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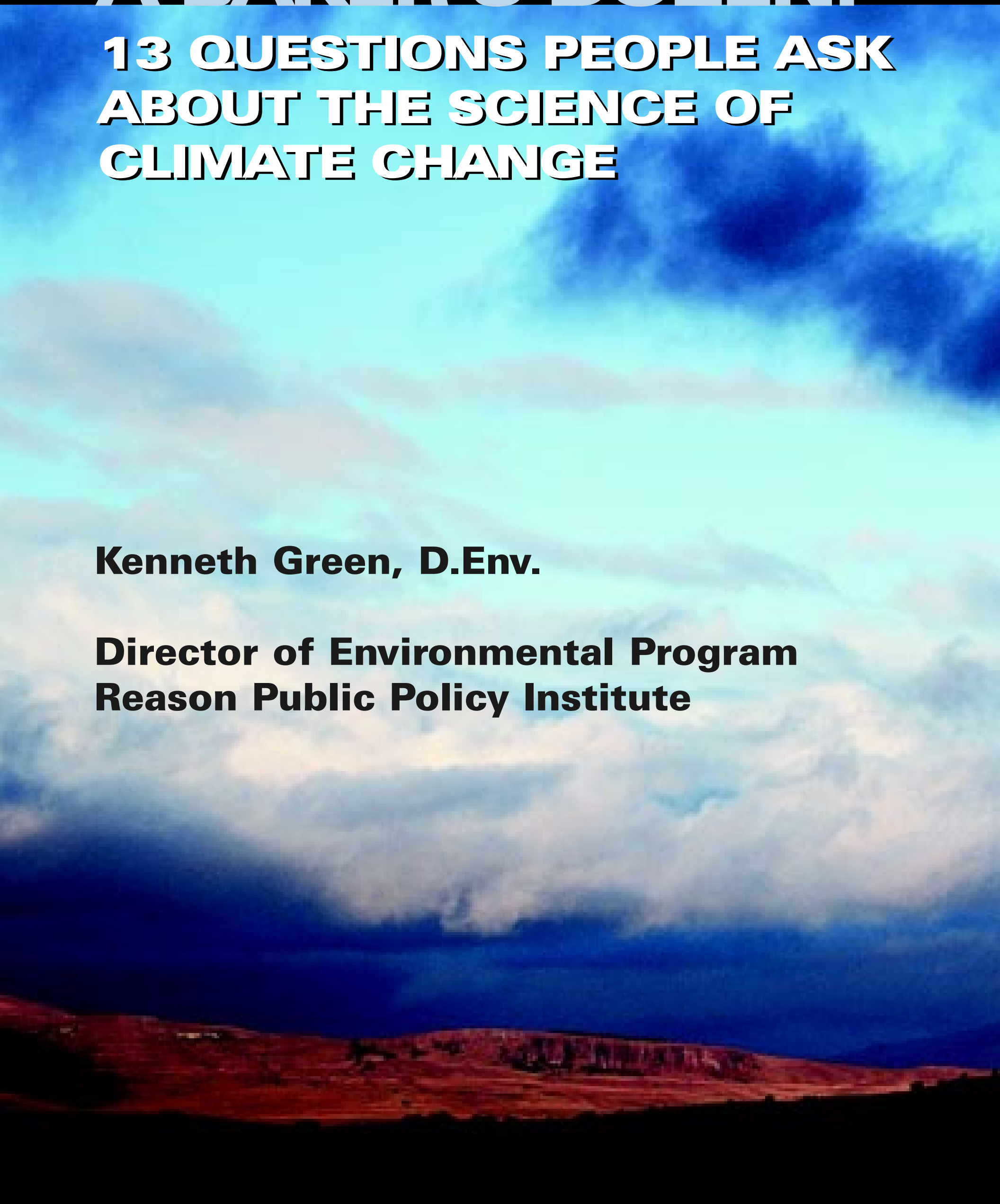
A BAKER'S DOZEN: 13 QUESTIONS PEOPLE ASK ABOUT THE SCIENCE OF CLIMATE CHANGE



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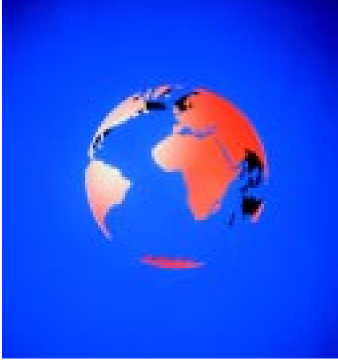
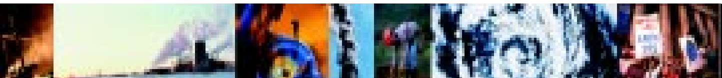


1. WHAT IS CLIMATE CHANGE?

The Earth's climate is a dynamic, constantly changing system in which biological activity influences various aspects of the climate: this has been the case since the earliest days of life on Earth. But changes within the range of historical norms or changes which are unrelated to human activity are not what "climate change," as the term is used in popular scientific and political discussion is about. Rather, that "climate change" refers to scientific studies of abnormal climate changes and associated impacts that are distinctly human in origin.

At the center of our understanding of climate change is the process known as global warming, which is basically the planet-wide application of a physical process called the greenhouse effect, named for the way that a closed system (like a greenhouse) retains heat.

On uncovered ground, incoming solar energy is either absorbed by the ground (which then heats up), or is reflected back into the atmosphere and, eventually, into space. The energy absorbed during the day is given back off at night as heat, one reason why cold-blooded animals like snakes tend to lie on roadways after dark. But in a greenhouse, things are different. Solar energy passes in through the glass panes of a greenhouse and is absorbed or reflected by the ground and other objects as usual, but when that energy is re-emitted immediately or later at night, the glass, through direct and indirect effects, stops some of it from passing back out of the greenhouse. Even more of the re-emitted energy is captured and prevented from passing back out of the greenhouse by the water vapor that comes into the warmed-up air from the plants and soil in the greenhouse.



Global warming scales up the greenhouse effect to the entire atmosphere, with various gases, called greenhouse gases, taking the role of the glass in the greenhouse. At this global level, the greenhouse effect is well validated, and is one of the forces that has shaped and will continue to shape the Earth's climate, causing warming above the level that would occur on a similar sized planet with similar solar input, but without an atmosphere. This warming process is a natural, and highly beneficial, phenomenon. In fact, without the basic greenhouse effect of the Earth, it would almost certainly be too cold on this planet to sustain life as we know it

In the study of manmade climate change, researchers take the theory of global warming, change some of the assumptions about various gas levels, their heat-retention ability, their persistence in the atmosphere, the impact of other atmospheric forces, and a host of other variables, and make predictions about what kinds of climate change might happen if human beings introduce certain atmospheric changes. Thus, questions such as "how will mankind's emissions of gas X to the atmosphere lead to changes in sea level in San Francisco," would be answered through experiments based on the theory of climate change.

2. WHAT ARE "GREENHOUSE GASES"?

"Greenhouse gases" are those components of the atmosphere that can, according to global warming theory, alter the way that the Earth's atmosphere retains heat.

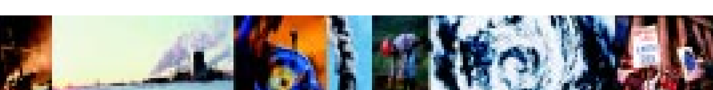
The four major manmade greenhouse gases are carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons, or CFCs. Not all greenhouse gases are alike, either in terms of concentration, or of their "warming potential," and some things called gases aren't even gases at all, but are families of gases, such as nitrous oxides. Besides the four major manmade gases are other gases and gas families that can affect the climate, such as the "particulate aerosols," fine dusts that stay suspended in the atmosphere

The actual potential of a given greenhouse gas to induce warming of the atmosphere is still unclear in some cases and for some "gases," such as aerosols. For such mixtures, in which some of the compounds can cause warming while others can cause cooling, the potential for them to cause warming is based on a sum of influences, some poorly understood. Particulate aerosols, for example, can have either warming or cooling effects, depending (partly) on whether they're light colored, or dark colored.

Relative concentrations also come into play, since the impact of smaller quantities of a more powerful warming gas could overwhelm large quantities of a more modest warming gas. The length of time that a given gas stays in the atmosphere is also an important factor in determining its overall "warming potential," since the process of trapping heat takes considerable time.

Carbon dioxide, for example, is less powerful as a warming agent, molecule for molecule, than is methane, but is much more prevalent in the atmosphere, and endures longer. Nitrous oxides have nearly 200 times the relative warming strength of carbon dioxide, but are found in much lower concentrations in the atmosphere. Some CFCs (most notably those banned as a way of protecting the high-altitude ozone layer) can actually have negative "warming potential," and can cause "global cooling," while their substitutes are more likely to be "warming gases." Ozone itself can be either a warming gas or a cooling gas, depending on where in the atmosphere it is found.

Water vapor is another important greenhouse gas, perhaps the most important because of the huge mass of it in the atmosphere at any given time. Changes in the atmospheric levels of water vapor, and the role of water vapor in heating and cooling the atmosphere are still largely a mystery.



3. WHERE DO GREENHOUSE

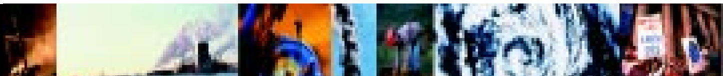
Most greenhouse gases are produced by natural processes such as animal metabolism, natural physical processes such as lightning and volcanos, and human activities, such as fuel use and manufacturing.

Once released into the atmosphere, greenhouse gas concentrations are affected by a variety of human-influenced and non-human-influenced climate processes, some of which increase certain gas concentrations, others of which reduce certain gas concentrations. Some fluctuations in greenhouse gas levels are still poorly understood.

Modern, reliable measurements of greenhouse gases are very new and have produced very limited data, beginning with carbon dioxide measurements at the South Pole in 1957, at Mauna Loa in 1958, and later for methane, nitrous oxides, and chlorofluorocarbons (CFCs).

Carbon dioxide is released into the atmosphere by biological processes, geological processes, combustion, and energy use. Human sources of carbon dioxide make up about 3.5 – 5.4 percent of the total carbon dioxide which enters the atmosphere in any given year. The other 95 – 97 percent of carbon dioxide that enters the atmosphere each year is the bulk of the planet's "carbon cycle," and comes from oceanic and terrestrial animals as a by-product of their metabolisms.

Methane is released into the atmosphere by biological processes and geological processes, some subject to human control, some not. Methane is released through en-



GASES COME FROM?

ergy use, rice cultivation, crop waste incineration, and animal husbandry. Human sources constitute about 70 percent of the methane that enters the atmosphere each year, the rest coming from natural sources like wetlands, termites, and aquatic life.

Nitrous oxides are released into the atmosphere through biological processes and through human activities including fuel use, soil cultivation, acid production, and combustion of wastes. Nitrous oxides have about 200 times the warming potential of carbon dioxide, and human activity contributes about one-third of the annual release to the atmosphere. The balance is released through the natural biological processes that take place in the oceans, soils, forests, grasslands, and other ecosystems.

Chlorofluorocarbons (CFCs) are all man-made chemicals used largely as refrigerants and cleaning agents. Some CFCs have positive warming potentials, while others have negative potentials.

Ozone can be produced directly by electrical discharges but is mainly produced by the action of sunlight, oxygen, and a variety of other airborne chemicals in the atmosphere.

Water vapor, of course, comes from evaporation and from plant transpiration, but the forces that maintain the levels of humidity throughout the atmosphere, and the points at which water vapor is removed from the atmosphere by precipitation and cloud formation are poorly understood.

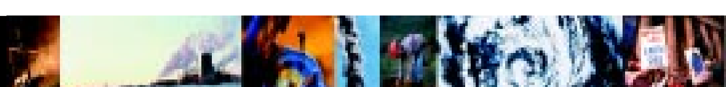
4. ARE GREENHOUSE GAS CONCENTRATIONS INCREASING?

This is a more complicated question than it seems because there are so many processes that put greenhouse gases into the atmosphere, and just as many "sink" processes that pull greenhouse gases back out of the atmosphere. Not all of those sources or sinks are well understood, and some are not even known. A time-scale factor complicates matters, since some sinks absorb and hold various greenhouse gases at different speeds, and for different lengths of time. The bottom line is that, as best as we can determine it with our limited information, some greenhouse gas concentrations have increased within the past century, as compared to estimates of historic gas levels.

Carbon dioxide, a gas which is present as a natural component of the Earth's "carbon cycle," constitutes about 0.034 percent of the atmosphere by volume. Though we must always keep in mind that our direct measurement history is sharply limited, the body of evidence indicates that the concentration of this gas has increased by about 30 percent since the late 18th century.

Methane, a gas which is present as a natural byproduct of animal metabolism, constitutes about 0.00016 percent of the atmosphere by volume. Methane levels in the atmosphere seem to have increased about 150 percent since the beginning of the 19th century, with current levels being the highest ever recorded, though the pattern of methane emissions is highly irregular and has actually shown a downturn in recent years, for reasons that are not clear.

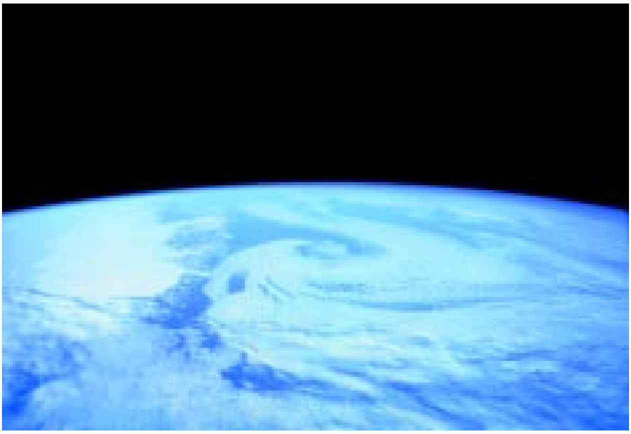
CFC concentrations are difficult to measure, vary geographically, and because of recent changes in the law regarding their production and use, are changing not only in concentration, but in composition. One can assume, barring activities of the black market in banned CFCs, that those CFCs which replaced the ozone-depleting CFCs banned by the Montreal Protocol are probably increasing, while those banned by the protocol are probably decreasing.

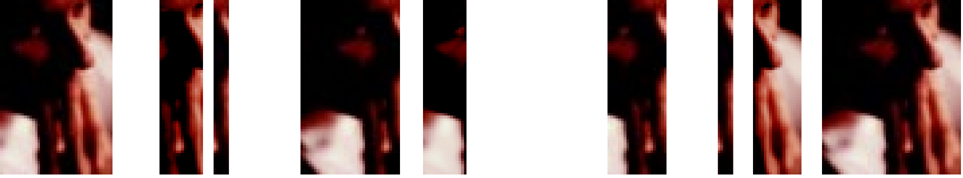


5. HOW MIGHT INCREASED LEVELS OF GREENHOUSE GASES CHANGE THE CLIMATE?

The relationship between climate dynamics and the concentrations of greenhouse gases is described by complex computer models, the details of which would easily fill several volumes. Changes in the Earth's average temperature—the primary element modeled in climate change studies—could lead to different impacts in different locations, such as increased crop growth and moderate winters in some places, and rising sea levels in others.

What frightens people about climate change is not the theory itself, nor the actual change in the global average temperature, which has both positive and negative implications. Rather, it's the non-temperature related implications of the theory that people focus on, and the fears aren't completely unfounded. The prospect of a warmer climate does imply at least the possibility of negative secondhand impacts along with whatever positive ones occur, including: more volatile and extreme weather; worse droughts in some areas; worse flooding in other areas; negative impacts on agriculture, aquaculture, livestock, fresh water, and so on; and shifting of the normal residency areas of various insects that carry diseases detrimental to human health.





6. HOW CERTAIN IS THE THEORY OF CLIMATE CHANGE?

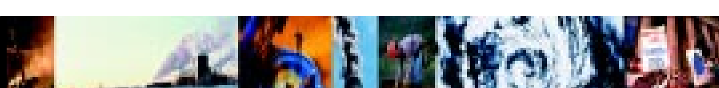
Climate change theory is quite complex — orders of magnitude more complex than the comparatively simple theories that underlie it. To understand the complexities of climate change theory, consider this analogy.

If you have a small vacuum chamber, and you drop ten different colored feathers, they fall straight down, and land at the same time. Predicting the path, and intercepting say, the red feather is a simple task. That's like the greenhouse effect, a simple cause / effect relationship.

If you drop the same ten feathers out of an airplane, they don't fall straight down, and they don't land at the same time. Some of them, in fact, won't land at all, because they'll stay aloft for so long that they'll get brittle and disintegrate, or be sucked into jet engines and destroyed. Still, one can assume that some of them do land eventually, since gravity is still a force in play. Global warming and the various potential causal factors, like greenhouse gases, embody a similarly complex set of interactions among many variables over time.

If you released ten different colored birds into the wild with all the other birds in the world, then tried to figure out where each of your birds would lose its feathers; where and when a specific feather would land; estimate the damage that the feather might cause; and figure out how you might avoid that damage by preventing the growth of the food that fed the bird that produced the feather, you'd be trying something nearly as complex and uncertain as we do with climate change theory.

Between our incomplete understanding of the climate system, and the difficulty of scaling up what we do know to the level of global climate effects, including effects on oceans, ecosystems, mountains, rivers, groundwater, solar variation, greenhouse gas emissions, clouds, aerosols,



water vapor, and historical variation, then trying to scale the impacts back down to the local and regional level, we are left with a view best characterized as "through a glass, darkly."

One need not look beyond the landmark 1995 Intergovernmental Panel on Climate Change (IPCC) reports themselves (the often-thumped but rarely read bible of climate change) for expressions of that uncertainty. Even a cursory review of the accepted uncertainties surrounding climate change show that uncertainties loom large, especially at the regional levels where, theoretically, impacts of climate change would be most significant:

Impacts are difficult to quantify, and existing studies are limited in scope. While our knowledge has increased significantly during the last decade and qualitative estimates can be developed, quantitative projections of the impacts of climate change on any particular system at any particular location are difficult because regional scale climate change projections are uncertain; our current understanding of many critical processes is limited; and systems are subject to multiple climatic and non-climatic stresses, the interaction of which are not always linear or additive. Most impact studies have assessed how systems would respond to climate changes resulting from an arbitrary doubling of equivalent atmospheric carbon dioxide concentrations. Furthermore, very few studies have considered greenhouse gas concentrations; fewer still have examined the consequences of increases beyond a doubling of equivalent atmospheric carbon dioxide concentrations, or assessed the implications of multiple stress factors.

— p. 346 of the 1995 IPCC Impacts volume

Tides, waves, and storm surges could be affected by regional climate changes, but future projections are, at present, highly uncertain.

— p. 41 of the 1995 IPCC Science volume

Confidence is higher in hemispheric to continental scale projections of climate change than at regional scales where confidence remains low.

— p. 41 of the 1995 IPCC Science volume

7. IS IT GETTING HOTTER?

Assuming that we can trust the temperature data that we have available to us, the answer seems to be "yes, in recent years, the average temperature of the Earth's atmosphere seems to be increasing a bit." But despite recent misleading statements to the contrary, arbitrarily pointing to months which are hotter than normal, compared to an equally arbitrary stretch of recent history is not "proof" of climate change. In fact, it's not proof of anything at all.

That's because the question of whether it's getting hotter is meaningless without a discussion of historical perspective and relevant measuring period. Climate has fluctuated, often wildly, for more than four billion years. Given that we have so little hard data about past climate conditions, the most honest answer to this question is "maybe" and even that answer is meaningless without some kind of qualifying time frame, and standard of comparison. We can construct crude temperature maps of the past based on a variety of surrogate measures such as evidence of glaciation, fossils, tree-rings, etc., but one must keep in mind that such profiles are inexact at best.

Our hard temperature data is more limited yet, an imperfect data set spanning only about 150 years, less than 0.000004 percent of the entire time-span of fluctuating temperatures. In fact, temperature records are spotty before about 40 years ago and only cover a tiny portion of the globe, mostly over land. In addition to that 150-year conventional surface temperature record, temperature readings taken from weather balloons cover the last 30 years, and satellite temperature readings cover only the last 18 years.

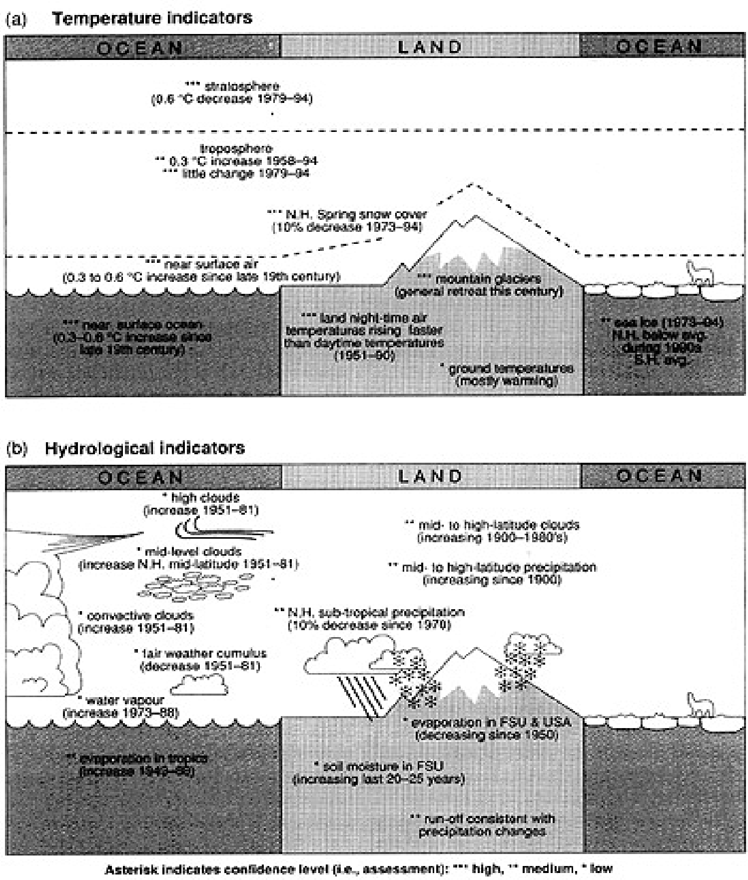
Though in recent times we seem to be seeing a minor warming in the Earth's average temperature, as best we can measure it, one has to keep in mind that historical perspective is crucial in figuring out what that means. Consider the stock market by analogy. If stocks fell for one day, would that be meaningful evidence of a 100-year decline? What if they fell for even one week? When one considers that the stock market is still largely unpredictable even with all the detailed data available about its rise and fall, all of the records about company performance, and all of the incentive that is implicit in developing a good predictive theory, one should be twice-cautious about giving undue weight to possibly short-term fluctuations in global temperatures.

8. IS THE CLIMATE CHANGING ABNORMALLY?

Outside of temperature, the climate changes in numerous ways, with fluctuations in the level of glaciation, rainfall, cloud cover, humidity levels, and so on. But our understanding of these changes is even less certain than is our understanding of the Earth's temperature record. As this chart from the IPCC climate science report shows, the data are decidedly mixed:

While the IPCC report holds that there is a discernable human influence on climate, this conclusion is not dependent on the evidence of actual changes in the Earth's climate as shown in this figure. On that note, the IPCC says,

Despite this consistency [in the pattern of change], it should be clear from the earlier parts of this chapter that current data and systems are inadequate for the complete description of climate change.



Summary of Temperature and Hydrological Changes
(Notes: NH=northern hemisphere, SH=southern hemisphere, FSU=former Soviet Union; Source: IPCC, Figure 3.22, p. 180)

9. ARE HUMANS CAUSING CLIMATE CHANGE?

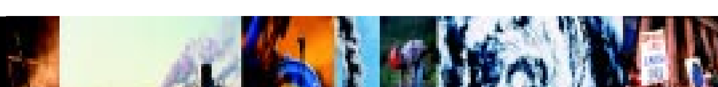
While the greenhouse effect is a relatively uncontroversial issue in the scientific sense, the theory of global, manmade (or *anthropogenic*) climate change is at a much younger stage of development. Although there are very few articles appearing in science journals that contradict either the overall theory or details of the underlying greenhouse effect, the same can not be said for the theory of manmade climate change. Indeed, studies jockey back and forth about key elements of manmade climate change nearly every month on the pages of leading science journals including America's premier science journal, *Science.*

On the difficult issue of attribution of human causality to the observed changes in the climate, the IPCC says:

Finally, we come to the difficult question of when the detection and attribution of human-induced climate change is likely to occur. The answer to this question must be subjective, particularly in the light of the large signal and noise uncertainties discussed in this chapter. Some scientists maintain that these uncertainties currently preclude any answer to the question posed above. Other scientists would and have claimed, on the basis of the statistical results presented in Section 8.4, that confident detection of a significant anthropogenic climate change has already occurred.

And, in explaining the changes shown in the figure above, the IPCC sums up the question of attributing observed climate changes to human action, thus:

Although these global mean results suggest that there is some anthropogenic component in the observed temperature record, they cannot be considered as compelling evidence of a clear cause-and-effect link between anthropogenic forcing and changes in the Earth's surface temperature.



10. IF HUMANS ARE CAUSING CLIMATE CHANGE, WHAT CAN WE DO ABOUT IT?

Environmental policy-making is not an objective, value-free activity, and science can't "dictate" the selection of a solution; but the various options can be identified, defined, and quantified using the organized, rationalist, and transparent modes of thought and analysis that we consider "scientific." Scientists can also weigh in on whether, in their analysis, a particular proposed solution is properly grounded in the data, and can reasonably be expected to describe the real world. While many values will come into play during the decisionmaking process, making maximal use of scientific thinking can only improve the chances of success.

That's because, for any risk we face, there are many available risk-reduction actions available to us that let us move toward the goal of decreased risk for ourselves and our children. Does the actual evidence tell us what to do in any given case? No. But it does suggest what we **can** do with any probability of success.

At the most generic level of classification, our options range from the resilient to the anticipatory — from doing more research, fostering the natural tendency of developed society to use more-efficient and safer fuels, and addressing specific

APPROPRIATE STRATEGIES FOR DIFFERENT CONDITIONS

Predictability of Future Change	Amount of Knowledge About What to Do: Small	Amount of Knowledge About What to Do: Large
High	More resilience, less anticipation	Anticipation
Low	Resilience	More resilience, less anticipation

Adapted from Aaron Wildavsky's *Searching For Safety*, Transaction Press, 1991.

observable problems as they become manifest — to picking specific climate interventions now, even in the face of uncertainty.

But do the quantity and nature of the evidence indicate whether it's time to act, or time to nurture the naturally risk-reducing, resilient growth that is a hallmark of our social system while we study the problem, and engage in other "no regrets" actions to improve energy efficiency?

A framework developed by risk-policy authority Aaron Wildavsky helps us answer that question. Wildavsky observed that the limiting factor in determining whether or not a potential anticipatory risk-reduction action is likely to be more beneficial than a resilient one depends not on what we know, but on what we don't know.

What becomes apparent in this type of "failure analysis" framework is that it is not our knowledge, but our **uncertainties** which most strongly indicate the choice of pathway because: 1) the conditions needed to assure a reasonable chance of success for anticipatory actions are quite stringent; 2) there are more ways to get things wrong than to get them right; and 3) costly experimentation leaves us less well prepared to deal with other current or future problems.

11. WHAT WILL THE KYOTO PROTOCOL DO?

Again, science, by itself, can't determine whether we should or should not adopt the Kyoto Protocol on Climate Change, (an international agreement accepted by the Clinton Administration in December of 1997, but as yet unratified by the United States Senate), but scientific methods can characterize the probable outcomes of doing so and facilitate fact-based decisionmaking.

The belief that the Kyoto Protocol by itself is unlikely to provide meaningful risk reduction benefits is widespread among those people cited as experts by proponents of the protocol at the 1997 Kyoto conference on climate change.

Jerry Mahlman, Director of the Geophysical Fluid Dynamics Laboratory at Princeton University, told the *Washington Post* that "The best Kyoto can do is to produce a small decrease in the rate of increase" In a post-Kyoto *Science* news brief, Mahlman says that "it might take another 30 Kyotos over the next century to cut global warming down to size."

Bert Bolin, the outgoing chairman of the United Nations Intergovernmental Panel on Climate Change, assessed the impact of Kyoto as a 0.4 percent reduction in greenhouse gas emissions compared to a no-protocol alternative, and concluded: "The Kyoto conference did not achieve much with regard to limiting the buildup of greenhouse gases in the atmosphere."

Robert Repetto at World Resources Institute acknowledges that the Kyoto accord is little more than a tiny step toward a distant end, rather than a significant step in itself: "Nobody thought in their wildest dreams that Kyoto would solve the climate problem…If implemented, the achievement at Kyoto will be to get nations off a business-as-usual trajectory, and onto a path that peaks, and then starts going down."

And as Tom Wigley, a climate researcher at the National Center for Atmospheric Research in Colorado, puts it, "A short-term target and timetable, like that adopted at Kyoto, avoids the issue of stabilizing concentrations [of greenhouse gases] entirely."

In other words, near-term benefits of the Kyoto Protocol are more tangible in political terms – as initiating a new direction in policy – than in terms of tangible environmental or risk-reduction benefits.

But there is also the long term to consider. Given that significant climate change might have the potential to cause great increases in risks to human health, consideration of the long-term policy implications of the Kyoto Protocol's "first step" is warranted.

Yet that's precisely where things get the least certain, since the scaling up of the modest and validated greenhouse effect to the level of global climate effects, including effects on oceans, ecosystems, mountains, rivers, groundwater, solar variation, greenhouse gas emissions, clouds, aerosols, water vapor, and historical variation, then trying to scale the impacts back down to the local and regional level blurs the situation terribly.

Based on our research, and that of other analysts, the most one can reliably say about the Kyoto Protocol approach to climate change, the selection of somewhat arbitrary greenhouse gas reductions as the first step in a long process of stabilizing greenhouse gas reductions, is that the short-term benefits are scant, and the long-term benefits are highly uncertain.

12. WHAT IS THE CONSENSUS OF THE SCIENTIFIC COMMUNITY?

A by-product of the climate change debate has been a great deal of acrimony and recrimination between groups advocating rapid anticipatory action, and others who advocate alternative responses. Both sides have periodically gone beyond the bounds of reasonable argumentation and descended into name calling and rhetoric. This politicization and other forms of political intervention in the scientific process have largely deprived us of the ability to use the "consensus of the scientific community" as a meaningful indicator of certainty.

In this atmosphere of mutual distrust, some industry and public policy groups have claimed that climate change is just a big hoax. Other groups have claimed that climate change is the biggest disaster man will ever face, justifying virtually any action, with small regard for consequences on our livelihoods and lifestyles. Some have claimed that the science is a "done deal," that the evidence is beyond question, and that our knowledge is well beyond what we need to know to act as strongly as we want to. Others have claimed that the science is "junk," nothing more than guesses, if not outright distortion and fabrication.

Some groups proclaim that the "consensus of scientists" overwhelmingly supports anticipatory approaches to climate change, while others claim that the "consensus of scientists" is insufficient to warrant anticipatory approaches to climate change. Each group has its own lists of scientists, with various celebrated Nobel prize winners among them.

Is there something in all this squabbling that really sheds light on what we know, or what we should do? The simple answer is "No." Science is a big tent, full of diverse opinions based on differing interpretations of evidence. It's a competitive process in which outright hoaxes or falsehoods tend to be discovered before the ink is dry on the first publication. And science is never "done," it's a process without a fixed goal. It's open 24 hours a day, 7 days a week, 365 days a year. Finally, science is not a "consen-

sus" process, it's an individualistic one in which scientists compete with theories that try to explain more about the world around us. It's both an evolutionary process and, sometimes a revolutionary one, where researchers compete to reveal more about how the world works.

Science can contribute to our understanding of climate change, and science is (and should remain) an integral part of the policymaking process. But the conflict-ridden climate change policy process has taught us one good lesson: we have a long way to go before we'll figure out how to keep what we value from science — its transparency and openness, its rigorous methodologies, its continuing process of discovery, its reliability based on the process of peer-review — when science becomes immersed in a political process that has very different and frequently incompatible values.

Surprisingly enough, the best answer to this science question might have been answered in a pre-scientific age, by Gautama Buddha, who said:

Do not believe in anything simply because you have heard it. Do not believe in anything simply because it is spoken and rumored by many. Do not believe in anything simply because it is found written in your religious books. Do not believe in anything merely on the authority of your teachers and elders. Do not believe in traditions because they have been handed down for many generations. But after observation and analysis, when you find that anything agrees with reason and is conducive to the good and benefit of one and all, then accept it and live up to it.

13. WHERE DO WE NEED MORE RESEARCH?

While recent studies of climate have contributed a great deal to our understanding of climate dynamics, there is still much to learn. The process of searching for evidence of manmade climate change, in fact, is both a search for new discoveries about how climate works, and continuing refinement of our understanding of the underlying theories we already have.

Many areas of uncertainty remain. Current climate change models have acknowledged weaknesses in their handling of changes in the sun's output, volcanic aerosols, oceanic processes, and land processes which can influence climate change.

Some of those uncertainties may be large enough to become the tail which wags the dog of climate change theory. Three of the major uncertainties which remain are discussed below.

A. The Natural Variability of Climate

Despite the extensive discussion of climate modeling and knowledge of past climate cycles, only the last 1000 years of climate variation are included in the two state-of-the-art climate models referred to by the IPCC. As discussed earlier, however, the framework in which we view climate variability makes a significant difference in the conclusions we draw regarding either the comparative magnitude or rate of climate changes, or the interpretation of those changes as being either inside or outside of the envelope of normal climate change variations. The IPCC report summarizes the situation succinctly:

Large and rapid climatic changes occurred during the last ice age and during the transition towards the present Holocene period. Some of these changes may have occurred on time-scales of a few decades, at least in the North Atlantic where they are best documented. They affected atmospheric and oceanic circulation and temperature, and the hydrologic cycle. There are suggestions that similar rapid changes may have also occurred during the last interglacial period (the Eemian), but this requires confirmation. The recent (20th century) warming needs to be considered in the light of evidence that rapid climatic changes can occur naturally in the climate. However, temperatures have been far less variable during the last 10,000 years (i.e., during the Holocene).

Until we know which perspective is more reflective of Earth's climate as a whole—the last 10,000 years, or a longer period of time—it will be difficult to put recent warming trends in perspective, or to relate those trends to potential impacts on the climate, and on the Earth's flora and fauna.

B. The Role of Solar Activity

At the front end of the climate cycle is the single largest source of energy which is put into the system, namely, the sun. And while great attention has been paid to most other aspects of climate, little attention has been paid to the sun's role in the heating or cooling of the Earth. Several recent studies have highlighted this uncertainty, showing that solar variability may play a far larger role in the Earth's climate than it was previously given credit for by the IPCC. If the sun has been heating up in recent times, researchers observe, the increased solar radiation could be responsible for up to half of the observed climate warming of the past century. Astrophysicist Sallie L. Baliunas attributes up to 71 percent of the observed climate warming of the past century to increased solar irradiance. Other researchers such as climatologist T.M.L. Wigley, however, rank the influence of solar activity on climate warming much lower, at "somewhere between 10 percent and 30 percent of the past warming." But as with satellite measurements of Earth's temperature, the short time line of satellite measurements of solar irradiance introduces significant uncertainty into the picture. Most researchers believe that at least another decade of solar radiation measurement will be needed to clearly define the influence of solar input on the global climate.

C. The Role of Clouds and Water Vapor

Between the emission of greenhouse gases and change in the climate are a range of climate and biological cycles that can influence the end result. Such effects are called "feedbacks" in the climate change literature.

One such feedback is the influence of clouds and water vapor. As the climate warms, more water vapor enters the atmosphere, but how much? And, which parts of the atmosphere, high or low? And how does the increased humidity affect cloud formation? We just don't know. And while the relationship between clouds, water vapor, and global climate is complicated in and of itself, the situation is further complicated by the fact that aerosols exert yet another poorly understood influence on clouds. Research suggests that aerosols alone may offset 20 percent of the expected impact of warming gases. In addition, though direct cooling impacts of aerosols are now being taken into account by climate models, aerosol impact on clouds remains a poorly defined effect with broad implications, given a range of additional cooling potential of up to 61 percent of the expected warming impact from the warming greenhouse gases.

As the IPCC report acknowledges: "the single largest uncertainty in determining the climate sensitivity to either natural or anthropogenic [or "manmade"] changes are clouds and their effects on radiation and their role in the hydrological cycle…At the present time, weaknesses in the parameterization of cloud formation and dissipation are probably the main impediment to improvements in the simulation of cloud effects on climate."

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Dr. Kenneth Green is Director of Environmental Program at the Reason Public Policy Institute. Dr. Green has published seven previous peer-reviewed policy studies on air quality and environmental risk including: *A Plain English Guide to the Science of Climate Change, Evaluating the Kyoto Approach to Climate Change, Rethinking EPA's Proposed Ozone and Particulate Standards, Estimating Fatalities Induced by Economic Impacts of EPA's proposed Ozone and Particulate Standards (co-authored), Looking Beyond ECO, Defending Automobility, and Checking Up on Smog Check.* Green, who received his doctorate in environmental science and engineering (D.Env.) from UCLA in 1994, joined RPPI soon after, and now works from his home-office in Central Texas.

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