# Climate Change: Addressing the Major Skeptic Arguments

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# Editorial

**Mark Fulton**
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***Addressing the Climate Change Skeptics***

The purpose of this paper is to examine the many claims and counter-claims being made in the public debate about climate change science.

For most of this year, the volume of this debate has turned way up as the 'skeptics' launched a determined assault on the climate findings accepted by the overwhelming majority of the scientific community. Unfortunately, the increased noise has only made it harder for people to untangle the arguments and form their own opinions. This is problematic because the way the public's views are shaped is critical to future political action on climate change.

For investors in particular, the implications are huge. While there are many arguments in favor of clean energy, water and sustainable agriculture – for instance, energy security, economic growth, and job opportunities – we at DB Climate Change Advisors (DBCCA) have always said that the science is one essential foundation of the whole climate change investment thesis. Navigating the scientific debate is therefore vitally important for investors in this space.

For these reasons, we asked our advisors at the Columbia Climate Center at the Earth Institute, Columbia University, to examine as many as possible of the major skeptic claims in the light of the latest peer reviewed scientific literature and to weigh the arguments of each side in the balance. Although the scientific community has already addressed the skeptic arguments in some detail, there is still a public perception that scientists have been dismissive of the skeptic viewpoint, so the intention in this report is to correct the balance. The result is, we believe, a balanced, expert, and detailed assessment of the scientific case for climate change that will help investors navigate these extremely complex issues.

**The paper's clear conclusion is that the primary claims of the skeptics do not undermine the assertion that human-made climate change is already happening and is a serious long term threat.** Indeed, the recent publication on the State of the Climate by the US National Oceanic and Atmospheric Administration (NOAA), analyzing over thirty indicators, or climate variables, concludes that the Earth is warming and that the past decade was the warmest on record. Quantifying cause and effect or projecting future conditions is always incomplete in a system as complex as Earth's climate, where multiple factors impact the observations. Conclusions are thus presented in terms of probabilities rather than dead certainties. This uncertainty is not always adequately explained in the public debate and, when discussed, can appear to be a challenge to the credibility of the field. However, uncertainty is an inevitable component in our understanding of any system for which perfect knowledge is unattainable, be it markets or climate.

To us, the most persuasive argument in support of climate change is that the basic laws of physics dictate that increasing carbon dioxide levels in the earth's atmosphere produce warming. (This will be the case irrespective of other climate events.) The only way that warming can be mitigated by natural processes is if there are countervailing 'feedback mechanisms', such as cooling from increased cloud cover caused by the changing climate. A key finding of the current research is that there has so far been no evidence of such countervailing factors. In fact, most observed and anticipated feedback mechanisms are actually working to amplify the warming process, not reduce it.

Simply put, the science shows us that climate change due to emissions of greenhouse gases is a serious problem. Furthermore, due to the persistence of carbon dioxide in the atmosphere and the lag in response of the climate system, there is a very high probability that we are already heading towards a future where warming will persist for thousands of years. Failing to insure against that high probability does not seem a gamble worth taking.

# Editorial

***Addressing the claims***

| Claims | Response |
|---|---|
| *Global average temperatures have not risen since 1998.* | In fact, the decade of 2000 to 2009 is the warmest since measurements have been made. Multiple factors affect global average temperatures, including the long-term warming trend from GHGs. This time-varying interaction of climate drivers can lead to periods of relatively stable temperatures interspersed with periods of warming. The anomalously high global average temperatures in 1998 associated with the El Niño have been followed by comparably high values that reflect a combination of long-term warming and shorter-term natural variability. Periods of relatively constant temperature are not evidence against global warming. |
| *Climate researchers are engaged in a conspiracy: global warming is a hoax.* | There is no evidence that scientists have engaged in alleged conspiracies. Three investigations discerned no scientific misconduct in emails stolen from University of East Anglia's Climatic Research Unit. It has been claimed that the decline in the number of weather stations in the global network since the 1990s was due to purposeful removal, but there is no evidence to support this; furthermore, the reduction in number of stations reporting data has introduced no detectable bias in the trend of the global average temperature anomaly. The IPCC reports undergo significant scrutiny, but as is inevitable in a 3000-page document, that scrutiny sometimes fails to detect errors. The few errors identified in the latest IPCC report were primarily in referencing and not in content. Their existence does not support a conspiracy to misrepresent climate research. |
| *Climate models are defective and therefore cannot provide reliable projections of future climate trends.* | We do not rely only on models for our understanding of the effect of greenhouse gases on climate. Theory (i.e. the physics and chemistry of the planet's atmosphere and ocean) and observations are the foundation of our ability to understand climate and to assess and quantify forcing and impacts. Models represent the most formal way in which to project and quantify future conditions. Despite well known limitations to climate models such as the uncertainties of clouds, aerosols, and spatial resolution, climate models are increasingly able to reproduce a range of physical processes and feedbacks. They unanimously predict warming with increasing greenhouse gases of a magnitude consistent with estimates independently derived from observed climate changes and past climate reconstructions. |
| *The greenhouse gas signature (tropospheric hot spot) is missing.* | Climate models predict that GHGs cause cooling in the stratosphere and warming at the surface and throughout the troposphere. Observations are consistent with these predictions. Furthermore, new measurements in the tropics suggest greater warming in the upper troposphere than at the surface, as predicted by the models. Although the tropospheric hot spot (signature) is not unique to greenhouse gas forcing, the new observational data lend support to climate simulations. |
| *The Medieval Warm Period was just as warm as, or warmer than, today.* | Northern hemisphere temperatures in the Medieval Warming Period (MWP) may have been comparable to today, but the estimates have high uncertainty because there are so few records and spatial coverage is spotty. However, a MWP warmer than the last decade does not challenge the case for anthropogenic warming. |
| *Carbon dioxide levels increase after temperatures rise in the ice core records.* | The correlation of records of atmospheric $CO_2$ and Antarctic temperature over the past 800,000 years indicates that $CO_2$ amplified the warming attributed to variability in Earth's orbit in the transition out the ice ages. Different processes can and do affect climate concurrently. |
| *Earth's climate is driven only by the sun.* | While Earth's climate is undoubtedly driven by the sun, the sun is not the only factor that determines climate. The observations of warming since the second half of the 20th century cannot be explained by solar activity because it has been decreasing. Sunspots, areas of the sun's surface that appear darker in a telescope, have been observed since the invention of telescopes in 1610. Although climate predictions from sunspots have long been attempted, the predictions have not held up. |
| *Water vapor is the most prevalent greenhouse gas.* | Water vapor plays a primary role in the natural greenhouse effect, but that does not diminish the impact of $CO_2$-induced warming. The concentration of water vapor is a positive feedback: as the earth warms, the atmosphere can hold more water vapor, which, in turn, warms it further. |
| *$CO_2$ in the atmosphere is already absorbing all of the infrared radiation that it can.* | Carbon dioxide in the atmosphere at pre-industrial levels already causes substantial radiation absorption. Anthropogenic increases in carbon dioxide concentration cause further absorption (over a broader range of wavelengths) and change the height distribution of the absorption. These effects generate warming and are fully incorporated in current climate models. |
| *Climate sensitivity is overestimated in current climate models.* | Climate sensitivity is defined as the change in global mean temperature that occurs in response to a doubling of atmospheric carbon dioxide. Values between 2 and 4.5$^{o}$C are consistent with our understanding of forcing and past and present climate shifts. Lower estimates tend to disregard feedbacks, like water vapor, and delays associated with slower earth system components, like the ocean. Furthermore, sensitivity values below 2.5$^{o}$C cannot explain the observed climate changes of |

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| Claims | Response |
|---|---|
| *Climate sensitivity is overestimated in current climate models.*<br><br>*(continued from page above)* | the past. |
| *Increasing carbon dioxide will stimulate plant growth and improve agricultural yield.* | Plant growth is stimulated by increased levels of $CO_2$ under equal conditions of temperature and availability of water and nutrients. However, altered growing conditions due to projected shifts in climate will likely counter the fertilization effect in large parts of the already food-insecure world. Experiments to quantify the impact of $CO_2$ enrichment indicate that increased growth does not occur for all plant species and that nutritional content of crops is sometimes negatively impacted. |
| *Human society and natural systems have adapted to past climate change.* | Past climate changes have often been accompanied by migration, war, and disease. The growing human population will inevitably make environmental change more disruptive in the future, even in the face of increased technological prowess. |

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# Executive Summary

Periodic summaries and reviews of the state of knowledge about Earth's climate come from several institutions, including the Intergovernmental Panel on Climate Change (IPCC) and national science academies of countries worldwide. These entities have concluded that the increasing body of observations is consistent with the physical principles by which greenhouse gases (GHGs) affect climate: the planet is warming and it will likely continue to warm due to GHG emissions. Although continued research is needed to quantify the timing, location, and extent of climate impacts, many experts are confident that the precautionary principle justifies action to reduce emissions. However, some individuals and organizations dispute this conclusion, asserting that the science isn't settled. These arguments fall into three general categories: Earth is not warming; Earth may be warming but human activity is not responsible; and Earth may be warming, and humans may be responsible, but we don't need to act to stop it. Here we briefly respond to the primary claims made under each of these categories with the current state of scientific knowledge. Each claim is addressed in detail in the body of the report.

***Earth is not warming***

**Claim: Global average temperatures have not risen since 1998.** Multiple factors affect global average temperatures, including the long-term warming trend from GHGs. This time-varying interaction of climate drivers can lead to periods of relatively stable temperatures interspersed with periods of warming. The anomalously high global average temperatures in 1998 associated with the El Niño have been followed by comparably high values that reflect a combination of long-term warming and shorter-term natural variability. Periods of relatively constant temperature are not evidence against global warming; in fact, the decade of 2000 to 2009 is the warmest in the instrumental record.

**Claim: Climate researchers are engaged in a conspiracy: global warming is a hoax.** There is no evidence that scientists have engaged in alleged conspiracies. Four investigations discerned no scientific misconduct in emails stolen from University of East Anglia's Climatic Research Unit. Weather stations have not been deleted purposefully from the global network since the 1990s, as has been claimed; furthermore, the reduction in number of stations reporting data has introduced no detectable bias in the trend of the global average temperature anomaly. The IPCC reports undergo significant scrutiny, but as is inevitable in a 3000-page document, that scrutiny sometimes fails to detect errors. The few errors identified in the latest IPCC report were primarily in referencing and not in content. Their existence does not support a conspiracy to misrepresent climate research.

**Claim: Climate models are defective and therefore cannot provide reliable projections of future climate trends.** Despite many weaknesses, climate models are increasingly able to represent a range of physical processes and feedbacks and thereby reproduce past and present observations. Consistency between models and observations lends confidence to model projections of future climate change. Models are but one tool, together with theory and observations, to assess and quantify climate processes.

***Earth may be warming but human activity is not responsible***

**Claim: The greenhouse gas signature is missing.** Global observations are consistent with the model-based prediction of GHG-induced cooling in the stratosphere and warming at the surface and throughout the troposphere. Furthermore, new measurements in the tropics suggest greater warming in the upper troposphere than at the surface, as predicted by the models.

**Claim: The Medieval Warm Period was just as warm as, or warmer than, today**. Scarce records and spotty spatial coverage make estimates of medieval temperatures uncertain. Northern hemisphere average temperatures during the medieval period do not appear to have been higher than those of the late 20th century. Furthermore, a warmer medieval period has no bearing on the conclusion that temperatures have increased in the past half-century, and that temperatures will continue to rise due to GHG emissions.

# Executive Summary

**Claim: Atmospheric $CO_2$ levels rise hundreds of years after temperature in ice cores.** The correlation of records of atmospheric $CO_2$ and Antarctic temperature over the past 800,000 years indicates that $CO_2$ amplified the warming attributed to variability in Earth's orbit in the transition out the ice ages. Different processes can and do affect climate concurrently.

**Claim: Earth's climate is driven only by the sun.** While the importance of the sun as a driver of Earth's climate is undeniable, the measured changes in solar activity over the last fifty years cannot explain the observed rise in temperature; solar activity has in fact decreased since the 1970s.

**Claim: Water vapor is the most prevalent greenhouse gas.** Although water vapor plays an important role in the natural greenhouse effect and as a positive feedback, $CO_2$ and other anthropogenic GHGs are perturbing the natural system.

**Claim: $CO_2$ in the atmosphere is already absorbing all of the infrared radiation that it can.** The absorption of infrared radiation by carbon dioxide is an integral part of our understanding of the greenhouse effect and of current climate models which take into account the details of the logarithmic absorption of infrared radiation by $CO_2$. Adding more $CO_2$ to the atmosphere will continue to perturb the climate system and warm the planet.

**Claim: Climate sensitivity is overestimated in current climate models.** Quantifying climate sensitivity, or the change in global mean temperature in response to doubling $CO_2$, is extremely complex because of the unknown rate and magnitude of feedbacks, such as changes in vegetation or ice cover. Attempts to identify negative feedback processes, which would counter the warming due to GHGs, have not been borne out by observations. Sensitivity values below $2.5^{o}$C cannot explain the observed climate changes of the past.

**Earth may be warming, and humans may be responsible, but we don't need to act to stop it.**
**Claim: Increasing carbon dioxide will stimulate plant growth and improve agricultural yield.** Despite the fertilization effect due to increased $CO_2$, it is likely that crop yields will be reduced in many regions by rising temperature and shifts in precipitation. Unfortunately, regions that are already food-insecure are expected to suffer the greatest negative impacts. While some locations are expected to benefit from the combination of shifting climate and $CO_2$ fertilization on the short-term, these yields are unlikely to continue indefinitely,

**Claim: Human society and natural systems have adapted to past climate change.** Past climate changes have often been accompanied by migration, war, and disease. The growing human population will inevitably make environmental change more disruptive in the future, even in the face of increased technological prowess.

Scientific debate is best carried out within the peer-review literature. However, translation of the scientific literature is a necessary step for the non-expert, as language, results, and implications are often narrowly focused and can be obscure even to those in closely related disciplines. The climate science community must work in a concerted fashion to provide regular state-of-the-art assessments and to answer questions about the current understanding. The present document aims to contribute to the effort by presenting scientific arguments in response to the major claims.

# 1. Introduction

In response to a growing body of research pointing to human-induced warming of Earth's climate, and in recognition of the global nature and potentially sweeping implications of a changing climate, the world's governments have launched national and international efforts to periodically assess the state of knowledge in the many areas of research that bear on climate change. The Intergovernmental Panel on Climate Change (IPCC), a consultative body of scientists from around the world, was established in 1988 under the auspices of the United Nations Environment Program and the World Meteorological Organization. Every six years the IPCC publishes a summary and review of hundreds of peer-reviewed studies relating to the state of knowledge about climate change. The IPCC reports serve as a common, authoritative source and they are a critical tool for enabling an effective international response.

The IPCC's Fourth Assessment Report (hereafter IPCC AR4), released in 2007, states that "[W]arming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC WGI 2007, p. 2). Furthermore, "[M]ost of the observed increase in global average temperatures since the mid-20$^{th}$ century is *very likely* due to the observed increase in anthropogenic GHG [*greenhouse gas*] concentrations" (IPCC WGI 2007, p. 3). This conclusion is similar to that of the US Global Change Research Program in their latest assessment: "global warming is unequivocal and primarily human-induced" (US GCRP 2009, p. 12). Most recently, the National Academy of Science summarized that "Climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems" (Matson et al. 2010).

However, a small but vocal group of individuals and organizations, including some scientists, argue that the current scientific evidence is not sufficient to conclude that human-induced climate change is underway or that it poses a clear and present danger to society (e.g. Nova 2009, 2010). Emails stolen from the University of East Anglia's Climatic Research Unit or CRU (Pearce 2009) and mistakes recently identified in the IPCC AR4 have exacerbated these criticisms (Leake 2010c).

These critics contend that "the science isn't settled." This is entirely correct in the sense that the scientific process of discovery, testing, peer review and re-assessment carries on*.* Significant uncertainties about specific dynamics within the climate system persist and scientists continue to pursue research aimed at filling gaps in our knowledge. For example, climate models make poor predictions at the regional scale, and our understanding of cloud dynamics, the distributions and characteristics of aerosols, the rates of glacial melt, and the magnitude of many feedback processes (such as vegetation responses) is still incomplete (Schiermeier 2010).

Despite these unanswered questions, the role of carbon dioxide as a driver of Earth's present and future climate is borne out by the increasing body of observations (e.g. Richardson et al. 2009, Allison et al. 2009). This is seen most clearly in the annual overviews of climate and weather observations compiled by the National Oceanic and Atmospheric Administration. Over thirty indicators, or climate variables, have been identified to characterize the earth system, including atmospheric levels of greenhouse gases, air temperature, sea level, and extreme weather events (NOAA NCDC 2010a). These indicators, which are measured using a wide array of observational techniques, are interpreted in a historical and global context. Some of the variables, like air temperature, are directly related to whether the climate is warming. Other indicators, such as ocean currents or precipitation patterns, need to be monitored over time to understand how the climate system evolves in response to natural and anthropogenic drivers. The latest report, *State of the Climate in 2009* **(Arndt et al 2010)**, concludes that Earth is warming and that the past decade was the warmest on record. Even if the thousands of weather stations that report air temperature were suspect, other indicators are consistent with this warming: glaciers continue to lose mass, northern hemisphere snow cover is falling as spring melt occurs earlier, sea levels are rising, and summer Arctic sea ice cover has been on a steadily decreasing trend **(Arndt et al. 2010)**. Progress in our understanding and more conclusive observational evidence are also manifest in the increased certainty of expressions in successive IPCC reports and of the evolving research. For example, **Stott et al. (2010)** concluded that human influence in regional climate impacts is now discernible throughout the globe based on a review of studies published since the last IPCC report.

# 1. Introduction

Science continues to progress as a discussion among peers and specialists within and across disciplines. Creative and careful research aiming for improved understanding is vital, preferably verified and evaluated via the peer-review process. Although much insight can be gained by scrutiny from people in other fields, the complexity and breadth of climate science do not make it readily or easily accessible in its entirety. Expertise in quantum mechanics does not qualify a person to perform a heart transplant, nor would a surgeon be likely to identify flaws in a finding from particle physics.

Critiques by people from outside the scientific community who aim to “audit” the research process can help identify errors or lead to improved understanding. These criticisms sometimes highlight insufficient transparency within the scientific process (e.g. Curry 2010). Both the hearing of the UK House of Commons Science and Technology Committee and the Independent Climate Change Email Review into whether the stolen CRU emails indicated misconduct recommended more open sharing of both data and methods (UK Parliament 2010b, Russell et al 2010). More transparency is always desirable, but making data sets and methods accessible to an untrained public would require significant additional resources for the research endeavor.

Many criticisms, however, center on matters that have been resolved scientifically or on selective use of observations that may be misinterpreted. Cook (2010) outlined five characteristics of attacks on science (originally from a study that focused on public health by **Diethelm and McKee 2009**) that apply to many claims from those skeptical of climate science: **(1) conspiracy theories**, by which the existence of a large body of accepted evidence is itself purported to be proof of a conspiracy, as has been expressed about the IPCC report; **(2) fake experts**, the presentation as experts of people with scant training in the field; **(3) selectivity**, by which isolated studies or graphs are presented out of context; **(4) impossible expectations**, the practice of demanding research to provide greater certainty than the study system permits, such as complete weather predictability; and **(5) use of misrepresentations and logical fallacies**, including straw man arguments, such as “$CO_2$ isn’t the only driver of climate;” this true statement is integral to our understanding, but is largely irrelevant for the case about anthropogenic change.

This study aims to respond to the most common misconceptions that are presented to challenge the position that GHG emissions are adversely impacting Earth’s climate and will continue to do so. We start with an example controversy that played out not only in the scientific journals but in the media and in political circles: that of the graph of surface temperatures for the past thousand years, also known as the hockey stick. Then we present scientific evidence in response to the most common skeptic claims, ranging from “Earth is not warming” to “Earth may be warming, and humans may be responsible, but we don’t need to act to stop it”. We close with conclusions and suggest resources for further reading in the appendix.

# 2. The Hockey Stick Controversy

Understanding past climate is key to our ability to interpret the climate of the present and to project future climate conditions. In the absence of an instrumental record prior to the 19th century, scientists recur to what are known as proxy records. Proxies for climate are biological or chemical markers within the Earth system that are affected by changes in climate, and thus provide indirect information about climate of the past. Some climate proxies include the width of tree rings, the isotopic composition of ice, or representative fossil micro-organisms in sediment cores. Analyzing and assembling data from proxy sources to create a credible picture of past climate is a difficult process and, like any scientific study, one that is open to differences of opinion and criticism. Thus, it is no surprise that the use of proxy data is at the root of one of the best known climate change controversies.

The controversy began with two articles on long-term temperature trends based on proxy records, which were published in the scientific journals *Nature* and *Geophysical Research Letters* (**Mann et al. 1998, 1999**) and included a graph of average northern hemisphere temperatures over the last millennium. The graph (and the data it represented) showed that northern hemisphere temperatures were currently higher than they had been in the last 1000 years and that the sharpest rise in temperature (the last 200 years) coincided with increasing greenhouse gas emissions from human activity.

After the figure was prominently displayed in the IPCC's Third Assessment Report (IPCC 2001), it became known as the "hockey stick," where the shape describes the sharp temperature increase toward the end of the record. Appearing in articles around the world, the hockey stick was seen as "visually arresting scientific support for the contention that fossil-fuel emissions are the cause of higher temperatures" (Wall Street Journal 2005).

However, Steve McIntyre, a Toronto-based minerals consultant, and Ross McKitrick, an economist at Canada's University of Guelph, argued in the social science journal *Energy and Environment* (**McIntyre and McKitrick 2003)**, that the temperature increase depicted in the hockey stick graph resulted from flawed methodology, including "collation errors, unjustifiable truncations of extrapolation of source data, obsolete data, geographical location errors, incorrect calculations of principal components, and other quality control defects." In response, Mann et al. (2004) published a correction in *Nature,* acknowledging errors in the list of proxy data sets provided in the Supplementary Information as part of **Mann et al. (1998)**; none of the results or analyses were affected.

Until this point the controversy followed the standard pattern of scientific discourse: discovery, publication, attempts at replication, criticism, adjustment, and re-publication. The debate entered the political arena when McIntyre and McKitrick met with Senator James Inhofe (R-OK), an outspoken denier of anthropogenic climate change; shortly afterward, Congressman Joseph Barton (R-TX) wrote to Michael Mann, demanding that he share all his data, methods and associated information with critics and congressional staff (Eilperin 2005). While Mann considered the request, House Science Committee Chairman Sherwood Boehlert (R-NY) asked Barton to withdraw what Boehlert called a "misguided and illegitimate investigation," arguing that the purpose of the investigation seemed to be "to intimidate scientists rather than to learn from them, and to substitute congressional political review for scientific review" (Eilperin 2005).

This led to two independent government-commissioned assessments of the "hockey stick." The House Science Committee commissioned the US National Academy of Science (NAS) to review the original Mann et al. study, while Barton and the House Energy and Commerce Committee asked Edward Wegman, chair of the NAS statistics panel, to investigate the statistical merit of the critiques made by McIntyre and McKitrick.

The National Academy of Sciences report (2006) supported Mann's conclusion that temperatures of the latter half of the twentieth century were the highest in the record, but asserted that the authors should have better communicated the uncertainty of data; namely a specific year or decade (1998 and the nineties) could not be identified as the warmest because of the uncertainty associated with proxy values for individual years or decades (especially prior to 1600). Overall, National Academy of Sciences (2006) rejected the claims of McIntyre and McKitrick and endorsed, with a few reservations, Mann et al's work.

# 2. The Hockey Stick Controversy

The second assessment, commissioned by the House Energy and Commerce Committee and the Sub Committee on Oversight, was carried out by a team of statisticians (Wegman et al. 2006). They also concluded that the methodological errors in the original Mann et al papers had no impact on the scientific conclusion. They carried out a social networking analysis of Mann's co-authorship network to evaluate whether "independent studies" could be unbiased. They interpreted the absence of McIntyre and McKitrick in Mann's co-author network (i.e. the authors who publish with the co-authors of Mann et al.) as evidence of bias, and stated that Mann and co-authors were disproportionately influential in climate literature and the peer review system. Although **Budd** (**2007**, see below) subsequently refuted this claim of disproportionate influence, similar allegations have been made in the wake of the CRU emails stolen in fall of 2009.

While the uncertainty associated with assessments of past climate might have been understated and there were minor methodological errors in the Mann et al. studies, both NAS (2006) and Wegman et al. (2006) confirmed the soundness of the research and concluded that the primary conclusions were unaffected by any methodological problems.

Subsequent attempts to analyze, critique, and reproduce Mann et al's results have led to adjustments and refinements of the technique, while attempts to reproduce the work of McIntyre and McKitrick have shown their original claims to be largely spurious **(Rutherford et al. 2005)**. Recent studies using various independent proxies and different statistical approaches continue to support the original conclusion of Mann et al; see for example **Kaufman et al. (2009)** discussed below in 3.2.b.

Ongoing support in the peer review literature for a similarly shaped temperature record of the past millennium could be questionable if, as Wegman et al. (2006) asserted, dissenting opinions were denied fair consideration due to bias from mutually reinforcing networks of likeminded scientists. However, **Budd (2007)** argues that by focusing on co-authors Wegman et al.'s social networking analysis was specious and did not demonstrate bias. Since "co-authorship is an intentional act," connectedness between authors is to be expected. McIntyre and McKitrick are from different scientific communities than Mann and thus naturally belong to mutually exclusive author networks.

This example demonstrates that despite the uncertainties associated with the scientific study of climate (discussed in more detail below), the scientific process is well suited for discovering and correcting errors through peer-review. Taking the scientific discussion into the political arena can succeed only by including a balanced and broad-based representation of views, which can be difficult in a political context (e.g. **Budd 2007**).

# 3. A Response to the Major Claims of those who are Skeptical of Climate Science

Most arguments used to refute evidence of climate change fall into three general categories:

- Earth is not warming.
- Earth may be warming but human activity is not responsible.
- Earth may be warming, and humans may be responsible, but we don't need to act to stop it.

**3.1. Earth is not warming**

**3.1.a. Claim: Global average temperatures have not increased since 1998**

The long-term warming trend from GHGs does not imply that each year will be warmer than the previous one. Many processes affect climate and global average temperatures, including the anthropogenic increase in atmospheric greenhouse gases and changes in solar forcing, or internal variability in the climate system (such as the 5-7 year El Niño-Southern Oscillation or the 20-30 year Pacific Decadal Oscillation). Because natural variability is superimposed on the long-term warming trend, there will be periods of relatively stable, or even cooler, temperatures. Global average temperatures were anomalously high in 1998 because of the unprecedented magnitude of that year's El Niño event. Since then, global air temperature has remained close to the 1998 level and the decade of 2000 to 2009 is the warmest in the instrumental record (NASA GISS 2010, WMO 2010, NOAA NCDC 2010b, Hansen et al. 2010, **Arndt et al. 2010**), consistent with a long term warming trend in Earth's climate. The global average temperature trend for each of the ten-year periods starting in 1990 has been close to or above the expected trend from anthropogenic forcing (Allison et al. 2009).

Furthermore, multiple sources of evidence support a long-term warming trend. Global average temperature includes air temperatures measured over land and the temperature of the ocean surface which have been collected since about 1850. Warming is greater over land than in the ocean because water is slow to change temperature, making the ocean less sensitive to short-term climate variability. The deep ocean is even slower to warm that the surface ocean. The ocean's heat content far surpasses that of the land and atmosphere and it has been increasing since the late 70s **(Murphy et al. 2009, Lyman et al. 2010)**. Satellite measurements of the temperature of the lower troposphere (the lowest 8 km, or 5 miles, of the atmosphere), which are free from biases due to urban heat island effects, indicate a comparable warming trend of 0.14 to 0.17$^{o}$C/decade since 1979 (NOAA NCDC 2010c).

Model simulations are consistent with these observations. For example, by analyzing a 5,000 year model simulation, **Hunt (2010)** found that internal variability in the climate system, such as El Niño, could lead to decadal scale episodes in which global average temperatures remained consistently above or below the long term trend. When the global temperature anomalies are negative (lower than the long-term mean), they can compensate for the warming due to GHGs and thus lead to stable or even cooler average temperatures. However, Hunt noted that the anomalies generated by the model do not persistently exceed 0.25$^{o}$C; thus with increased GHG-induced warming, natural variability will not be able to counteract the current long-term warming trend.

Conclusion: All instrumental records show that Earth's temperature continues to warm, even in the presence of short term variability. Periods of stable average temperature are consistent with the interaction of the multiple factors that determine climate.

**Subclaim: Record cold in winter 2009-2010 in the US proves that global warming is not real**

Low temperatures and heavy snowfall observed during the winter of 2009-2010 in parts of the United States and Europe did not reflect temperatures for the entire northern hemisphere or of the planet. Climate represents average weather conditions over decades at a given location. Despite the record cold weather in much of the US and Europe, the global average temperature anomalies for January, February ,and March 2010 were the fourth warmest in the measurement record (NOAA NCDC 2010d). Satellite measurements of the global temperature anomaly of the lower troposphere for the first three months of 2010 were the highest observed since 1979 (NOAA NCDC 2010c).

# 3. A Response to the Major Claims of those who are Skeptical of Climate Science

The low temperatures observed in parts of the northern hemisphere in December 2009 through February 2010 resulted in part from extreme negative values of the Arctic Oscillation, a well-known periodic phenomenon in which high atmospheric pressure in the polar region leads to a weaker jet stream and exchange of cold arctic air with milder mid-latitude air (Hansen et al. 2010, Herring et al. 2010). The frigid conditions observed in Washington DC and Texas (Bolton 2010, Neefus 2010) were accompanied by unseasonable warmth in the Arctic and elsewhere, much to the dismay of the organizers of the Winter Olympics in Vancouver, Canada (Branch and Austin 2010).

Conclusion: Despite the cold conditions experienced in portions of North America and Europe, the average global temperature anomalies for 2009 and for early 2010 were among the highest in the instrumental record.

**3.1.b. Claim: Climate researchers are engaged in a conspiracy: global warming is a hoax**

When attempting to deny accepted knowledge, it is common to recur to conspiracy theories **(Diethelm and McKee 2009)**, which are extremely hard to refute. How would one prove the 1969 Moon landing to those that insist it was filmed in Hollywood? Here we attempt to break down the diffuse "conspiracy" claim by addressing specific lines of argument that aim to characterize the evidence of anthropogenic climate change as a result of a conspiracy rather than a rigorously assembled body of research: the fact that governments provide funding for climate research; the content of emails recently stolen from the University of East Anglia; a decrease in numbers of weather stations in major temperature data sets; and the errors in the IPCC AR4 report.

**3.1.b.1. Significant government research funds prove that scientists are in it for the money**

The considerable government funding for global change research (which includes climate) in the United States (e.g. $2.6B in the 2011 US budget, OSTP 2010) represents an alleged proof that scientists are "in it for the money." However, funding for global change research is less than 2% of the 2011 US investment in research and development (R&D); it is dwarfed by R&D spending on defense ($77.5B) or health ($32B) (OSTP 2010). Furthermore, the amount assigned to global change is dominated by the cost of expensive infrastructure, including satellites that measure variables that are not restricted to climate-related research, such as air quality or fire occurrence. Finally, while this funding reflects a significant investment into climate science, it has little bearing on the gains to be had for individual researchers whose salaries are generally covered by their universities or by their government positions.

Pennsylvania State University recently completed a two-part inquiry of Michael Mann to address allegations of misconduct that arose from the emails stolen from University of East Anglia (Kintisch 2010). He was cleared of research improprieties (for an analysis of press coverage of the news regarding the first part of the inquiry, see Dawson 2010). Following the findings, it was asserted that the inquiry was a mere formality because of Mann's success in bringing large grants to the university (Barnes 2010, Lombardi 2010). However, a top-tier university, as is Pennsylvania State, is unlikely to jeopardize its reputation for an individual researcher. The motivation of greed is put into context by the meager contribution (0.06%) of Mann's grants to the $765million in research funding that the university receives annually (Angliss 2010, Fischer 2010).

Conclusion: Climate science funding is a very small component of government investments for research and development. Research funds do not represent financial gain for individual researchers because they are paid by their institutions.

**3.1.b.2. Stolen emails of climate researchers demonstrate conspiracy**

In November 2009 several files, including emails sent between 1990 and 2009, were removed from a server at the University of East Anglia's Climatic Research Unit (CRU) and put on a third party computer. While the emails are alleged to show evidence of a conspiracy among climate scientists and of scientific malpractice, various investigations have concluded that accusations of misconduct are not supported.

Regardless of whether the files were hacked or leaked, they were obtained by criminal means, a fact that is frequently forgotten by commentators. The emails do not represent the broader community of climate scientists, as ninety-four percent of the posted emails were to or from four individuals at CRU (Arthur 2010). In fact, the emails are a very small subset of the actual email sent and received by these individuals during the 19-year time period. These emails not only eavesdrop on other people, but the incomplete view of their conversations offers little or no context to the statements being made. For a general overview see RealClimate (2009a, 2009b).

Despite the inevitable absence of context for the information in the emails, they have generated considerable controversy and press coverage, with allegations that “data may have been manipulated or deleted in order to produce evidence of global warming” (UK Parliament 2010a, 2010b). Sarah Palin (2009) asserted that based on the emails, US President Obama should not attend the Fifteenth Conference of Parties of the UNFCCC in Copenhagen in December 2009. Senator Inhofe has proposed criminal investigations of several climate scientists (Goldenberg 2010), and the Virginia Attorney General has made a civil investigative demand of documentary material to determine whether Michael Mann, a former professor at University of Virginia, defrauded taxpayers (Helderman 2010).

The major assertions refer to withholding data, attempts to subvert the peer review process, misleading methods, and undue influence in the IPCC process. As these allegations hold potentially significant implications, and given the extraordinary response in political spheres, it is worth examining each of these claims.

**Data access:** CRU scientists were criticized for failing to make all of their data publicly available, implying that this is part of a conspiracy to misrepresent climate change. The CRU is not a data archiving center; CRU uses observations made by National Meteorological Offices and others to create, for example, long-term instrumental records of temperature. While government funded research in many countries is generally made available to all parties, this does not apply to data obtained by Meteorological Offices. In many cases the data that the CRU did not make available was provided to the CRU under the condition that it would not be shared (UK Parliament 2010b).

**Misleading methods:** One of the e-mails mentioned a “trick” to plot long-term temperature records. Critics have argued that this indicates an attempt to mislead the public. In fact, the “trick” refers to the use of the instrumental record after 1960 instead of temperatures estimated from tree ring widths. The two sources were then labeled accordingly. Instrumental data were used after 1960 because some high-altitude tree ring records show declining growth after 1960 despite warming temperatures. The same tree ring records are very closely related to temperature for about 110 years for which thermometer readings are available, but not for the last fifty years. This phenomenon, known as divergence, may be due to decreased water availability or to greater water requirements at higher temperatures. Divergence has been discussed openly in the scientific literature (e.g. **Esper et al. 2010**, **D’Arrigo et al. 2008**), as is the approach of using thermometer measurements for that time period (see Velasquez-Manoff (2009) for an excellent account). The instrumental record is the most reliable measure of temperature.

**Undue influence in the IPCC processes:** Critics contend that scientists involved in the IPCC excluded reference to papers by **McKitrick and Michaels (2004)** and **Kalnay and Cai (2003)** that presumably contradicted their conclusions. The extremely complex multi-stage IPCC process, with multiple authors (450 lead and 800 contributing authors) and reviews (see below),makes it very difficult for a small group of individuals to influence it (IPCC 2010a). Most noteworthy, the two papers that were discussed in the CRU emails were in fact cited and discussed in Chapter 3 of the IPCC AR4 report, so any desire to omit them was not implemented.

**Attempts to subvert the peer-review process:** Several emails refer to a paper published in the journal *Climate Research* by Soon and Baliunas in 2003. It has been asserted that the emails indicate a lack of respect for the peer-review process with regards to this publication. The Soon and Baliunas paper was the object of much controversy when it was published; a controversy that was reflected in the stolen emails. The paper, a literature review with no new data, was heavily and promptly criticized for its interpretations (see for example Regalado 2003, Mooney 2004). The review process at *Climate Research*, which allows authors to submit to specific editors, had long been a matter of concern throughout the climate science community. After the controversy following the Soon and Baliunas publication, the editor in chief, Hans von Storch (for his explanation, see von Storch 2009) and three editors resigned in protest of the journal's review procedures. Otto Kinne (2003), publisher of the journal, noted in an editorial following the resignations: "While these statements [made in Soon and Baliunas, 2003] may be true, the critics point out that they cannot be concluded convincingly from the evidence provided in the paper. *Climate Research* should have requested appropriate revisions of the manuscript prior to publication."

**Investigation of the allegations:** Several inquiries have been initiated to address the perception of misconduct from the email contents, including a review by the University of East Anglia (UEA 2009, CCE 2010), a UK Parliamentary Inquiry (UK Parliament 2010), scientific misconduct investigation of Michael Mann by Penn State, and a scientific assessment of CRU's key publications (UEA 2010). The four investigations completed to date (by Penn State, the UK House of Commons, the science assessment, and the independent email inquiry) have concluded that there is no evidence of scientific malpractice (Dawson 2010, UK Parliament 2010b, Oxburgh et al. 2010, Russell et al 2010).

Both the UK House of Commons Science and Technology Committee and the Independent Climate Change Email Review noted that while the sharing of data and approaches was consistent with common scientific practice and that the accusations of misconduct were not substantiated, greater openness and sharing of information were desirable (UK Parliament 2010b, Russell et al 2010). Handling of the Freedom of Information requests was found to be inadequate, but it was concluded that the responsibility lies primarily with the university administration, not individual research units such as the CRU.

Conclusion: The emails stolen from CRU demonstrate that climate scientists are human. As such, they expressed impatience and frustration at what they perceived as organized harassment rather than a sincere desire to further knowledge. No evidence has been found of data manipulation or misrepresentation.

**3.1.b.3. Climate researchers have removed stations from the Global Historic Climate Network (GHCN)**

Station numbers decrease in the GHCN in the last twenty years because the bulk of the data is retrieved by time-consuming retroactive compilations of information, with inevitable delays. Multiple comparisons demonstrate that the observed warming trend is not affected by the decrease in station numbers.

In a January 2010 show on KUSI-TV in San Diego hosted by John Coleman, TV weatherman and cofounder of The Weather Channel (see KUSI-TV 2010 for broadcast, Coleman 2010), meteorologist Joseph D'Aleo and computer scientist E.M. Smith alleged that stations from high latitude, high altitude (i.e. colder), and rural (not affected by the urban heat island) locations had been systematically removed from the dataset that is used worldwide to estimate land temperature (the Global Historic Climate Network, GHCN) leading to a bias towards greater warming (Smith 2009, D'Aleo and Watts 2010).

These claims have been shown to have no foundation (e.g., Hausfather 2010a, Freedman 2010). Station numbers fall after the 1970s maximum (around 6000) because the presence of a station in a given year depends on whether the data has been made available from the originating station and the data quality controls have been completed. Retroactive compilations of information are time-consuming **(Peterson and Vose 1997)**. Consequently, in ten years, the number of stations in the database corresponding to the decade of the 1990s will be much larger than is the case at present. Not only is there no purposeful effort to exclude stations from high latitude or altitude, the goal is to rely as much as possible on rural stations. D'Aleo and Watts (2010, p. 12) note that more rural stations were dropped in absolute numbers, as the database includes more rural stations overall. Their graph on p. 12 indicates that the proportion of rural stations in 1970 (<60%) is comparable to that in 2000 (~54% of the total number). For information on historical temperature records see NOAA NCDC (2010e).

Removing weather stations from high altitude or high latitude will not introduce a warming bias. Stations in cold regions have experienced greater warming than those in warm regions. Thus, while removing the former could lead to higher average global temperature, it would likely reduce the warming trend, which is expressed in terms of temperature anomalies relative to a baseline period for each station. Hansen et al. (2010) note that the global data compilation from the Hadley Center and CRU (HadCRUT), which includes fewer Arctic stations, produces a cooler global average temperature anomaly than the compilation from NASA Goddard Institute of Space Studies (NASA GISS); furthermore, when NASA GISS masks the areas where HadCRUT doesn't have data, the NASA GISS anomaly is cooler.

Comparison of the temperature anomaly for the set of stations with measurements through 2010 against those whose observations end in 1992 shows that the loss of stations does not affect the trend in global average land temperature anomaly in the period for which data from all of the stations are available (e.g. Clear Climate Code 2010, Hausfather 2010b; for an overview see Hausfather 2010c).

Conclusion: The reduction in number of stations reporting data is not the result of selection (cherry picking), but of data availability. Furthermore, the reduction in number of stations shows no significant effect on the reported global average temperature anomaly.

**Microsite influences:** A parallel claim is that the surface station network providing the land temperature records is flawed because the thermometers are located near air conditioners, parking lots, highways, and airports (Watts 2009, D'Aleo and Watts 2010). The Surfacestations Project (2009) compiles photographic evidence of poor station siting. However, a comparison of temperature anomalies measured by the entire network of over 1200 stations versus those measured at the 70 stations that the Surfacestations Project identifies as well sited shows no discernible difference in anomaly or trend over time (NOAA Climate Services 2009, p. 3). **Menne et al. (2010)** found furthermore that the temperature records from poorly-sited stations were cooler and had weaker warming trends than those from stations with better characteristics, opposite of the bias implied by the concern for siting.

It is true that some thermometers have been moved to locations that are less desirable. After the switch to electronic thermistors, which require cable connection for the readout, thermometers had to be placed much closer to buildings. This type of thermometer tends to register cooler maximum values and slightly warmer minimum values, with net cooler temperature **(Menne et al. 2010)**. The careful documentation done through the Surfacestations Project allowed improved understanding of the impact of micrositing.

Conclusion: There is no evidence of any purposeful manipulation of temperature records. Information from weather stations is incorporated into the GHCN as soon as it becomes available. The warming trend prior to 1990 measured by stations that are not present in the GHCN after 1990 is the same as that measured by those stations that remain. That is, the reduction in the number of weather stations has introduced no detectable bias in the observed warming trend. Furthermore, the surface temperature trend is of comparable magnitude to that of the satellites. Concerns that the poor placement of weather stations (microsite influences) translates into higher (and incorrect) warming trends have not been substantiated by comparing results from stations with differing site characteristics.

#### 3.1.b.4. The IPCC AR4 report is ridden with erroneous data and references that overstate the impacts of global warming

The writing and review process of IPCC reports aims to comprehensively represent the latest scientific understanding, to involve a large number of experts from around the world, and to ensure an open and transparent review (IPCC 2008). Authors and reviewers are nominated by governments and non-governmental organizations and chosen by a technical board of experts. The review process takes place in three stages: expert review of the first-order draft, a review by both experts and governments of the second-order draft and the draft Summary for Policy Makers, and finally government review of the revised draft Summary for Policy Makers (IPCC 2008). The drafts, the reviews, and the response to the reviews by the lead authors and review editors are archived and available; for example, the reviews of IPCC Working Group II can be found at IPCC WG II (2006).

Despite this careful and transparent scrutiny, mistakes have been identified in early 2010 in the IPCC AR4 and received a flurry of coverage in the blogosphere and the mainstream media. In response to these concerns, a review of internal IPCC processes and procedures is underway (Webster 2010, InterAcademy Council 2010). It has been suggested that the IPCC establish a webpage with errata and corrections (e.g. Watson 2010, Yohe et al 2010, Netherlands Environmental Assessment Agency 2010a). Regardless of mistakes in the IPCC AR4, new observations and findings since 2007 strengthen the case for anthropogenic impacts on climate.

While several criticisms have centered on IPCC's use of non peer-reviewed literature, IPCC guidelines clearly articulate the need to recur to "gray" literature, including publications from government and international organizations, industry journals and conference proceedings, especially in the context of adaptation and mitigation activities (IPCC 2008, IPCC 2010a; see also Russell et al. 2010). Procedure dictates that when using such sources, the authors are compelled to critically assess and review the information and claims should always be based on multiple lines of evidence (IPCC 2008, IPCC 2010a). Bibliometric analysis of the Third Assessment Report (TAR) indicates that 84% of the references of Working Group I are peer-reviewed, while peer-reviewed articles make up 59% and 36% in Working Group reports II and III respectively (Bjurström 2010). This is consistent with the needs as expressed in the IPCC procedures.

Five specific claims about observed or potential climate change impacts have been the focus of criticism of the integrity of the IPCC AR4 report and of the IPCC as an institution. These are as follows: The statement that Himalayan glaciers are likely to melt by 2035; attribution of observed trends in disaster losses to climate change; the threat of drastic losses in Amazon forest cover in response to small changes in precipitation resulting from climate change; the potential for dramatic decrease in crop yield across Africa in response to climate change; and the percentage of the territory of the Netherlands that is below sea level and therefore highly vulnerable to rising sea levels caused by climate change. We address each in turn below.

**Himalayan glaciers:** On January 17, Leake and Hastings (2010) noted errors in two statements in section 6.2 of Chapter 10 of the Working Group II report on Impacts, Adaptation, and Vulnerability (IPCC WGII 2007, p. 493-494):

"Glaciers in the Himalaya are receding faster than in any other part of the world (see Table 10.9) and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 km2 by the year 2035 (WWF, 2005)."

The first and second sentences contradict each other (disappearance versus 80% loss). The area of 500,000$km^2$ in the second sentence refers to the entirety of extra-polar glaciers and the correct year was 2350, not 2035 (Banerjee and Collins 2010). A further concern is the reference. The World Wildlife Foundation report cited a 1999 article in *New Scientist*, which in turn was based on an interview. Banerjee and Collins (2010) provide compelling evidence that the most likely source of the phrasing is in fact an article from an Indian environmental magazine by Chettri in 1999. This article also seems to be the primary source of IPCC Table 10.9, in which there is an arithmetic error:

"Pindari Glacier (Uttaranchal); Period: 1845 to 1966; Retreat of snout in m: 2,840; Average retreat in m/year: 135.2."

The speed of retreat should be 23 m/year. An analogous table in the WWF report is quite different, and it does not include the arithmetic mistake, despite claims to the contrary (Rose 2010).

Some of these errors were identified by reviewers of the second-order draft of Chapter 10 but, unfortunately, they were not corrected in the final version (IPCC WGII 2006, Banerjee and Collins 2010). Thus it is clear that the strict IPCC procedures (validation of non-peer reviewed sources followed by careful attention to the government and expert reviews) were not followed in this case.

The IPCC issued a response to the criticisms, acknowledging the error and regretting the “poor application of well-established IPCC procedures” (IPCC 2010b). Uncontested scientific projections of glacier decline are provided in Chapters 4 and 10 of Working Group I, which apparently were not consulted by the authors of Working Group II (RealClimate 2010c).

Banerjee and Collins (2010) carry out a thorough analysis of the source of the mistaken information and of the media commentary, remarking upon “the challenges of reading and reproducing electronic information in our globalized world.” They note that almost every media accounting of the glacier error a mistake, either by omission or by repeating an error from earlier accounts.

Notwithstanding the factual errors and incorrect referencing in this single case, glaciers worldwide are indisputably retreating **(Arndt et al. 2010, p. S49)**. For example, **Lopez et al. (2010)** show that the majority of 72 Patagonian glaciers retreated over the last 60 years, with shrinking of up to 37%, while glacier extent in regions of the Tien Shan Mountains of central Asia has decreased between 9 and 19% in the last 30 years **(Narama et al. 2010)**.

***Improper attribution of disaster losses to climate change:*** Chapter 1 of Working Group II (IPCC WGII 2007, p. 100) addresses an increase in disaster losses that may be attributed to climate change:

“A global catalogue of catastrophe losses was constructed (Muir-Wood et al., 2006), normalised to account for changes that have resulted from variations in wealth and the number and value of properties located in the path of the catastrophes […] Once the data were normalised, a small statistically significant trend was found for an increase in annual catastrophe loss since 1970 of 2% per year (see Supplementary Material Figure SM1.1).”

Leake (2010a) on January 24 claimed that these statements and chart SM1.1 from the Supplementary Material originated in a 2006 study by Muir-Wood et al. that was still unpublished at the time of the cut-off to be included in the IPCC. Quoting Roger Pielke Jr, an expert in losses associated with hurricanes and storms, Leake (2010a) asserts that the wording on p 100 of Working Group II does not reflect the consensus understanding at the time, which is that the trend to greater losses can be explained solely by socio-economic factors. In fact, the research finding mentioned is not found within the Muir-Wood 2006 reference, but was instead published in 2008 (RMS 2010).

The IPCC issued a statement noting that the presentation of studies on disaster losses was balanced as it also discussed research attributing observed trends to increased coastal populations and wealth (IPCC 2010c). While allowing that the bulk of the information is not in the publication referenced by the IPCC, Muir-Wood (RMS 2010) has indicated that it was an appropriate citation because the complete study had been accepted for publication, and because the referenced work was the only study of global multi-peril losses that had been normalized for exposure (RMS 2010). They agree that the graph that was used in the Supplementary Material should not have been included.

The discussion of normalized losses and a graph similar to the one found in the final version’s Supplementary Material was not present in the first-order draft. A version of the graph was used in the second-order draft of Chapter 1 with a reference to an unpublished paper by Miller and Muir-Wood (IPCC WGII 2006). Five expert reviewers expressed concerns about the reference (an unpublished study), the graph and the interpretation, so the figure was modified and moved to the Supplementary Material. The Miller and Muir-Wood paper was replaced with the published study by Muir-Wood et al. Comments about the interpretation reflected the active ongoing debate about disaster losses.

The discussion appears to be primarily a case of improper referencing, but without any factual error. While there continues to be academic debate on the role of climate change in the increase in disaster losses, an increased frequency of extreme precipitation events is widely accepted (e.g. US GCRP 2009, **Arndt et al. 2010**). For example, Spierre and Wake (2010) found a statistically significant increase in rainfall in the northeastern US where two-inch precipitation events have increased in frequency for 92% of the 219 stations examined.

***Amazonian vulnerability to drought:*** Chapter 13 of Working Group II on Impacts, Adaptation, and Vulnerability in Latin America states (IPCC WGII 2007, p. 596):

"Up to 40% of the Amazonian forests could react drastically to even a slight reduction in precipitation; this means that the tropical vegetation, hydrology and climate system in South America could change very rapidly to another steady state, not necessarily producing gradual changes between the current and the future situation (Rowell and Moore, 2000). It is more probable that forests will be replaced by ecosystems that have more resistance to multiple stresses caused by temperature increase, droughts and fires, such as tropical savannas."

Leake (2010b), based on research from North (2010a), expressed concerns with the statement and gray literature reference. Rowell and Moore (2000) make a similar assertion (on p. 15 of their report) about the vulnerability to drought, however their statement is not substantiated by the reference they cite, **Nepstad et al. (1999)**, which focuses on the impacts of fires and logging. Leake quoted Simon Lewis, a tropical ecologist, as critical of the IPCC statement (Leake 2010b). The reference and the statement were in both first-order and second-order drafts. Neither expert nor government reviewers challenged either the reference or the statement (IPCC WGII 2006).

In response to the Leake article, Nepstad (2010) issued a statement that the IPCC wording is factually correct, noting that several articles that directly address the lack of resilience to drought were not included in the Rowell and Moore report. Lewis submitted a complaint to the UK Press Complaint Commission alleging that Leake (2010b) was "materially misleading" (Lewis 2010, Adam 2010).

This is a case of factual accuracy and incorrect referencing. As in the case of the Himalayan glaciers, the IPCC authors failed to validate the primary reference. In this case, abundant peer-reviewed literature existed to support the statement (see Nepstad 2010 for references). Recent findings confirm the IPCC statement and indicate enhanced concern regarding the ability of Amazonian forests to recover from drought. For example, **Phillips et al. (2009)** found that the 2005 drought led to long-term increase in tree mortality and that the forest switched from taking up carbon dioxide to releasing it back to the atmosphere.

***African crop yields:*** The Synthesis for Policy Makers (SPM) of Working Group II (IPCC WGII 2007, p.13) states:

"In some [African] countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020,"

The statement links back to section 9.4 of the Working Group II report (Impacts, Adaptation and Vulnerability) on Africa.

"In other countries, additional risks that could be exacerbated by climate change include greater erosion, deficiencies in yields from rain-fed agriculture of up to 50% during the 2000-2020 period, and reductions in crop growth period (Agoumi, 2003),"

On February 7, Leake (2010c), using again research from North (2010b), questioned the statements in the Synthesis for Policy Makers and in Chapter 9. Although the discussion of negative and positive impacts risk is more nuanced in Chapter 9 than in the SPM, the agricultural impact appears to apply generally to Africa, although the Agoumi (2003) study is limited to Morocco, Tunisia, and Algeria. The concern, as noted by North, arises in tracing the information further. Agoumi's statements regarding agricultural impacts are not referenced clearly. The primary sources seem to be the national reports to the COP-7 (Algeria 2001, Morocco 2001, Tunisia 2001), legitimate IPCC references. The Moroccan report identifies a potential decrease of 50% in cereal crop yield during drought years by 2020 (Morocco 2001, p. 11), while the Algeria report describes a modeled reduction in yield of 5 to 8% for different scenarios by 2020 (Algeria 2001, Table 49, p. 95). The 50% decrease in rain-fed agriculture thus refers to Morocco, not to African nations in general.

The sentence in Chapter 9 and the reference to Agoumi do not appear in either the first- or second-order drafts which express agricultural vulnerability due to climate change in terms of impacts on GDP (IPCC WGII 2006). In the government review of the second-order draft, Finland noted that expressing impacts on agriculture as a change in GDP tends to underemphasize the potential impact of the decreases in water supply for rain-fed agriculture in northern Africa, which were discussed elsewhere in the chapter. This might have led to the addition of a statement regarding impacts for northern Africa, but which failed to explicitly indicate the regional scope.

This is a case of factual imprecision (it was only substantiated for Morocco) and sketchy referencing. It is unfortunately also a case where precision and careful attribution were especially important. The claim of a 50% reduction in rain-fed agriculture by 2020 has been repeated more generally for Africa in various instances, such as for example by IPCC Chairman Pachauri (Flynn 2008). Recent research indicates considerable regional variability in the impacts of climate change on agriculture. While **Lobell et al. (2008)** found that crop yields of several food-insecure nations of southern Africa will be negatively impacted by projected changes in temperature and precipitation, model projections for eastern Africa suggest that enhanced precipitation and the $CO_2$ fertilization effect will increase yields **(Doherty et al. 2010)**.

***Area of the Netherlands that is below sea level:*** In Chapter 12 of Working Group II on Europe (IPCC WGII 2007, p. 547) it is stated:

“The Netherlands is an example of a country highly susceptible to both sea-level rise and river flooding because 55% of its territory is below sea level where 60% of its population lives and 65% of its Gross National Product (GNP) is produced.”

In fact, twenty per cent of the country is below sea level, and twenty-nine per cent is susceptible to river flooding (Netherlands Environmental Assessment Agency 2010b). When this erroneous addition of overlapping areas was identified, the Dutch Environment Minister expressed displeasure, saying she had based environmental policies on the IPCC report; however, it was soon revealed that the Netherlands Environmental Assessment Agency itself had provided the incorrect information (Handelsblad 2010). This phrase did not appear until the second-order draft, in a slightly different form but with the same 55% value; no country or expert reviewer identified the error (IPCC WGII 2006).

The Netherlands Environmental Assessment Agency has subsequently issued a correction in wording: that instead of “55% of the territory is below sea level”, that “55% of the Netherlands is at risk of flooding” (Netherlands Environmental Assessment Agency 2010b).

This is a factual error, but it does not have any effect on any of the main conclusions of the report.

**IPCC review:** January and February 2010 saw a flurry of reporting about the above mistakes, often accompanied by allegations of excessive influence of advocacy groups, in the mainstream media (e.g. Ball and Johnson 2010) and the blogosphere. On March 10, the IPCC announced that the InterAcademy Council, which represents the national academies of science of over fifteen countries, would lead a review of the IPCC internal processes and procedures including management functions, use of non-peer reviewed literature and modes of communication with the public (Webster 2010). The focus of the review will be on future reports but past “mistakes” may be used as case studies (Farenthold 2010). The InterAcademy Council Review of the IPCC commenced in May 2010; results will be presented at the October meeting of the IPCC (Black 2010). Initial presentations can be seen at the review webpage (InterAcademy Council 2010).

# 3. A Response to the Major Claims of those who are Skeptical of Climate Science

The Netherlands Environmental Assessment Agency was tasked by the Dutch Parliament in January 2010 with evaluating potential errors in the regional chapters on climate change impacts of the IPCC WGII (2007). They concluded that the section on summary conclusions was error-free, although it tended to emphasize negative impacts; they noted that this was the agreed-upon approach for AR4, but suggested a broader range of impacts be included in the next assessment (Netherlands Environmental Assessment Agency 2010a). While the regional chapters presented strong evidence of climate change impacts and risks, the Agency felt that the background evidence in some cases was not always transparent and recommended that the reasoning behind the expert judgments be more explicit. They also recommended stricter quality control in referencing (Netherlands Environmental Assessment Agency 2010a).

The structure of the IPCC and the 6-year reporting process have been debated in the past but the recent criticisms, especially following the theft of the University of East Anglia emails, has revitalized the discussion. Thoughtful ideas from five climate scientists about alternative structures for IPCC can be found in a *Nature* opinion piece (Hulme et al. 2010). Suggestions include more stringent enforcement of the current model; more frequent shorter reports; breaking it up into three organizations focusing on science, regional impacts, and policy analysis; and wikipedia-style contributions. No matter what the proposed final form, critics and supporters alike heartily recommend a transparent forum to identify and correct mistakes (e.g. Watson 2010, Pielke Jr 2010, Netherlands Environmental Assessment Agency 2010a).

Conclusion: The IPCC reports undergo significant scrutiny, with multiple levels of review, but that scrutiny sometimes fails, as is inevitable in a 3000 page document with over 18,000 references. Despite frequent claims to the contrary, IPCC guidelines allow the use of non-peer reviewed literature as a source reference. In the cases examined above, the proper procedure of careful evaluation of multiple sources was not effectively carried out. However, none of these cases of incorrect referencing change the fundamental conclusions of the report which have been substantiated by subsequent research.

#### 3.1.c. Claim: Climate models are defective

We do not rely only on models for our understanding of the effect of greenhouse gases on climate. Theory (i.e. the physics and chemistry of the planet's atmosphere and ocean) and observations are the foundation of our ability to understand climate and to assess and quantify forcing and impacts. Models represent the most formal way in which to project and quantify future conditions. Despite well known limitations to climate models, such as describing small time and space scales, or the dynamics of clouds or aerosols, they are able to simulate past and present climate changes.

As it is impossible to conduct repeated experiments on the earth's atmosphere, computer models are indispensable in allowing scientists to understand how the earth system will respond to changes in various parameters, such as continued increase in levels of greenhouse gases. Models allow us to project the likely climate of the future. To entirely validate such models would require waiting for 50 to 100 years to see if the prediction was true. Given the inefficiency of this approach, model predictions are compared with data for historical periods for which good climate records exist. If a mismatch between the model's predictions and the known record occurs, then the model is reexamined, adjusted and improved (or eventually discarded). Thus, the process by which climate models are developed is consistent with the scientific method (Downie et al. 2009).

Computer models are tools and as such are designed to answer specific questions, from climate variation at global scales to weather patterns in a small region. A model that simulates the global climate for hundreds of years is not a good tool to look at day to day variations in a small geographic region, and vice versa. As computers become faster, greater complexity can be included in the models. Current climate models are designed to address hundred-year variability but they increasingly include improved representation of internal variability on shorter time scales.

Trying to understand natural climate variability is an active area of climate research (for example efforts to understand the spatial patterns associated with the Medieval Warm Period or the Little Ice Age in **Mann et al. 2009**). Several different approaches are taken in this regard, frequently by comparing output from models that look at century scales and those that address seasonal to inter-annual (year to year) variability. Variability on the decade- to-decade scale is a current area of open research and still a very new endeavor partly because the instrumental temperature record is relatively short. The fact that models cannot provide unequivocal representation or understanding of all scales of natural climate variability does not diminish the importance of anthropogenic perturbations to the climate system in the form of greenhouse gases.

Our confidence in climate models comes from three major points: (a) climate models are based on established physical laws and on observations; (b) climate models show increasing skill in reproducing average distributions, temporal changes, and variability when compared with observations; and (c) climate models reproduce past climates and past changes (IPCC WGI 2007, p. 117-118).That said, climate models have limitations. Any process for which we have limited scientific understanding or observations, such as clouds, aerosols, or regional climate dynamics, cannot be represented properly in models.

***Clouds:*** According to the IPCC, the largest source of uncertainty, as well as the cause of discrepancies among models in predictions of global average temperatures, is the representation of clouds (IPCC WGI 2007, p. 275). Clouds generally warm the earth by absorbing infrared radiation, but because they are light-colored, they are also effective at reflecting sunlight, thus counteracting the warming of the greenhouse effect (IPCC WGI 2007, p. 99). Clouds are physically small compared to model resolution and any change in type, location, altitude, water content, shape or lifetime affects whether and how much the cloud warms or cools (Grumbine 2010). Research is actively underway to improve our understanding and the ability of models to represent clouds effectively.

***Aerosols:*** Aerosols, small particles or liquid droplets suspended in the atmosphere, play a direct role in climate by influencing the absorption or reflection of radiation and an indirect one by allowing water vapor to condense upon them, thus affecting cloud characteristics. Natural aerosols include sea spray or dust. Some aerosols, such as sulfate aerosols, are produced naturally (such as volcanoes) and by human activities. Most aerosols counter the greenhouse effect by reducing the amount of sunlight (radiation) that reaches the surface and increasing the amount that leaves the earth through scattering **(Wild 2009)**.

Surface radiation measured on the ground and by satellite decreased noticeably between the 1960s and the 1990s (also called global dimming) and increased from the 1990s to the present (global brightening). These two periods correspond to growing industrial emissions of aerosols and subsequent regulatory reductions of emissions. In locations where air pollution is less regulated, the observed brightening has been less. Thus despite reduced emissions, the planet remains under the effect of dimming. Although the IPCC AR4 climate models reproduce both dimming and brightening, they underestimate the magnitude. This is likely due to the uncertainty in estimates of historic emissions and aerosol burden, because when models have access to improved estimates, the magnitude of dimming and brightening is closer to observations **(Wild 2009)**.

**Subclaim: Aerosols and their decrease due to pollution control explain the observed warming trend.** This claim does not correspond to the timing of recent reduction in aerosols and increased warming. The fastest rate of warming started after the mid-70s while aerosol reduction did not have a noticeable effect until the 1990s. Furthermore, aerosol-induced dimming is still cooling air temperatures. The observed changes can only be explained by warming due to greenhouse gases onto which the shifts due to dimming/brightening are superimposed **(Wild 2009)**.

***Small spatial scales:*** Errors also derive from processes that occur at small physical or temporal scale. Since climate models need to represent conditions over the entire globe for long time periods, computational capacity limits the degree to which small scales can be resolved. Schiermeier (2010) recently included regional climate forecasts (i.e., forecasts that depend on model resolution) among the “real holes” in climate science that require further research. The challenge is multiple: computational capacity, understanding of the interaction of regional and large scale processes, and good observational data over time.

Conclusion: Despite the uncertainties of clouds, aerosols, and spatial resolution, climate models are increasingly able to reproduce a range of physical processes and feedbacks. They unanimously predict warming with increasing greenhouse gases of a magnitude consistent with estimates independently derived from observed climate changes and past climate reconstructions.

**3.2. $CO_2$ is not responsible for any warming of the Earth system that may be occurring.**

**3.2.a. Claim: The greenhouse gas signature is missing from in the tropical atmosphere**

Simulations of Earth's climate responding to greenhouse gas forcing show warming at the surface and through the troposphere (extending about 16 km, 10 miles, above the surface) and cooling in the stratosphere (the layer above the troposphere). This prediction has been confirmed by observations (Karl et al. 2006, **Arndt et al. 2010**). Models additionally predict that warming, whether in response to GHGs or to increased solar forcing, is greater in the upper troposphere (altitudes of 5 to 16 km) of the tropics than at the surface, in what is known as vertical intensification. Although the tropospheric "hot spot" is not a signature of GHG forcing, it is often mistakenly considered to be (e.g. Nova 2009). Until recently radiosonde and satellite observations did not show increased warming in the upper troposphere relative to the surface in the tropics. However, new observational datasets and updates of older ones are consistent with modeled warming trends at the surface and in the upper troposphere **(Santer et al. 2008)**.

Prior to about 2006, upper tropospheric temperature measured by satellites and weather balloons (radiosondes) showed slight cooling over the last 20 to 30 years. Subsequently, this observed cooling trend was found to result from systematic errors in the satellite temperature data: Karl et al. (2006) noted that the newer satellite and weather balloon datasets showed "no significant discrepancy" between the warming trends at the surface and in the upper troposphere on the global scale, as seen in the computer model results. However, modeled and observed temperature changes still could not be reconciled in the tropics (Karl et al. 2006).

**Douglass et al. (2008)** reported that the discrepancy between modeled and observed trends in temperature at the surface and in the upper troposphere exceeded the uncertainty associated with either models or observations. They interpreted their results as evidence that computer models are seriously flawed, rendering climate projections untrustworthy. However, when **Santer et al. (2008)** applied a statistical test to the same data as Douglass et al., in addition to updated and new datasets, the observed temperature trends in the tropics were consistent with modeled ones at all heights. They noted that **Douglass et al. (2008)** had neglected the effect of interannual variability and used old versions of observational data. Improved tropical surface temperature estimates show a slightly reduced warming trend, while new inter-satellite comparisons lead to greater warming in the upper troposphere **(Santer et al. 2008)**, in both cases moving observational data closer to the relationship predicted by models.

Rapid glacier melt provides corroborating evidence of vertical intensification of warming in the tropics. **Thompson et al. (2009)** consider the tropospheric hot spot a likely driver of the widespread mass loss and retreat of glaciers at high altitude (over 5km) in the tropics. The Quelccaya Ice Cap (Peru, ~13$^{o}$S) is shrinking at the margins despite consistent accumulation rates at the summit. This is consistent with warmer air temperatures aloft. Vertical intensification is also thought to play a role in explaining the retreat and thinning of the ice fields in Mt Kilimanjaro (Tanzania, ~3$^{o}$S), which have persisted for 11,700 years, even throughout a 300-year drought 4200 years ago **(Thompson et al. 2009)**.

Conclusion: Climate models predict that GHGs cause cooling in the stratosphere and warming at the surface and throughout the troposphere. Observations are consistent with these predictions. Furthermore, new measurements in the tropics suggest greater warming in the upper troposphere than at the surface, as predicted by the models. Although the tropospheric hot spot is not unique to greenhouse gas forcing, the new observational data lend support to climate simulations.

**3.2.b. Claim: The Medieval Warm Period was just as warm or warmer than today, so GHG emissions don't affect climate**

The comparison between temperatures today and during the Medieval Warm Period (MWP, approximately between 950 and 1250CE) is at the heart of criticisms of the hockey stick. Evidence for the MWP comes from historical accounts and from various proxy records of temperature. However, the paucity of data prior to 1600 makes it very hard to derive a hemispheric or global average temperature. Furthermore, statements comparing the MWP and the present frequently correspond to inconsistent time periods. Warm periods at any time between 800 and 1500 may be called the MWP, while "the present" can refer to the end of a specific proxy record or to an unspecified time of instrumental measurements. In any case, a warm MWP does not disprove the role of GHGs in the current warming episode.

The average global or hemispheric temperature for the MWP is highly uncertain because of the small number of proxy records (NAS 2006, p. 18-19, IPCC WGI 2007, p. 468-469). Of over 1200 proxy records of annually and decadally resolved temperatures, only 50 records extended to 1000 CE and 36 records to 500 CE **(Mann et al. 2008)**. This study found average northern hemisphere temperature was at most 0.4$^{o}$C warmer between 950 and 1150 CE than during the base period of 1961-1990, but was still cooler than average temperatures after 1990. Temperature between 950 and 1250 CE was not uniformly warm according to **Mann et al. (2009)**: central Eurasia, northwestern North America and the equatorial Pacific were cooler than the base period (1961-1990).

**Frank et al. (2010)** used 521 ensembles of proxy-based reconstructions to conclude that northern hemisphere average temperature in the warmest pre-anthropogenic period (1071-1100, during the MWP) was 0.38$^{o}$C warmer than the coldest period in the past millennium (1601-1630); by contrast temperatures were 0.7$^{o}$C warmer in 1971-2000 than in 1601-1630. Likewise a reconstruction of circum-Arctic summer temperatures (north of 60$^{o}$N) using multiple proxies from lake sediments and ice cores, in addition to tree rings, revealed a 2000-year cooling trend caused by well-known changes in the orbit of the earth, with only moderately warmer temperatures around 1000 CE **(Kaufman et al. 2009)**. The authors noted that the circum-Arctic average temperature during the late 20th century was about 1.4°C warmer than expected based on extrapolating the trend of the previous 1900 years. Tropical mountain glaciers, mentioned above, provide a robust indicator that temperatures during the MWP were not greater than today at those sites. There, Thompson and coworkers have documented melting in the late 20th century where no ice had melted for thousands of years.

The Medieval Warm Period Project ($CO_2$ Science 2010) compiles peer-reviewed papers to build a case that the MWP was warmer for most of the planet than current conditions (Nova 2010). However, closer examination indicates that evidence for the MWP corresponds to various non-concurrent periods between 450 and 1500CE: for example between 450 to 900CE for Chesapeake Bay **(Cronin et al. 2003)**; 1100 to 1400CE for New Zealand **(Wilson et al. 1979)**; or 1200 to 1300CE in Switzerland **(Fillipi et al. 1999)**. The definition of "current" conditions is equally vague: with different definitions for "today" or "the present," and with many proxies that do not reach the warmer second half of the 20$^{th}$ century. Without carefully evaluating the precise bounds of the study period, study compilation can be misleading.

While the sparse data and the imprecise bounds of the MWP make it very difficult to conclusively affirm whether the world was as warm as today, the fact of whether or not it was warmer does not impact the case of anthropogenic warming (RealClimate 2005a). Earth's climate varies naturally over all time scales and there have been much warmer periods in Earth history. The observed warming today is consistent with basic physics of greenhouse gases and the planet's heat budget. It cannot be reproduced in models that do not include anthropogenic emissions of GHGs (IPCC WGI 2007, p. 120-121), i.e. there is no known natural forcing that could account for the observations.

Conclusion:  Northern hemisphere temperatures in the MWP may have been comparable to today, but the estimates have high uncertainty because there are so few records and spatial coverage is spotty. However, a MWP warmer than the last decade does not challenge the case for anthropogenic warming.

**3.2.c. Claim: Atmospheric $CO_2$ levels rise hundreds of years *after* temperature in ice cores, so $CO_2$ does not cause climate to change.**

The warming periods of the past are not identical to the current warming period. For the largest climate changes recorded by Antarctic ice cores, $CO_2$ served as a feedback to amplify climate change that was initiated by other factors.  Today, rising concentrations of atmospheric $CO_2$ and other greenhouse gases represent the primary factor initiating climate change.

When interpreting the ice core data of past climate, scientists have always considered $CO_2$ to be a feedback that amplifies changes in climate caused by other factors, rather than serving as the initial cause of climate change **(**e.g., **Lorius et al. 1990**, **Hansen et al. 2007)**.  Therefore, it is not surprising that changes in climate may precede changes in atmospheric $CO_2$ by as much as a few hundred years (IPCC WGI 2007, p. 444).  The largest changes in temperature recorded in Antarctic ice cores are attributed to variability in Earth's orbit **(**e.g., **Kawamura et al. 2007)**, also known as the Milankovitch hypothesis. Changes in temperature and $CO_2$ are highly correlated over the past 800,000 years **(Lüthi et al., 2008)**, supporting the view that $CO_2$ serves to amplify climate change that is initiated by variability in Earth's orbit.

It is sometimes claimed that warming climate caused $CO_2$ to rise "because as the oceans warm they release more $CO_2$" (Nova 2009, p. 5). While warm water indeed holds less gas (including $CO_2$) than cold water, the well-known temperature dependence of $CO_2$ solubility in seawater is such that the ocean cannot outgas sufficient carbon dioxide to explain either the observed rise in $CO_2$ or its correlation with temperature **(Broecker 1982)**.  Current scientific thinking attributes the changes in the $CO_2$ content of the atmosphere to climate-related variability in winds and ocean currents which regulate the exchange of gases (including $CO_2$) between the atmosphere and the deep sea **(Anderson et al. 2009)**.

The climate changes of the past do not undermine the evidence that the current warming is caused by anthropogenic $CO_2$. They demonstrate that multiple factors have affected past changes in climate, just as they do today. Observations and theory indicate that the *current* warming is caused primarily by increased atmospheric concentrations of $CO_2$, and that human activities are the main source of the increase in $CO_2$ (e.g. IPCC WGI 2007, p. 448).

Conclusion: Different processes can and do affect climate concurrently. The correlation of records of atmospheric $CO_2$ and Antarctic temperature over the past 800,000 years indicates the important role that $CO_2$ played in the transition out of the ice ages: to amplify the warming attributed to variability in Earth's orbit. In the present situation, atmospheric GHGs are increasing due to human activities.

**3.2.d. Earth's climate is driven only by the sun**

While Earth's climate is undoubtedly driven by the sun, the sun is not the only factor that determines climate. The observations of warming since the second half of the $20^{th}$ century cannot be explained by solar activity because it has been decreasing.

Direct measurements of solar activity have only been possible since the 1960s **(Lean 2010, Lockwood 2010)**. Sunspots, areas of the sun's surface that appear darker in a telescope, have been observed since the invention of telescopes in 1610. Sunspots are associated with intense magnetic activity, or solar wind, which encloses the solar system and deflects galactic cosmic radiation (GCR). Solar activity and sunspot number follow an approximate 11-year cycle. Records beyond 1610 come from radionuclides that form as GCR penetrates the atmosphere; these are stored in tree rings and polar ice deposits. Atmospheric and biological processes also impact the concentrations of these isotopes so their use to infer GCR in the past should be applied with caution.

# 3. A Response to the Major Claims of those who are Skeptical of Climate Science

Observed trends in total solar irradiance are inconsistent with current climate shifts **(Lockwood 2010)**. Several studies that quantify the impact of irradiance on climate find that it cannot explain more than 15% of trends in temperature since the 1950s (e.g. **Erlykin 2009**, **Benestad and Schmidt 2009**; see also Cook 2009). In fact, recent solar activity has been the lowest since the early 20th century (NASA 2009, **Lockwood 2010**). **Feulner and Rahmstorf (2010)** assessed the potential impact of an extended solar minimum on 21st century temperature projections. They found that for emission scenarios close to business as usual, projected temperature increases between 3.7-4.5$^{o}$C for 2100 would be reduced by no more 0.3$^{o}$C.

Although climate predictions from sunspots have long been attempted, the predictions have not held up (Weart 2008, **Lean and Rind 1996**). **Svensmark (2007)** proposed a causal relationship by which GCR ionizes the atmosphere and creates condensation nuclei that increase the cover due to low clouds that then cool the earth. However, global satellite earth observations indicate that cloud cover and GCR are not consistently correlated **(**e.g. **Kristjansson et al. 2008)**. Reported correlations often rely on lags (inconsistent with rapid cloud dynamics), apply only to restricted time periods, or use questionable data sets **(**e.g. **Kristjansson et al. 2008**, **Lockwood 2010)**. **Kulmala et al. (2010)** bypassed concerns about cloud datasets by directly comparing atmospheric aerosol formation and GCR between 1996 and 2008 and found no relationship between the two.

Conclusion: While the importance of the sun as a driver of Earth climate is undeniable, the measured changes in solar activity in the last fifty years cannot explain the observed warming as they would instead lead to cooling. The hypothesis that GCR increases cloud cover via cloud condensation nuclei is not supported by observations of aerosol formation and comparison with cloud data is inconsistent with measurements of GCR.

**3.2.e. Claim: Water vapor is the most prevalent greenhouse gas.**
Although water vapor plays a primary role in the natural greenhouse effect, that does not diminish the impact of $CO_2$-induced warming. The concentration of water vapor is a positive feedback: as the earth warms, the atmosphere can hold more water vapor, which, in turn, warms it further.

Water vapor is by mass and volume the most prevalent greenhouse gas and contributes the most to the natural greenhouse effect. The second most important natural greenhouse gas is $CO_2$. By elevating the global average temperature by 33$^{o}$C, the greenhouse effect makes the earth habitable. Anthropogenic emissions of $CO_2$ have intensified the greenhouse effect, thus warming the planet even further. Because of its positive feedback effect, water vapor approximately doubles the warming associated with carbon dioxide (IPCC WGI 2007, p. 99).

Atmospheric water vapor increases in response to warming because high temperatures increase evaporation and a warm atmosphere can hold more water vapor. Thus water vapor exacerbates the greenhouse effect under warming conditions in a classical positive feedback (IPCC WGI 2007, p. 135). The rapid response of water vapor to changes in temperature give it a short residence time in the atmosphere compared to that of carbon dioxide. The $CO_2$ that humans add to the atmosphere will cause concentrations to remain elevated for centuries. If the atmosphere cools or warms because of shifts in solar activity, carbon dioxide will not respond. By contrast, water vapor will increase with higher temperatures, in turn warming the earth more, but under cooler conditions it leaves the atmosphere in the form of precipitation. That is why it is considered a feedback and not forcing (RealClimate 2005b).

Conclusion: Although water vapor plays an important role in the natural greenhouse effect and as a positive feedback, $CO_2$ and other GHGs are perturbing the natural system.

**Subclaim: Climate models cannot simulate the effect of water vapor because they lack detailed cloud physics.**
Despite the complexity of small scale cloud processes, the positive feedback of water vapor is simulated effectively in current climate models, as is confirmed by the models' ability to reproduce temporal shifts in temperature due to volcanic eruptions or El Niño events and to simulate outgoing radiation.

Climate models rely on large-scale processes to govern changes and redistribution of water vapor, a key variable for the water cycle. Modeling the water cycle is an object of active research because precipitation is so important to characterize climate, yet the complex small scale processes that govern humidity and cloud formation are not described in full detail in climate models. However, recently available satellite observations show that models effectively depict the feedback associated with water vapor. Models are able to successfully reproduce observed changes in temperature and atmospheric humidity through El Nino cycles and volcanic eruptions **(Dessler and Sherwood 2009** and references therein**)**. Even in a set of models with known biases in reproducing humidity and temperature, the net effect of water vapor on outgoing radiation was consistent with satellite observations over a range of climate conditions and time scales **(Chung et al. 2010)**.

Conclusion: Water vapor in the atmosphere is governed primarily by large-scale processes which are effectively expressed in current climate models. The positive feedback effect of water vapor is confirmed.

**3.2.f. Claim: $CO_2$ in the atmosphere is already absorbing all of the infrared radiation that it can.**

Carbon dioxide in the atmosphere absorbs radiation logarithmically, such that any doubling of $CO_2$ concentration leads to an equivalent change in absorbed energy. Pre-industrial levels of carbon dioxide in the atmosphere cause substantial radiation absorption. Anthropogenic increases in carbon dioxide cause further absorption (over a broader range of wavelengths) and change the height distribution of the absorption. These effects generate warming and they are fully incorporated in current climate models. $CO_2$ in the atmosphere absorbs infrared radiation (IR) over a band, or range, of wavelengths. Near the center of the band the IR is absorbed completely by existing levels of $CO_2$. Thus, adding more $CO_2$ to the atmosphere will not cause more IR to be absorbed at wavelengths near the center of the $CO_2$ absorption band. However, adding $CO_2$ to the atmosphere effectively widens the band of wavelengths over which $CO_2$ absorbs IR. As a consequence of this broadening, any doubling of $CO_2$ concentration leads to an equivalent change in absorbed energy (warming), amounting to about 4 $W/m^2$ (Archer 2007). Adding increments of $CO_2$ to the atmosphere will affect the heat budget, even if the next increment has a smaller warming effect than the preceding increment. This behavior is incorporated in physical analyses and in climate models. The ModTran program at University of Chicago (Archer and Archer 2009) can be used to estimate the radiative forcing associated with changes in carbon dioxide.

Venus has 96% $CO_2$ in its atmosphere and a surface temperature of 467$^{o}$C. As more carbon dioxide is added to a planetary atmosphere, the layer in which $CO_2$ is saturated becomes thicker and the level at which radiation can escape to space moves further away from the surface; this effectively warms the surface further (e.g. Allison et al. 2009). Venus illustrates what is known as the “runaway greenhouse effect,” but this shift in the heat distribution of the absorption occurs in Earth as well. Thus, increases in atmospheric carbon dioxide levels will continue to have a warming effect.

Conclusion: The absorption of radiation by carbon dioxide is an integral part of current climate models and the logarithmic absorption of infrared radiation by $CO_2$ is adequately accounted for. The 4 $W/m^2$ increase in heating is large compared to natural variability, for example, due to changes in solar output.

**Claim 3.2.g. Climate sensitivity is overestimated in current climate models**

Climate sensitivity is defined as the change in global mean temperature that occurs in response to a doubling of atmospheric carbon dioxide. Values ranging between 2 and 4.5$^{o}$C are consistent with our understanding of forcing and responses of past and present climate. Lower estimates tend to disregard feedbacks, such as water vapor (see above), and delays associated with slower earth system components, such as the ocean.

Some researchers argue that climate sensitivity is as little as 0.5 to 1°C (e.g. Lindzen 2009). Some low estimates assume that the positive feedbacks, such as changing albedo or water vapor content, are small or that negative feedbacks will compensate. Low climate sensitivities often ignore the delay between changes in the radiation balance and a resulting change in the surface temperature. Oceans absorb most of the additional energy trapped by the greenhouse gases, thus delaying the increase in surface temperature. Other feedbacks include melting ice or increased northern forest cover, which affect how much light is reflected from the planet (albedo), or changes in cloud cover, which may amplify or dampen the progress of change (Kump et al. 2004).

MIT professor of meteorology Richard Lindzen has researched several possible negative feedbacks. In the Iris Hypothesis **(Lindzen et al. 2001)** cirrus clouds in the tropics would respond to high sea surface temperatures in a way that would reduce warming, much as the iris closes in the human eye in the presence of excessive light. Increased sea surface temperatures would enhance convection in the tropics and reduce the formation of high cirrus clouds. This would allow more heat to escape the tropical regions and act as a negative feedback to decrease warming. However, **Lin et al. (2002)** observed that while cirrus clouds indeed responded to warming surface ocean temperatures, the clouds then led to greater warming rather than less. Subsequent research confirms the warming effect of upper tropospheric clouds in response to increased ocean temperatures **(Su et al 2008)**.

**Lindzen and Choi (2009)** compared observations of radiation fluxes at the top of the atmosphere in the tropics and sea surface temperature with the output of eleven climate models. When the sea surface warmed, satellite measurements showed an increase in outgoing radiation, thus providing a negative feedback and, consequently, reducing climate sensitivity. This negative feedback was not replicated by the models, leading **Lindzen and Choi (2009)** to further conclude that climate predictions are compromised. However, **Trenberth et al. (2010)** noted that Lindzen and Choi's assumption that the heat balance in the tropics is a closed system is incorrect: the intense heat exchange between tropics and subtropics mean that cloud variation does not depend solely on ocean surface temperature. Furthermore, the choice of time intervals used to carry out the analysis had a large impact on the results. Shifting Lindzen and Choi's chosen interval endpoints by a month caused the cloud-temperature relationship to disappear **(Trenberth et al. 2010)**. Finally, the subset of models that Lindzen and Choi compared with the observations were limited in that they used incomplete forcings; the sea surface temperatures were fixed and unable to change in response to atmospheric forcing (**Trenberth et al. 2010**, Spencer 2009). Spencer (2009) also noted concerns with how the observed radiation fluxes were averaged to overcome drifting of the satellite orbit. For an overview of the concerns, see Revkin (2010) and RealClimate (2010a, 2010b).

The study of past climate changes can also provide insight into the sensitivity of the climate system. During the Pliocene period, three to five million years ago, proxy temperatures indicate it was 3-4$^{o}$C warmer in the tropics and 10$^{o}$C warmer in the poles than in pre-industrial times. Independent estimates suggest Pliocene $CO_2$ levels of around 400ppm **(**see references in **Schneider and Schneider 2010)**. This evidence implies a far greater climate sensitivity than 2-4.5$^{o}$C and suggests that long term feedbacks, such as widespread changes in vegetation or collapse of ice sheets, may determine higher equilibrium temperatures under even moderate increases in $CO_2$ levels **(**e.g. **Schneider and Schneider 2010)**.

The complexity of feedback factors makes it difficult to determine the precise path that global warming will take, which in turn feeds debate about the value of climate sensitivity and of the threat posed by anthropogenic warming. Some scientists and other observers use this uncertainty to argue that climate change impacts may be small. A much larger number of experts asserts that while it is impossible to predict precisely how much warming will occur, models, first principles, and observations of past change, continue to affirm that it will be significant (IPCC WGI 2007, **Knutti and Hegerl 2008**).

Conclusion: Quantifying climate sensitivity, or the change in global mean temperature in response to doubling $CO_2$, is extremely complex because of the unknown rate and magnitude of feedbacks, such as changes in vegetation or ice cover. Attempts to identify negative feedback processes have not been borne out by observations. Furthermore, sensitivity values below 2.5$^{o}$C cannot explain the observed climate changes of the past.

### 3.3. Earth may be warming, and humans may be responsible, but we don't need to act to stop it.

#### 3.3.a. Claim: Increasing carbon dioxide will stimulate plant growth and improve agricultural yield

Plant growth is stimulated by increased levels of $CO_2$ under equal conditions of temperature and availability of water and nutrients. However, altered growing conditions due to projected shifts in climate will likely counter the fertilization effect in large parts of the already food-insecure world. Experiments to quantify the impact of $CO_2$ enrichment indicate that increased growth does not occur for all plant species and that nutritional content of crops is sometimes negatively impacted.

Photosynthesis is the conversion of carbon dioxide and water into sugars through the effect of sunlight. As such, increasing carbon dioxide can enhance photosynthetic yield, especially in those plants known as C3, such as wheat or soybeans, whose photosynthetic apparatus is slightly less efficient in $CO_2$ uptake than the C4 plants, such as corn (maize). Adding $CO_2$ will lead to increased growth when there is adequate water, nitrogen, and phosphorus (IPCC WGI 2007, p. 526-527). To this end, commercial growers frequently increase air levels of carbon dioxide in greenhouses.

However, the changes in atmospheric $CO_2$ leading to climate change are accompanied by shifts in temperature and usually also rainfall. And the vast majority of world agriculture does not take place under controlled conditions such as in a greenhouse. Free Air $CO_2$ Enrichment (FACE) is an approach to enrich $CO_2$ in the atmosphere surrounding a terrestrial ecosystem without using chambers or walls (Brookhaven FACE Program 2009). The photosynthetic response observed in FACE experiments varies widely, as factors other than carbon dioxide come to limit growth. **Leakey et al. (2009)** summarize twenty years of FACE studies: although photosynthesis is enhanced and efficiency of use of nitrogen and water improved under $CO_2$ fertilization, crop plants undergo a smaller fertilization effect than expected from lab and chamber studies, and yield enhancement is less than observed in tree species.

Furthermore, it has been found that even in species for which yield is stimulated, such as wheat, increased growth translates into more starch and less protein in the grain, with potentially negative impact on its nutritional value **(Högy et al. 2009)**. High $CO_2$ conditions appear to favor enhanced production of cyanide (and less protein) in clover, a key foraging crop for livestock, thus reducing the nutritional content and requiring longer grazing time **(Gleadow et al. 2009)**. **Bloom et al. (2010)** found that $CO_2$ fertilization led to a reduction in uptake of nitrate, a primary source of nitrogen for food crops, and subsequent reduction in protein content of wheat; as the plants acclimate to higher carbon dioxide over time the crop yields fall.

Impacts associated with increased temperature and with changing precipitation patterns as temperatures continue to rise can be either negative or positive depending on the location. Rising temperatures are of special concern because seed geneticists have long been selecting for drought resistance. It is particularly difficult to quantify the response of crop yield to temperature changes because the projected temperature shifts fall outside of historical observations **(Lobell and Burke 2008, Burke et al. 2009, Battisti and Naylor 2009)**. Each degree Celsius of increased temperature, in the absence of water limitations, leads to an approximate drop in yield of 10% **(Battisti and Naylor 2009)**.

**Schlenker and Roberts (2009)** applied both a time-series and cross-sectional approach (which takes into account potential adaptation measures) and found that United States yields of wheat, soybeans, and cotton would decrease between 30 to 82% by end of century depending on the climate change scenario. The combination of higher temperature and changing rainfall patterns is estimated to have a net negative effect in several currently food-insecure regions, such as Africa and South Asia **(Lobell et al. 2008, Burke et al. 2009)**. Other areas may benefit; for example, **Doherty et al. (2010)** found that projections of enhanced precipitation and the $CO_2$ fertilization effect will increase yields in eastern Africa. This is consistent with cross-sectional analyses for eleven African nations, which indicate significant differences in marginal climate impacts for irrigated versus dryland agriculture. These analyses predict maximum negative impacts in locations that are currently dry and warm, while irrigated crops in cool areas are expected to show benefits (**Kurukulasuriya et al. 2006)**. A more extensive cross-sectional study, applied to the sixteen agro-ecological regions of Africa, finds greater resilience of agriculture and livestock than suggested by **Kurukulasuriya et al. (2006)**, although the degree of negative/positive impact depends greatly on the region and on the projected climate scenario **(Seo et al. 2009)**.

Conclusion: Although a fertilization effect due to increased $CO_2$ will lead to enhanced photosynthesis on the short term and in some regions, crop yields will likely be impacted by rising temperature and shifts in water availability, especially in areas that are already warm and dry. Unfortunately, regions that are already food-insecure are projected by some studies to suffer the greatest negative impacts.

**3.3.b. Claim: Human societies have adapted to previous warming periods**

Although adaptation is possible, historical shifts in climate have never occurred under conditions of such high human population numbers. Natural resources and ecosystems are already taxed and further climate perturbation is likely to be disruptive. Climate shifts in the past have frequently been accompanied by collapse of governments or extensive mortality. Increasing population pressure exacerbates the likelihood of pandemics and the destabilization of food-insecure regions can lead to failed states and threats to global security.

Humans have survived numerous past changes in climate, but survival of the species is a poor measure of the true consequences and costs associated with adaptation to climate change. Archeology provides numerous examples of civilizations that failed to survive climate change (e.g. Diamond 2005; **Weiss and Bradley 2001**; **de Menocal 2001; Brooks 2006**). North Africa has widespread remains of settlements that were abandoned at the end of the African Humid Period between 6000 and 5000 years ago **(Kuper and Kröpelin 2006)**. The Old Kingdom of Egypt (**Hassan 1997**; BBC 2009) and the Akkadian Empire **(de Menocal 2001)** collapsed under stress associated with a multi-century drought ca. 4200 years ago. Drought is also thought to have contributed to the collapse of Mayan and Anasazi cultures in the 9$^{th}$ and 13$^{th}$ centuries, respectively (e.g. Diamond 2005).

Human systems are thus a primary motivation to curtail greenhouse gas emissions. Not only will the projected climate change alter the world to which societies have adapted, but human population is already close to 7 billion and growing. Global society's ability to provide adequate food, water, and shelter is already compromised by sheer numbers, but climate change will likely increase the challenge (e.g. Sachs 2008). Greenhouse gas concentrations have not been as high as they are today in at least 800,000 years. Global average temperatures have risen by approximately 0.7˚C in the past 100 years. We are undoubtedly an ingenious species, but we are entering uncharted territory in terms of our ability to adapt to a changing climate. Current patterns of human settlement and productive activity have evolved in the context of the prevailing climate in the 10,000 years since the end of the last ice age. It is optimistic to assume that we will be able to adapt to the changes that are likely to occur if greenhouse gas emissions continue on their present trajectory and if the climate response is consistent with current projections **(**e.g. **Sokolov et al. 2009)**.

While developed countries may be better able to cope with many of the changes, developing countries, home to nearly 80% percent of the world population, face imminent challenges. Climate change adds to the difficulties imposed by existing stressors such as poverty, food insecurity, unequal access to resources and weak governance (IPCC WGII 2007, p. 813). Broadly speaking, developing country governments have fewer resources to invest in building resilience. Likewise, poor communities and individuals have limited options for changing livelihoods in response to the impacts of climate change. The increased global temperatures and accompanying disruptions brought about by the addition of GHGs to the atmosphere will likely persist for a millennium after all emissions are halted **(Solomon et al 2009)**. Temperatures will continue to rise with emissions, along with the risks of catastrophic change. By 2100, even in the presence of aggressive mitigation of emissions and adaptation measures, it is likely that the impacts of climate change will exceed adaptive capacity in many regions (IPCC WGII 2007, p. 813).

Climate change is already contributing to increased variability in weather patterns (e.g. Spierre and Wake 2010), particularly impacting communities that are highly dependent on natural systems for their livelihoods. Changing rainfall patterns are projected to lead to increased drought in areas that are already drought-prone and increased flooding in low-lying, flood-prone areas. As glaciers melt and annual snowpack decreases, populations that rely on these sources for water will be at greater risk for water stress. **Immerzeel et al. (2010)** quantified the impact of Asian glacier retreat in water and food security: although they found that the impact was less than expected for some basins (namely the Yangtze, Yellow and Ganges river basins for which monsoonal dynamics prevail), projected shifts in melt water in the Indus and Brahmaputra could threaten food security for 65 million people. Poor countries and their people face the greatest risks, as their resource bases are already tenuous. For example, food availability in Africa, where many depend on rain-fed agriculture, is likely to be impacted by reduced rainfall and increased desertification. Millions of people live in and take their livelihoods from mega-delta ecosystems in Asia. Climate change will likely bring more intense storms and higher sea levels, both representing severe threats to these regions.

Recent research indicates that climate change and other environmental degradation will play an ever-more important role in uprooting people (Warner et al. 2009). In an increasingly crowded and inter-connected world, destabilization in one region will impact distant societies. The security community (e.g. CNA 2007, Blair 2009) is working to understand the likely areas of impact because poverty and weak governance are already aggravated by chronic and abrupt climate events, leading to destabilization and threats to world peace as the developing and developed world alike face increasing numbers of environmental and economic refugees.  Feng et al. (2010) estimated that the 2080 rate of emigration from Mexico to the United States could increase between 3 and 9% for a temperature rise of 1-3oC and accompanying decreases in crop yield; the lower estimate, which represents approximately two million more migrants, assumes both a carbon dioxide fertilization effect on the primary crops and the implementation of adaptation measures, including different farming practices or policies.

Conclusion: One of the most compelling reasons to reduce emissions is to reduce the likelihood of negative impacts on society, especially in developing nations. Past climate changes have often been accompanied by migration, war, and disease. In the future, the growing human population will inevitably make environmental change more disruptive, even in the face of increased technological prowess.

# 4. Conclusion

The foundation of the science of human-induced climate change is the understanding of the physical effect of increasing concentrations of greenhouse gases on the planet's heat budget. Observations made throughout the instrumental record are consistent with this understanding: warming, melting land-based glaciers, reduced snowpack and Arctic sea ice, shifts in rainfall, and responses in ecosystems worldwide (IPCC AR4, Richardson et al. 2009, **Stott et al. 2010, Arndt et al. 2010**). The study of past climate through proxy records provides additional insight into the response of the climate system to various forcing mechanisms. Model simulations of present and past changes assist in interpreting these observations while also providing a means to quantify the climate response to each forcing factor and to project these dynamics into the future. These three avenues of investigation- theory, observations, and modeling- are crucial to build our understanding of Earth's climate and how it changes.

Climate research straddles multiple disciplines, from the physics of light interacting with aerosol particles to the relationship between ecosystems and human societies. It involves processes that occur at a broad range of temporal and spatial scales (e.g., from molecular to astronomical). The complexity and diversity of climate science requires independent bodies that can summarize, assess and integrate results, such as the national academies of countries worldwide (e.g. National Academy of Sciences 2008) or the IPCC. In response to a request from US Congress, the National Academies has released a series of reports on **America's Climate Choices** which address the strategies to reduce human influence on climate, actions to reduce vulnerability and increase adaptive capacity to climate change, and steps to advance scientific understanding of natural and human-induced climate change (NRC 2009).

The scientific process relies on skepticism. Results and conclusions are routinely questioned. Existing data and methods are re-evaluated while new data are constantly being acquired. Theory, data, principles and methods are discussed openly. The scientific endeavor with regards to climate change exemplifies this process, as is clearly seen in the successive assessment reports of the IPCC, where uncertainties are reduced, new processes identified, and approaches refined. Key climate indicators that characterize the climate system are consistent with warming (Arndt et al. 2010). Although continued research is needed to quantify the timing, location, and extent of climate impacts, many experts are confident that "global warming is unequivocal and primarily human-induced" (US GCRP 2009).

However, some individuals and organizations dispute this conclusion (e.g. Nova 2009, 2010). These challenges sometimes allege the existence of conspiracies, such as an effort to purposefully remove weather stations from the GHCN or to locate them in close proximity to buildings or airports with the aim of modifying the long-term temperature trend (D'Aleo and Watts 2010). The claims of conspiracy are not borne out by the facts. Similarly, the recent theft of 15 years of emails from the Climatic Research Unit of University of East Anglia failed to provide any evidence of scientific misconduct or conspiracy (AP 2009, UK Parliament 2010b, Russell et al. 2010). A few errors identified in the IPCC AR4 have added to an atmosphere of criticism (Leake 2010c). While some assert that these discussions may have had a negative impact on public perception of climate science (Pew 2009, but also see Krosnick 2010), the identified errors provide no evidence of conspiracy and have no impact on the scientific conclusions concerning climate change expressed in the IPCC AR4 (Russell et al. 2010, Netherlands Environmental Assessment Agency 2010a).

In an information-rich world, where sophisticated lay-people question the scientific tenets that inform societal decisions, open access to information and transparency in methods are key to the increased democratization of ideas. The climate community is working to meet this need by facilitating access to observational datasets, method descriptions, and to model code and output. Some examples include the data portal of the National Climate Data Center (NOAA NCDC 2010a), the surface temperature datasets maintained by the UK Meteorological Office (UK Met Office 2010), the model code of the NASA Goddard Institute of Space Studies (NASA GISS 2004), or the output of the models from the IPCC AR4, maintained by the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory in the US (PCMDI 2007).

# 4. Conclusion

Challenges to scientific understanding are rarely resolved in the mainstream media, as journalists seldom have the training to interpret and present the complex concepts involved. Furthermore, the reader can be easily overwhelmed by journalistic whiplash when competing views are presented (Revkin 2010). The scientific debate is best addressed within the scientific literature, but translation is required for the non-expert, as language, results, and implications are often narrowly focused and can be obscure even to those in closely related disciplines. The climate science community has the responsibility to provide regular state-of-the-art assessments and to answer questions about the current understanding. Several books, web pages, and blogs work to this end (see Appendix) and the present document aims to contribute to the effort by presenting scientific arguments in response to the major claims.

The conclusion that climate is changing in response to human emissions of greenhouse gases does not preclude the existence of other drivers of climate variability, such as solar activity or orbital forcing. Multiple drivers of climate act concurrently today as they have throughout Earth history. The fact that climate has changed in the past without human influence, including a Medieval Warm Period, does not reduce the likelihood of human-induced changes today. Rather, it demonstrates the sensitivity of Earth's climate to perturbation, thereby heightening concern as humans perturb the system by increasing atmospheric carbon dioxide to levels not observed in 800,000 years **(Lüthi et al. 2008)**. Natural variability in climate will continue to occur and the conditions that we experience will result from the interaction of all climate drivers. This is likely to produce periods of warming interspersed with periods of more stable temperatures, as well as trends that vary from one region to another. Regional conditions and short-term variability also can depart from longer-term global trends. Cold conditions observed in parts of the United States and Europe in winter of 2009-2010 were not representative of global temperature anomalies, which were among the highest in the instrumental record **(Arndt et al. 2010)**.

Science cannot "prove" that a specific feature observed in historical climate records was caused by greenhouse gases, but the scientific method allows general inferences about trends and patterns by rejecting competing hypotheses. For example, the observed long-term warming since the 1950s cannot be reproduced in models that do not include anthropogenic emissions of GHGs (IPCC WGI 2007, p. 120-121). There is no other forcing that could account for the observations. Solar activity declined while Earth warmed (Cook 2009) and global brightening due to increased regulation of air pollutants is inadequate to explain the warming **(Wild 2009)**.

The planet is warming and it is likely to continue to warm as a consequence of increased greenhouse gas emissions. Ultimately, questions revolve around sensitivity: how much will Earth warm, what will be the impacts, and when will they occur. As discussed above, sensitivity estimates below $2.5^{o}C$ cannot account for past climate changes. Atmospheric carbon dioxide levels are expected to have doubled by the end of the century if we continue with business as usual (IPCC WGI 2007). Failing to reduce emissions will thus lead the planet beyond the guardrail of $2^{o}C$ average global warming (e.g. Richardson et al. 2009, **Sokolov et al. 2009**).

Lower values of sensitivity require the existence of negative feedbacks, processes that would act to counteract warming. The strongest hypotheses of negative feedbacks put forth to date regard shifts in the dynamics of cloud formation; however, they have not been borne out by further research. Instead, as discussed above, warming is accompanied predominantly by positive feedbacks that further heat the planet: a warmer atmosphere holds more water vapor and forests stressed by water and temperature take up less carbon dioxide.

In addition, $CO_2$ has a direct effect on plant growth, with complex consequences for ecosystems. Crop yields may see a fertilization effect due to increased $CO_2$ in some regions, but they are likely to be negatively impacted by rising temperature and shifts in water availability elsewhere, especially in regions that are already food-insecure. Our best projections indicate that the most negative impacts of climate change will occur in nations that are already vulnerable to other stressors such as rapid population growth and extreme poverty. Humans have survived climate changes of the past, though never with global populations of the current magnitude. One might ask whether survival of the human species is an adequate standard of success.

# References


Adam, D. 2010. Forests expert officially complains about 'distorted' Sunday Times article. *The Guardian.* March 24. http://www.guardian.co.uk/environment/2010/mar/24/sunday-times-ipcc-amazon-rainforest

Agoumi, A. 2003. *Vulnerability of North African countries to climatic changes: adaptation and implementation strategies for climatic change.* Developing Perspectives on Climate Change: Issues and Analysis from Developing Countries and Countries with Economies in Transition. IISD/Climate Change Knowledge Network. 14 pp. http://www.cckn.net//pdf/north_africa.pdf.

Algeria. 2001. *Elaboration de la stratégie et du plan d'action national des changements climatiques.* Communication Nationale Initiale. Republique Algerienne Democratique et Populaire. March. 155 pages. http://unfccc.int/resource/docs/natc/algnc1.pdf

Allison,I., N. L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K.Steffen, E.J. Steig, M. Visbeck, A.J. Weaver. 2009. *The Copenhagen Diagnosis, 2009: Updating the world on the Latest Climate Science.* The University of New South Wales Climate Change Research Centre (CCRC). Sydney, Australia. 60pp.

Anderson, R. F., S. Ali, L.I. Bradtmiller, S.H.H. Nielsen, M.Q. Fleisher, B.E. Anderson, and L.H. Burckle. 2009. Wind-driven upwelling in the Southern Ocean and the deglacial rise in atmospheric $CO_2$. *Science* 323: 1443-1448.

Angliss, B. 2010. Experts say alleged PSU cover up of Mann misconduct "extremely unlikely." *Scholars and Rogues.* February 15. http://www.scholarsandrogues.com/2010/02/15/psu-cover-up-extremely-unlikely/

AP. 2009. Associated Press Impact: Science not faked, but not pretty. *Associated Press*. December 12. http://www.washingtonexaminer.com/economy/ap-impact-climate-scientist-e-mails-show-effort-to-not-share-data-pettiness-but-no-fakery-79122277.html

Archer, D. 2007. *Global warming: understanding the forecast*. Blackwell Publishing. 194 pp.

Archer, D. and J. Archer. 2009. *Modtran Infrared Radiation in the Atmosphere*. Accessed April 18 2010. http://geoflop.uchicago.edu/forecast/docs/Projects/modtran.html

Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., 2010. State of the Climate in 2009. Bull. Amer. Meteor. Soc. 91 (6), S1–S224. http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/climate-assessment-2009-hi-rez.pdf

Arthur, C. 2010. Hacking into the mind of the CRU climate change hacker. *The Guardian*. February 5. http://www.guardian.co.uk/environment/blog/2010/feb/05/cru-climate-change-hacker

Ball, J. and K. Johnson. 2010. Push to Oversimplify at Climate Panel. *Wall Street Journal.* February 26. http://online.wsj.com/article/SB10001424052748704188104575083681319834978.html?mod=rss_Today%27s_Most_Popular

Banerjee, B. and G. Collins, 2010. Anatomy of IPCC's Mistake on Himalayan Glaciers and Year 2035: Undoing 'The Curse' of a Chain of Errors. *The Yale Forum in Climate Change & The Media*. February 4. http://www.yaleclimatemediaforum.org/2010/02/anatomy-of-ipccs-himalayan-glacier-year-2035-mess/

# References

Barnes, E. 2010. Penn State Probe into Mann's Wrongdoing a 'Total Whitewash.' *FOXNews*. February 5. http://www.foxnews.com/scitech/2010/02/05/penn-state-probe-michael-mann-total-whitewash/

Battisti, D.S. and R.L. Naylor. 2009. Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. *Science* 323 (5911) 240-244.

BBC. 2009. Ancient History in Depth: The Fall of the Egyptian Old Kingdom. Updated November 5 2009. Accessed April 18 2010. http://www.bbc.co.uk/history/ancient/egyptians/ apocalypse_egypt_01.shtml

Benestad, R. E. and G. A. Schmidt. 2009 Solar trends and global warming. *J. Geophys. Res.* 114, D14101. doi:10.1029/2008JD011639.

Bjurström, A. 2010. Gray literature in the IPCC TAR, a guest post by Andreas Bjurstom. *Roger Pielke Jr's Blog*. March 5. http://rogerpielkejr.blogspot.com/2010/03/gray-literature-in-ipcc-tar-guest-post.html

Black, R. 2010. IPCC's Pachauri says climate body must 'listen and learn.' May 14. *BBC News.* http://news.bbc.co.uk/2/hi/science_and_environment/10112136.stm.

Blair, D.C. 2009. *Annual Threat Assessment of the Intelligence Community for the Senate Select Committee on Intelligence*. 46 pp. 12 February. http://intelligence.senate.gov/090212/blair.pdf

Bloom, A., M. Burger, J. Rubio Asensio, and A. Cousins. 2010. Carbon dioxide enrichment inhibits nitrate assimilation in wheat and *Arabidopsis. Science* 328: 899-901. 10.1126/science.11864

Bolton, A. 2010. Climate-change legislation buried under record snowfall in capital. *The Hill.* February 9. http://thehill.com/homenews/senate/80485-climate-bill-buried-under-record-snowfall

Branch, J. and I. Austin. 2010. As Olympics Near, They're Ordering Snow*. The New York Times*. January 21. http://www.nytimes.com/2010/01/22/sports/olympics/22snow.html?hp

Broecker, W.S., 1982. Glacial to interglacial changes in ocean chemistry. *Progress in Oceanography* 2: 151-197.

Brookhaven FACE Program. 2009. *Free-Air CO2 Enrichment (FACE).* Brookhaven National Laboratory. Updated September 14 2009. Accessed April 18 2010. http://www.bnl.gov/face/

Brooks, N. 2006. Cultural responses to aridity in the Middle Holocene and increased social complexity. *Quaternary International* 151: 29-49.

Budd, J. 2007. Information, Analysis, and Ideology: A Case Study of Science and the Public Interest. *Journal of the American Society for Information Science and Technology* 58(14):2366–2371.

Burke, M., D.B. Lobell, and L. Guarino. 2009. Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Global Environmental Change* 19: 317–325.

CCE. 2010. The Independent Climate Change Email Inquiry. Accessed April 18 2010. http://www.cce-review.org/index.php

Chung, E.-S., D. Yeomans, and B. Soden. 2010. An assessment of climate feedback processes using satellite observations of clear-sky OLR. *Geophys. Res. Lett.* 37: L02702. doi:10.1029/ 2009GL041889.

# References


Clear Climate Code. 2010. The 1990s station dropout does not have a warming effect. February 26. http://clearclimatecode.org/the-1990s-station-dropout-does-not-have-a-warming-effect/

CNA. 2007. *National security and the threat of climate change*. The CNA Corporation. 35 pp. http://securityandclimate.cna.org/report/National%20Security%20and%20the%20Threat%20of%20Climate%20Change.pdf

CO2 Science. 2010. *Medieval Warm Period Project*. Center for the Study of Carbon Dioxide and Global Change. 2010. Accessed April 18 2010. http://www.co2science.org/data/mwp/description.php

Coleman, J. 2010. Primary United States climate centers now caught in data manipulation*. Daily Blog: Coleman's Comments.* January 14. http://www.kusi.com/weather/colemanscorner/ 81532492.html

Cook, J. 2009. Solar activity & climate: is the sun causing global warming? *Skeptical Science.* http://www.skepticalscience.com/solar-activity-sunspots-global-warming.htm

Cook, J. 2010. The 5 characteristics of scientific denialism. *Skeptical Science*. March 5. http://www.skepticalscience.com/5-characteristics-of-scientific-denialism.html

Cronin, T.M., G. Dwyer, T. Kamiya, S. Schwede, and D. Willard. 2003. Medieval Warm Period, Little Ice Age and 20th century temperature variability from Chesapeake Bay. *Global and Planetary Change* **36**: 17-29.

Curry, J. 2010. Opinion: Can scientists rebuild the public trust in climate science? February 24. *Physics Today.* http://blogs.physicstoday.org/politics/2010/02/opinion-can-scientists-rebuild.html

D'Aleo, J. and A. Watts. 2010. *Surface Temperature Records: Policy Driven Deception?* Science and Public Policy Institute. 111 pp. January 27, update April 16. http://scienceandpublicpolicy.org/images/stories/papers/originals/surface_temp.pdf

D'Arrigo, R., R. Wilson, B. Liepert, and P. Cherubini. 2008. On the 'Divergence Problem' in Northern Forests: A review of the tree-ring evidence and possible causes. *Global and Planetary Change* 60: 289-305. doi:10.1016/j.gloplacha.2007.03.004.

Dawson, B. 2010. Analyzing headlines and lead sentences. *The Yale Forum in Climate Change & The Media.* March 18. http://www.yaleclimatemediaforum.org/2010/03/headlines-and-lead-sentences/

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed.* Penguin. 575 pp.

deMenocal, P. B. 2001. Cultural responses to climate change during the Late Holocene. *Science* 292: 667-673.

Dessler, A., and S. Sherwood. 2009. A Matter of Humidity. *Science* 323 (5917): 1020 - 1021.DOI: 10.1126/science.1171264

Diethelm, P.A. and M. McKee. 2009. Denialism: what is it and how should scientists respond? *European Journal of Public Health* 19 (1): 2–4.

Doherty, R., S. Sitch, B. Smith, S. Lewis, P. K. Thornton. Implications of future climate and atmospheric CO2 content for regional biogeochemistry, biogeography and ecosystem services across East Africa. *Global Change Biology* 16 (2): 617-640

# References


Douglass DH, J. Christy, B. Pearson, and S.F. Singer. 2007. A comparison of tropical temperature trends with model predictions. *International Journal of Climatology* 27: doi:10.1002/joc.1651.

Downie, D., K. Brash, and C. Vaughan. 2009. *Climate Change: A Reference Handbook*. ABC-CLIO. 337 pp.

Eilperin, J. 2005. GOP Chairman Face Off on Global Warming. Public Tiff over Probe of Study Highlights Divide on Issue. *The Washington Post*. July 18. http://www.washingtonpost.com/wp-dyn/content/article/2005/07/17/AR2005071701056.html

Erlykin, A., T. Sloan, and A. Wolfendale. 2009. Solar Activity and the Mean Global Temperature. *Environmental Research Letters* 4 (1).

Esper, J., D. Frank, U. Büntgen, A. Verstege, R. Hantemirov, and A. Kirdyanov. 2010. Trends and uncertainties in Siberian indicators of 20th century warming. *Global Change Biology* 16: 386–398. doi: 10.1111/j.1365-2486.2009.01913.x.

Farenthold, D. A. 2010. Review of U.N. panel's report on climate change won't reexamine errors. *The Washington Post*. 11 March http://www.washingtonpost.com/wp-dyn/content/article/2010/03/10/AR2010031002891.html

Feng, S., A. Krueger, and M. Oppenheimer. 2010. Linkages among climate change, crop yields and Mexico–US cross-border migration. *Proceedings of the National Academy of Sciences of the United States of America* 107 (32): 14257-14262. doi:10.1073/ pnas.1002632107

Feulner, G., and S. Rahmstorf. 2010. On the effect of a new grand minimum of solar activity on the future climate on Earth. *Geophys. Res. Lett.* 37 L05707. doi:10.1029/2010GL042710.

Filippi, M.L., P. Lambert, J. Hunziker, B. Kubler, and S. Bernasconi. 1999. Climatic and anthropogenic influence on the stable isotope record from bulk carbonates and ostracodes in Lake Neuchatel, Switzerland, during the last two millennia. *Journal of Paleolimnology* 21: 19-34.

Fischer, D. 2010. Climategate Scientist Cleared in Inquiry, Again. ScientificAmerican.com. July 1 2010. http://www.scientificamerican.com/article.cfm?id=climategate-scientist-cleared-in-inquiry-again

Flynn, D. 2008. Climate change can stoke Africa conflicts. April 22. *Reuters*. http://www.reuters.com/article/idUSL22658148

Frank, D., J. Esper, C. Raible, U. Büntgen, V. Trouet, B. Stocker, and F. Joos.2010. Ensemble reconstruction constraints on the global carbon cycle sensitivity to climate. *Nature* 463 (7280): 527-U143. doi:10.1038/nature08769

Freedman, A. 2010. John Coleman's climate change conspiracy theory. Capital Weather Gang. *The Washington Post*. January. http://voices.washingtonpost.com/capitalweathergang/2010/01/a_new_nasa_temperature_analysi.html

Gleadow, R.M., E.J. Edwards, and J. R. Evans. 2009. Changes in Nutritional Value of Cyanogenic Trifolium repens Grown at Elevated Atmospheric $CO_2$. *J. Chem Ecol* 35: 476–478. DOI 10.1007/s10886-009-9617-5.

Goldenberg, S. 2010. US Senate's top climate sceptic accused of waging 'McCarthyite witch-hunt.' *The Guardian.* March 1. http://www.guardian.co.uk/environment/2010/mar/01/inhofe-climate-mccarthyite

Grumbine, R. 2010. Cloud temperature feedback. *More Grumbine Science*. February 12. http://moregrumbinescience.blogspot.com/2010/02/cloud-temperature-feedback.html

# References


Handelsblad, N. 2010. IPCC climate report error #3: "the Netherlands is 55% below sea level." Signs of the Times. February 4. http://www.sott.net/articles/show/202500-IPCC-climate-report-error-3-the-Netherlands-is-55-below-sea-level-

Hansen, J., M. Sato, P. Kharecha, G. Russell, D.W. Lea, and M. Siddall. 2007. Climate change and trace gases. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences* 365: 1925-1954.

Hansen, J., R. Ruedy, M. Sato, and K. Lo. 2010. Current GISS Global Surface Temperature Analysis. Draft journal article. March 18. 34 pp. http://data.giss.nasa.gov/gistemp/paper/gistemp2010_draft0319.pdf

Hassan, F.A. 1997. *Nile floods and political disorder in early Egypt*. In N. Dalfes, G. Kukla, & H. Weiss (Eds.), Third Millennium BC climate change and Old World collapse, NATO ASI Series 1 (Volume 49, pp. 1–24). New York: Springer.

Hausfather, Z. 2010a. 'Extraordinary Claims' in KUSI Broadcast on NOAA, NASA … but 'Extraordinary Evidence?' *Yale Forum on Climate Change & The Media*. January 21. http://www.yaleclimatemediaforum.org/2010/01/kusi-noaa-nasa/

Hausfather, Z. 2010b. A simple model for spatially-weighted temp analysis. *The Blackboard.* March 1. http://rankexploits.com/musings/2010/a-simple-model-for-spatially-weighted-temp-analysis/

Hausfather, Z. 2010c. However One Slices It ... A Warming World: Reconstructing Surface Temperatures Leads to 'Remarkably Similar Results. *Yale Forum on Climate Change & The Media*. April 8. http://www.yaleclimatemediaforum.org/2010/04/reconstructing-surface-temperatures/

Helderman, R. 2010. State attorney general demands ex-professor's files from University of Virginia. *The Washington Post.* May 4. http://www.washingtonpost.com/wpdyn/content/article/2010/05/03/AR2010050304139.html

Herring, D., W. Higgins, and M. Halpert. Can Record Snowstorms and Global Warming Coexist? *ClimateWatch Magazine.* NOAA Climate Services. March 26. http://www.climatewatch.noaa.gov/2010/articles/can-record-snowstorms-global-warming-coexist

Högy, P., H. Wieser, P. Köhler, K. Schwadorf, J. Breuer, J. Franzaring, R. Muntifering, and A. Fangmeier. 2009. Effects of elevated CO2 on grain yield and quality of wheat: results from a 3-year free-air CO2 enrichment experiment. *Plant Biology* 11 (S1): 60 - 69. doi. 1111/j.1438-8677.2009.00230.x

Hulme M., E. Zorita, T. F. Stocker, J. Price and J.R. Christy. 2010. IPCC: cherish it, tweak it or scrap it? *Nature* 463 (7282): 730-732.

Hunt, B.G. 2010. The role of natural climatic variation in perturbing the observed global mean temperature trend. *Climate Dynamics* 10.1007/s00382-010-0799-x.

Immerzeel, W., L. van Beek, and M. Bierkens. 2010, Climate Change Will Affect the Asian Water Towers. *Science* 328: 1382-1385. 10.1126/science.1183188.

InterAcademy Council. 2010. InterAcademy Council Media Advisory: IPCC review committee to hold public sessions on May 14 in Amsterdam. May 14. Accessed May 15 2010. http://reviewipcc.interacademycouncil.net/IACMediaAdvisory.html

IPCC. 2001. *Third Assessment Report: Climate Change 2001.* IPCC: Geneva, Switzerland. http://www.ipcc.ch/pub/online.htm

# References

IPCC WGII. 2006. Working Group II: Impacts, adaptation and vulnerability. Fourth Assessment draft chapters and reviews. http://ipcc-wg2.gov/publications/AR4/ar4review.html

IPCC WGI 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report.* [Solomon, S. Qin, D. Manning, M., Chen, Z. Marquis, M., Averyt, K., Tignor, M. and H.L. Miller (eds.)]. Cambridge, UK: Cambridge University Press.

IPCC WGII 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report.* [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)], Cambridge University Press, Cambridge, UK. : Cambridge University Press. 976pp.

IPCC. 2008. Appendix A to the Principles Governing IPCC Work: procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports. http://www.ipcc.ch/pdf/ipcc-principles/ipcc-principles-appendix-a.pdf

IPCC 2010a. The role of the IPCC and key elements of the IPCC assessment process. Geneva, 4 February 2010. http://www.ipcc.ch/pdf/press/role_ipcc_key_elements_assessment_process_04022010 .pdf

IPCC 2010b. IPCC statement on the melting of Himalayan glaciers. January 20. http://ipcc.ch/pdf/presentations/himalaya-statement-20january2010.pdf

IPCC 2010c. IPCC statement on trends in disaster losses. January 25. http://www.ipcc.ch/pdf/presentations/statement_25_01 _2010.pdf

Jones, P.D., T.J. Osborn, and K.R. Briffa. 2001. The evolution of climate over the last millennium. *Science*, 292 (5517): 662-667.

Jones, P. D., and M. E. Mann. 2004. Climate over past millennia, *Rev. Geophys.* 42, RG2002, doi:10.1029/2003RG000143.

Kalnay, E. M. and M. Cai. 2003. Impact of urbanization and land-use change on climate. *Nature* 423(6939): 528-531.

Karl T.R., S.J. Hassol, C.D. Miller, L.W. Murray (eds). 2006. *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. National Oceanic and Atmospheric Administration, National Climatic Data Center: Asheville, NC. 164pp.

Kaufman, D. S., D.P. Schneider, N.P. McKay, C.M. Ammann, R.S. Bradley, K.R. Briffa, G.H. Miller, B.L. Otto-Bliesner, J.T. Overpeck, B.M. Vinther, and Arctic Lakes 2k Project Member. 2009. Recent warming reverses long-term Arctic cooling. *Science*, 325: 1236-1239.

Kawamura, K., F. Parrenin, L. Lisiecki, R. Uemura, F. Vimeux, J.P. Severinghaus, M.A. Hutterli, T. Nakazawa, S. Aoki, J. Jouzel, M.E. Raymo, K. Matsumoto, H. Nakata, H. Motoyama, S. Fujita, K. Goto-Azuma, Y. Fujii, O. Watanabe. 2007. Northern Hemisphere forcing of climatic cycles in Antarctica over the past 360,000 years. *Nature* 448: 912-916.

Kinne, O. 2003. Climate Research: an article unleashed worldwide storms. *Climate Research* 24: 197–198. http://www.int-res.com/articles/misc/CREditorial.pdf

Kintisch, E, 2010. Michael Mann Exonerated as Penn State Inquiry Finds 'No Substance' To Allegations. *ScienceInsider*. July 1 2010. http://news.sciencemag.org/scienceinsider/2010/07/michael-mann-exonerated-as-penn.html

# References

Knutti, R. and G. Hegerl. 2008. The equilibrium sensitivity of the Earth's temperature to radiation changes. *Nature Geoscience* 1 (11): 735-743.

Kristjánsson, J. E., C. Stjern, F. Stordal, A. Fjoéraa, G. Myhre, and K. Jónasson. 2008. Cosmic rays, cloud condensation nuclei and clouds-a reassessment using MODIS data. *Atmos. Chem. Phys.* 8: 7373-7387.

Krosnick, J. 2010. The Climate Majority. *The New York Times.* June 8. http://www.nytimes.com/2010/06/09/opinion/09krosnick.html

Kulmala, M., I. Riipinen, T. Nieminen, M. Hulkkonen, L. Sogacheva, H. E. Manninen, P. Paasonen,T. Petaja, M. Dal Maso, P. P. Aalto, A. Viljanen, I. Usoskin, R. Vainio, S. Mirme, A. Mirme, A. Minikin, A. Petzold, U. Horrak, C. Plaß-Dulmer, W. Birmili, and V.-M. Kerminen. 2010. Atmospheric data over a solar cycle: no connection between galactic cosmic rays and new particle formation. *Atmos. Chem. Phys*. 10: 1885–1898.

Kump, L.R., J.F. Kasting, and R.G. Crane. 2004. *The Earth System*. Upper Saddle River, NJ: Pearson, Prentice Hall.

Kuper, R. and S. Kröpelin. 2006. Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. *Science* 313: 803-807.

Kurukulasuriya, P., R. Mendelsohn, R. Hassan, J. Benhin, M. Diop, H. Eid, K. Fosu, G. Gbetibouo, S. Jain, A. Mahamadou A, S. El-Marsafawy, S. Ouda, M. Ouedraogo, I. Sène, D. Maddision, N. Seo, A. Dinar. 2006. Will African agriculture survive climate change? *World Bank Econ Rev* 20:367–388. doi:10.1093/wber/lhl004

KUSI-TV. 2010**.** KUSI Special Report, Global Warming: The Other Side. Accessed April 18 2010. (Broadcast) http://www.kusi.com/weather/colemanscorner/81583352.html

Leake, J. and C. Hastings. 2010. World misled over Himalayan glacier meltdown. *The Times*. January 17. http://www.timesonline.co.uk/tol/news/environment/article6991177.ece

Leake, J. 2010a. UN wrongly linked global warming to natural disasters. *The Sunday Times.* January 24. http://www.timesonline.co.uk/tol/news/environment/article7000063.ece

Leake, J. 2010b. The UN climate panel and the rainforest claim. *The Times*. January 31. http://www.timesonline.co.uk/tol/news/environment/article7009705.ece

Leake, J. 2010c. Africagate: top British scientist says UN panel is losing credibility. *The Sunday Times.* February 7. http://www.timesonline.co.uk/tol/news/environment/article7017907.ece

Leakey, A., E. Ainsworth, C. Bernacchi, A. Rogers, S. Long, and D. Or. 2009. Elevated $CO_2$ effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *Journal of Experimental Botany* 60 (10): 2859–2876. doi:10.1093/jxb/erp096

Lean, J. 2010. Cycles and trends in solar irradiance and climate. *Wiley Interdisciplinary Reviews: Climate Change* 1 (1): 111-122. DOI: 10.1002/wcc.18

Lean, J. and D. Rind. 1996. The Sun and Climate. *Consequences*. 2: 27-36.

# References

Leiserowitz, A., E. Maibach, and C. Roser-Renouf. 2010. *Climate Change in the American Mind: Public Support for Climate & Energy Policies in January 2010.* Yale F&ES Project on Climate Change. http://environment.yale.edu/uploads/PolicySupportJan2010.pdf

Lewis, S. 2010. *A complaint about the article 'UN climate panel shamed by bogus rainforest claim' by Jonathan Leake*. March 24. Accessed June 14 2010. http://climateprogress.org/wp-content/uploads/2010/03/Lewis_S_Times_PCC_Complaint_As_Sent1.pdf

Lindzen, R.S., M.-D. Chou, and A.Y. Hou. 2001. Does the Earth have an adaptive infrared iris? *Bull. Amer. Met. Soc.* 82: 417–432. doi:10.1175/1520-0477

Lindzen, R.S. 2009. The Climate Science Isn't Settled. *The Wall Street Journal.* November 30.http://online.wsj.com/article/SB10001424052748703939404574567423917025400.html

Lindzen, R. S., and Y.-S. Choi. 2009. On the determination of climate feedbacks from ERBE data, *Geophys. Res. Lett.* 36 L16705, doi:10.1029/2009GL039628.

Lin, B., B. Wielicki, L. Chambers, Y. Hu, and K.-M. Xu. 2002. The Iris Hypothesis: A Negative or Positive Cloud Feedback? *Journal of Climate* 15 (1): 3–7. doi:10.1175/1520-0442.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319 (5863): 607-610.

Lobell, D.B. and M. B. Burke. 2008. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. *Environ. Res. Lett.* 3 034007. doi:10.1088/1748-9326/3/3/034007

Lockwood, M. 2010. Solar change and climate: an update in the light of the current exceptional solar minimum. *Proc. R. Soc. A* 466 (2114): 303-329.

Lombardi, L. 2010. Investigation reveals conflict of interest. *Centre Daily Times.* July 13 2010. http://www.centredaily.com/2010/07/13/2089906/investigation-reveals-conflict.html

Lopez, P., P. Chevallier, V. Favier, B. Pouyauda, F. Ordenes and J. Oerlemans. 2010. A regional view of fluctuations in glacier length in southern South America. *Global and Planetary Change* 71 (1-2): 85-108.

Lorius, C., Jouzel, J., Raynaud, D., Hansen, J. and LeTreut, H. 1990. The ice-core record: Climate sensitivity and future greenhouse warming. *Nature* 347(6289): 139-145.

Lüthi, D., M. Le Floch, B. Bereiter, T. Blunier, J.M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, and T.F. Stocker. 2008. High-resolution carbon dioxide concentration record 650,000-800,000 years before present. *Nature* 453: 379-382.

Lyman, J., S. Good, V. Gouretski, M. Ishii, G. Johnson, M. Palmer, D. Smith, and J. Willis. 2010. Robust warming of the global upper ocean. *Nature* 465: 334–337.

Mann, M.E., R. S. Bradley, and M. K. Hughes. 1998. Global-Scale Temperature Patterns and Climate Forcing over the Past Six Centuries. *Nature* 392 (6678): 779-787.

# References


Mann, M.E., R.S. Bradley, and M.K. Hughes. 1999. Northern Hemisphere Temperatures during the Past Millennium: Inferences, Uncertainties, and Limitations. *Geophysical Research Letters* 26(6): 759-762.

Mann, M.E., R. S. Bradley, and M. K. Hughes. 2004. Global-Scale Temperature Patterns and Climate Forcing over the Past Six Centuries (vol 392, pg 779, 1998), corrigendum. *Nature* 430 (6995): 105.

Mann, M., Z. Zhang, M. Hughes, R. Bradley, S. Miller, S. Rutherford, and F. Ni. 2008. Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proc. Natl. Acad. Sci. U.S.A.* 105 (36): 13252–13257.

Mann, M., Z. Zhang, S. Rutherford, R. Bradley, M. Hughes, D. Shindell, C. Amman, G. Faluvegi, and F. Ni. 2009. Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly. *Science* 326 (5957): 1256-1260.

Matson, P., T, Dietz, W. Abdalati, A. Busalacchi, K. Caldeira, R. Corell, R. DeFries, I. Fung, S. Gaines, G. Hornberger, M.C. Lemos, S. Moser, R. Moss, E,. Parson, A. Ravishankara, R. Schmitt, B. Turner II, W. Washington, J. Weyant, and D. Whelan. 2010. *Advancing the Science of Climate Change.* America's Climate Choices: Panel on Advancing the Science of Climate Change. National Research Council. Washington D.C. Pre-publication. 506 pp.

Menne, M., C. N. Williams, Jr., and M. A. Palecki. 2010. On the reliability of the U.S. Surface Temperature Record. *Journal of Geophysical Research – Atmospheres* 115 D11108.doi:10.1029/2009JD013094 http://www1.ncdc.noaa.gov/pub/data/ushcn/v2/monthly/menne-etal2010.pdf

McKitrick, R. and P. J. Michaels. 2004. A test of corrections for extraneous signals in gridded surface temperature data. *Climate Research* 26(2): 159-173.

McIntyre, S. and R. McKitrick. 2003. Corrections to the Mann et al. (1998) Proxy Data Base and Northern Hemispheric Average Temperature Series. *Energy and Environment* 14(6): 751-771.

Mooney, C. 2004. Déjà vu All Over Again: Doubt and About. *The Skeptical Inquirer.* September 13. http://www.csicop.org/specialarticles/show/deja_vu_all_over_again/

Morocco. 2001. *Executive summary. First National Communication United Nations Framework Convention on Climate Change.* Kingdom of Morocco. October. 24 pages. http://unfccc.int/resource/docs/natc/mornc1e.pdf

Murphy, D. M., S. Solomon, R. W. Portmann, K. H. Rosenlof, P. M. Forster, and T. Wong. 2009. An observationally based energy balance for the Earth since 1950. *J. Geophys. Res.* 114 D17107. doi:10.1029/2009JD012105.

Narama, C., A. Kääb, M. Duishonakunov, K. Abdrakhmatov. 2010. Spatial variability of recent glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~ 1970), Landsat (~ 2000), and ALOS (~ 2007) satellite data. *Global and Planetary Change* 71 (1-2): 42-54. doi:10.1016/j.gloplacha.2009.08.002

NASA. 2009. How Low Can It Go? Sun Plunges into the Quietest Solar Minimum in a Century. April 1 2009. Accessed April 19 2010. http://www.nasa.gov/topics/solarsystem/features/ solar_minimum09.html

NASA GISS. 2004. GISS GCM ModelE. February 1. Accessed August 22 2010. http://www.giss.nasa.gov/tools/modelE

NASA GISS. 2010. 2009: Second Warmest Year on Record; End of Warmest Decade. *Goddard Institute for Space Studies Research News*. January 21. Accessed April 18 2010. http://www.giss.nasa.gov/research/news/20100121/

# References


National Academy of Sciences. 2006. *Surface Temperature Reconstructions for the Last 2000 Years*. Washington, DC: National Academy of the Sciences. http://www.nap.edu/catalog/11676.html

National Academy of Sciences. 2008. *Understanding and responding to climate change. Highlights of National Academies Reports. 2008 Edition*. 23 pp. Washington, DC: National Academy of the Sciences. http://americasclimatechoices.org/climate_change_2008_final.pdf

Neefus, C. 2010. Sen. Inhofe's Family Builds Igloo for Global Warming Spokesman Al Gore in Snow-laden D.C. February 9 2010. *CNSNews.com.* http://www.cnsnews.com/news/article/61146

Nepstad, D. C., A.Veríssimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Mountinho, E. Mendoza, M. Cochrane, V. Brooks. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature* 398: 505-508.

Nepstad, D. 2010. Senior Scientist Daniel Nepstad endorses the correctness of the IPCC's (AR4) statement on Amazon forest susceptibility to rainfall reduction. February. Woods Hole Research Center. http://www.whrc.org/resources/online_publications/essays/2010-02-Nepstad_Amazon.htm

Nepstad, D., A. Alencar, G. Asner, P. Brando, F. Brown, M. Bustamante, E. Davidson, S. Goetz, R. Houghton, M. Keller, S. Lewis, T. Lovejoy, P Meier, P. Moutinho, C. Nobre, S. Ollinger, O. Phillips, G. Woodwell. 2010. Scientists' statement on recent press release on Amazon susceptibility to reductions in rainfall: no Amazon rainforest "myths" have been debunked. March 18. http://www.whrc.org/assets/scientists_amazon_response.pdf.

Netherlands Environmental Assessment Agency (PBL). 2010a. *Assessing an IPCC assessment. An analysis of statements on projected regional impacts in the 2007 report.* The Hague/Bilthoven. PBL publication number: 500216002. 100pp. http://www.pbl.nl/en/publications/2010/Assessing-an-IPCC-assessment.-An-analysis-of-statements-on-projected-regional-impacts-in-the-2007-report.html.

Netherlands Environmental Assessment Agency (PBL). 2010b. *Correction wording flood risks for the Netherlands in IPCC report.* June 16 2010. Accessed July 26 2010. http://www.pbl.nl/en/dossiers/Climatechange/content/correction-wording-flood-risks.html

NOAA Climate Services. 2009. *Talking Points related to concerns about whether the U.S. temperature record is reliable.* July 6. Accessed April 18 2010. http://www.ncdc.noaa.gov/oa/about/ response-v2.pdf

NOAA NCDC. 2010a. Climate Indicators*. Updated August 19. Accessed August 22 2010. http://www.ncdc.noaa.gov/bams-state-of-the-climate/2009-time-series/*

NOAA NCDC. 2010b. *State of the Climate Global Analysis, Annual 2009*. February 12. Accessed April 18 2010. http://www.ncdc.noaa.gov/sotc/?report=global&year=2009&month=13

NOAA NCDC. 2010c. *State of the Climate Global Analysis, March 2010*. April 16. Accessed May 15 2010. http://www.ncdc.noaa.gov/sotc/?report=global&year=2010&month=3

NOAA NCDC. 2010d. *The Monthly Global (land and ocean combined into an anomaly) Index (degrees C).* April 18. Accessed July 27 2010. ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/monthly.land_ocean.90S.90N.df_1901-2000mean.dat

# References


NOAA NCDC. 2010e. *Monitoring Global and U.S. Temperatures at NOAA's National Climatic Data Center.* March 1. Accessed July 27 2010. http://www.ncdc.noaa.gov/cmb-faq/temperature-monitoring.html

North, R. 2010a. And now for Amazongate. *EU Referendum*. January 24. http://eureferendum.blogspot.com/2010/01/and-now-for-amazongate.html

North, R. 2010b. And now for Africagate. *EU Referendum*. February 6. http://eureferendum.blogspot.com/2010/02/and-now-for-africagate.html

Nova, J. 2009. *The skeptic's handbook*. The Heartland Institute. 16 pp. http://joannenova.com.au/globalwarming/the_skeptics_handbook_2-3_lq.pdf

Nova, J. 2010. *The skeptic's handbook II. Global bullies want your money*. The Heartland Institute. 20 pp. http://joannenova.com.au/2009/11/skeptics-handbook-ii-global-bullies-want-your-money/

NRC. 2009. *America's Climate Choices.* National Research Council of The National Academies. Accessed May 16 2010. http://americasclimatechoices.org/index.shtml

OSTP. 2010. *Investing in the Building Blocks of American Innovation: Federal R&D, Technology, and STEM Education in the 2010.* Office of Science and Technology Policy, Executive Office of the President. February 1. 10pp. Accessed April 18 2010. http://www.whitehouse.gov/sites/default/files/fy2011rd%20final.pdf

Oxburgh, R., H. Davies, K. Emmanuel, L. Graumlich, D. Hand, H. Huppert, M. Kelly. *Science Assessment Panel Report*. 8pp. April 14. http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/Report+of+the+Science+Assessment+Panel

Palin, S. 2009. Sarah Palin on the politicization of the Copenhagen climate conference. *The Washington Post.* December 9. http://www.washingtonpost.com/wp-dyn/content/article/2009/12/08/AR2009120803402.html

PCMDI 2007. About the WCRP CMIP3 Multi-Model Dataset Archive at PCMDI. Program for Climate Model Diagnosis and Intercomparison. Accessed August 22 2010. http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

Pearce, F. 2009. Climategate: Anatomy of A Public Relations Disaster. December 10. *Yale Environment 360*. http://www.e360.yale.edu/content/feature.msp?id=2221

Peterson, T.C. and R.S. Vose. 1997. An overview of the Global Historical Climatology Network temperature database. *Bulletin of the American Meteorological Society* 78: 2837-2849.

Pew. 2009. Fewer Americans See Solid Evidence of Global Warming. October 22. http://people-press.org/report/556/global-warming

Phillips O.L., L. Aragão, S. Lewis, J. Fisher, J. Lloyd, G. López-González, Y. Malhi, A. Monteagudo, J. Peacock, C. Quesada, G. van der Heijden, S. Almeida, I. Amaral, L. Arroyo, G. Aymard, T. Baker,O. Bánki, L. Blanc, D. Bonal, P. Brando, J. Chave, A. C. Alves de Oliveira, N. Dávila Cardozo, C. Czimczik, T. Feldpausch, M. Aparecida Freitas, E. Gloor, N. Higuchi, E. Jiménez, G. Lloyd, P. Meir, C. Mendoza, A. Morel, D. Neill, D. Nepstad, S. Patiño, M. C. Peñuela, A. Prieto, F. Ramírez, M. Schwarz, J. Silva, M. Silveira, A. Sota Thomas, H. ter Steege, J. Stropp, R. Vásquez, P. Zelazowski, E. Alvarez Dávila, S. Andelman, A. Andrade, K-J Chao, T. Erwin, A. Di Fiore, E. Honorio C.,34 Helen Keeling, T. Killeen, W. Laurance, A. Peña Cruz, N. Pitman, P. Núñez Vargas, H. Ramírez-Angulo,38 A. Rudas, R. Salamão, N. Silva, J. Terborgh, A. Torres-Lezama. 2009. Drought Sensitivity of the Amazon Rainforest. *Science* 323: 1344-1347

# References


Pielke Jr., R. 2010. Major change is needed if the IPCC hopes to survive. *Yale Environment 360*. February 25. http://e360.yale.edu/content/feature.msp?id=2244

RealClimate 2005a. What If … the "Hockey Stick" Were Wrong? January 27. http://www.realclimate.org/index.php/archives/2005/01/what-if-the-hockey-stick-were-wrong/

RealClimate. 2005b. Water vapour: feedback or forcing? April 6. http://www.realclimate.org/index.php/archives/2005/04/water-vapour-feedback-or-forcing/

RealClimate. 2009a. The CRU hack. November 20. http://www.realclimate.org/index.php/archives/2009/11/the-cru-hack/.

RealClimate. 2009b. The CRU hack: Context. November 23. http://www.realclimate.org/index.php/archives/2009/11/the-cru-hack-context/.

RealClimate. 2010a. First published response to Lindzen and Choi. January 8.

RealClimate. 2010b. Lindzen and Choi Unraveled. Guest Commentary by John Fasullo, Kevin Trenberth and Chris O'Dell. January 8. http://www.realclimate.org/index.php/archives/2010/01/lindzen-and-choi-unraveled/

RealClimate. 2010c. IPCC errors: facts and spin. February 14. http://www.realclimate.org/index.php/archives/2010/02/ipcc-errors-facts-and-spin/

RealClimate. 2010d. Up is Down, Brown is Green (with apologies to Orwell). March 15. http://www.realclimate.org/index.php/archives/2010/03/up-is-down-brown-is-green-with-apologies-to-orwell/

Regalado, A., 2003: Debating Global Warming – Global Warming Skeptics Are Facing Storm Clouds, *The Wall Street Journal.* July 31.

Revkin, A. 2010. A Rebuttal to a Cool Climate Paper. January 8. *Dot Earth. The New York Times.* http://dotearth.blogs.nytimes.com/2010/01/08/a-rebuttal-to-a-cool-climate-paper/

Richardson, K., W. Steffen, H.J. Schellnhuber, J Alcamo, T Barker, D. Kammen, R. Leemans, D. Liverman, M. Munasinghe, B. Osman-Elasha, N. Stern, O. Wæver. 2009. *Synthesis report from* *Climate Change: Global Risks, Challenges and Decisions, Copenhagen 2009, 10-12 March*. 39pp.

RMS. 2010. Risk Management Solutions FAQ: Research on Climate Change and Disaster Loss Costs and the IPCC. http://www.rms.com/Publications/2010_FAQ_IPCC.pdf

Rose, D. 2010. Glacier scientist: I knew data hadn't been verified. *Daily Mail.* January 24. http://www.dailymail.co.uk/news/article-1245636/Glacier-scientists-says-knew-data-verified.html#ixzz0jgCIuEFP

Rowell, A. and P.F. Moore, 2000: *Global Review of Forest Fires*. WWF/IUCN, Gland, Switzerland, 66 pp. http://data.iucn.org/dbtw-wpd/edocs/2000-047.pdf

Russell, M., G. Boulton, P. Clarke, D. Eyton, and J. Norton. 2010.*The Independent Climate Change E-mails Review*. University of East Anglia. 160pp. http://www.cce-review.org/pdf/FINAL%20REPORT.pdf

# References


Rutherford, S., M.E. Mann, T.J .Osborn, R.S. Bradley, K.R. Briffa, M.K. Hughes, and P.D. Jones. 2005. Proxy-based northern hemisphere surface temperature reconstructions: sensitivity to methodology, predictor network, target season and target domain. *Journal of Climate* 18: 2308-2329. http://holocene.meteo.psu.edu/shared/articles/RuthetalJClimate05.pdf.

Sachs, J. A. 2008. *Common Wealth: Economics for a Crowded Planet*. Penguin. 400 pp.

Santer, B.D., P. W. Thorne, L. Haimberger, K. E. Taylor, T. M. L. Wigley, J. R. Lanzante, S. Solomon, M. Free, P. J. Gleckler, P. D. Jones, T. R. Karl, S. A. Klein, C. Mears, D. Nychka, G. A. Schmidt, S. C. Sherwood, and F. J. Wentz. 2008. Consistency of modelled and observed temperature trends in the tropical troposphere. *Int. J. Climatol*. 28: 1703–1722

Schiermeier, Q. 2010. The Real Holes in Climate Science. *Nature* 463 (7279): 284-287

Schlenker, W. and M.J. Roberts. 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl. Acad. Sci. USA* 106 (37): 15594–15598. doi: 10.1073/pnas.0906865106. http://www.pnas.org/content/106/37/15594.full.

Schneider, B. and R. Schneider. 2010. Global warmth with little extra $CO_2$. *Nature Geoscience* 3: 6-7.

Seo, S.N., R. Mendelsohn, A. Dinar, R. Hassan, P. Kurukulasuriya. 2009. A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa. *Environ Resource Econ.* 43:313–332. DOI 10.1007/s10640-009-9270-z

Smith, E. M. 2009. NOAA/NCDC: GHCN – The Global Analysis. *Musings from the Chiefio*. November 3. http://chiefio.wordpress.com/2009/11/03/ghcn-the-global-analysis/

Sokolov, A.P. , P.H. Stone, C.E. Forest, R. Prinn, M.C. Sarofim, M. Webster, S. Paltsev, C.A. Schlosser, D. Kicklighter, S. Dutkiewicz, J. Reilly, C. Wang, B Felzer, J.M. Melillo, H.D. Jacoby. 2009. Probabilistic forecast for 21st century climate based on uncertainties in emissions (without policy) and climate parameters. *Journal of Climate* 22(19): 5175-5204.

Solomon, S., G. K. Plattner, R. Knutti and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences of the United States of America* 106(6): 1704-1709.

Soon, W. and S. Baliunas. 2003. Climatic and environmental changes of the past 1000 years. *Climate Research* 23: 89–110.

Spencer, R. 2009. Some Comments on the Lindzen and Choi (2009) Feedback Study. November 2. http://www.drroyspencer.com/2009/11/some-comments-on-the-lindzen-and-choi-2009-feedback-study/

Spierre, S.G. and C. Wake. 2010. *Trends in Extreme Precipitation Events for the Northeastern United States: 1948-2007*. Carbon Solutions New England. 17pp. http://www.carbonsolutionsne.org/resources/ne_climate_reports/pdf/2010_NortheastExtremePrecip.pdf

Stott, P., N. Gillett, G. Hegerl, D. Karoly, D. Stone, X. Zhang, and F. Zwiers. 2010. Detection and attribution of climate change: a regional perspective. *WIREs Climate Change* 1: 192-197. DOI: 10.1002/wcc.34

Su, H., J. Jiang, Y. Gu, D. Neelin, B. Kahn, D. Feldman, Y. Yung, J. Waters, N. Livesay, M. Santee, and W. Read. 2008. Variations of tropical upper tropospheric clouds with sea surface temperature and implications for radiative effects. *J. Geophys. Res.* 113 D10211. doi:10.1029/2007JD009624.

# References

Surfacestions Project. 2009. Surfacestations Project. A resource for climate station records and surveys. Updated July 16. Accessed April 18 2010. http://surfacestations.org/

Svensmark, H. 2007. Cosmoclimatology: a new theory emerges. *Astronomy & Geophysics* 48 (1): 18–24. doi:10.1111/j.1468-4004.2007.48118.

Tebaldi, C. and D. B. Lobell. 2008. Towards probabilistic projections of climate change impacts on global crop yields. *Geophysical Research Letters* 35, L08705, doi:10.1029/2008GL033423

Thompson, L.G., H. H. Brecher, E. Mosley-Thompson, D. R. Hardy, and B. G. Mark. 2009. Glacier loss on Kilimanjaro continues unabated. *Proceedings of the National Academy of Sciences of the United States of America* 106 (47): 19770–19775.

Trenberth, K. E., J. T. Fasullo, C. O'Dell, and T. Wong. 2010. Relationships between tropical sea surface temperature and top-of-atmosphere radiation. *Geophys. Res. Lett.* 37 L03702. doi:10.1029/2009GL042314.

Tunisia. 2001. *Initial Communication of Tunisia under the United Nations Framework Convention on Climate Change*. Republic of Tunisia. October.
http://209.85.229.132/search?q=cache%3A65qymU0qn_8J%3Aunfccc.int%2Fresource%2Fdocs%2Fnatc%2Ftunnc1esum.pdf+http%3A%2F%2Funfccc.int%2Fresource%2Fdocs%2Fnatc%2Ftunnc1esum.pdf&hl=en&gl=uk

UEA. 2009. Sir Muir Russell to head the Independent Review into the allegations against the Climatic Research Unit (CRU). December 3. Accessed April 18 2010. http://www.uea.ac.uk/mac/comm/media/press/2009/dec/CRUreview

UEA. 2010. New scientific assessment of climatic research publications announced. February 11. Accessed April 18 2010. http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/New+scientific+assessment+of+climatic+research+publications+announced

UK Met Office 2010. Surface temperature datasets for the 21st Century. Updated August 20. Accessed August 22. http://www.surfacetemperatures.org/ August 20 updat

UK Parliament. 2010a. *The disclosure of climate data from the Climatic Research Unit at the University of East Anglia.* House of Commons. Science and Technology Committee.
http://www.parliament.uk/parliamentary_committees/science_technology/s_t_cru_inquiry.cfm

UK Parliament. 2010b. *The disclosure of climate data from the Climatic Research Unit at the University of East Anglia.* House of Commons. Science and Technology Committee. HC 387-I. March 31. 63 pp.
http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/387/387i.pdf

US GCRP. 2009. *Global Climate Change Impacts in the United States.* T.R. Karl, J.M. Melillo, and T.C. Peterson, (eds.). Cambridge University Press.196 pp. www.globalchange.gov/usimpacts

von Storch, H. 2009. *The CR Problem*. November 2009. Accessed April 18 2010. http://coast.gkss.de/staff/storch/CR-problem/cr.2003.htm

Velasquez-Manoff, M. 2009. Climategate, global warming, and the tree rings divergence problem. *Christian Science Monitor*. December 14. http://www.csmonitor.com/Environment/Bright-Green/2009/1215/Climategate-global-warming-and-the-tree-rings-divergence-problem

# References


Wall Street Journal. 2005. “Hockey Stick on Ice – Politicizing the Science of Global Warming.” *The Wall Street Journal*. February 18.

Warner, K., C. Ehrhart, A. de Sherbinin, S. Adamo, and T. Chai-Onn. 2009. *In Search of Shelter: Mapping the Effects of Climate Change on Human Migration and Displacement*. 36 pp. http://www.ciesin.columbia.edu/documents/clim-migr-report-june09_final.pdf

Watts, A. 2009. *Is the surface temperature record reliable?* The Heartland Institute. 31 pp. http://wattsupwiththat.files.wordpress.com/2009/05/surfacestationsreport_spring09.pdf

Watson, R.T. 2010. The IPCC Needs to Change, But the Science Remains Sound. *Yale Environment 360*. February 25. http://e360.yale.edu/content/feature.msp?id=2245

Weart, S. 2008. *The Discovery of Global Warming - A History. Revised and Expanded Edition*. Harvard University Press. 240 pp.

Webster, B. 2010. UN to review errors made by Intergovernmental Panel on Climate Change. *The Times.* March 10. http://www.timesonline.co.uk/tol/news/world/us_and_americas/article7055999.ece

Wegman, E., D. Scott, and Y. Said. 2006. *Ad hoc committee report on the ‘hockey stick’ global climate reconstruction*. A report to Chairman Barton, House Committee on Energy and Commerce and to Chairman Whitfield, House Subcommittee on Oversight and Investigations. 92 pp. http://republicans.energycommerce.house.gov/108/home/07142006_Wegman_Report.pdf

Weiss, H. and R.S. Bradley. 2001. Archaeology - What drives societal collapse? *Science* 291: 609-610.

Wild, D. 2009. Global dimming and brightening: A review. *Journal of Geophysical Research-Atmospheres* 114. D00D16.

Wilson, A.T., C. H. Hendy, and C.P. Reynolds. 1979. Short-term climate change and New Zealand temperatures during the last millennium. *Nature* **279**: 315-317.

WMO. 2010. *World Meteorological Organization statement on the status of the global climate in 2009*. WMO-No. 1055. 16 pp. http://www.wmo.int/pages/publications/showcase/documents/ 1055_en.pdf

Yohe, G., S. Schneider, C. Rosenzweig, and W. Easterling. 2010. *Open Letter from U.S. Scientists on the IPCC*. March 13. (Over 250 signatories). Accessed April 18 2010. http://www.openletterfromscientists.com/

# Appendix: Selected Resources


Angliss, B. 2007. Anti-global heating claims – a reasonably thorough debunking. *Scholars and Rogues.* July 23. Accessed August 22 2010. http://www.scholarsandrogues.com/2007/07/23/anti-global-heating-claims-a-reasonably-thorough-debunking/

Huessner, K. 2010. Climate Science Skepticism: 5 Controversial Claims. Is Earth Really Warming? Are Humans Responsible? Why Climate Skeptics Doubt. *ABC News* April 20 2010. http://abcnews.go.com/Technology/Eco/climate-science-skepticism-controversial-claims/story?id=10387379&page=1

Neu, U. 2009. Climate sceptic arguments and their scientific background. Climate change facts compiled by ProClim. Swiss Reinsurance Company. 32 pp. http://media.swissre.com/documents/rethinking_factsheet_climate_sceptic.pdf

*NOAA NCDC. 2010. The State of the Climate 2009. Highlights. Updated August 3. Accessed August 22 2010.* 10pp. *http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/2009/bams-sotc-2009-brochure-hi-rez.pdf*

RealClimate. http://www.realclimate.org

Rennie, J. 2009. Seven Answers to Climate Contrarian Nonsense. Evidence for human interference with Earth's climate continues to accumulate. *Scientific American.* November 30. http://www.scientificamerican.com/article.cfm?id=seven-answers-to-climate-contrarian-nonsense

Smith, R.L., L.M. Berliner, and P. Guttorp. 2010. Statisticians Comment on Status of Climate Change Science. *AMSTAT News. The Membership Magazine of the American Statistical Association*. March 1. http://magazine.amstat.org/2010/03/climatemar10/

SourceWatch. Climate change skeptics: common claims and rebuttal. Accessed June 16 2010. http://www.sourcewatch.org/index.php?title=Climate_change_skeptics/common_claims_and_rebuttal

Skeptical Science, John Cook. http://www.skeptical.science.com

The Blackboard, Lucia Liljegren. http://rankexploits.com/musings/

Union of Concerned Scientists: Global Warming Contrarians. http://www.ucsusa.org/global_warming/science_and_impacts/global_warming_contrarians/

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