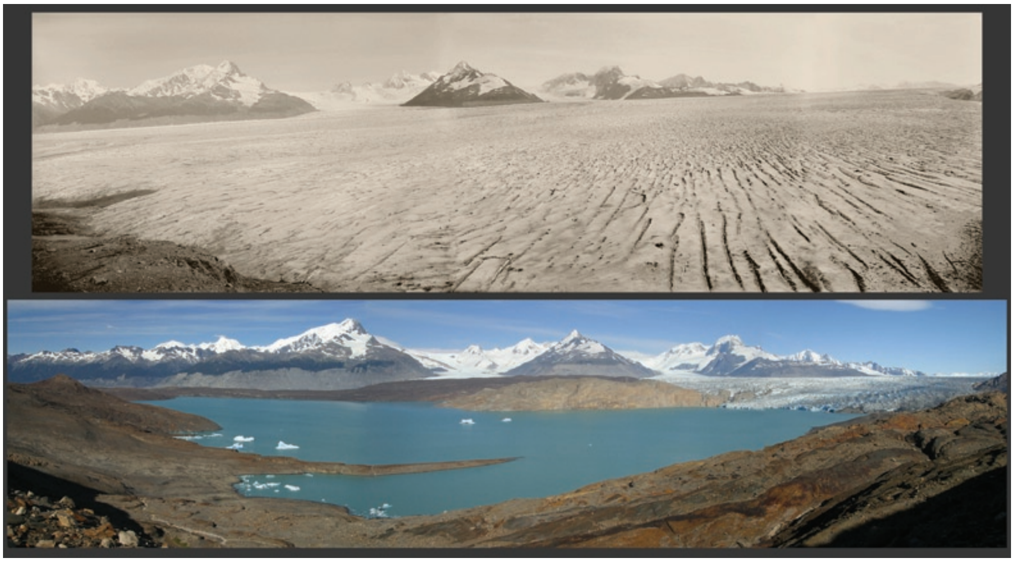
Climate Models and Their Critics

by Alan S. Brown

Models used to predict climate change have powerful strengths and significant flaws. Yet all too often, the focus is on the politics of climate change rather than the science.



The Upsala Glacier in Patagonia, Argentina, is shown on top in 1928 (©Archivo Museo Salesiano) and below in 2004 (©Daniel Beltra/Greenpeace).

It is getting more and more difficult to have a public conversation about global climate change.

The vast majority of climate scientists believes human-made greenhouse gases, especially carbon dioxide from combustion, are increasing global temperatures and destabilizing the climate (page 23). The view is backed by the world's leading research agencies, including America's National Academy of Sciences, and seconded by scientific organizations as diverse as the American Association for the Advancement of Science (AAAS), American Geophysical Union, and the American Statistical Association.

Yet climatology is a young science. Its practitioners rarely work in laboratories. They must rely on highly variable field measurements and complex mathematical models that have very visible limitations.

Arrayed against them are a smaller number of scientists and engineers. Only some have degrees in climate-related sciences. They charge that governments and climate activists have a pro-global warming agenda that stifles true scientific debate and that climate data and models are flawed.

Many of these so-called *skeptics* have a clear agenda. They seem bent on denying climate change at any cost. Few do original research or publish in peer-reviewed climate journals (some submit articles to *friendly* journals in unrelated fields). Nor do they propose research to resolve the contradictions they claim to find, a common practice among the climate scientists whom they also claim lack skepticism. It is a recipe for controversy. And on the Internet, these scientific debates take on a life of their own.

Hockey Sticks

Take, for example, the flare-up over the "hockey stick" graph that appeared in the 2001 report of the Intergovernmental Panel on Climate Change (IPCC), a multinational scientific body that reviews climate research. The graph showed a relatively narrow range of temperatures until 100 years ago, when it suddenly arced upward like the blade of a hockey stick.

The graph was part of a pioneering effort by Dr. Michael E. Mann, now an associate professor at Pennsylvania State University, to reconstruct past temperatures from tree ring, coral, ice core, and other data. His graph suggested that temperatures were soaring out of control because of human activities. Or did it?

"Two things about that graph were striking," recalled Dr. Andrew R. Solow, director of the marine policy center at Woods Hole Oceanographic Institute in Woods Hole, MA. "First, the variability of temperatures before the recent period were much more stable than most people believe. The graph failed to show the Medieval Warm Period or the cooler Little Ice Age that started around 1500."

"Second, Mann claimed that 1998 was the warmest year in the past 1,000 years. You can have lots of variability from year to year, with some warming years even in a period of cooling, so it's hard to make a statement like that," Solow said.

The graph drew the attention of Stephen McIntyre, a retired mining executive, and Dr. Ross R. McKitrick, a professor of environmental economics at Canada's University of Guelph. They charged that Mann's statistical treatment made recent global warming seem explosive when it was really *unexceptional* when compared with variations in the historical record.

The charges focused on Mann's statistical approach. Over the next few years, McIntyre and McKitrick showed that they could use Mann's methodology to produce hockey stick graphs from random data. Mann's defenders argued that McKitrick's approach was equally flawed, eliminating critical data and showing warming rather than cooling during the Little Ice Age.

Ordinarily, this type of argument is fought out in scholarly symposia and the back pages of academic journals. Instead, the debate leapt into the public arena.

Mann's team defended its approach. Some of his critics did not even bother with the statistics. Instead, they attacked Mann's defenders, claiming they were former students and collaborators rather than outside experts. They claimed Mann had a hidden agenda to dramatize global warming. (Of course, some critics also had an agenda.) Bloggers used the controversy to *prove* that human-driven global warming was based on bad science or that scientists were making it all up because the earth was not warming at all.

The language was similar to any other political controversy—personal, abusive, and only marginally based on facts. It even featured a Congressman, ferocious climate critic Rep. **Joe L. Barton,** *Texas Delta '72*, (R-TX), P.E., demanding all of Mann's data and the AAAS warning of a witch hunt.

Finally, the National Research Council entered the fray. It found that newer climate reconstructions all showed 100 years of rapidly rising temperatures (though none rose as fast as the direct thermometer measurements of the past century). It found some issues with Mann's methodology. Although it rated Mann's original conclusion—that today's temperatures are the highest in 1,000 years—*plausible*, it had a "high level of confidence" that current global mean temperatures are the warmest in 400 years.

"Mann might have been able to prevent this circus if he had been more open to criticism from outside the field in the beginning," Solow said. "Yet no matter how much we work our models and data, global temperature warming is in the data and it won't go away."

Motives

Misuse of scientific evidence—disprove anything and you've disproven everything—and attacks that turn personal are nothing new in terms of the climate debate. Each side is quick to question the other's motives.

Take, for example, **S. Fred Singer,** *Ohio Gamma '43*, perhaps the nation's best-known climate denier and a former top NASA engineer. In 2005, he teamed with other climate deniers to form the Nongovernmental International Panel on Climate Change to challenge IPCC findings.

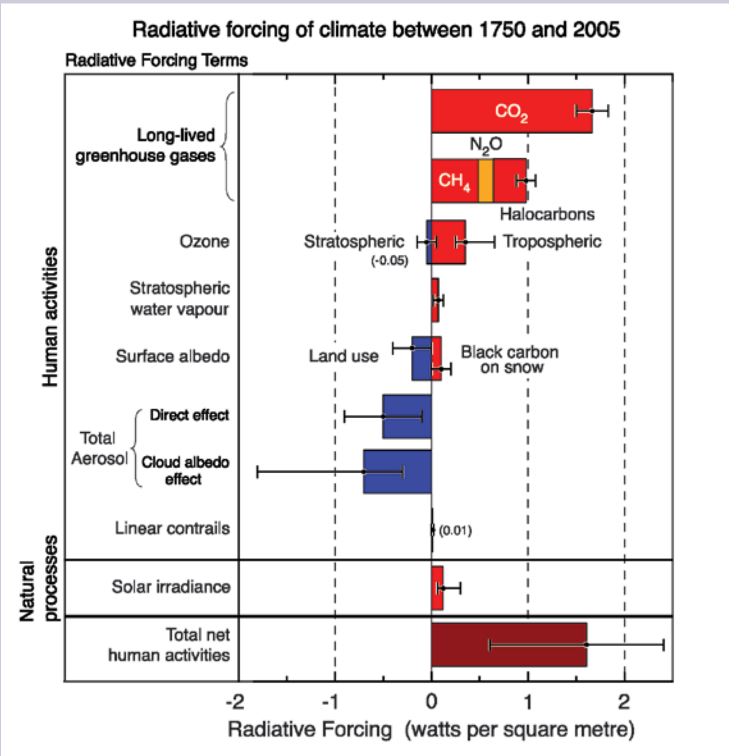
In his summary, Singer charged that the IPCC has an "agenda to find evidence of a human role in climate change" and that it is "a government entity beholden to political agendas." Rewards, including conferences "at exotic locations," go to researchers who "are willing to bend scientific facts to match those agendas."

Peer review is often a flash point. Singer charges that "refereeing standards for many climate-change papers are inadequate, often because of the use of an 'invisible college' of reviewers of like inclination to a paper's authors." In other words, these journals do not publish papers from climate deniers.

Singer does little to substantiate his charges in the report. Yet, emails stolen in November 2009 from the climatic research unit of Britain's University of East Anglia, one of four groups that charts global surface temperatures, may indicate that some climate scientists sought to advance their views. According to critics, the stolen documents show that they suppressed data that did not show global warming, made

Climate System Balance

Radiative forcings are factors that alter the energy balance of the climate system. This chart shows the difference in forcings from the start of the industrial era (1750) until 2005. Human activity has caused changes in gases, ozone, water vapor, surface reflectivity (albedo), aerosols, and aircraft streaks (contrails). Colored bars represent the most likely magnitude of the changes, while the thin black lines attached to them show the error range.



Text and image: Intergovernmental Panel of Climate Change it difficult for others to access data, criticized papers from critics of global warming, and deliberately chose statistical treatments to accentuate warming trends. The researchers replied that 95 percent of their data has been online for years and that their rejection of denier papers was justified by the research and arguments in them.

Despite flaws, Singer's nongovernmental report makes extensive use of peer-reviewed papers from the same government-funded research he bashes. He appears to justify this by stating that researchers fail to draw the right conclusions from their data. His critics charge him with using evidence out of context to support his own prejudices.

When deniers do seek to publish, they may pick journals far afield from climate research. Take, for example, "Environmental Effects of Increased Atmospheric Carbon Dioxide," by Drs. Arthur B. and Noah E. Robinson, both biochemists, and Dr. Willie W.-H. Soon, an aerospace engineer. The 12-page paper attempts to refute that notion that rising CO_2 levels have anything to do with temperature.

The paper raises several red flags. The authors are not experts in their field. To establish credibility, they would want to publish in a trustworthy journal in the field. Instead, they submitted the paper to the *Journal of American Physicians and Surgeons*, a medical policy journal. This is like letting doctors judge a paper on structural engineering because both have scientific training. The journal itself is published by the very conservative Association of American Physicians and Surgeons, which describes Medicare as *evil* and *immoral*. Scientists charge the association with having a political agenda of its own.

Some climate skeptics have less trouble publishing, often because their work is more narrowly focused. Dr. Richard S. Lindzen, a professor of meteorology at MIT, publishes regularly in peer-reviewed journals and has the respect of his opponents. He says the peer-review system works, though not as well as it could. He also finds a bias in general science magazines. "I was describing an article to the editor of a magazine when he stopped me and said, 'This is a story that denies global warming? I'd no more publish that than that Einstein was wrong.' "

Lindzen charges the environmental movement with "co-opting the sources of authority" in climate research institutions and claims that many scientific organizations accepted the conclusions of the IPCC "simply as a mantra." He also charges that some Wall Street firms have supported green organizations and cap-and-trade legislation because they hope to profit from trading carbon credits.

Money

Proponents of human-driven climate change give as good as they get. Take, for example, Dr. James J. McCarthy, who appeared before Congress in 2007, when he was president of the AAAS, the nation's largest scientific organization.

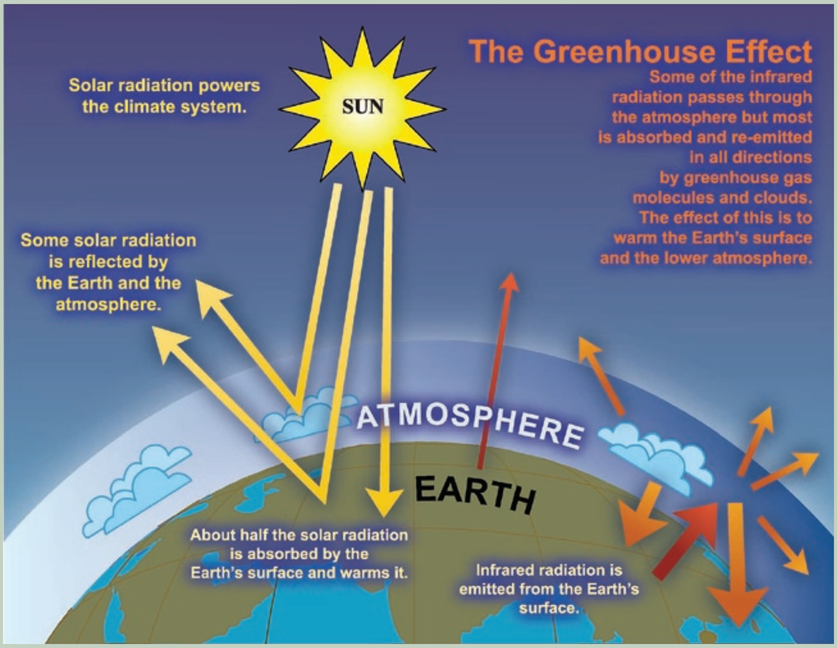
McCarthy claimed that the government was silencing climate researchers. He pointed to a survey of governmental scientists in which 150 of 279 respondents had "personally experienced" at least one incident of political interference with their work between 2002 and 2007. He also presented emails and faxes that demonstrated how politicians had rewritten scientific documents to make them less threatening.

Like skeptic Lindzen, McCarthy followed the money. He alleged that ExxonMobil and other companies concerned about CO_2 regulations were trying to cloud the global

The Greenhouse Effect

Solar radiation drives climate. Three factors determine how the sun's rays heat and stir the atmosphere: (1) changes in solar output (including distance from the sun); (2) the amount of radiation reflected by clouds, snow, atmospheric particles, and vegetation; and (3) greenhouse gases (chiefly water vapor and carbon dioxide, plus methane, nitrous oxide, and halocarbons) that absorb some of the escaping heat and reflect it to earth.

Like any black body in space, the amount of heat absorbed by the earth and its atmosphere equals the amount of heat released into space as long-wave infrared radiation. Greenhouse gases act as an insulating blanket to slow that release. Without them, the planet's average temperature would be -19°C. The vast majority of climate scientists believe that CO_2 released from combustion is increasing the atmosphere's blanketing effect and warming the planet.



Text and image: Intergovernmental Panel of Climate Change temperature issue, just as tobacco companies had earlier tried to obscure the link between cancer and smoking. ExxonMobil did it by funding institutes that dispute climate change.

"These groups promote spokespeople who misrepresent peer-reviewed scientific findings or cherry-pick facts in an attempt to mislead the media and public into thinking there is vigorous debate in the mainstream scientific community about climate change," McCarthy told Congress.

Drawing on a Union of Concerned Scientists report, he charged that between 1998 and 2005, ExxonMobil directed $16 million to 43 mostly small organizations that oppose climate change. Many of the recipients shared the same board members and science advisors and published papers from the same relatively small group of researchers. Noted critic Singer, for example, headed his own institute and held positions on 10 other anti-climate-change organizations. (While still listed as an expert or associate at several institutions, he maintained in a recent email that he has no "financial connections with any group, industry, or government.")

ExxonMobil claims that its donations are transparent (denier groups are categorized under "Public Information and Policy Research"). Its website now notes that it has "discontinued contributions to several public-policy research groups whose position on climate change diverted attention" from meeting energy demand while managing greenhouse gases.

One group that lost funding was the Heartland Institute, the libertarian group that published Singer's nongovernmental report. It received $676,500 from ExxonMobil between 1998 and 2006, but nothing during 2007-08.

Heartland likes controversy. In 2007, senior fellow Dennis T. Avery published a list of "500 Scientists Whose Research Contradicts Man-Made Global Warming Scares." The list named researchers at top institutions around the globe. But were they really skeptics?

When editors at the climate-change-is-real website *desmogblog.com* contacted 122 of the scientists, 45 replied within two days that they knew nothing about the list. Many wanted off. "I am horrified to find my name on such a list. I have spent the last 20 years arguing the opposite," wrote back David E. Sugden, a professor of geography at the University of Edinburgh. "They have taken our ice-core research in Wyoming and twisted it to meet their own agenda," replied Paul F. Schuster, a U.S. Geological Survey hydrologist.

Avery refused. He said the names came from papers cited in a book he co-authored with Singer, *Unstoppable Global Warming—Every 1,500 Years*. That made the list a bibliography, and Avery recompiled it to look like one. "Not all of these researchers would describe themselves as global warming skeptics," said Avery, "but the evidence in their studies is there for all to see."

Deniers have compiled other lists. The most visible is the Petition Project. It claims more than 31,000 people, including 9,000 Ph.D.s, with "scientific training" have signed. Because it lists names but no affiliations or degrees, its claims are nearly impossible to verify.

Of course, if there really were an army of deniers out there, their research would show up in true peer-reviewed science journals.

Outside the Mainstream

Some criticism of climate models falls far outside the mainstream. An example is "Falsification of the Atmospheric CO_2 Greenhouse Effects within the Frame of Physics," a 90-page tome written by theoretical physicists Dr. Gerhard Gerlich and Ralf D. Tscheuschner. They believe the greenhouse effect violates the second law of thermodynamics. The authors argue that greenhouse gases in a cool atmosphere cannot reflect radiation back to a warmer Earth. They also suggest a more accurate way to calculate average temperatures. When this yields results far lower than Earth's actual temperature, they hold it up as evidence that the greenhouse effect does not exist.

Climate denier websites like *ilovemycarbondioxide.com*, *smalldeadanimals.com*, and *denialdepot.blogspot.com*, embraced Gerlich and Tscheuschner as gospel, as if a single, unsupported paper erases decades of lab and field measurements.

Four years after it appeared on the Web, the *International Journal of Modern Physics B* published "Falsification." The topic is far outside the peer-reviewed journal's stated interests in condensed matter, statistics, applied physics, and superconductivity.

Most physicists and climatologists ignored the paper, but a few attacked it. "It's balderdash," said Dr. Raymond T. Pierrehumbert, a professor of geophysical science at the University of Chicago and a lead author of the 2001 IPCC report. "Many of the things they say are in doubt have been confirmed in labs thousands of times. You can take almost any page of this paper and find many major mistakes." He argues that even with the greenhouse effect, the net flow of radiation is from the warm earth into cold space. Greenhouse gases merely slow the flow. The fact that the paper's calculations fail to yield realistic average temperatures discredits the two authors.

Climate scientists said that the paper proved that their critics are either ignorant or crackpots. Arthur Smith, a physicist and IT manager at the American Physical Institute, wrote a formal rebuttal. Although his article has not yet been accepted for publication, Smith did receive an email from Fred Singer, arguably America's best known global-warming critic. "He thanked me for my paper because he thought the Gerlich and Tscheuschner paper discredited all climate skeptics," he said.

Targets

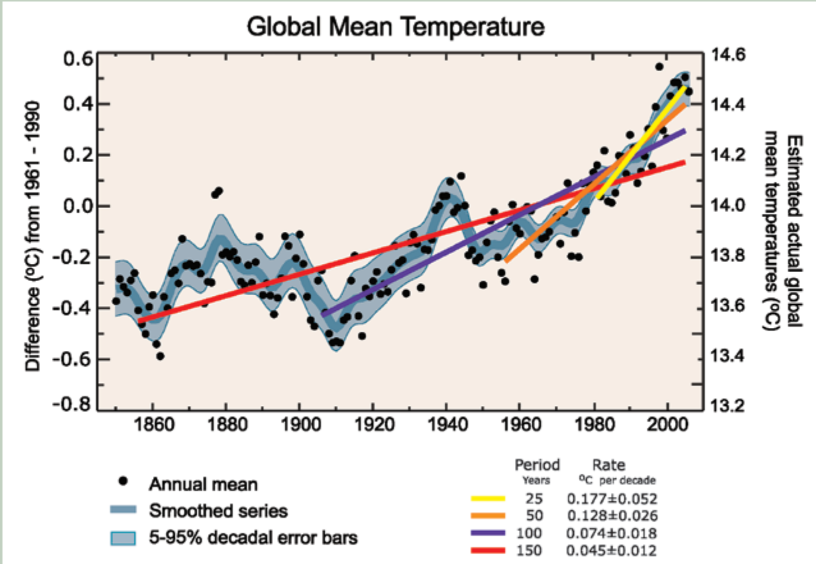
On the other hand, skeptics in the true sense of the word—researchers who question every new piece of evidence—are everywhere. Climate models invite skepticism because, as climate scientists are quick to state, there are gaping holes in our understanding of climate and our ability to model it mathematically.

The problem is that while researchers can quantify some things in the lab, like the amount of radiation absorbed by CO_2, they cannot reproduce clouds and ocean currents. Instead, they must rely on models. Scientists use models to test and refine their understanding of complex systems. When they see variability, they attack it by making better observations, refining hypotheses, and retooling algorithms. The same approach has advanced fields as diverse as astronomy, chemistry, materials, and pharmaceuticals.

At its core, climate modeling is computational fluid dynamics on a heroic scale. The typical climate model runs 500,000 to 600,000 lines of code that divide the world, from the ocean far into the stratosphere, into a mesh of cubes, hexagons, pyramids, prisms, and other shapes.

Each segment of the mesh describes the temperature, wind, pressure, solar radiation, greenhouse-gas concentration, cloud coverage, and other conditions within it. As the model steps forward in time, the conditions in each segment interact with those in the adjacent segments.

This generates climate, but the iterative calculations put an enormous burden even on the fastest supercomputers. To ease that challenge, models use large meshes, usually 100 to 200 kilometers on a side. Even with such coarse resolution, supercomputers typically take a full day to calculate about two-to-three years of climate change. Most large models require months to run.



Text and Image: Intergovernmental Panel of Climate Change

Given their coarse resolution, models miss a lot of local detail. Yet Ronald J. Stouffer insists they capture the big picture. He likens them to impressionist paintings. Close up, local weather patterns look like dots and dabs of paint. Step back, though, and those seemingly random blotches resolve into a clear representation of global climate.

Stouffer is a senior scientist at the National Oceanic and Atmospheric Administration's geophysical fluid dynamics laboratory in Princeton. He heads the lab's effort to tie together the earth's physical climate and biosystems and was a coordinating lead author for the 2007 IPCC report. The best models align well with observations, but good correlations are not enough. "Just because it gives you the right answer, that doesn't mean the model is right. We want to understand why it's behaving the way it behaves," said Stouffer.

Answering those questions requires what Stouffer calls "nonphysical experiments." Sometimes he simulates aspects of past climate and looks at areas where the model performs poorly. Other times, he creates idealized conditions—a world with constant sunshine and no change in greenhouse gases—and changes one variable at a time to see how other aspects of the model react to those changes. The discrepancies that he finds indicate where more research is needed.

Clouds

There are plenty of discrepancies. Take, for example, clouds. Clouds play several roles in the atmosphere. On one hand, white clouds reflect sunlight into space and prevent it from warming the ground. On the other, they consist of water vapor, the planet's most common greenhouse gas, and act like a blanket to slow the re-emission of heat into space. The question is: Which of these effects dominates, and under what conditions?

"Clouds are real important, and we do a lousy job of modeling them. They are important enough to change the magnitude of global warming. They will not cause the models to go from warming to cooling, but they can push them from a small amount of warming to a large amount of warming or vice versa," Stouffer continued.

Not everyone agrees. Critic Lindzen, for example, charges that even the latest high-resolution cloud models "use cloud physics from the 1950s" that produces large errors. "When you're calculating the response of the atmosphere to CO_2, clouds are big enough uncertainty to gum that up."

The problem is that some factors, such as aerosols, are devilishly hard to model. Aerosols are tiny airborne particles that can contribute to or interfere with cloud formation, noted Dr. Sam Levis, who works on land-vegetation climate interactions at the National Center for Atmospheric Research (NCAR). He noted that the fluid and thermal dynamics of the atmosphere—Lindzen's 1950s physics—are well understood, but cloud physics is more complicated.

Aerosols are small and interact very fast. For models to include them accurately, they must show how these interactions scale to affect clouds, which are orders of magnitude larger and slower. "Aerosols are one of the reasons cloud physics have to be represented empirically," Levis added.

"To large extent, the variation in cloud models causes many of the differences in climate models, and those variations are there because different modelers have chosen different ways to represent the process. Where we understand the physics well, there is less discrepancy between models," Levis said.

Life and More

The influence of biological systems on climate—also an area of great uncertainty—could rival the impact of clouds on models, said Stouffer. By combining climate physics with biological systems in a single model, researchers hope to describe the circular movement of carbon dioxide from natural and human sources into the atmosphere, where it is recycled into oxygen by land and sea vegetation.

Some of the results are surprising. "In the past," Stouffer said, "we assumed that as CO_2 rose, plants would grow better. In the real world, though, CO_2 is only one factor in plant growth. We found that in some cases, maybe nutrient supply puts a limit on plant growth, or maybe surface water evaporates before the plant can use it. There's a lot of uncertainty in how this impacts CO_2 balances."

Other interactions are equally hard to quantify. NCAR's Levis, for example, found that forests would gradually move north into the Arctic tundra as the earth warms. That would increase the number of trees that convert CO_2 into oxygen. However, forests would also shade snow, reducing the reflection of heat into space. In the tropics, the transformation of forests into farmland reduces the amount of CO_2 converted to oxygen, but increases the planet's reflectivity.

Oceans play a critical role in the carbon cycle. On one hand, they absorb carbon dioxide. On the other, CO_2 lowers the water's pH. Many biologists believe that lower pH is the most likely cause of recent coral-reef bleaching. They worry that falling pH could reduce the ability of plankton and other ocean plants to recycle CO_2. "The modeling of life is a relatively new field that doesn't have enough observations to constrain theory," Stouffer said.

There are plenty of other uncertainties. For example, models predict that the tropical upper troposphere should be warming, reaching a maximum temperature about 8 kilometers over the equator. "Data from the U.S. global change research program generally doesn't show that. There's a little bit of a peak, much less than the models get. If you stretch the models and data, you can marginally avoid this discrepancy, but the presumption is that there is a discrepancy," critic Lindzen explained.

Dr. Benjamin D. Santer, a senior scientist who analyzes climate models at the Lawrence Livermore National Laboratory, has tried to reconcile models and data. He argues that the discrepancy was based on measurement biases among the satellites monitoring the region. Critics have challenged how he removed those biases, but further measurement and discussion are likely to resolve this issue.

Others suggest variations in solar radiation as the cause of global warming. Nearly everyone agrees that this caused past ice ages. Yet IPCC models show that changes in sunspot intensity (which reflect variations in the sun's output of magnetized plasma, called solar wind) have little effect on climate.

Henrik Svensmark of the Danish national space center argues that cosmic radiation from distant stars affects cloud formation. He suggests that increasing solar winds during the past century have blocked cosmic rays. This reduced the formation of clouds that would otherwise reflect solar radiation back into space, thus warming Earth. Critics note that changes in solar output correlate poorly with mean global temperatures. Meanwhile, European researchers are planning experiments to test Svensmark's hypothesis.

Predictions

If models raise so many questions, why does anyone trust them? The answer is that they do a surprisingly good job of predicting climate.

"As models become more complex, we're getting more and more realism that you see outside your windows into the models," said Stouffer. "I can then interrogate a small section of the model as it's running and find a process that I can measure, such as atmospheric convection. I can look at the details and fly a plane or send up a balloon and take observations and compare it to the simulation in the model."

While observations rarely align precisely with model predictions, the trends look right and the data increasingly fall within an allowable range of error. Moreover, according to the IPCC, models accurately represent such important climate features as temperature distribution, precipitation, wind, ocean currents, and sea ice cover.

They also simulate such patterns as the advance and retreat of major monsoon systems, seasonal temperatures, storm tracks and rain belts, and hemispheric-scale seesawing of surface pressures. During the past 20 years, models have done a good job of predicting global temperature changes. This suggests that the models have captured the fundamental physical processes that drive variations in climate.

Models can also simulate the past. They have, for example, described the ebb and flow of the warm mid-Holocene 6,000 years ago and the glacial maximum of 21,000 years ago (though it is hard to measure how accurately).

Closer to home, they have simulated twentieth century climate using nineteenth century data. Those projections are easy to check and show good alignment with actual recorded temperatures. The simulations also produce some unusual details, such as the faster rise in nighttime versus daytime temperatures, accelerated Arctic warming, and increased precipitation. Those simulations fail when they include only natural factors, such as solar output and volcanic activity. Only when the models add greenhouse emissions—whose physical effects on heat emission have been defined thousands of times in the lab—do they reflect the rapid warming of the past 50 years.

Yet models remain far from perfect and even fall apart at smaller scales. On larger scales, they miss major climate features such as El Niño, tropical rain, and the cycle of tropical winds and rain. According to IPCC researchers, this is because our simulations are so coarse—our mesh is too big to capture details, and they need to approximate such important processes as cloud formation and the carbon cycle.

Critics are not as kind. When asked if any model could predict climate, Lindzen answered, "It depends on your question. Eventually, gross change in temperature might in fact be answerable."

When Lindzen looks at climate models, he sees major flaws, like how they handle topography. "We have a boundary condition and say no fluid should go through the boundary. But when we have topography—hills, valleys—the numerical errors in calculating the velocity normal to that surface give you an error term that carries mass into or out of the earth. We have to pump up the model every so often. We claim the models are based on known equations, but when you have to approximate your answers, you know less and less," he explained.

Yet despite their flaws, models still have powerful predictive capacities, backed by thousands of observations. This is why IPCC places *very high confidence* in the conclusion that human activity is warming the planet. Even when models are run with optimistic assumptions about cloud cover, carbon cycle, and solar output, the conclusion is still the same: human activity is warming the planet.

Thus, even though the science is far from perfectly understood, IPCC and the vast majority of climate scientists believe thaat their models do work on a global scale.

For some people, that is enough. For deniers, the models will never deliver the right answers. For modelers and true skeptics, however, inconsistencies and problematic results are normal; these scientists will continue to wrestle with the issues in order to improve our understanding of climate.

With so much science to be learned, it is a shame the discussion cannot be more civil.

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