

The Latest Myths and Facts on Global Warming



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The Latest Myths and Facts on Global Warming

AUTHORS

Dr. James Wang

SCIENTIST, CLIMATE AND AIR PROGRAM, ENVIRONMENTAL DEFENSE

Dr. Michael Oppenheimer

PROFESSOR OF GEOSCIENCES AND INTERNATIONAL AFFAIRS, PRINCETON UNIVERSITY

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Contents

Executive summary	iv
Introduction	1
Part I. Is global warming happening?	2
MYTH #1: Winters have been getting colder	2
MYTH #2: Satellite measurements show a smaller warming than surface measurements	2
MYTH #3: The warming over the past century is nothing unusual; it is part of a natural cycle	3
MYTH #4: Earth's climate is self-regulating	5
MYTH #5: Recent extreme events have no link to climate change	5
Part II. Is global warming being caused by human activities?	8
MYTH #6: Humans cannot be responsible for the increase in atmospheric CO ₂	8
MYTH #7: The warming of the past century has been caused by natural factors, such as solar variability, a recovery from the Little Ice Age, cosmic rays	8
MYTH #8: Global warming has been caused by the urban heat island effect	10
Part III. Can we have any confidence in predictions of future climate change?	11
MYTH #9: Models cannot predict the climate many years in advance	11
MYTH #10: Models have many flaws that make them useless in predicting climate	11
MYTH #11: The growth of emissions in the IPCC scenarios is unrealistically high	11
MYTH #12: We can't trust global warming predictions since scientists just a few decades ago warned that a new ice age was approaching	12
MYTH #13: The science behind the theory of global warming is too uncertain for policy making	13
Part IV. How harmful would the predicted warming be?	14
MYTH #14: The warming predicted by the IPCC is small and hardly a cause for concern	14
MYTH #15: Global warming and increased CO ₂ would be beneficial	14
Part V. What should we do about global warming?	16
MYTH #16: Society can easily adapt to climate change	16
MYTH #17: Forests in the Northern Hemisphere are absorbing as much CO ₂ as is emitted by burning fossil fuels	16
MYTH #18: It would be safe and more effective to wait to solve the problem rather than act now	17
MYTH #19: Humankind is foolish to believe it is capable of controlling the climate	17
References	18
Figures	
Figure 1: Temperature trends for the Northern Hemisphere over the past 1,000–2,000 years.	4
Figure 2: Comparison of modeled and observed temperature trends since 1860	9

Executive summary

This summary provides a brief overview of the most common myths regarding global warming. For a more comprehensive and in-depth discussion of the scientific issues, please see the main body of the report. While written for a general audience, the main body of the report includes citations of peer-reviewed scientific literature.

MYTH: *Global warming can't be happening, since winters have been getting colder.*

FACT: Winters have been getting warmer. Measurements show that Earth's climate has warmed overall over the past century, in all seasons, and in most regions. The skeptics mislead the public when they bill the winter of 2003–2004 as record cold in the northeastern United States. That winter was only the 33rd coldest in the region since records began in 1896. Furthermore, a single spell of cold *weather* in one small region is no indication of cooling of the global *climate*, which refers to a long-term average over the entire planet.

MYTH: *Satellite measurements of temperature over the past two decades show a much smaller warming in the atmosphere than is measured by thermometers at the surface. This contradicts global warming predictions based on climate models.*

FACT: Recent research has corrected problems that led to underestimates of the warming trend in earlier analyses of satellite data. The new results show an atmospheric warming trend slightly larger than at the surface, exactly as models predict.

MYTH: *The global warming over the past century is nothing unusual. For example, the Medieval Warm Period (MWP), roughly from A.D. 1000 to 1400, was warmer than the 20th century. This indicates the global warming we are experiencing now is part of a natural cycle.*

FACT: Ten independent scientific studies all have found a large 20th-century warming trend compared to temperature changes over the past millennium or two. Uncertainty exists as to exactly how warm the present is compared to the MWP. Some studies have received valid criticism for possibly underestimating the magnitude of longer-lasting, century-scale temperature changes, such as the warming during the MWP. However, other studies, using different methods, still find no evidence of any period during the last 2,000 years that was warmer than the 1990s. Most importantly, any uncertainty about whether the present is warmer than the MWP has little effect on the finding that humans likely have caused most of the warming over the past 50 years. A separate body of studies has provided the main evidence for this finding. (See the Myth on causes of warming.)

MYTH: *Human activities contribute only a small fraction of carbon dioxide (CO₂) emissions, far too small to have a significant effect on the concentration of the greenhouse gas in the atmosphere.*

FACT: Before the Industrial Revolution, the amount of CO₂ emitted from large natural sources closely matched the amount that was removed through natural processes. That balance has now been upset by human activities, which since the

Industrial Revolution have put twice as much CO₂ into the atmosphere as can be readily removed by the oceans and forests. This has resulted in the accumulation of CO₂ to the highest levels in 420,000 years.

MYTH: *The Earth's warming is caused by natural factors like increased sunlight and sunspots or decreased cosmic rays, not by greenhouse gases (GHGs).*

FACT: Modeling studies indicate that most of the warming over the past several decades was probably caused by the increase in human-produced GHGs. Climate models have difficulty reproducing the observed temperature changes over the past 150 years unless they account for the increase in GHGs as well as natural factors, such as sunlight and volcanic eruptions, and changes in the amount of human-produced sulfate particles, which cool the planet. Satellite measurements of the intensity of sunlight exhibit little or no trend over the past 25 years, when there was rapid warming on Earth. The purported correlations between the amount of cosmic rays and Earth's temperature are the result of flawed analysis methods.

MYTH: *The warming observed during the past century was caused by urbanization (urban heat island effect).*

FACT: Urbanization does increase temperatures locally, affecting thermometer readings in certain areas. But the temperature data used in trend analyses are adjusted to remove any bias from urbanization. In any case, urbanization has an insignificant effect on global temperature trends.

MYTH: *Models have trouble predicting the weather a few days in advance. How can we have any confidence in model projections of the climate many years from now?*

FACT: Climate prediction is different from weather prediction, just as climate is different from weather. Models are now sophisticated enough to be able to reproduce the observed global average climates over the past century as well as over other periods in the past. Thus, scientists are confident in the models' ability to produce reliable projections of future climate for large regions. Furthermore, climate assessments typically consider the results from a range of models and scenarios for future GHG emissions, in order to identify the most likely range for future climatic change.

MYTH: *The science behind the theory of global warming is too uncertain to draw conclusions useful to policy makers.*

FACT: The primary scientific debate is about how much and how fast, rather than whether, additional warming will occur as a result of human-produced GHG emissions. While skeptics like to emphasize the lower end of warming projections, uncertainty actually applies to both ends of the spectrum—the climate could change even more dramatically than most models predict. Finally, in matters other than climate change, policy decisions based on uncertain information are made routinely by governments to ensure against undesirable outcomes. In the case of global warming, scientists have given society an early warning on its possibly dangerous, irreversible and widespread impacts.

MYTH: *Global warming and increased CO₂ would be beneficial, reducing cold-related deaths and increasing plant growth ("greening the Earth").*

FACT: If society does not limit further warming, the beneficial effects probably will be heavily outweighed by negative effects. Regarding cold-related deaths, studies have indicated that they might not decrease enough to compensate for a significant increase in heat-related deaths. Even though higher levels of CO₂ can act as a plant fertilizer under some conditions, they do not necessarily benefit the planet, since the fertilization effect can diminish after a few years in natural ecosystems as plants acclimate. Furthermore, increased CO₂ may benefit undesirable, weedy species more than others.

MYTH: *Society can easily adapt to climate change; after all, human civilization has survived through climatic changes in the past.*

FACT: While humans as a species have survived through past climatic changes, individual civilizations have collapsed. Unless we limit GHGs in the atmosphere, we will face a warming trend unseen since the beginning of human civilization. Many densely populated areas, such as low-lying coastal zones, are highly vulnerable to climate shifts. A middle-of-the-range projection indicates the homes of 13 to 88 million people would be flooded by the sea each year in the 2080s. Many ecosystems and species already threatened by other human activities may be pushed to the point of extinction.

MYTH: *CO₂ is removed from the atmosphere fairly quickly, so we can wait to take action until after we start to see dangerous impacts from global warming.*

FACT: Global warming cannot be halted quickly. CO₂ and other GHGs can remain in the atmosphere for many centuries. Even if emissions were eliminated today, it would take centuries for the heat-trapping GHGs now in the atmosphere to fall to pre-industrial levels. Only by starting to cut emissions now can humanity avoid the increasingly dangerous and irreversible consequences of climate change.

Introduction

A vast majority of climate scientists agree that global warming is happening and that it poses a serious threat to society. They also agree that it is being caused largely by human activities that release greenhouse gases, such as burning fossil fuels in power plants and cars and deforesting the land. This scientific consensus emerged gradually over decades of research and debate. The current state of knowledge on climate is summed up in the periodic reports of the Intergovernmental Panel on Climate Change (IPCC), which are compiled by thousands of scientists. Unfortunately, much of the American public remains unaware of this overwhelming scientific agreement. Part of the blame for this lies with coordinated efforts within certain industries to spread misinformation about global warming.

This report is intended to provide a comprehensive discussion of common myths and misunderstandings regarding climate change. Our goal is to provide members of Congress and their staff, journalists and the public with detailed, well-researched and user-friendly information on these issues. This will allow readers to see that global warming science is not split between two opposing camps, as the public may often believe. Our rebuttals of myths are based on peer-reviewed, widely accepted scientific publications, which are cited and listed at the end of the report. For a less technical summary of only the most common myths, see the executive summary.¹

¹ This report will be updated in response to new developments. Suggestions for improvements and additions are welcome. Please send suggestions to Dr. James Wang, Environmental Defense, 257 Park Ave. S., New York, NY 10010; jwang@environmentaldefense.org

Is global warming happening?

MYTH #1: *Winters have been getting colder; for example, the winter of 2003–2004 in the northeastern U.S. was the coldest on record. Therefore global warming can't be happening.*

FACT: Winters have been getting warmer. Independent analyses of measurements by different scientists show that the Earth's climate has warmed overall over the past century, in all seasons, and in most regions. (The studies are summarized in the Third Assessment Report of the Intergovernmental Panel on Climate Change, 2001.)

The skeptics are doubly misleading when they bill the winter of 2003–2004 as record cold in the northeastern U.S. and imply that it disproves global warming predictions. While that winter was colder than average in the Northeast, it ranked as only the 33rd coldest in that region since records began in 1896 (NCDC, *Climate of 2004*, 2004). January 2004, when the most severe cold of the season occurred, was the 11th coldest January in the Northeast. No all-time low temperature records were broken in the Northeast that winter (NCDC, *Climate of 2004*, 2004). Only records for a given day of the year, such as January 16th, were broken, which is nothing unusual; the temperatures were not the coldest that had ever been experienced on any day. This contrasts with the 2003 heat waves in Europe, during which many all-time record high temperatures occurred (see Myth #5).

In addition, *a single spell of cold weather in one small region is no indication that the Earth's climate is not warming.* “Weather” refers to the atmospheric conditions at a particular time and location, while “climate” refers to the long-term average weather for a location. Scientists say that the Earth's climate has been warming, since, on average, temperatures have been increasing over a long period of time in most regions. The global average temperature for January 2004 ranked as the fourth warmest on record (NCDC, *Climate of 2004*, 2004), showing that colder-than-usual weather was limited to a small area. Even with global warming, we will occasionally experience an unusually cold winter somewhere on Earth, since weather varies naturally from year to year and from place to place. But record-breaking cold is expected to become less common as the climate continues to warm, shifting the bounds within which weather fluctuates.

MYTH #2: *Satellite measurements of temperature over the past two decades show a much smaller warming a few miles above Earth's surface than is measured by thermometers at the surface.² These observations show that computer climate models are wrong, since they predict that increasing amounts of greenhouse gases should cause slightly greater warming above the surface.*

FACT: Recent research has corrected problems that led to underestimates of the warming trend in earlier analyses of satellite data. The early work of Spencer and Christy (1990), as well as subsequent revisions (Christy et al. 2003, and references therein), found little or no warming in the troposphere based on satellite data. Skeptics continue to cite these results.

But two recent studies made different corrections to those analyses which, when added together, completely eliminate the discrepancy between climate models and

² The region of the atmosphere examined in these satellite analyses, comprising the lowermost part of the atmosphere, is known as the *troposphere*.

observations. Mears et al. (2003), in a reanalysis of the satellite data, took into account various difficulties in determining a temperature trend from weather satellites. First, since no single satellite has been monitoring temperatures for a long period of time, researchers have had to rely on combining data from different satellites. However, different satellites have different instruments that need to be calibrated precisely against one another. Second, even one satellite may not produce consistent measurements over time, since satellite orbits can drift. After accounting for these factors, Mears et al. found a satellite temperature trend closer in size to the surface trend than in previous studies.

Fu et al. (2004) found another major problem with previous analyses. Satellite data that actually blend temperature readings in the stratosphere (the layer of atmosphere above the troposphere) with those in the troposphere were previously misinterpreted as representing only tropospheric temperatures. A strong cooling of the stratosphere over the same time period partly cancels out the tropospheric warming in the satellite measurements (the averaging of a warming trend and a cooling trend results in little trend).³ Fu et al. isolated the portion of the data that represented just the troposphere, and, accounting also for the corrections by Mears et al., found that the troposphere warmed slightly more than the surface, exactly as models predict. This finding dispels the notion that satellite data disprove the role of greenhouse gases in global warming.

Weather balloon measurements may also show a smaller tropospheric warming trend than that observed at the surface. But here again, the interpretation of these measurements suffers from difficulties, such as sparse spatial coverage and inconsistencies among instruments (Fu et al. 2004). So trends derived from balloon data are not reliable.

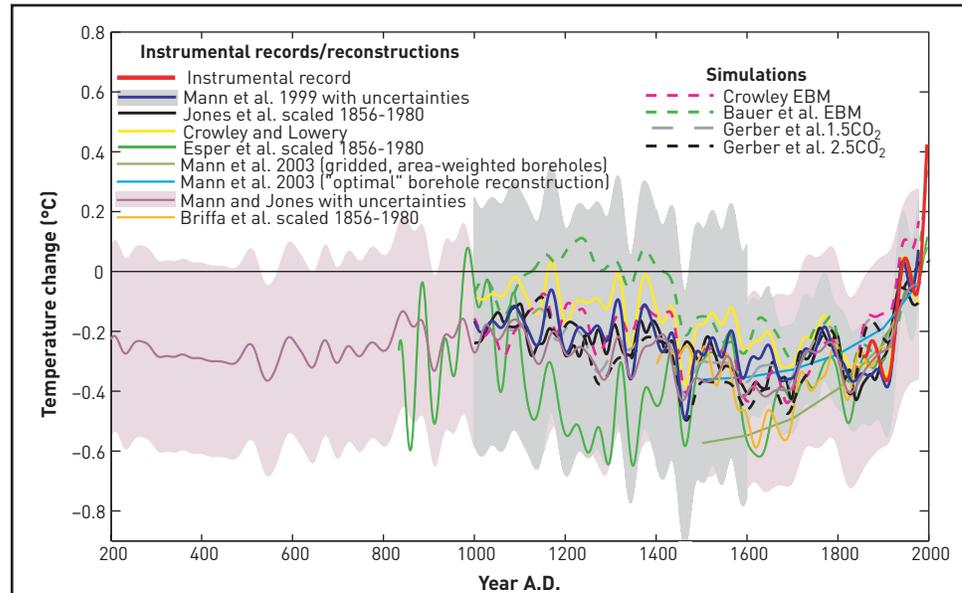
MYTH #3: *Even if Earth has been warming over the past century, it is nothing unusual. For example, temperature reconstructions show that there was a period known as the Medieval Warm Period, roughly from A.D. 1000 to 1400, that was warmer than the 20th century. This means that the global warming we are experiencing now is part of a natural cycle.*

FACT: Ten independent scientific studies have all found a large 20th-century warming trend compared to other temperature changes over the past millennium or two. (See Figure 1a.) Some of the studies carefully reconstructed a history of temperatures across the globe over the past 1,000 years or more based on different kinds of records (ice cores, tree rings, historical documents, etc.) The rest of the studies calculated past temperature changes using climate models and an estimate of how climatic factors such as sunlight, volcanic eruptions and greenhouse gases changed over time.

Uncertainty exists as to exactly how warm the present is compared to the Medieval Warm Period. Recently, von Storch et al. (2004) argued validly that the method used in some temperature reconstruction studies may underestimate the magnitude of past climate changes; however, the study does not answer the question of how warm the Medieval Warm Period actually was. Further support for the idea of an unusual 20th century warming is provided by a recent temperature reconstruction by Moberg et al. (2005), who consciously avoided the method criticized by von Storch et al. Although

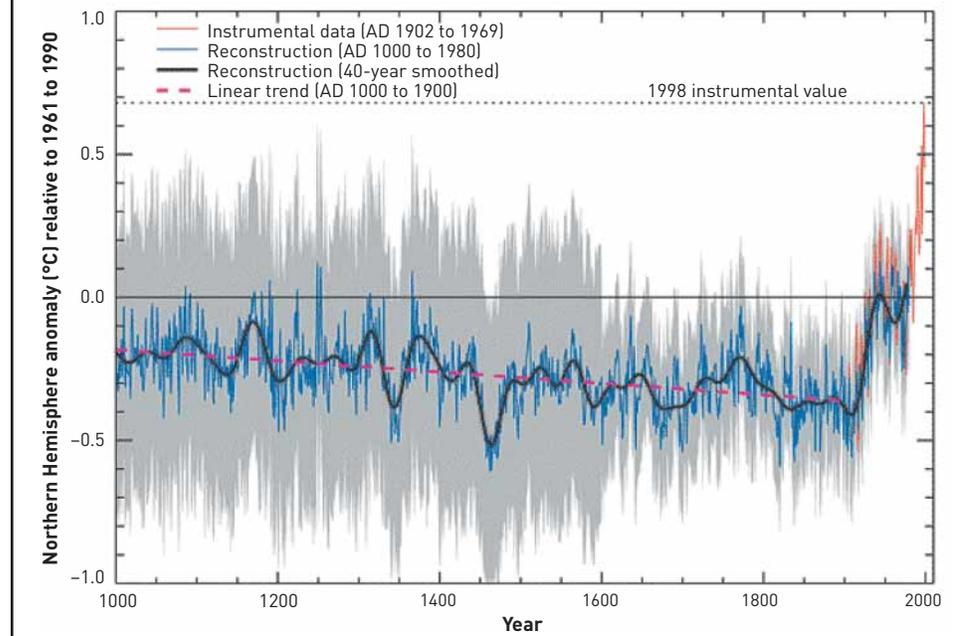
³ The cooling of the stratosphere was largely a result of ozone depletion caused by chlorofluorocarbons (CFCs) and other human-produced chemicals.

FIGURE 1
Temperature trends for the Northern Hemisphere over the past 1,000–2,000 years.



a) Comparison of various temperature reconstructions and model simulations for the Northern Hemisphere (more data is available here than in the Southern Hemisphere) for the last 2,000 years. All show anomalous warming in the 20th century.

Source: Mann et al. (2003a). Copyright 2003 American Geophysical Union. Reprinted by permission of American Geophysical Union.



b) Northern Hemisphere temperature changes over the past millennium based on the work of Mann et al. (1999). The gray vertical lines represent the uncertainty (two standard deviations).

Source: Reprinted with permission from the IPCC Third Assessment Report (2001).

Whether or not the Medieval Warm Period was warmer than the present provides only one piece of evidence in determining what is causing the current warming.

they find that the Medieval Warm Period may have been warmer than previously estimated, they “find no evidence for any earlier periods in the last two millennia with warmer conditions than the post-1990 period—in agreement with previous similar studies.” In contrast to these two studies, a number of papers arguing for a very warm Medieval Warm Period contain serious flaws. These include articles by Willie Soon and Sallie Baliunas, and Stephen McIntyre and Ross McKittrick. See the box on “The ‘hockey stick’ controversy.”

But what if future research were to produce results drastically different from the scientific studies to date, indicating with a high degree of certainty that the Medieval Warm Period was warmer than the present? That would have very little impact on the scientific case for a human cause of the current warming; whether or not the Medieval Warm Period was warmer provides only one piece of evidence in determining what is causing the current warming. That there were warmer periods in the past caused by natural factors (such as millions of years ago when tropical species flourished in polar regions) is insufficient reason to assume that the current warming also is natural. In fact, a whole body of studies separate from the ones discussed above have focused on the physical factors potentially responsible for changing the climate over the past 150 years, and they indicate with a high degree of confidence that most of the warming over the past 50 years was caused by human-produced greenhouse gases. (See Myth #7.)

The current warming is unlikely to be entirely natural and inevitable. Humanity largely controls how much climate change will unfold over the coming centuries.

MYTH #4: *The Earth’s climate is self-regulating—natural control mechanisms prevent very large swings. For example, Richard Lindzen claims that the Earth has a planetary “iris,” consisting of tropical cloud cover that expands or contracts to control the amount of heat that escapes from the surface out to space (Lindzen et al. 2001).*

FACT: The Earth’s climate actually has been very unstable in the distant past. There have been times, hundreds of millions of years ago, when much of the planet was covered in ice. Tens of millions of years ago, tropical species flourished in polar regions (such as during the era of the dinosaurs). A wealth of scientific evidence indicates that the climate has changed significantly and abruptly (within one or a few decades) numerous times in the past. (For a comprehensive review of the literature on this subject, see the 2002 report by the National Academy of Sciences.) While the climate has been relatively stable since human civilization started around 10,000 years ago, the warming projected to occur over the next century with unrestrained emissions of greenhouse gases is likely to exceed anything seen in the last 10,000 years (IPCC 2001). This warming could cross certain thresholds for abrupt climate change, triggering such dangerous events as a shutdown of the ocean currents that supply nutrients to important fisheries and moderate the climate in Europe and other regions (Sarmiento et al. 2004).

MYTH #5: *Recent extreme events such as record heat waves, intense precipitation, massive forest fires and worldwide coral bleaching have no link to climate change.*

FACT: These recent events are all consistent with a warming world and can be expected to occur more frequently with global warming.

Heat waves and extreme precipitation: Weather fluctuates naturally, resulting at times in extreme events, even in the absence of climate change. However, the increase

The “hockey stick” controversy

Many critiques by global warming skeptics have focused on the work of one particular group of climate scientists, Dr. Michael Mann and colleagues. Their graph of temperature variations over the past 1,000 years (Mann et al. 1999) is featured prominently in the 2001 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The temperature trend is often known as the “hockey stick” because of its shape: nearly flat for most of the millennium and then a sharp upward turn in the 20th century (see Figure 1b). In their critiques of Mann’s findings, the skeptics claim that they have weakened a primary pillar on which the IPCC’s conclusions about human-produced warming rest. That claim is incorrect. The truth is that other independent studies have found similar temperature trends; the differences that do arise do not affect the overall conclusion that 20th century warming is relatively large and long-lasting (see Figure 1a). Furthermore, how warm the Medieval Warm Period was compared to the present, which is the focal point of the skeptics’ critiques, is only a secondary piece of evidence for what is causing the present warming. *The IPCC actually assessed an entirely different body of studies to come to the conclusion that humans caused most of the recent climatic change.*⁴

Some of the analyses critiquing the work of Mann et al. have serious flaws. For example, a pair of similar papers by Willie Soon and Sallie Baliunas use subjective and unscientific methods to paint a picture of a Medieval Warm Period that was much warmer than the present. A rebuttal was published by thirteen climate scientists (Mann et al. 2003a, b). Soon and Baliunas use incorrect criteria for defining past warm periods. They actually consider a period to be warm even if it was simply unusually wet or dry, rather than basing their judgment strictly on direct indicators of temperature. The authors also consider the entire interval, A.D. 800–1300, to be warm, even though their data indicate that the warmth occurred only in scattered regions at any given time. True global warming occurs when temperatures over large areas increase simultaneously. Also, many scientists have found that the results of their

studies were misinterpreted by Soon and Baliunas in a way that bolstered the authors’ thesis (Monastersky 2003).

A paper published in 2003 by Stephen McIntyre and Ross McKittrick, claiming to be an audit of a study by Mann et al. (1998), used data from a corrupted electronic file, arbitrarily omitted 80% of the data before 1600, and replaced certain data with incompatible data, artificially resulting in temperatures during the 1400s that were warmer than during the late 1900s (Rutherford et al., in press, 2005). A paper published in 2005 by McIntyre and McKittrick claims that the hockey stick pattern is an artificial result of the method used by Mann et al. rather than an unbiased compilation of the data. Mann et al. used a version of a method known as principal components analysis, which basically boils a large amount of data down to its main features, or “principal components.” One main problem with McIntyre and McKittrick’s critique is that they misunderstand why Mann et al. used principal components analysis—Mann et al. used it to summarize *all* the important features of the data, not to extract only the *one* chief feature. The reason McIntyre and McKittrick’s version of the data doesn’t have a hockey stick pattern is that they display only the first principal component, omitting other critical principal components. In addition, scientists have shown that the hockey stick pattern emerges regardless of what version of principal components analysis is used or even whether principal components analysis is used (Rutherford et al., in press, 2005).

Recently, von Storch et al. (2004) argued validly that the method used in Mann et al. and some other temperature reconstruction studies may underestimate the magnitude of past climate changes, particularly the longer-lasting, century-scale changes such as during the Medieval Warm Period. But this paper provides no definitive answer as to how large the underestimates are (Osborn and Briffa 2004). Also, the temperature reconstruction of Moberg et al. (2005), which avoids the method criticized by von Storch et al., still provides no indication that there were any periods in the past 2,000 years that were warmer than the 1990s.

⁴ Chapter 2 in volume 1 (“The Scientific Basis”) of the Third Assessment Report describes the hockey stick, while Chapter 12 analyzes the causes of climate change.

in global average temperature over the past century, which constitutes a change in climate, shifts the bounds within which weather fluctuates. This climate change increases the likelihood that high temperature records will be broken and intense precipitation events will occur. (Precipitation becomes more intense because higher temperatures promote increased evaporation and thus higher moisture content in the atmosphere.) In fact, some scientists estimate that human-produced greenhouse gases have already at least doubled the chance of an extreme heat wave like the one that scorched Europe in 2003 (Stott et al. 2004). According to measurements, precipitation appears to have increased in intensity over recent decades, at least in certain regions (IPCC 2001).

During the 2003 heat waves in Europe, many all-time high temperature records were broken. The temperature surpassed 100°F in the United Kingdom for the first time since records began (NCDC, *Climate of 2003*, 2004). Furthermore, the European heat waves were part of an unusually warm summer overall, which appears to have been the hottest in Europe in at least the last 500 years (Luterbacher et al. 2004).

Forest fires: Global warming is expected to cause, and may already have caused, more severe droughts in many regions. The ongoing drought in the western U.S., possibly the worst in 500 years, may be caused by unusually warm waters in the western Pacific and other effects of global warming (Cook et al. 2004; Hoerling and Kumar 2003). Parched conditions and high temperatures associated with drought create ideal conditions for wildfires to spread. Global warming also lengthens the fire season and promotes outbreaks of tree-killing insects, which create a large amount of dry fuel to stoke forest fires (ACIA 2004). The amount of forest burned annually has been increasing over recent decades in some regions, such as the Arctic (ACIA 2004). Alaska experienced its worst fire year ever in 2004, a year with the warmest and third driest summer on record (NIFC 2004).

Coral bleaching: The incidence of large-scale coral “bleaching” events has increased around the world since 1979, and most evidence indicates that these mass bleachings, which can lead to coral death, are caused by global warming (Hoegh-Guldberg 1999). An increase in water temperature causes coral bleaching, and the average surface ocean temperature in many tropical regions rose by almost one degree C (1.8°F) over the last century. In 1997–98, the largest bleaching event on record damaged 16% of the reefs in the world and killed 1,000-year-old corals (Global Coral Reef Monitoring Network 2004; Hoegh-Guldberg 1999).

Is global warming being caused by human activities?

MYTH #6: *The amount of carbon dioxide (CO₂) generated by human activities is much smaller than natural sources; therefore, human activities cannot be responsible for the large observed increase in atmospheric CO₂ over the past few centuries.*

FACT: It is undisputed that humans are entirely responsible for the increase in atmospheric CO₂ over the past few centuries. In pre-industrial times, large natural sources of CO₂ were balanced by equally large natural removal processes, such as photosynthesis in plants, maintaining a stable level of CO₂ in the atmosphere for thousands of years. Human-produced emissions, though smaller than natural emissions, upset this balance. Because human-produced emissions aren't completely absorbed by natural processes, they accumulate in the atmosphere, increasing the concentration of CO₂ (McElroy 2002).

MYTH #7: *The warming of the past century has been caused by natural factors, such as solar variability, a recovery from the Little Ice Age, cosmic rays, etc.; the warming was not caused by the increase in greenhouse gases (GHGs). This is shown by the fact that the warming has not followed the trend of GHG concentrations.*

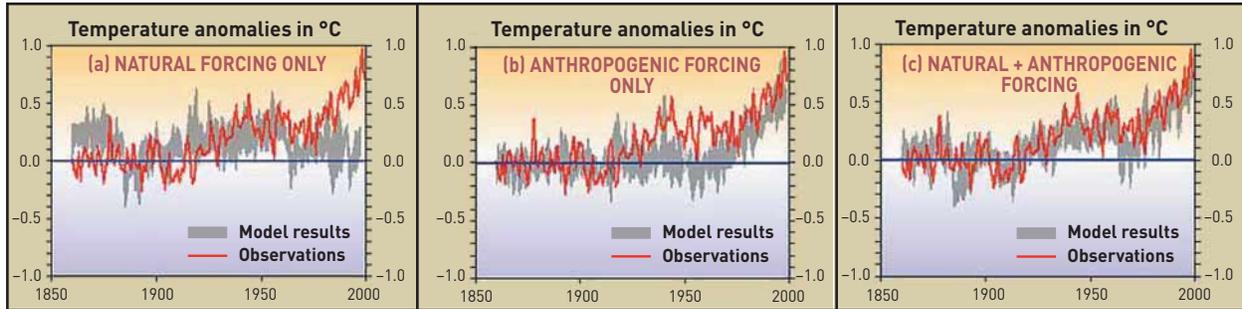
FACT: While natural factors have been important causes of climatic changes in the past, human-produced GHGs have become increasingly dominant over the last century. Scientists know with certainty that GHGs have an important effect on climate. GHG molecules absorb infrared radiation emitted by the Earth's surface and re-emit it downward, acting as a blanket that traps heat at the surface and warms the planet. Without the naturally occurring "greenhouse effect," the average temperature of the Earth would be about 35°C (63°F) colder than at present, or an inhospitable -20°C (-4°F) (McElroy 2002). The problem is that humans are increasing the amount of GHGs in the atmosphere.

Scientists have conducted studies to calculate how much of the warming over the past century was caused by GHGs as opposed to natural factors. When human influences (including the effects of GHGs and cooling sulfate particles⁵) and natural factors (including solar variations, volcanic eruptions and random variability) are both taken into account in climate models, the simulated temperature changes over the past 140 years agree closely with observed changes (see Figure 2). If, however, human influences are omitted from the models, the simulated temperature changes do not match the observed changes. These results provide strong evidence that human influences have contributed to the observed warming. In fact, it is likely that human-produced GHGs have been the *dominant* cause of the observed global warming over the past few decades, as can be seen in Figure 2. Natural factors are unlikely to explain the increased rate of warming since the middle of the 20th century, as the overall trend in natural forcing (warming effect) was likely small or even negative over the last two to four decades, according to measurements (IPCC 2001).

Trends of temperature vs. GHGs: It is true that temperatures have not strictly followed the trend of GHGs—over the past century, temperatures first rose, then fell slightly, then rose again, while GHGs rose steadily the entire time. But our

⁵ Human-produced sulfate particles originate primarily from the combustion of fossil fuels, especially coal. Sulfate particles in the air reflect sunlight and cool the Earth.

FIGURE 2
Comparison of modeled and observed temperature trends since 1860



Source: Figure adapted from IPCC (2001) by permission.

discussion in the previous paragraph provides an obvious explanation. There are factors besides GHGs that affect climate, including natural forces and human-produced sulfate emissions. Since these other factors changed over time, especially early in the century, the pattern of observed temperature changes does not follow just the trend of GHGs.

Solar variability and sunspots: Skeptics often claim that an increase in solar activity and sunspots is responsible for most of the warming over the past century. (Sunspots are small dark areas on the sun. The number of sunspots is higher during periods of high solar activity and high overall sunlight intensity.) The fact is that direct satellite measurements of solar intensity exhibit little or no trend over the past 25 years, a time of rapid warming (IPCC 2001). Thus, changes in sunlight contributed little if anything to recent warming. Changes in the sun are thought to have been an important factor in climate change in the past, such as the first half of the 20th century and the Little Ice Age.

Direct satellite measurements of solar intensity exhibit little or no trend over the past 25 years, a time of rapid warming.

Recovery from the Little Ice Age: Skeptics have claimed that the warming over the 20th century is simply a natural recovery from the Little Ice Age (roughly A.D. 1600–1850), a cool period caused by changes in natural forces. The facts are similar to what we have discussed above: Climate studies have taken into account all the major forces that can change the climate, and have shown that the warming over the second half of the 20th century can be explained only if GHGs are included. While changes in sunlight and volcanic activity can possibly explain the transition into the Little Ice Age, they cannot fully explain the warming since the end of the Little Ice Age.

Cosmic rays: The purported correlations over recent decades and centuries between the amount of cosmic rays hitting the Earth (which is influenced by fluctuations in the solar wind) and cloudiness (which influences surface temperatures) appear to be the result of incorrect treatment of data, as pointed out in a review paper by Laut (2003). For example, the correction of a few erroneous data points removes much of the correlation in several of the graphs that have brought attention to the issue of cosmic rays. Furthermore, there is no proven physical mechanism connecting cosmic rays to the amount of clouds in the atmosphere (Ramaswamy et al. 2001).

Shaviv and Veizer (2003) took a skeptical stance in arguing that the amount of cosmic rays hitting the Earth is highly correlated with the Earth's temperature over time scales of hundreds of millions of years. From this result, the authors made a leap

in logic and asserted that the current centuries-long increase in CO₂ concentrations due to human activities will have only a small warming effect.⁶ Also, Shaviv and Veizer used questionable methods to obtain a high correlation between cosmic ray flux and temperature (Rahmstorf et al. 2004). Furthermore, Royer et al. (2004) found that the non-standard temperature history used by Shaviv and Veizer contained major errors. Royer et al. conclude that there is no reason to revise the conventional view that CO₂ has had a dominant influence on climate variations over the past 545 million years.

MYTH #8: *The global warming observed for the past century at Earth's surface has been caused by urbanization (urban heat island effect) and other changes in land surfaces, such as deforestation, not greenhouse gases.*

FACT: It is true that urbanization increases temperatures locally, and can potentially affect the determination of the global trend, since some measurement sites are located in urban areas. Buildings and pavement absorb sunlight, heating up their surroundings, and dense human settlements release significant amounts of waste heat. Urban and agricultural areas also replace trees, which cool the Earth's surface by providing shade and evaporating water drawn up from the soil. But the claim that the observed increase in global average temperature is due to these changes in land surfaces is wrong, since the analyses showing the warming account for and remove any biases caused by urbanization (for example Hansen et al. 1999; Jones et al. 2001). In any case, it has been shown that urbanization has had an insignificant effect on global and even regional temperature trends (Peterson 2003). In addition, temperatures have risen significantly over oceans as well as over land, providing further evidence that changes in land surfaces are not the primary cause of the observed warming.⁷

⁶ One major flaw in the analysis of Shaviv and Veizer is that the averaging of the data over very long intervals of 50 million years removes information on shorter-term fluctuations in CO₂ and temperature, such as the high correlation between CO₂ and temperature over the past 400,000 years. Thus, it is no wonder that they calculated a weak response of temperature to changes in CO₂.

⁷ The warming has been less over oceans than over land, but the size of the land-ocean contrast agrees quite well with what models predict will occur with increasing greenhouse gases (for example, Karoly et al. 2003).

Can we have any confidence in predictions of future climate change?

MYTH #9: *Models have trouble predicting the weather a few days in advance. What makes us think we can predict the climate many years in advance?*

FACT: Climate prediction is different from weather prediction. For example, although it is notoriously difficult to predict if it will rain on any particular day at a specific location, scientists can predict with near certainty that on average, at high latitudes of the Northern Hemisphere, it will be colder in December than in July. Climate models are now sophisticated enough to be able to recreate past global mean climates, including climate change over the last 100 years, with reasonable accuracy. Finally, climate assessments usually report results from a range of models that represent the boundaries of scientific projections. (For example, they report the least that global average temperature is likely to change, and the most). All this adds to our confidence that projections of future climate over broad regions are increasingly reliable.

MYTH #10: *Climate models have many flaws and cannot even simulate past climate changes properly, making them useless in predicting global warming.*

FACT: Computer models are an integral part of climate science, as well as many other fields of science, such as astrophysics and biomedicine. Climate models consist of mathematical representations of physical, chemical and biological processes. The first models to simulate the effects of increasing GHGs on climate were developed in the 1960s (e.g. Manabe and Wetherald 1967), and climate models have improved steadily ever since. They include more and more processes, rely on fewer approximations or parameterizations (simplifications), and achieve better spatial resolution (in other words, models compute the climate from place to place in greater and greater detail, like using “zoomed in” maps rather than less detailed ones) (IPCC 2001). State-of-the-art statistical techniques are used in evaluating model results. Recent models have demonstrated the ability to reproduce the climate changes observed over the past century (see Figure 2) as well as over other periods. Thus, scientists are increasingly confident in the models’ ability to project many of the key features of future climate over broad regions. Modeling studies are regularly published in peer-reviewed scientific journals and subject to intensive examination.

Assessments such as those conducted by the Intergovernmental Panel on Climate Change (IPCC) recognize that “no single model can be considered ‘best’ and it is important to utilize results from a range of coupled models.” The models represented in the IPCC *Third Assessment Report* were developed by separate research groups in the United States, the United Kingdom, Germany, Japan, France, Canada, Australia, China and Switzerland. The 1.4 to 5.8°C (2.5–10.4°F) range for projected warming over the next century reflects the results from the various models, taking into consideration a wide range of scenarios for future emissions.

MYTH #11: *Ian Castles and David Henderson, as well as Bjorn Lomborg, claim that the growth of emissions in the scenarios chosen for the 2001 IPCC assessment is unrealistically high. For example, the growth of CO₂ emissions in the 1990s fell below the IPCC projections. Also, most of the scenarios involve significant increases in*

methane (CH₄) over the next century, whereas recent observations indicate that CH₄ has stopped increasing. Lomborg claims that solar and other renewable sources of energy will dominate the market within decades with minimal policy intervention, and that therefore all but the lowest-emission IPCC scenarios are unlikely.

FACT: It is unrealistic to write off scenarios designed for 100-year analysis based on comparison with 10 years of data. Short-term fluctuations in economic activity are bound to happen. The economic downturn in transition economies during the past decade and the recession in Asia in the late 1990s slowed the growth of CO₂ and CH₄ emissions (for example, Streets et al. 2001; Wang et al. 2004).⁸ (Of course, GHG emissions do not always vary in lock-step with economic activity—if an economy improves its energy efficiency and increases the use of renewable energy, GHG emissions can fall as the economy grows. The IPCC scenarios do assume various levels of increases in energy efficiency and renewables over time.) Furthermore, model analyses indicate that the rate of chemical removal of CH₄ from the atmosphere has increased over the past decade, further slowing the increase in CH₄ concentrations. But this trend may be temporary.⁹

Castles and Henderson argue that the use of market exchange rates (MER) rather than purchasing power parities (PPP) leads to an overestimate of GDP and emissions for developing countries in the IPCC projections. But Nakicenovic et al. (2003) reply that both PPP and MER were used in the scenarios development, with little difference in results between the two methods at the end of the 21st century.

Contrary to Lomborg's claim, a transition from a fossil fuel-based economy to an economy based on renewable energy will not happen automatically. It would take political action to significantly restructure energy systems in a way that would guarantee timely and significant reductions in GHG emissions. Thus, those IPCC scenarios with higher emissions represent a real possibility.

MYTH #12: *Just a few decades ago, scientists warned that a new ice age was approaching or that pollutant dust would cool the climate. What makes scientists think they are right this time?*

FACT: Climate science has come a long way since those early studies. Advances have been made in theory, modeling and paleoclimate (climate in the distant past) analysis. Even when the idea of a globally cooling climate was being considered, many scientists warned about the consequences of GHG emissions; they just weren't sure which effect would win out—warming due to GHGs or cooling due to particulates that reflect sunlight. Although particulates do have a significant effect on climate in many regions, we now know that overall, the effect of human-produced GHGs is dominant.

⁸ In addition, reports by the government of China of decreases in coal use in the late 1990s may have been inaccurate, as suggested by the subsequent report of a 28% increase in coal use from 2001 to 2002. That inaccuracy may have contributed to an underestimate of global growth in CO₂ emissions.

⁹ The increased removal of atmospheric CH₄ over the past decade appears to have been driven largely by depletion of the stratospheric ozone layer, according to some analyses (for example, Wang et al., 2004). Because the ozone layer is expected to recover within several decades in response to the Montreal Protocol ban on substances that deplete ozone, the recent increase in the removal of atmospheric CH₄ is probably temporary.

MYTH #13: *The science behind the theory of global warming is too uncertain to draw conclusions useful to policy making.*

FACT: Uncertainties are an inherent part of scientific knowledge. However, some findings about global warming are certain:

- The basic physics of the greenhouse effect is well understood. That there has been a dramatic increase in the concentrations of GHGs since pre-industrial times, and that the increase is caused by human activities, is undisputed (IPCC 2001).
- That the global average surface temperature has increased by about $0.6 \pm 0.2^{\circ}\text{C}$ ($1.1 \pm 0.4^{\circ}\text{F}$) in the past century is certain (IPCC 2001).
- It is likely that natural factors alone cannot explain the warming observed over the past 50 years. Human-produced GHGs are likely to have been the dominant contributor to this warming (IPCC 2001).

The primary scientific debate is about how much and how fast, rather than whether, additional warming will occur as a result of human-produced GHG emissions. This idea is expressed in assessments published recently by the IPCC, the U.S. National Academy of Sciences, the American Geophysical Union and the American Meteorological Society.

Uncertainty applies to both ends of the climate spectrum—catastrophic climate surprises are as likely to occur as much smaller-than-expected changes.

Uncertainty applies to both ends of the climate spectrum.

In matters other than climate change, policy decisions based on uncertain information are made routinely by governments to insure against undesirable outcomes. For example, the nations of the world came together to ratify the Montreal Protocol, which resulted in a ban on chemicals that deplete the ozone layer, in order to protect against the threat of increased incidence of skin cancer, even while scientists were learning more about the threat. Countries including the United States banned imports of meat from other countries in which mad cow disease (bovine spongiform encephalitis) occurred, even though the vast majority of cattle in the afflicted countries were healthy. The reason immediate action is warranted in the case of global warming is that the climate system and economic systems need time to adjust. Climate changes occur with a delay but continue inexorably: Emissions in the near future will continue to warm the climate for many decades and to increase sea level for centuries. Slowing the growth of emissions will take time, given the large number of emitters across the world and the typically long replacement times for infrastructure such as power plants. We may have only a narrow window of time, perhaps a decade or so, to act before the levels of emissions reductions needed to prevent dangerous and irreversible climatic changes become prohibitively expensive (O'Neill and Oppenheimer 2002). One of the uses of science is providing society with early warnings on potentially dangerous occurrences. In most cases, it is not possible to obtain complete knowledge of a threat before it is too late to stop it. In the case of global warming, scientists have given society an early warning, loud and clear, on its possibly dangerous, irreversible and widespread impacts.

How harmful would the predicted warming be?

MYTH #14: *The IPCC predicts an increase in global average temperature of only 1.4–5.8°C (2.5–10.4°F) over the next century. This small change, less than the current daily temperature range for many locations, is hardly a cause for concern.*

FACT: Global average temperature generally varies little over time. Projected warming would be much larger and faster than anything that has occurred over the past 10,000 years (IPCC 2001). The difference in average temperature between the last major ice age and the present is only about 5°C (9°F); during that period, ice a kilometer thick covered much of North America as far south as New York City. Future warming would be greater at higher latitudes (closer to the poles) and over continents than for the global average. In several decades, the climate of Boston, Massachusetts, might resemble that of present-day Raleigh, North Carolina.

MYTH #15: *Global warming and increased CO₂ would be beneficial, moderating the climate in cold regions, reducing cold-related deaths, and increasing plant growth (“greening the Earth”).*

FACT: A small amount of warming may benefit limited areas. But if society does not make an immediate effort to limit further warming, the beneficial effects probably would be heavily outweighed by negative effects. Likely effects include increases in heat waves, flooding rainstorms, droughts, forest fires, and species extinctions. Coastal flooding due to rising sea levels would affect 13 to 88 million people across the globe each year (IPCC 2001; McLean et al. 2001). A lower probability exists that warming could trigger abrupt climate changes with catastrophic effects, such as a shutdown of the ocean currents that moderate the climate in Europe and other regions (NAS 2002; Sarmiento et al. 2004), and a rapid break-up of huge ice sheets in Greenland and Antarctica, leading to a dramatic rise in sea level (NAS 2002).

Studies have indicated that increases in average temperature would significantly increase the number of heat-related deaths but might not decrease cold-related deaths enough to compensate (McGeehin and Mirabelli 2001; Kalkstein and Greene 1997). Current mortality rates are generally higher in the winter than in the summer, but changes in mortality rates with global warming are expected to be smaller for winter. The reason is that cold-related mortality is complex and not as strongly tied to the severity of the cold as heat-related mortality is tied to the severity of the heat. For example, hypothermia (a life-threatening drop in body temperature) occurs in warmer regions of the United States as well as in colder ones, and can occur at temperatures above freezing (McGeehin and Mirabelli 2001). Also, a large portion of cold-related deaths involves respiratory illnesses, which are also influenced by factors other than temperature, such as people’s degree of confinement indoors. In fact, there does not appear to be a detectable correlation between the number of influenza cases and monthly temperature in the winter (Kalkstein and Greene 1997).

Increasing the amount of CO₂ in the air can enhance plant growth under certain conditions; this is referred to as the “CO₂ fertilization effect.” But higher CO₂ does not necessarily benefit the planet: Experiments have shown that in natural

ecosystems, the CO₂ fertilization effect can diminish after a few years, as the plants acclimate to the higher CO₂ levels (Ainsworth et al. 2003; Temperton et al. 2003). Furthermore, elevated CO₂ may benefit certain types of plants (such as invasive weeds) but not others, potentially resulting in the elimination of certain species through competition.

What should we do about global warming?

MYTH #16: *Society can easily adapt to climate change; after all, human civilization has survived through climatic changes in the past. We should put our resources into adapting to, rather than preventing, climate change.*

FACT: While humans as a species have survived through past climatic changes, individual civilizations have collapsed. Many climate and archeological studies provide firm evidence that the demise of various civilizations, including the Classic Maya, Mochica and Anasazi in the Americas and the Akkadian in Mesopotamia, was due at least in part to climatic shifts including prolonged droughts (deMenocal 2001). If global warming is allowed to continue unrestrained, the rate and amount of warming may exceed anything seen in the last 10,000 years, the period during which human civilization has existed (IPCC 2001).

A warming in the middle of the range of IPCC projections would have significant impacts on many sectors of the economy—agriculture, water supply, coastal and Arctic infrastructure, etc. Even more troubling, there might be increased loss of lives due to heat waves, storms, floods, famine in developing countries and smog-induced respiratory diseases (higher temperatures promote the formation of ozone smog). By the 2080s, the number of people in the world flooded by coastal storm surges in a typical year could be more than five times higher than today, even if protective measures are included (McLean et al. 2001). The above impacts would occur even with moderate, gradual climate change. Obviously, larger or abrupt climate change would have even more severe consequences.

Poorer countries may not have the resources to adapt. Adaptation measures for sea-level rise alone may cost several percent of GDP for certain developing countries and small island nations (McLean et al. 2001), and would be infeasible for many of the latter. Climate change would likely exacerbate economic and political problems. Disasters spawned by global warming could create many refugees, affecting both developed and developing countries. Increased scarcity of resources such as water and food could lead to conflicts across borders that might have broad ripple effects.

Natural ecosystems may not have the capacity to adapt to rapid climate change, especially when combined with other human activities already affecting them.

MYTH #17: *Forests in the Northern Hemisphere are absorbing as much CO₂ as is emitted through the burning of fossil fuels. Therefore, it is developing countries in the south that are to blame for increasing CO₂.*

FACT: The absorption of CO₂ by forests in the Northern Hemisphere is not large enough to completely offset fossil fuel emissions from that hemisphere. For example, one reliable estimate places the U.S. carbon uptake at 0.30 to 0.58 billion metric tons of carbon per year (Pacala et al. 2001), while U.S. fossil fuel emissions are around 1.5 billion metric tons per year.

The carbon uptake in the Northern Hemisphere is thought to arise largely from regrowth on previously deforested land. It would be counterproductive to give northern countries credit for this carbon “sink,” which is simply reabsorption of some of the CO₂ that accumulated in the atmosphere as a result of past deforestation.

Natural ecosystems may not have the capacity to adapt to rapid climate change.

MYTH #18: *It would be more effective to wait until we have definitive proof of global warming and more advanced technology to solve the problem rather than act now; the environment is resilient and recovers if given a chance.*

FACT: CO₂ has a long lifetime in the atmosphere. A quarter of present-day emissions will remain in the atmosphere after several centuries (IPCC 2001). Some will still be there in a millennium. Some other GHGs (such as sulfur hexafluoride) have even longer lifetimes. Delaying action will make it more difficult to stabilize GHG concentrations at levels that would prevent severe consequences (O'Neill and Oppenheimer 2002).

We cannot just sit back and wait for advanced technologies that reduce GHGs—they may never be developed without mandatory emissions limits and incentives for developing GHG-reducing technologies. These require public acceptance and political will, both of which take time to develop.

The environment is not always so resilient. For example, species extinctions are irreversible. A recent study suggested that a significant fraction of all species worldwide (15–37% of the 1,103 species they studied) could be pushed toward extinction by 2050 unless quick action is taken to cut GHG emissions (Thomas et al. 2004).

MYTH #19: *Humankind is foolish to believe it is capable of controlling the climate, either to cause warming or to avoid it.*

FACT: We are capable of having an immense impact on the climate. Current GHG concentrations are higher than at any other time in at least the past 420,000 years and possibly the past 20 million years, as a direct consequence of human activities (IPCC 2001). The projected future increase in temperature as a result of increases in GHGs is much more rapid and larger than any change during the past 10,000 years (IPCC 2001), and the increase would occur relative to an already warm, non-ice-age climate.

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National Headquarters

257 Park Avenue South
New York, NY 10010
212-505-2100

1875 Connecticut Avenue, NW
Washington, DC 20009
202-387-3500

5655 College Avenue
Oakland, CA 94618
510-658-8008

2334 North Broadway
Boulder, CO 80304
303-440-4901

2500 Blue Ridge Road
Raleigh, NC 27607
919-881-2601

44 East Avenue
Austin, TX 78701
512-478-5161

18 Tremont Street
Boston, MA 02108
617-723-5111

Project Office

3250 Wilshire Boulevard
Los Angeles, CA 90010
213-386-5501