." This is complicated by the tendency of the media to present "both sides" of an issue, elevating the level of perceived uncertainty and disagreement present. The result is that acceptance of a particular view is viewed simply as an appeal to authority. Theories come to be seen as philosophically or politically motivated, rather than based on evidence.

The scientific conclusion that the earth's global average temperature has been rising over the past century and that much of this increase can be attributed to human activities (primarily the burning of fossil fuels) is a well-established consensus of the scientific community. The reports of the Intergovernmental Panel on Climate Change (IPCC) are an expression of this consensus.[14] The IPCC reports represent summaries of the very large and growing body of published research on climate change. The IPCC has a very detailed and thorough process established for the preparation and review of its reports.[15] The first drafts of the various chapters are written by an international group of experts who summarize the peer-reviewed and internationally available literature. For the 2007 Synthesis Report, the core writing team included forty authors representing twenty-four countries. The draft of the 2007 Synthesis Report was sent out for review to over 2,400 individual experts, in addition to the 193 member governments of the IPCC.[16] These reports are extraordinary consensus statements of the climate science community. They are also inherently conservative reports because all those involved have to agree to the conclusions. As a result, this process eliminates the more extreme views. In many cases, past IPCC reports have underestimated subsequent climate change effects.

In addition to the IPCC, there are a large number of scientific, government, and corporate organizations that have made formal statements and reports on climate change. These include the American Association for the Advancement of Science (AAAS), the National Academy of Sciences (NAS), the Geological Society of America (GSA), the American Meteorological Society, the National Oceanic and Atmospheric Administration (NOAA), the US Global Change Research Program, the National Intelligence Assessment, and the US Climate Action Partnership (a coalition of major US Corporations).[17]

Despite the overwhelming consensus on global warming, it is still common to see reference to one or more dissenting arguments as sufficient to overturn that consensus. Joanne Nova's *Skeptics Handbook* has several statements that illustrate this low view of consensus:

> No matter how qualified, how green, or how dedicated, their names and opinions prove nothing about carbon because *"argument by authority"* never can … The IPCC is an international committee, it's not evidence. Argument by authority is not proof of anything except that a committee paid to find a particular result can produce a long document … It only takes *one* scientist to prove a theory is wrong.[18] (Author's emphasis)

It is interesting that the consensus reports of the IPCC are viewed as arguments by authority when they are simply summaries of the peer-reviewed literature. The denigration of the process of peer review is a common approach of those who reject consensus. But it is also a rejection of the entire scientific enterprise which relies on the independent testing and confirmation of interpretations to make progress in understanding our natural world. Scientific consensus is not based on the opinion of a perceived authority, but on the repeated successful testing and confirmation of the argument itself.

Consensus is also often rejected because of a perception that the majority is driven by social, political, or religious motives. In our current media-saturated world, advocacy for causes has become increasingly separated from a concern for accuracy or faithfulness to the facts. It is therefore assumed by many that all advocacy, regardless of its source, is based on manipulation and distortion.[19] Uncomfortable scientific conclusions are dismissed as attempts to advance a hidden agenda. This is seen in the charges of materialism and atheism leveled at evolutionary biologists by those who see evolution as in conflict with the Bible. Charges against the climate science community are often that they are driven by a particular social or political agenda. At the 2009 International Conference on Climate Change, a gathering of global warming skeptics, John Sununu stated:

> This is a very significant event because it will give focus to the false underpinnings of the current international "rush to judgment" and the calls for implementation of drastic policies to deal with this rashly proclaimed "crisis." My message today is to make sure we recognize that no matter how effectively we deal with exposing the errors and games behind that agenda, we need to know the battle will never end, because it's not really about global warming. The global warming crisis is just the latest surrogate for an over-arching agenda of anti-growth and anti-development.[20]

A consensus view of the scientific community is not guaranteed to be correct, but it cannot be easily dismissed. The scientific community is a very diverse one, including individuals from many different cultures and holding a wide range of religious, philosophical, political, and economic views. This diversity provides an important check on personal bias, and on political or social agendas trumping good science.

Conclusions

In the public discussion of important scientific issues, we must be attentive to the role of misconceptions about the nature of scientific explanation in determining people's views. When we fail to address how science works, we will only perpetuate popular misconceptions.

The scientific case for a particular conclusion must be made in terms of its power to explain patterns and trends in observations. The recognition of patterns and their interpretation through the construction of theories is the only path to a scientific understanding of climate change, or of any natural process. Furthermore, the interpretation of patterns and trends must always be done within the context of particular scales of time and space. Explanations must be scale-specific because the underlying causal processes act at particular scales. This is extremely important when evaluating claims concerning climate change.

Uncertainty is a given within science. Science never provides absolute proof but rather relative degrees of confidence. Overwhelming observational support for a particular scientific explanation is expressed by a consensus of the scientific community. This is not an appeal to authority, but rather to replicated independent observation. Anthropogenic global warming is one such consensus conclusion. Such conclusions need to be treated with great respect, and they provide the most reasonable basis upon which to base decisions and actions. To proceed otherwise is to ignore the very nature of scientific investigation itself. ✭

Acknowledgments

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Notes

1. Keith B. Miller, "Countering Public Misconceptions about the Nature of Evolutionary Science," *Georgia Journal of Science* 63 (2005): 175–89.
2. Keith B. Miller, "The Similarity of Theory Testing in the Historical and 'Hard' Sciences," *Perspectives on Science and Christian Faith* 54, no. 2 (2002): 119–22.
3. Joanne Nova, *The Skeptics Handbook* (2009). Copies of the booklet can be obtained online, http://joannenova.com.au/global-warming/.
4. Don Aitkin, "A Cool Look at Global Warming," a presentation made to the Planning Institute of Australia at Canberra on April 2, 2008, http://onlineopinion.com.au/documents/articles/A_Cool_Look_5-4-08.pdf.
5. Ed Morrissey, "Coldest Winter in a Decade Coming?" (September 29, 2009), http://hotair.com/archives/2009/09/29/coldest-winter-in-a-decade-coming/.
6. James Hansen, Reto Ruedy, Makiko Sato, and Ken Lo, "Global Temperature in 2011, Trends and Prospects" (January 18, 2012). NASA Goddard Institute for Space Studies, http://data.giss.nasa.gov/gistemp/2011/.
7. The confusion of weather events and climate change, and of local and global observations, is discussed in the book by Katharine Hayhoe and Andrew Farley, *A Climate for Change: Global Warming Facts for Faith-Based Decisions* (New York: Faith Words, 2009).
8. Steve McIntyre, "Southern Hemisphere Sea Ice Reaches 'Unprecedented' Levels" (May 4, 2008), http://climateaudit.org/2008/05/04/world-sea-ice-reaches-levels-unprecedented-in-25-years/.
9. James M. Taylor, "Himalayan Glaciers Are Growing … and Confounding Global Warming Alarmists" (November 1, 2006), http://www.heartland.org/policybot/results/20073/Himalayan_Glaciers_Are_Growing_and_Confounding_Global _Warming_Alarmists.html.
10. The most complete data set for subpolar mountain glaciers is Mark Dyurgerov, "Glacier Mass Balance and Regime: Data of Measurements and Analysis," *INSTAAR Occasional Paper No. 55*, ed. M. Meier and R. Armstrong (Boulder, CO: Institute of Arctic and Alpine Research, University of Colorado, 2002). Distributed by National Snow and Ice Data Center, Boulder, CO, http://nsidc.org/data/docs/daac/nsidc0109_instaar.gd.html.
11. A new long-term study of over 7,000 glaciers of the Tibetan Plateau is the most comprehensive ever and documents glacial retreat and mass loss for glaciers over much of the Himalayas. See Tandong Yao et al., "Different Glacier Status with Atmospheric Circulations in Tibetan Plateau and Surroundings," *Nature Climate Change* 2 (September 2012): 663–7.
12. Nova, *The Skeptics Handbook*.
13. Peter D. Ward, *Under a Green Sky* (Washington, DC: Smithsonian Books, 2007); Michael J. Benton and Richard J. Twitchett, "How to Kill (Almost) All Life: The End-Permian Extinction Event," *TRENDS in Ecology and Evolution* 18, no. 7 (2003): 358–65; D. H. Erwin, *The Great Paleozoic Crisis: Life and Death in the Permian* (New York: Columbia University Press, 1993).
14. The IPCC reports can be downloaded at http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml.
15. "Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports," Appendix A to the Principles Governing IPCC (Intergovernmental Panel on Climate Change) Work, 28 pages. Adopted at the Fifteenth Session (San Jose, 15–18 April 1999, and amended most recently at the Thirty-Fifth Session (Geneva,

6–9 June 2012). Available online at http://www.ipcc.ch/pdf/ipcc-principles/ipcc-principles-appendix-a-final.pdf.

[16]See the Appendix in IPCC, 2007: Core Writing Team, R. K. Pachauri and A. Reisinger, eds., *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland: IPCC, 2007), 104 pp.

[17]A source that discusses some of these statements in a lighthearted but effective way is Greg Craven, *What's the Worst That Could Happen? A Rational Response to the Climate Change Debate* (New York: Penguin Group, 2009). For the 2010 NOAA climate report, see J. Blunden, D. S. Arndt, and M. O. Baringer, eds., "State of the Climate in 2010," *Bulletin of the American Meteorological Society* 92, no. 6 (2011): S1–S266. The Geological Society of America Position Statement on Climate Change (adopted October 2006, revised April 2010) can be found at http://www.geosociety.org/positions/.

[18]Nova, *The Skeptics Handbook* (author's emphasis).

[19]A very interesting article by Todd Leopold discusses this loss of connection between advocacy and accuracy. Todd Leopold, "Seeking the Truth in an 'American' Controversy" (March 21, 2012), http://articles.cnn.com/2012-03-21/us/us_american-truth-daisey_1_daisey-storyteller-fiction?_s=PM:US.

[20]John H. Sununu, "The Politics of Global Warming." Remarks delivered at the 2009 International Conference on Climate Change sponsored by the Heartland Institute. http://www.heartland.org/full/24851/The_Politics_of_Global_Warming.html.

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