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The Geosciences, Climate Change, and the Virtues of Ignorance

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ABSTRACT

To play a useful social role in challenging times, geologists need a better understanding for how to relate knowledge to public interest. This essay proposes an alternative, post-disciplinary framing for scientific knowledge, where scientific knowledge is produced in the context of its application. Using current policy debates surrounding climate change as an example, I argue that they reveal a flaw in the presumption that improved empirical knowledge leads to societal consensus as to the 'right' course of action. Rather, we can expect that the dire consequences of climate change, if and when they occur, will cause a rapid shift from impotent squabbling to public and political pressure to geoengineer the climate. Thus the causal arrow between science and values should be understood as flowing in both directions. Moreover, this essay argues that given these dynamics, geologists and society at large need to learn how to make effective use of geological ignorance as well as geological knowledge.

Keywords: geosciences; geologic time; climate change; environmental ethics; science policy; policy studies

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INTRODUCTION

Science has both disciplinary and transdisciplinary aspects to its work—the disciplinary part being of interest primarily to other specialists, and the transdisciplinary part mattering to society at large. In terms of the latter, the societal benefit of different scientific fields varies. Fields such as biology and nanoscience have a natural attractiveness, for they conjure dreams of a scientifically improved future. Society loves to hear of possibilities such as extending our lifespans or increasing our technological reach.

The Earth sciences have a rougher time, since often their message is often one of limit. (Although recently, the message has again turned cornucopian, with the growth of shale gas.) But this should not distract us from the social and political relevance of the Earth sciences. While less showy, and somewhat out of fashion today, geoscientific information will be fundamental for addressing issues such as resource shortages, the loss of biodiversity, and the civilizational threat of climate change. Moreover, the virtues of geology are not limited to geologic facts. Living sustainably also means to learn to think in terms of geological perspectives on time. One of the greatest contributions that geology can make to social welfare is to encourage a scalar type of temporal thinking. For the health of both human society and the environment, politicians, business people, and everyday citizens need to think in terms of the next 10 and 100 and 1000 years as well as the next economic quarter (Cervato and Frodeman, 2012).

To play the role that they are capable of, however, geologists need a better mental model for how to relate knowledge to public interests. For knowledge, scientific or otherwise, does not simply and unequivocally determine policy decisions. Moreover, the virtues of geological knowledge are not limited to what we actually know. Strange as it may be to contemplate, the gaps and rough granularity of geological knowledge also have a role to play in the social uses of geology.

Using climate change and geoengineering as a point of departure, this essay offers a different account of the relation between scientific knowledge and political decision making. It is time we abandon the belief that knowledge leads in a straight line to changes in values, perspective, and action. But more provocatively, this essay also argues that we should attend to the political uses of (geological) ignorance. For not only what we know, but also what we do not know can be of real value to society. We have been making insufficient use of our ignorance. Now, much attention has been paid recently to dubious uses of ignorance by tobacco and oil corporations—acts of doubt-mongering that seek to justify the status quo (Oreskes and Conway, 2010; Proctor 2012). True enough. But such arguments do not account for the more virtuous uses of ignorance that I develop here.

Geology set the 19th century on its ear. Geologic time introduced spans that boggled the mind, resetting social relations, politics, and theology. The country learned a new, geologically based aesthetics of nature from the Grand Canyon and the America West generally (Pyne, 1999). Marsh and Cope unearthed the remains of ancient creatures as paleontology became part of the American consciousness. Europe may have castles and cathedrals; but America had Yosemite Valley and Colter's Hell. Even Darwin's theory of evolution—another shock to the body politic—depended on geologic spans of time.

Across the 19th century physics and geology battled for dominance. In 1864, William Thompson—later, Lord Kelvin—calculated the age of the Earth as being between 20 and 400 million years. Further refinements led him to announce in 1897 that the Earth was between 20 to 40 million years old, a time much too brief to allow for Darwinian evolution.

Geology won that debate, but in the 20th century it was physics whose prestige rose sky-high. In the 1940s physics gave us radar as well as the atom bomb, and in the aftermath of World War II physicists held the key to the threat of nuclear annihilation. The 20th century witnessed the development of a kind of physics envy, as physics became the gold standard for science because of its supposedly quantitative and deterministic nature. In contrast, geology seemed to suffer from a lamentable lack of precision in its findings. Worse yet, it was hardly a predictive science at all—relying on rules of thumb (e.g., Walther's law) rather than the ironclad rules of the laws of thermodynamics or nuclear decay.

Geology—aka the Earth sciences, the geosciences, or even the environmental sciences—gained in cultural cachet in the 1960s and 70s. The degradation of ecosystems and the specter of resource shortages of all kinds made the geosciences the most socially relevant of the sciences. But this status was to be short-lived. The social status of geology fell victim to twin blows. A society whose favorite cultural trope was the myth of the endless frontier—uniting Vannevar Bush with Star Trek—had little patience with talk of limits. And by the 1990s the revolution in genomics seemed to herald a new technoscientific golden age. Personalized medicine seemed a possibility, as did the lengthening of the human lifespan and even the redefinition of the aging process itself as a disease. In the 2000s climate skepticism intensified even as the temperature grew warmer.

Such are the vagaries in the social status of the sciences. But the wheel will turn again. It is likely that the geosciences will once again become a science of central societal importance. Facts on (or under, or above) the ground are likely to push the geosciences to the fore. As the keepers of such insights, geoscientists should consider how they can respond more adequately to societal needs.

20th century science was built on a disciplinary model of knowledge production—a fact that has had clear policy implications. In disciplinary knowledge production, standards of excellence are internal to a given discipline. Thus biologists (for instance) have been the sole arbiters of the fitness of the work of other biologists. The academy, with the acquiescence of society at large, created an entire political and philosophical architecture supporting the view that science was a uniquely authoritative, self-regulating form of knowledge. This allowed science to manage the trick of being simultaneously discrete from the realm of politics while also the authoritative source for decision-making (Pielke, and Byerly, 1998). The flow of information was unidirectional, from the scientist to the policy maker or the public. There was little sense that data needed to be interpreted, or that scientists should interact with non-scientists.

Today society no longer assumes that scientific knowledge automatically contributes to social good. Governments now demand that science provide an account of itself. In the US, the Government Performance and Results Act (GPRA) of 1993 and the 1997 inclusion of the 'broader impacts' criterion within the peer review process at the National Science Foundation are two signs of this change (Frodeman and Parker, 2009). Science now operates within an 'audit culture' where scientists are subject to inter- and transdisciplinary standards of evaluation, being judged by specialists outside their field and by non-academics across society.

Scientists sometimes treat these changed circumstances as an occasion for despair. But we should not be too much nostalgic for a point of view that painted an unrealistic view of science both internally, and in its relationship to society (Frodeman et al., 2013). By adjusting to these new circumstances geologists can provide an improved model for how science and society relate to one another. The geosciences can exemplify a post-disciplinary model of the science-society relationship.

In what follows I explore these points through an account of climate change and geoengineering. Once dismissed, geoengineering is becoming a live option for addressing the problem of climate change. The point of this essay is not to argue for—or against—geoengineering. Rather, it seeks to challenge the ontological framing that has underlain investigations of climate change, and many other controversies, over the last few decades. I say 'ontological,' because at issue here are our basic ways of categorizing our thought. Society has assumed that climate change is basically an epistemological issue, a matter of getting the facts of climate science right. The argument is then seen as moving from epistemology to ethics, values, and policy. Instead, I will argue that framing the climate change debate in terms of the progression epistemology-ethics-policy has become counter-productive. I propose another way to think about climate change that makes positive use of our inescapable ignorance concerning climate change.

THE CLIMATE CHANGE DEBATE

In a 2011 talk available on the Internet, Kevin Anderson of the Tyndall Center for Climate Change Research argued that the trend lines for climate change have gone 'beyond dangerous'. Society faces catastrophic climate change unless we make truly radical changes across the next five to ten years. These include the wholesale collapse of ecosystems, mass human migrations on the order of millions, and temperatures that exceed the capacities of modern urban infrastructures (e.g., New York City will not function with steady temperatures of 115 degrees). Without immediate and radical action we are looking at the failure of the global community (Anderson, 2011).

What are we to make of such claims? If we respond as we have over the 20th century we will turn this into a debate over epistemology. Epistemology is the formal name for an everyday occurrence: trying to figure out the truth about things. Epistemology asks, what is the nature and scope of knowledge? How do we know what we know, and demonstrate that knowledge to others? In the case of climate change, taking an epistemological approach means that Anderson's argument will be weighed, his models evaluated, and his inferences challenged. In the natural course of things more controversies will irrupt as academics think through his points. More research will be called for, more money appropriated, and faster computers procured, in order to rerun more intricate climate models in search of ever greater specificity and detail.

More accurately, climate change becomes a debate in *social* epistemology. Over the last couple of decades social epistemology has developed into a successor discipline to traditional epistemology and philosophy of science. Social epistemology recognizes that facts are to a significant degree socially constructed. To what degree remains an open question, and varies case by case; but one does not have to go very far to recognize that intricate arguments, such as those concerning climate science, can be interpreted in a number of different ways and that a person's standing will have an effect on our view of things.

In the case before us, Anderson is Professor of Energy and Climate Change at the Tyndall Center, a prominent place for climate studies. His findings have been reviewed by a jury of his disciplinary peers. We can also take into account the academic pedigree, as well as the evidence and arguments, of those who dispute Anderson's claims—disciplinary, and increasingly inter- and transdisciplinary. The latter group could include claims made by those who see the entirety of the climate change community 'in the tank' for a leftist political agenda. Or, as Senator Inhofe of Oklahoma put it, climate change "is the greatest hoax ever perpetrated on mankind" (Inhofe, 2012).

There is only one thing certain about this entire process: the arguments will continue. Different disciplinary perspectives, different funding sources, different national contexts, different computer models, different data sets: academic debate invariably engenders more academic debate. 20th and now 21st century academic discourse embodies a style of argumentation where very few matters are ever settled, and where we rarely declare that we know enough on a subject and can turn to something else. That is, academia lives under the sign of infinity: there is no end to the pursuit of knowledge. In the case of climate change, there will never be unanimity on Anderson's (or anyone else's) claims. The only time we will ever know whether Anderson's arguments are correct are if and when we actually experience the conditions that he has predicted.

But—will we even know even then? How *will* we ever know that climate change has occurred? It is a truism that it is impossible to attribute any given event—a heat wave, a hurricane, even a hurricane season—to climate change. But what is not included with these comments is a clear set of criteria for when we will know that climate change will have occurred. Global mean temperatures have risen 0.9 degrees C since 1880, and 9 of the 10 warmest years since 1895 have occurred in the last 10 years. Does this demonstrate that climate change has occurred? If this is not sufficient to signify that climate change has occurred, what would count as proof? A 2 degree C rise in global mean temperature? 4 degrees? 8?

The point here is one part logical, one part definitional. There will always be uncertainty about a given 'event' is simply anomalous, or part of a changed pattern. And it does not matter how long the given event lasts—whether it is a weeklong cold snap, a summer long heat wave, or a decades long drought. This is because the term 'event' has no clear or natural temporal boundaries. Put differently, there is no epistemological basis for distinguishing between the terms weather and climate. 'Weather' is what happens today; climate is the long-term average conditions. But what defines 'long-term'? For that matter, what defines 'today'?

Yes, ‘today’ means October 25, 2012. But today or ‘now’ also means the fall, the Obama Administration, and the Holocene. For the US National Weather Service, the distinction between weather and climate is defined in terms of a 30 year rolling average. In 2011, the average high temperature for Dallas was calculated by taking the average high for a given date across the period from 1980 to 2010; in 2012 it was drawn from the period from 1981 to 2011. There is nothing particularly significant geologically or mathematically about the period of thirty years. It is just a reasonable measuring stick given a) that temperature records for most places go back to the late 19th century, and b) 30 years encompasses a significant amount of time for human beings, who only live roughly double that.

Now, I grant that there is a certain folk wisdom to such an approach. But the question becomes problematic when we begin talking about the *science* of climate change. When we examine the history of climate we see that change is constant at all scales. Consider six graphs that map the climate record (Figure 1).

I hope that I will not taken as a climate skeptic if I note that there are any number of conclusions that can be drawn from these graphs. Yes, temperatures have risen in recent decades. Moreover, back of the envelope calculations (as were done by Arrhenius in 1896, without the merest hint of a global circulation model) strongly support the claim that putting more greenhouse gases into the atmosphere will raise temperatures. But one can draw reasonable, and contrasting, conclusions about where we are today depending on the temporal scale used. The last four graphs all suggest that we are in a cooler than normal period. As a thought experiment, imagine that temperatures dropped over the next 10 years. Wouldn't climatologists come up with any number of *ex poste facto* and *ad hoc* explanations for why this does not undercut the basic theory of climate change?

Again: I am not suggesting that the conclusions of the great majority of climate scientists are wrong, or disingenuous, or that climate change is not a real threat. My own reading of the climate change literature (such as it is, with a PhD in philosophy and a masters in paleoclimatology—such are my epistemological bona fides) is that it clear that climate change is occurring, and that it is being caused by human activities. But isn't the point not the absolute temperature, or how it's changing, but rather what range of temperatures our social systems have evolved to operate within? In any case, basing our response to the prospect of climate change on epistemological clarity has become a fool's errand.

The approach that I am questioning here has been codified as follows by Moore and Nelson (2011):

> Any argument that leads to a conclusion about how we ought to act or what policies we ought to adopt must have two premises. The first premise is empirical, based on observation and experiment, often grounded in science. This is the way the world is, this is the way the world may soon be. The second premise is normative, based on cultural values and ethical norms. Here is the collected human wisdom about what is of value, an affirmation of what is worthy and worth doing. From this combination of facts and values, but from neither alone, we reach conclusions about what we ought to do.

Moore and Nelson claim that this method of argumentation will spur action on climate change. Their approach nicely encapsulates the underlying assumptions of the climate change debate over the last 20 years. But this is an oddly Cartesian way to describe the world, as neatly breaking up into the two categories of fact and values. It's a point of view one seldom sees explicitly stated today by humanist academics, although it does underlie the common sense thinking of many people, including most scientists, engineers, and policy makers. More to the point, however, it misses the central issue I have sought to emphasize: that the climate debate shows no sign of getting beyond what Moore and Nelson call the first premise. As is visible daily in climate change debates, there is no 'fact of the matter' beyond dispute. Set up like this, the argument never gets to a 'second premise' of what should be done.

In part, we are in need of a better analysis of the relation between facts and values. In the first instance—although it is rather rarely acknowledged—facts seldom change one's values. It is much more common for new facts to be placed within the pre-existing value systems that people have. Facts are cherry picked: one side of the debate looks at the best case scenario, another the worst; a third at economic costs of addressing a problem like climate change; a fourth at the economic opportunities of developing clean energy technologies. And another side might observe that research scientists draw a handsome salary that gives them reasons for keeping a good thing going.

Overall, however, note the meager practical results that have come from twenty years and tens of billions of dollars of climate change research funded by the United States Government. Advocates and critics both would be hard pressed to identify specific policy differences that have resulted from decades and billions of climate science research. Which raises the possibility that we have been barking up the wrong tree.

REFRAMING THE DEBATE: GEOENGINEERING

Let's begin again. Anderson predicts that dire global consequences will occur without immediate global action. Assume this is true; is it likely that nations such as the United States and China (which together produce more than 40% of current carbon dioxide emissions) are going to upend their economy in order to cut greenhouse gases by the 90% necessary to achieve stabilization? Bear in mind that in the collapse of the Russian economy in the 1990s, energy use dropped by 25%, still a far cry from what climate scientists claim is needed. Whether because of skepticism, self-interest, shortsightedness, or a combination of all three, little is likely to be done about climate change until the world is hit by a truly shocking set of weather events.

And at that point, as Anderson and others note, additional climate change will already be embedded within the climate system. The dampening effect of the oceans ensures that there will be a significant lag time in the response of the climate system, first to maximum levels of CO2, and then to any progress we might make at lowering CO2 and other greenhouse gases. Moreover, if and when they face a state of political and ecological emergency, policy makers are likely to grab onto whatever blunt instruments they can find in order to respond.

These are likely to involve geoengineering. Geoengineering has received increased attention in recent years. The shift dates to 2006, when atmospheric scientist and Nobel

Prize winner Paul Crutzen wrote an editorial in *Climate Change* where he argued that geoengineering deserved serious consideration (Crutzen, 2006). Subsequently a growing number of reports, books, and essays have explored the mechanics, policy implications, and ethics of geoengineering.

The Royal Society's *Geoengineering the Climate: Science, Governance and Uncertainty* (GTC) stands out for its balanced and synoptic account of the possible ways forward in geoengineering the climate (GTC 2009). GTC divides approaches to modifying the climate into two categories, what it calls carbon dioxide removal (CDR) and solar radiation management (SRM). Carbon dioxide removal is viewed as the preferable approach, for it would simply eliminate the offending gases. This could take place through enhancing natural weathering processes, increasing oceanic uptake of CO2, or direct air capture (DAC). Unfortunately, there is no feasible technology on the horizon for direct air capture. Other approaches (for instance, scrubbers to remove CO2 before it comes out of the stack at power plants, or fertilizing the oceans) have serious environmental risks or will not be practical for quite some time (GTC 2009).

This leaves us with the second approach, solar radiation management, as the most likely option. SRM involves a number of possibilities. These include installing mirrors in space, spraying aerosols into the upper atmosphere, or even painting the roofs of buildings white worldwide. The obvious danger as compared with CDR is that, rather than simply moving the climate system back toward the previous norm, SRM changes the Earth's radiation balance, thereby introducing new elements into the climate system. While some of the approaches being discussed have natural analogues (for instance, volcanoes have a similar effect as spraying sulphate aerosols into the atmosphere would have), there is no way to predict the consequences that can result from such unparalleled human interference in the climate system. Attempts to model the effects of such efforts via computer simulations suffer from the same problem of all simulations: they depend on a series of interpretive assumptions built into the programming code itself and into the inputs of the model.

It thus seems likely that, if we are forced to act quickly, we will be using some combination of invasive approaches (e.g., fertilizing the oceans or injecting aerosols) over the short term, while hoping that we can turn toward a combination of direct carbon capture and weaning ourselves from a carbon energy system over the longer term.

Note how this reframes the climate change debate—as well as the growing debate over geoengineering. Rather than forming a 'first premise' or zero point for our thinking, science is caught *in media res*—in the middle of things. Rather than generating unimpeachable knowledge that then drives policy debates, the science is sufficiently complex to be open to varying interpretations. Instead, our thinking begins with the political realities that are likely to shape any discussion of climate change. We then seek knowledge—scientific or otherwise—that can help ameliorate the situation.

Such an approach connotes a vast shift from our typical attitude toward the relation between knowledge and action. Whether in the sciences or the humanities, we have been trained to search for first principles, which will supposedly drive subsequent decisions. The problem, however, is that we never finish arguing about the first principles. Nor do we often agree about the process or procedure for moving from first principles to a course of action.

The academy thus faces a rethinking of its implicit policy of knowledge production and consumption. The challenge begins with the fact that the academy's knowledge policy has never been more than implicit: there has never been a clearly articulated and worked out theory of the relation between knowledge production (in whatever field) and its use by non-disciplinary audiences. Disciplinarians have simply hidden behind terms such as 'dissemination', 'outreach', and even 'dumbing down'. The older point of view eschewed any sustained thinking about knowledge policy. Knowledge was viewed as disciplinary in nature, and criteria for excellence were disciplinary as well. The dissemination of knowledge beyond disciplinary boundaries was considered to be an automatic process, and in any case not a task for disciplinary professionals themselves. But in an age of academic accountability this attitude is no longer adequate. In the future knowledge production needs to occur in the context of its possible use.

The lack of thought about how to build relevance into academic knowledge from the beginning has afflicted philosophy as much as the sciences. Environmental ethics is an area of philosophy that should be quite relevant to the climate debate and environmental thinking. And in fact, recently there has been a great deal of work about the philosophical aspects of geoengineering. But environmental ethicists have suffered from the notion of the relation between knowledge and action described by Moore and Nelson (themselves two prominent environmental ethicists).

The challenge to the geoscientific community, and the academy in general, is to think beyond the disciplinary boundaries that defined the academic work across the 20th century. This means to build the concerns of policy into research from the beginning. This in turn implies that geoscientists, and academics in general, will need to become conversant with the field of policy studies. The geosciences should be a natural leader in creating inter- and transdisciplinary types of knowledge production, where policy concerns help frame research, not just in terms of the topic of research, but also in terms of the style of presentation, the degree of rigor, and the amount of integration with social scientists, humanists, and policy researchers.

DISCUSSION

The climate change debate has been caught in a Catch 22: as we discover more about it, we at the same time expand our uncertainties concerning the climate system. So, for instance, while our understanding of the climate system increased markedly between the IPCC's Second Assessment Report (1996) and the Third Assessment Report (2001), the range of possible outcomes for the year 2100 increased rather than declined. Moreover, continued research has served as a reason for political inaction, as politicians have claimed that the 'jury is still out' on climate change (Sarewitz, 1996). The continued search for greater epistemological certainty ignores the political reality that governments are not going to act on climate change until absolutely forced to by events on the ground. Finally, if the climate does in fact change, the mode of academic knowledge production typified by global climate change science will likely be trumped by the public and political call to embrace geoengineering.

Today one finds two main objections to geoengineering, what might be called intrinsic and instrumental. There is first a set of objections within the environmental ethics literature concerning the 'naturalness' of such activities. These objections were originally developed in response to issues arising within the field of restoration ecology, but have now been applied to questions of geoengineering. Second, as noted above, there is no real way to predict the effects of such interference with the climate system. Consequences could be minor or profound.

Concerning the first point, the claim is that geoengineering turns the entire atmospheric system and the Earth itself into a construct. According to David Keith, geoengineering would involve "…the end of wildness – or at least our idea of wildness. It means consciously admitting that we live on a managed planet" (Goodell, 2010, p. 45). We have heard similar arguments before the issue of geoengineering came up. Thus in the 1989 *The End of Nature* Bill McKibben has said that in a warming world, '…each cubic yard of air, each square foot of soil, is stamped indelibly with our crude imprint, our X' (McKibben, 1989, p. 96).

These claims are reminiscent of the debates within environmental ethics in the 1990s. Environmental ethicists such as Robert Elliot and Eric Katz complained that environmental restoration consisted of the attempt to 'fake nature' (Elliot, 1982, Katz, 1992). A mining area may be restored down to the last jot as compared with its original condition; still what we would have is an artifact, a construct, or a fake. Like the case of an art forgery, even a perfect copy of the Mona Lisa remains just a copy.

It is not entirely clear what purchase these arguments are thought to gain. Such objections to ecological restoration are metaphysical in nature. It did not matter whether the actual physical qualities were identical. The difference was meta-physical: we would *know* that the landscape is not the original. And in that knowledge lay all the difference. But what is the standard of wildness that people like Keith assume? Humans have been modifying the natural world for millennia; what makes this the decisive intervention? Second, the comparison with works of art such as the Mona Lisa misses the fact that nature displays its own purposiveness and directionality. All a painting can do is decay, while a natural landscape—or the atmosphere—can and will eventually 'renature'. The atmosphere is not a machine, but an organic entity that can seek its own (perhaps new) equilibrium, as it has constantly across geologic history.

Such debates will strike most people as impractical and abstruse. Not so for the other main objection—that geoengineering raises the specter of unknown consequences and untold harm. Intervening into the climate system could have worldwide effects—in fact, that is precisely the point of intervention. But how are we going to apportion responsibility for untoward effects, regionally, nationally, or internationally?

These are legitimate concerns. In part, they imply an international mechanism of governance to adjudicate such claims and concerns. But this is also to miss the chance to make effective use of our ignorance. As noted earlier, there is no real way to effectively distinguish between weather and climate. But in this case, this fact can work to our common advantage. For it means that we will not be able to identify whether a given weather event was the result of our intercession with the climate system, or are part of the continual stochastic variation of the natural world. In other words, no one will know whose hand is on the thermostat.

As I write Hurricane Sandy is churning up the East Coast of the United States. Warnings have been issued from Florida to Maine. Subway systems have been shut down; low-lying areas evacuated. Predictions range up to the catastrophic for what is by all accounts a historic storm. Is the storm the result, wholly or in part, of climate change? We will never know. But neither will we know about the next storm, or the storm (or drought, or heat wave) that occurs after our first massive intervention into the climate system. This is ignorance that we can make use of: not to dodge responsibility, or to neglect caring for those injured by weather (or climate) event, but to look beyond questions of causality to address the needs of vulnerable populations.

Geoengineering is likely to be the first real line of defense against catastrophe. While the effects of geoengineering may be far from benign, it does represent an opportunity to reconstruct the way we discuss climate, and by extension model a more fruitful approach to knowledge policy than we had across the 20th century.

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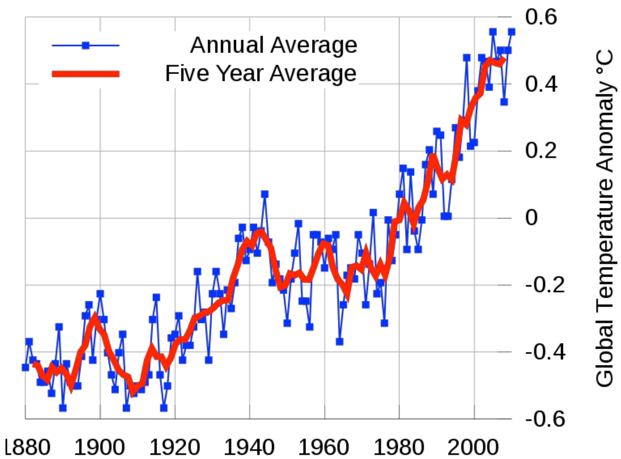
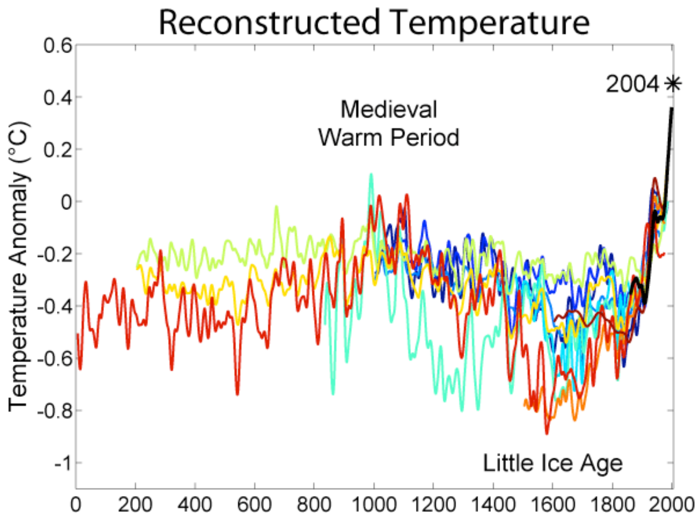
FIGURE CAPTION

Figure 1. Six representation of climate change. A. From NASA, at http://www.nasa.gov/centers/goddard/news/topstory/2006/2006_warm.html B. From the Global Warming Art Project, at http://www.globalwarmingart.com/wiki/Temperature_Gallery C. A graph prepared by Robert A. Rohde from publicly available data. D. From the European Project for Ice Coring in Antarctica (EPICA), at http://en.wikipedia.org/wiki/Temperature_record. E. From Lisiecki and Raymo (2005) as presented in the same source as F. F. From the Global Warming Art Project, at http://www.globalwarmingart.com/wiki/Temperature_Gallery

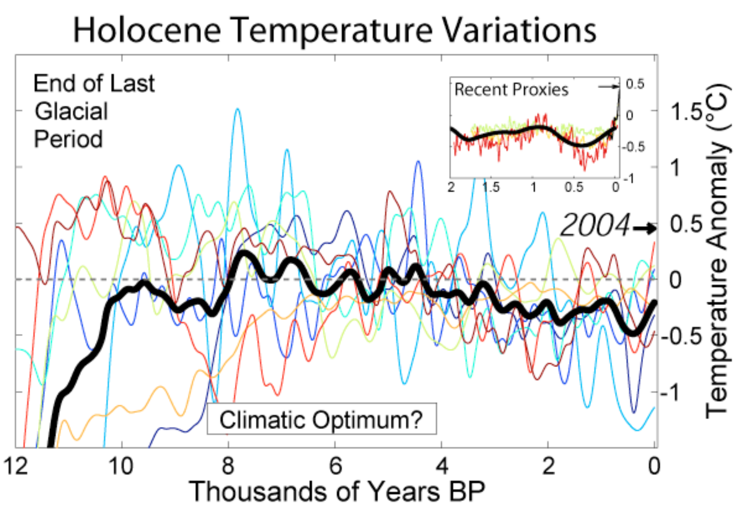
A.



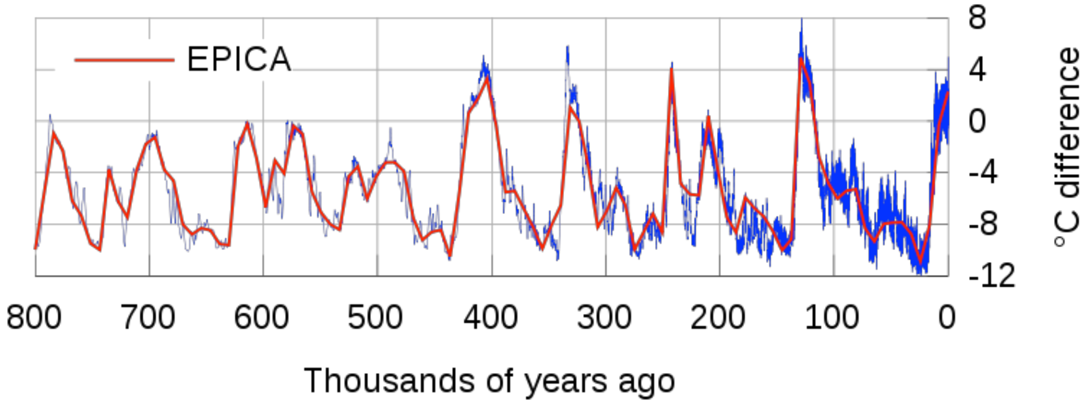
B.


Reconstructed Temperature
Medieval Warm Period
2004
Little Ice Age
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
200
400
600
800
1000
1200
1400
1600
1800
2000

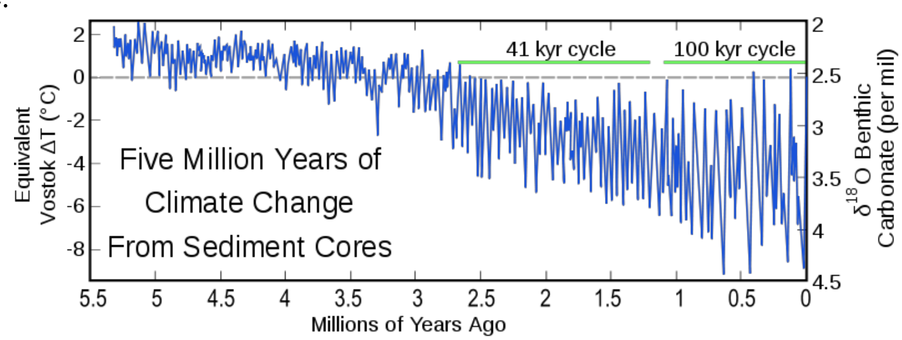
C.


Holocene Temperature Variations
End of Last Glacial Period
Recent Proxies
2004
Climatic Optimum?
Temperature Anomaly (°C)
Thousands of Years BP
1.5
1
0.5
0
-0.5
-1
12
10
8
6
4
2
0

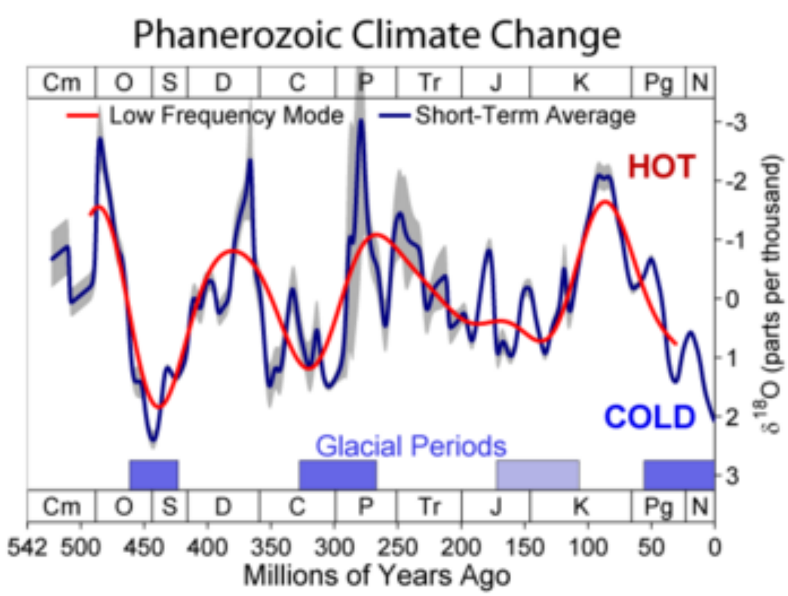
D.


EPICA
8
4
0
-4
-8
-12
°C difference
800 700 600 500 400 300 200 100 0
Thousands of years ago

E.


Equivalent Vostok ΔT (°C)
2
0
-2
-4
-6
-8
41 kyr cycle
100 kyr cycle
Five Million Years of
Climate Change
From Sediment Cores
2
2.5
3
3.5
4
4.5
δ18O Benthic Carbonate (per mil)
5.5 5 4.5 4 3.5 3 2.5 2 1.5 1 0.5 0
Millions of Years Ago

F.


Phanerozoic Climate Change
Cm O S D C P Tr J K Pg N
Low Frequency Mode
Short-Term Average
HOT
COLD
Glacial Periods
-3
-2
-1
0
1
2
3
δ18O (parts per thousand)
542 500 450 400 350 300 250 200 150 100 50 0
Millions of Years Ago