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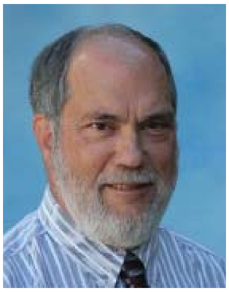

Thomas P. Ackerman

Christian Action in the Face of Climate Change

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Basic physics and chemistry tell us that adding carbon dioxide (CO_2) to the Earth's atmosphere will certainly result in warmer surface temperatures, rising sea levels, and ocean acidification. While the directions of change are certain, the exact magnitude and precise timing remain somewhat uncertain due to our lack of understanding of the complex climate system of Earth. Climate models represent our most complete understanding of the climate system and our only means to project the future climate of Earth. These models are not expected to precisely predict the trajectory of Earth's climate because climate variability is due to a combination of two types of change: deterministic change due to external forcings and stochastic or random change due to internal variations in the climate system. On timescales of years to decades, the stochastic variability dominates, making it extremely difficult to predict annual and decadal changes in climate. The uncertainty in our understanding of climate change caused by increasing CO_2 concentrations should drive society to make every effort to reduce these emissions and reduce the risk of disastrous change. Christians should be leading these efforts because we are charged to love God, including his creation, and to love our neighbors, including future generations. We know what we should do; unfortunately, we lack the will to do it.

Humankind is engaged in a large-scale modification of Earth's climate through the emission of carbon dioxide (CO_2) to the atmosphere and partial solution into the ocean. The inevitable result will be a warmer planet with rising sea levels and increasing acidification of the ocean. These outcomes are the result of straightforward applications of the laws of chemistry and physics. The exact magnitude and timing of these effects remain somewhat uncertain due to the complexity of the climate system and limitations of increasingly complex climate models.

Christians are called to be stewards of creation and seekers of justice for the poor and powerless. In the face of uncertainty about the magnitude of the effects, principles of risk management argue for caution regarding heedless production of more CO_2. Rather than using the uncertainty in predictions of amount and timing of effects to argue for nonaction, Christians should be calling for immediate action to reduce the effects of climate change by reducing, and ultimately stopping, emissions of human-made CO_2.

Thomas P. Ackerman, *PhD, is Professor of Atmospheric Sciences and Director, Joint Institute for the Study of the Atmosphere and Ocean at the University of Washington, Seattle WA.*

Global Warming Certainties

Do not be confused. Increasing the concentration of CO_2 in the atmosphere must warm Earth's surface. Planet Earth has a strong greenhouse effect that is critical to maintaining our present climate. That greenhouse effect is caused by the absorption and emission of thermal (heat) radiation, primarily by three naturally occurring gases: CO_2, water vapor, and ozone. Water vapor is the most important of the three, but its atmospheric concentration is limited by the temperature of the atmosphere; higher atmospheric temperatures result in more water vapor in the atmosphere. CO_2 is the second-most-important greenhouse gas; its atmospheric concentration is not limited by short-term climate processes and has increased by 40% over the past 150 years due to human activity, namely the burning of fossil carbon. This additional CO_2 increases the greenhouse effect of the atmosphere that, in turn, must increase the temperature of Earth's surface. The laws of physics do not permit any other outcome. Because removal of CO_2 from the atmosphere occurs very slowly, the CO_2 that we are now emitting into the atmosphere will, for the most part, remain in the atmosphere for hundreds of years.

We have multiple paths of evidence for a warmer climate, including increasing atmospheric temperatures, increasing heat storage (warming) in the ocean, rapidly declining amount of summer sea ice in the Arctic, lengthening of the growing season in the Northern Hemisphere mid-latitudes, and earlier arrivals of migratory birds and blooming of spring plants. A warmer ocean means expansion of ocean water and an increase in sea-level height. In addition, the Greenland ice sheet is melting at an ever more rapid rate, and there are disturbing indications of the collapse of ice shelves in the Antarctic, which may lead to a more rapid slippage of Antarctic ice sheets into the ocean. Both effects will also increase sea level. Roughly half of the CO_2 emitted since the start of the industrial revolution is in the atmosphere. Much of the rest has dissolved in the mixed layer of the ocean (roughly the top few hundred feet), forming carbonic acid and acidifying the ocean. Both ocean acidification and sea level rise are inevitable consequences of increasing CO_2 concentrations in the atmosphere.[1]

We, the human race, are currently engaged in a huge, uncontrolled climate experiment on planet Earth. We are burning fossil fuels at an ever-increasing rate. The concentration of CO_2 in the atmosphere is not only increasing, but increasing at an ever-greater rate; the increase each year exceeds the increase in the previous year. At current rates of increase, the CO_2 concentration in the atmosphere will be more than double the pre-industrial revolution value before the end of this century. Global temperatures will warm, sea level will rise, and the ocean will continue to become more acidic.

Global Warming Uncertainties and Climate Models

Donald Morton presents a number of well-worn criticisms of climate models. These criticisms have all been addressed before by many different individuals and organizations. The end of this article contains a brief list of reports on climate science written in the last few years by teams of scientists in the United States and worldwide. The interested reader is referred to these reports for discussion and refutation of the criticisms raised by Morton.

The one issue that I wish to address here is the purpose and validity of climate models. Climate models were originally developed to help guide our understanding of how the physical climate system works. Early models were quite primitive due to a lack of computer power, but even these very early models suggested that doubling the concentration of CO_2 in the atmosphere would produce a surface temperature rise of 2–4 °C.[2] The interesting feature of this warming is that it arises from a combination of direct warming from an increasing CO_2 concentration and warming due to feedback processes, primarily an increasing water vapor concentration associated with a warmer atmosphere.

As our scientific understanding of climate processes grew through the 1970s and early 1980s, climate scientists became increasingly concerned about the distinct possibility of warming Earth through human activity. Scientific investigation moved from whether increasing CO_2 concentrations would increase temperature to questions of how much warming would occur (determined to a large degree by climate feedbacks) and how fast it would occur (determined largely by heat storage in the ocean). The only way to answer these questions, short of waiting many decades, is to build a climate model capable of simulating climate and changes in the climate system. This task has engaged climate scientists for the past three to four decades.

Climate models that started out as simple one-dimensional atmospheric columns now include a three-dimensional (3D) representation of atmosphere and ocean, cloud processes, sea and land, ice and snow, atmospheric chemistry, land surface vegetation, and carbon cycles. Early 3D climate models (which share the same basic mathematical structure with forecasting models) were extensions of atmospheric forecasting models that were designed to predict atmospheric behavior on timescales of a week or two, but were streamlined computationally in order to allow simulation times of years in order to understand the behavior of climate. The current generation of forecasting models is much more complex than previous versions, and these models are used to forecast both immediate weather (one to two weeks) and the statistical probability of seasonal (three to nine months) weather. Climate models, originally simpler than atmospheric forecasting models, now exceed forecasting models in terms of size and complexity and are arguably the largest and most complex scientific computer codes that have been built. Our use of them has expanded as well. The original purpose was to understand the complex interactions of the climate system, a use that we continue to exploit, but we now also use them to understand how climate will change in the future and to examine climate change in the past.

How accurate are these models and how should we view their output compared to the actual trajectory of Earth climate? Or, in other words, with what fidelity should we expect climate models to simulate Earth climate and on what timescales? This is, as one might expect, a very knotty issue. We have learned that the earth climate system, in all its beauty and complexity, is both deterministic and stochastic. This latter term simply means that there is an element of randomness or unpredictability in the climate system, which may arise because the system is truly random or because the processes causing the apparent random behavior are too small or too complex for us to understand completely. An example may help here. Imagine you are somewhere in the central United States on a warm summer day. In the morning, the sky is relatively clear but scattered clouds develop as the day wears on. We can predict that these clouds are very likely to occur (deterministic), but we cannot predict exactly where or precisely when they will form (stochastic). By midafternoon, some of these clouds grow into thunder clouds and produce rain. Again, we can predict the likelihood that this will occur, but we cannot predict exactly when and where the rain will fall.

Climate simulation has a very similar problem. Climate has both deterministic processes, such as the response of atmospheric thermal radiation to increasing greenhouse gas concentrations, and stochastic processes, such as the occurrence of an El Niño event in the equatorial Pacific. We cannot predict the timing of El Niño events, perhaps because our knowledge is incomplete or perhaps because these events are truly unpredictable and depend on random interactions between the atmosphere and ocean. One way we seek to understand the relationship between deterministic and stochastic processes is to run our models many times for the same set of prescribed external climate forcings such as solar variability and changing greenhouse gas concentrations. We can then look at the multiple runs to identify which aspects are similar (or deterministic) and which are dissimilar (due to stochastic processes). What we find is that deterministic processes generally have long timescales on the order of a decade or more, while stochastic variability occurs on shorter timescales. We all recognize this latter variability as the difference in climate from one year to the next, including successive years of above average precipitation or drought.

So how does all this relate to climate change? The climate we have on Earth is only one possible climate history out of many, many possible histories. If I start my climate model in 2000 and run it out to 2015 one hundred times, I might be fortunate enough to reproduce the exact observed history of Earth one time. The more likely outcome, however, is that I have no exact simulation but several that are somewhat close. Given the stochastic nature of climate, it is unreasonable to expect that any climate model will exactly duplicate the climate history of Earth from year to year for a decade or perhaps even two decades. Climate scientists have known this for many years. We recognize that "decadal" prediction is the most difficult problem that we face in forecasting.

Does this mean then, as Morton states, that "the divergence between the models and temperatures … is sufficient reason to conclude that we do not yet understand climate"?[3] Not so. The fact that the actual trajectory of Earth climate over the past decade[4] has diverged from most model simulations indicates that the short-term stochastic processes are not occurring in our models in the same way that they are currently occurring in the one actual climate realization that we have, namely the climate of Earth for the last decade. Climate scientists, such as I, see this not as an indication that we do not understand climate, but as a challenge to improve our understanding of the complex interactions that determine the intricate details of climate. Why is this current pause in warming occurring? Well, our best answer at this point is that the extra heat being produced by the greater greenhouse warming is warming the ocean rather than the atmosphere. We have evidence that the ocean is, in fact, warming,[5] but we do not have a complete explanation of why this warming has occurred at a greater rate over the last decade than in the previous couple of decades, resulting in a decadal hiatus of atmospheric warming. We also have evidence of increased volcanic aerosol concentrations in the stratosphere over the last decade that may have helped cool the planet. Give us a few years and we may be able to give you a better answer.

So where does this leave us? Increasing greenhouse gas concentrations must increase the temperature of Earth. We can provide reasonable estimates of the magnitude of that increase on timescales of several decades or more. Model estimates of global surface temperature change for a doubling of CO_2 have remained remarkably constant at around 2–5 °C (multiply by 2 if you prefer an estimate in degrees F). The exact timing of that warming is open to discussion, but there is very little doubt that it will happen before the end of this century. Increasing heat storage in the ocean leads to a warmer ocean that is expanding in volume and producing a rising sea level. Increasing ice melt from Greenland and Antarctic ice sheets will increase that rise. Best estimates are for sea level rise of at least a meter by the end of the century. Ocean acidification is perhaps the most certain outcome because it depends only on simple solubility relationships that have been known for more than a hundred years. The outcome of ocean acidification is not well understood, but it will certainly impact negatively the plankton at the bottom of the ocean food web, and that damage to the bottom of the food web will then propagate up through the ocean ecosystem.

What Then Should We Do as Christians?

Morton argues:

> It is my view that we [Christians] should use this time of uncertainty in the predictions to pause in our actions and review the usefulness of the current and proposed projects. With whatever policies we choose, we must ask some basic questions. Will any of the mitigation schemes have a noticeable effect on the increasing atmospheric CO_2? Where is adaptation to be preferred? Could the available funds be spent better some other way? What are the unintended consequences? Also we should adopt a little humility and stop claiming that climate science is settled or that we understand climate well enough to be sure that we know how to control it.[6]

Not surprisingly, I have a different view. Morton does not specify what "actions" he thinks should be paused, but I doubt that it is the most obvious and important action that we are taking. We are dumping CO_2 into our atmosphere at an unprecedented rate. Between the last glacial maximum (about 20,000 years ago) and 10,000 years before present, atmospheric CO_2 increased from around 180 to 260 ppm.[7] Between 10,000 years before present and about 1850, CO_2 increased a mere 20 ppm to a value of about 280 ppm. In the last 160 years, CO_2 has increased from 280 to 400 ppm which is more than in the preceding 18,000 years! In 1957, when David Keeling began his measurements of background CO_2 concentrations at the atmospheric observatory on Mauna Loa in Hawaii, the measured value was about 315 ppm. Twenty-five years later the value was about 342 ppm; another twenty-five years later, the value was 385 or so. Thus, it took about one hundred years to add 35 ppm (315–280) or 9 ppm per quarter century. We then added about 27 ppm in the next quarter century and 43 ppm in the last quarter century (1985 to 2010).

These rates of CO_2 change show that we are now conducting an unprecedented climate experiment. If someone told us that "they" were going to begin dumping some gas into the atmosphere today and its concentration would increase by 35% in the next one hundred years but that we should not worry because everything would be fine, we would all be upset and rightly so. Just because we have been doing this for one hundred years is no reason to continue to do it, especially in the face of rising scientific knowledge and consensus about probable outcomes that are deleterious to most ecosystems. I and other climate scientists are *not* claiming that we know enough to control climate; we are considerably more humble than that. I am stating exactly the opposite: please *stop* putting CO_2 into the atmosphere because we collectively do not understand completely the consequences of our actions.

Morton is apparently willing to discuss the unintended consequences (which by definition are unknown) of mitigation strategies, but he is not willing to consider that there are known consequences, and may be unintended consequences, of continuing to pour ever-increasing amounts of CO_2 into the atmosphere. As a climate scientist, I am continually baffled by the willingness of our society to ignore the known consequences of our ongoing actions while being fearful of the unintended consequences of stopping, or even reducing, the magnitude of those actions.

I want to take a moment here to discuss the idea of consensus in science. Scientific research is, in large part, an attempt to reach consensus among scientists about specific questions. We have a consensus about gravitational attraction, and those who defy that consensus do so at their own peril. We also have a scientific consensus about thermodynamics, electromagnetic wave propagation, and fluid dynamics (the principal scientific elements of climate science). The lone scientist who defies consensus and establishes a new paradigm is largely a mythical figure, particularly in Earth sciences, because those sciences are almost entirely based on well-established classical physics and chemistry. Yes, that scientist does exist in the history of science, but a lot less frequently than one may be led to believe. To suggest that the vast mainstream of climate science is incorrect after decades of research and is going to be overturned by one heroic "skeptic" is, simply put, ridiculous. (And, if indeed that were the case, I would love to be that scientist because it would ensure my enshrinement in the pantheon of science!)

Science does indeed progress "by the relentless questioning of every hypothesis," but *only* if that questioning is done in the context of proper scientific investigation. Sniping from the sidelines and posting unreviewed comments on a blog is not science. Challenging established climate science requires developing new theories of climate behavior grounded in well-established laws of physics and chemistry, construction of new and/or improved climate models, testing and validation of these models, and publication of results in the peer-reviewed literature, showing how the results of these new models differ from existing model results. No such articles exist because no such models exist. The direct or implied statements of the "skeptics" that climate scientists are ignoring certain mechanisms or suppressing inconvenient evidence is nonsense and insulting to climate scientists. It is especially insulting to climate scientists who are Christians when this canard is parroted by members of the Christian community.

We scientists do not think that climate science is "settled," depending on your definition of that term. We do have more to learn, but we also have learned a great deal. One might say that the scientific conclusion that lung cancer is caused by smoking is not "settled" because we still cannot predict who will get lung cancer from smoking and at what age. But that is not the same as saying "keep smoking" because we have not settled all the science yet. We understand very well the fundamental basis of climate science and climate change. We are still working on short-term (decadal) prediction and exact magnitudes and timing.

What we should be doing as Christians is to ask, what are the likely consequences of our current actions? What is the probability that the climate science community is correct in its projections, and what does that mean for the future of ecosystems and human life on this planet? We need to approach these questions from the point of view of creation stewardship, social justice, and risk management. We are charged to love God, including the creation that he gave us. We are charged to love our neighbors, which includes not doing harm to the least among us or to our children and our children's children. We are called to use the intelligence that we have been given to assess the probability of risk and to take actions to mitigate that risk for current and future generations. We know how to do this. What we lack is the will to assume our responsibility for reducing carbon emissions. Even if the consequences of climate change are less than currently predicted, reducing emissions will benefit air and water quality, reduce our dependence on the production and producers of fossil fuel (enhancing our national security along the way), stimulate the economy through investment in new technology, and preserve our limited store of fossil fuels for important uses other than burning.

If climate scientists are correct, or perhaps underestimating projections of climate change (which is certainly as probable as overestimating them), then actions to reduce CO_2 emissions now may be critically important for maintaining our climate near its current values.

Christians should be at the forefront of care for creation and love for humankind. We should be leading the calls for action in our countries. Our Christian witness should be that God's love for us and our love for God compels us to act. Instead, we use slivers of doubt and modest uncertainties in scientific projections to argue for a continuation of our problematic behavior and a maintenance of our wasteful lifestyle. My prayer is that Christians will emulate the persistent widow (Luke 18:1–8) so that our government officials will say, "Even though I don't fear God or care what people think, yet because [these Christians] keep bothering me, I will see that [they] get justice" for those affected by changing climate.

Notes

[1]Evidence is summarized in a variety of places. Graphs of some physical changes are provided, for example, by NASA at http://climate.nasa.gov/evidence. Links to a wide variety of published scientific studies on physical and biological changes can be found at http://www.skepticalscience.com/evidence-for-global-warming-intermediate.htm.

[2]See, for example, S. Manabe and R. T. Wetherald, "Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity," *Journal of the Atmospheric Sciences* 24, (1967): 241–59.

[3]D. C. Morton, "Climate Science and the Dilemma for Christians," *Perspectives on Science and Christian Faith* 66, no. 4 (2014): 238.

[4]Morton uses the figure of sixteen years, which is incorrect. (See Morton, "Climate Science and the Dilemma for Christians," 236.) Climate warming (or cooling) should not be based on one year but rather on an average of no less than ten years. A running average (that is an average for each year based on averaging the five years before and after that year) shows that it is approximately the last decade in which Earth surface air temperature has been relatively constant.

[5]G. C. Johnson et al., "State of the Climate 2012: [Global Oceans] Ocean Heat Content," *Bulletin of the American Meteorological Society* 94, no. 8 (2013): S50–S53. Graphs of ocean heat storage and sea level are provided by the NOAA National Oceanographic Data Center (NODC), http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/.

[6]D. Morton, "Climate Science and the Dilemma for Christians," 240–1.

[7]Parts per million; i.e., in every one million molecules of dry air, 260 molecules are CO_2.

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